HyMeX

HYdrological cycle in Mediterranean EXperiment

TOWARDS A MAJOR FIELD EXPERIMENT IN 2010-2020

WHITE BOOK

Draft 1.3.2

February 2008

http://www.cnrm.meteo.fr/hymex/

Coordinated by:

Philippe Drobinski
Véronique Ducrocq

Contributors:
Karine Béranger, Isabelle Braud, François Carlotti, André Chanzy, Chantal Claud, Guy Delrieu, Alexis Doerenbecher, Stéphane Despiau, Philippe Drobinski, Véronique Ducrocq, François Dulac, Xavier Durrieu de Madron, Françoise Elbaz-Poulichet, Richard Escadafal, Claude Estournel, Hervé Giordani, Cécile Guieu, Joël Guiot, Stéphane Hallegate, Masa Kageyama, Frédéric Jacob, Patrick Lachassagne, Michel Lang, Laurent Li, Eric Martin, Frédéric Médail, Joël Noilhan, Roger Moussa, Jean-Louis Perrin, Matthieu Plu, Louis Prieur, Didier Ricard, Jean-Claude Rinaudo, Olivier Radakovitch, Frank Roux, Celine Lutoff, Samuel Somot, Isabelle Taupier-Letage.

Summary

HyMEX (HYdrological cycle in the Mediterranean Experiment) is a major experimental program aiming at a better quantification and understanding of the hydrological cycle and related processes in the Mediterranean, with emphases put on high-impact weather events and regional impacts of the global change including those on ecosystems and the human activities.

HyMeX aims at producing a **new long-term and highly temporally and spatially resolved data-set** over the Mediterranean basin to:

1. provide an accurate description of the water cycle and its variability and trend (accurate documentation of the **different terms of the water budget** over the different compartments and **at their interfaces**; documentation of the key **processes** driving the water cycle)
2. understand how the Mediterranean water cycle processes contribute to the regional climate (explore and model the various mechanisms determining the space and time variability of **water budget** of the Mediterranean region; relate the regional mechanisms to the **large-scale circulation systems in the atmosphere** and oceans over the globe)
3. validate the regional oceanic, atmospheric and hydrological models and develop improved parameterizations

HyMeX also aims at developing **methodologies and models** in order to contribute to basic needs of **weather prediction, regional climate studies, climate impact, and environmental research by:**

1. determining and/or improving the predictability of the water cycle, its variability and associated high-impact weather events
2. performing regional climate change scenario

HyMeX focuses on the interactions and feedbacks between the various compartments (atmosphere, sea, continental surface and interfaces) and thus associates major disciplines such as meteorology, oceanography, hydrology and climatology. In particular, HyMeX addresses key issues related to (1) the water budget of the Mediterranean basin, (2) the continental hydrological cycle and related water resources, (3) heavy precipitation and flash-flooding, (4) intense air-sea exchanges and (5) coastal dynamics.

- ***Water budget of the Mediterranean basin***: The Mediterranean sea is characterized by a negative water budget (excess evaporation over freshwater input) balanced by a two-layer exchange at the Strait of Gibraltar composed of a warm and fresh upper water inflow from the Atlantic superimposed to a cooler and saltier Mediterranean outflow. Light and fresh Atlantic water (AW) is transformed into denser waters through interactions with the atmosphere that renew the Mediterranean waters at intermediate and deep levels, and generate the thermohaline circulation. Although the scheme of this thermohaline circulation is reasonably well drawn, little is known about its variability at seasonal and inter-annual scales. For example, a better understanding of the formation of Levantine Intermediate Water (LIW) in the eastern Mediterranean is needed because LIW plays a major role in the formation of other dense waters in the whole Mediterranean (its signature is still visible in the Mediterranean outflow at the Strait of Gibraltar). Also visible are the feedbacks of the

Mediterranean basin on the atmosphere through the terms of the water budget. The budget of the Mediterranean Sea has also to be examined in the context of the global warming, and in particular by highlighting the impact of an increase of the Sea Surface Temperature (SST) on high-impact weather frequency and intensity..

- ***Hydrological continental cycle***: The rainfall climatology of the Mediterranean region is characterized by dry summers frequently associated with very long drought periods, followed by fall and winter precipitation that are mostly very intense. This results in high daily/seasonal variability in aquifer recharge, river discharge, soil water content and vegetation characteristics, for which the interaction with the atmosphere is not well known. This includes for example the impact of the large extension forest fires associated with drought during summer on the evapotranspiration component of the hydrological cycle. The role of the surface states (land use/land cover) and of the soils on the modulation of the rainfall needs also to be better understood. Hydrological and hydrogeological transfer functions are also characteristic of the Mediterranean basin, notably because of the specificities of the peri-mediterranean karstic and sedimentary aquifers. Progress in their understanding is of primary importance for the development of integrated management of the hydrosystems, and its adaptation to anthropogenic pressure and the the climate change.

- ***Heavy precipitation, flash-flooding and flooding:*** During the fall season, western Mediterranean is prone to heavy precipitation and devastating flash-flooding and floods. Daily precipitation above 200 mm are not rare during this season, reaching in some cases values as exceptional as 700 mm recorded in September 2002 during the Gard (France) catastrophe. Large amounts of precipitation can accumulate over several day-long periods when frontal disturbances are slowed down and strengthened by the relief (e.g. Massif Central and the Alps), but also, huge rainfall totals can be recorded in less than a day when a mesoscale convective system (MCS) stays over the same area for several hours. Whereas large scale environment propitious to heavy precipitation is relatively well known, progress has to be made on the understanding of the mechanisms that govern the precise location of the anchoring region of the system as well as of those that produce in some cases uncommon amount of precipitation. The constrasted topography, the complexity of the continental surfaces in terms of geology and land use, the difficulty to characterize the initial moisture state of the watersheds make the hydrological impact of such extreme rainfall events very difficult to assess and predict.

- ***Intense sea-air exchanges:*** The Mediterranean Sea is characterized by several key spots of intense sea-air exchanges associated with very strong winds which are caused by deep cyclogeneses or by the orographic response to the large scale forcing (Mistral, Bora, Genoa cyclogeneses, etc). These intense sea-air interactions and the associated sea surface cooling affect considerably the heat and water budgets of the Mediterranean Sea through the formation of deep deep (offshore) winter oceanic convection. Modifications of the oceanic mixed layer characteristics within the oceanic convection regions in their turn influence the lower part of the atmosphere. Hydrological and dynamical characteristics and inter-annual variability of the oceanic convection, as well as the strong wind systems, need to be better documented in order to stress the respective roles of the atmospheric forcing and oceanic processes, together with their interactions, and to progress in the modelling of these processes. Ecosystems functioning are strongly related to this complex dynamic which need to be better understood.

- ***Coastal dynamics:*** A good knowledge of the water circulation and of mixing in the coastal zone are keys to understand the transport and transformation of continental rivers and aquifers inputs (biogeochemical and sediment transport), the cycle of major constituents in the coastal zone, as well as the formation and cascading of dense waters toward the open sea. Momentum transfer from atmospheric winds largely governs the residence time of the water and nutrients over the continental shelves. The functioning of the coastal zone is therefore very sensitive to the spatial and temporal variability of the fine scale wind field, which results from not wellknown interactions with the complex topography of the Mediterranean region.

Table of Content

1. Introduction

Coordinator: V. Ducrocq

The Mediterranean basin has quite a unique character that results both from physiographic conditions and historical and societal developments. The region features a nearly enclosed sea surrounded by very urbanized littorals and mountains from which numerous rivers originate (see insert 1). In numerous countries, the quasi-totality of the rivers is intermittent as well as ephemeral. This results in a lot of interactions and feedbacks between oceanic-atmospheric-hydrological processes that play a predominant role on climate and ecosystems. These processes frequently cause extreme events that produce heavy damages up to human losses; heavy precipitation and flash-flooding during the fall season, severe cyclogeneses associated with strong winds and large swell or heat waves and droughts accompanied by forest fires during summer are examples of Mediterranean high-impact weather events. The capability to predict such dramatic events remains weak because of the contribution of very fine-scale processes and their non-linear interactions with the larger scale processes. Advances in the identification of the predominant processes and interactions at the different scales are needed in order to improve the forecast of these events and to reduce uncertainties on the prediction of their evolution (e.g. frequency, intensity) in the future climate. Mediterranean regions have been identified as one of the two main “hot-spots” of the climate change. These issues are not only of primary importance for providing tangible basis to the design of early warning procedures and mitigation measures to avoid loss of life and reduce damage, but also for the assessment of their impacts on the terrestrial and marine ecosystems which may be irreversible.

The French research community, during the recent INSU[1] Ocean-Atmosphere 4-year prospective exercise, has recognised the lack of an experimental project relying on up-to-date innovative instrumentation in order to go one step further in the understanding and predictability of the Mediterranean intense events. The international research community has already expressed his interest to transform it into an international experimental programme. The hydrological cycle in the Mediterranean region has been identified as a crucial issue that has to be addressed within such experimental project. In the climate change context, the hydrological cycle in the Mediterranean region is a key scientific, environmental and socio-economical issue for a wide region including southern Europe, northern Africa and the Middle East. Freshwater in the Mediterranean region is rare, fragile and unevenly distributed in a situation of increasing water demands. Progress in the understanding of the functioning and evolution of the water cycle in Mediterranean has thus important environmental, societal and economical implications. ***HyMEX (HYdrological cycle in the Mediterranean Experiment) aims at a better quantification and understanding of the hydrological cycle and related processes in the Mediterranean, with emphases put on high-impact weather events and regional impacts of the global change*** including those on ecosystems and human activities. It should be a multi-disciplinary and multi-scale experimental project as not only processes within each compartment have to be better understood but also those at the interfaces. The targeted period is [2010-2020]; a phasing of the special observing period with a European THORPEX[2] Regional Campaign (named T-NAWDEX) **in 2011**, in connection with the Medex Phase 2, is looked for.

[1] INSU: National Institut of Sciences of Universe.
[2] THORPEX is an international global atmospheric research and development program of the WMO World Weather Research Program (http://www.wmo.ch/thorpex/).

The present "White book" aims at providing a description of the scientific objectives of HyMeX for a comprehensive study of the water cycle at different time and temporal scales in the Mediterranean as well as a broad overview of the experimental strategy to answer the different questions. It mainly emanates from discussions with the French research community and should serve now as a basis for broadening discussions to the international community to lead to the International Science Plan for HyMeX.

This document is organised as follows: Section 2 introduces the main characteristics of the water cycle in Mediterranean. The impacts of the water cycle on marine and terrestrial ecosystems as well as the role of the chemical composition of the atmosphere on the Mediterranean hydrological cycle are also discussed in section 2. Then, section 3 details the main scientific questions about the water cycle in Mediterranean, identifies the questions still open and makes suggestions to address them. Scientific questions concerning the societal and economical impacts related to the water cycle in the Mediterranean are presented in section 4. Section 5 aims at describing the general experimental strategy envisaged to achieve these scientific objectives[3]. Links with the other national and international programs in the Mediterranean are presented in section 6.

INSERT 1: The Mediterranean region characteristics, geography and ecology

The Mediterranean basin has a distinctive character that results both from physiographic conditions and historical and societal developments. The ***Mediterranean region*** defines generally the lands around the ***Mediterranean Sea*** that have a ***Mediterranean climate***. The Mediterranean climate is characterized by hot long and dry summers, mild winters during which rainfalls occur (between September and April depending on regions). Köppen (1936) defined the Mediterranean climate as one in which winter rainfall is more than three times the summer rainfall.

The Mediterranean Sea covers an area of about 2.5 millions km^2, containing about 4.6 millions km^3 of water. Uncommon are its longitudinal extent (3800 km from Gibraltar to Levant) and its coastline length (46,000 km). The Mediterranean Sea is thus almost completely enclosed by land. Its morphology is also unique (Fig. 1.1). The Strait of Gibraltar, only 14-km wide and about 300-m deep, connects it to the Atlantic Ocean. To the east, the Dardanelles and the Bosphorus connect the Mediterranean Sea to the Marmara and Black Sea and, to the southeast, the man-made Suez Canal connects it to the Red Sea. About 200 islands are distributed over the Mediterranean Sea and prominent northern peninsula (Iberian Peninsula, Italy, Balkan Peninsula, Asia Minor) protrude towards the African coast favouring regional flow circulation. The Mediterranean Sea is not as deep as open seas with an averaged depth of only 1500 m, even though sea depth reaches locally more than 5000 m in the Ionan Sea. A shallow submarine ridge between Sicily and Tunisia splits the Mediterranean region in two main subregions: the ***Western Mediterranean,*** which covers an area of about 0.85 millions km^2, and the ***Eastern Mediterranean,*** about 1.65 millions km^2.

The Mediterranean region covers parts of three continents (Europe, Africa and Asia). Its medium to high mountains that surround the Mediterranean Sea have a strong influence on air flow circulation: the Pyrenees, the Alps, the Dinaric Alps, the Balkan and Rhodope

[3] It will be the aim of the Science Plan document to detail the experimental and modeling implementation for HyMeX.

mountains north of the basin, the Atlas Mountain south of the basin separating the region with Mediterranean climate from the Sahara desert. The highest ridge is the Alps, reaching a maximum height of 4800 m. The Mediterranean basin extends into western Asia, including the Levant/Middle-East at the eastern end of the Mediterranean, bordered by the Syrian and Negev deserts.

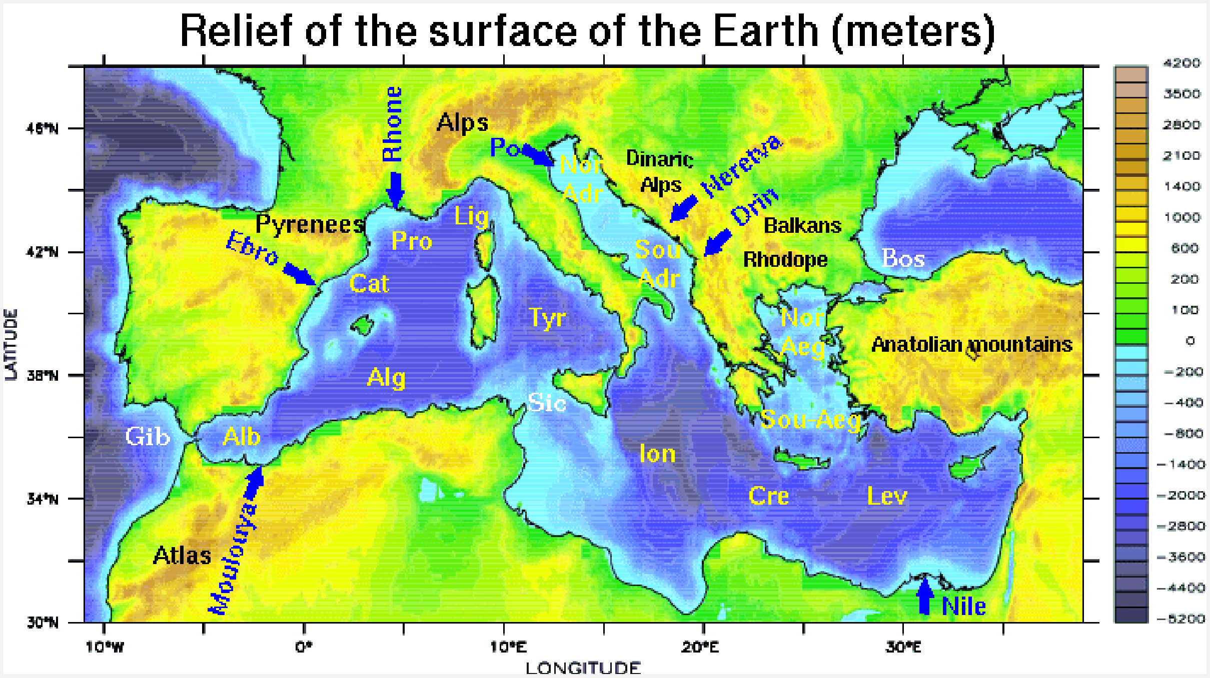


Figure 1.1: Geographical locations. The Strait of Sicily (Sic) splits the Mediterranean Sea in the Western and Eastern basins, which are composed of the Alboran (Alb), Algerian (Alg), Tyrrhenian (Tyr), North and South Adriatic (Adr), Ionian (Ion), North and South Aegean (Aeg), Cretan (Cre), Levantine (Lev), Catalan (Cat), Provencal (Pro), Ligurian (Lig) sub-basins. The Mediterranean Sea is connected to the Atlantic Ocean by the Strait of Gibraltar (Gib), and to the Black Sea by the Bosphorus strait (Bos).

The hydrological Mediterranean basin is also quite unique, with a strong coastal component. Only 21 catchments have an area of more than 10,000 km², of which only 6 have an area of more than 50,000 km²: Nile, Rhone, Ebro, Po, Moulouya and Evros. All together, these 21 catchments represent only 42% of the total Mediterranean basin (1 700,000 km² - without the Nile river). The construction of dams during the last century has reduced by about 50% the inflow of freshwater. The most remarkable one is that of the Aswan High dam across the Nile River, in the 1960s, that has considerably reduced the inflow of freshwater and nutrient-rich silts from the Nile into the Eastern basinpas de ref ailleurs. The remaining part of the hydrological Mediterranean basin is constituted of small to medium size watersheds associated with numerous small rivers originating from the surrounding mountains. Most of these small rivers - wadi during the dry summer season - become powerful torrential rivers during flash-flooding episodes in autumn. As a consequence of this hydrological regime, most of the freshwater used in the Mediterranean area (potable water, irrigation, etc.), even along its Northern shore, is taped in the aquifers, the natural reservoirs constituting the basement of these catchments.

As an outcome of a similar geological history at the scale of the whole Mediterranean region, these watersheds exhibit a very similar hydrogeological pattern. The sedimentation within the Thetis Sea that occurred during the Secondary Era produced huge pilling-up of limestone rocks. The sea level variations since the closure of this sea and their emersion (mostly at the end of the Cretaceous) is at the origin of a multiphase karstification process that culminated recently, during the Messinian period (6 million years ago), when the basin was quite completely dried up. As a consequence of this event, unique worldwide, the Mediterranean karstic aquifers are very thick. Deep and large valleys were also dug out during this Messinian period that were eventually filled with porous sediments when the sea level came back up (for instance, the resulting Rhone ria extended north of the city of Lyon). These filled valleys constitute most of the presently exploited Plio-Quaternary coastal aquifers that are widespread all around the Mediterranean shore and are heavily exploited.

The marine biota of the Mediterranean are derived primarily from the Atlantic Ocean, but with a five million years adaptation to a warmer and less nutrient-rich sea water. With the opening of the Suez Canal in 1869, plants and animals from the Red Sea have progressively colonized the eastern Mediterranean. Despite a rather limited quantity of biomass, the Mediterranean region exhibits considerable biodiversity, including 22,500 endemic vascular plant species. The plants vary with rainfall, elevation, latitude and soils: scrublands near the seacoast, shrublands which are the commonest plant community around the Mediterranean, woodland and forests generally composed of evergreen trees, predominantly oak and pine. Man has also gradually transformed the landscapes into a complex patchwork of horticulture, vineyards, olive groves, orchards, etc

A further important characteristic of the Mediterranean region is the growing demographic pressure and the development of mass tourism. The Mediterranean coastal regions of the rim countries are twice as densely populated as the countries as a whole. The urban population experienced strong growth, from 94 million in 1950 (44% of the population) to 274 million in 2000 (64%). Built-up areas cover nearly 40% of the coastline. It results in a continuous degradation of the marine and coastal areas: twofold increase of nitrates input in 20 years, accumulation of persistent toxic substances in food chains, etc. Mediterranean land is particularly vulnerable to water erosion, due to specific climate conditions and slopes. Deterioration occurs faster than renewal, caused either by desertification, urban sprawl, poor farming practices, etc.

2. An overview of the main characteristics of the water cycle and related phenomena

2.1 Mediterranean atmospheric circulations

Coordinator : C. Claud

2.1.1 Links to the global climate

The Mediterranean basin presents several specificities: first, because of the latitudes that it covers, it is a transition area under the influence of both mid-latitudes and tropical variability: to the north, a large part of the atmospheric variability is linked to the North Atlantic Oscillation (NAO) and other mid-latitude teleconnection patterns (Xoplaki, 2002; Trigo *et al.,* 2004), while the southern part of the region is under the influence of the descending branch of the Hadley cell materialized through the Azores High, with in addition El Niño Southern Oscillation (ENSO) influence to the east (Rodwell and Hoskins, 1996 ; Price *et al.,* 1998). At the southern limit of the North Atlantic storm tracks, the Western Mediterranean region is particularly sensitive to interannual displacement of the trajectories of mid-latitude cyclones that can modulate the precipitation over the region mainly during the winter season when the impact of the NAO is greatest (Rodriguez-Fonseca and Castro, 2002). As no significant correlation is found with evaporation, the impact of the NAO on the variability of the fresh water cycle is mostly due to the precipitation anomalies. The Mediterranean climate is also influenced by tropical and subtropical systems, such as ENSO, tropical cyclones, Saharan dust and South Asian Monsoon. Several cases of heavy precipitation over the western Mediterranean could be traced back to tropical cyclones over the Atlantic Ocean (Reale *et al,* 2001). There is still no general agreement on the extent of the ENSO impact on the interannual variability of the Mediterranean climate. A decrease of precipitation during spring following El Niño events has been stated by Rodo *et al.* (1997) for Spain, whereas Mariotti et al (2002) found an increase of rainfall during the fall season for El Niño. Klein *et al.* (1999) and Rodo (2001) have found that some cooling of the Western Mediterranean Sea can found its root in a sequence of ocean-atmosphere couplings that initiate in the warm tropical Pacific during El Niño event. All these influences lead to a large variability at different scales, going from the multi-decadal scale to the mesoscale.

2.1.2 High-Impact Weather

The Mediterranean region features a nearly-closed sea with high Sea Surface Temperatures (SST) during summer and fall surrounded by an almost continuous barrier of mountains from which a number of rivers originate. The complex topography of the Mediterranean basin plays a crucial role in steering air flow and the Mediterranean Sea acts as a moisture and heat reservoir, so that energetic mesoscale features are present in the atmospheric circulation which can evolve to high-impact weather systems such as heavy precipitation and flash flooding, cyclogenesis and wind storms or heat waves and droughts. The ability to predict such high-impact weather events and their consequences is still low because of the contribution of fine-scale processes and their non-linear interactions with large-scale processes as well as not well-known interactions between oceanic, atmospheric and hydrological processes.

2.1.2.1 Heavy Precipitation

In Mediterranean Europe as well as in many other temperate areas in the world, flooding is one of the most devastating natural hazards in terms of human life loss along with windstorms. As a matter of interest, the storm flooding in Algiers on 10 November 2001 caused 886 victims whereas in France, over the last two decades, more than 100 deaths and several billion of euros of damages were reported. In September 2002, flash floods in France brought additional losses of 1.2 billion € (Huet *et al.,* 2003).

The Mediterranean region is characterized by intense rainfall events on a variety of space and time scales (Siccardi, 1996), resulting partly from atmospheric forcings ranging through spatial scales. The seasonal distribution of heavy rain events in the western Mediterranean – with a maximum in late summer and during autumn – suggests a relevant role of the Mediterranean Sea; high SST during this period of the year allows large water vapour loading of the atmospheric lower layer. Combined with northern upper-level cold air masses progressing towards the region at this period of year, the warm and wet Mediterranean air masses become conditionally unstable. The link, even though complex, between heavy precipitation and synoptic-scale trough and cyclones has been well established in the past. Heavy precipitation occurs preferentially downstream of a cyclone aloft (Doswell *et al.,* 1998), although some cases of heavy precipitation without any significant cyclone developing in the vicinity of the areas affected by precipitation have also been documented (Turato *et al.,* 2004). At low-levels, a long fetch of flow over the Mediterranean Sea interacts with terrain features, driving local low-level circulation favourable to triggering of deep convection and enhancement of precipitation.

2.1.2.2 Intense cyclogeneses and wind storms

The Mediterranean Basin is known to present one of the highest concentration of cyclones in the world, especially in winter (Pettersen, 1956). Density of cyclones in the Mediterranean has been mapped through objective climatologies (e.g. Alpert et al., 1990; Joly and Joly, 2004), pointing out the Genoa region as the area where the concentration of cyclones is maximal. Secondary maxima are located in the Cyprus and Aegean region and other relative maxima are situated in the Adriatic (Flocas and Karacostas, 1994), in the Palos-Algerian Sea and in the Catalonian-Balearic Sea and Gulf of Lion (Jansa, 1986). A review of the elements that make Mediterranean cyclones particular is proposed in the following.

The Atlantic storm-track and upper-level jet stream play an essential role for the formation of Mediterranean cyclones. Upper-level precursors that come from the Atlantic favour the birth of cyclones (Trigo *et al*., 2002) and may also be linked to intense precipitation (Massacand *et al.,* 1998; Stein *et al*., 2000). Particularly in autumn, Rossby wave-packets and anomalies of moisture are brought after the extratropical transition of former tropical cyclones from the Gulf of Mexico (Krichak *et al*., 2004).

The continental topography around the Mediterranean Sea forces several cyclonic developments. In spring and summer, thermal lows over the warm continental areas may appear during the day. The Genoa depression, Cyprus lows, Red Sea troughs and cyclones located at the exit of the subtropical jet near the Atlas Mountains are very frequent examples of lee depressions. If such a depression is associated with upper-tropospheric southward airmass intrusions or tropopause foldings, convection and precipitation may occur (Chaboureau and Claud, 2006). These cyclones are also often associated with strong local winds such as the Mistral and Tramontane (e.g. Georgelin and Richard, 1996; Drobinski *et al.* 2001, 2005; Guénard *et al.* 2005, 2006), Cierzo (Masson and Bougeault, 1996), Ponent, Levante, Scirocco, Etesians, Bora (Smith 1987; Grubišić, 2004), Shamsin, Sharav and others (see Reiter, 1975 for a general description). These winds generate low-level potential vorticity banners, with alternate positive and negative vorticity.

Mediterranean cyclones have generally a smaller scale than Atlantic cyclones (*Trigo et al*., 2002). The high SST of the Mediterranean Sea in autumn destabilizes air masses and favours the release of latent heat during the formation of cyclones. Rarely, some hurricane-like, or polar-low-like, cyclones may develop (Pytharoulis *et al.,* 2000), for which convective processes are predominant over baroclinic interaction.

2.1.2.3 Heat waves, droughts

Summer for southern Mediterranean regions is characterized by high temperatures, lack of rainfall and long periods of drought. As stated by Xoplaki *et al.* (2004), the summer half-year precipitation accounts for between only 20 % of the annual total amounts (southern and eastern regions) and 30% (western and northern regions). The heat waves over Southern Europe result generally from a zone of strong high pressure over Western Europe that persists for many days (atmospheric "blocking" situation) and pushes Atlantic perturbations northwards. Diabatic heating, subsidence and stability are associated with the high-pressure air mass. Brikas *et al.* (2006) studied the role of subtropical jet stream in the occurrence of heat waves in Greece and South Balkans. They found that a strengthening and a poleward shift of the subtropical jet favours heat waves over the region. Intense heat waves are favoured in these regions when the subtropical jet is anticyclonically curved to the north of the Balkans.

2.1.3 Climate change

The area is also very sensitive to global climate change at short (decadal) and long (millennial) time scales. There is a general agreement that global climate change is taking place. The IPCC (2001) assessed that global mean surface temperatures had increased by between 0.4 to 0.8°C since the late 19^{th} century. More specifically for the Mediterranean region, Quereda-Sala *et al*. (2000) reported an increase of the mean annual temperature of 0.5°C to 1.2°C between 1870 and 1996 in the Mediterranean basin. A similar tendency is observed by Moisselin et al. (2002). When considering only the summer surface air temperature, the warming trend over Mediterranean region for the period 1950-1999 was 0.008 K/year (Xoplaki *et al,* 2003), reaching the value of 0.01 K/year for 1976-2000 (IPCC, 2001), one of the highest rates over the entire globe.

The IPCC (2001) has projected an increase of global warming of 1.4–5.8°C above 1990 levels by 2100 (for the full set of emissions scenarios). Indeed the majority of the 21^{st} century scenario show a decrease in average precipitation with a peak signal in summer with either global AOGCMs (Giorgi and Bi, 2005; IPCC, 2007), atmosphere Regional Climate Models (Gibelin and Déqué, 2003, Déqué *et al.* 2005, Gao et al., 2006, Ulbrich *et al.,* 2006; GICC-MedWater project report) or coupled Atmosphere-Ocean Regional Climate Models (Somot *et al*., 2007). In winter, the agreement is weaker with some models showing an increase in precipitation. There is however no consensus on the frequency and intensity of the extreme events in such conditions over Mediterranean regions, even though an increase in precipitation variability during the dry (warm) season is expected (Giorgi, 2006) and an increased probability of occurrence of events conducive to both floods and droughts is suggested (Gao *et al*, 2006). Globally, Giorgi (2006) defines the Mediterranean area as one of the two main "hot-spots" of the climate change with an increase in the interannual variability in addition to a strong warming and drying. This combination leads to a very important increase in the intensity and length of the droughts and of the heat waves.

At even larger time scales, the region has experienced several changes in the past. Paleorecords are based on climate indicators (or proxies) that record climate changes because they are sensitive to climatic stresses (e.g. pollens, lake levels, tree rings…). For the Mediterranean area, continental and marine records show that the climate and the sea state have widely varied in the past, sometimes very quickly, showing the high sensitivity of the climate and the circulation of this region (e.g. Allen *et al.,* 1999; Tzedakis *et al.,* 2003; Combourieu Nebout *et al.,* 2002; Sanchez-Goñi *et al.,* 2000).

2.2 Mediterranean water budget

Coordinator : L. Prieur

The Mediterranean water budget concerns the different compartments of the Earth system (atmosphere, ocean, continental surfaces, hydrology) for which the water residence timescale vary from one day to several centuries. In the atmosphere, the water (gas, liquid or solid) residence time is short and the atmospheric water content is largely driven by the typical regional atmospheric circulation (*see* Section 2.1). For terrestrial hydrology, the interaction with the atmosphere is strong and studies generally focus on specific watersheds (*see* Section 2.3). Conversely, the residence time in the ocean can reach several centuries due to the constraints of a weak flow rate imposed at the very narrow and shallow Gibraltar Strait and to the formation of dense water by intense surface latent and sensible heat exchanges during strong wintertime wind conditions. Most of the studies were conducted in the past on a single compartment, the other compartments being seen as boundary conditions only. Only very recently, attempts of global Mediterranean water budget estimate have been made using fully coupled oceanic and atmospheric climate simulations (Somot *et al*, 2005).

2.2.1 The thermohaline circulation (THC)

The Mediterranean Sea has a negative water budget (this applies to both Western and Eastern basins): the loss in the atmosphere by evaporation (E) is larger than the gains by precipitation (P), runoff ® from the main rivers and input from the Black Sea.. Since both basins are limited by the shallow Gibraltar and Sicily Straits, the warm surface inflow of atlantic water (AW) transformed into dense mediterranean waters (MW) remains mostly trapped and occupies the deeper areas. The characteristics (density, temperature and salinity) of the deep waters are determined by the long time accumulation of the dense waters formed during successive winters up to a level above the sills. Upon exiting the Gibraltar Strait, the outflow of Mediterranean water (saltier) dives along the slope in the Atlantic Ocean with a flow rate (depending on the water density difference and the strait geometry) 10 to 20 times larger than the Mediterranean E-P-R, and affects the deep layer and thermohaline circulation in the Atlantic Ocean (Béthoux *et al.,* 1999; Artale *et al.,* 2006, Millot et al., 2006). However the Mediterranean sea level and salinity remain mostly unchanged, since a fresher surface flow enters from the Atlantic Ocean, driven by the sea surface height difference and the strait geometry (Price *et al.,* 1994). Hydraulics thus forces the mean depth of the interface between inflow and outflow to be near the mid-depth of the sill, as long as the volume of new dense water formed each year is able to replenish the whole dense water reservoir (Bryden *et al*.,1994).

While progressing (north)eastwards, AW gets progressively denser before being transformed into dense water in specific areas of both basins (for a review of the characteristics and circulation of the water masses in the Mediterranean see Millot and Taupier-Letage, 2005a), mostly in the northern and coastal parts, where large ocean-atmosphere exchanges are experienced during winter. The contribution of the water formed in the Eastern basin (the Levantine Intermediate Water: LIW) is essential to the formation of deep water in Western basin. The volumes of water exchanged at Gibraltar are mainly fixed by local conditions (near the strait), but the intensity of the THC and the long-term (time) change of the outflow density and characteristics are fixed by changes in E-P-R over the whole Mediterranean basin. The THC in both Western and Eastern basins displays similar features with, however, slight quantitative differences of flow rate, E-P-R and straits geometry. The water budget largely controls the budget in nutrients and carbon (Copin Montegut, 1993; Durrieu de Madron, 2005).

2.2.2 Quantitative estimation of the water cycle budget and uncertainties

Despite this fairly accurate conceptual scheme of the water cycle at the Mediterranean basin scale, the annually averaged values of the flow rates estimated at the Gibraltar and Sicily straits and E-P-R vary in the last 30-year literature, depending on the processing techniques and dataset used. One major hypothesis made for the computation of these terms is the annual steady-state assumption, which allows relating the water flow rates near the strait and E-P-R but prevents accounting for any sea-surface height variation.

At present, there is a consensus for a value of 0.70 Sv[4] for the outflow (rate) and 0.1 Sv for E-P-R, but these values can range between 0.5 and 1.5 Sv, and 0 and 0.45 Sv, respectively (Astraldi *et al.,* 1999). Direct measurements of the flow rate at the Gibraltar Strait are extremely difficult to perform and are very few (Bryden *et al.,* 1994; Bray *et al.,* 1995; Tsimplis and Bryden, 2000). At Gibraltar Strait, substantial biases can affect the mean flow rate due to high frequency variation of the flow rate caused by the tide and local atmospheric forcing (Hopkins, 1999, Astraldi *et al.,* 1999). Price *et al.* (1994) and Béthoux (1979) also show that the estimates of the outflow rate is sensitive to the inflow salinity and E-P-R. A key point is that the flow rate at the Gibraltar Strait displays a pronounced seasonal variability (Bormans *et al*, 1986; Astraldi *et al.,* 1999; Garret, 1996), which could in turn affect the long-term evolution of the flow rate by modulating the dense water formation rate upstream of the Strait.

2.2.3 Observed trends

The key hypothesis underlying the above-mentioned studies is the annual steady-state assumption both on water and salinity budgets, which proved not to be effective (Mariotti *et al.,* 2002). For instance, the properties of the LIW observed in the Corsica Channel have changed with large inter-annual variations, apparently correlated with the NAO index (Astraldi *et al.,* 1999). Deep waters in the Western basin have been evolving slowly since 1970 with increasing temperature and salinity (Bethoux *et al*.,1990, Rixen *et al*., 2005), whereas the SST has increased in annual mean by about 1°C in 30 years, mainly due to warmer wintertime temperature (Prieur, 2003, Tsimplis *et al.*, 2006). Faster events such as the Eastern Mediterranean Transient (EMT) in the late 1980s affected the THC in the Eastern basin: the amount of Aegean deep water (AeDW) formed greatly exceeded that of the Adriatic deep water (AdDW), which was previously the main source for the Eastern Mediterranean deep water (EMDW). AeDW flowed out into the Ionian and Levantine sub-basins, uplifting progressively the older EMDW (Tsimplis *et al*., 2006; Lascaratos *et al*., 1999). First hints of the EMT-induced THC modification are already visible at the Gibraltar Strait (Millot *et al.,* 2006). Also, the dense water formed in winter on the continental shelf of the Gulf of Lions could contribute significantly to the modification of the characteristics of the western deep waters, generally thought to be formed only offshore (Béthoux *et al*., 2002; Canals *et al.,* 2006). Finally, altimetric measurements have shown that the sea surface height has changed for the last decade unevenly over the Mediterranean basin (Cazenave *et al*., 2001). The improvement of the sensors that nowadays monitor the Mediterranean region at higher temporal resolution has made possible the observation of these changes, which could be related to climate change (Somot *et al*, 2006) or to natural variability associated to the NAO (Mariotti *et al*, 2002).

In terms of climate change impact on water budget, two key variables have to be accurately acquired to reduce uncertainties on E-P-R, which is the leading term in the dense water formation and THC: the volume of dense waters formed each winter and the characteristics of these new dense waters.

---

[4] 1 Sv= 10^6 m^3/s

2.3 Hydrological regimes

Coordinators: R. Moussa, P. Lachassagne, F. Elbaz

In the Mediterranean climatic zone, also labelled as semi-arid or sub-humid (Piñol *et al.,* 1991), hydrological processes are largely variable both in time and space due to the high variability of rainfall regime, the influence of topography and the spatial distribution of geology, soil and land use (Pilgrim *et al.,* 1988; Thornes *et al*., 1996; Kosmas *et al.,* 1997). The temporal variability of precipitation within and between years is one of the specific characteristics of this climate characterised by a succession of drought and flash-flood periods. Precipitation is also variable in space and its variability is accentuated with altitude in mountainous regions (as instance, in Mediterranean southern France, the mean annual rainfall varies between 500 mm near the coast and 1950 mm at the 1567 m AMSL Mont-Aigoual, Fig. 2.1).

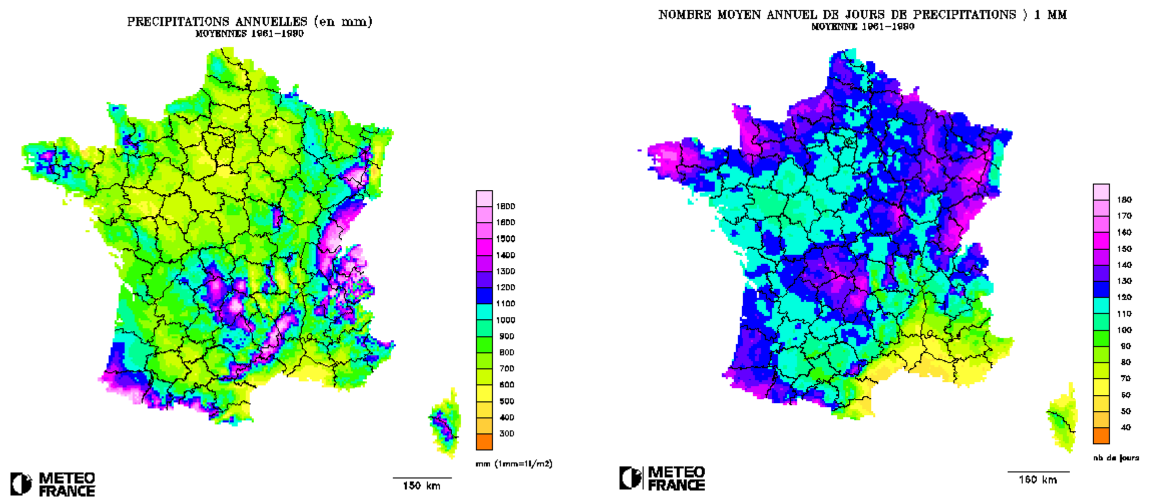


Figure 2.1: Mean annual Precipitation (left) and mean number of days with precipitation above 1mm (right) from 1961 to 1990 over France (from CDROM-pluies extremes sur le sud de la France, Météo-France and MATE)

Due to the strong spatio-temporal contrast of climate, the hydrological regime of the Mediterranean rivers is quite specific (Malanotte-Rizzoli and Eremeev, 1999; Servat *et al.,* 2003; Thornes and Wainwright, 2003). The differences between low and high water discharges can be extreme. Often, most of the water discharge occurs during short-duration floods concentrated in small to medium watersheds, the importance of the base flow being mostly related to the hydrogeological structure of the watershed. As a consequence, the ratio of peak discharge on mean annual discharge in drainage basins of 1000 to 10000 km² is frequently one order greater than for rivers in non-Mediterranean areas. This makes runoff less predictable than in other regions because of the low predictability of precipitation (mostly convective) and the complexity of surface run off processes associated with complex topography and sparse vegetation. This also represents a major difficulty for the monitoring of rivers as well as for the analysis of the rainfall-runoff processes. Most of the works have focused in separating the flow components of the hydrological balance in natural Mediterranean catchments.

2.3.1 Temporal and spatial scales

At the annual scale, hydrological processes are driven by the climate and the land surface properties such as the seasonal cycle in precipitation and evaporation, and by the geological structure of the watershed that may favour or not storage in aquifers (Aunay *et al*., 2003;

Bakalowicz *et al*., 2003; Blöschl and Sivapalan, 1995; Ceballos and Schnabel, 1998). Considering seasonal variability, most of the Mediterranean rivers have maximum discharge values between February and May and lowest discharge values during summer (July to September) because of strongly reduced precipitation and the elevated temperatures and evapotranspiration during this season. At this scale, the main hydrological processes in forested areas were extensively studied (Ibáñez *et al.,* 1990; Piñol *et al.* 1991; 1992; Ávila *et al*.; 1992; Llorens and Gallart; 1992) and compared to clear catchments (Burch *et al*., 1987); other authors studied the impact of natural phenomenon such as destruction by fire (Lavabre *et al.,* 1991), afforestation (Sorriso-Valvo *et al.,* 1995) or climate change implications (Ávila *et al.,* 1996). Evapotranspiration is a key process of the water budget at the annual scale and may represent between 50 and 75% of the total rainfall. Using a distributed hydrometeorological model driven by observed atmospheric forcing over the Rhone basin, Etchevers (2000) showed that the annual ratio between evaporation over precipitation was roughly 80% for the Mediterranean basins. This ratio was significantly lower for the basins influenced by continental or alpine climates north of the Rhone basin. In arid Mediterranean regions, surface water flow in water courses occur only for short periods of time and are highly variable, and stream channels are dry for long periods (Pilgrim *et al*., 1988). When floods occurs in normally dry stream channels, the channel network may replenish the water table by re-infiltration of the runoff water and consequently the volume of flow is reduced by infiltration into the bed, the banks, and possibly the flood plain (Lane *et al.,* 1971; Jones, 1997). These losses due to aquifers reduce not only the volume of the hydrograph, but also the peak discharge (Lane, 1983). Where and when the water table is higher than the channel bed, the channel network drains the water table and a base flow is locally observed. Consequently, it is very difficult to predict the behaviour of channel-aquifer water exchanges because of the strong dependence on local conditions.

At the event scale, runoff events in the Mediterranean region are usually caused by high-intensity, short-duration thunderstorms and are dominated by hortonian overland flow and/or subsurface flow. In calcareous watersheds, karstic aquifers often greatly contribute to the floods. Many factors influence runoff genesis, including the soil surface properties, the vegetation cover, soil hydrodynamic properties and the initial water content. Many studies have already proved the importance of initial soil moisture on the run off response. This is a very important issue for runoff modelling and particular procedures have been proposed based on river flow assimilation to better define the initial soil moisture in rainfall – runoff models. As runoff represents the main process during flood events in Mediterranean region, many studies have quantified the amount of rainfall available for runoff (Harvey, 1984; Lastenet and Mudry, 1995; Cerdà, 1996; Wainwright, 1996); besides, some studies focused on the stream flow processes (Marc *et al.,* 1996), the erosion (Tropeano, 1983; Gallart *et al.,* 1993; Kutiel *et al*., 1995) and the sedimentation processes (Clotet and Gallart, 1986).

In space, hydrological regimes depend on geographical and anthropogenic factors such as the basin size (large basins like the Nile, Rhone, Po, Ebro versus small basins < 1000 km²), the topographic position (mountainous basins like the Alps, Pyrenees, Cévennes, Atlas versus plain basins like Camargue), the hydrogeologic and aquifer system (e.g. specific processes in karstic regions), the urbanization (e.g. Marseilles, Barcelona, Napoli,...), islands (e.g. Cyprus, Sicilia, Corsica), the role of dams and reservoirs (e.g. Assouan), the lakes (e.g. more than 1000 artificial lakes constructed in Tunisia during the last two decades), human activities (farming practices, irrigation, artificial recharge of aquifers, hydroelectricity, industrial activities), etc.

2.3.2 Global change

According to Ludwig and Meybeck (2003), the mean annual rainfall has decreased during the last century by about 6% for the western Mediterranean basin, and about 10% for the eastern basin (not including the Nile). Interestingly, except in the Danube basin where a decrease in precipitation is apparent, no change was detected over the largest rivers basins (e.g. the Rhone and the Po). The study highlights also a significant decrease for most river discharges since the beginning of the 19^{th} century except for the Têt River (France) whose discharge has increased by 50% and for the Rhone, Danube and Po Rivers where no significant long-term trend could be detected. In fact, the watersheds, depending on their hydrological properties, act as filters, or transfer function, that may thus amplify or attenuate the effects of the climate change. As a whole, it is estimated that the riverine freshwater inputs to the Mediterranean might actually only represent about 50% of what they were at the beginning of the 20^{th} century (Poulos and Drakopoulos, 2001). However, the decrease in discharge that varies according to Mediterranean sub-basin cannot be fully accounted for by climate change, as direct anthropogenic influence could be more important at present. For example, Ludwig and Meybeck (2003) estimate that one fifth of the water discharge to the Adriatic Sea is affected by anthropogenic consumption. The strongest reduction of water discharge is found for rivers that are affected by the construction of dams such as the Nile or the Ebro River, and where this water is mainly used for irrigation (most of the tapped water is then evapotranspired). Montanary *et al.* (1998) show evidence of a decrease of rain events in Italy and an increase of their intensity. Conversely, in Languedoc-Roussillon (France), Neppel *et al*. (2003) found no significant increase of the extreme rainfall frequency and therefore attribute the observed increase in flood frequency to land use/land cover modifications of drainage basin by human activities rather than to climate change.

The hydrological changes that could be driven by the climate change may result in an increase of the pollution peaks that occur during floods in relation to the mobilization of the pollutants that had accumulated in drainage basins during dry periods. This process is particularly important in small Mediterranean basins which comprise intermittent rivers (Elbaz-Poulichet *et al*., 2003; Rabiet, 2006; Tournoud *et al*., 2005). The global change may also result in reduced discharges in the perennial streams during the low water stage, associated with longer low water stages, with strong consequences related to a lower dilution of the anthropogenic pollutants, with adverse effects on the ecosystems, including wetlands, etc.

2.4 Impacts of water cycle on Mediterranean terrestrial and marine ecosystems

Coordinators: F. Carlotti, C. Guieu, J. Guiot, S. Rambal

2.4.1 Impacts on Mediterranean terrestrial ecosystems

The Mediterranean terrestrial ecosystems, and in particular the vegetation is the result of a long history of climatic changes (several millions of years) and anthropogenic changes in the few last millennia (Suc, 1984; Svenning, 2003). For the last two millions years, the succession of glaciations have imposed to the northern Mediterranean basin to be the refuge of temperate vegetation (Petit *et al*., 2002). After the last glaciation (at about 15000 years BC), there was recolonization of the continent with hybridation and diversification. Until 6000 years ago, the Mediterranean region was wetter and cooler than in the present and afterwards, the climate became dryer in summer and warmer in winter (Cheddadi *et al.,* 1997) favouring drought-resistant plants. Anthropogenic deforestation and fires have accentuated this. All this history, unique in the world due to the geographical location of the region, is responsible of ecological plasticity, large diversity and the ability of the plants to adapt to abrupt climatic and environmental changes (Medail, 2005). Nevertheless, this biological heritage remains fragile because of the rapidity and amplitude of the forecasted changes for the next century and mainly the synergy of several key factors (land use changes, climatic changes, nitrogen depot increase) (Sala *et al*., 2000).

Mediterranean forests are crucial for preserving this high biodiversity but also to provide essential ecosystem services, such as soil protection, water conservation and climate regulation (Eamus *et al*., 2005). Climate models predict a significant warming and decrease in precipitation in the Mediterranean basin (Gibelin and Déqué, 2003). Giorgi (2006) identified the Mediterranean basin as the most prominent hot-spot of climate change over the world with more than 20% decline of precipitation over April to September. These changes can trigger a positive feedback on climate change by decreasing CO_2 sequestration in ecosystems, as it has been the case during the 2003 heat wave (Ciais *et al.,* 2005). It is important to quantify the short-term consequences but also after-effects and acclimation processes, which calls for an approach at multiple time-scales. In addition, impacts of extreme events have always been studied retrospectively, which limits their understanding and the scientific formulation of thresholds for damage.

While tremendous advances were made in the 20^{th} century concerning models of photosynthetic CO_2 assimilation, respiration loss by ecosystems is still represented by empirical temperature equations, which have been modified very little since the 19^{th} century. Challenges for modelling soil respiration in the short term includes taking into account the effects of soil moisture and substrate supply separately (Davidson *et al*., 2006). Studies explicitly coupling field experiments (e.g. effect of water exclusion on forest experimental sites) and modelling exercises across multiple scales are needed to better understand the part of the vegetation in the water cycle.

2.4.2 Impacts on Mediterranean marine ecosystems

Mediterranean sea waters are generally oligothropic (*i.e.* low concentrations of nutrients and low productivity) except in the vicinity of the river mouths, where river discharges bring nutrients to the sea, and in areas where wind mixing and upwelling allows vertical transport of nutrients, favouring local fertilization (e.g. in both northern parts of the Mediterranean where deep water formation occurs).

In the Mediterranean Sea, changes have occurred in the last few decades as responses to climate change, as sea warming (Béthoux *et al.,* 1990; Sparnocchia *et al*., 1994), sea-level rise, reduced river runoff, up to possible modifications of the THC . Their impacts on the Mediterranean marine ecosystems start to be observed on biological communities and biogeochemical fluxes. Changes in evaporation, precipitation, salinity, river runoffs, currents and wind patterns and strengths... will necessarily accompany changes in population distributions. These rapid changes led to the recent appearance and population establishment of warm-waters species of planktonic organisms, pelagic fish and benthic organisms in the northern sectors (Astraldi *et al*., 1995). It is well known that fish respond to changes in ocean climate (Cushing, 1982). The impact of climate on the marine ecosystem is not limited to fish but also extends to the lower trophic levels as well. For example, it is known that inter-annual variability of both phytoplankton and zooplankton reflects changes in winds and ocean temperatures (Beaugrand, 2003, *see* INSERT 2). Climate affects zooplankton partially through its influence on phytoplankton production. Temperature determines development rates of the zooplankton and the rate at which phytoplankton cells divide (their turnover rates); wind-induced turbulent mixing is important in controlling the onset of the spring phytoplankton bloom and affects the contact rates of zooplankton with their food. Thus, it is very likely that the expected climatic changes will cause changes within the ecosystem. Due to global change, existing ecological balances and chains can be broken, and new ones would be formed. The biomass of some species will decline, benefiting other species whose biomass will increase.

To detect such linkages requires long-term datasets for the different biotic component of the marine ecosystem (Drinkwater *et al*., 2003). For plankton, there are generally rare; however, one invaluable dataset is that collected by the Continuous Plankton Recorder (CPR) survey in the North Atlantic and the North Sea. This survey began in 1931 in England and presently consists of a network of CPR transects towed monthly across the major geographical regions of the North Atlantic. For fish and benthos, this is suggested from sedimentary records, which in the absence of fishing indicate large variability in the abundance of fish. Historical records also offer insight into the effects of climate change on fish stocks. Numerous other studies have reported relationships between environmental conditions and changes in recruitment, abundance, distribution or the growth of fish and shellfish. Excepted the records in fisheries (Lloret *et al*. 2001), long-term datasets are limited for the Mediterranean sea, excepted in several local marine stations giving a few examples of impacts of extreme events and climate variability on given planktonic and benthic species... Impact on community structure and marine food webs still need to be investigated. These impacts could be attenuated by the fact that Mediterranean biota is somewhat adapted to common high seasonal and interannual variability in hydrographic variables.

INSERT 2: Impacts on some specific Mediterranean marine ecosystems

Impact on phytoplankton species

The influence of water temperature on productivity of Mediterranean phytoplankton is quite complex. In general, colder years tend to be more productive, partly because mixing in the water column may reach a greater depth and incorporate more nutrients and partly because the formation of deep water may occur over a larger area. Marty *et al*. (2002) showed that over 10 years of data acquired at the DYFAMED site, there was a general increase in total phytoplankton biomass between 1991 and 1999. The authors concluded that this increase was mainly due to small-sized phytoplankton as a specific response to the lengthening of the summer stratification period, a period favouring the growth of species supporting the regeneration production. According to Bosc *et al.* (2004), a comparison of ocean colour data acquired for the periods (1978-1986) and (1998-2001) revealed, in the northwestern sub-basin, conspicuous differences such as the reduction of the deep convection zone, the earlier start of the spring bloom and the quasi absence of the autumn bloom. Those changes likely result, if not from a little-known several-year variability, from actual environmental changes. Those examples illustrate the utility of time series/observations data to identify the possible shift/evolution of ecosystem submitted to new forcing related to climate change. Climate change may also lead to increase atmospheric deposition. These atmospheric particles, P and Fe-rich, may be able to favour the N_2 fixation by diazotrophs organisms (Bonnet *et al*., 2005), providing new nitrogen for the system, in particular during the season characterized by strong stratification and low productivity when nutrients are totally depleted in the surface mixed layer. Global warming atmosphere may have strong effects on stratification of the surface waters in the Mediterranean Sea, by increasing its depth and its duration. This would thus enhance the fertilizing role of the atmosphere, at the expense of that of the deeper ocean. .

Impact on zooplankton species

In the Gulf of Lions (Western basin), changes were observed in the copepod communities from 1957-1964 to 1986-1988 and 1993-1994 periods, such as a decrease in the abundances of *Temora stylifera* and *Centropages typicus* and an increase of two *Clausocalanus* specie, changes that were attributed to the increase of the sub-surface salinity and the winter temperature in that area (Kouwenberg, 1998). In the Eastern basin, dramatic modifications of the deep and intermediate circulation started during the EMT (late 1980s) (Roether et al., 1996) whose consequences echoed in the epipelagic zooplankton in the Ionian Sea (Mazzocchi et al., 2003) and Adriatic Sea (Kamburska and Fonda Umani, in press). Some monotonous trends in the decadal changes observed in the Mediterranean marine ecosystem have been however interpreted as more affected by anthropogenic than climatic forcing (Duarte et al., 1999). Along the Levantine coast, anthropogenic factors such as the Aswan High Dam and deepening of Suez Canal (which has induced the migration of planktonic fauna from the Red Sea), might be signed by a rise in temperature and salinity (Lakkis, 1997; Lakkis and Zeidane, 2004).

Impact on benthos

It has already been established that changes occurring offshore are reflected in easily surveyed benthic indicators. A rise in both the salinity and temperature of the sea will result in a decrease of oxygen solubility and an increase in organic matter decomposition. This may enhance the oxygen depletion in some coastal, shallow areas (e.g. bays), which may negatively affect benthic species.

2.5 Role of the chemical composition of the atmosphere on the Mediterranean climate and severe events

Coordinator: C. Guieu

The variable atmospheric chemical composition in trace substances has two major effects in the Mediterranean. First, due to high tropospheric aerosol concentrations in particular, it impacts the radiative balance and therefore the regional climate. Second, due to high deposition fluxes of desert dust and pollution aerosols, it impacts the nutrient concentration in surface waters and therefore the regional ecosystems.

The Mediterranean Sea, the “Sea in the middle of lands” as its name indicates, is submitted to numerous and intense sources of aerosols from the continents nearby. The chemical composition of the Mediterranean particulate aerosol is controlled by the extent to which an anthropogenic-rich “background” material, having a mainly European origin, is perturbed by mixing with crustal components of desert origin (Chester *et al*., 1993). On a yearly average, satellite data show that the aerosol load shows a north to south increasing trend (Moulin *et al*., 1998) so that dust dominates the aerosol optical and mass load. Indeed, the Mediterranean Sea receives one of the highest rates of aeolian material deposition in the world (Guerzoni *et al*., 1999). Other aerosols such as pyrogenic and volcanic also provides short/discontinuous but intense aerosol emissions that superimpose with anthropogenic background originally from industrial activity, traffic, agricultural and domestic burning that are emitted from all the countries around the Basin (e.g. western basin: Bergametti *et al*., 1992; Ridame *et al*., 1999; central basin: Pace *et al*., 2006; eastern basin: Sciare *et al*., 2005). The role played by these particles in water cycle and their impact on the Mediterranean ecosystem and climate are related to their specific physical, chemical and hygroscopic properties.

2.5.1 Aerosol and climate

Aerosols affect the atmospheric energy budget by scattering and absorbing solar radiation, reducing solar radiation absorption by the sea by approximately 10% and altering the heating profile of the lower troposphere (Lelieveld *et al*., 2002). In addition to provide support for nucleation of clouds, aerosols surfaces favour uptake and reaction of gases, such as uptake of anthropogenic HNO_3 (Dentener *et al*., 1996) that modify the pH in the close environment of the particle. This will have two types of effects depending on the relative proportion of anthropogenic/mineral particles: the buffering capacity of mineral dust can reduce or even neutralize the strong acidity of anthropogenic aerosols (Loÿe-Pilot and Martin, 1996; Dentener *et al.,* 1996); on the other hand, the strong acidity of anthropogenic aerosols may enhance the solubility of elements associated with the mineral particles (Guieu *et al*., 1997). Hygroscopy properties and CCN (cloud condensation nuclei) activity can be greatly enhanced during atmospheric transportation and aging (Gibson *et al*. 2006).

In the perspective of anthropogenic climate change, models predict profound changes concerning the regime and intensity of precipitation in the Mediterranean region (e.g. Gibelin and Déqué, 2003) that may have profound implications on the atmospheric fluxes and forms of the deposition (dry vs. wet; particulate vs. dissolved) and directly impact the bioavailability of elements reaching the seawater and their potential effect on biological productivity. On the other hand, effect of anthropogenic climate change may lead to increase atmospheric input, meaning higher concentrations of aerosols in the atmosphere that may have a feedback effect on the climate. As a matter of fact, increase in Saharan dust transport occurrences over the past decade was reported from satellite monitoring (Antoine and Nobileau, 2006). Moreover, due to increasing demographic pressure, atmospheric fluxes from anthropogenic sources are expected to also increase rapidly (Lionello *et al.,* 2006). Pyrogenic emissions are closely linked to drought and summer heat waves. Heat waves like the one recently experienced in Europe in 2003 may be also a phenomenon more common in the future (Beniston, 2004), with therefore consequences on the pyrogenic emissions.

There have been a number of international studies over the past two decades dealing with chemical composition and fate of aerosols in the Mediterranean Sea (EROS, MEDUSE, ADIOS, CYCLOPS, MINOS, ESCOMPTE, ...). Most of them have focused on the western sub-basin and to our knowledge, none of them did an exhaustive attempt to identify the role of aerosols in this environment upon hydrological cycle and how those particles – whose emissions are increasing, in particular in relation to anthropogenic global change – can have a feedback effect on the Mediterranean Basin climate.

2.5.2 Aerosol and severe events

The most common severe, large-scale aerosol emissions in the Mediterranean environment are related to long-lasting forest fires from southern Europe and to desert dust plumes from Africa. Because both aerosol types are significantly absorbing the solar light (Meloni *et al*., 2006) and contain trace elements like phosphorus and iron (Guieu *et al*., 2005; Bonnet and Guieu, 2006), they can play a significant role on the atmospheric physics and on the marine biogeochemistry of the Mediterranean. The impact is especially worth of investigation during severe events of atmospheric heat waves and marine stratification and oligotrophy. Heat waves like the one of summer 2003 are related to long-lasting high pressure systems above Europe (Luterbacher *et al.,* 2004) and stagnant conditions favour the accumulation of aerosols in the atmosphere. Such events are believed to become frequent due to global warming. On the contrary, summer high deposition events to the western Mediterranean are favoured by low pressure frontal systems from the Atlantic with rains able to scavenge both the dust and the pollution particles that accumulate during the dry season (Bergametti *et al.,* 1992). Finally, events of desert dust severely impact the aerosol load at the surface and are responsible for most of the PM10[5] alerts in urban environments. Given the observed increase

[5] PM10 [PM2.5] refered to Particulate Matter smaller than about 10 [2.5] micrometers (which cause health problems as not filtered in the nose and throat like the larger particles)

in African dust transport in the Mediterranean (Antoine and Nobileau, 2006), it is expected that the frequency of high PM10 and PM2.5 will increase in the future and this should have consequences on aerosol abatement policies.

3. Scientific Objectives

Besides societal and economic aspects (*see* section 4), five main overall scientific issues (also called objects hereafter, Fig. 3.1) have been identified for the water cycle in the Mediterranean. As the Mediterranean system is highly coupled, these objects involve generally more than one single compartment of the Earth system (ocean, atmosphere, continental surfaces and hydrology) and need, in order to be addressed, to consider interactions between compartments. Considering the time-scales, the first two objects span from the seasonal to the century scale in priority, without ignoring the impact of extreme events on the average values. The three others mainly range/span from the event to the seasonal scales, without disconnecting them from the climate change evolution.

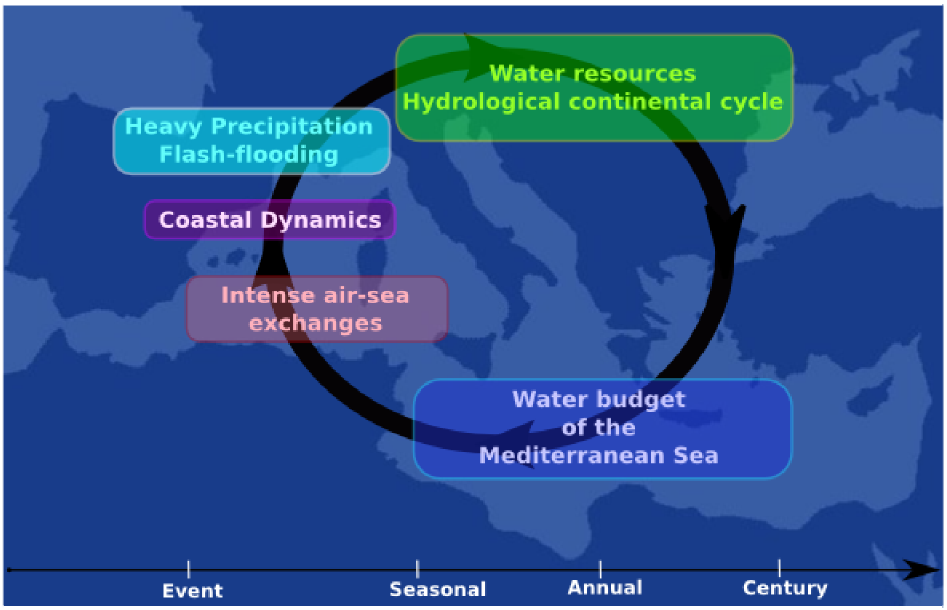


Figure 3.1: The HyMeX Objects.

3.1 Water budget of the Mediterranean Sea

Coordinators : S. Somot / L. Prieur

3.1.1 Introduction

In the Mediterranean basin, fresh water is often either too rare (summer droughts) or in excess (heavy precipitation event). These extreme events are part of the regional Mediterranean water cycle, which is a continuous process dealing with the different parts of the regional climate system (atmosphere, sea, land, vegetation, river, , …) and with the different climate time scales (seasonal, interannual and decadal variability, long-term trends). Its continuous and integrated characteristic is essential in the case of the Mediterranean Sea which responds to the E-P-R budget (evaporation - precipitation - river runoff) over its surface at different time scales. Section 2.2 underlines **the importance of accurately knowing the E-P-R budget of the Mediterranean Sea and its variability which constrain two key components of the Mediterranean circulation**:

- the yearly dense water formation rate as well as the temperature and salinity characteristics of the water formed — this newly formed water then drives the Mediterranean thermohaline circulation

- the density of the Mediterranean water flowing at depth at the Gibraltar Strait and influencing the Atlantic ocean characteristics at intermediate depth.

Section 2.2 also points out that the Mediterranean Sea could influence **the atmosphere water content over the sea, the behaviour of the low level atmosphere and then the coastal intense precipitation events through the terms of the water budget**. The water budget is **not only driven by the atmospheric characteristics, but also depends on the ocean characteristics** (SST, heat content of the ocean mixed layer, depth of the mixed layer). So that the feedback of the Mediterranean Sea on the atmosphere through the terms of the water budget should not be disregarded.

In the past, the different terms of the Mediterranean water budget and their variability at different time scales have been studied separately over land or over sea but only very few times in an integrated way associating the different compartments of the Earth system. Compared to the numerous data available over land at different time scales, the available data over the sea are very few and sparse. The estimate of the E-P-R budget, its uncertainties, its seasonal-to-interannual variability and its future evolution thus deserve a particular attention in HyMeX. **Obtaining an accurate estimation of every term of the Mediterranean water budget and for every time scale (seasonal, interannual, decadal, trends, 21st century climate change) is quite a challenging goal for the observation and modelling community and is a main objective of HyMeX**.

In this section, we analyze the different terms of the Mediterranean water cycle focusing on the current lacks and needs and on possible proposals in terms of observation strategy and modelling development. A climate point of view is adopted, *i.e.* we have chosen to deal with climate time scales from the seasonal to the century scale, without forgetting the impact of daily or extreme events on the average values. We also focus on the whole Mediterranean basin (or on large sub-basins) contrary to the following sections. As shown in Figure 3.2, the different terms of the Mediterranean water cycle are the precipitation (section 3.1.2.1), the evaporation (section 3.1.2.2), the moisture convergence (3.1.2.3), the hydrological transfer function between the precipitation over land and the rivers, the runoff flux at the river mouths (3.1.2.4) and the exchanges with the Atlantic Ocean, the Indian Ocean and the Black Sea through the corresponding straits (3.1.2.5). This term splitting is adopted for the outlook of this "scientific questions" section.

3.1.2 Scientific questions

3.1.2.1 Precipitation

- Over land

The precipitation observing system around the Mediterranean Sea is not homogeneous in quality and space but data are generally available over a long period of time and they can be used for climate study. Homogenized station data are available in many countries (Caussinus and Mestre, 2004) but often with restricted rights. Gridded datasets such as the CRU database (New *et al*., 2002) are also available but only at a monthly time scale. Gridded datasets at a daily time scale and covering a long period of time also start to be available (see the ENAC and ENSEMBLES European projects for example).

For the Euro-Mediterranean area, climate studies have already been performed using the CRU dataset (Jacob *et al*., 2006). The local daily station data allow the study of the local trends in precipitation (Moisselin *et al*., 2002; Alpert *et al*., 2002) and daily precipitation extremes (Déqué *et al*., 2007). Studies going back to year 1500 have even been conducted for the Mediterranean area and have yielded very long time series or reconstructed indexes (*see* Luterbacher *et al,*. 2006 for a review). These studies conclude to a high interannual variability in precipitation and often drying long-term trends for the 20th century in many areas around the Mediterranean Sea. Further back in time, palaeoindicators such as pollens show that the Mediterranean climate has been even drier than today in periods like the last glacial period, and that at that time, both the climate and vegetation have undergone abrupt and large changes (e.g. Combourieu Nebout, 2002; Allen *et al*, 1999)

- Over the sea

Direct measurements of precipitation over the sea are rare and indirect estimations from coastal stations can only be approximate. However using other sources of data (reanalysis, indirect estimation), some authors tried to evaluate the precipitation amount for the Mediterranean sea surface (Boukthir and Barnier 2000, Mariotti *et al.,* 2002). Mariotti *et al.* (2002) give a range of 331-447 mm/yr for the 1979-1993 average value for precipitation with a seasonal cycle amplitude of 700 mm/yr (see Fig. 3.3 for comparison between data and two GCMs).

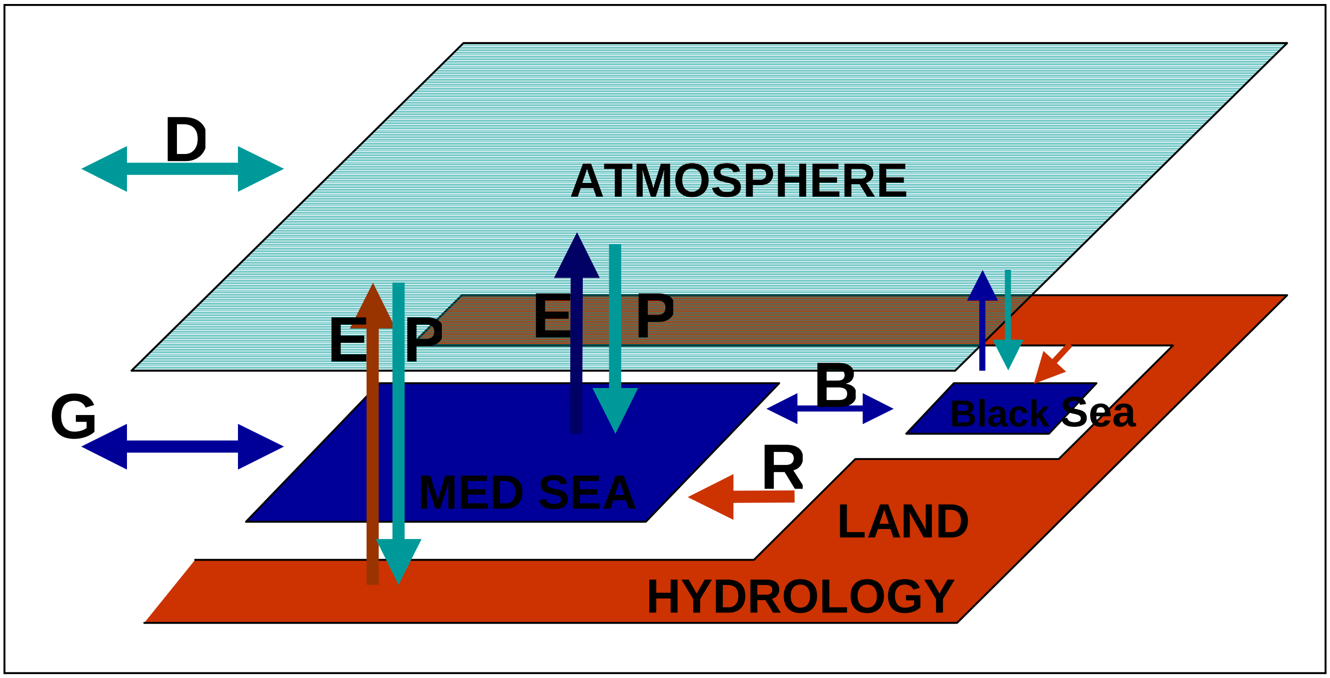


Figure 3.2: A schematic 3D box diagram illustrating the main components of the Mediterranean basin . P stands for precipitation, E for evaporation, R for river runoff, D for water divergence, G for Gibraltar transport, B for Black Sea transport.

Needs and proposals:

→*Development of a meta-database of existing precipitation observations over land*: precipitation over land is the best-known term of the Mediterranean water budget at different time scales. However, data in southern Mediterranean remain sparse and daily data are not always available (for scientists abroad). A meta-database dedicated to Mediterranean studies and listing the existing datasets and their availability is then needed by the climate community. The development of Mediterranean integrated working group or projects such as MedClivar, HyMeX or CIRCE should contribute to this specific goal.

→*Fine scale and long-term precipitation products over land*: precipitation over land contributes to the Mediterranean Sea water budget through the catchments of the Mediterranean Sea or Black Sea rivers, which thus implies a fine-scale monitoring of precipitation over these river catchments. Increasing the density of the rainfall gauge is a solution but will never permit to recover the last 40-year high-resolution variability of this field. Therefore, approaches combining dynamical or statistical downscaling methods applied on reanalysis dataset and local validation with high-resolution station data are necessary. Indeed, a homogeneous dataset of high quality all around the basin for at least daily time scale and over a period of time long enough to study decadal variability and long-term trends possibly due to climate change are necessary.

→ <u>*More accurate estimation of precipitation over sea*</u>: until now, the precipitation estimates over the Mediterranean Sea depend on reanalyzes and indirect measurements. Reanalyzes are however not accurate enough in terms of precipitation (Mariotti *et al*., 2002; Josey, 2003) and the land-sea correction of the precipitation are rather empiric. This results in a too large uncertainty for the evaluation of this term of the budget. Precipitation measurements over the sea are essential for a thorough validation of the reanalyzes or GCM/RCM and the improvement of their physical parameterizations. Over the sea, the satellite- based products should also be taken into account when developing the precipitation (and evaporation) dataset.

→<u>*Detection and attribution of the observed trends in precipitation*</u> for the Mediterranean basin are also questions completely open. Regional technique should be developed and applied to the Mediterranean dataset.

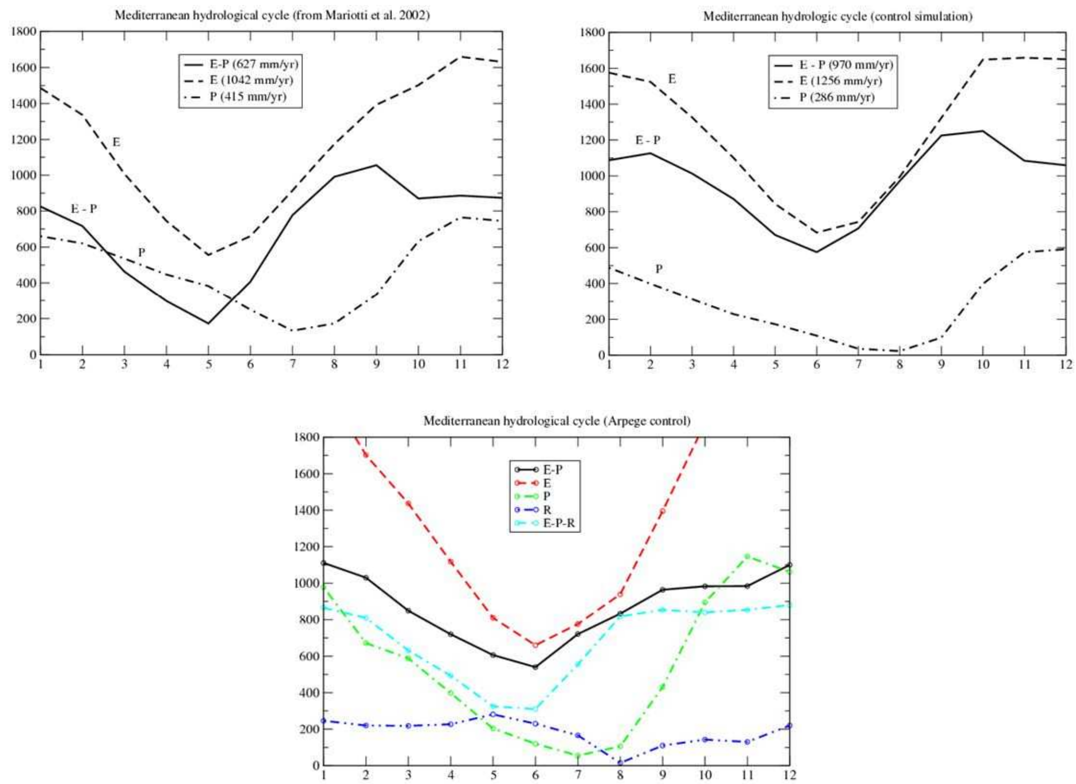


Figure 3.3: Mean seasonal cycle (over the Mediterranean Sea) of the precipitation (P), evaporation (E), river runoff flux (R), E-P budget and E-P-R budget for the observations after Mariotti *et al*. (2002) (top left), the Mediterranean version of LMDZ (top right) and the Mediterranean version of ARPEGE-Climate (bottom).

3.1.2.2 Evaporation

Observations of evaporation over land exist but are sparse. They do not cover the whole Mediterranean basin with accurate and homogeneous data and thus do not permit an accurate evaluation of the E-P budget over the Mediterranean river catchment for instance. This matter will be discussed more thoroughly in Section 3.2.

Over the sea, large latent heat surface fluxes are experienced especially in winter when northern dry and cold air masses flow (over the sea). At short time scales, large latent heat fluxes feed heavy precipitating systems (section 3.3), govern deep water formation (section 3.4) and impact coastal dynamics (section 3.5). However this term is also crucial at longer time scale because it is strongly correlated with the interannual variability of the water and heat budgets of the Mediterranean Sea. Few direct observations are available, mainly coming from ship campaigns (and thus limited in time and space), others retrieved from satellite imagery (Bourras *et al*., 2002a,b). Consequently, data of latent heat flux over the Mediterranean Sea have low space and time resolutions (see SOC and COADS database, Josey *et al.,* 1999 and da Silva *et al*, 1994) and contain biases as for reanalyzes. It is also worth noting that indirect methods based on ocean water budget for a given area could also provide evaporation estimates. These methods (see section 3.1.2.6) do not require knowing the water flux in the straits but require a well-defined experimental strategy covering the area of interest.

The estimation provided by Mariotti *et al*. (2002) is of 934-1176 mm/yr with a large seasonal amplitude (1000 mm/yr, see Fig. 3.3). The latent heat flux is thus not only the largest term of the E-P-R budget and one of the most variable, but also the one which is the worst observed and simulated. Moreover a strong modification of it is foreseen during the 21st century. Consequently HyMeX should focus on this term, with the simultaneous aims to acquire a better knowledge of the factors controlling its interannual and decadal variability.

Needs and proposals:

→ *Direct observations of evaporation* are needed for a better estimation of this term. Ship campaigns are necessary to obtain spatial high-resolution gridded data for direct and indirect estimates, and also to calibrate climate time scale monitoring systems using fixed buoy stations or satellite measurements.

→ *Improvement of the latent heat flux parameterizations over the sea*. Focus on the bulk formulae and the physics of the marine atmospheric boundary layer is needed. This development requires high-resolution in-situ data on short time scale for validation and will profit both to Numerical Weather Prediction models and Climate models.

3.1.2.3 Atmospheric water transport

As E-P over the sea is positive, and as E-P-R is also positive, it means that the Mediterranean basin (Mediterranean Sea and river catchment basin) exports water towards the other Earth compartments, mainly towards the land area around the Mediterranean Sea. Atmospheric water flux divergence has been analyzed by Mariotti *et al*. (2002) and Fernandez *et al*. (2003) using reanalysis data (NCEP, ERA-15). Moisture enters the Mediterranean area from the west and northwest whereas it exits to the east and south (Eastern Europe, Middle East and northeastern Africa). The moisture transport is mainly zonal in winter (classical wintertime large-scale weather regimes in this area, Fernandez *et al*., 2003) and more southeast in summer explaining part of the link between the Mediterranean Sea and the African monsoon (Rowell, 2003; Peyrillé *et al*., 2006; Sultan *et al*., 2007).

Needs and proposals:

→ *Identification/quantification of moisture transport*: The evaluation of moisture transport in the water budget (and the water flux divergence) and its contribution to E-P-R at high temporal resolution (to investigate the seasonal variability) remain key issues like in other recent large field experiments (IHOP_2002, AMMA, COPS). Both should be better quantified using (suited) observations, mesoscale assimilation systems (for continental surfaces, ocean and atmosphere) and high-resolution regional models with thoroughful validation.

→ *Air-sea coupling*: estimates of water vapor transport from the Mediterranean area towards the southern and eastern part of Europe are different when using a fully coupled atmospheric/oceanic model instead of an atmospheric model alone (Somot *et al.*, 2007). Moreover, switching from a non-coupled to a coupled regional model can enhance the warming and drying simulated for Europe for the 21st century. Regional SST patterns and/or regional air-sea interactions seem to be the key processes explaining this behaviour. Their links with the regional water transport should be investigated during HyMeX.

3.1.2.4 River runoff to the Mediterranean Sea

The transfer of the water from the land area to the sea is performed trough a very complex system linking the vegetation, the land surface and the rivers and aquifers. This hydrological transfer function is described in details in section 3.2. and leads to the river runoff flux in the river mouth and, to a lesser extent, through the aquifers.

The river runoff flux is not negligible for the Mediterranean Sea, neither locally nor globally. For example, locally, the Rhone area of influence in the Western basin is quite large and isolates the coastal zone from the open-sea (see section 3.5). It is accepted that the rivers represent about 10% of the E-P-R budget. Their strong influence on the Mediterranean salinity evolution in a climate change scenario has also been proved (Somot *et al.,* 2006). Many authors have tried to evaluate the mean annual river discharge for the whole Mediterranean Sea. Estimations vary significantly: Béthoux *et al*. (1979) give a value of 270 mm/yr whereas Mariotti *et al.* (2002) propose a weaker value of 100 mm/yr.

The RivDis database is freely available (Vörösmarty *et al*., 1996) and can be used to set up a multi-year monthly mean climatology as currently done (Somot 2005, total river runoff equal to 200 mm/yr). Moreover this database also contains interannual values which can be used. Note however that the role of the interannual variability of the river runoff on the Mediterranean salinity evolution has never been studied up to now. Figure 3.4 shows its possible influence. This figure compares the interannual time series of the salt content of the Mediterranean Sea for in-situ observations (Rixen *et al.*, 2005) with the equivalent time series for a simulation carried out with the OPAMED8 model (Somot *et al*., 2006) forced by air-sea fluxes coming from a dynamical downscaling of the ERA40 reanalysis. The interannual variability of the air-sea fluxes is then reproduced but the river runoff and the Atlantic inflow are kept constant throughout the simulation. Figure 3.4 shows that the model is not able to simulate the interannual variability of the salinity budget. If we trust the air-sea flux variability and the hypothesis that the Gibraltar Strait transport variability is negligible, it can be concluded that the river interannual variability should be the lacking term. This should however be demonstrated in future studies in considering the interannual variability of the river runoff.

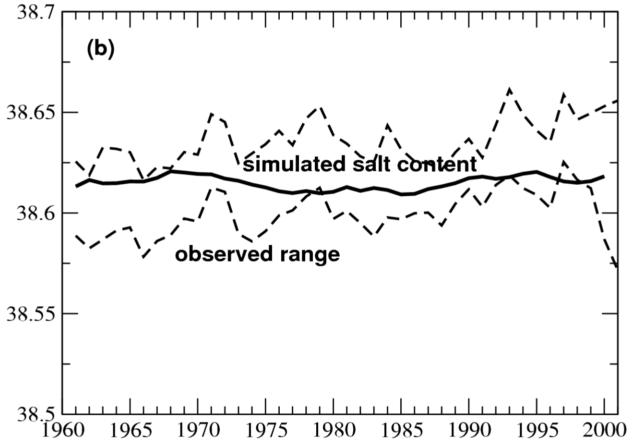


Figure 3.4: 1961-2001 time series of the 3D integrated Mediterranean salinity (in psu). The observation range from Rixen et al. (2005) is comprised between the two dashed curves and model values (F. Sevault, personal communication) are displayed in thick black line. See details about the model in the text (section 3.1.2.4).

Needs and proposals:

→ *Accurate estimation of river runoff:* The first goal is clearly to estimate an accurate total river runoff flux for the Mediterranean Sea to decrease the current uncertainty. This might be achieved from already existing database in taking into account the decadal temporal variation of the discharge.

→ *Observed trends in river run-off:* As an integrated system, the rivers allow to point out long-term trends in the water cycle, even if the anthropogenic changes of these rivers are a problem in that issue. Then we can ask two specific questions: is it possible to isolate some long-term trends in this part of the budget and evaluate its impact on the Mediterranean Sea hydrology? For this long-term trend, can we besides separate the direct anthropogenic changes (dam, irrigation) from the indirect changes (increase in GHG concentration)?

3.1.2.5 Gibraltar Strait transport and exchanges with the Black and Red seas

- Gibraltar transport

The major impact of the Gibraltar Strait water and heat transports has been described in details in section 2.2. The conclusions are that some good estimates of these transports start to be available -at least in average- and that transports depend on density difference between the Atlantic ocean and the Mediterranean Sea. However strong uncertainties remain and their temporal variability is largely unknown.

- Black Sea – Aegean Sea exchanges

The Black Sea – Aegean Sea exchanges are as complex as the exchanges through the Gibraltar Strait with a two-layer flow constrained by the physical characteristics of the strait. Fresher water comes at the surface from the Black Sea and an opposite salty water flux is observed below. However the heat net transport is weak and the water net transport can be summarized as freshwater inflow for the Aegean Sea. Thus the Black Sea – Aegean Sea exchanges are often simulated as a river flowing into the Mediterranean Sea. The value of the "equivalent runoff" is again not very well known, but a seasonal cycle has been evaluated from the study of the Black Sea water budget (Stanev *et al*. 2000). However as for the other rivers, this flux has an important interannual variability and also long-term trends. Moreover the decrease observed over the last decades (mainly due to the building of dams along the Black Sea rivers and irrigation) has perhaps already have had an impact on the Mediterranean

Sea thermohaline circulation through the Eastern Mediterranean Transient event (*see* section 2.2). As this "river" is the most important one in the Mediterranean Sea and has then a large impact on the Mediterranean water budget, it should be taken into account whatever the Mediterranean area of interest.

- Red Sea – Levantine sub-basin exchanges

Up-to-now these exchanges through the Suez canal have always been neglected in the E-P-R estimations and in the Mediterranean Sea modeling, as they seem to be very small compared to the two others.

Needs and proposals:

→ *Find alternatives to the stationarity hypothesis*: If we would like to go further than the previous studies in the HyMeX project, we should forget the stationarity hypothesis (*i.e.* balance between the surface water flux and the Gibraltar transport, see section 2.2) and we should focus on direct measurements with a high temporal and spatial resolution and over a long period of time. Multi time-scale observations are needed from seasonal to interannual variability and long-term trends.

→ *Develop multiple-level nested ocean models approaches*: In terms of modeling, the Gibraltar Strait transports is simulated either at very high resolution by limited area models for short time period and with idealized forcings, or at low resolution by Mediterranean or global ocean models but over longer periods and more realistic forcings (see Artale *et al.* 2006 for a review and Sannino *et al.* 2007). The two approaches should now converge in using nested and coupled models. A three-nested level system coupling an Atlantic ocean model, a very high resolution and non-hydrostatic Gibraltar Strait model and a high resolution Mediterranean Sea model could be a modelling challenge of the HyMeX project. Targeted resolution for these three models could be 1/2° (50 km), 1/64° (1.5 km) and 1/16° (6 km), respectively. These models already exist and should be coupled. This complex tool and the different resolution are scientifically legitimated by the physical processes to resolve in each part of the ocean (see also Artale et al. 2006). A first step toward this complex coupling is planed within the ANR-CICLE and the FP6-CIRCE projects.

→ *Study the impact of the Black Sea – Aegean Sea exchanges*: The impact of the Black Sea – Aegean Sea exchanges on the Mediterranean water budget as well as on the Mediterranean thermohaline circulation is uncertain up to now and could be evaluated through sensitivity experiments at the different time scales (as made in Skirlis *et al.*, 2007 on the influence of the Nile river). These experiments must include tests on the way of modeling the strait exchanges in introducing at least a strait model but perhaps also a Black Sea model in the Mediterranean Sea model.

→ *Evaluate the influence of the Suez canal*: First estimates from observations and first sensitivity tests in modelling have to be done in order to close or open the question of the influence of the Suez canal.

3.1.2.6 Global Mediterranean water budget

3.1.2.6.1 Water mass formation and mixed layer budget as a constrain to evaluate the Mediterranean water budget

As seen above, obtaining an accurate estimation of every term of the Mediterranean water budget and for every time scale (seasonal, interannual, decadal, trends, 21st century climate change) is quite a challenging goal for the observation and modeling communities. However the global Mediterranean water budget, and more generally the Mediterranean air-sea fluxes, can also be estimated indirectly from heat and salt budgets of the ocean mixed layer. At least two methods are already available using in-situ observations and regional modelling tools. The first one (Walin, 1982; Tziperman and Speer, 1994; Somot, 2005) computes water volume budget for different density classes. For a given area, knowing the time evolution of the volume of the density classes and the advection at the boundaries leads to constrain the value of the air-sea heat and salt fluxes. The second one is based on the estimate of the time evolution of the mixed layer heat and salt budgets during at least one year for a given area. Algorithms merging data and model outputs allow then optimizing the air-sea fluxes which led to these budgets. This method was applied with success during the POMME campaign (Caniaux *et al*, 2005; Giordani *et al.,* 2005).

Needs and proposals:

→ *Dedicated in-situ oceanographic campaigns:* data of temperature, salinity and mixed layer depth should be acquired during a one-year period on a defined area. Heat and salt advection terms should be measured at the boundaries and air-sea flux estimates should be obtained for the same area and period of time. Spatial high-resolution measurements are required as well as two or three in-situ campaigns. The river inflow term should not be neglected *a priori* when working on the Mediterranean Sea.

→ *Dedicated ocean and coupled regional models:* specific modelling tools (preferably atmosphere-ocean coupled models) should be set up to re-do the given period with or without assimilation of the in-situ data of temperature and salinity. Walin's method and mixed layer heat and salt budgets should be computed from the model outputs.

3.1.2.6.2 Influence of the intense events on the global Mediterranean water budget

So far, in this section, we have focused on the basin averaged and yearly averaged values of the terms of the water budget. However the impact of the local and short-duration intense events of each term on the global budget is unknown yet. These intense events are frequent for the precipitation, for the latent heat flux and the evaporation under low-level jet associated with heavy precipitation, under dry and cold winter continental air masses and for the local winds (Mistral, Mediterranean cyclones). Moreover the ocean does not respond linearly to such local intense forcings. The ocean circulation is indeed mainly driven by the geostrophy and by the mesoscale features which can react in few days to inhomogeneous forcing events of pressure, precipitation, wind or evaporation. The intense events can locally modify the surface layers and then can modify non-linearly the heat and salt content of the mixed layer creating horizontal density gradients. This may lead to changes in the surface circulation, in the instability of the surface currents (Béthoux *et al*. 1988) and then in the mixing of the water mass characteristics for instance. The non-linearity of the regional water budget linked to the local intense events is also observed for the vegetation-soil-river system (impact of intense precipitation, see sections 3.2 and 3.3) and for the dense water formation events and coastal dynamics (see sections 3.4 and 3.5). For example, the temporal variability of the extreme events (when in a given season) certainly plays a role on the dense water formation in preconditioning or not the surface layers at the right period. Madec *et al*. (1991) and Artale *et al*. (2002) showed for instance that the daily variability of the heat flux during the autumn and winter seasons influences the formation rate and the temperature and salinity characteristics of the dense water formed. This intermittent regime also plays a role during the restratification phase in spring, in delaying the surface layer warming and in changing the pelagic ecosystem evolution (Andersen and Prieur, 2000). The maximum SST can reach 30°C in the northwestern part of the Mediterranean Sea some years (July 2006, I.Taupier-Letage pers. comm., TRANSMED thermosalinograph data time series) and only 21°C for others (August 2006) in relation with the wind gusts and the air masses crossing this area during summer. The atmospheric or river intense events show not only a temporal but also a spatial intermittent regime; eventhough they are mainly local or regional they have an impact on the global Mediterranean water budget. They also can locally modify the sea surface characteristics and have a feedback on the atmosphere and then on the water budget itself.

Needs and proposals:

→ *Quantify the impact of the high-frequency temporal and spatial variability* on the different terms of the water budget and on the various processes by sensitivity studies with appropriate models. The impact of the intense events on the interannual variability of the water budget should also be studied. Note that the intense events can be found at different time scales: daily intense events could have an impact on monthly mean but monthly intense events can influence yearly mean and then the interannual variability. The impact of spatiallyevents on the global Mediterranean water budget should also be quantified. The periods of strong evaporation under dry and cold air masses, of intense precipitation events and of floods have to be documented during HyMeX Observation Periods and examined with respect to the anomalies of the Mediterranean Thermohaline Circulation (MTHC).

3.1.2.6.3 Impact of the climate change on the global Mediterranean water budget

Mariotti *et al.* (2002) studied the interannual variability of the precipitation finding the now established anti-correlation with the NAO index and a decreasing trend over the last decades. This trend is in agreement with the trend foreseen in the climate change scenarios for the precipitation over the Mediterranean Basin (see section 2.1). However, the quantitative value of the drying is far from being well known and the evaluation of the various uncertainty sources has only started. The atmospheric climate change would also directly impact the Mediterranean Sea. During the 21st century, the sea might experience a large warming and salting as well as a weakening of its thermohaline circulation (Thorpe and Bigg, 2000; Somot *et al.*, 2006). The issue of the occurrence of the extreme events linked with the regional water cycle (droughts, heat waves, intense precipitation) should also be quantified. The impact of the climate change on the Mediterranean water budget and the associated uncertainties remain then open issues. For example the changes in the evaporation term over the sea or the changes in the river inflows are largely unknown.

This is illustrated by the scenarios of climate change for the Mediterranean Sea, which underline the key role of the rivers in changing the surface salinity of the Mediterranean Sea, then the surface density and consequently the MTHC. Somot *et al* (2006) pointed out that the large uncertainties due to this earlier term should be evaluated in forthcoming studies. Figure 3.5 shows the uncertainty concerning the impact of the climate change on the river runoff flows for three main Mediterranean rivers. The ratio between the present-day climate and the future climate (end of the 21st century, IPCC-A2 scenario) is plotted. The outcome is a general decrease in river runoff. However a large uncertainty is also obtained when comparing different models. The uncertainty range goes from a ratio equal to 0.3 to a ratio of 0.75 for the Ebro for instance. Using one or another scenario can thus have a completely different impact on the Adriatic surface salinity and then on the formation of the Eastern Mediterranean Deep Water in winter.

Evaluating the modification of the Mediterranean water budget will also participate to estimate the regional sea level rise during the 21st century. This estimation is a complex (Tsimplis *et al.,* 2007) but key issue in the Mediterranean framework as it could impact a large part of the Mediterranean coast inhabitants.

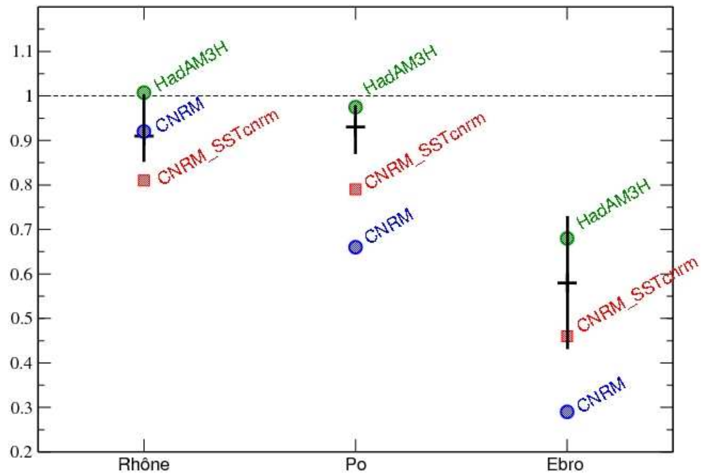


Figure 3.5: 30-year annual mean ratio of the river runoff flows between the 1960-1989 period and the 2070-2099 period in an IPCC-A2 climate change scenario (S. Somot, personal communication). The value one (dashed line) means no change between present and future climate. Values less than one mean a decrease in river runoff. The green dots represent the HadAM3H simulation forced by the Hadley Center (HC) SST anomalies, the black crosses represent the average value of 9 regional climate simulations performed with limited area models forced by HadAM3H and the HC SST (data from the PRUDENCE European project, S. Hagemann, personal communication), the black bar is the full range of uncertainty from these 9 models, the blue dots represent the CNRM simulation with the stretched version of ARPEGE-Climate (same resolution as the other RCMs, 50 km, and same HC SST anomaly) and the red squares represent the CNRM simulation with CNRM SST anomalies.

Needs and proposals:

→ *Quantify drying and associated uncertainties with the climate change*: A multi-model approach covering the wide range of uncertainties in regional climate change scenario should be used. Among the sources of uncertainty we can cite the choice of the GHG concentration scenario, of the global coupled model, of the downscaling technique (statistical or dynamical), of the regional climate model in case of dynamical downscaling, of the resolution/domain size of the RCM, of forcing or coupling with the Mediterranean Sea. In the HyMeX project, this uncertainty cascade has to be assessed for the whole Mediterranean area to give more confidence in the first results obtained on the regional impact of climate change. HyMeX will actually complete the already ongoing work in European projects such as ENSEMBLES, CIRCE and SESAME in bringing a better validation of the regional models and methods used to assess the Mediterranean climate change.

→ *Validation of the regional climate models on evaporation over sea:* This will lead to better confidence concerning the regional climate change scenarios. The evaluation of the uncertainty for this term has not been done yet, even if multi-model datasets starts to become available.

→ *Evaluate uncertainties due to river runoff changes*: This should be done thanks to a multi-model approach (e.g. the PRUDENCE, ENSEMBLES, SESAME or CIRCE European projects) and in collaboration with hydrologists.

→ *Evaluate uncertainties due to exchanges with the Black Sea:* In the climate change scenarios, the exchanges with the Black Sea are one of the E-P-R terms for which the uncertainty is the most important. Indeed this term integrates the contribution of the E, P and R terms of the Black Sea water budget. Quantifying the uncertainty around this term is then a goal toward a more robust estimation of the possible evolution of the Mediterranean Sea salinity and THC.

→ *Evaluate the regional sea level change:* for the Mediterranean Sea, it requires at least the use of free-surface regional ocean models as well as the estimate of the mass exchanges with the Atlantic Ocean and of the local sea level behaviour due to the changes in the salt content, the heat content and the river inflows.

3.2 Hydrological continental cycle

Coordinators: P. Lachassagne / E. Martin

3.2.1 Introduction

The main characteristics affecting the hydrological cycle of the continental surfaces in the Mediterranean region are:

- **a water resource which is scarce and unevenly distributed in space and time:** the region is characterized by few short duration heavy precipitation events and long drought periods, hot summers, very sharp transition seasons (spring and autumn), the southern shore being significantly dryer than the northern one,
- **the physiographic features of the watersheds**: most of them are medium to small in size, having an upstream mountainous area, and a downstream quite flat coastal outlet, and comprising typically both karstic and Messinian to Quaternary porous-type aquifers (e. g. alluviums, sandy/clayey sedimentary aquifers),
- **the anthropogenic pressures**, with recent changes in land use/land cover (intensification/depletion of agriculture), strong urbanization and population growth, particularly in the coastal areas, tourism, etc.

With respect to the continental surfaces, **one of the main achievements of the HyMeX project** will be:

- to **quantify and simulate the various natural and anthropogenic components of the water cycle (quantity, quality)**: rainfall, evapotranspiration, runoff, hydrographic flows, surface water storage (lakes, dams, etc.), infiltration, storage in soils and vadose zone, aquifer recharges, storage in aquifers, aquifer and river discharges, water abstraction for various purposes (irrigation, drinking water, industries), return flow to surface and groundwater (irrigation return flow, sewage networks discharge, leaks, etc.),
- **from the local to the regional scale** (i.e. for all the catchments reaching the Mediterranean sea),
- and **from the rainfall event to a few years or decades** for the temporal scale.

A complete handling of the water cycle is necessary in order to be able to simulate and analyse past and present evolutions and to run scenarios for quantifying the impact of global change (climatic and anthropogenic) in the near and distant futures, on the hydrological system, both in terms of **water resources management** and **extreme events**.

In the following, the presentation of the scientific questions related to the hydrological continental cycle will first focus on **processes and mechanisms, which will be addressed through detailed approaches and modelling at small scale** (3.2.2.1). Then the issue of **water budget computation at the regional scale** (3.2.2.2) will be addressed through improvements of existing approaches and/or upscaling of the methods inferred from the small scale studies. The **water quality issues** are described in 3.2.2.3, while the aspects linked to the **anthropogenic pressure and to the climate change** are treated in 3.2.2.4. Finally, part

3.2.2.5 shows how new prospects in **remote sensing and assimilation research** could contribute to these objectives.

Flash floods are an intrinsic but specific component of the continental surfaces hydrological cycle. They are usually linked to intense rainfall related to convective events. All the issues specifically related to flash floods are presented in the next section of this white book (3.3).

3.2.2 Scientific questions

3.2.2.1 Process studies and small catchment scale modelling of the water and energy balance

In order to understand and model the processes that govern the water and energy balance at small scale (*i.e.* from the local scale to 10-100 km^2 catchments), the heterogeneity of the structure of the continental surfaces must be taken into account (Braud *et al*., 2005). This includes the effect of natural factors such as topography, geology but also the effects of human-induced features, such as those produced by agricultural practices, urbanisation, reservoirs and dams. Furthermore, specificities of the Mediterranean regions such as topographical particularities, typical vegetation species, geology (karstic areas) must be taken into account and are not fully understood yet, requiring **field experiments** to progress in the understanding of the mechanisms.
In conjunction with field experiments, a **modelling effort**, aiming at coupling the various processes and representing explicitly the heterogeneity of continental surfaces must be performed.

3.2.2.1.1 Understanding and modelling the role of vegetation in the water and energy budget

In recent years significant progress has been made in the modelling of the role of the vegetation through field campaigns documenting the various components of the water and energy budget, especially in the Mediterranean areas. Examples are EFEDA (Bolle *et al*., 1993), Alpilles-ReSeDA (Olioso *et al*., 2002), and SudMed (Chehbouni *et al*., 2007). At the same time, Soil-Vegetation-Atmosphere-Transfer models (SVATs) (e.g. ISBA, SiSPAT, AliBi, S-model, SECHIBA, etc.) and vegetation models (*e.g.* STICS, CropSyst, STEP, V-model, etc.) have been developed and/or improved. Recent works showed the benefit of coupling both: STICS – ISBA (Olioso *et al*., 2005), V-S models (Cayrol *et al*., 2000); or including vegetation growth into SVAT models: ISBA-A-gs (Calvet *et al*., 1998; Gibelin *et al*., 2006), ORCHIDEE (Krinner *et al*., 2005). This category of SVATs is also able to account for the carbon cycle, which is closely related to the water cycle. SVATs allow the determination of parameters controlling transpiration and root water uptake for various kind of crops (Alpilles-ReSeDA, Sud-Med), vineyards and natural vegetation (EFEDA) for the Mediterranean areas. However, the adaptive strategies developed by natural Mediterranean vegetation species to manage water stress (*e.g.* drought avoiding or drought-tolerant strategies, Calvet, 2000; Calvet *et al*, 2004) remain mostly unknown. Some results were obtained on trees (*e.g*. Rambal, 2002), but they must be generalised to other Mediterranean species.

Needs and proposals:

→ *Local scale monitoring of Mediterranean vegetation species*: Field experiments, including the water energy and carbon balance, will be performed in order to derive parameterisations of vegetation functioning.

→ *Parameterisation of the Mediterranean vegetation in SVATs:* Efforts on modelling are required to include the Mediterranean vegetation features when parameterising SVAT and vegetation models, as well as for deepening the coupling existing between both models.

→ *Calibration of SVATs models and assimilation:* The calibration must take into account the specific Mediterranean conditions about soil, vegetation and water. It has to be addressed using multiobjective criteria. Assimilation techniques (as adjoint modelling) can also strengthen the calibration.

3.2.2.1.2 Monitoring evapotranspiration over complex terrains

Evapotranspiration is one of the major components of the water cycle but its direct quantification remains a challenge, especially in mountainous areas due to fetch requirements and the dependence on wind direction. Eddy Correlation (EC) has been recognised as the most accurate method, but the spatial coverage is limited. Scintillometers offer an alternative to address larger scales as they provide an integrated measure over transects and heterogeneous terrains (Meijninger *et al.,* 2006). However, solar sensors provide sensible heat flux only, and evapotranspiration still must be derived as the residual of the surface energy balance. Micro-wave sensors are promising in giving directly the evapotranspiration flux but they require further developments (Green *et al*., 2001; Lüdi *et al*., 2005). The combined use of eddy correlation and scintillometer requires an accurate determination of the footprint, including the contribution of each component to the fluxes. Nevertheless, they can provide an efficient way to validate modelling approaches at scales larger than the local one (Bsaibes, 2007; see Fig. 3.6).

Needs and proposals:

→*Develop the use of advanced methods for the monitoring of evapotranspiration over complex terrains:* The understanding of eddy correlation measurements should be improved. The use of scintillometers should also be developed. Both have to be used over heterogeneous and hilly (or mountainous) catchments.

→*Design experiments dedicated to the validation of evapotranspiration measurements:* The experiments should take place in heterogeneous and hilly catchments. The synergistic use of EC and scintillometer must be encouraged in order to improve the relevance of upscale procedure.

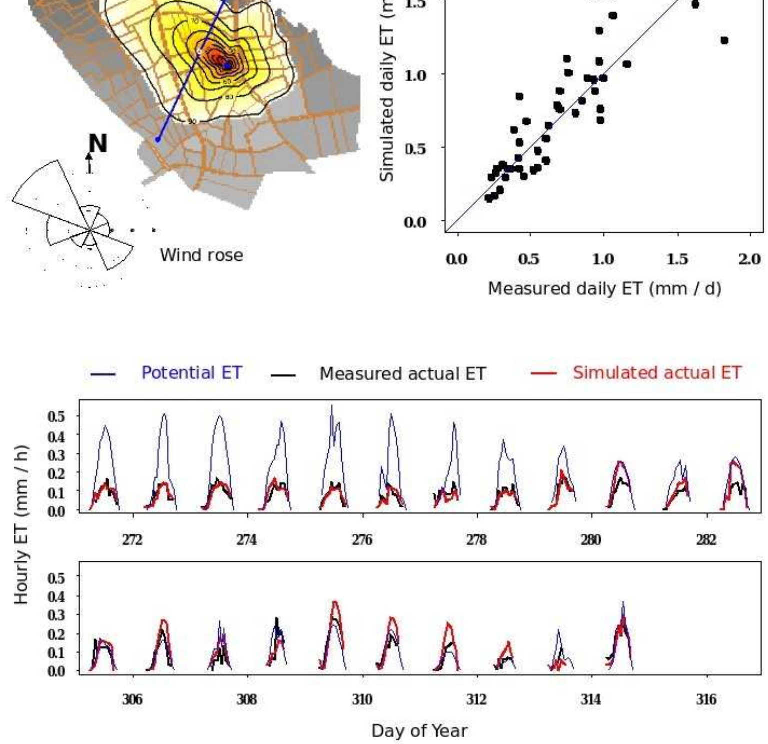


Figure 3.6: Spatially integrated evapotranspiration (hourly and daily) over the 1 km^2 size Roujan subwatershed (ORE "OMERE") during the MOBHYDIC experiment in 2005. Spatially integrated evapotranspiration is estimated from multilocal SVAT simulations and compared against eddy covariance measurements. Top left: wind direction driven eddy covariance footprint, used for spatially weighting multilocal SVAT simulations, is displayed after averaging over the whole simulation period (around 3 months). Top right: validation, against eddy covariance measurements, of spatially integrated evapotranspiration (hourly) from multilocal SVAT simulations. Bottom: comparison between measured and simulated chronicles of daily evapotranspiration (potential evapotranspiration is additionally plotted) for 10 day periods at the beginnings of October and November 2005. The first period (October) is characterized by an atmospheric demanding significantly larger than the surface offering, while both are very similar over the second period (November). The decrease of potential evapotranspiration during the first period results from cloudy conditions which induce changes in micrometeorological conditions. From Bsaibes, 2007.

3.2.2.1.3 Snow processes

The snow cover can play a significant role in the water cycle, by delaying the runoff and limiting the evapotranspiration. Numerous models (included in SVATs or in hydrological models) exist, with various complexity degrees: NOAH, MOSAIC and VIC snow modules (Pan *et al.*, 2003), SNOW17 (Slater and Clark, 2006), SnowModel (Liston and Elder 2006), ISBA, with 1 and 3 layers (Douville *et al.*, 1995; Boone *et al.*, 2000; Boone and Etchevers, 2001), and SWAT snowmelt parametrization (Wang and Melesse 2005). These models consider the main processes such as energy exchanges, melting, soil infiltration, vegetation screening and in some case a very simplified physics of the snow cover (e.g. albedo, density evolution, liquid water in the snow pack,…). However, present models reproduce with difficulty the evolution of shallow snow covers, which are typical of the Mediterranean context, and where the interaction between the snow, the soil (heat fluxes) and the vegetation (interception, melting) are preponderant. Dry deposition may also modify albedo and hence the melting rate.

Needs and proposals:

→*Characterize the effects of the high spatio-temporal variability of snow cover* within mountainous semi-arid regions, or medium altitude watersheds, where the snow coverage is ephemeral and the snowline is extremely variable (Chaponnière *et al*., 2006), which is a critical issue for adequate monitoring of snow dynamics (Sheffield *et al.,* 2003).

→*Improve the snowmelt parametrization* to simulate shallow snow taking into account the interaction with the soil and vegetation, combined with other physical processes. This can be performed by refining the physical processes described in the model or by local calibration (*e.g.* Chaponnière, 2005 for the Atlas Mountains).

3.2.2.1.4 Understanding and modelling water pathways at the hill slope scale

Water pathways both in natural and human-impacted zones are not fully understood. Their role during rainfall events in redistributing water, for instance along slopes, must be better documented and modelled as well as the impact of this redistribution on runoff, aquifer recharge and evapotranspiration. One of the most challenging tasks within HyMeX is also to take into account **human activities** and their impacts on landuse/landcover, given the high anthropisation of the Mediterranean region (intense anthropisation of some areas, agricultural depletion in others; i.e. modelling the role of crust and tillage practices on runoff genesis on Mediterranean farmed plots in Chahinian et al., 2006a, 2006b) and the increasing of urbanised areas. The impact of human-induced features must therefore be assessed and included into hydrological modelling.

We need to understand how water is redistributed both in space and time by topography, vegetation, fauna, soils and the subsoil (the properties of this latest being driven by its geological structure and by the impacts of the weathering processes on the rocks; see for instance Dewandel *et al*., 2006) and by man-induced pathways (ditches, roads, terraced slopes, etc.), and how this water may be further used by vegetation for evapotranspiration. The detailed knowledge of the 3-D processes describing the interactions between the surface waters and the shallow aquifers is also crucial for the simulation of low flows and is not sufficiently understood (Marofi, 1999; Dagés, 2006). All these experiments are very complementary to the experiments on water pathways dedicated to flash floods (see section 3.3).

Lots of hillslope models have been developed, but they often only represent a few dominant processes (e.g. VanderKwaak and Loague, 2001; Troch et al., 2003; Esclaffer, 2006) and/or they are only dedicated to the modelling of rainfall events. Their coupling with SVATs and the accurate modelling of the interactions between hillslopes, shallow aquifers and streams is necessary for the representation of longer term processes.

Needs and proposals:

→ *Hillslope experiments:* complement the experiments dedicated to floods (see section 3.3) with geological (both geology and weathering mapping, particularly in karstic and hard rock [granite- and metamorphic-type rocks] regions) and geophysical soil and subsoil structural characterizations, long term 3-D high frequency monitoring of soil moisture, and shallow aquifers using piezometers, tensiometers, soil water content local measurements, complemented with geophysical monitoring, and also with discharges measurements at local, perennial or temporal, springs and outlets, and within the river network. Geochemical tracing is also to be used for providing information on water pathways and transfer mechanisms, highly complementary to the above described physical approaches. The flux and interaction with the river network must also be monitored in details.

→ *Develop 3D modelling of the water fluxes within the soil and subsoil and their interactions with the surface water network:* development and validation of coupled models representing 3D water transfer and storage at the surface, within soils, subsoil and the interactions with the river network. The modelling of ephemeral networks and springs, flux and storage at the interfaces, etc. which can significantly modify the dynamics of water transfer, is also a challenge. Inclusion of hydrological discontinuities such as ditches, roads, must also be achieved. Special attention must be paid to the efficiency of the numerical solutions, in order to be able to use the models from the hillslope to the small catchment scale (up a few km^2) and also for short time scales. Coupling with SVATs must be performed to model the whole hydrological cycle.

3.2.2.1.5 Understanding and modelling aquifers at catchment scales

All the Mediterranean aquifers exhibit a very similar hydrogeological pattern, due to a very similar geological history (see INSERT 1, section 1, and Fig. 3.7).The **karstic aquifers** are widespread around the Mediterranean basin (Bakalowicz *et al*., 2003), specifically on its West, East and Northern parts; they may be very thick and they play a major hydrological role (storage during the rainy season, springs and river feeding during the dry periods). They constitute huge groundwater reservoirs, which exploitation is only at its beginning. Knowledge about the structure and functioning of karstic aquifers still need improvement, particularly for the characterisation of the geometry of the voids, and for the development of the tools to be used for the sustainable exploitation of the groundwater resource, to support the economical development (needs of the population, tourism, agriculture, industries, etc.), ensure the preservation/restoration of the aquatic ecosystems (increase of low stage river discharges) and to mitigate the flood risks by quantifying their storage capacities (see also §3.3.).

The deep and large valleys of the Messinian period all around the Mediterranean shore were completely filled up with porous and clayey sediments when the sea level came back up. These filled valleys constitute most of the **coastal aquifers** that are widespread all around the Mediterranean shore and are heavily exploited, even overexploited in some regions (Spain for instance; Nixon *et al*., 2003), leading to sea water intrusion. Their geological structure has recently been precisely described (Duvail *et al*., 2006; Gorini *et al*., 2005) but its influence on their hydrogeological behaviour still needs to be refined, particularly along their coastal fringe (Aunay, 2007).

<u>Needs and proposals</u>

⟶ *<u>Structure and functioning of karstic aquifers.</u>* Until now, these aquifers have mainly been characterized through a functional approach (Input/Output; see for instance Pinault et al., 2001). The present needs (comprehension of the natural functioning of the karstic watersheds, management of their various resources) require developing a deterministic structural approach, and particularly:

- to better characterise the geometry of the hydrogeologically active (transmissive and capacitive) karstic network from the local scale (epikarst features) to the catchment scale, notably through deterministic speleogenesis modelling,
- on this basis, the building-up of modelling tools to propose their semi-deterministic (Maréchal et al., *submitted*) or deterministic hydrodynamic modelling.

⟶ *<u>Functioning of the coastal porous aquifers.</u>* The emphasis should be put on a better understanding and modelling of the fresh to saline water relationships which, among others, require an enhanced characterization of the structure and the hydrodynamic properties of these aquifers. The 3D geometry of the aquifers, aquitards and aquicludes, and a better evaluation of the permeability and storativity of the aquitards should particularly be investigated through various types of monitoring, including the use of geochemical tools, and modelling. The precise description and modelling of the (fresh/brackish/saline) groundwater to surface water relationships (from the coastal rivers to the sea, through the lagoons and wetlands) must also be addressed.

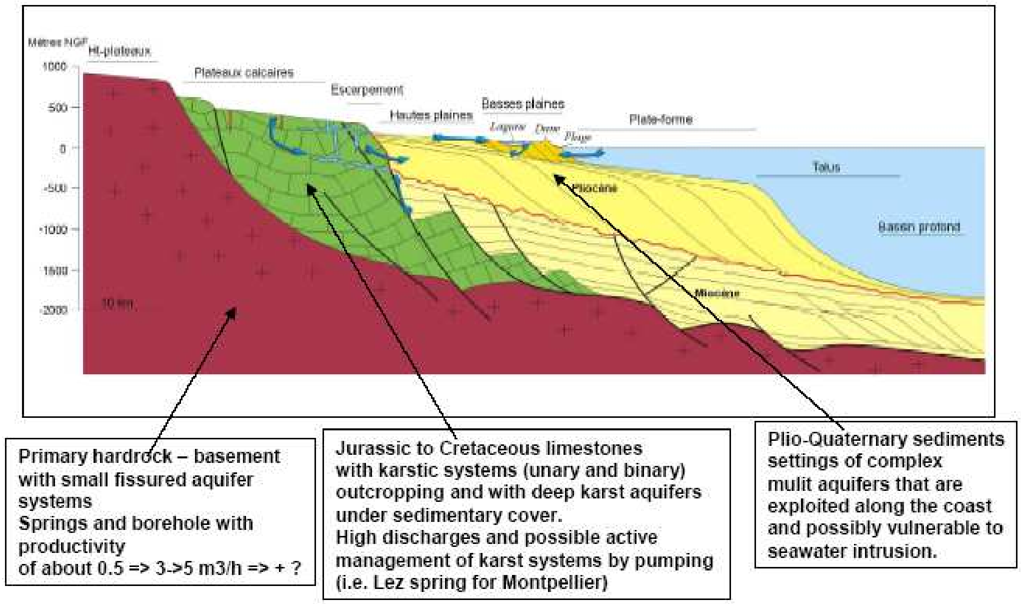


Figure 3.7: A typical cross section of aquifers along the Northern shore of the Mediterranean basin (Aunay, 2007)

3.2.2.1.6 Integrated modelling for catchments of a few km² to tens of km²

Once surface (3.2.2.1.1, 2 & 3), subsurface (3.2.2.1.5) and coupled surface and subsurface (3.2.2.1.4) processes are better understood and modelled at the local scale, their interactions must be taken into account through the development of integrated modelling, taking into account the complexity of the continental surfaces, including those induced by human activity (Fig. 3.8). A review of existing practices and propositions for the building-up of such an integrated model were done within the French SEVE project (Braud *et al*., 2005). HyMeX will offer the opportunity to progress in the development and validation of the concepts. Additional data collections (complementary to those acquired at the local scale) and research about the specification of parameters, the delineation of modelling units, and the calibration and validation procedures are particularly required (Chahinian, 2004). **The following needs and proposals also apply to the regional scale modelling (see section 3.2.2.2) and for flash-flood modelling (section 3.3).**

Needs and proposals:

→*Characterization of soil properties at the scale of the modelling units*: Soil characteristics are difficult to obtain although some effort has been dedicated towards the constitution of soil data bases and landscape classification. But research is still needed to be able to derive quantitative information about soil hydraulic properties, which are crucial for water transfer within soils and to develop pedo-transfer functions adapted to the Mediterranean region.

→*Use of remote sensing data and GIS layers to represent the heterogeneity of the surface, derive water pathways, describe the sub-grid scale variability of elements which are not resolved explicitly* (for instance anthropogenic networks such as ditches, ephemeral river networks, roads, etc.)*, and to define modelling units.* Appropriate methods must be proposed and automatized in order to represent such heterogeneity of the surface. Techniques such as multi-objective calibration or adjoint modelling, Kalman filtering can be used to assimilate remote sensing data (about vegetation characteristics, surface soil moisture, etc..) to constrain or to initialize the models (see section 3.2.2.5).

→*Linking the hydrologic response and the landscape characteristics.* High-resolution products concerning topography, geology (including weathering), karstification (and particularly karstification at the kilometric scale, with the associated temporary springs), soil, land use, vegetation cover, need to be considered to link the hydrologic response to the landscape characteristics and hence allow extrapolations/ parameterizations for ungauged basins.

→ *Development of parameterisation, calibration and validation strategies.* Acquire the complementary observations needed for a multi-site, multi-scale (plot scale, hillslope, small and large basins), and multi-tools (physical parameters, tracers, etc.) approach. Specific parameterisation strategies must be developed in order to avoid over-parameterisation and "equifinality" problems. Error propagation analysis must be conducted: error on input variables and parameters (e.g. measured or predicted precipitation, soil and subsoil characteristics, channel network geometry, aquifer hydrodynamic properties, etc.)

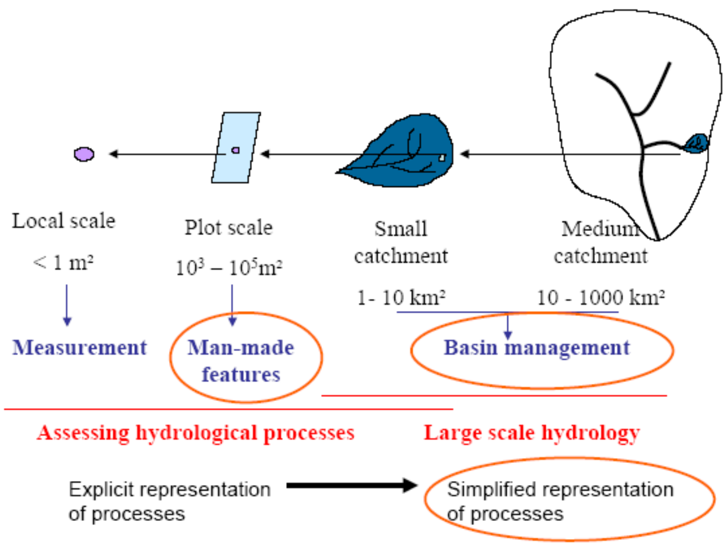


Figure 3.8: Scales and processes representations

3.2.2.2 The regional scale contribution of the continental surfaces to the water budget

In order to evaluate the contribution of continental surfaces to the water budget, hydrological modelling at the larger scales than a single small to medium catchment is a key issue. Effort must be done in order to build a coupled hydrometeorological modelling at **the regional scale**. The target will be the **description of the water budget on a significant part of the whole Mediterranean watershed at high resolution**: for instance the western part of the basin (including at least the Mediterranean part of Spain, France and Italy for the north shore). The target spatial resolution should be a few km to encompass all the type of basins. This modelling approach will allow studies dedicated to the continental surfaces at the regional scale and will benefit from the detailed process studies at small scale in the Mediterranean environment. **It is also a unique tool to address the interfaces with the other compartments of the Earth system**: the role of the surface sensible and latent heat fluxes on the atmosphere evolution (especially during extreme events) and the river inputs to the Mediterranean sea, either during floods or drought periods (including quantity and quality aspects). The regional approach could also provide the initial soil moisture conditions for flash flood models (Le Lay and Saulnier, 2007). The time step should allow to describe the diurnal cycle (typically 1 hour) and this modelling should cover the present period (in particular the experimental phase), but should also cover a significant period of the past (more than 10-20 years) in order to reproduce the observed interannual variability.

At the regional scale, few modelling systems simulating the various components of the water budget have been developed. In the framework of the Baltex such an attempt was done, but without a full interaction between the hydrological models and the land surface models (Graham and Bergström, 2000). In France, a coupled hydrometeorological model has been built for the Rhone basin under the framework of GEWEX (Habets *et al*., 1999). In this approach, the hydrogeological model MODCOU has been coupled to the land surface model ISBA. The meteorological analysis SAFRAN forced ISBA at a 8x8 km grid. Later, this approach (namely referred to the SIM model) has been extended to France and run on a daily basis by Météo-France (in particular for soil wetness and water resources monitoring). However this system in its present state does not account for the particularities of the Mediterranean region (fine scale hydrological processes, karstic aquifers, anthropogenic components, …)

The **coupled hydrometeorological model** should be composed of **a meteorological analysis system**, **a modelling of the soil-vegetation continuum and a hydrological model**, including both surface and groundwater components. The following subsections describe the main issues needed to be addressed in order to achieve this objective.

3.2.2.2.1 Development of a near-surface atmospheric analysis database on the Mediterranean region

A consistent atmospheric analysis of low level parameters and radiative fluxes, at a sufficient spatial resolution (a few km) is mandatory in order to properly handle the surface – atmosphere feedbacks. The needed variables are those required for calculating surface budget (temperature, humidity, wind speed, precipitation and radiative fluxes). At the scale of the Mediterranean basin, the only atmospheric data set currently available is the GSWP2 (Global soil wetness project) global data set covering a 10-year period but with a spatial resolution of approximately 100 km, which is probably insufficient to fulfil the objectives of HyMeX. Several near surface analysis systems exist in the meteorological community (*e.g* the Mesan, in Sweden or SAFRAN, in France). SAFRAN (Quintana-Seguí *et al*, 2007) has been able to calculate the needed parameters for a long period (more than 30 years), but only over France. A spatial extension of this type of high-resolution analysis of low-level atmospheric variables will be promoted, provided that a relevant data base of observations could be organized for different neighbouring countries (for instance Italy, France and Spain).

In addition to the use of conventional data, a special emphasis should be put on remote sensing data for precipitation (radars) and radiative fluxes (*e.g*. Land SAF developments).

Needs and proposals:

→ *Conduct an atmospheric analysis of low-level parameters:* The analysis should cover a long term period. A particular emphasis should be put on high quality precipitation fields, by using radars. Satellite data will be used for surface radiative fluxes estimation. The target spatial and temporal resolution is one to a few km^2 and one hour, respectively.

3.2.2.2.2 Improvement of land cover description

For the surface modelling, a large effort will have to be made in order to accurately estimate the land cover and land use maps representative of Mediterranean ecosystems. The current land cover classifications (Corinne, GLC, Ecoclimap – Masson *et al*., 2003) are not accurate enough and are site-specific, which is not satisfactory in an area characterized by a very high spatial heterogeneity. A classification with an approximately 100-m pixel is needed. This is an important point since the sensitivity of the soil–vegetation surface schemes to the prescribed land cover is very high, particularly for the state of the art schemes which include the CO_2 cycle and interactive biomass modelling. In this domain, the input of satellite data should be very important not only to improve existing land cover but also in order to represent the dynamic development of natural vegetation and crops (maps of Leaf Area Index, surface albedo, etc.).

Needs and proposals:

→ *Improve the land use and land cover maps* for the Mediterranean area on the basis of existing classification schemes (e.g. Ecoclimap, …) and high resolution satellite data. The target spatial resolution is 100x100 m^2.

→ *Derive maps of surface biogeological parameters* (LAI, albedo, …) from satellite data. The target spatial resolution is 100x100 m^2.

3.2.2.2.2 Sub-grid scale parameterisation for the land surface models

The modelling of surface processes should be performed by integrated SVAT schemes previously improved and calibrated from observations and detailed modelling at the local, hill slope and watershed scales. Given the grid box size considered in the regional model (a few km), a number of sub-grid scale processes will have to be parameterized. These parameterizations or sub-grid processes should be based on modelling results using a detailed hydro-meteorological model – such as that developed within the SEVE project – which are able to simulate the 3D complexity of coupled soil-atmosphere exchanges and which are proposed in section 3.2.2.1. The parameterization of the effect of sub-grid orography on runoff and lateral redistribution of water should be improved as a first priority (*see* for instance Saulnier and Habets, 2000). Improvements are also expected to take into account the sub-grid horizontal variability of vegetation and soils, using, for instance, an explicit treatment of surface processes such as the tiling approach. Vertical heterogeneity of soils also has to be better accounted in integrated SVAT models which usually assume constant properties with depth.

Needs and proposals:

→ *Develop sub-grid scale parameterisations for SVAT:* The emphasis should be put on the influence of orography, landscape organisation and anthropogenic impact on water pathways.

3.2.2.2.3 Development of a regional hydrological modelling, including the aquifers

The development of a regional hydrological modelling (like the Safran–ISBA–MODCOU model, Fig. 3.9) integrating the aquifers is a big challenge, given the high spatial heterogeneities of both surface and underground components, such as for the karstic aquifers for instance. The regional modelling should be based on existing distributed hydrological models applied in the region (*e.g* Moussa *et al*, 2007, Habets *et al*., 2007) and take advantage of existing hydrogeological models for karstic basins which have already been developed and calibrated in France (for instance for the Corbières area, the Hérault basin, including both coastal and inland karstic aquifers, the area of Nimes, the Lez aquifer, the Fontaine de

Vaucluse, etc.; see for instance Fleury *et al*., 2007, Marechal *et al*., 2007, Pinault *et al*., 2004).

The regional modelling should include the anthropogenic aspects and must reproduce with accuracy some important features, such as intermittent rivers, encountered in the region. An explicit consideration of aquifers has to be introduced into the regional hydro meteorological model. This is particularly important in order to simulate the storage (and also the anthropogenic pumping) of groundwater and the related dynamics governing water flow to the rivers or eventually to the sea. The modelling may be twofold. On the one hand the deterministic representation of the porous aquifers, including horizontal advection, as well as the coupling with the surface scheme and the rivers, will be performed, based on geological and hydrogeological knowledge and the existing piezometric and hydrologic networks in order to calibrate transmissivity and storage coefficients. On the other hand, particularly for karstic aquifers, transfer functions (already calibrated through previous studies or completely calibrated during the regional model building process) will be implemented in the regional model in order to adequately store and route water in the karstic aquifers from the impluviums (that will be explicitly delineated) towards the main outlets. After a development phase focused on the French portion of the study area, extension to the domain selected in HyMeX should be attempted.

<u>Needs and proposals:</u>

→ *<u>Build a hydrological model based on existing work:</u>* A special emphasis should be put on the Mediterranean characteristics, such as orography, vegetation, dry soils, intermittent rivers and the anthropogenic influence.

→ *<u>Integrate the groundwater component in the regional modelling,</u>* both for porous and karstic aquifers, at the scale of the regional model.

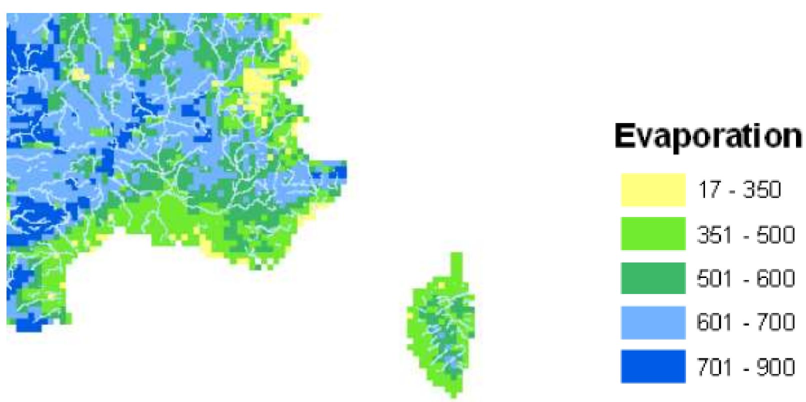


Figure 3.9: Evaporation (in mm/year simulated by the model SIM over the South of France

3.2.2.2.4 Transversal issues: interfaces and databases

The coupled hydrometeorological modelling need to follow some interfacing rules in order to be as efficient as possible. A general interface between the atmosphere and land surface models has been proposed by Best *et al.* (2004) and is progressively used in all the application involving atmospheric and land-surface models in forced or fully coupled mode. In 2001, workshop dealing with the atmospherical and hydrological coupling was launched by two French scientific programs. The main conclusion was to propose a strategy to interface SVATs and hydrological models (vertical transfers being treated by SVATs while horizontal transfers being treated by hydrological models). This definition on interfaces must go further in order to address the interfacing between aquifer models and SVATs or surface hydrological models.

The success of the regional approach will rely on the capacity of the community to build a comprehensive database of observations over the region of interest in order to feed, calibrate and validate the model. This database should contain:

- Meteorological data to be used by the atmospheric analysis.
- Data to be used either as input, calibration or validation of land surface models (land cover data, vegetation, albedo, soil wetness, …).
- Data to be used as calibration and/or validation of the hydrological models (river flows, aquifer levels, …).

This task is strategic. A high priority must be put on this action as soon as possible.

Needs and proposals:

→ *Generalise the already existing interface rules between models and apply them to the regional modelling.* A strict respect of these rules will allow an easy exchange of the various components of the coupled model and enhance our ability to improve the quality of the results.

→ *Build a database of observations:* This action must have a high priority. At first, a definition of the data to be included in the database must be conducted.

3.2.2.3 Pollutant dynamics in intermittent rivers

The intermittent regime of most Mediterranean rivers, combined with the high population living near the coast (150 million of inhabitants) and the concentration of industries, agriculture and tourism in the same area makes the water quality issue very specific in the area. Compared to the large rivers coming from the northern Mediterranean basin, the temporary rivers have not been sufficiently recognised until now (Froebrich *et al*, 2007), especially in terms of their impact on the quality of receiving waters, and of the distinctive dynamics which are introduced when severe flood events follow intensive dry periods. The absence of baseflow over long dry periods and the spatial discontinuity of river flow, even during floods (Dunkerley and Brown, 1999), can be considered the most significant characteristics of these rivers. The variations in water quality dynamics will be highly dependent to this behaviour (Graf, 1988).

During low flow conditions, domestic and industrial point sources frequently constitute the main part of pollutant inputs to rivers, even in areas of intensive farming. In fact, nutrients and especially phosphorus discharged by waste water treatment plants are mainly responsible for river eutrophication during summer: a period during which the agricultural diffuse pollutions are not significant (Neal et al., 2005).

The impact of direct inputs of pollutants on the ecological status of the river is highly significant (Torrecilla et al., 2005): dilution effects cannot take place. Pollutant accumulation and transformation are observed in pools (De Groot and Van Wijicj, 1993; Tournoud et al., 2005). During this period, riverbed sediments and biotas play a major role in constituting a pollutant reservoir that will be remobilized during floods (Dorioz et al., 1998).

The first floods are considered to be a critical moment in the hydrological and hydrochemical functioning of these rivers (Durand et al., 1993). The remobilization of the accumulated pollutants in the riverbed depends on both the physico chemical conditions and the bioavailability of the compounds (Baldwin and Mitchell, 2000; Qui and McComb, 1996; Qui and McComb, 2002). The transport capacity of the remobilized elements will also depend upon the hydraulic conditions, (flow magnitude and flow continuity). These combined factors help the occurrence of high concentrations of dissolved and particulate chemical coumpounds and high abundance of bacteria of sanitary concern.

Therefore the specific hydrological behaviour of intermittent rivers has significant influence both upon the impact of direct inputs on the riverbed during low flow periods and upon the flushing effect of floods that may affect lagoons or coastal downstream ecosystems.

<u>Needs and proposals:</u>

→ *<u>Hydrological behaviour :</u>*

- Characterize the hydrological behaviour of the intermittent rivers and determine the processes of flow generation by the acquisition of the required data at the catchment scale.
- Determine the duration of the low flow and dry periods taking into account the persistence of pools in the riverbed and water storage in neighbouring shallow aquifers as well as determine the flood frequency and magnitude.

→ *<u>The pollutant dynamics:</u>*

- Characterize continuous or non-continuous pollution point sources, in terms of flow and concentrations.
- Analyse the spatial variability and temporal dynamics of pollutants in the water column, in link with the hydrological conditions and the variability of the pollution point sources.
- Analyse the relationship between the water column and the riverbed as well as to determine the pollutant accumulation, transformation and bioavailability in the sediments.

→ *<u>Management :</u>*

- Evaluate the impact of point source pollution inputs on intermittent rivers, in particular, the acceptable levels of pollutant discharges into these rivers.
- Develop a model for management purposes.

3.2.2.4 Climatic and anthropogenic forcings

The human pressure on environment in the Mediterranean region is already very high. Ongoing trends (Benoit and Aline, 2005) are toward an increase in population, especially marked in the South and East rims. The increase in urban and coastal population will be an important feature with all related effects on the environment. This will lead to an increased vulnerability of systems to the ongoing climate trends.

During this century, the **global warming** over Mediterranean regions will probably cause more droughts and more precipitation during warmer winters despite shorter rainy seasons (Gibelin and Déqué, 2003; Rowell, 2005; Wang, 2005). Uncertainties about the extreme rainfall events and droughts intensity in the future are still important (Neppel *et al*., 2003; Rowell, 2005; Renard *et al*., 2006; Renard, 2006, CYPRIM project: www.cnrm.meteo.fr/cyprim/), while some studies point out a variability increase (Jones and Reid, 2001; Voss *et al*., 2002; Diodato, 2004). On the South shore, the main impact will be the increase in drought, the precipitation evolution (and extremes) is still rather uncertain. In the North shore, several detailed impact studies (Etchevers *et al*., 2002; Leblois, 2002; Ducharne *et al*., 2003; Booij, 2005; Ludwig et al., 2004; Zierl and Bugmann, 2005; Caballero *et al*., 2006; Merritt *et al*., 2006) showed higher river discharges during the fall and the winter, an earlier snowmelt, longer periods of low flows and a reduced aquifer recharge. However, the impact studies only partially considered some important factors, such as a change in land use, agricultural and irrigation practices, direct CO_2 effect on plants, evolution of water demand, etc. and then must be consolidated by including additional processes.

Considering **non climatic trends**, change in population, industry, economic policy will modify the water demand (for domestic water, agriculture, industry and tourism), the waste water produced and the land use. The general increase in vulnerability will be modulated by economic of political measures: in the E.U. the implementation of the Water Framework Directive (EC, 2002), which aims at restoring good ecological status for all water bodies (notably through an increase of stream water flows) is an example of this type of measure.

Furthermore, it is virtually certain that the effects of other kinds of changes (land use / land cover (Loukas *et al*., 2002), surface states, soil degradation (Feddema and Freire, 2001), impact of forest fires and salt water intrusion due to rising sea (Bobba, 2002), human works, changes in water demand (e.g. Alderwish and Al-Eryani, 1999; Chen *et al*., 2001; Loaiciga *et al*., 2000; Meigh *et al*., 1999; Döll, 2002; Montginoul *et al*., 2005) will have much more severe impacts that the climate change alone. A pluridisciplinary research is needed in order to consider the water resource management in a holistical approach which: “takes into account the direct and indirect contributions of climate change and socio-economic change, and considering the uncertainties and potential shortcomings which are pertinent” (Holman, 2006).

Needs and proposals:

→ *Build a database of high resolution regional climate scenarios for the region, in order to run impact models.* A special effort should be put on desagregation approaches, which are mandatory in order to downscale the outputs of the GCMs predictions at fine scale. Another important issue is to achieve a realistic estimation of extreme events trends (rainfall, droughts) and the associated uncertainty.

→ *Improve our knowledge on socio economic feed backs induced by global change*. It thus also requires the building up of prospective socio-economic scenarios (for which a key methodological challenge will lie in developing methodologies for downscaling the socio-economic component of the SRES scenario [Arnell *et al*., 2004] from a global to a very local level: quantitative assumptions related to the main socio-economic drivers as well as the narrative storylines developed at the local level will have to be consistent with assumptions made at the global level), and the linking up of physical and socio-economic modelling tools.

→ *Provide land-use change scenarios (and past-reconstruction) consistent with the socio-economic scenario* in order to evaluate the impact of land-use change on the hydrological cycle. Reconstruction of past land-use and of its evolution, especially in relation with urbanisation and the modifications of agricultural practices, would also be useful to assess the predictive capacity of models.

→ *Improve impact models on both physical and socio economic aspects.* The models must properly simulate the physical feedbacks induced by climate change like the direct effect of $CO2$ on plants, change in sea level, change in land use, … The validation of these models on the present climate should also be focussed on aspects critical for the future (e.g. low flows, dry soils, aquifer recharge, …).

3.2.2.5 Remote sensing observations for informing processes and models

Within HyMeX, remote sensing is a unique mean for collecting observations in a spatially distributed manner over Mediterranean land surfaces, including natural and cropped ecosystems, forests, snow covers, rivers and lakes. Parameters and variables of interest are related to the dynamics of vegetation, soil and water, from subsurface to lower boundary layer. At both local and regional scales, potential benefits include the understanding of temporal evolutions by analysing past records, the establishment of current diagnostics and short term prognostics, and the betterment of long term prognostics by improving process models.

Airborne and spaceborne sensors, active or passive, collect data over the solar, thermal infrared (TIR) and microwave domains, from submetric to kilometric spatial resolutions, and from hourly to monthly temporal samplings. Information has become richer according to sensor configurations, with now hyperspectral, multiangular and multipolarization possibilities, including recent LIDAR technology for describing canopy and landscape structures. This makes possible better retrieving several observables at different spatial scales, in relation with radiative processes, vegetation biophysical and structural variables, soil and landscape hydrodynamical properties, surface hydric status, dynamics of snow and free water. Main issues focus on retrieving observables, and next using them to inform process models.

3.2.2.5.1 Remotely sensed observations for retrieving model observables

A new generation of EO missions will greatly improve the monitoring of land surfaces. In particular high resolution (~10 m) images will permit to monitor the land use over key sites at a high sampling time (2-3 days). Such images will be provided by FORMOSAT and by VENµS (to be launched in 2009). Moreover, the observation of soil moisture from space is developing fast (ASCAT on METOP, SMOS –to be launched in 2008-, ALOS). As far as low resolution (~30 km) sensors are concerned (ASCAT and SMOS) Mediterranean areas are affected by the proximity to the sea (water surfaces “contaminate” the signal over land), and by mountainous areas, but these effects can be corrected.

Inversion remains an ill-posed problem, with the inclusion of numerous canopy and soil properties into emission and reflection mechanisms (Wigneron *et al*., 2003; Zribi *et al*., 2005; Bacour *et al*., 2006; Du *et al*., 2007). It is also mathematically complex regardless of considered approach, e.g. iterative solving (Wigneron *et al.,* 2006) or learning machine methods (Camps-Valls *et al*., 2006). Upscaling requires accounting for differences between modelling and measurements - e.g. LAI (Weiss *et al*., 2004) or surface temperature (Jacob *et al.,* 2007). It also requires accounting for combined effects between spatial resolution, local heterogeneities and landscape patterns (Garrigues *et al*., 2006).

Over Mediterranean land surfaces, additional difficulties raise when considering hilly and mountainous watersheds which depict strong spatial heterogeneities: efforts are necessary for characterizing the consequences on remote sensing measurements. Further, thermal regimes of semi-arid sparse canopies can not be adequately characterized with standard single viewing TIR observations, while dynamics of snow cover, free and subsurface water are poorly monitored from a unique spectral range only. Overall, promises rely on using different spectral ranges together, viewing capabilities, and very high spatial resolution.

Needs and proposals:

→ *Efforts on measuring by synergistically using ground based, airborne and spaceborne data,* with benefits from Environmental Regional Observatories (OMERE, OHMCV, RESYST), extension of some networks (e.g. SMOSMANIA for the soil moisture), and from the planned CAL/VAL sites (SMOS, VENµS).

At local scale, assessing the potential of solar (hyperspectral and LIDAR) and microwave (SAR including polarimetric interferometry), for a 3D description of landscape and canopy structures, and for the monitoring of river flow and snow cover.

At coarser scales, adequately retrieving observables by quantifying influences of local heterogeneities thanks to high spatial resolution. Also, deepening the potentials of solar hyperspectral, multiangular TIR, and low frequency microwave, for characterizing soil properties, canopy thermal regime and subsurface moisture, respectively.

→ *Efforts on modelling and inversion for improving performances of retrieval algorithms*.

Locally, refining radiative transfer modelling over the three spectral ranges: solar (soil reflectance, 3D vegetation structure, biochemistry), TIR (canopy thermal regime), and microwave (soil and vegetation scattering over dry areas, canopy backscattering). Also, improving inversion using a priori information, i.e. spatio-temporal constraints.

At coarser scales, modelling relief and heterogeneity effects, and characterizing differences between modelled and measured observables.

3.2.2.5.2 Assimilating remotely sensed observables into process models

For diagnostics, forcing methods use observables as model inputs. For short term prognostics, correction methods constrain dynamic variables with observables, by correcting state variables, or reinitializing parameters and initial variables. This makes use of Ensemble Kalman filtering (Pellenq and Boulet, 2004), iterative algorithms (Verhoef and Bach, 2003), multiobjective calibration (Vrugt *et al.,* 2003; Demarty *et al.,* 2005; Coudert *et al*., 2006, Engeland *et al.*, 2006), or adjoint modelling (Lauvernet *et al.,* 2003, Castaings *et al.,* 2006). For SVAT, vegetation and hydrological models, variables to be reinitialized or corrected are field capacity, initial soil moisture, plant growth parameters, root zone soil moisture, stomatal resistance, etc.. Recent works suggested considering the three spectral ranges together (Cayrol *et al.*, 2000; Prévot *et al.*, 2003; Schuurmans *et al*., 2003; Olioso *et al.,* 2005; Jarlan *et al*., 2005).

Mediterranean watersheds with strong spatial heterogeneities require handling the lack of spaceborne sensors with both fine revisiting rates and spatial resolutions. Potential solutions are aggregation and disaggregation techniques (Pellenq *et al.,* 2003; Merlin *et al.,* 2006). Though several model parameters and initial conditions can be retrieved, most are still unknown in terms of hydrodynamic and phenology, while model non linearities limit numerical stabilities and predictability. Finally, assimilation techniques devoted to the modelling of Mediterranean watersheds should embrace the various temporal dynamics of vegetation and water processes, including low frequency processes and extreme events.

Needs and proposals:

→ *Efforts on assimilation techniques*.

Deepening the selection of relevant variables to be considered according to the environmental context - e.g. soil and vegetation contributions. This includes sensitivity studies by accounting for model and measurement uncertainties.

Investigating the lack of information for the numerous model unknowns. This includes considering non Gaussian statistical processes, and using a priori information about variable range and Probability Density Function.

→ *Efforts on appropriately using available spaceborne observations*.

Disaggregating kilometric observations using space segmentation, i.e. spatial patterns related to functional typologies in terms of soil, vegetation and water processes. This requires synergistically using field and remote sensing data.

Deepening data fusion and combination, to strengthen multisensor and possibly multiscale assimilation.

Investigating data assimilation into coupling schemes which account for low and high frequency processes, in order to handle non periodically recurrent events.

3.3 Heavy rainfall events, flash-floods and floods

Coordinators: G. Delrieu / D. Ricard

3.3.1 A matter of scales

Heavy precipitation events (HPE) and flash-floods (FF) are not uncommon phenomena over the Mediterranean region. The peculiar topography and geographical location of this area make it especially favourable to occurrence of intense events. The Mediterranean Sea acts as a vast heat and moisture reservoir from which convective and baroclinic atmospheric systems pump a part of their energy. The steep orography surrounding the Mediterranean Sea favours lifting of the low-level unstable air and initiation of condensation processes. Moreover, the morphology of the Mediterranean basin with numerous small and steep river catchments can turn the intense precipitation into severe devastating flash-floods and flooding. As detailed in Fig. 3.10, these intense rainfall events result from complex interactions between the atmosphere, ocean and continental surfaces and may have severe impacts on marine and terrestrial Mediterranean ecosystems.

A clear link exists between the hydrologic response, defined as a time lag between the rain time series (hyetograph) and the discharge time series (hydrograph), and the size of a watershed subject to a heavy rainfall event (Fig. 3.11a). Typical response times are 10 min and 1 hour for urban watersheds of 10 and 100 km², respectively, 1 to 5 hours for natural basins in mountainous settings extending from 10 to 1000 km². A clear relation also exists between the space-time scales of the generating rainfall events (storms, MCS, frontal systems as defined by Orlanski 1975) and the hydrologic response characteristics. This fact supports the concept of **scale resonance**, *i.e.,* a convective storm will be able to generate flash-floods for basins of some tenths of km² while a stationary MCS is required to produce flash-floods and floods over watersheds of 500-2000 km². Floods in larger settings are associated to frontal systems with much larger spatial extension and temporal duration. For instance, floods of the Rhône river result from blockages of Mediterranean frontal systems that allow a generalized contribution over significant portions of the basin.

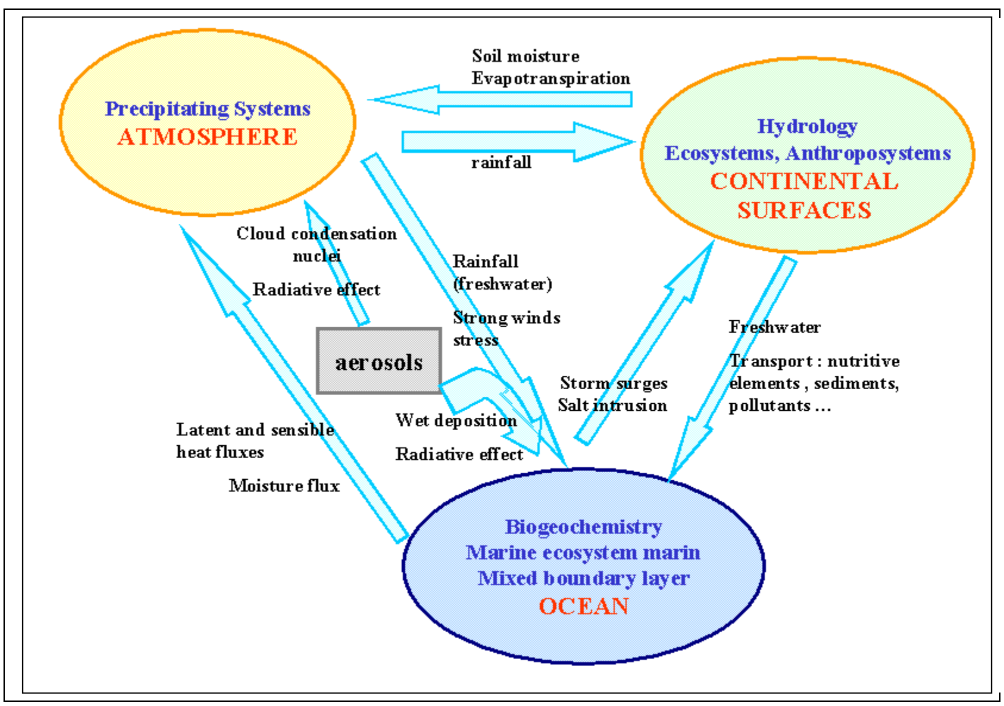


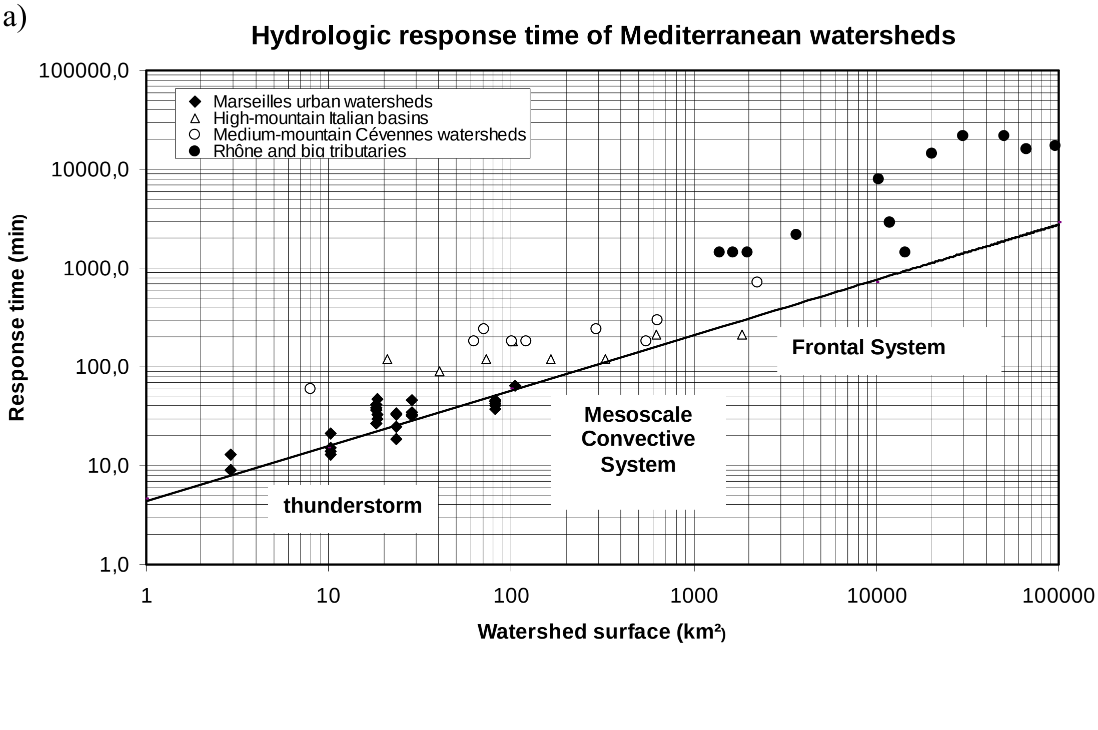
Figure 3.10: Interactions between the atmosphere, ocean and continental surfaces during precipitating events

A classical measure of the magnitude of a flood is the maximum specific discharge, *i.e.* the maximum discharge observed during the event scaled by the watershed area. A compilation of maximum specific discharge values found in the literature for extreme rain events all around the world is presented in Figure 3.11b; it is complemented by some estimates realized for the Aude 1999 (Gaume *et al*., 2004) and Gard 2002 floods (Delrieu *et al*., 2005). The dependence of the maximum specific discharge on the watershed area is clear, as well as the significant spread of the maximum specific discharge estimates for a given watershed area. This last point may result from climatological factors but one should realize that the diverse discharge estimation methodologies, based on hydraulic modeling, extrapolated rating curves and/or flood marks analysis, can contribute very significant errors.

Figure 3.11 provides an illustration of the complexity of the characterization of HPEs and FFs at the regional scale since very intense and dangerous hydrologic responses are likely to occur at very small space-time scales: observation systems with very high space-time resolution are therefore required over large domains.

In the following, the presentation of the scientific questions related to heavy precipitation and flash-flooding is organized in four sections describing **process studies, multi-scale observation and modelling** for **improving prediction and forecasting** of heavy precipitation systems (3.3.2.1) and flood and flash-flood events (3.3.2.4). The impact of the Mediterranean Sea (3.3.2.2) and the role of the aerosols (3.3.2.3) in the heavy precipitation systems formation are treated in two specific sections. A fifth section is dedicated to the question of the impact of the **climate and global change** on the occurrence of extreme events (3.3.2.5).

a)



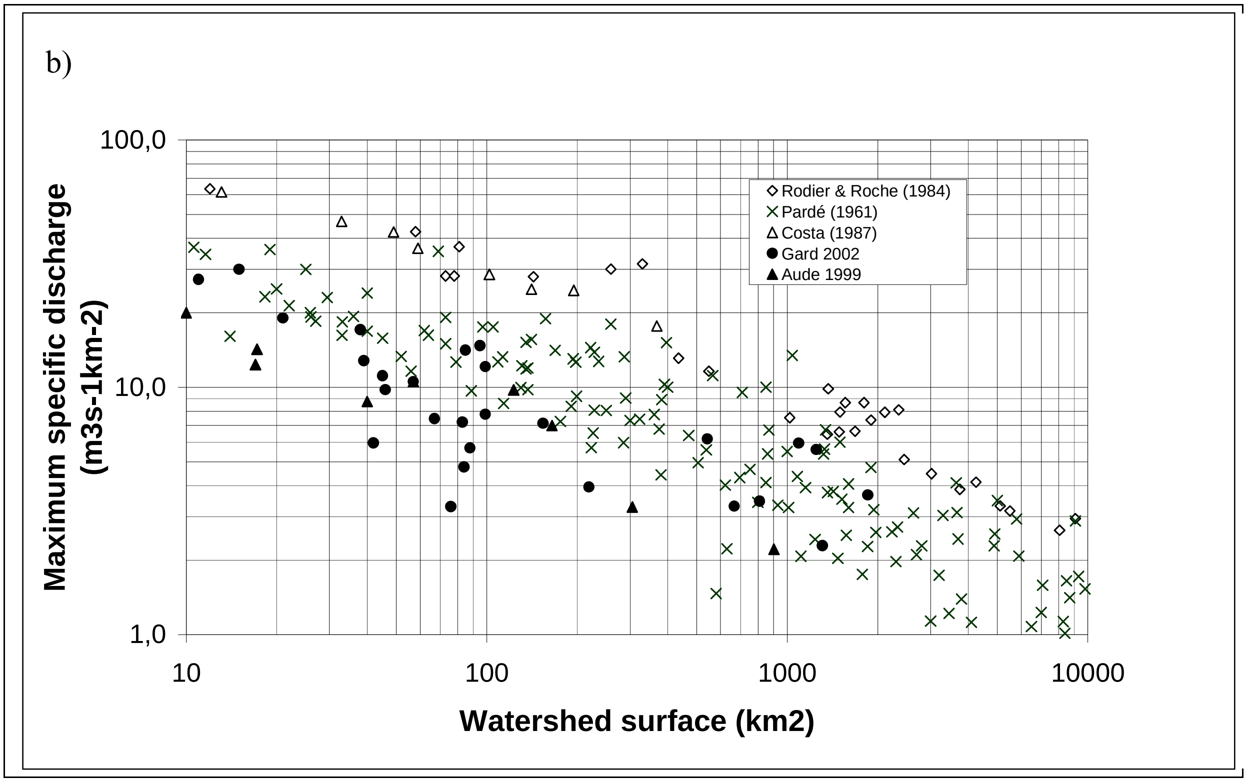


Figure 3.11: a) Response times of several urban and natural watersheds subject to high rainfall events in the Mediterranean region (compilation by G. Delrieu). The black line refers to the typical spatial extension and duration of the generating rain events, after Orlanski (1975). b) Maximum specific discharges as function of the watershed area for a number of extreme rain events reported in various regions of the world (compilation by E. Gaume). The black triangles and dots are relative to two events that occurred recently in the French Mediterranean region (Aude 12-13 November 1999; Gard 8-9 September 2002).

3.3.2 Scientific questions

3.3.2.1 Heavy precipitation systems

3.3.2.1.1 Heavy precipitation climatology

Many different categories of precipitating systems affect the Mediterranean areas, according to the season, region and mechanisms of formation. They include orographic precipitation, rainy frontal systems, mesoscale convective systems (MCSs) and isolated thunderstorms. This precipitating system spectrum is also enlarged by the diversity of cyclones encountered over the Mediterranean region: Atlantic cyclones, African cyclones, thermal lows, hurricanes-like lows, Middle-East lows, and orographic cyclones …

A characteristic of the Mediterranean precipitating systems is their inclination to produce heavy rain. Daily surface rainfall greater than 200 mm is not uncommon for Mediterranean precipitation events. Most of these intense precipitation events occur during the “autumn season” (from August to December) over the western Mediterranean region (Fig. 3.12); the peak of precipitation over the eastern Mediterranean occurring between December and February. Even though mesoscale precipitation climatology is available for some parts of the Mediterranean basin (e.g. the 20-year assembled Alpine-scale daily rainfall data-base of Frei and Schar (1998), Fig. 3.13), a detailed climatology of precipitation covering the whole

Mediterranean basin doesn't exist. Indeed, lack of observation over the sea, the absence of common databases for the Mediterranean countries limit the knowledge of precipitation distribution, the more so because precipitation fields exhibit mesoscale patterns due to the scale of atmospheric systems involved and small-scale details of the Mediterranean topography.

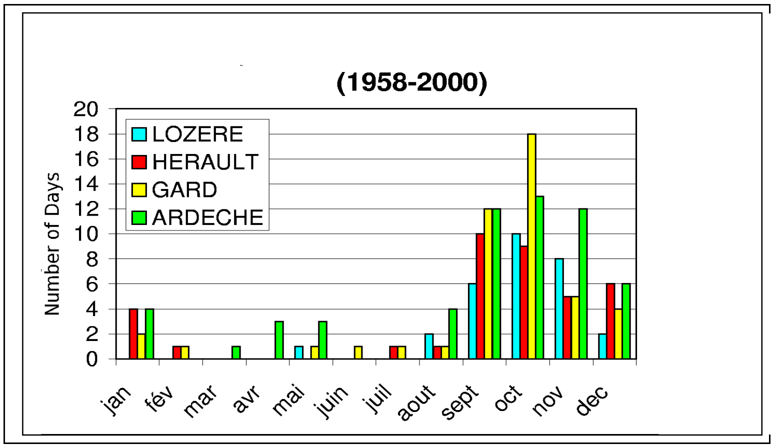


Figure 3.12: Monthly distribution of number of days with daily precipitation above 200 mm from 1958 to 2000 for 4 southern France departments (from CDROM-pluies extrêmes sur le sud de la France, METEO-FRANCE and MATE, 2002)

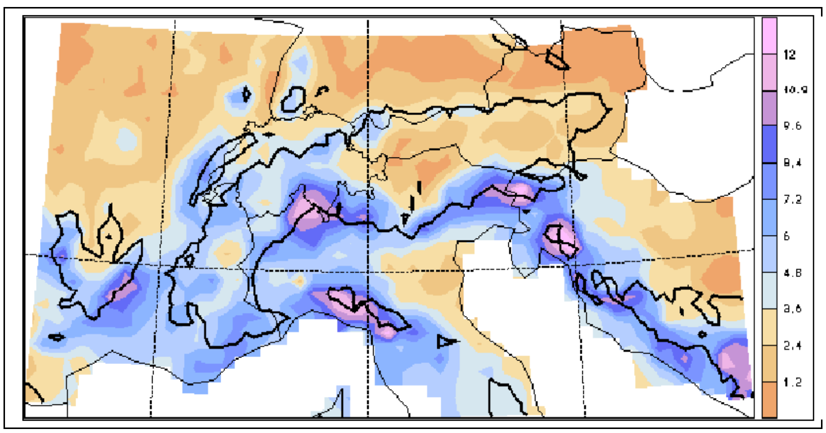


Figure 3.13: Climatology of the frequency of heavy precipitation for October over the Alpine region and the surrounding area (percentage of days with daily precipitation above 20 mm). The bold line represents the 800 m topographic contour. (Frei and Schar, 1998)

Occurrence of HPEs is related to specific synoptic patterns. Based on automatic classification of the autumnal atmospheric large-scale and synoptic variability (500 hPa geopotential from ERA40), Joly and Joly (2006) found six persistent and recurrent weather regimes in the Mediterranean basin. The HPEs in the Gulf of Lion are found in the majority associated with a peculiar regime which is characterized by a trough-ridge system, with a low pressure over Spain and high pressure over the Central Europe. The conditioning of heavy precipitation systems by weather regimes is a key characteristic that should help to design new strategies to understand and handle the predictability of these extreme events, as well as for the assessment of the climate-change impact on the intensity and the frequency of these extreme events (see as example IMFREX or CYPRIM projects). **Improvement in the determination of weather regimes associated with HPEs** may be searched by classifying more appropriate fields for Mediterranean weather events, such as potential vorticity and humidity for instance.

Large amount of precipitation can be accumulated over several day periods when a single or a succession of several frontal systems are slowed down and enhanced by the relief of the region. In other cases, the large rainfall amount can be recorded in only few hours when a MCS, sometimes in association with an extratropical cyclone, becomes stationary over an area during several hours (Riosalido, 1990; Rivrain, 1997). The amount of precipitation is related to the characteristics (intensity, duration, organization) of the precipitating systems and in particular to their motion. Indeed, the more a precipitating system stays over the same area, the higher is the amount of precipitation. The quasi-stationary convective systems are therefore powerful flash-flood producing precipitating systems. Frequently, **these quasi-stationary MCSs are backward regenerative systems** that take a V-shape in the infrared satellite imagery (Scofield, 1985) and in some cases in the radar reflectivity images. Backward regeneration is obtained by a continuous generation of new cells at the tip of the V, whereas the mature and old cells are transported toward the V branches (Rivrain, 1997; Benech *et al*, 1993; Ducrocq *et al*, 2003); the V-shape resulting from the interaction of the divergent convective motions at the top of the anvil with the upper south to south-westerly diffluent environmental flow that prevails generally during these heavy precipitation episodes). Knowing the sensitivity of the hydrological response (*see* section 3.3.1) to the temporal and spatial scales of the precipitating systems in Mediterranean region, it is essential to better document them as well as the nature of the precipitating systems that lead to extreme precipitation event. Literature not necessary agrees on this question. For example, according to Turato *et al* (2004) the more frequent extreme rainfall events are the ones for which no intense cyclone is observed over the Mediterranean area. On the other hand, in the framework of the MEDEX program, it has been found that there was a cyclone in the vicinity of most cases of heavy rain in the Western Mediterranean (Jansa *et al*, 2001). Quantitative determination about what types of weather systems are most often responsible for producing extreme rainfall exists for other areas. For instance, Schumacher and Jonhson (2006) examined the characteristics of extreme rains over the eastern two-third of United States over a 5-yr period; they found that 66 % of all the events and 74 % of the warm-season events are associated with MCSs.

Needs and proposals:

→ *Long-term rainfall space-time series*: Efforts to elaborate assembled precipitation climatology from radar and rain gauge data should be undertaken. Very seldom raingauge time series exceed a period of 100 years in the Mediterranean region. Raingauge networks with acceptable densities exist since the 60’s in some parts of the Mediterranean region. Radar QPE (see section 3.3.2.2) at the regional scale starts to be feasible since the end of the 90’s thanks to progress in radar coverage and processing techniques. Another lead to identify and characterize HPE should be a more intensive use of radar and satellite data over the sea. Refined merging techniques accounting for the physical and sampling properties of the sensors used and the space-time structure of rainfall need to be developed for this purpose.

→ *HPE space-time structure:* Characterization of the intermittency and space-time structure of Mediterranean rain fields for the various rain types (storms, MCS, orographic rain, fronts…) is useful for implementing downscaling procedures, developing stochastic rainfall models and better understand the flood genesis as the convolution of rain and geomorphological factors.

→ *Relationship between weather regimes/cyclogeneses and HPEs*: Identify weather regimes prone to HPEs by extending classification methods to other fields more characteristic of Mediterranean weather events and using mesoscale rainfall analyses to identify HPEs; Use long term meteorological reanalyses (ERA40, NCEP/NCAR) and satellite data to document the link between cyclogeneses and HPEs;

→ *Documentation of the nature, organization and life cycle of precipitating systems*: Determine the proportion of HPEs that can be attributed to quasi-stationary MCSs, slow moving frontal rainy systems, or combination of different precipitating systems by documenting the lifecycle (initiation, mature and dissipation stages) and internal dynamics of precipitating systems. Document the inter-annual and seasonal variability of the various types of precipitating systems with regard to those of large-scale meteorological conditions and sea surface temperature. Pay a special attention to extreme events within the HPE distribution by making for instance an extreme event database over the Mediterranean based on past case studies.

3.3.2.1.2 Factors leading to HPE

HPEs are multiscale atmospheric phenomena that result from a complex interaction of upper-level synoptic flow and local topography (Rudari *et al*., 2004). The synoptic and mesoscale environmental ingredients leading to HPEs over mountainous regions are the same as those encountered for HPEs over other mountainous regions of the world (Doswell *et al*., 1998; Lin *et al*., 2001; Nuissier *et al*., 2007):

- conditionally or potentially unstable air masses,
- moist low-level jets (LLJ) that impinge the first foothills,
- steep orography which helps to release the conditionally instability associated with the low-level jet,
- a slow evolving synoptic pattern that slows down the advance of heavy precipitation system or maintains the same favourable environment to heavy precipitation.

For some cases, upper-level precursors as upper-level Potential Vorticity (PV) streamers (Felhman *et al*, 2000; Massacand *et al*, 1998; Homar and Stensrud, 2004) or a deep short trough can be found to approach the triggering area of convection. By reducing the static stability, intensifying low-level jets and upper-level divergence, these upper-level dynamical structures favours the upward motion and consequently convection. However, the orography as well as diabatic processes associated with convection can altered the streamer's evolution (Morgenstern and Davies, 1999; Hoinka *et al*., 2003), so that the relationship between **fine scale structures of PV** and heavy rainfall events remains to be clarified.

Upslope triggering is not the only process involved in the conditional instability release in this region. Using simulations with an idealized orography, Rotunno and Ferreti (2001) explored for the 1994 Piedmont flash-flood the effect of the convergence produced between a western moist part of the airstream that tends to flow over the mountains and an eastern unsaturated part that is deflected westward around the obstacle. Romero *et al* (2000) and Ricard (2002) have also pointed out the role of the **nearby mountain ridges in enhancing the low-level jet and/or inducing upwind low-level convergence**. A number of convective systems form indeed over the Mediterranean Sea before to anchor inland as example the extreme rainy event that occurred in September 2002 in South-eastern France (Delrieu *et al*, 2005). The **shape and fine-scale structure of the mountain range** play also a role in modulating the precipitation. Scheidereit and Schär (2000) have shown that the specific arc-shape of the Alpine topography may intensify the Coriolis-induced asymmetry of the flow and concentrate precipitation in some small areas. Cosma *et al* (2002) and Ricard (2005) have shown for instance that the small-scale orographic features of the Massif Central, focus and intensify the precipitation due to the convergence of low-level air masses within the succession of oriented east-west ridges and penetrating valleys. Even small and low ridges seem to contribute to the triggering of convective cells. These results obtained from numerical simulations need to be confirmed by observations. In some cases, **cold pool resulting from evaporation/sublimation/melting of the falling precipitation** may trigger new cells at its leading edge, far upstream of the mountain (Ducrocq *et al*, 2007). All these factors interact in a not well known way which make difficult the forecast of the exact location of the anchoring of the precipitating systems and their intensity; non-linearity of physical processes involved, importance of fine scale structures, lack of mesoscale observations over the Mediterranean sea and over mountainous regions are accounting for that. Progress has also to be made to understand what differentiates an intense event from a paroxysmal one for which daily surface rainfall greater than 500 mm can be recorded.

One issue of the Mesoscale Alpine Program (MAP) was the study of microphysical modes of production or enhancement of precipitation by topography. Dominant microphysical processes were found to differ according to the flow regimes (un-blocked or flow-over regime, Durran, 1990; Medina and Houze, 2003). Identifying **dominant microphysical processes that increase the efficiency of the Mediterranean rainy systems** is a key point along with processes that lead to stationarity and continuous energy (moisture, instability) supply.

Needs and proposals:

→ *Better understanding the role of upper-level dynamics on HPEs*: Investigate the role of synoptic-scale and upper level dynamics on the triggering of HPEs, by better documenting PV streamers and their fine scale structures and studying their interaction with orography and condensation processes.

→ *Characterization of the low-level mesoscale environment:* Improve the knowledge of mesoscale features such as LLJ (intensity, orientation, moisture transport ….) and other key ingredients (CAPE, Precipitable Water …) related to HPEs by making use of fine scale data (through possible mesoscale reanalyses) and of high-resolution numerical simulations.

→ *Understanding the role of the complex orography of the region*: Analyse not only the individual role of the mountain ridges under different flow regimes, but also those resulting from the combination of these reliefs (including small and low-mountains). Understand the modulation of precipitation induced by the fine scale structures of relief as well as the role of neighbouring mountains.

→ *Identifying mechanisms leading to high-accumulated surface rainfall:* Further investigate the mechanisms leading to stationarity of the MCSs, in particular study the interaction between cold pool dynamics, incident low-level flow and relief; investigate the interactions between the large-scale upper-level dynamics and the low-level mesoscale circulation; identify dominant microphysical processes and environmental factors that lead to highly efficient precipitating systems (e.g. extreme events).

3.3.2.1.3 Moisture monitoring and origin

The Mediterranean Sea constitutes an important local source of moisture which is transported by low-level flows toward the target region where the heavy precipitation occur (Rudari *et al*., 2004). Moisture monitoring at the regional scale with adequate space-time resolution remains a challenge. Indeed, operational radio-soundings network hasn't a sufficient temporal and spatial resolution to capture the high spatial and temporal variability of the moisture field. With the development of ground-GPS recievers networks – foremost for positionning purposes - as well as of meteorological-dedicated mesoscale ground-GPS networks deployed as instance within the OHM-CV and RENAG observatories, high temporal and spatial resolution GPS data are now available and are valuable observations for monitoring moisture field associated with HPEs (Champollion *et al*, 2004; Brenot *et al*, 2006). In addition, the value of phase measurements of ground targets for estimating changes in the atmospheric refractivity between a weather radar and that targets has been demonstrated (Fabry 2004). However, such data provide in most case only Integrated Water Vapour (IWV) along the waves path and over land . Airborne vapour Lidar measurements and observation from space (AIRS and IASI on METOP), are promising instruments to complement such observations during specific campaigns and over seas. Synergitical use of all these moisture measurements through atmospheric data assimilation or tomography techniques should be encouraged to obtain 3D high resolution moisture information at the mesoscale.

Besides the local sources, some recent studies have shown a possible influence of tropical-extratropical interaction on moisture advection. Reale *et al*. (2001) showed that several cases of severe floods over the Western Mediterranean could be related to hurricanes. Turato *et al*. (2004) investigated the role of large-scale moisture sources on a major precipitating and flooding event that affected Piedmont. Using water vapour backward-trajectory, they found that a large amount of moisture originated outside the Mediterranean region. According to Pinto *et al*. (2001), recurring tropical depressions can influence the formation of through-ridge systems over the Atlantic and enhance moisture transport across the Atlantic into Southern Europe. Also, mid-level dry air masses are worth documenting and their interaction with convective systems better understanding.

Evapotranspiration over continental surfaces can also constitute a local source of moisture and has been previously found to have an impact on the development and evolution of convection over continental areas (Clark and Arrit, 1995; Pan *et al*., 1996; Gallus and Segal, 2000). However, it is not certain that the quasi-stationary convection over the western Mediterranean region is very sensitive to soil moisture, as the low-level flows that feed up the convective systems do not cover a long distance over the continent.

Needs and proposals:

→ *Moisture monitoring:* Explore new capabilities of instruments and promote mesoscale assimilation of their data together with satellite observations to provide 3D mesoscale moisture fields.

→ *Identification of water vapour origin*: Determine the part of local source for moisture and heat (Mediterranean Sea) and that of remote influences (tropical-extratropical interaction) by performing water vapour budget and backward trajectory analyses; Study the impact of soil moisture on the life cycle of precipitating systems.

→ *Role of mid-level dry air masses:* Identify origin of mid-level dry air masses and investigate their interaction with the dynamics of convective systems.

3.3.2.1.4 Impact of Mediterranean Sea on severe precipitation events

In the fall season, the Mediterranean Sea is still quite warm after the long sunshine periods of the summer, whereas, upper cold air, transported from northern Europe, begins to concern the area; the both produce propitious conditions to HPEs occurrence (low static stability, large scale lifting and sustain of moisture). It is well known that a warmer (colder) SST increases (decreases) air-sea surface heat fluxes which in turn moisten (drains) and destabilize (stabilize) the marine atmospheric boundary layer. It results in an increase (decrease) of the available energy and moisture for the atmospheric convection and thus precipitation. Lebeaupin *et al.* (2006) highlighted some dynamical important effects of the SST on the low-level jet and the motion speed of the precipitating systems. If a SST increase (decrease) induces systematically a CAPE increase (decrease) and vice versa, the link between the SST and the displacement speed of the precipitating system is not so univocal. In fact, a SST anomaly can induce different atmospheric responses which seem mainly associated with different types of precipitating systems. Estimation of surface fluxes is not however straightforward and lack of database over the Mediterranean limit the validation of the turbulent fluxes bulk algorithms.

As for tropical cyclones, the SST could not be the discriminating factor in explosive cyclogeneses or heavy precipitation events but rather the thermal heat content of the oceanic mixed layer. The thermal heat content can be considered as energy tank available for the atmosphere (CAPE) via the surface turbulent heat fluxes (sensible and latent). The spatial distribution of the energy sources seems to play a role as important as their intensities. In order to progress in the understanding of the role of the thermal heat content in the life cycle of the strong atmospheric events, development and validation of coupling of mixed-layer oceanic model to atmospheric model should be encouraged in HyMeX.

Needs and proposals:

→ *Impact of the sea surface temperature and thermal heat content on strong atmospheric events (HPE and cyclogeneses):* Develop coupling between mesoscale atmospheric and oceanic layer models to study the impact of thermal heat content (and SST) during the different phases of the life cycle of strong atmospheric events; Acquire the observations needed for validation of the coupled models; determine the spatial scales and amplitude of THC/SST anomalies that influence the atmospheric events.

→ *Validation of surface fluxes parameterizations:* Acquire the observations needed for validation of surface fluxes parameterizations suitable for conditions encountered during the Mediterranean heavy precipitation and intense marine low-level winds that often prevail during HPE.

3.3.2.1.5 Role of aerosols

Increase in atmospheric input from various sources (Saharan dust; Pyrogenic - in relation to increasing heat waves; anthropogenic particles - due to increasing demographic pressure) will act at 2 levels: 1) atmospheric physic and 2) marine biogeochemistry. As concerned the atmospheric physics and in particular precipitating systems, questions are how these higher concentrations of aerosols in the atmosphere will affect the cloud formation. Marine aerosols may play in particular a significant role in terms of potential CCN/IN. More generally, the types of Cloud Condensation Nuclei (CCN) and ice nuclei (IN) encountered during heavy precipitation events have to be documented and their ability to produce more or less efficient rainfall-producer systems. Higher aerosols concentrations also act to reduce the incoming solar radiation and therefore may reduce energy available for atmospheric convection triggering.

Needs and proposals:

→ *Role of aerosols as CCN*: document the types of aerosols encountered during HPEs (marine, industrial and urban, dusts, erosion aerosols, ...). Study the aerosol indirect effect in contributing to increase/decrease precipitation production? Are the marine aerosols injected in the boundary layer able to modify, through their possible role of CCN/ICN, significantly the cloud development?

→ *Radiative effect of aerosols*: better quantify the aerosols impact on the sea-surface temperature (SST) in reducing the incoming solar radiation? Can the aerosol direct effect contribute to inhibiting convection by reducing the surface latent/heat fluxes?

3.3.2.1.6 Modelling and predictability issues

Non-hydrostatic models employing grid-spacing of about several kilometres have shown substantial success in simulating realistic heavy precipitation systems (Stein *et al*, 2000; Richard *et al*, 2003; Asencio *et al*, 2003, …). A number of National Weather Services use or plan to use in a near future such models in their operational suite. The success of the high-resolution model may however depend strongly of the initial conditions. Ducrocq *et al* (2002) found that using high resolution observations to produce detailed initial conditions results in more realistic simulations of HPEs and better hydrological response when forecasting precipitation is supplied to a flash-flood hydrological model (Chancibault *et al*, 2006). Development of mesoscale data assimilation, with emphasis put on assimilation of observations within cloudy and precipitating systems, is a promising lead of improvement. Even though high-resolution models make a step forward in the simulation of convective systems by removing the need for a convective parameterization, progresses are still needed, as instance, on how the model simulates the initiation phase (cumulus stage), the details of the microphysical processes within the precipitating systems, or the high-gradients interface at the periphery of the convective cells. High-resolution observations inside precipitation systems and within the boundary layer are currently missing for validation and improving of parameterizations of physical processes involved in HPEs (microphysical parameterization, subgrid scale condensation and turbulence, etc)

Predictability limits results from the nonlinearity and instability of the dynamics of the atmosphere, together with the lack of a precise knowledge of the atmospheric state at any time and location. The atmospheric predictability depends on flow regime. Synoptic and large mesoscale systems possess more intrinsic predictability than cloud-scale convective systems (Tennekes, 1978). However, some factors can increase the predictability on the mesoscale, such as surface heating, synoptic-scale disturbance or topography forcing which are often present for Mediterranean HPEs. The management of the risk occurrence of a flash-flood event requires early warnings. Since the dynamical and physical processes associated with HPEs involve small-scale processes that have a low predictability on a long-term, a risk assessment should be necessary calculated by indirect strategies combining weather regimes and ensemble prediction at various scales. Open questions concerning such a system would be how to design optimally the ensemble prediction systems for mid-term and short-term forecasts. For short-term mesoscale ensemble forecasting, strategies for perturbing the initial conditions thanks to the assimilation system, the synoptic-scale scenarios, the boundary conditions and the model parameters will have to be designed and assessed.

Needs and proposals:

→ *Mesoscale data assimilation within cloudy and precipitating systems*: Progress in the assimilation of non-conventional data (cloudy radiances, radar, lidar, etc); Assess the benefit of Rapid Update high-resolution data assimilation cycle.

→ *Improving physical parameterizations of mesoscale models*: Test sensitivity to different parameterizations (microphysical schemes, turbulence parameterization).

→ *Predictability of HPEs*: Design and assess ensemble prediction systems for mid-term and short-term that will help to refine the prediction of the position, evolution and the rainfall amount of the HPEs; Characterize the predictability of HPEs by investigating the characteristics of initial conditions errors and of uncertainties in model physics on perturbation growth.

3.3.2.2 Floods and Flash-floods

During the last two decades, extreme flood events which occurred in Southern France (e.g. Nîmes, October 1988 ; Vaison-la-Romaine, September 1992 ; Puisserguier, January 1996 ; Aude, November 1999 ; Gard, September 2002) are a major threat to human life and infrastructures, as well as a major source of erosion and pollutant transfer. There is no doubt that flash floods represent the most destructive natural hazard in the Mediterranean region causing around a billion Euros of damage in France over the last two decades (Gaume *et al*., 2004). These events are poorly understood due to the lack of experimental sites and long-term hydro-meteorological data with adequate space-time resolution (Gheith and Sultan, 2002; Foody *et al*., 2004; Delrieu *et al*., 2005).

3.3.2.2.1 Quantitative precipitation estimation (QPE)

Rainfall monitoring at the regional scale is essential to provide accurate and localized information for flash-flood warnings, in particular to assess the hydrologic impact of the heavy rain events.

Although raingauges represent the reference sensors for measuring rainfall at ground level, their use for the spatial estimation of rainfall in mountainous regions poses a number of problems: (i) the network density needs to be adapted to the required time resolution; (ii) there is often an altitude bias in terms of sampling since the maintenance of the rain gauge networks is more difficult at high altitudes; (iii) the respective contributions of liquid and solid precipitation is difficult to assess at high altitudes. To be more specific about the first problem, Mediterranean urban catchments of 10 km^2 (100 km^2, respectively) would require a temporal resolution of about 5 min (12 min, resp.) and a spatial resolution of about 3 km (5.2 km, resp.) (Berne *et al*., 2004). A similar evaluation for natural catchments yields, for areas of 100 and 1000 km^2, a temporal resolution of about 25 and 100 min, respectively, and a spatial resolution of 6 and 10 km, respectively. Except in a number of urban areas, actual rain gauge network resolutions are in the best cases of 10 km for the daily time step and drop to about 15 km for the infra-daily time steps. The spatial resolution of existing raingauge networks is therefore not adequate for providing valuable **spatial QPE**. Telemetered rain gauges may provide **point estimates** during the rain event that can be very useful for complementing radar and satellite imagery and checking their quality. However, due to the actual densities, rain gauge networks take their full value for estimating spatial rain amounts at the event time scale; they are essential for post-flood investigations.

Compared to rain gauges, weather radar systems offer a number of advantages in the real-time monitoring context with spatial and temporal resolutions of typically 1 km^2 and 5 min, a large spatial coverage and an immediate availability. However, in mountainous regions, the indirect radar measurement of rainfall is even more complex than in flat regions and the radar QPE quality varies strongly, depending on the location and notably the range to the radar site (Joss and Waldvogel, 1990; Andrieu *et al.,* 1997; Pellarin *et al.*, 2002; Berne *et al.*, 2004). During the last three decades, research efforts were devoted to optimize the radar sitting and operating protocols, develop identification and correction algorithms for the various error sources (e.g., Andrieu *et al*., 1995; Delrieu *et al.,* 1997; Vignal *et al*., 1999; Delrieu *et al*., 2007) and assess radar QPE with reference to QPE derived from raingauge networks (Creutin *et al*., 1993; Boudevillain *et al.,* 2007). During the same time, an important effort has been dedicated to development of weather radar networks in the Mediterranean region (e.g. in France with the “Arc Méditerranée” project of Météo-France) and improve the operational radar data processing algorithms (e.g., Germann et al. 2006; Tabary 2007; Tabary et al. 2007). An encouraging convergence of research and operational efforts to improve radar QPE is noticeable in the recent period.

Due to the fast hydrologic dynamics of Mediterranean watersheds, quantitative precipitation forecasts (QPF) are critically needed for lead times ranging from several days (early warning) down to some tens of minutes (nowcasting). Regarding radar nowcasting techniques, those based on the "frozen-field" hypothesis are likely to be of limited interest to improve QPF in Mediterranean regions due the strong influence of the sea-land transition and of the relief on the convection triggering. The development of the Doppler and polarimetric capabilities for operational radar networks (e.g., Bousquet et al. 2007) combined with the assimilation of such "non-conventional" data by high-resolution atmospheric models is probably a more promising track. Merging radar, satellite and model QPF should also be considered (Wilson *et al*., 1998).

Needs and proposals:

→ *Quantitative precipitation estimates (QPE) with high spatial and temporal resolution (1 km^2, 10 min, typically) at the regional scale*. Weather radars are the most promising systems for this objective. The combined use of several radar systems operating with volume-scanning strategies and implementation of physically-based regionalized and adaptive radar processing algorithms are required to produce reliable radar QPE. Radar-raingauge merging may still be needed to remove spatial biases; however, such a merging should be implemented with great care, and probably avoided in the real-time monitoring context.

→ *Radar QPE error models.* Radar QPE error models need to be established to assess uncertainties on spatial rainfall estimates. It should be recognized that such uncertainties are radar range, intensity, integration time step and rain-type dependent.

→ *Nowcasting techniques.* Due to the fast hydrologic dynamics of Mediterranean watersheds, QPF are critically needed for lead times ranging from several days (early warning) down to some tens of minutes (nowcasting).

→ *Evaluation procedures for QPE and QPF.* Reference QPE provided by high-quality raingauge networks with adequate densities are required over large parts of the regions of interest (hydrometeorological observatories) to assess the quality of QPE and QPF derived from observations and numerical models.

3.3.2.2.2 Hydrologic responses to HPE

There is no unique and simple theory about the runoff production on watersheds during flood events. The main reason is that a variety of processes can be involved which are usually grouped in two categories: saturation excess (Dunne process) or infiltration excess (Horton runoff). Due to the high heterogeneity and space variability of the watershed characteristics (land use, soil type and depth, subsoil, local slope, usptream contributing area) and to antecedent moisture conditioning, these processes are likely to be active at the same time in various combinations (Ambroise, 1998). In addition, the karstic terrains, that are widespread in the Mediterranean regions, lead to specific behaviours with in particular strong non-linearities, the response of the local karst being strongly dependant on the initial conditions (status of the epikarst and, if any, of the saturated zone of the aquifer). At the catchment scale, watersheds for which Hortonian process is dominant are characterized by hydrologic responses rather directly related to the rainrate time series. Responses of "Dunnean" watersheds are more determined by the cumulated rain amounts. Hortonian processes contribute quick responses to the river streams. However, quick responses can also be observed in some specific areas (e.g., head watersheds in the Cévennes region) while there is a huge (infinite with reference to possible rain rates) infiltration capability at the soil surface. The fast horizontal transfer in the subsoil can be explained by the formation of temporary perched watertables and the existence of preferential flows within soil macropores that can be activated when thresholds of connectivity are exceeded. A characterization of the sub soil and in particular of the bedrock topography may be important in this context (Freer *et al.*, 2002). The riparian aquifer is also a sensitive interface between the hillslopes, the river and the watertable with a complex behaviour (threshold effects and non-linear responses). It controls the water storages from one rain event to the next and the river baseflows.

Needs and proposals:

→ *Hydrologic experiments at the hillslope scale.* Field experiments are needed to further understand hydrologic processes at very small scales from the hillslope down to the riparian aquifer and to the river. The newly available hydrogeophysical probing techniques (Robinson *et al.*, 2006) should be used together with more classical hydrologic instrumentation for a non-destructive characterization of the subsoil and the water fluxes occurring there during HPEs.

→ *Linking the hydrologic response and the landscape characteristics*. Such experiments should be performed for various types of landscapes. High-resolution products concerning topography, geology, soil, land use, vegetation cover need to be considered to link the hydrologic response to the landscape characteristics and hence allow extrapolations/parameterizations for ungauged basins. Compiling data on past FFs and performing intensive post-flood campaigns for the extreme events to occur in the Mediterranean region with a unified methodology is a complementary way for increasing such a knowledge. Developing post-event analysis is a major objective of the HYDRATE STREP (http://www.hydrate.tesaf.unipd.it/).

3.3.2.2.3 Hydraulic responses to HPE

Mediterranean rivers are characterized by very intermittent regimes which make their observation particularly difficult. The classical technique for discharge measurement is based on a water stage measurement in a river section not prone to backwater effects, coupled with a calibration of the stage-discharge relation. The so-called rating curve is established point by point for a series of stage-discharge values by means of flow velocity sampling over the river section. The establishment of the rating curve is therefore time-demanding, especially to sample the medium to high discharge range. During floods, the velocity probing methods (current meter with sounding weight, ADCP techniques…) may be impracticable for obvious reasons of safety of the operating personnel and preservation of the probing equipment. The rating curves are often extrapolated for medium and high discharges by means of hydraulic formulas that require the subjective evaluation of river rugosities. Hydroworks may offer more satisfactory discharge estimation methods based on the hydraulics laws of the regulating works (weirs, sills, sluice gates, etc). Other factors making the flooding river characterization difficult are linked to (i) overflows in the major river beds, (ii) solid transport that modifies the water viscosity, (iii) turbulence, (iv) possible modification of the river beds and (v) the often-observed destruction of the stage equipment during floods. A profound lack of knowledge results in terms of river discharge, particularly for high waters which are of special importance for the scientific question of interest.

The Mediterranean rivers react quickly, but the flow period is generally short, because the discharge is generally poorly sustained by groundwater. Erosion and sediment transport processes are obviously active mostly during floods and may profoundly modify the river morphology and impact their ecosystems. The absence of base flow during the long dry period and the discontinuity of the flow (even during floods) are the main characteristics of these rivers. The river hydraulicity does not allow the evacuation of the pollutant downstream and the river sediments constitute a reservoir of pollutants which could be potentially available during the big flood events. The beginning of the flowing period must be considered as a critical period for the hydrological and hydrochemical behaviour of the river. The peculiar hydrological behaviour of these intermittent rivers has a significant impact on the direct pollutant inputs during low flow conditions but also on their remobilisation and transport to the downstream environment (coastal lagoons, coastal zones) during the flood events. As pointed out by Froelich and Kirby (2006), these temporary rivers have not been sufficiently recognized until now, especially in terms of their impact on the quality of receiving waters, and of the distinctive dynamics which are introduced when severe flood events follow intensive dry periods.

Needs and proposals:

→ *Remote sensing techniques for flooding-river characterization*. Due to the lack of knowledge concerning high-flood discharges, the development of remote sensing techniques for discharge measurement of flooding rivers should be encouraged. Such techniques are already employed for height measurements (e.g. ultra-sonic probes fixed on bridges…). In addition, performing velocity measurements is especially critical: large scale PIV techniques based on video imagery (Creutin *et al.*, 2003) or radar techniques need to be developed and implemented for estimating surface velocities. Bathymetry of the changing river beds is also a concern. Light and mobile hydrometry equipment should also be assembled for opportunistic discharge rough estimates during floods.

→ *Distributed hydrometry.* The capability to measure discharges in many places is certainly a very important subject to develop in the future to constrain distributed hydrologic and hydraulic modeling at the regional scale. In a first step, one can imagine to implement new remote sensing systems over already operational control points in order to assess the new techniques with direct flow measurements for low to medium floods and increase the existing rating curves robustness for high floods. This would allow an improved processing of the historical time series. In a second step, distributed hydrometry plans should be established to dramatically increase the number of control points over selected watersheds for an in-depth spatial characterization of their spatial response.

→ *Sediment yields and pollutant fluxes in intermittent rivers.* It is important to develop models to better describe the evolution of sediment yields and pollutant fluxes on intermittent rivers taking into account the magnitude and frequency of floods and the land uses. This requires a better knowledge of the specific biogeochemical processes that may influence the release and/or retention and/or degradation of pollutants on temporary catchments. The continuous monitoring of selected rivers using automatic sampling systems has to be implemented.

→ *Karst and flooding river interactions.* The karstic parts of a watershed may strongly modulate the river regime during floods through fast or delayed transfer of the rainfall to the stream, localized losses and (temporal or perennial) springs, non linear in time behaviours, etc. It is thus very important to integrate this knowledge to the classical hydrological one in order to better understand the processes involved in the concerned watershed.

3.3.2.2.4 Modelling and predictability issues

Besides the development of regional hydrological modeling aimed at assessing the water budget (see section 3.2.2.2) of Mediterranean watersheds over a range of scales (tenths to thousands of square kilometers, days to decades..), there is undoubtedly a need for developing flood-event hydrological modeling systems able to efficiently convolve rainfall and landscape space-time structures and perform warnings in a distributed way at the regional scale in the real-time context.

In the Mediterranean region, "lumped" models were applied in order to simulate flood events or to calculate and regionalize peak-flows return period (Prudhomme, 1995; Neppel et Bouvier, 1997; Arnaud and Lavabre, 2000; Perrin *et al*., 2003). These models are parsimonious in terms of parameterization and prove to be efficient provided that long rainfall-runoff time series (typically 20 years) are available for their calibration. However, they cannot predict hydrographs for each single point in space while the hydrological risk is by nature "diffuse" (e.g., urban settings, roads and bridges, camp sites, etc). In addition, they cannot take into account the spatial variability of input data and the impact of land use changes.

Distributed hydrological models, including the original and adapted versions of TOPMODEL (Beven and Kirby, 1979), were successfully implemented in the Mediterranean region to simulate flood events for catchments of some tenths up to some hundreds of km^2 (e.g. Todini, 1996; Moussa, 1997; Moussa et al., 2002; Sempere-Torres et al. 1992; Obled et al. 1994; Saulnier *et al*. 1997; Chahinian, 2004). Based on hydrological similarity, this modeling approach is pretty efficient in terms of computation compared to fully distributed models (Beven 2001). Both quality of the rainfall estimation in time and space and the initial moisture state of the watersheds are known to have a dramatic impact on the performance of such models (Hébrard, 2004; Hébrard et al., 2006; Le Lay and Saulnier 2007).

Flood-event hydrological models include routing components (transfer functions) that allow a simplified representation of the hydraulic processes occurring in the rivers. More complete solutions are required when larger catchments are considered: the most popular approach to model flood routing has been one-dimensional solutions of the full De Saint-Venant (1871) equations (Fread, 1993; Moussa and Bocquillon, 1996) such as in hydraulic models (MIKE11, ONDA, HEC-RAS, HEC, 2002) or the diffusive wave model such as in MHYDAS (Moussa et al., 2002). In order to overcome the limitations of the one-dimensional model in the simulation of overflows in the inundation zones, the 1D/2D combination model LISFLOOD-FD (Bates and De Roo, 2000), quasi-2D models (CARIMA or STREAM) and the two-dimensional finite difference and finite element models (e.g. Bates *et al*., 1992) such as TELEMAC-2D (Galland *et al*., 1991) were developed.

Like for water-budget models, research efforts are required to improve coupling of hydrologic and hydraulic processes through a number of sensitive interfaces, e.g., hillslope-river, river-aquifer, river major and minor beds, spatial discontinuities in urban and agricultural zones. Spatially-distributed data are needed for their implementation (rainfall, snow cover, soil hydrodynamic properties, land use, vegetation cover and geometric properties of the channel network). Rigorous parameterization, calibration and validation procedures are also required (Chahinian, 2004). In addition to the needs and proposals already listed in section 3.2.2 for water-budget hydrological models regarding the geophysical description of the watersheds and the parameterization/calibration/evaluation procedures, specific points for flood-event hydrological models are:

Needs and proposals:

→ *Initial soil moisture characterization.* A critical point for the flood-event models is related to the determination of the initial moisture state of the watersheds. Research needs to be realized to assess the ability of regional water-budget models to provide such an initial state.

→ *Use of real-time quantitative precipitation estimates (QPE).* Specific problems arise for QPE in the real-time context (sensor drifts or failures, telemetry failures…) which need to be addressed very pragmatically.

→ *Use of real-time quantitative precipitation forecasts (QPF).* Due to the fast response times of the Mediterranean catchments, the use of QPF is compulsory to extend the forecasting lead times further than the watershed response times. QPF provided by numerical models and nowcasting techniques may take diverse forms and generally need to be disaggregated in space and/or in time before to be used as forcing variables. A number of research and practical questions arise from this necessary adaptation.

→ *Test beds.* Test-beds need to be implemented for assessing hydro-meteorological forecasting systems in the real-time context. Special attention needs to be paid to uncertainty characterization and propagation through the observation/modeling system (e.g. COST Action 731 "Propagation of uncertainty in advanced meteo-hydrological forecast systems"; "Bassins Versants Numériques Expérimentaux" of SCHAPI; "Hydrologic Ensemble Prediction Experiment (HEPEX)").

3.3.2.3 Impact of climate change on HPE and FF

Extreme climate events receive increased attention. The main focus, motivated by the increase in deaths and in economic losses, is to identify if extreme weather events, including heavy precipitation events and subsequent floods, are increasing or not in frequency.

3.3.2.3.1 Extreme rainfall and discharge: observed trends

A rather considerable amount of quantitative and qualitative information is available on extreme rainfall, flash-flood and flood events that occurred in the past. This includes the "systematic" rainfall and discharge observations of the last 50 years, the observations that can be reconstructed more locally from historical data sources and palaeo-hydrological observations.

Raingauge data from networks operated during the last 50 years allowed production of **maps of extreme rainfall parameters**, e.g. the point rainfall with decennial or centennial return periods for various integration time steps (1 h, 24 h…). For instance Bois *et al.* (1995) and Kieffer *et al.* (2001) produced maps of extreme rainfall parameters estimated with a Gumbel distribution for the Cévennes-Vivarais and the French-Italian Alps, respectively. Using a set of 20 long French **rainfall series with at least 100 years** of record, Muller (2006) showed that the Gumbel distribution adjustment is not satisfactory for one third of the stations, while a Generelized Extreme Values (GEV) distribution seems more appropriate. Arnaud and Lavabre (2002) developed the Shypre model, based on a stochastic rainfall generator, which gives larger reference values for a given frequency than the Gumbel distribution. Flood **frequency analysis of extreme discharges** in France is generally based on hydrometeorological approaches, such as the Gradex (Guillot and Duband, 1967), the Agregee (Margoum *et al.,* 1994) and the Shypre methods. Such methods provide larger reference values for a given frequency than the fitting of extreme value distributions on discharge series of the systematic observation period. Muller *et al.* (2007) showed that rainfall information reduces the final uncertainty on the flood distribution. **Regional approaches** aggregate at a regional scale flood records from a homogeneous hydrological area (e.g., the index flood method; Dalrymple, 1960). A comparison between the Shypre results and a regional rainfall approach developed by Mora et *al.* (2005) showed that these two approaches are in agreement.

Historical approach has been tested during the SPHERE European project (2000-2002). The observation period is extended by a multi-disciplinary work associating historians, hydraulicians and hydrologists, exploring **historical archives up to the sixteenth century** to detect past events and the water levels reached for specific hydraulic sections. Hydraulic modelling can then be used to estimate the corresponding maximum discharges. Finally, statistical analyses can be performed over such heterogeneous time series to refine the discharge frequency curves. An interesting example of this approach is provided by Naulet *et al.* (2005) for the Ardèche river at Sauze Saint Martin. Extreme flood assessment by the Gradex method and historical series from 1644 are found to be coherent. During the InondHis project (2005-2007), Neppel *et al.* (2007) studied historical rainfall and discharge events of the Gard, the Hérault and the Aude rivers. Ten additional long historical discharge series are available with 200 to 400 years of record.

The palaeoflood approach has been tested during the SPHERE project on the Ardèche river, based on geological evidence of flood deposits in a number of caves during several millenia (Sheffer *et al.*, 2003). More generally, since catastrophic flood events bring tremendous amounts of sediments to the karstic systems, deltas and lagoons, the study of sediment records from these media should help obtaining the long records necessary to study the evolution of these types of events. Precise description of the sediment archive, based on measurements of its physical properties (through X rays, spectrophotometry, magnetic susceptibility techniques), allows determination of the nature and the origin of the sediment, a critical information for the identification of the climatic extremes. In addition, geo- and bio-indicators can be used to reconstruct past climatic conditions (temperature, precipitation…). These sedimentological analyses, completed by analyses of the malacofauna have already given promising results for the reconstructions of extreme events in the Mediterranean region (Dezileau *et al*., 2005; Sabatier *et al*., 2007).

Needs and proposals:

→ *Extreme rainfall assessment:* The compilation of raingauge data from the networks available during the systematic observation period (last 50 years) is in progress for the Cévennes region, France. This dataset will allow to re-assess extreme rainfall parameters and their spatial dependence and variability. Such information will be linked with geomorphological factors, rain physical processes and vulnerability considerations.

→ *Intercomparison of extreme rainfall and flood distribution assessment:*. Various approaches will be compared: standard application of extreme value distribution on systematic records, rainfall-runoff approaches (Gradex, Agregee, Schadex, Shyreg), and regional approaches. The ten long historical discharge series available in the Mediterranean area will be used as a reference.

→ *Palaeo-hydrometeorology:* A strategy has to be defined for collecting and analysing sediment records in a number of Mediterranean media region (karstic systems, deltas, lagoons…) to elaborate information on extreme events and the climatic variability for a long duration (last millennium, at least). Such palaeo series and proxies should be put in relation with historical records, when available. A specific work is required to understand the climatic variability reconstructed in the Haut Languedoc by using regional climate models in order to relate changes in frequency and characteristics of the extreme events to those of the climate average. The Haut Languedoc area could be a good pilote site for that.

3.2.3.3.2 Projections of HPE and FF in climate scenarios

The results of **climate models** tend to indicate an increase in the relative variability of seasonal and annual precipitation as well as an increase of the frequency of heavy precipitation events with global warming. Gao *et al* (2006) found both shift and broadening of the precipitation distribution, suggesting an increased probability of occurrence of events conducive to both floods and droughts Confidence on these results must however be considered with respect to the current limitations of the climate models in reproducing the observed patterns of variability and especially in simulating precipitation at **regional scales**. So that it is still beyond our reach to conclude to an increase or decrease of extreme precipitation events due to global warming for the Mediterranean regions.

The detection of **trends within flood and drought regimes** has been examined on a set of 200 long discharge series in France. Renard (2006) showed that no consistent trend can be detected at a local scale, but a new regional methodology allowed detection of significant changes in the Alps and Pyrenees area and the North-East of France. The two former can be related to an increasing of temperature and the latter can be explained of the number of rainy days. At the current time, no significant trend has been found in the Mediterranean area, but increasing of temperature is expected to major rainfall and flood risk. From a methodological point of view, Bayesian approaches developed (Renard *et al.*, 2006) to incorporate the uncertainty related to **non-stationarity** still have to demonstrate their benefits when applying them to climate scenarios outputs.

Needs and proposals:

→ *Heavy precipitation and flood frequency analysis in a non stationary context.* Statistical models need to be developed, in order to combine observed trends on rainfall and flood extremes and the predicted evolution by climate models, using co-variables. A specific work is expected to model the dependence of extreme values, and to infer the spatial extent of such catastrophic events.

→ *Climate change impact on frequency and intensity of heavy precipitation and flash-flood extremes*: To further increase confidence in climate model results for the rainfall over the western Mediterranean regions, through the use of regional climate models. Development of precursor-based approach based on weather regimes as the one developed within IMFREX for the Atlantic region should be encouraged. Such approach is currently investigated for Western Mediterranean heavy precipitation within the CYPRIM project.

3.4 Intense sea-atmosphere interactions

Coordinators: K. Béranger, P. Drobinski

3.4.1 Introduction

Sea-atmosphere interactions play an important role on the ocean-atmosphere circulations at various spatial and temporal scales. In the Mediterranean Sea, several regions are key spots of intense air-sea interactions which affect considerably the heat and water budgets. These regions are regions of very strong storms which are caused by deep cyclogenesis or by the orographic response to the large-scale forcing. These regional strong winds such as the Mistral, Tramontane or Bora are frequently observed to extend as far as a few hundred kilometres from the coast (Jansa, 1987) and during winter, they bring cold and dry continental air over the warm western Mediterranean basin, generating intense air–sea heat exchanges (evaporation enhancement) (Flamant, 2003) and sea surface cooling (Millot, 1979), inducing the formation of the western Mediterranean deep waters that move into the Atlantic Ocean (Rhein, 1995; Schott et al., 1996; for a review on the circulation in the Mediterranean see Millot and Taupier-Letage, 2005a). The locations of the intense air-sea exchanges which correspond to the location of dense water formation are shown in the figure below with a additional area southeast of Corsica (strait of Bonifaccio; Fuda *et al.*, 2002).

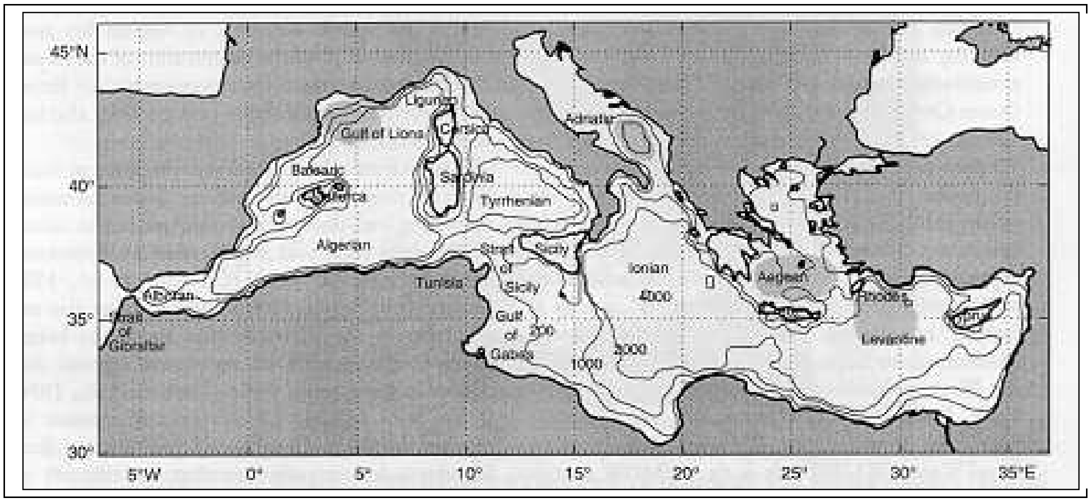


Figure 3.4.1: Zones of deep oceanic convection (Candela 2001)

A consequence of the large modulation of the air-sea exchanges (water and heat fluxes) is the dense water formation (DWF) in the Mediterranean Sea, which is the motor of the thermohaline circulation. This oceanic thermohaline circulation is the slow branch of the Mediterranean water cycle, because it interacts with the thermal content of the mixed layer and thus the SST and thus modifies the upper hydrological characteristics of the ocean (mixed layer, SST, sea-surface salinity SSS). It may in turn modify the characteristic of the lower part of the atmosphere (temperature and heat fluxes) and may play a major role in the life cycle of cyclones and atmospheric fronts through temperature gradient and moisture fluxes.

There is a large variety of spatial and temporal scales involved in the ocean-atmosphere interactions, which depend on the characteristic of spatial and temporal scales of the processes involved in each compartment and this makes difficult the determination of the deterministic link relating the atmospheric and oceanic circulations. Air-sea exchanges, interactions and feedbacks are thus relatively not well known and difficult to parameterize in models even though they are essential to better understand and quantify the water cycle between the atmosphere and the Mediterranean Sea.

3.4.2 Scientific questions

3.4.2.1 Strong winds over the Mediterranean Sea

During fall, winter and early spring seasons, the regional wind storms advect cool air over the Mediterranean Sea and contribute to sea-surface cooling in very short period of time (several hours only) and enhanced upwellings which modify the heat and salt content of the oceanic surface layer. The frequent occurrence of these wind storms in the Mediterranean region is primarily due to the high frequency of apparition of lee-warm-primary-depressions and low-level-PV-positive-banners, both are the consequence of the particular geography of the Mediterranean region. These strong winds blow generally offshore and because of their large frequency, thus affect significantly the air-sea exchanges at various time scales (e.g. local strong winds are essential for deep water formation pre-conditionning during fall and deep water formation during winter).

Latent heat release is usually a mechanism to sustain and intensify most of the cyclogenetic processes. The effect seems to be quite important in the eastern Mediterranean region (Alpert and Ziv, 1989). Nevertheless it is only a secondary effect in the case of the most important orographic cyclogeneses, both Alpine (Dell'Osso and Radinovic, 1984; Stein and Alpert, 1993; Alpert et al., 1995) or non-Alpine (Garcia-Moya *et al*., 1989). So, the most of the strong winds observed in the Mediterranean belong to the category of local winds. These are the Mistral and Tramontane (e.g. Georgelin and Richard, 1996; Drobinski et al., 2001, 2005; Guénard et al., 2005, 2006), Cierzo (Masson and Bougeault, 1996), Ponent, Levante, Scirocco, Etesians, Bora (Smith, 1987; Grubišić, 2004), Shamsin, Sharav and other (see Reiter, 1975 for a general description). The high frequency, recurrence and physical identity of the Mediterranean local winds suggest a close link of these winds to geographical factors. When the large-scale or synoptic-scale flow interacts favorably with the orography, a primary pressure perturbation, the lee depression and/or the associated windward high-pressure are induced. The orographic perturbation breaks the geostrophic balance that prevails at syoptic-scale and can create local areas of strong baric gradient which provide the acceleration that lead to the intense local winds. Past the narrow accelerating zone, the winds continue blowing and spreading in an inertial way which permits to find intense local winds even far from the orographic region of origin (Campins et al., 1995).

Despite the fairly known basic ingredients giving birth to these regional strong winds, there is a need to better understand and predict the time and spatial variability of the strong local winds in order to better quantify the air-sea exchanges. There is a need to evaluate the respective roles of the large-scale circulation, atmosphere stratification, and topographical elements in the intensification of the local winds, to quantify the water vapor and heat transport associated with these local winds. HyMeX must aim at establishing predicting variables for near-surface winds and associated heat and water transport, needed to quantify more accurately air-sea exchanges, to validate simulated surface fluxes and to provide projections of surface heat fluxes in the context of climate change. Concerning strong wind, particular objectives of the HyMeX project should be:

<u>Needs and proposals:</u>

→ *<u>Multi-scale space-time series of near-surface winds, temperature and humidity:</u>* Elaboration of an extensive dataset of surface winds, temperature and humidity over land **and sea** combining in-situ measurements (buoys, weather stations), and airborne and spaceborne remote sensor measurements (SAR, lidar), as well as wind profilers to identify the upper-level features (mountain waves,…) contributing to low-level wind reinforcement and vertical profiles of temperature, humidity and pressure to analyze the role of stability in the low-level wind dynamics. Combination of wind, temperature and humidity sensors should be privileged to evaluate water and heat advection associated with the strng winds.

→ *<u>Relation between strong surface winds and large-scale predictors:</u>* Derivation of predictors (large-scale circulations, local topography, coastline shape,…) of the regional strong winds (including the relationship between cyclones and strong wind). In the framework of HyMeX, the physical or statistical relationship between the predictors and the predictands (surface wind and heat transport) may be determined and/or validated using the collected dataset and be evaluated as forecast systems. Special focus should be made on the sensitivity of the local wind response to any change of the set of predictors.

→ *<u>Quantification of strong-wind induced heat advection</u>:* Measurements and analysis of the dominant temporal and spatial variability scales of the regional strong winds and associated temperature and humidity advections which are key terms to estimate the air-sea exchanges.

3.4.2.2 Mediterranean Sea response to strong wind forcing

3.4.2.2.1 Fast response of the Mediterranean Sea

- Surface processes

The hydrological properties of the oceanic mixed layer and the thermocline depth result from typically one-year averaged air-sea surface buoyancy and mass (E-P) fluxes. Both evolve quite slowly, whereas the occurrence of severe regional wind storms that produce local strong buoyancy loss and trigger oceanic convection at some specific spots (see Fig. 3.15) induce rapid water mass transformation.

Due to the strong wind storms, the sea-surface sensible and latent heat fluxes thus change very quickly. However the response of the Mediterranean Sea is not well known since typical time and spatial scales of the dynamical processes differ between the atmosphere and the ocean.

There is thus a large uncertainty on the spatial coverage, the occurrence and the duration of intense air-sea exchanges at very fine spatial and time scales. In particular these large uncertainties remain during deep oceanic convection events (Schott and Leaman, 1991; THETIS Group, 1994; Schott *et al.*, 1996; Mertens and Schott, 1998; Robinson *et al.*, 1991; Artegiani *et al.,* 1997; Manca *et al.*, 2006) in each major regions (Fig. 3.14). During these events, oceanic plumes, sub-mesoscale/mesoscale eddies and baroclinic instabilities actively contribute to vertical mixing. Moreover, coastal waters can be mixed with matter and sink down to the seabed, either following the slope or catched by canyons during some extreme events that occur on an interannual scale.

There is a need to monitor at fine temporal and spatial scales the hydrological properties of the oceanic mixed layer, of the thermocline depth and of the air-sea surface buoyancy and mass (E-P) fluxes over a long period of time in order to better document the different scales of variability, the correlation of the oceanic processes with the atmospheric forcing (heat and water advection with winds) and the possible lag between the atmospheric forcing and the oceanic response.

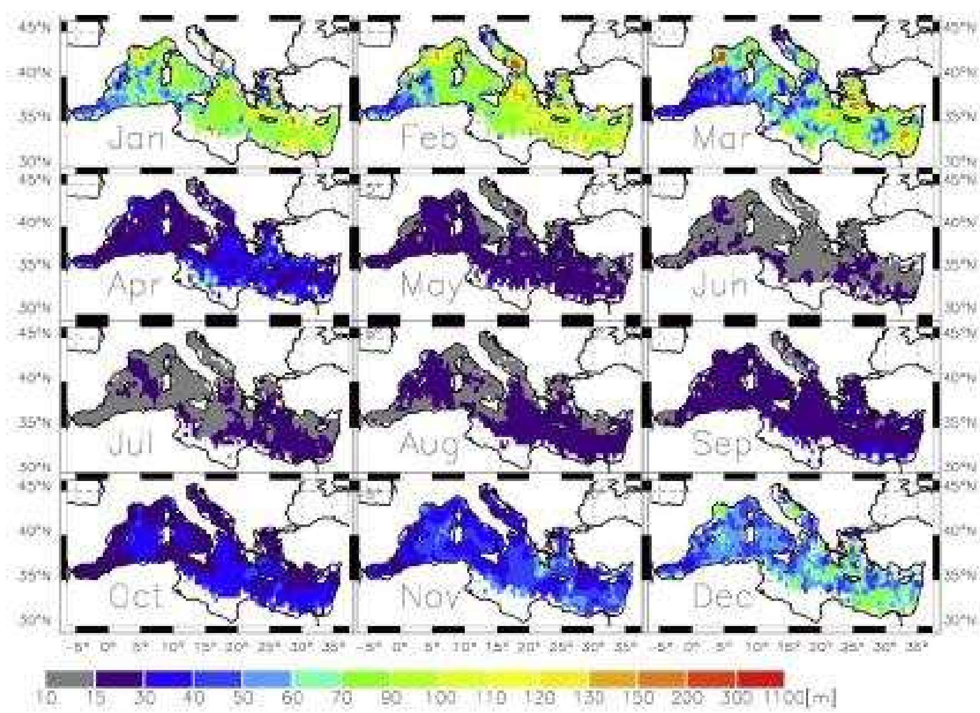


Figure 3.15: Monthly averaged oceanic mixed layer depth (Ortenzio *et al,* 2005)

Needs and proposals:

→ *Space-time series of oceanic hydrological characteristics:* Elaboration of a data base with measurements of surface heat fluxes during several autumn and winter periods (using in-situ sensors at the surface on buoys; using space-borne measurements of surface fluxes like SSMI, Bourras *et al.*, 2002).

→ *Variability intense air-sea exchanges:* Documentation of the interannual variability of intense air-sea exchanges and associated deep oceanic convection in the four major formation sites (spatial extension, occurrence and time-duration of the convective chimneys) using moored CTDs in key-points (explore the hypothesis of a DWF area in the southeast of Corsica). Evaluation of the impact of surface wind variability (including diurnal variability) on air-sea exchanges and oceanic convection (in particular preconditioning and oceanic mixing).

→ *Air-sea exchanges parameterizations:* Evaluation and improvement of parameterizations of heat fluxes in the presence of strong (and weak) winds.

- Modulation of air-sea fluxes and DWF by the ocean dynamics

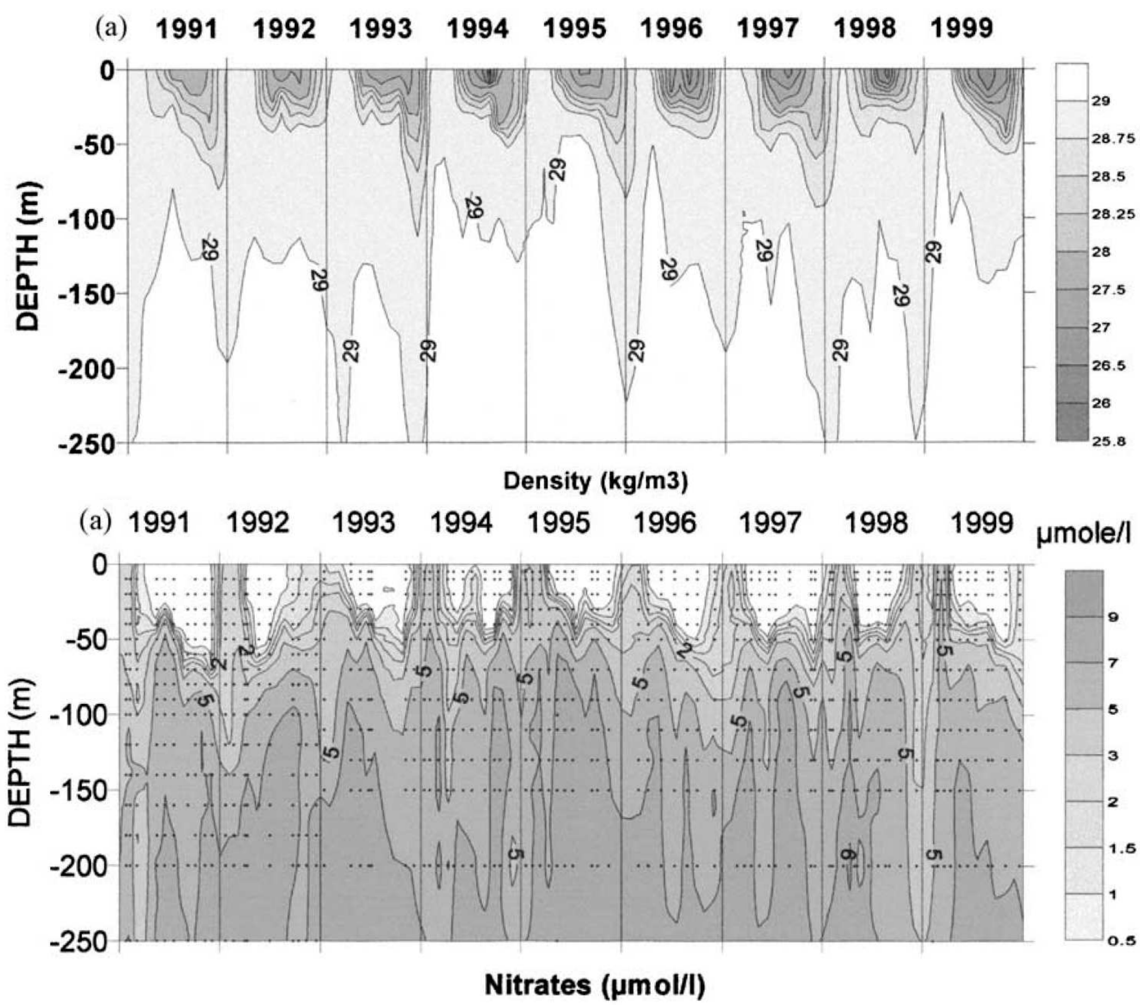
If wind storms were the only cause of surface cooling, oceanic convection and DWF, then the associated buoyancy loss should provide a deeper mixing and entrainment at the seabed. During convection, oceanic dynamical features such as eddies, submesoscale coherent vortices (SCVs), filaments, boundary currents, which inhibit or enhance part of the atmospheric contribution to oceanic convection, are at best partly understood (Madec *et al.*, 1996; Marshall and Schott, 1999; Lascaratos and Nittis, 1998; Wu *et al.*, 2000; Mantziafou and Lascaratos, 2004 ; Testor and Gascard, 2005). These oceanic (sub)mesoscale features and currents can cause mixing inhibition by re-stratification due to horizontal mixing or can increase vertical mixing by exporting upper mixed waters to the bottom and around the region of mixing and by uplifting deep waters to the surface, affecting in turn the air-sea exchanges.

Needs and proposals:

→ *Space-time series of oceanic hydrological characteristics:* Elaboration of a data base with measurements of oceanic hydrological characteristics at high temporal resolution during and outside strong wind events (e.g. using hydrographic profilers or gliders, moorings or regular ferries transects surface measurements).

→ *Impact of the oceanic dynamics on the modulation of air-sea fluxes, oceanic mixing and dense water formation* (eddy, current, waves, etc): Evaluation of the possible correlation between surface heat fluxes and the evolution of the oceanic dynamics and oceanic mixing layer properties.

The dynamics of DWF can also be monitored indirectly by marine ecosystems. Indeed, DWF creates vertical movements that constitute a mechanism for the surface waters to be nutrient-enriched after their mixing with intermediate and deep waters. This mechanism depends to a large extent on the characteristics of the winter mixing (number, intensity, frequency and interval between wind events) and is highly interannually variable as seen in DYFAMED measurements (Figure 3.16). The vertical mixing enhances the primary productivity and the sink of organic matter to the seabed.



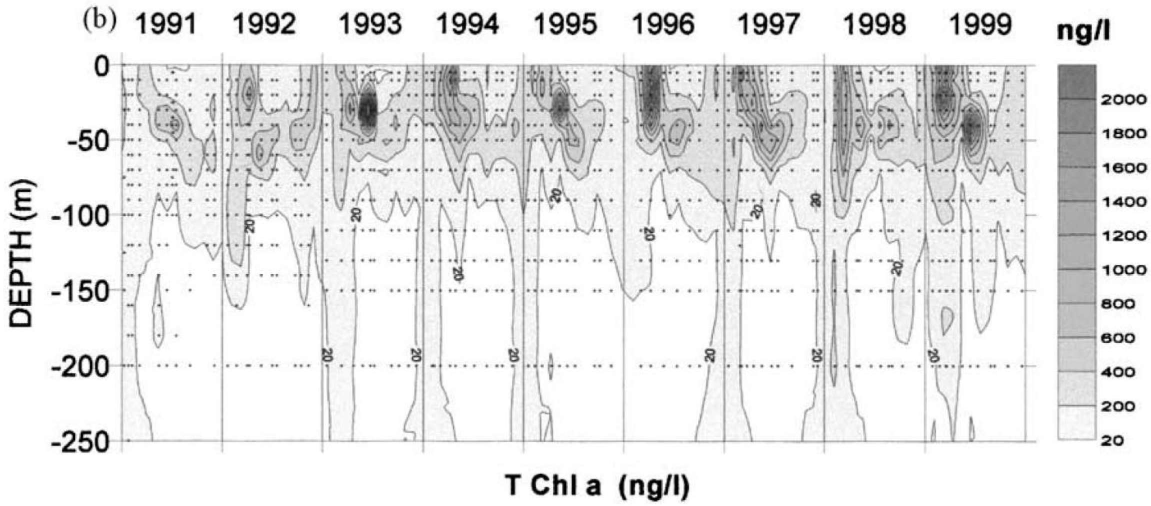


Figure 3.16: Evolution of the vertical distribution in density and in Nitrate and Chlorophyll concentrations for the upper 250 m at DYFAMED station during the period 1991-1999.

The marine ecosystems are also good indicators of the climatic trend of the atmospheric and oceanic dynamics. An increase of biomass between 1991 and 1999 was observed at DYFAMED and was interpreted as a response to an increasing atmospheric CO_2 concentration, inducing an increase of SST which could lengthen the stratification period and thus impact the general oceanic circulation (Marty *et al.*, 2002). There is thus a need to better understand the relation between the marine ecosystems dynamics and the physical functioning of the atmospheric (nutrient inputs) and oceanic (nutrients and transport) circulations.

Needs and proposals:

→ *Relation between ecosystems dynamics and physical processes in the atmosphere and ocean*: Identification of the different time scales of the ecosystems response to intense events (floods, flushing of the coastal zone/ shelf by storms or by dense water cascading, strong winds) and of the effects of these intense events on the structure and functioning of the ecosystems

→ *Relation between DWF and ecosystem properties*: Quantification of the influence of the periods of strong mixing and convection on the phytoplanktonic production and the structure of the pelagic ecosystem. Evaluation of the relation between spatio-temporal variability of bloom events and DWF, and of the impact of changes in bloom events and primary production on the SST and the upper stratification of the sea.

3.4.2.2.2 The slow branch of the Mediterranean water cycle

Strong wind induced cooling and evaporation allow vertical mixing to occur down to intermediate and great depths. This ventilates the intermediate and deep layers of the Mediterranean Sea and noteworthy, brings deeper waters in contact with the atmosphere again. Four major sites of deep offshore winter convection have been identified (Fig. 3.4.1): The Gulf of Lions in the western Mediterranean basin, and, in the eastern Mediterranean basin, the Adriatic, Aegean and Levantine sub-basins. DWF can also occur in the Ligurian sub-basin, and an additional (though limited) source point could be possibly located between Corsica and Sardinia.

After the winter convection, the oceanic restratification occurs and several water masses spread into the Mediterranean Sea, contributing to the thermohaline circulation. The transport of dense waters away from the region of their formation is mainly achieved by boundary currents. But if the main pathways of the intermediate and deep waters are mostly well described in the Western basin, they are mainly hypothetical in the Eastern one yet (Millot and Taupier-Letage, 2005a). Transport of deeper waters can also be achieved through interactions with (sub)mesoscale oceanic eddies or SCVs (e.g. Testor and Gascard, 2003; Millot and Taupier-Letage, 2005b; Demirov and Pinardi, 2007), interactions that are not really well understood yet. Transport of deeper waters can also be modified when water with a maximum density is created: upon filling the deepest layer it uplifts the formerly densest water (as for the EMT, see *e.g.* Klein *et al.*, 1999; Astraldi *et al*., 2002; Manca *et al*., 2006). This new shallower depth may then allow the water to exit through sills. Finally, the deeper waters will be involved several years after their formation in winter deep convection events in another sub-basin (as in the case for instance of the Levantine Intermediate Water, a component of the WMDW).

<u>Needs and proposals:</u>

→ *<u>Dense water and upper oceanic layer properties</u>*: Determination of the role of the deeper waters in the hydrological characteristics of the upper oceanic layer

→ *<u>Dense water export</u>*: Determination of the mechanisms driving the export of intermediate and deep waters far from their formation region (boundary currents, oceanic eddies, SCVs,)

→ *<u>DWF and climate trends</u>*: Monitoring of the DWF and the thermohaline circulation with long term measurements since DWF is a proxy for the detection of climatic trends.

3.4.2.3 Air-sea feedbacks

3.4.2.3.1 Atmospheric and oceanic circulations

The sea-surface sensible and latent heat fluxes change very quickly during wind storm and may modulate the intensity of the lee-side surface cyclone and the wind storm (e.g. Genoa cyclone for the Mistral wind) and the thermal properties of the upper oceanic layer. It is known that a warmer (colder) SST increases (decreases) air-sea surface heat flux exchanges which in turn moisten (drain) and destabilize (stabilize) the marine atmospheric boundary layer. Lebeaupin *et al.* (2006) highlighted some dynamical important effects of the SST on the low-level jet and the displacement speed of the mesoscale convective systems. Giordani *et al.* (2001) have shown that the differential surface heating/moistening and thus the spatial variability of surface fluxes can be a significant source of ageostrophy, vertical velocity and vorticity for the atmosphere that plays a fundamental role in the cyclone development. The THC can thus be considered as an energy tank available for the atmosphere via the surface turbulent heat fluxes (sensible and latent). For example, the interaction of a significant THC and a polar low expelled over the Mediterranean Sea can induce tropical-like cyclogeneses. Nevertheless, some more advanced studies have also shown that the THC spatial distribution and specially the THC gradient play a role in explosive cyclogeneses or tropical cyclones as important as the single THC (Goni and Trinanes, 2003). The impact of air-sea feedbacks on the wind storms dynamics and cyclogenesis, as well as oceanic circulation due to the possible modulation of the buoyancy fluxes is unkown and has never been addressed in this context.

<u>Needs and proposals:</u>

→ *<u>Time and spatial scales for air-sea feedbacks</u>*: Determination of how and on what spatial and time scales air-sea interactions modulate the atmospheric forcing (strong wind, cyclone) and the oceanic mixing and thermal content of the upper oceanic layer

→*Air-sea feedback parameterization:* Evaluation and improvement of parameterizations of heat fluxes in the presence of strong (and weak) winds.

3.4.2.3.2 Role of marine aerosols on air-sea fluxes

Marine aerosols are mechanically produced by the interaction between wind and waves. When the wind speed increases, the energy of the wind becomes too much to be absorbed by the waves, which break to dissipate the excess of energy. This is characterized by the occurrence of whitecaps (Monahan and O'Muircheartaigh, 1980). Three varieties of marine aerosols are then generated: film, jet and spume droplets. Film and jet droplets derive from air bubbles entrained below the sea surface by the breaking waves. These bubbles then rise to the sea surface and burst. This process becomes active from wind speeds about 4-5 m s^{-1} and produce droplets with sizes ranging roughly between 0.5 to 50 µm. For wind speeds larger of about 10 m/s, spume droplets are tore from the wave crest resulting in larger droplets from 20 to about 500 µm. All these droplets compose the sea spray generation function (SSGF) commonly denoted as dF/dr_0, which quantifies how many droplets with initial radius r_0 are produced per square meter of the surface per second per micrometer increment in droplet radius. Various relationships have been proposed for this function but there are still strong uncertainties even if these uncertainties were recently reduced from a factor of 5 (Andreas, 2004).

As soon as they are introduced in the first air layer above the sea surface the droplets exchange an amount of heat and moisture depending on their initial size, the temperature and humidity of the thin air layer above sea (about 1/3 of the mean wave height) and their "life time" above the sea, leading to a decrease in size of all the droplets. However, the behaviour of the spume droplets differs from that of film and jet droplets. The smallest (film and jet) evaporate quickly and participate few to heat and moisture exchange (Andreas and Monahan, 2000), but most of them are transported into the boundary layer and may, next, act as cloud condensation nuclei (CCN). On the other hand, part of the spume droplets may fall down to the sea by sedimentation but, due to their initial size, they are much more efficient in terms of heat and moisture exchange. According to Andreas and Decosmo (2001) the "spume" latent heat flux may represents 10% of the total turbulent flux for a wind speed of 10 m s^{-1} and 10 to 40% for 15 to 18 m s^{-1} wind speeds; the sensible heat flux is estimated to 10%, at least, of the total flux at 15 m s^{-1}.

It is then obvious that marine aerosols play a significant role in terms of heat and moisture exchange. Nevertheless large uncertainties remain to quantify more precisely these effects. Among them, the source function is likely the most important and needs to be assessed. Actually the relation proposed by Monahan in 1986 is still considered as the best for film and jet droplets and the Smith *et al*. function (1993) modified by Andreas (1998, 2004) could be used as reference for spume droplets.

Needs and proposals:

→ *Space-time series of oceanic aerosol properties:* Measurement of aerosols properties (aerosol speciation, size,..)

→ *Relation between aerosols and surface heat fluxes*: Quantification of the correlation between heat fluxes with aerosol concentration and properties and to suspension efficiency (directly related to the wind speed). Evaluation whether marine aerosol and heat and moisture exchange are linked to the Mediterranean meteorological conditions that prevail during strong wind events

→ *Relation between aerosols and cloud formation*: Evaluation of the ability of the aerosols in suspension to produce low-level clouds and eventually precipitation (in relation with section 3.3)

→ *Parameterization of sea-atmosphere turbulent fluxes parameterization accounting for marine aerosol contribution*: Quantification the contribution of the role of the aersol on heat and water fluxes and evaluation of the necessity to develop new sea-atmosphere turbulent fluxes parameterization accounting for aerosol contribution.

3.4.2.4 Modelling air-sea interactions

A shown by Somot *et al.* (2007), water vapor transport over the Mediterranean basin differs when using a fully coupled atmospheric/oceanic model instead of a forced atmospheric model and it is suggested that regional air-sea interactions may be a key process explaining this difference. However, air-sea interactions are complex to model due multi-time and spatial scale processes and a large interannual variability.

Needs and proposals:

Coupled simulations are needed to resolve the complex air-sea interactions, in particular to reproduce the interannual variability of THC and the observed trends in the Mediterranean water masses, and to be able to predict the evolution of the circulations along the 21st century:

→ *Model configurations*: Determination of the optimal configuration of atmospheric and oceanic models (time frequency, parameterization, horizontal and vertical resolution) and identification of the relevant key variables to use for the coupling (at which time frequency and spatial resolution).

3.5 The Coastal zone

Coordination: C. Estournel, X. Durrieu de Madron

3.5.1 Introduction

The coastal zone interacts with the various compartments which surround it: the continent (mainly by the rivers), the open ocean and the atmosphere. It can be seen as a zone in which the properties of water undergo strong modifications, as (i) it receives freshwater and (ii) a number of coastal areas are sources of intermediate water, or even deep water, for the adjacent basin. These modifications are essentially related to the water and heat exchanges with the atmosphere, and to freshwater input from the continent. The northern coastal zones of the Mediterranean are on this standpoint remarkable because they are subjected to predominant northerly winds (dry and cold in winter), and locally significant river discharges. Despite the gain of buoyancy induced by freshwater inputs, the intense winter cooling of shallow coastal waters induced by strong northerly winds produces waters denser than the off-shore water located at the same depth and sometimes even denser than the deep water created by the deep offshore convection (WMDW).

Any assessment of the water and matter budgets in the coastal zone must also take into account the exchanges through the margin. It should address in particular the exchanges close to the surface and the bottom, and consider the distinctive temporal and space variability of each physical mechanism. A corollary to these budgets concerns the time of residence of continental water and its constituents in the coastal zone. Indeed, it governs the fate of particulate and dissolved elements, the cycle of river-borne nutrients, the functioning and structure of ecosystems.

Key questions concern the scales of ocean-atmosphere exchanges, the formations and fate of water masses, the variability and intensity of shelf-slope exchanges, and their impacts on the pelagic and benthic ecosystems.

3.5.2 Scientific questions

3.5.2.1 Scales of ocean-atmosphere exchanges

Ocean-atmosphere exchanges are of prime importance for the modification water in coastal zones Water and heat transfers strongly affect their thermohaline characteristics and the transfer of the wind's momentum to the ocean partly governs their residence time on the continental shelf. The spatial structure of the wind field along the northern Mediterranean is dependent on the complex orography of these regions. Previous works showed that their complex patterns are fundamental to explain coastal circulations. It is undoubtedly close to the coast that the spatial and temporal wind patterns are the most complex (e.g., modulation of the wind by sea-breezes), and that the oceanic layer reacts the most rapidly to atmospheric forcings.

Needs and proposals:
The point concerns the coupling between the atmosphere and the coastal ocean (in particular the quantification of water and heat exchanges) and the best way to address this coupling in the models. Key questions thus arising concern:

→ *The bulk parameterizations* used in state of the art coastal models, which allow some feedbacks under strong fluxes conditions. Is this approach adequate? What are its limits?

→ *Do we need fully coupled atmospheric and oceanic models*? If yes, is this need shared by the meteorological community? What improvements of the spatial and temporal resolution of meteorological models are necessary for the coastal ocean (spectral response of the coastal ocean to the spectrum of the atmospheric forcing)?

3.5.2.2 Inputs and fate of freshwater

Floodings of Mediterranean rivers, which are generally related to E-SE winds in the northwestern basin, discharge very large amounts of freshwater, particulate, and dissolved elements that are dispersed and diluted along the coast (Fig. 3.17a). These conditions are scarcely documented because of the episodic and brief character of the floods. Little is known about the dilution processes that determine the extent of the regions influenced by brackish water (e.g., on some occasions the effect of Rhone River flood on the surface salinity has been felt as far as Barcelona, c.f. Fig. 3.17b) and, on the longer-term, about their effect on the evolution of the density field of the coastal zone (e.g., at which point an autumnal flood can inhibit dense water formation and thus act on the interannuality of the related physical and biogeochemical processes).

Submarine groundwater discharges (SGD) in coastal zone can contribute also for an important part to the land-ocean exchanges of water. Even if their fluxes and impacts are much more difficult to quantify than those of rivers, it is now recognized that groundwater fluxes may be very important in some coastal areas. These discharges correspond to fresh or brackish waters inputs in the coastal zone. They are well known in the case of karstic aquifers where these inputs are chanellized, but they are more difficult to evidence for sedimentary aquifers like those of river deltas where inputs occur by diffusion process through the sediment. Fresh groundwater flow is driven by hydraulic gradients on land, but there are also several oceanic processes (wave or tidal pumping) that drive advective flow of recirculated seawater through permeable sediments. Estimates done on the quantification of the SGD at the global scale range within 0.3 to 16 % of the global river flow (Burnett et al., 2003). However, these flux can be more important in particular places like for example the eastern coast of Florida where it reached 40% of the river flux (Moore, 1996). Even in river-dominated area this input can correspond to 20 % of the river flow with howver large variations within the hydrological year (Dulaiova et al., 2006). Most of these estimates have been done during the last ten years especially with the use of short-live radioactive nuclides (radium isotopes). These nuclides are 100 to 1000 times more concentrated in groundwater compare to coastal water and thus even a small input of water can be evidenced and determined by their budget in the coastal area. In the same way, nutrients, iron or silica inputs can be very important if their concentrations are elevated in groundwaters compare to those of coastal area (Windom et al., 2006 ; Slomp & Van cappellen, 2004).

The mediterranean Sea is surrounded by large and thicks karstic aquifers as well as Plio-quaternary coastal aquifers that could constitue important places of groundwater exchanges. The overall input of groundwater into the Gulf of Lion for example was estimated around 6 % of the Rhone water input (Ollivier, 2006). If such inputs are probably low in the southern mediterranean sea due to the paucity of the aquifers, they could have an impact in the Adriatic Sea for example or for some inlands (Majorca, Sicilia, Greek islands). HYMEX should benefit of a global knowledge of potential sites for such inputs around the Mediterranean sea as well as a global input estimation for the basin. Some of the sites should be also choosen for a more focus study in order to determine the driven processes of these exchanges. Furthermore, many coastal aquifers of the Mediterranean Sea are also affected by seawater intrusion, generally associated to decreasing of hydraulic pressure due to increasing water demand and large pumping. Even if this do not affect so much the global water cycle of the Mediterranean sea , seawater intrusion and the way to control it is a societal problem that should be studied within project like HYMEX.

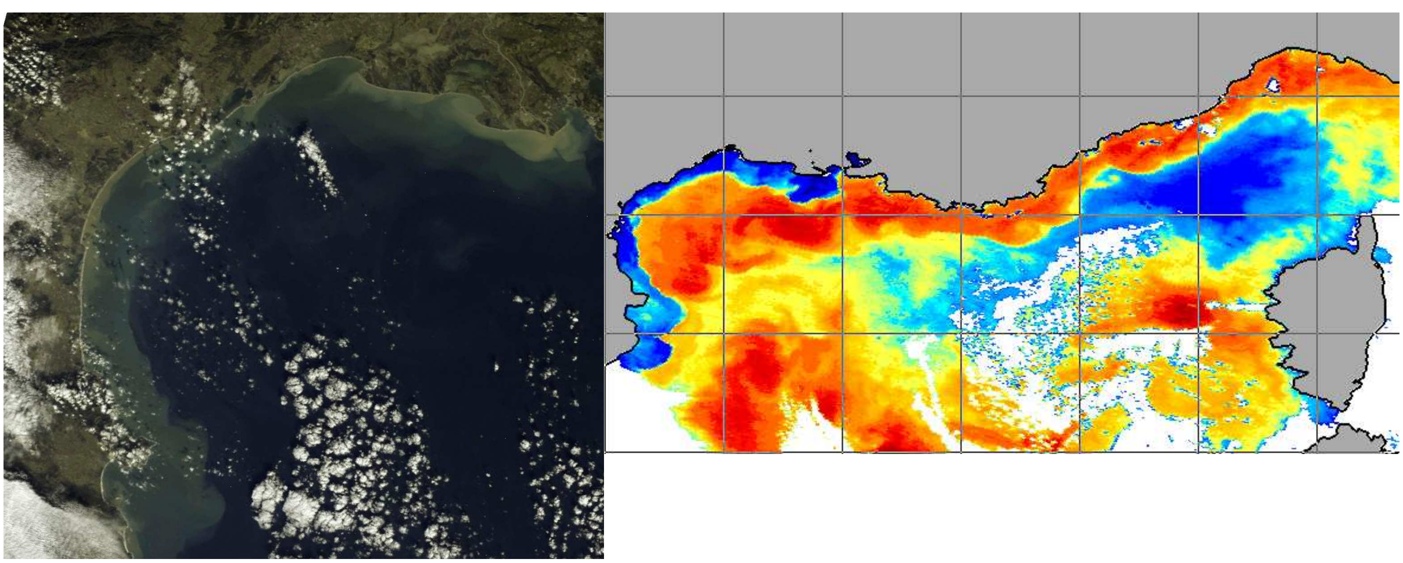


Figure 3.17: Impact of the major Rhône Flooding in December 2003. (a) MODIS image for December 8, 2003 in the Gulf of Lions (4 days after an exceptional flood of the Gulf of Lion rivers). This image shows high turbidity all along the coast; (b) SST, December 9, 2003.

Needs and proposals:
The **dilution processes** need to be clearly understood to be able to understand and model the dispersal of large freshwater inputs and associated elements, and subsequently its impact on the biogeochemistry of the coastal zone. These dilution processes include:

→ the *complex turbulence* related to buoyancy effects associated to the mixing induced both by the wind and the waves, and

→ the *coastal processes*, such as downwellings forced by onshore winds, upwelling, alternation of wind regimes.

Submarine groundwater exchanges in coastal zone neeed to be better estimated, as well the processes driven these exchanges identified. A better understanting of seawater intrusion is also needed.

3.5.2.3 Formation and fate of intermediate and deep water formed on the shelves

The cold and dense water formed in winter on some coastal zones contributes each year to the renewal of winter intermediate water and, more occasionally, of deep water of the basin (see section 3.4 and Fig. 3.18).

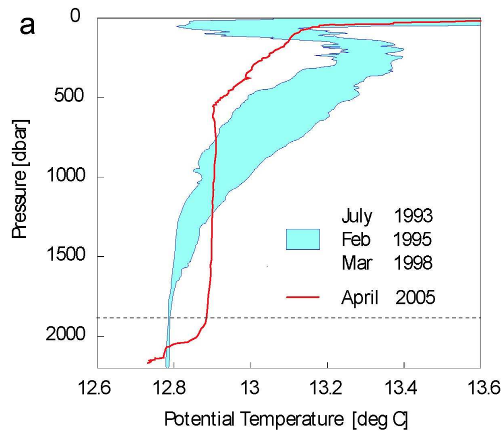


Figure 3.18: Potential temperature profile of April 2005 compared to normal profiles (blue shadowed area) The homogeneous water mass observed from 1993 to 1998 corresponds to the Western Mediterranean Deep Water. The April 2005 profiles revealed a large anomaly, with warmer water in the lower half of the water column, resulting from off-shelf dense water formation, overlying a near-bottom, abnormally cold water layer (below dotted line). From Canals *et al.*, 2006.

The Gulf of Lions appears as a privileged zone of formation (Fig.3.19), but other coastal regions (e.g., Strait of Bonifacio, Catalan continental shelf) are also believed to contribute to the formation of such waters. The quantities and the characteristics of the newly formed waters have a strong interannual variability, because they are related to the meteorological conditions and to the freshwater inputs of the previous autumnal and winter periods.

Needs and proposals:
A quantitative assessment of the dense water formed on the continental shelves and their contribution to intermediate and deep waters need to be performed. This assessment can be performed in two phases:

→ *the prospecting of the potential sites* based on the analysis of the existing data bases, the occurrence of favourable criteria (e.g., significant air-sea fluxes coupled to significant residence times), satellite imagery, modeling and direct observations.

→ *the description of the fate of these waters* once they are exported of the coastal zone. Their dispersion and dilution are expected to be quite different according to their density and equilibrium level.

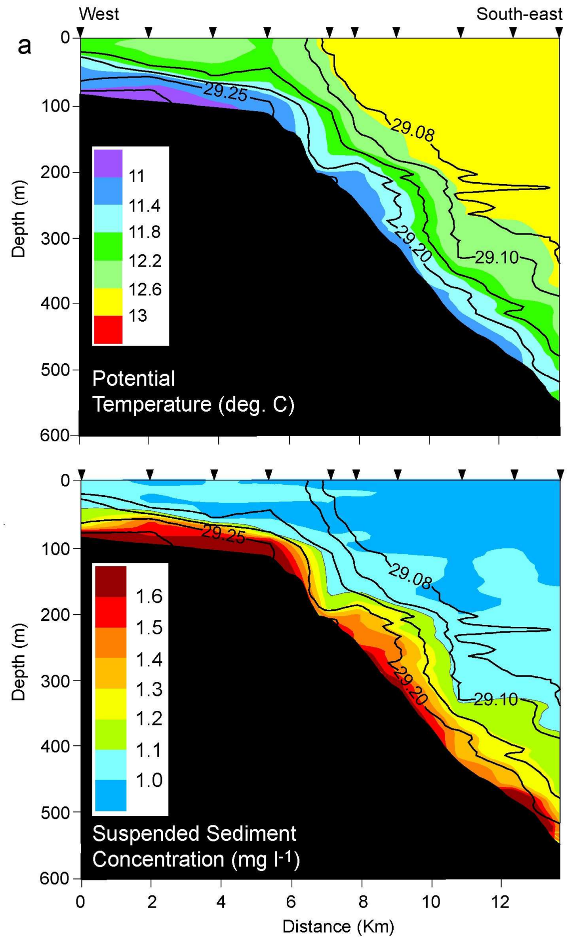


Figure 3.19: Potential temperature and suspended sediment concentration section with potential density anomalies (black contours) along the Cap Creus canyon (southwest Gulf of Lion) on February 2005. (From Canals et al., 2006)

3.5.2.4 Intensity and variability of shelf-slope exchanges

Exchanges between the coastal zones and the deep basin result from various hydrodynamical processes associated primarily to the various wind regimes, to the transitions between these regimes, and to the position and the stability of the slope current. They governs the export of dissolved and particulate elements in suspension in the water column, in particular that of organic matter. Whenever these currents interact with the bottom (upwelling or downwelling), they possibly induce the remobilization and subsequent advection of sedimentary material. Most exchanges take place in specific places due to topographic constraints (shelf broadening or narrowing, promontory, submarine canyons). The quantification of the exchanges at the scale of the western basin, and the determination of the respective role of the various mechanisms remain basically unknown.

OGCMs still badly represent the density characteristics of the along slope circulation, its position with respect to the slope, and even its presence in some regions (e.g., eastern basin, Catalan margin). These defects are prejudicial to the accuracy of coastal models, that are forced by OGCM, and in turn for the correct representation and quantification of shelf-slope exchanges. Locally, one also knows little about the modulations of the general circulation in response to topographic irregularities, wind forcings, variations of the density of coastal or deep basin waters.

Needs and proposals:
There is a clear need for studies at the regional scale to elucidate the mechanisms controlling the general circulation in the slope region. Such studies should federate the coastal and deep-sea research communities. A dedicated effort to correctly assess the coupling between the coastal zones and the deep-sea at the basin scale represent a major challenge.

→ *The objective would be the quantification of the shelf-slope exchanges of water* along the entire boundary of the basin and the residence times of coastal water. Different test areas with distinctive characteristics could be defined (broad shelves vs. narrow shelves, presence or not of canyons, predominant wind regimes, characteristic of stability of the slope current). The quantification of the exchanges of particulate and dissolved matter exchanges would directly benefit from this global quantification.

3.5.2.5 Impact on pelagic and benthic ecosystems

The repeated occurrence of episodic disturbances constitutes one of the fundamental features of the coastal ecosystems. These disturbances, associated with hydrological (floods) or hydrodynamical events (sediment resuspension, mixing of the water column…), generally result in a relative enrichment in organic matter and nutrients. The effects of these individual events on the first levels of the coastal pelagic and benthic trophic networks are largely unknown.

Needs and proposals:
Some key objectives of study are:

→ *Impacts of severe weather and flooding events:* What are the different time scales of the ecosystems response to strong events (floods, flushing of the coastal zone by storms or by dense water cascading, strong winds)? Do strong events produce a strong coupling between pelagic and benthic ecosystems?

→ *Impact of oceanic mixing*: What are the influence of the periods of strong mixing and convection on the phytoplanktonic production and the structure of the pelagic ecosystem? How does this production vary according to the depth, to freshwater inputs, confinement?

→ *Effects on the mid-term*: What are the effects of events (flood, resuspension) and their recurrence on the mid-term on the structure and the functioning (e.g., diagenetic processes) of the benthic communities and their persistency?

3.5.2.6 Status of modelling and observations

The observational part should proceed with the effort made offshore at the time of the intensive phase of the MFS project, with extensive use of XBT, MEDARGO floats, gliders, multi-sensored buoys and moorings. In coastal zone, the instrumented sites were almost non-existent a few years ago, but gradually appear nowadays. They can include physical and various biogeochemical parameters. The advent of gliders and AUV should allow a regular monitoring of selected zones. The development of benthic observatory allowing the sampling at high frequency of biogeochemical parameters also constitutes a need.

Analysis of satellite images remains often problematic in the coastal zone; they are often under-utilized (ocean colour, SST) or difficult to use (altimetry)… The joint use of in-situ observations, the development of processing techniques for specific Mediterranean zones could be an objective which could lead to the constitution of particularly useful data bases.

One should thus have access to an increasing number of operational observation systems, which will need to be harmonized and combined with satellite observations. Furthermore, it will be necessary to use models. The possibilities of near real time acquisition of these observations and their assimilation in models would represent a major improvement for the management of future field experiments.

Concerning models, it would be necessary for the study of the coastal zone and the shelf-slope exchanges that the regional models could correct biases of OGCM by modifying for example in the initial state and the boundary conditions the vertical structure of the slope current (from observations or climatologies) while preserving its high frequency fluctuations. The assimilation of data in regional and coastal models remains to be developed.

3.6 Synthesis

Previous sections review the scientific questions that need to be addressed within HyMeX. HyMeX should therefore be a major experimental program aiming at a better quantification and understanding of the hydrological cycle and related processes in the Mediterranean, with emphases put on high-impact weather events and regional impacts of the global change.

HyMeX should aim at producing a **new long-term and highly temporally and spatially resolved data-set** over the Mediterranean basin to:

- provide an accurate description of the water cycle and its variability and trend (accurate documentation of the **different terms of the water budget** over the different compartments and **at their interfaces**; documentation of the key **processes** driving the water cycle)
- understand how the Mediterranean water cycle processes contribute to the regional climate (explore and model the various mechanisms determining the space and time variability of **water budget** of the Mediterranean region; relate the regional mechanisms to the **large-scale circulation systems in the atmosphere** and oceans over the globe)
- validate the regional oceanic, atmospheric and hydrological models and develop improved parameterizations

HyMeX should also aim at developing **methodologies and models** in order to contribute to basic needs of **weather prediction, regional climate studies, climate impact, and environmental research by:**

- determining and/or improving the predictability of the water cycle, its variability and associated high-impact weather events
- performing regional climate change scenario

4. Societal and economical Impacts

Coordinators: J.-D. Rinaudo / S. Hallegatte

The interactions between the environment and socio-economic systems are highly uncertain. They are, indeed, difficult to capture by the scientific community for several reasons, among which the facts (i) that the interfaces between these systems are very complex and involve multiple agents and components (agricultural systems, energy production, standard of living, pollution...); (ii) that human systems (cities, societies, economies) are different in nature from physical systems (climate, ecosystems,...) in that human systems can react in different ways to external stimulus (adaptation to climate change, anticipation of future changes, over-reaction to environment crises). The consequence of these difficulties is that these interactions are poorly understood, while their importance has never been as broadly recognized.

To improve this situation, two kinds of investigation can be distinguished. The first one deals with how socio-economic evolutions will affect environment in the future. One important component of this question is the development of long-term scenarios that can be used as input to environment (e.g., climate or biodiversity) models. The second kind of investigation deals with the socio-economic impacts of environmental events, from short-term extreme events (e.g., flash-floods, wind storms) to long-term evolutions (e.g., climate change or biodiversity erosion).

4.1 Long-term scenarios

In the Mediterranean basin, the water cycle is strongly impacted by the socio-economic activities due to the quantitative (water samples) and qualitative (diffuse pollution, salinisation) pressures which they exert on the water resources. The importance of these pressures is at the same time due to socio-economic specificities of the area (dominant irrigated agriculture, summer tourism strongly consuming water, strong demographic growth in littoral zone) and to the particular characteristics of the Mediterranean water resources (e.g. severe low water levels of the rivers at the time when water sample is maximum).

The development of models to represent the water cycle and simulate its long-term evolution under certain assumptions of climatic change, for instance, must thus imperatively account for the determining role played by the socio-economic uses. Those are not static but are to evolve because of trend evolutions of the socio-economic environment (economic growth, demographic trends, technological innovation, change of mode of governorship in environment, public policies of environment management, etc) and of the state of environment (state of the water resources, level of ground erosion, climate evolution, frequency of extreme events, etc). The developed integrated models will thus not only have to account for the awaited socio-economic evolutions but also represent feedbacks existing between water cycle modifications and economic activities. This will imply the development of specific socio-economic models and their coupling with climatic and hydrological models (Holman and Loveland, 2001; Holmann, 2006; on irrigation see Döll, 2002; on drinking water demand see Herrington 1996; Downings et al., 2003).

From a scientific point of view, these issues call upon multi-disciplinary approaches aiming at working out scenarios being based on models of simulation (Alcamo *et al..* , 2003), systemic approaches (Cup 1997) or more participative approaches aiming at mobilizing water experts and actors (stakeholders) through talks, prospective seminars, etc. The development of scenarios will have to be carried out on sub-national or national scales, in order to account for hydrological and socio-economic heterogeneities existing within the Mediterranean basin. The developed scenarios will have to be coherent at the same time with the assumptions of

SRES scenarios defined at global scale, and with finer assumptions carried out at the basin scale (Plan Blue Méditerranée for instance). Downscaling raises methodological questions that the scientific community hardly starts to address (Arnell *et al.*. 2004).

4.2 Impacts of environmental events

The assessment of socio-economic impacts due to environment events (at all scales, from flash-floods to global warming) is now clearly identified as a priority. Indeed, this assessment is required to carry out the risk analyses that should help define building norms, urban planning, flood protection design, insurance regulation, climate change policies, etc. Using such explicit risk analyses would allow a better use of public and private resources and avoid costly (and often partly irreversible) mistakes, like the urbanization of flood-prone areas.

To do so, however, numerous challenges have to be taken up. The first one is the definition of what we call an adverse impact. Considering climate change for instance, one has to distinguish between direct impacts on welfare and existence values. Indeed, the extinction of species or the possibility that the Provence's landscapes would change significantly can be considered as an adverse outcome of climate change, even independently from any impact on welfare; one may want to pay to protect an animal species even though its existence does not change his or her life. This component should not be neglected in any aggregated analysis. Direct impacts on welfare are probably easiest to define. Reduced consumption due to a need for large investment in adaptation infrastructure is an example of such direct impacts. A decrease of thermal comfort in building is another one. Also, ethical and equity considerations have to be included in the analysis: what if an environment change leads to impacts that affect particularly the poorest? What if our actions today cause negative outcomes for future generations, as it is the case for climate change ?

Defining adverse impacts without considering value judgment is impossible, which leads to very specific problems in the assessment. It is important to note, however, that a large literature exists on these topics, especially from the climate change and health communities (e.g., Portney and Weyant, 1999).

When adverse impacts have been defined, their assessment is still extremely difficult. To do so, the first step is to focus the analysis, through the definition of the considered time and spatial scales. Two main questions can be highlighted in the Mediterranean basin. The first one deals with the short term (the next 10 years) and focus on extreme events (heavy rainfall and flash-flooding, drought, etc.). The second one concerns the long term (next decades and more), and focus on the interaction between long-term socio-economic scenarios (demography, economy, technology) and environment constraints (climate change, soil exhaustion, water scarcity, etc.).

Considering first short-term extreme events, it is noteworthy that our ability to assess the consequences of heavy rains, wind storms or other extreme meteorological events is surprisingly low. Even a posteriori, it is often impossible to know the exact consequences of an event. To go further on this issue, it will be necessary to improve our ability to link our knowledge of natural event (rainfall temporal and spatial distribution, hydrological models…) to regional models of the economic activity. The insurance industry (e.g., RMS, 2005) has developed a set of tools to assess the total costs of natural disasters, through the coupling of natural event models (often statistical), of building damage models and of economic models. Their results, however, are still very uncertain, and numerous mechanisms are hardly taken into account (e.g., economic propagations between sectors, definitive loss of clients, role of public infrastructures in the economic production, etc.). For instance, it has been shown that the ability of an economy to fund and carry out reconstruction is an important parameter in the assessment of natural disaster costs (Hallegatte *et al.*, 2006a). Interesting actions can be conceived to progress in this direction. In particular, the development of regional models (e.g., Brookshire *et al*., 1997; Okuyama, 2004; Rose and Liao, 2005) to evaluate the consequences of specific events in the Mediterranean basin, together with surveys to collect precise data, would be very valuable. These developments would help (i) assess risks in the Mediterranean basin and, therefore, design protection infrastructures (Hallegatte, 2006); (ii) conceive insurance schemes adapted to the specific situations met in developing countries; (iii) prepare and manage recovery and reconstruction in disaster aftermaths in a better way, to limit immediate damages and reduce future vulnerability.

A second approach to evaluate vulnerability to short term extreme events, mostly developed in France, is more qualitative and is called the systemic or synthetic approach. In this case, vulnerability is not expressed in terms of economic damages but in terms of vulnerability factors and stakes, which traduce one system's fragility and its capacity to overcome the crisis triggered by the hazard. Here, the objective is to understand why a territory or a society is more or less vulnerable to hazard in the purpose of risk preventive planning. The qualitative approach aims at evaluating the propensity of a society to suffer damages from a natural phenomenon, but also, at measuring its capacity to respond to a crisis situation (D'Ercole, 1994). This notion of vulnerability is not any more a sum of damages but a state function of multiple factors:

- Socio-demographic and economic attributes: they permit to identify exposed population as function of demography, land use and cohesion of existing social structures,
- Psycho-socio-cultural factors: they traduce the population exposition as function of its individual and collective knowledge and perception of risk. These factors have a strong effect on public behaviour and social response, flood memory, traditional self-flood warning or risk acceptability,
- Infrastructure and functional status: refers to constructions and infrastructures quality and also accessibility, operational of civil security services and emergency plans, networks reliability facing crisis…
- Geographical and temporal attributes: it concerns all limiting or triggering parameters that are associated with the precise localisation and time schedule of the event, and also temporary and unpredictable dysfunctions that may happen during the crisis,
- Institutional and politico-administrative factors: they tend to focus on strategic and political stakes that are susceptible to slow down a rational risk management.

This vulnerability analysis has to identify these factors in order to measure the ability of communities to respond and recover from the impact of an event of given intensity. Evaluating vulnerability to hazards is a complex process because of its variability in time. All vulnerability factors and exposed elements are likely to change in time. It is obvious that in the long-term vulnerability factors such as risk sensibility, demography or infrastructures may evolve. But even in the short-term of the crisis period, interactions between elements of the systems, which are also dynamic by themselves, may influence vulnerability. To progress on this domain, several actions can be conduct such as: i) mapping of evolution of vulnerability during the last decades, ii) progressing in the understanding of loss of life process in extreme event in order to create a "loss of life" model and to develop a methodology for mapping life risks in time and space, iii) better understanding how communities cope with flash flood events by performing surveys about risk perception of population, expert and decision makers and by studying recent past events in order to characterize human behavior during crisis and public responses to warnings

Considering long-term processes, the link with the development of scenarios is crucial. One of the most interesting topics nowadays is the investigation of climate change impacts, taking into account possible adaptation strategies (e.g., Hallegatte *et al*., 2006b).

Clearly, accounting for adaptation capacity requires detailed socio-economic scenarios, since adaptation capacity is found to depend strongly on population education, financial and technical capacities, and institutional organization, which may change significantly in the next decades (e.g., Fankhauser et al., 1999 ; Kates, 2000). Facing the high complexity of this issue, case studies should be considered. One example can be the assessment of the role of investments in water management, from small investments to reduce leakages and consumptions to large-scale investments in reservoirs and water transportation, to help mitigate water scarcity stress in countries where population is growing at high rates and climate change is likely to reduce rainfall. A focus on agriculture would be interesting, considering the role of this sector in developing countries (Mendelsohn and Williams, 2004; Bosello *et al*., 2006). Three important components of this question are (i) how available water is distributed among different users (electricity production, agriculture, urban consumption); (ii) how water is priced and paid by users and how the pricing strategy influence consumption and investment in production and distribution; (iii) how uncertainty on future climate makes some adaptation strategies more or less robust. These researches would participate in the assessment of climate change impacts and anticipated adaptation strategies, in order to inform decision-makers involved in the design of climate policies.

Finally, at the highest level of complexity, it would be important to assess how environmental events (extreme events, water scarcity, climate change, etc.) will interact with socio-economic development. It has been shown that natural disasters can represent a strong obstacle to economic development (IMF, 2003; Benson and Clay, 2004; Hallegatte *et al*., 2006a). In the same way, health issues (especially those due to poor water quality) and malnutrition have a cost in terms of development and can impair poverty reduction. These questions can be investigated using long-term macro-economic models and are of the highest importance for a fair assessment of the dangerousness of climate change.

INSERT 3 : Impact of the global change on fisheries

In the Mediterranean Sea, changes in structure of fish catching has been related to the overexploitation of some species and, to the impact of some environmental factors (Lloret *et al.,* 2001). Exploitation takes place at sea, estuaries and coastal lagoons by artisanal, semi-industrial and industrial fleets. The fisheries yield is low compared to other oceans, probably because of low primary productivity and narrow continental shelves. Landings are multispecific: small pelagics such as sardine and anchovy, and medium size-pelagics such as mackerel and bonite are the main contributors to total landings (about 50%). Large size pelagics such as bluefin tuna and swordfish and many demersal species such as red mullet, hake, blue whiting, Norway lobster and red shrimp are economically very important, even though their landings represent less than 10% of the total landings. The loss of fish habitats due to anthropogenic effects (e.g. tourism, trawling, pollution, etc) has the most adverse impact on fisheries. It is also likely that climate change (e.g. sea warming, sea-level rise, reduced river runoff, ...) will affect the fisheries in the Mediterranean Sea. Indeed, river runoff, wind mixing and upwelling, or water temperature can play a role on the productivity of stocks and the distribution of fish species. Landings are generally low when river runoff or wind mixing and upwelling are reduced, recruitment of demersal and pelagic species in the northwestern Mediterranean is positively influenced by runoffs of the Rhône and Ebro rivers (e.g. anchovy, red mullet, octopus). These rivers are important sources of phosphorus, nitrogen and other nutrients that are introduced at the surface, thus becoming directly available for phytoplankton that will be then consumed by zooplankton, which is the main food items for many fish larvae of many species, and for small pelagic fishes such as anchovy and sardine. Similar positive effects of river runoff on fish local production have been reported in other Mediterranean areas, e.g. the northern Adriatic Sea (Po River outflow), the Black Sea (several rivers) and the southeastern Mediterranean (Nile River).

5. Experimental strategy

Coordinator: F. Roux/I. Taupier-Letage

The aim of the **Implementation Plan** document will be to detail the **modelling and experimental strategy** to fullfill the scientific objectives of HyMeX identified in the present White Book. In order to design the most adequate experimental strategy, a first step has been to collect a comprehensive inventory of the observational means in the Mediterranean region. This includes the existing databases, the observational networks, the on-going or future strategies, means and actions. To contribute please see the web site http://www.cnrm.meteo.fr/hymex/.
Only a broad outline of the experimental strategy is therefore provided here that will have to be refined in the next two years.

Previous major experimental programs such as MAP or AMMA have shown that a "nested" approach is necessary to tackle the whole range of processes and interactions. A three-level nested experimental strategy is thus assumed for the HyMeX field component:

- *A long-term observation period (LOP) lasting about 10 years* to gather and provide additional observations of the whole coupled system that support analysis of the seasonal-to-interannual variability of the water cycle through budget analyses.
- *An enhanced observation period (EOP) lasting about 4 years*, for both budget and process studies.
- *Special observation periods (SOP) of several months,* which will aim at providing detailed and specific observations to study key processes of the water cycle in specific Mediterranean regions, with emphases put on heavy precipitation systems and intense air-sea fluxes and DWF.

The envisaged calendar for these phases is shown in Figure 5.1. EOP and LOP start both in 2010 and SOPs are scheduled for 2011-2012.

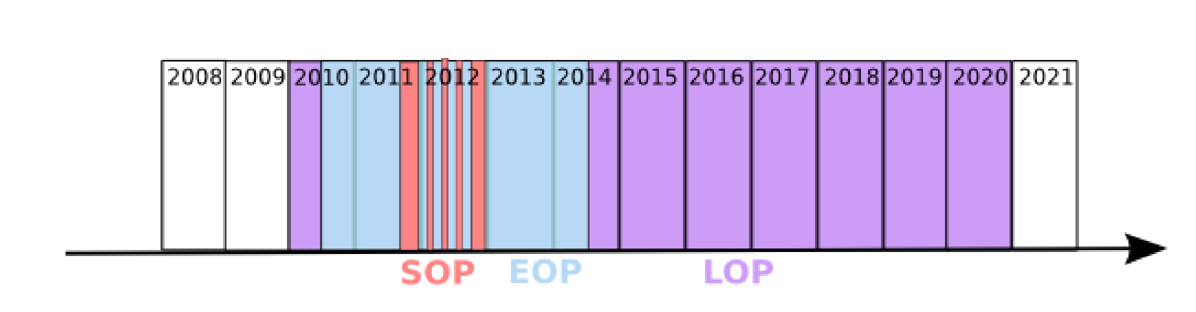


Figure 5.1: Proposed calendar for the SOP, EOP and LOP phases.

5.1 Long-term Observation Period (LOP)

It is proposed that the LOP consists in enhancing the current operational observing systems and existing long-term observatories in hydrology, oceanography and meteorology, not excluding the setup of new networks There is a general agreement that the LOP will have to cover the whole Mediterranean basin, developing and maintaining the acquisition of the long-term time series required to study the seasonal and interannual variability.

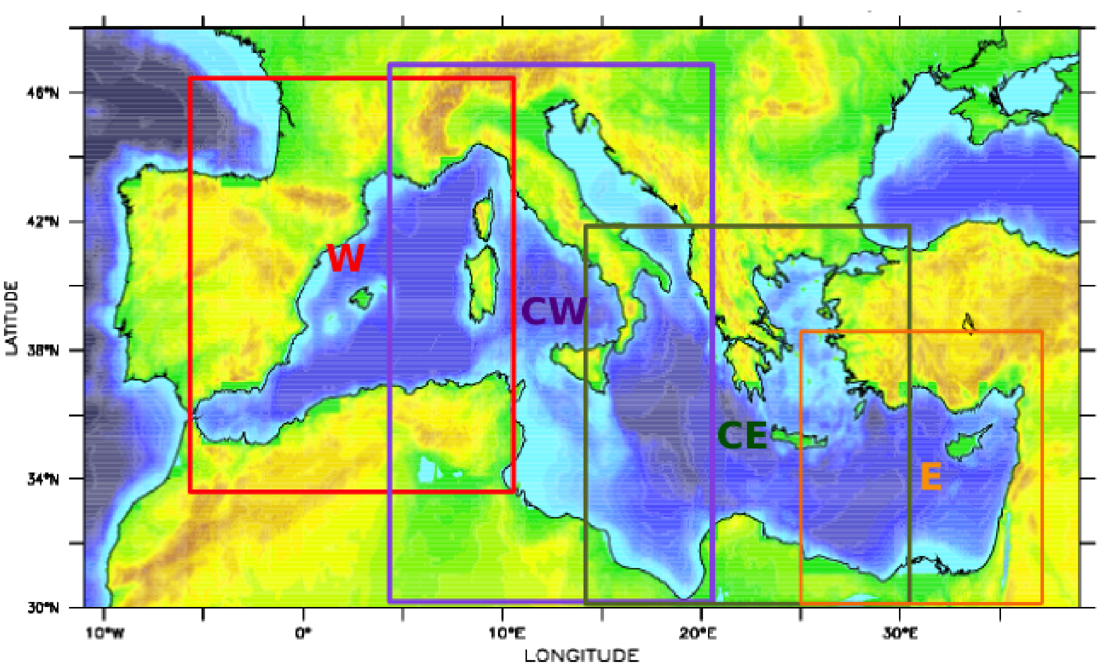
One aim of the LOP will be to favour the networks of Mediterranean observatories to converge toward the same quality of data and common databases. Such a network is currently developed for the northwestern Mediterranean hydrometeorological observatories within the HYDRATE project. Low-cost measurements (such as measurements of opportunity), performed systematically each year at a specific period to document the inter-annual variability, are also part of the LOP.

Satellite observations should complement in situ observations to document the seasonal to inter-annual scales over sea and continents. Easy access to archives and development of dedicated products should be encouraged. Specific approaches need to be developed to tackle the high heterogeneity of the Mediterranean region in both space (coastal zones, mountains, sub-basins…) and time scales of the processes.

5.2 Enhanced Observation Period (EOP)

The Enhanced Observation Period is envisaged for at least 4 years, embracing the SOP periods. However EOP may not span the whole year, *i.e.* activities may be restricted for some aspects to specific periods (e.g. autumns for heavy precipitation, extending to winter for severe cyclogenesses and strong winds).

The whole Mediterranean could be divided in 4 overlapping large "analogous areas", spanning from northern to southern shores, each including an area of intense events (heavy precipitation, intense air-sea fluxes and dense water formation areas). Figure 5.2 suggests what could be these 4 regions without prejudging their exact boundaries until the Implementation Plan defines them. It is hoped and expected that the international collaborations will allow studying these 4 areas, even though experimental efforts might be different for each area.



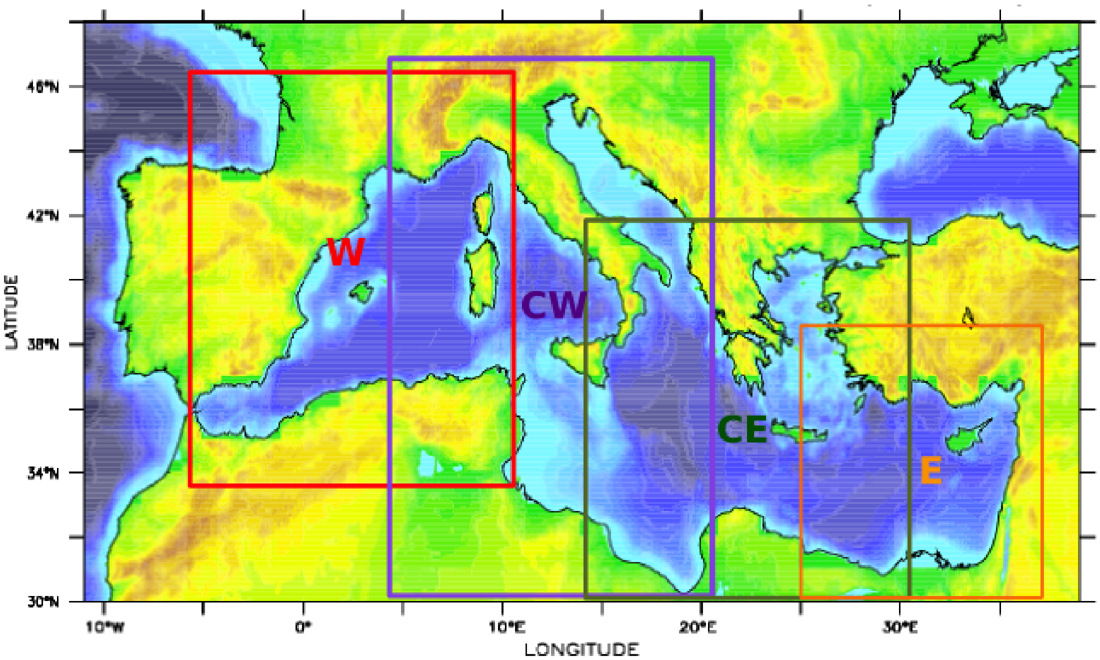


Figure 5.2: The 4 sub-regions for EOP

5.3 Special Observation Period (SOP)

It seems hardly realistic to envisage conducting all specific observations during a unique long SOP. In any case, the SOP(s) duration will be adapted to the probability of occurence of the considered phenomena. The SOP areas are included within the EOP sub-regions. As example, for the western region, the targeted SOP area could be limited to the northwestern part of the Mediterranean. Since key processes are interrelated between the atmospheric, oceanic and continental compartments but not always concomitant (e.g. fall and winter for flash flooding and strong winds, winter and early spring for DWF, spring for phytoplankton blooms…), SOPs will have most probably to be scheduled at different periods (Fig. 5.1). The SOP dedicated to heavy precipitation and flash-flooding **should be concomitant with the THORPEX European Regional Campaign, called T-NAWDEX, scheduled for 2011** and in phase with the Medex Phase 2 Plan.

One challenge will be to connect the SOPs, the EOP and the LOP and their strategies in such ways that questions regarding other compartments and/or processes are answered and the information gained is optimum for the following SOP.

The development of networks should be fostered, be them operational or research-based. Attempts have also to be made to extend their duration (up to several decades for some) and their space scale (Mediterranean basin-wide), as well as to reach a reasonable level of homogeneity of the databases. The monitoring of oceanic, atmospheric and continental environments will require using multiple platforms (from ground-based platforms to ships, moorings, airplanes and satellites). And the need for long-term time series may imply developing new platforms/new technologies in order to achieve a greater amount of measurements made autonomously.

6. Links with international and national programs and organizations

Coordinator: P. Drobinski

The study of the Mediterranean climate and its important socio-economic implications is particularly relevant to all countries surrounding the Mediterranean Sea. The HyMeX project would thus greatly benefit from cooperation with southern European, North-African and Middle East countries (which belong to the Mediterranean region) and also the involvement of northern European and non-European scientists.

Up to now, HyMeX has mainly been discussed within the French scientific community and especially during the first HyMeX workshop in January 2007 which has also constituted one of the opportunities to discuss and integrate propositions of the international community. Some efforts have already been undertaken to promote this project abroad (towards European and Mediterranean countries in particular). During 2006 and 2007, several presentations were and will be given in international workshops and conferences in order to promote HyMeX (2nd THORPEX symposium in Dec. 2006, CIESM in April 2007, EGU in April 2007, ICAM in June 2007, 9th Plinius Conference in Sept. 2007, EMS annual meeting in Oct. 2007).

The aim is to have the planned HyMeX EOP and SOP as part of both the European network of hydrological observatories activities and as part of the world weather atmospheric research programme THORPEX, sub-programme MEDEX, which can be seen as international labelization and coordination bodies. In particular, the HyMeX SOP should coincide with a new THORPEX-MEDEX observational field phase in 2011, to be rehearsed during fall 2007.

6.1 National programs in France

At the national level, several actions are already carried out to prepare this future field campaign in the Mediterranean, including the preparation of the white book and the promotion of the HyMeX project abroad. Links with other national projects (e.g. CYPRIM, ANR proposals) on the Mediterranean are naturally established through a significant participation of the HyMeX team members to these projects.

HyMeX received financial support from **INSU** and **Météo-France** for the white book preparation, the organisation of a national workshop in January 2007 in Toulouse. In the 2007 LEFE call, the “Mediterranean program” appeared explicitly. In addition to this support, INSU attempts to organize at national level a large inter-disciplinary program on the Mediterranean (including biochemistry, geology and seismology) program in which HyMeX appears as the water cycle component. This organization should be in place in 2007 with a multi-disciplinary scientific committee.

INSU provides also financial support to hydrometeorological, oceanic and atmospheric research observatories (e.g. OHM-CV, OMERE, OHP, Glacio-Clim) which are the backbone of the HyMeX LOP/EOP and ensure a multi-disciplinary experimental investigation of the Mediterranean coupled system. We can note that some of these observatories wish to integrate or have already integrated observatory networks which could facilitate the extension of HyMeX to Mediterranean countries (e.g. OHM-CV is part of a network with Italian and Spanish hydrometeorological observatories in the framework of the FP6 STREP Hydrate, and OMERE has long-term experimental catchments in northern Tunisia).

).

Preparation scientific actions are also supported by the **ANR** VMC[6] program "Vulnerability: climate and environment" This include as example the MEDUP project dedicated to the development of methodologies allowing the identification and quantification of uncertainty sources and their possible propagation associated with the forecast of extreme events (heavy precipitations and strong winds) over the northwestern Mediterranean basin.

One major point of the experimental aspect of the HyMeX project is the documentation of the thermodynamics of the atmosphere over the Mediterranean Sea. The HyMeX project will thus rely on satellite observations but also on balloon-borne in-situ measurements. In the period 2010, the ADM-AEOLUS ESA mission carrying a Doppler lidar will be in space and support could be asked to CNES and/or ESA for ADM product validation. In addition, in the context of adaptative observations in the Mediterranean region to document the sensitive regions for the development of high-impact weather events (especially cyclogenesis, heavy precipitations and strong winds) and improve their forecast, the deployment of CNES boundary layer super-pressured balloons (BLPB) and driftsondes (jointly developed with NCAR) could be of high benefit. **CNES** financial support, through the TOSCA program, is looked for in order to improve the sensors on board the gondola (feedback from the AMMA and VASCO experiments), to develop new low-cost small BLPB, to analyze the feasibility and the benefits of the deployment of such balloons especially through identification of sensitive regions.

6.2 International programs

During the first HyMeX workshop, suggestion was made to quickly form an international HyMeX scientific committee in order to facilitate the HyMeX promotion to international programs and to help the formation of European consortium to build up proposals to be submitted to future FP7 and INTERREG calls.

Links with other major international projects (CLIVAR, MEDEX, etc) have to be officially established in the near-future to ensure the presence of their representatives in the HyMeX project. The links with the other projects will be naturally established through the participation of HyMeX editorial committee members to these projects.. Althoug non-exhaustive, we can list the following major international programs related to the HyMeX objectives:

- **CLIVAR:**

The link with CLIVAR (CLImate VARiability) activity will be established through the program MedCLIVAR. MedCLIVAR, because of its scientific objectives, is connected with the CLIVAR's working groups and research areas. MedCLIVAR promotes research on Mediterranean climate by organizing meetings and workshops, help cooperation by favoring exchange of students and researchers, and, more in general, establish a network of institutes and scientists actively involved in regional climate research. MedCLIVAR is expected to help establishing partnerships capable of attracting European funds on the study of the Mediterranean climate. The frame of this MedCLIVAR project is perfectly adapted to promote the HyMeX project, to identify international partners. (*L. Li will act as link between MedCLIVAR and HyMeX).*

- **MEDEX:**

The Mediterranean cyclones that produce high impact weather are the main subject of MEDEX. They will be studied in HyMeX from mesoscale processes to climatological point of views. HyMeX will contribute to the climatology of cyclones and high impact events which is among the most important target of MEDEX, to the determination of areas which are most

[6] VMC: Vulnérabilité: Milieux et Climat,/ Vulnerability: environment and climate.

sensitive to the variability and changes of cyclone climatic regimes and to the evaluation of the societal impacts of their variability and changes. This cooperation has been already discussed with coordinators of MEDEX. *(J. Pailleux acts as link between MEDEX and HyMeX).*

- **GEWEX:**

The Global Energy and Water Cycle Experiment (GEWEX) is a program initiated by the World Climate Research Programme (WCRP) to observe, understand and model the hydrological cycle and energy fluxes in the atmosphere, at land surface and in the upper oceans. GEWEX is an integrated program of research, observations, and science activities ultimately leading to the prediction of global and regional climate change. The International GEWEX Project Office (IGPO) is the focal point for the planning and implementation of all GEWEX Projects and activities. As suggested by H.J. Isemer (PI of the BALTEX project, similar to the HyMeX project in the Baltic Sea, and supported by GEWEX) during the first HyMeX workshop, HyMeX could also become a GEWEX project.

- **THORPEX:**

THORPEX is a component program of the WMO World Weather Research Programme (WWRP). During the first HyMeX workshop, the representative of Euro-THORPEX (G. Craig) confirmed the cooperation between HyMeX and THORPEX, already discussed in previous THORPEX meetings. They proposed to have the T-NADWEX experiment over the Atlantic Ocean (planned in 2010/2011) in phase with the HyMeX SOP to document the "upstream boundary conditions" of the extreme events in the Mediterranean area. During the T-NADWEX experiment, the new German aircraft HALO which will carry a Doppler lidar, is already funded. (*E. Richard and J. Pailleux will act as link between THORPEX and HyMeX.)*

- **EUROMEDANET:**

The Euro-MEDANet projects aim at opening up the European Research Area to the Mediterranean countries by creating and developing a stable and effective Information Point (InP) system, modelled on the National Contact Point network, that supports the European Union's external relations with the Mediterranean area and also acts as a vehicle for promoting the active participation of relevant local actors in the European Union framework programs.P. Drobinski and R. Escadafal attended the last EuroMedANET seminar in March 2006. Contacts were made with the InP of the Mediterranean countries (Algeria, Tunisia, Morocco, Egypt, Lebanon and Israël).

- **GMES:**

The monitoring of relevant environmental parameters is coordinated at the international level by the GEO (Group on Earth Monitoring). The contribution of the European countries to GEO goes through the joint European Commission/ESA program called GMES (Global Monitoring for Environment and Security).

GMES is a framework from integrated projects which can eventually lead to operational services to end users. Several groups working on the Mediterranean already contribute to GMES projects. In the field of oceanography, we have the MFSTEP project dedicated to the development of a multi-scale operational forecast system based on quasi real-time observations and numerical modelling of the Mediterranean basin and at regional and coastal scales. The RISK projects (RISK-EOS, EURORISK-PREVIEW) deal with risks of intense precipitation and flash-flooding, and storms. RISK is subdivided in geographical zones, one of them being southeastern France. HyMeX could provide unique observation datasets for validation of the GMES services.

- **MOON:**

MOON (Mediterranean Operational Oceanography Network)specific objectives are to:

- consolidate and expand the Mediterranean Sea concerted monitoring and forecasting systems, and ensure full integration to the overall operational oceanography global ocean European capacity,
- co-ordinate, improve and harmonise observation and information systems,
- increase the quality of, and harmonise user-oriented operational products,
- identify new customers and further develop the market for operational oceanographic products,
- co-operate with UNEP-MAP and other relevant bodies acting at regional level,
- improve and further establish services to meet the requirements of environmental and maritime user groups,
- encourage Mediterranean scientific research on monitoring/forecasting activities and their link with operational oceanographic services,
- facilitate the availability and dissemination of long term high quality data required to advance the scientific understanding of the Mediterranean Sea,
- promote the transfer of operational oceanography expertise through training and education,

During the first HyMeX workshop, the MOON representative (N. Pinardi) has declared its interest in the experimental aspects of HyMeX in oceanography and would like to give maximum support with available data and models.

6.3 Ressource consuming major projects

In the next few years, several major field campaigns will be conducted and will use most of the instrumental resources of the community:

1. AMMA which has used a large part of the shipborne and airborne fleets in 2006 and early 2007;
2. COPS, associated with MAP-D Phase and integrated within TReC 2007 is a project on summer convection over the Black forest and Vosges. COPS will use a most of the european airborne fleet as well as the French GPS receivers which are key instruments for the HyMeX project.
3. International Polar Year (IPY) between 2006 and 2008 will finally require the available research ships.

The 2010-2013 period is thus a reasonable period for the HyMeX SOPs.

References

A

Abbott MB, Bathurst JC, Cunge JA, O'Connell PE, Rasmussen J., 1986: An introduction to the European Hydrological System - Système Hydrologique Européen, "SHE", 1: History and philosophy of a physically-based, distributed modelling system. *Journal of Hydrology,* ***8*7(1):** 45-59.

Albérola C. and C. Millot, 2003. Circulation in the French Mediterranean coastal zone near Marseilles : the influence of the wind and the Northern Current. Cont. Shelf Res., 23, 6, 587-610.

Albérola C., C. Millot and J. Font, 1995. On the seasonal and mesoscale variabilities of the Northern Current during the PRIMO-0 experiment in the western Mediterranean Sea. Oceanol. Acta, 18, 2, 163-192.

Alcamo, J., P. Doll, et al., 2003: "Development and testing of the WaterGAP 2 global model of water use and availability." *Hydrological Science Journal,* **48** (3): 317 – 337

Alderwish, A. and M. Al-Eryani, 1999: An approach for assessing the vulnerability of the water resources of Yemen to climate change, *Clim. Res.*, **12**, 85-89.

Alhammoud B, Béranger K, Mortier L, Crépon M, 2005: Surface circulation of the Levantine Basin: comparison of model results with observations, *Progress in Oceanography*, doi:10.1016/j.pocean.2004.07.015.

Allen, D.M., D. C. Mackie and M. Wei., 2004: Groundwater and climate change: a sensitivity analysis for the Grand Forks aquifer, southern British Columbia, Canada, *Hydrogeol. J.,* **13(3),** 270-290.

Allen, J. R. M., U. Brandt, A. Brauer, H. W. Hubberten, B. Huntley, J. Keller, M. Kraml, A. Mackensen, J. Mingram, J. F. W. Negendank, N. R. Nowaczyk, H. Oberhansli, W. A. Watts, S. Wulf, and B. Zolitschka, 1999: Rapid environmental changes in southern Europe during the last glacial period, *Nature*, **400**, 740-743.

Alpert, P. and Ben-gai, T. and Baharad, A. and Benjamini, Y. and Yekutieli, D. and Colacino, M. and Diodato, L. and Ramis, C. and Homar, V. and Romero, R. and Michaelides, S. and Manes, A., 2002: The parodoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. *Geophys. Res. Lett.* **29, (11),** 31-1-31-4.

Alpert, P., and B. Ziv, 1989: The Sharav cyclome, observations and some thoretical considerations, *J. Geophys. Res*., **94**, 18495-18514.

Alpert, P., B.U. Neeman and Y. Shay-El, 1990: Climatological analysis of Mediterranean cyclones using ECMWF data. *Tellus*, **42A**, 65-77.

Ambroise, B., 1999: La dynamique du cycle de l'eau dans un bassin versant : processus, facteurs et modèles. Editions *H*G*A*, Bucarest, 200 pp.

Andersen, J., Refsgaard, J.C., Jensen, K.H., 2001: Distributed hydrological modelling of the Senegal River Basin – model construction and validation. *J. Hydrolog*y, **247,** 200-214.

Andersen, V., Prieur, L., 2000: High Frequency time series observations in the open Northwestern Mediterranean sea and effects of wind events (DYNAPROC study, May 1985). *Deep Sea Res. I*, **47**, 3, 397-422.

Andrieu, H., J. D. Creutin, G. Delrieu, and D. Faure, 1997: Use of a weather radar for the hydrology of a mountainous area. Part I : Radar measurement interpretation. *Journal of Hydrology*, **193,** 1-25.

Antoine D, Nobileau D, 2006, Recent increase of Saharan dust transport over the Mediterranean Sea, as revealed from ocean color satellite (SeaWiFS) observations, *J. Geophys. Res*., **111** (D12): Art. No. D12214

Arnaud P, Lavabre J. 2000 : A Stochastic Model of Hourly Rainfall with Rainfall-Runoff Transformation for Predicting Flood Frequency. *Revue des Sciences de l'Eau,* **13 (4)**, 441-462

Arnaud, P., Lavabre, J., 2002 : Coupled rainfall model and discharge model for flood frequency estimation. *Water Resources Research*, vol. 38, n° 6, 10 p

Arnell, N. W., 1999: The effects of climate change don hydrological regimes in Europe: a continental perspective, *Global Environ.Change*, 95-23.

Arnell, N. W., M. J. L. Livermoreb, et al., 2004: "Climate and socio-economic scenarios for global-scale climate change impacts assessments: characterising the SRES storylines." *Global Environmental Change,* **14:** 3 - 20.

Artale V, Iudicone D, Santoleri R, Rupolo V, Marullo S, D'Ortenzio F, 2002: Role of surface fluxes in ocean general circulation models using satellite sea surface temperature: validation of and sensitivity to the forcing frequency of the Mediterranean circulation, *J. Geophys. Res*., **107(0)**, 10.1029/2000JC000452.

Artale, V., Calmanti, S., Malanotte-Rizzoli, P., Piscane, G., Rupolo, V., Tsimplis, M., 2006 : The Atlantic and Mediterranean sea as connected systems. *In: Mediterranean Climate Variability*, Lionello P., Malanotte-Rizzoli P. and R. Boscolo *eds*., Elsevier; Chap. 5, pp283-323.

Artegiani A, Bregant D, Paschini E, Pinardi N, Raicich F, Russo A, 1997: The Adriatic Sea General Circulation. Part I: air-sea interactions and water mass structure, *J. Phys. Ocean*., **27**(8), 1492-1514.

Asencio, N., J. Stein, M. Chong and F. Gheusi, 2003 , Analysis and simulation of local and regional conditions for the rianfall over the Lago Maggiore Target Area during MAP IOP 2b, *Q. J. R. Meteorol. Soc*., **129**, 565-586.

Ashagrie, A.G., de Laat, P.J.M., de Wit, M.J.M., Tu, M.and S. Uhlenbrook, 2006: Detecting the influence of land use changes on discharges and floods in the Meuse River Basin – the predictive power of a ninety-year rainfall-runoff relation?, *Hydrol. Earth Syst. Sci*., **10**, 691–701.

Astraldi, M., Balopoulos, S., Candela, J., Font, J., Gacic, M., Gasparini, G.P., Manca, B., Theocaris, A., Tintore, J., 1999: The role of straits and channels in understanding the characteristics of Mediterranean circulation. *Prog. Oceanog.,* 44, 65-108.

Astraldi, M., Bianchi, C.N., Gasparini, G.P., Morri, C., 1995. Climatic fluctuations, current variability and marine species distribution: a case study in the Ligurian Sea (north-western Mediterranean). *Oceanologica Acta,* **18**, 139-149.

Astraldi M, Gasparini G-P, 1992: The seasonal characteristics of the circulation in the North Mediterranean Basin and their relationship with the atmospheric-climatic conditions, *J. Geophys. Res*., **97**:9531-9540.

Astraldi M., G.-P. Gasparini, L. Gervasio and E. Salusti, 2001. Dense water dynamics along the Strait of Sicily (Mediterranean Sea). J. Phys. Oceanogr., 31, 12, 3457-3475.

Astraldi M, Gasparini GP, Vetrano A, Vignudelli S, 2002: Hydrographic characteristics and interannual variability of water masses in the central Mediterranean: a sensitivity test for long-term changes in the Mediterranean Sea, *Deep-Sea Research I*, **49**, 661-680.

Aunay, B., 2007: Apport de la connaissance géologique fine des aquifères côtiers à la fiabilité des modèles de simulation hydrodynamique pour la gestion des ressources en eau de la frange littorale, Thèse de Doctorat, Université de Montpellier II, en cours.

Aunay B., Le Strat P., Dörfliger N., Bakalowicz M., 2006a: Methodology for the study of karstification. Application to the Corbières karst (France), submitted to *Sedimentary Geology*.

Aunay, B., Dörfliger, N., Duvail, C., Grelot, F., Le Strat, P., Montginoul, M. & Rinaudo, J.-D., 2006b: Hydro-socio-economic implications for water management strategies: the case of Roussillon coastal aquifer. In "AIH: Gestion des grands aquifères." Dijon (30 mai - 1er juin 2006). p133.

Aunay B., Le Strat P., Duvail C., Dörfliger N. & Ladouche B., 2003: Methods of geological analysis for the karstification in the eastern Corbieres and its influence on Neogene events; Tortonian-Messinian. IAHS publ. n°278, Hydrology of Mediterranean and Semiarid Regions, pp. 124-129.

Aunay B., Dorfiger N., Duvail C., Grelot F., Le Strap P. Montginoul M. ? Rinaudo J. D., 2006) : Designing effective water management strategies of coastoal aquifers at risk of salt water intrusion: a pluridisciplinary approach, in AIH 2006 GIRE3D – Marakech – Maroc – 23-25/05/2006, Soumis.

Ávila, A., Dinol, J., Rodà, F. and Neal, C., 1992: Storm solute behavior in a mountainous Mediterranean forested catchment. *J. Hydrology*, **140**, 143-161.

Ávila, A., Neal, C. and Terradas, J., 1996: Climate change implications for streamflow and streamwater chemistry in a Mediterranean catchment. *J. Hydrology*, **177**, 99- 116.

B

Bacour, C., Baret, F., Beal, D., Weiss, M., Pavageau, K., 2006. Neural network estimation of LAI, fAPAR, fCover and LAI×Cab, from top of canopy MERIS reflectance data: Principles and validation. Remote Sensing of Environment, 105, 313-325.

Bahurel P, De Mey P, Le Provost C, Le Traon P-Y, Mercator project, 2002: GODAE Prototype system with applications, Example of the Mercator system, *European Geophysical Society XXVII General Assembly*, Nice, France, April 2002.

Bakalowicz M., Aunay B., Le Strat P., Dörfliger N. & Fleury P., 2003: Karst development potential and base level changes in Mediterranean regions: a unique reference model. International Conference on Karst Hydrogeology and Ecosystems. Bowling Green, USA, June 3-6, 2003.

Baldwin DS, Mitchell AM. 2000. The effects of drying and re-flooding on the sediment and soil nutrient dynamics of lowland river-floodplain systems: a synthesis. *Regulated rivers research and management* 16(5): 457-467.

Bardossy, A., 1998: Generating precipitation time series using simulated annealing, *Water Resour. Res*., **34(7),** 1737- 1744.

Barnier B, Siefridt L, Marchesiello P, 1995: Thermal forcing for a global ocean circulation model using a three-year climatology of ECMWF analyses, *J. Marine Sys*., 363-380.

Barth et al PiO 2005

Bastin S., Champollion C., Bock O., Drobinski P., Masson F., 2005: On the Use of GPS Tomography to Investigate Water Vapor Variability During a Mistral/Sea Breeze Event in Southeastern France. *Geophys. Res. Let*, **32**, L05808, doi:10.1029/2004GL021907

Bastin S., Drobinski P., Guénard V., Caccia J.L., Campistron B., Dabas A. M., Delville P., Reitebuch O., Werner C., 2006: On the Interaction Between Sea Breeze and Summer Mistral at the Exit of the Rhône Valley. *Mon. Wea. Rev*., **134**, 1647-1668

Bates PD, De Roo APJ. 2000 : A simple raster-based model for flood inundation simulation. *J. Hydrology,* **236**, 54-77.

Beaugrand, G. 2003 Long-term changes in copepod abundance and diversity in the north-east Atlantic in relation to fluctuations in the hydroclimatic environment, Fish. Oceanogr. 12:4/5, 270-283.

Beckers J-M, Rixen M, Brasseur P, Brankart J-M, Elmoussaoui A, Crépon M, Herbaut C, Martel F, Van den Berghe F, Mortier L, Lascaratos A, Drakopoulos P, Korres G, Nittis K, Pinardi N, Masetti E, Castellari S, Carini P, Tintore J, Alvarez A, Monserrat S, Parrilla D, Vautard R, Speich S, 2002: Model intercomparison in the Mediterranean: MEDMEX simulations of the seasonal cycle. *J. Marine Sys*., **33-34**, 215-251.

Benech B., H. Brunet V. Jacq, M. Payen, J.-Ch. Rivrain and P. Santurette, 1993, La catastrophe de Vaison-la-Romaine et les violentes précipitations de septembre 1992, aspects météorologiques, *La Météorologie*, série 8, **1**, 72—90.

Beniston M, 2004: The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatological data and model simulations, *Geophys. Res. Let*, **31** (2): Art. No. L02202

Benoit G., Aline C. (Eds.), 2005: A Sustainable Future for the Mediterranean: The Blue Plan's Environment and Development Outlook, Earthscan (8-12 Camden High Street, London. NW1 OJH, UK), 464 p.

Benson, C. and E. Clay, 2004: 'understanding the economic and financial impacts of natural disasters', Washington, DC: World Bank.

Béranger K, Mortier L, Gasparini GP, Gervasio L, Astraldi M, Crépon M, 2004: The dynamics of the Sicily Strait : a comprehensive study from observations and models, *Deep Sea Research,* II 51:411-440.

Béranger K, Mortier L, Crépon M, 2005: Seasonal variability of water transports through the Straits of Gibraltar, Sicily and Corsica, derived from a high resolution model of the Mediterranean circulation, Progress in Oceanography, doi:10.1016/j.pocean.2004.07.013.

Bergametti, G., E. Remoudaki, R. Losno, E. Steiner, B. 1992: Chatenet, and P. Buat-Menard, Source, transport and deposition of atmospheric phos¬phorus over the north-western Mediterranean, *J.Atmos.Chem*., **14**, 501 – 513.

Berne, A., G. Delrieu, J. D. Creutin, and C. Obled, 2004: Temporal and spatial resolution of rainfall measurements required for urban hydrology. *Journal of Hydrology*, **299,** 166-179.

Best M., A. Beljaars, J. Polcher, P. Viterbo, 2004: A proposed structure for coupling tiled surfaces with the planetary boundary layer. J. of Hydrometeorology, 5, 1271-1278

Bethoux, J.P., 1979: Budgets of the Mediterranean sea. Their dependence on the local climate and on the characteristics of the Atlantic waters. *Oceanol. Acta*, **2**, 157-162.

Béthoux, J. -P., Prieur, L., Bong, J. H., 1988: Le courant Ligure au large de Nice. *Oceanol. Acta* n°sp 9 , 59-67.

Béthoux J.P., Durieu de Madron X., Nyffeler F., Taillez D., 2002: Deep water in the western Mediterranean : peculiar 1999 and 2000 characteristics, shelf formation hypothesis, variability since 1970 and geochemical inferences, *J. Marine Sys.,* **33-34**:117-131.

Béthoux, J.P., Gentili, B., Raunet, J., Taillez, D.,1990: Warming trend in the western Mediterranean deep water. *Nature*, **347**, 660-662.

Béthoux, J.P.,Gentili, B., Morin, P., Nicolas, E., Pierre, C., Ruiz-Pino, D., 1999 : The Mediterranean sea : a miniature ocean for climatic and envirnmental studies ans a key for the climatic functioning of the North Atlantic. *Prog. Oceanog,* **44** (1-3) 131-146.

Beven, K.J. 1996: Response to comments on 'A discussion of distributed hydrological modelling' by J.C. Refsgaard et al. In: Abbott, M.B., Refsgaard J.C. (Eds). Distributed Hydrological Modelling, Kluwer Academic, Dordrecht, The Netherlands, pp. 289-295.

Beven, K.J., Binley, A.M., 1992: The future of distributed models: model calibration and uncertainty prediction. *Hydrological Processes,* **6**, 279-298.

Beven KJ, Kirkby MJ. 1979: A physically based variable contributing area model of basin hydrology. *Hydrological Science Bulletin,* **24**(1), 44-69.

Bjerklie, D. M., Dingman, S. L., Vorosmarty, C. J., Bolster, C. H., and Congalton, R. G., 2003: Evaluating the potential for measuring river discharge from space, *J. Hydrol*., **278(14),** 17–38

Blöschl, G., Sivapalan, M., 1995: Scale issues in hydrological modelling: a review. *Hydrological Processes*, **9**, 251-290.

Bobba, A. G., 2002: Numerical modelling of salt-water intrusion due to human activities and sea-level change in the Godavari Delta, India, *Hydrol. Sci. J.-J. Sci. Hydrol*., **47,** S67-S80.

Boé, J., L. Terray, F. Habets and E. Martin, 2006: A simple statistical-dynamical downscaling scheme based on weather types and conditional resampling, *J. Geophys. Res*., (in press).
Bois P., Mois P., Mailloux H., Obled C., De Saintignon F. (1995). *Atlas expérimental des risques de pluie intense dans la région Cévennes Vivarais.* Pôle Grenoblois des Risques Naturels (LAMA BP53 38041 Grenoble Cedex).
Bolle, H. J., and e. al. 1993. EFEDA: European field experiment in a desertification-threatened area. Annales Geophysicae 11:173-189.
Bonnet, S., G. C., J. Chiaverini, J. Ras, and A. Stock, 2005: Effect of atmospheric nutrients on the autotrophic communities in a low nutrient, low chlorophyll system, *Limn. Oceanogr.,* **50**, 1810-1819.
Bonnet S., Guieu C., 2006: Atmospheric Forcing on the Annual Iron Cycle in the Mediterranean Sea. A one-year Survey. *J. Geophys. Res*., **111** , C09010, doi:10.1029/2005JC003213.
Booij, M.J., 2005: Impact of climate change on river flooding assessed with different spatial model resolutions, *J. Hydrology*, **303(1-4),** 176-198
Boone A., Masson V., Meyers T. and Noilhan J., 2000. The influence of the inclusion of soil freezing on simulation by a soil-atmosphere-transfer scheme, J. Appl. Meteor. , 9 , 1544-1569.
Boone A. and Etchevers P., 2001. An intercomparaison of three snow scheme of varying complexity coupled to the same land surface model : local-scale evaluation at an alpine site., J. of Hydrometeo. , 2 , 374-394.
Bormans, M., Garrett, C., Thompson, K.R.,1986: Seasonal variability of the surface inflow through the Strait of Gibraltar. *Oceanol. Acta*, 9, 403-414.
Bosc E., Bricaud A. and Antoine D., 2004: Seasonal and interannual variability in algal biomass and primary production in the Mediterranean Sea, as derived from 4 years of SeaWiFs observations, *Global Biogeochemical Cycles*, **18**, GB1005, doi: 10.1 029/2003 GB002034.
Bosello, F., Roson, R., and Tol, R.S.J., 2006: Economy-wide estimates of the implications of climate change: Human health, *Ecological Economics*, **58**, 579-591.
Boudevillain, B., P.-E. Kirstetter, G. Delrieu, B. Chapon, and J. Nicol, 2007: Bollène 2002 experiment: radar rainfall estimation in the Cévennes-Vivarais region, France. Part 2 implementation and evaluation of several processing strategies. In preparation for *Journal of Hydrometeorology*.
Boukthir, M. and Barnier, B., 2000: Seasonal and inter-annual variations in the surface freshwater flux in the Mediterranean Sea from the ECMWF re-analysis project. *J Mar Syst* 24: 343--354
Bourras D., L. Eymard, W. T. Liu, H. Dupuis, 2002: An Integrated Approach to Estimate Instantaneous Near-Surface Air Temperature and Sensible Heat Flux Fields during the SEMAPHORE Experiment. *J. Appl. Meteorol.*, **41**, 241–252
Bourras D., L. Eymard , W.T. Liu, 2002: A neural network to estimate the latent heat flux over oceans from satellite observations. *Int. J. Remote Sens*., **23**, 2405-2423
Bousquet, O., P. Tabary and J. Parent-du-Châtelet, 2007: /Operational 3-D wind field retrieval over the greater Paris area, /Geophysical Research Letters/, in press.
Bouzinac C, Font J, Millot C, 1999: Hydrology and currents observed in the channel of Sardinia during the PRIMO-1 experiment from November 1993 to October 1994, *J. Marine Sys*, **20**, 333-355.
Bozec A, 2006 : La circulation thermohaline de la mer Méditerranée sous des climats présent et futur. *PhD Université Pierre et Marie Curie, Paris*.
Bozec A., P. Bouruet-Aubertot, K. Béranger, M. Crépon, 2006: Mediterranean oceanic response to the interannual variability of a high-resolution atmospheric forcing: A focus on the Aegean Sea, J. *Geophys. Res*., **111**, C11013, doi:10.1029/2005JC003427.
Bray, N.A., Ochoa, J., Kinder, T.H., 1995. The role of the interface in exchange through the Strait of Gibraltar. J. *Geophysical Res*., **100** (6), 10755-10766.
Brankart JM, Brasseur P, 1998: The general circulation in the Mediterranean Sea: a climatological approach. *J. Marine Sys*., **18**, 41-70.
Braud, I., Dedieu, G. et Borrell, V. et al., 2005. Propositions pour la construction d'un système de modélisation du fonctionnement des surfaces continentales SEVE – Sol Eau Végétation Energie-. Projet ECCO/PNRH-PNBC 2003-2006, 47 pp. http://www.cesbio.ups-tlse.fr/seve/index.php
Brenot, H., V. Ducrocq, A. Walpersdorf, C. Champollion and O. Caumont, 2006 : GPS Zenith delay sensitivity evaluated from high-resolution NWP simulations of the 8–9 september 2002 flash–flood over southeastern France. JGR, vol.111, n°D15, D15105 doi : 10.1029/2004JDOO5726
BRLi, 2006: AQUA 2020 - Volet Ressource : Définition d'une stratégie de gestion de la ressource en eau en Languedoc Roussillon sur la base d'un bilan besoins-ressources - Région Languedoc Roussillon ; Départements 11, 30, 34, 48, 66. (Alais C., Citeau JM., Chazot S., Le T.).
Brikas D.P., Karacostas T.S., Pennas P.J., Flocas A.A., 2006 : The role of the subtropical jet stream during heat wave events over north-central Greece. *Meteorol Atmos Phys*, **94**, 219-233.
Brookshire, D. S., Chang, S. E., Cochrane, H., Olson, R., Rose, A., Steenson, J., 1997: Direct and indirect economic losses for earthquake damage. *Earthquake Spectra*, **13** (4), 683-701.

Bryden, H. L., and Boscolo, R., 2002: Understanding climate changes in Mediterranean water masses. In: Tracking long-term hydrological change in the Mediterranean Sea (ed: F. Briand). *CIESM Workshop series* 16, 134p.

Bryden HL, Candela J, Kinder TH, 1994: Exchange through the Strait of Gibraltar, *Progress in Oceanography*, **33**, 201-248.

Bryden HL, Kinder TH, 1991: Recent progresses in strait dynamics. *Review of Geophysics (Suppl.),* 617-631.

Bryden HL, Stommel H, 1984: Limiting processes that determine basic features of the circulation in the Mediterranean. *Oceanologica Acta*, **7**, 289-296.

Bsaibes, A., 2007. Evaluation d'une approche multi-locale d'estimation spatiale de l'évapotranspiration sur un bassin versant agricole hétérogène en région méditerranéenne. Thèse de l'Université Montpellier II.

Bubnova R, Horanyi A, Malardel S, 1993: International project ARPEGE-ALADIN. *EWGLAM Newsletter 22*, Institut Royal Météorologique de Belgique, 117-130.

Burch, G.J., Bath, R.K., Moore, I.D., O'Loughlin, E.M., 1987 :Comparative hydrological behaviour of forested and cleared catchments in Southeastern Australia. *J. Hydrology*, **90**, 19-42.

Buzzi, A., and L. Foschini, 2000: Mesoscale meteorological features associated with heavy precipitation in the Southern Alpine region, *Meteor. Atmos. Phys*., **72 (2-4)**, 131-146.

C

Caballero,Y., Voirin-Morel,S., Habets,F., Noilhan,J., LeMoigne, P., Lehenaff,A., Boone, A.(2007), Hydrological sensitivity of the Adour-Garonne river basin to climate change. WRR (sous-presse).

Caddy, J. F., Refk, R. and Do-Chi. T., 1995: Productivity estimates for the Mediterranean: evidence of accelerating ecological change. *Ocean Coastal Management*, 26, 1-18.

Calvet, J.-C., Noilhan, J., Roujean, J.-L., Bessemoulin, P., Cabelguenne, M., Olioso, A., Wigneron, J.-P., 1998: An interactive vegetation SVAT model tested against data from six contrasting sites, Agricultural and Forest Meteorology, Vol. 92, pp. 73-95.

Calvet, J.-C., "Investigating soil and atmospheric plant water stress using physiological and micrometeorological data sets", Agricultural and Forest Meteorology, Vol. 103, No. 3, pp. 229-247, 2000.

Calvet, J.-C., Rivalland, V., Picon-Cochard, C., Guehl, J.-M., "Modelling forest transpiration and CO_2 fluxes - response to soil moisture stress". Agric. For. Meteorol., Vol. 124(3-4), pp. 143-156, doi: 10.1016/j.agrformet.2004.01.007, 2004.

Camps-Valls, G., Bruzzone, L., Rojo-Alvarez, J.L., Melgani F., 2006. Robust support vector regression for biophysical variable estimation from remotely sensed images. IEEE Geoscience and Remote Sensing Letters, Vol. 3, No. 3., pp. 339-343.

Canals, M., Puig, P., Durrieu de Madron, X., Heussner, S., Palenques, A., Fabres, J., 2006. *Nature*, 444, 16 Nov 2006, doi : 10.1038/nature05271.

Candela J, 2001: Mediterranean water and global circulation. Observing and Modelling the Global Ocean, J. Siedler, J. Church, and J. Gould, eds., Academic San Diego, Californie, 419-429.

Caniaux, G., and S. Planton, 1998: A 3D Ocean Mesoscale simulation using data from the SEMAPHORE Experiment, Mixed Layer Heat Budget. *J. Geophys. Res., 103*, **C11**, 25081-25099

Caniaux G, Redelsperger J-L, Lafore J-P, 1994: A Numerical Study of the Stratiform Region of a Fast-Moving Squall Line. Part I: General Description and Water and Heat Budgets, *J. Atmos. Sci*., **51**(14):2046-2074.

Caniaux, G., Belamari, S., Giordani, H., Paci, A., Prieur, L., Reverdin, G., 2005. A one year sea surface heat budget in the north-eastern Atlantic basin during the POMME experiment. Part 2: Flux optimization. J. Geophys. Res., 110, C07S03, doi:10.129/2004JC002695.

Castaings, W., D. Dartus, F. X. Le Dimet, and G.-M. Saulnier. 2007. Sensitivity analysis and parameter estimation for the distributed modeling of infiltration excess overland flow. Hydrology and Earth System Sciences Discussion 4:363-405.

Castellari S, Pinardi N, Leaman K, 2000: Simulation of water mass formation processes in the Mediterranean Sea: Influence of the time frequency of the atmospheric forcing, *J. Geophys. Res*., **105(C10),** 24157-24181.

Caussinus, H. and Mestre, O., 2004: Detection and correction of artificial shifts in climate series. *Appl. Statist.* **53** (part 3), 405-425

Cayrol, P., Kergoat, L., Moulin, S., Dedieu, G., Chehbouni, A., 2000. Calibrating a coupled SVAT-Vegetation growth model with remotely sensed reflectance and surface temperature : A case study for the HAPEX-Sahel Grassland sites. Journal of Applied Meteorology, 39, 2452-2472.

Cazenave, A., Cabanes, C., Dominh, K., Mangiarotti, S., 2001: Recent sealevel changes in the Mediterranean Sea revealed by TOPEX/POSEIDON satellite altimetry. *Geophys. Res. Let*., **28(8),** 1607-1610.

Ceballos, A., Schnabel, S., 1998. Hydrological behaviour of a small catchment in the dehesa landuse system (Extremadura, SW Spain). *J. Hydrology*, **210**, 146-160.
Cerdà, A., 1996: Seasonal variability of infiltration rates under contrasting slope conditions in southeast Spain. *J. Hydrology*, **69,** 217-232.
Chaboureau, J. P. and C. Claud, 2005: Satellite-based climatology of Mediterranean cloud systems and their association with large-scale circulation. *J. Geophys. Res*., **111**, D01 102, doi:10.1029/2005JD006460.
Champollion, C., F. Masson, J. Van Baelen, A. Walpersdorf, J. Chéry,and E. Doerflinger, 2004: Monitoring of the tropospheric water vapour distribution and variation during the September 9, 2002 torrential precipitation episode in the Cévennes (Southern France), J. Geophys. Res., 109, D24.
Chancibault, K., Anquetin, S., Ducrocq, **V**., Saulnier, G.M., 2006 : Hydrological evaluation of high-resolution precipitation forecasts of the Gard flash-flood event (8-9 September 2002), *Q. J. R. Meteor. Soc.,* **617**, 1091-1117.
Chahinian N. 2004 : Paramétrisation multi-critère et multi-échelle d'un modèle hydrologique spatialisé de crue en milieu agricole. *Thèse de doctorat de l'Université Montpellier II,* 238 p.
Chahinian N, Voltz M, Moussa R, Trotoux G. 2006a : Assessing the impact of hydraulic properties of a crusted soil on overland flow modelling at the field scale. *Hydrological Processes* , **20** : 1701-1722 (DOI : 10.1002/hyp.5948).
Chahinian N, Moussa R, Andrieux P, Voltz M. 2006b : Accounting for temporal variation in soil hydrological properties when simulating surface runoff on tilled plots. *Journal of Hydrology,* **326**(1-4):135-152 (doi:10.1016/j.jhydrol.2005.10.038).
Chaponnière A., 2005. Fonctionnement hydrologique d'un bassin versant montagneux semi-aride. Cas du bassin versant du Rehraya (Haut Atlas marocain), Thèse INA-PG, 268 pp.
Chaponnière, A., Maisongrande, P., Duchemin, B., Hanich, L., Boulet, G., Escadafal, R., Elouaddat, S. 2006. A combined high and low spatial resolution approach for mapping snow covered areas in the Atlas mountains. International Journal of Remote Sensing 26 (13): 2755-2777.
Cheddadi, R., Yu, G., Guiot, J., Harrison, S. P., and Prentice, I. C., 1997:The climate 6000 years ago in Europe. *Climate Dynamics*, **13**, 1-9.
Chen, C. C., D. Gillig and B. McCarl, 2001: Effects of Climatic Change on a Water Dependent Regional Economy: A Study of the Texas Edwards Aquifer, *Clim.Change*, **49(4),** 397-409. doi:10.1023/A:1010617531401
Chehbouni, A., Escadafal, R. et al., 2007. An integrated modelling and remote sensing approach for hydrological study in arid and semi-arid regions: the SUDMED Program, International Journal of Remote Sensing, Submitted.
Chen, C. C., D. Gillig and B. McCarl, 2001: Effects of Climatic Change on a Water Dependent Regional Economy: A Study of the Texas Edwards Aquifer, *Clim.Change*, **49(4),** 397-409. doi:10.1023/A:1010617531401
Chester, R., M. Nimmo, M. Alarcon, M. Saydam, C. Murphy, G. S. Sanders, and P. Corcoran, 1993: Defining the chemical character of aerosols from the atmosphere of the Mediterranean Sea and surrounding regions, *Oceanol.Acta*, **16,** 231 – 246.
Ciais, P. et al., 2005 : Europe-wide reduction in primary productivity caused by the heat and drought in 2003. *Nature*, **437(7058),** 529-533.
Clark C.A. and R.W. Arritt, 1995: Numerical Simulations of the Effect of Soil Moisture and Vegetation Cover on the Development of Deep Convection, *J. Appl. Meteor*., **34**, 2029—2045.
Clotet, N., Gallart, F., 1986. Sediment yield in a mountainous basin under high Mediterranean climate. *Z. Geomorphol. Suppl*., **60**, 205-216.
Combourieu Nebout, N., J.-L. Turon, R. Zahn, L. Capotondi, L. Londeix, K. Pahnke, 2002: Enhanced aridity and atmospheric high-pressure stability over the western Mediterranean during the North Atlantic cold events of the past 50 k.y., *Geology*, **30**, 863-866.
Copin Montégut, C., 1994 : Alkalinity and carbon budget in the Mediterranean Sea. *Global Biogeochemical Cycles* , 7 (4), 915-925.
Corsmeier U., Behrendt R., Drobinski P., Kottmeier C., 2005: The Mistral and its Effect on Air Pollution Transport and Vertical Mixing. *Atmos. Res*., **74**, 275-302
Cosma S., Richard E., Miniscloux F., 2002: The role of small-scale orographic features in the spatial distribution of precipitation. *Q. J. R. Meteorol. Soc*.
Costa, J. E., 1987: Hydraulics and basin morphometry of the largest flash floods in the conterminous United States. *Journal of Hydrology.*, **93,** 313-338.
Coudert, B., Ottlé, C., Boudevillain, B., Demarty, J., Guillevic, P., 2006. Contribution of Thermal Infrared Remote Sensing Data in Multiobjective Calibration of a Dual-Source SVAT Model. Journal of Hydrometeorology, 7, 404-420.

Courtier P, Freydier C, Geleyn J-F, Rabier F, Rochas M, 1991: The ARPEGE project at Météo-France, ECMWF Seminar Proceedings 7:193-231.

Crépon, M., Boukthir, M., Barnier, B., Aikman III, F., 1989. Horizontal ocean circulation forced by deep water formation: Part I. An analytical study. J. Phys. Oceanogr. 19, 1781–1792.

Creutin, J. D., H. Andrieu, and D. Faure, 1997: Use of a weather radar for the hydrology of a mountainous area. Part II : Radar measurement validation. *J. Hydrology*, **193,** 26-44.

Creutin, J. D., M. Muste, A. A. Bradley, S. C. Kim, and A. Kruger, 2003: River gauging using PIV technique : proof of concept experiment on the Iowa River. *J. Hydrology*, **277,** 182-194.

Cushing D.H., 1982. Climate and fisheries. Academic Press, London, 373 pp

D

Dagés C. 2006. Analyse et modélisation de l'influence de réseaux de fossés sur les échanges surface-souterrain en bassin versant méditerranéen. *Thèse de doctorat de l'Université Montpellier II,* 243 p.

Dalrymple T., 1960:*Flood frequency analysis.* US Geol. Surv. Water Supply, 1543A.

Da Silva, A. and Young, C. and Levitus, S., 1994: Atlas of surface marine data. Algorithms and Procedure. Natl. Oceanic. and Atmos. Admin. *NOAA Atlas Ser., 1.* Silver Spring, Md

Davidson, E.A. and Janssens, I.A., 2006: Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, **440(7081)**, 165-173.

De Groot C.J., Van Wijck C., 1993. The impact of desiccation of a freshwater marsh (Garcines Nord, Camargue, France) on the sediment-water-vegetation interactions. Part 1 : The sediment chemistry. *Hydrobiologia*, 252, 83-94.

Delrieu, G., S. Caoudal, and J. D. Creutin, 1997: Feasibility of using mountain return for the correction of ground based X-band weather radar data. *Journal of Atmospheric and Oceanic Technology*, **14,** 368-385.

Delrieu, G., 2004 : L'Observatoire Hydro-météorologique Méditerranéen Cévennes-Vivarais (The Cévennes-Vivarais Mediterranean Hydro-meteorological Observatory). *La Houille Blanche*, 6-2003, 83-88.

Delrieu, G., V. Ducrocq, E. Gaume, J. Nicol, O. Payrastre, E. Yates, P.-E. Kirstetter, H. Andrieu, P. A. Ayral, C. Bouvier, J. D. Creutin, M. Livet, A. Anquetin, M. Lang, L. Neppel, C. Obled, J. Parent-du-Chatelet, G. M. Saulnier, A. Walpersdorf, and W. Wobrock, 2005 : The catastrophic flash-flood event of 8-9 September 2002 in the Gard region, France: a first case study for the Cévennes-Vivarais Mediterranean Hydro-meteorological Observatory. *J. Hydrometeorology*, **6**, 34-52.

Delrieu, G., J. Nicol, B. Chapon, B. Boudevillain, P.-E. Kirstetter, and H. Andrieu, 2007: Bollène 2002 experiment: radar rainfall estimation in the Cévennes-Vivarais region, France. Part 1: innovative identification procedures.. in preparation for *Journal of Hydrometeorology*

Demarty, J., C. Ottlé, I. Braud, J. P. Frangi, H. V. Gupta, and L. A. Bastidas. 2005. Constraining a physically based SVAT model with surface water content and thermal infrared measurements using a multiobjective approach. Water Resources Research **41**:doi:10.1029/2004WR003695.

Demirov E, Pinardi N, 2002: Simulation of the Mediterranean Sea circulation from 1979 to 1993: Part 1: the Inter-annual variability. *J. Marine Sys.,* **33-34**, 23-50.

Demirov E.and Pinardi N., 2007: On the relationship between the water mass pathways and eddy variability in the western Mediterranean Sea Journal of Physical Research, **112**, C02024 doi:10.1029/2005JC003174.

Dentener FJ, Carmichael GR, Zhang Y, et al., 1996: Role of mineral aerosol as a reactive surface in the global troposphere, *J. Geophys. Res*., **101 (D17),** 22869-22889 OCT 20

Déqué, M., 2007: Frequency of precipitation and temperature extremes over France in an anthropogenic scenario: model results and statistical correction according to observed values. *Global and Planetary Change* (in press)

Déqué, M., Jones, R.G., Wild, M., Giorgi, F., Christensen, J.H., Hassell, D.C., Vidale, P.L., Rockel., B., Jacob, D., Kjellström, E., de Castro, M., Kucharski, F., van den Hurk, B., 2005. Global high resolution versus Limited Area Model scenarios over Europe: results from the PRUDENCE project. Clim. Dyn., 25, 653-670.

Déqué, M. and Rowell, D. and Lüthi, D. and Giorgi, F. and Christensen, J.H. and Rockel, B. and Jacob, D. and Kjellström, E. and de Castro, M. and van den Hurk, B., 2007: An intercomparison of regional climate models for Europe: assessing uncertainties in model projections. *Climatic Chang,* **81**,53-70.

De Saint-Venant B. 1871. Théorie du mouvement non permanent des eaux, avec application aux crues des rivières et à l'introduction des marées dans leurs lits. *Comptes Rendus des Séances de l'Académie des Sciences,* **73**, 147-154; 237-240.

Dewandel B., Lachassagne P., Marechal J.C., Wyns R., Krishnamurthy N.S., 2006 : A generalized 3–D geological and hydrogeological conceptual model of granite aquifer controlled by single or multiphase weathering.- *Journal of Hydrology*, Vol. 330, pp. 260-284.

Dezileau L., Sabatier P., Condomines M., Briqueu L., Colin C., Bouchette F., Blanchemanche P., 2007 : Reconstitution des évènements climatiques extrêmes (crues et tempêtes) dans le Golfe d'Aigues-Mortes à partir de l'étude des archives sédimentaires, 2005, Pub ASF, Paris, n°51, p91.

Diodato, N. , 2004: Local models for rainstorm-induced hazard analysis on Mediterranean river-torrential geomorphological systems, *Natural Hazards and Earth System Sciences*, **4(0),** 389-397.

Diodato, L. and Ramis, C. and Homar, V. and Romero, R. and Michaelides, S. and Manes, A., 2002: The parodoxical increase of Mediterranean extreme daily rainfall in spite of decrease in total values. *Geophys. Res. Lett.* **29**.

Döll, P., 2002: Impact of climate change and variability on irrigation requirements: a global perspective. *Climatic Change,* **54**, 269 - 293.

Dorioz J.M., Cassell E.A., Orand A., Eisenman K.G., 1998. Phosphorus storage, transport and export dynamics in the Foron river watershed. *Hydrological processes*, 12: 285-309.

D'Ortenzio, Iudicone D, Boyer Montegut C, Testor P, Antoine D, Marullo S, Santoreli R, Madec G., 2005: Seasonal variability of the Mixed layer depth in the Mediterranean Sea as derived from in-situ profiles. *Geophys. Res. Let.,* **32**, LI2605, doi:10.1029/20005GL022463.

Doswell C.A., Ramis C., Romero R., Alonso S., 1998 : A diagnostic study of three heavy precipitation episodes in the Western Mediterranean region. *Wea. Forecasting*. **13**, 102-124.

Douville H., Royer J.F and Mahfouf J.F, 1995. A new snow parameterization for the Meteo-France climate model. Part I: validation in stand-alone experiment, Climate Dyn. , 12 , 21-35.

Downings T.E., Butterfield R.E., Edmonds, B., Knox J.W., Moss S., Piper B.S. and Weatherhead E.K., 2003: Climate change and demand for Water: final report. *Stockholm Environmental Institute*, Oxford Office, Oxford.

Drillet et al. JGR 2003?

Drinkwater K, Belgrano A, Borja A, Conversi A, Edwards M, Greene C, Ottersen G, Pershing A, Walker H. 2003. The Response of Marine Ecosystems to Climate Variability Associated with the North Atlantic Oscillation. In: Hurrell J, Kushnir Y, Ottersen G, Visbeck M, editors. The North Atlantic Oscillation: Climatic Significance and Environmental Impact: American Geophysical Union. pp. 211-234.

Drobinski P., Bastin S., Guénard V., Caccia J.L., Dabas A. M., Delville P., Protat A., Reitebuch O., Werner C., 2005: Summer Mistral at the Exit of the Rhône Valley. *Quart. J. Roy. Meteorol. Soc*., **131**, 353-375

Drobinski P., 2004: Progress in Understanding the Mistral. *Bull. Amer. Meteorol. Soc*., **85**, 944

Drobinski P., Flamant C., Dusek J., Flamant P.H., Pelon J., 2001: Observational Evidence and Modeling of an Internal Hydraulic Jump at the Atmospheric Boundary Layer Top During a Tramontane Event. *Boundary Layer Meteorol*., **98,** 497-515

Drogue, G., L. Pfister and T. Leviandier, et al., 2004: Simulating the spatio-temporal variability of streamflow response to climate change scenarios in a mesoscale basin, *J. Hydrology*, **293**, 255-269.

Du, Y., Liu, Q., Chen, L., Liu, Q., Yu, T., 2007. Modeling Directional Brightness Temperature of the Winter Wheat Canopy at the Ear Stage. IEEE Transactions on Geoscience and Remote Sensing, in revision.

Duarte, C.M., Agusti, S., Kennedy, H., Vaqué, D., 1999. The Mediterranean climate as a template for Mediterranean marine ecosystems: the example of the northeast Spanish littoral. *Prog. in Oceanogr*., **44,** 245-270.

Ducharne, A., S. Théry, P. Viennot, E. Ledoux, E. Gomez and M. Déqué, 2003: Influence du changement climatique sur l'hydrologie du bassin de la Seine, *Vertigo*, **4(3),** 1-13.

Ducrocq V., D. Ricard, J.P. Lafore and F. Orain, 2002, Storm-scale numerical rainfall prediction for five precipitating events over France: on the importance of the initial humidity field, *Weather and Forecasting*, **17**, 1236 – 1256

Ducrocq, V., G. Aullo and P. Santurette, 2003 : Les précipitations intenses des 12 et 13 novembre 1999 sur le Sud de la France. *La Météorologie*, 42, 18-27.

Ducrocq V, Bouttier F, Malardel S, Montmerle T, Seity Y, 2005: The AROME project. *La Houille Blanche*, **2**, 39-43.

Ducrocq, V., O. Nuissier, D. Ricard, C. Lebeaupin and T. Thouvenin, 2006: A numerical study of three catastrophic precipitating events over Western Mediterranean region (Southern France). Part II: Mesoscale triggering and stationarity factors, *soumis au Q.J.R. Meteorol. Soc.*

Dufau-Julliand C, Marsaleix P, Petrenko A, Dekeyser I, 2004: Three dimensional modelling of the Gulf of Lion's hydrodynamics (northwest Mediterranean) during January 1999 (MOOGLI3 Experiment) and late winter 1999: Western Mediterranean Intermediate Water's (WIW) formation and its cascading over the shelf break, *J. Geophys. Res*., **109(C11002),** doi:10.1029/2003JC002019.

Dunkerley D., Brown K., 1999: Flow behaviour, suspended sediment transport and transmission losses in a small (sub-bank-full) flow event in an Australian desert stream. *Hydrological Processes*, 13: 1577-1588.

Durran, D., 1990: Mountain waves and downslope winds. In Atmospheric processes over Complex terrain. Ed. W. Blumen, American Meteorological Society, Boston, USA.

Durand P., Neal M., Neal C., 1993. Variations in stable oxygen isotope and solute concentration in small submediterranean montane streams. *Journal of Hydrology*, 144:283-290

Durrieu de Madron, X., Civitarese, G., Gacic, M., Ribera d'Alcalà, M., Raimbault, P., Krasakopoulou, E., Goyet, C., 2005: Shelf-slope nutrients and carbone fluxes in the Mediterranean sea. *In*: Mediterranean sea.

Duvail, C.; Gorini, C.; Lofi, J.; Le Strait, P.; Clauzon, G. and Dos Reis, A.T. (2006).- Correlation between on-shore and offshore Pliocene-Quaternary systems tracts below the Roussillon Basin (eastern Pyrenees, France). Marine and Petroleum Geology.

E

Eamus, D. et al., 2005 : Ecosystem services: an ecophysiological examination. *Austral. J. Botany*, **53(1)**, 1-19.

Easterling D.R., Evans, P. Y. Groisman, T.R.Karl, K.E. Kunkel and P. Ambeneje, 2000: Observed variability and trends in extreme climate events: a brief review, *Bulletin Amer. Meteorol.*, **81**, 417-424.

EC (European Commission), 2002, Tap into it! The European water framework directive. Bruxelles. Available from: http://www.europa.eu.int/comm/environment/water/water-framework/pdf/brochure-en-pdf

Esclaffer, T., 2006. Mécanismes et dynamique de mise en place du ruissellement superficiel sur les versants lors des épisodes de pluie intense, Thèse de l'Ecole Nationale des Ponts et Chaussée.

Echevin V, Crépon M, Mortier L, 2003: Interaction of a coastal current with a gulf: application to the shelf circulation of the Gulf of Lions in the Mediterranean Sea, *J. Phys. Ocean*., **33(1),** 188-206.

EEA (2004), Impacts of Europe's changing climate. An indicator-based assessment. EEA Report No. 2/2004, Luxembourg, 107 p. (http://www.eea.eu.int).

Eder, G., M. Sivapalan, and H. P. Nachtnebel. 2003. Modelling water balances in an Alpine catchment through exploitation of emergent properties over changing time scales. Hydrological Processes 17:2125-2149.

Elbaz-Poulichet, F., Seidel J.L., Devez A., Van Exter S., Casellas C., Voltz M., Andrieux P., 2003: Dynamic and origin of trace elements in a Mediterranean river (la Peyne)-Relations to lithology, discharge, and agricultural practices. *Proceedings of International Symposium on Hydrology of the Mediterranean and Semiarid Regions,* Montpellier 2003. IAHS Publication n°278, 410-416.

Engeland, K., I. Braud, L. Gottschalk, and E. Leblois. 2006. Multi-objective regional modelling. Journal of Hydrology **327**:339-351.

Etchevers, P., 2000: Modélisation du cycle continental de l'eau à l'échelle régionale : impact de la modélisation de l'enneigement sur l'hydrologie du bassin versant du Rhône ? Ph. D. Thesis, Université Paul Sabatier, Toulouse, France, 361 pp.

Etchevers, P. , C. Golaz, F. Habets and J. Noilhan, 2002: Impact of a climate change on the Rhone river catchment hydrology, *J. Geophys. Res*., 107(D16).

EUROMODEL GROUP, 1995. Progress from 1989 to 1992 in understanding the circulation of the western Mediterranean Sea. *Oceanol. Acta*, 18, 2, 255-271.

F

Fabry, F., 2004: Meteorological value of ground target measurements by radar. *Journal of Atmospheric and Oceanic Technology*, 21(4), 560-573.

Fankhauser, S., J.B. Smith and R.S.J. Tol, 1999: 'Weathering Climate Change: Some Simple Rules to Guide Adaptation Decisions', Ecological Economics, 30, 67-78.

Feddema, J. and S. Freire, 2001: Soil degradation, global warming and climate impacts, *Clim. Res*., **17**, 209-216.

Fehlmann R., C. Quadri and H.C. Davies, 2000: An alpine rainstorm: sensitivity to the mesoscale upper-level structure, *Wea. Forecasting*, **15**, 4-28.

Fernandez, J. and Saenz, J. and Zorita, E., 2003: Analysis of wintertime atmospheric moisture transport and its variability over southern Europe in the NCEP-Reanalyses. *Clim Res.,* **23**, 195-215.

Fleury, P., Plagnes, V., Bakalowicz, M., 2007: Modelling of the functioning of karst aquifers with a reservoir model: application to Fontaine de Vaucluse (South of France).- Journal of hydrology (in Press).

Flexas MM, Gomis D, Ruiz S, Pascual A, Leon P, 2006: In situ and satellite observations of the eastward migration of the Western Alboran Sea Gyre, *Progress in Oceanography*, in press.

Flocas, H.A. and T. S. Karacostas, 1994: Synoptic and dynamic characteristics of cyclogenesis over the Aegean Sea. International Symposium on the Life Cycles of Extratropical Cyclones, Bergen, Norway, 186-191.

Fread, D.L., 1993: In: Maidment, D.R. (Ed.). Handbook of Applied Hydrology, McGraw-Hill, New York (chap. 10).

Freer, J., J. McDonnell, K. J. Beven, N. E. Peters, D. Burns, R. P. Hooper, B. Aulenbach, and C. Kendal, 2002: The role of bedrock topography on subsurface stormflow. *Water Resources Research*, **38(12),** 10.1029/2001WR000872.

Frei, C. and C. Schär, 1998: A precipitation climatology of the Alps from high-resolution raingauge observations. *Int. J. Climatol*., 18, 873-900.

Froebrich J., Nikolaidis N., Gallart F., Kirkby M., Lo Porto A., De Girolamo A.M., 2007: The Distribution of Temporary Streams in Southern Europe and their Importance for the Eu Water Framework Directive, Journal of Hydrology (submitted)

Fuda JL, Millot C, Taupier-Letage I, Send U, Bocognano JM, 2000: XBT monitoring of a meridian section across the western Mediterranean Sea, *Deep-Sea Research I*, **47**, 2191-2218.

Fuda J.-L. , G. Etiope, C. Millot, P. Favali, M. Calcara, G. Smriglio and E. Boschi, 2002. Warming, salting and origin of the Tyrrhenian Deep Water. Geophys. Res. Letters, 29(18), 1886, doi:10.1029/2001GL014072, 2002.

G

Galland JC, Goutal N, Hervouet JM. 1991 : TELEMAC : A new numerical model for solving shallow water equation. *Advances in Water Resources*, **14(3),** 143-148.

Gallart, F., Puigdefábregas, J., Del Barrio, G., 1993: Computer simulation of high mountainous terracettes as interaction between vegetation growth and sediment movement. *Catena*, **20**, 529-542.

Gallus W.A.and M. Segal, 2000, Sensitivity of Forecast Rainfall in a Texas Convective System to Soil Moisture and Convective Parameterization, *Wea. Forecasting*, **15**, 509—525

Gao, X. and Pal, J.S. and Giorgi, F., 2006: Projected changes in mean and extreme precipitation over the Mediterranean region from high resolution double nested RCM simulation. *Geophys Res Lett*, **33**, L03706

Garrett C, 1996: The role of the Strait of Gibraltar in the evolution of the Mediterranean water properties and circulation, In: F. Briand, Dynamics of Mediterranean straits and channels, *CIESM Science series*.

Garrigues, S., Allard, D., Baret, F., Weiss, M., 2006. Influence of landscape spatial heterogeneity on the non-linear estimation of leaf area index from moderate spatial resolution remote sensing data. Remote Sensing of Environment, 105, 286-298.

Gascard J-C, Rouault C, Testor P, 1999: General ocean circulation and subsurface mesoscale eddies in the Algerian basin, 4^{th} MTP workshop MATER, Perpignan, France, 28-30 October 1999.

Gascard J-C, Richez C, 1985: Water masses and circulation in the western Alboran Sea and in the Strait of Gibraltar, *Progress in Oceanography*, **15**, 157-216.

Gascard J-C (1978)

Gaspar P, Grégoris Y, Lefevre J-M, 1990: A simple Eddy Kinetic Energy Model for simulations of the oceanic vertical mixing: Tests at Station Papa and Long-Term Upper Ocean Study Site, *J. Geophys. Res*., **C95(9),** 16179-16193.

Gasparini GP, Astraldi M, 2002: Experimental evidence of the interannual variability of the currents in two Mediterranean straits: the Strait of Sicily and the Corsica Channel. In: Tracking long-term hydrological change in the Mediterranean Sea, CIESM Workshop Series, n^o: 16, Monaco, 45-52.

Gaume, E., M. Livet, M. Desbordes, and J. P. Villeneuve, 2004: Hydrological analysis of the river Aude flash-flood on 12 and 13 November 1999. *Journal of Hydrology*, **286,** 135-154.

Georgelin, M., and Richard, E., 1996: Numerical simulation of flow diversion around the Pyrenees: A tramontana case study, *Mon. Weather Rev*., **124**, 687-700.

Germann, U., G. Galli, M. Boscacci, and M. Bolliger, 2006: Radar precipitation measurement in a mountainous region. *Q. J.R. Meteor. Soc.*, **132,** 16669-1692.

Gibelin, A.-L. and Déqué, M.(2003) Anthropogenic climate change over the Mediterranean region simulated by a global variable resolution model. *Clim. Dyn,*. 20, 327-339

Gibelin, A.-L., Calvet, J.-C., Roujean, J.-L., Jarlan, L., Los, S. O. 2006. Ability of the land surface model ISBA-A-gs to simulate leaf area index at the global scale: Comparison with satellites products, Journal of Geophysical Research, 111, D18102, doi:10.1029/2005JD006691

Gibson ER, Hudson PK, Grassian VH, 2006: Physicochemical properties of nitrate aerosols: Implications for the atmosphere, *J. Phys. Chemistry*, **A 110 (42),** 11785-11799

Giordani H., G. Caniaux and L. Prieur, 2005 : A simplified Oceanic Model Assimilating Geostrophic Currents: Application to the POMME Experiment. *J. Phys. Oceanogr*., **35**, 628--644

Giordani, H., Caniaux, G., Prieur, L., Paci, A., Giraud, S., 2005b. A one year mesoscale simulation of the North-East Atlantic : mixed layer heat and mass budgets during the POMME experiment. *J. Geophys. Res*., **110**, C07S08, doi:10.1029/2004JC002765

Gibelin, A.-L. and Déqué, M.(2003) Anthropogenic climate change over the Mediterranean region simulated by a global variable resolution model. *Clim. Dyn,*. 20, 327-339

Giorgi, F. (2006) Climate change hot-spots. *Geophys Res Lett*, 33

Giorgi, F. and Bi, X. (2005) Updated regional precipitation and temperature changes for the 21st century from ensembles of recent AOGCM simulations. *Geophys Res Lett*, 32, L21715

Godet Michel, 1997: Manuel de prospective stratégique. Dunod, Paris.

Gorini C., J. Lofi, C. Duvail, A.T. Dos Reis, P. Guennoc, P. Le Strat, A. Mauffret (2005). The late Messinian salinity crisis and Late Miocene tectonism: interaction and consequences of the physiography and post-rift evolution of the Gulf of Lions margin. Marine and Petroleum Geology, 22, 695-712.

Gorsky G., L. Prieur, I. Taupier-Letage, L. Stemmann and M. Picheral, 2002: Large Particulate Matter (LPM) in the Western Mediterranean. I - LPM distribution related to hydrodynamics. *Journal of Marine Syst.,* 33-34: 289-311.

Graf W.L., 1988: Fluvial processes in dryland rivers. Springer, Berlin.

Graham, L. P., and S. Bergström. 2000. Land surface modelling in hydrology and meteorology - lessons learned from the Baltic basin. Hydrology and Earth System Sciences 4:13-22.

Grainger, R.J.R. and Garcia, S.M., 1996: FAO Fisheries Department Chronicles of Marine Fishery Landings (1950-1994): Trend Analysis and Fisheries Potential. FAO Fisheries Technical Paper 359.

Green, A. E., Astill, M. S., McAneney, K. J., Nieveen, J. P., 2001. Path-averaged surface fluxes determined from infrared and microwave scintillometers. Agricultural and Forest Meteorology, 109(3), 233-247.

Grubisic, V., 2004: Bora-driven potential vorticity banners over the Adriatic, *Quart. J. Roy. Meteorol. Soc*., **130**, 2571-2603.

Guénard V., Drobinski P., Caccia J.L., Tedeschi G., Currier P., 2006: Dynamics of the MAP IOP-15 Severe Mistral Event: Observations and High-Resolution Numerical Simulations. *Quart. J. Roy. Meteorol. Soc*., **132**, 757-778

Guénard V., Drobinski P., Caccia J.L., Campistron B., Bénech B., 2005: An Observational Study of the Mesoscale Mistral Dynamics. *Boundary Layer Meteorol*., **115**, 263-288

Guerzoni S, Chester R, Dulac F, Herut B, Loye-Pilot MD, Measures C, Migon C, Molinaroli E, Moulin C, Rossini P, Saydam C, Soudine A, Ziveri P, 1999: The role of atmospheric deposition in the biogeochemistry of the Mediterranean Sea, *Progress in Oceanography*, **44 (1-3),** 147-190

Guieu C., Bonnet S., Wagener T., 2005: Loÿe-Pilot M.D, Biomass burning as a source of dissolved iron to open ocean? *Geophys. Res. Let*., **32**, L1960810.1029/2005GL022962

Guieu, C., Chester, R., Nimmo, M., Martin, J.M., Guerzoni, S., Nicolas, E., Mateu, J. and Keyse, S., 1997: Atmospheric input of dissolved and particulate metals to the northwestern Mediterranean,. *Deep-Sea Research II*, **44**, 3-4, 655-674.

Guillot, P., Duband, D., 1967: La méthode du Gradex pour le calcul de la probabilité des crues à partir des pluies, Colloque International sur les crues et leur évaluation, Leningrad, 15–22 Août, IASH, publication no 84. Symposium International d'Hydrologie, Fort Collins pp. 560–569.

H

Haas, L., 2002: Mediterranean water resources planning and climate change adaptation. Water, wetlands and climate change. Building Linkages for their Integrated Management. Mediterranean Regional Roundtable. Athens, Greece, December 10-11, 2002. Draft for Discussion. 62 pp.

Habets, F., J. Noilhan, C. Golaz, J. P. Goutorbe, P. Lacarère, E. Leblois, E. Ledoux, E. Martin, C. Ottlé, and D. Vidal-Madjar. 1999. The ISBA surface scheme in macroscale hydrological model applied to the Hapex-Mobilhy are. Part I: Model and database. Journal of Hydrology 217:75-96

Habets, F., and G.M. Saulnier, 2001: Subgrid Runoff Parameterization, Phys. Chem. Earth (B), vol. 26, no 5-6, 455-459.

Habets, F., A. Boone, J.L Champeaux, P. Etchevers, L. Franchistéguy, E. Leblois, E. Ledoux, P. Le Moigne, E. Martin, S. Morel, J. Noilhan, P.Quintana Seguí F. Rousset-Regimbeau, P. Viennot (2007) : The SAFRAN-ISBA-MODCOU hydrometeorological model applied over France, submitted to JGR.

Hallegatte, S., 2006: A cost-benefit analysis of the New Orleans flood protection system. AEI-Brookings Joint Center, Regulatory Analysis 06-02.

Hallegatte, S., Hourcade, J.-C., Dumas, P., 2006a: Why economic dynamics matter in the assessment of climate change damages: illustration on extreme events. *Ecological Economics*, accepted.

Hallegatte, S., Hourcade, J.-C., and Ambrosi, P., 2006b: Using climate analogues for assessing climate change economic impacts in urban areas, *Climatic Chang,* accepted

Hamad N, Millot C, Taupier-Letage I, 2005: A new hypothesis about the surface circulation in the eastern basin of the Mediterranean Sea, *Progress in Oceanography*, 66, 287-298.

Hamad N., C. Millot & I. Taupier-Letage, 2006. The surface circulation in the eastern basin of the Mediterranean Sea. Scientia Marina, 70(3), 457-503.

Harvey, A.M., 1984: Geomorphological response to an extreme flood: a case study from southeast Spain. Earth Surface Processes and Landforms 9, 267-279.

Hébrard O. 2004 : Stratégie de paramétrisation des humidités de surface sur un bassin versant agricole en milieu méditerranéen. *Thèse de doctorat de l'Université Montpellier II, Ecole Doctorale « Sciences de la Terre et de l'Eau »,* 230 p.

Hébrard O, Voltz M, Andrieux P, Moussa R. 2006 : Spatio-temporal distribution of soil surface moisture in a heterogeneously farmed Mediterranean catchment. *Journal of Hydrology*, **329**: 110-121 (doi: 10.1016/j.jhydrol.2006.02.012).

HEC. 2002. HEC-RAS, River analysis system, user' manual. US Army Corps of Engineers, Hydrological Engineering Center, Davis, CA, report N° CPD-68.

Herbaut C, Codron F, Crépon M, 1998: Separation of a coastal current at a strait level: Case of the Sicily Strait. *J. Phys. Oceanography*, **28**, 1346-1362.

Herburn GW, La Violette PE, 1990: Variations in the structure of the anticyclonic gyres found in the Alboran Sea, *J. Geophys. Res*., **95(C2),** 1599-1613.

Hermann PhD Thesis

Herrington P., 1996: Ciamte change and the demand for water. HMSO, London.

Homar V , C. Ramis, and S. Alonso, 2002: A deep cyclone of African origin in the western Mediterranean : diagnosis and numerical simulations, *Ann. Geophys*., **20**, 93-106.

Homar V., and D. J. Stensrud, 2004: Sensitivities of an intense cyclone over the western Mediterranean. *Quart. J. Roy. Meteor. Soc.,* 130, 2519-2540.

Holman I P and Loveland P J (Eds), 2001: Regional climate change impact and response studies in East Anglia and North West England. Final report of MAFF Project No. CC0337. Available at www.ukcip.org.uk

Hopkins TS, 1999: The thermohaline forcing of the Gibraltar exchange, *J. Marine Sys*., **20**, 1-31.

Horton C, Kerling J, Athey G, Schmitz J, Clifford M, 1994: Airborne expendable bathythermograph surveys of the eastern Mediterranean, *J. Geophys. Res*., **99(C5)**, 9891-9905.

Hoinka, K.P., E. Richard, G. Poberaj, R. Busen, J.-L. Caccia, A. Fix and H. Mannstein, 2003: Analysis of a potential-vorticity streamer crossing the Alps during MAP IOP 15 on 6 November 1999. *Q. J. Meteorol. Soc*., **129**, 609-632.

Holman I P and Loveland P J (Eds), 2001: Regional climate change impact and response studies in East Anglia and North West England. Final report of MAFF Project No. CC0337. Available at www.ukcip.org.uk

Huet P., Martin X., Prime J.L., Foin P., Laurin C., Cannard P., 2003: Retour d'expérience des crues de Septembre 2002 dans les departments du Gard, de l'Hérault, du Vaucluse, des Bouches du Rhône, de l'Ardèche et de la Drome. *Rapport de l'Inspection Générale de l'Environnement, Ministère de l'écologie et du développement durable, République Française*, 133 pp.

I

Ibáñez, J.J., Jiménez Ballesta, R., García Alvarez, A., 1990 : Soil landscapes and drainage basins in Mediterranean mountain areas. *Catena,* **17**, 573-583.

International Monetary Fund, 2003: 'Fund assistance for countries facing exogenous shocks'. prepared by the Policy Development and Review Department (In consultation with the Area, Finance, and Fiscal Affairs Departments), Washington, DC: IMF.

IPCC 2001: Climate Change 2001, The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate change, Cambridge University Press, Cambridge, United Kingdom and New York, USA, 881 pp.

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

J

Jacob D., Bärring L., Christensen O.B., Christensen J.H., de Castro M., Déqué M., Giorgi F., Hagemann S., Hirschi M., Jones R., Kjellström E., Lenderink G., Rockel B., Sànchez E.S., Schär C., Seneviratne S.I., Somot S., van Ulden A., van den Hurk B., 2006: An inter-comparison of regional climate models for Europe: Model performance in Present-Day Climate. *Climatic Change* (in press)

Jacob, F., Schmugge, T., Olioso, A., French, A., Courault, D., Ogawa, K., Petitcolin, F., Chehbouni, G., Pinheiro, A. Privette, J., 2007. Modeling and inversion in thermal infrared remote sensing over vegetated land surfaces. In "Advances in Land Remote Sensing: System, Modeling, Inversion and Application". S. Liang (Ed.), Springer, in press.

Jacq V., 1994, Inventaire des situations à précipitations diluviennes sur la région Languedoc-Roussillon, la Provence – Alpes Cotes d'azur et la Corse, période 1958-1994. *Phénomènes remarquables*, n°3, Météo-France, SCEM, 1994, 190 pp.

Jansà, A., 1986: Genoa cyclones and other Western Mediterranean cyclones. *WMO/TD No. 128*, App 8., 59-70.

Jansà, A., Genoves, A., Picornell, M. A., Campins, J. and Riosalido, R., and Carretero, O., 2001: Western Mediterranean cyclones and heavy rain. Part 2: Statistical approach. *Meteorol. Appl*., **8**, 43-56.

Jarlan, L., Mougin, E., Mazzega, P., Schoenauer, M., Tracol, Y., Hiemaux, P., 2005. Using coarse remote sensing radar observations to control the trajectory of a simple Sahelian land surface model. Remote Sensing of Environment, 94, 269 – 285.

Joly, B. and A. Joly, 2004: Cyclone tracking and weather regimes in the Mediterranean. *EGU First General Assembly*, Nice, France, 25-30 April.

Jones, J.A.A., 1997: Pipeflow contributing areas and runoff response. *Hydrological Processes*, **11**, 35-41.

Jones, P. D. and P. A. Reid, 2001: Assessing future changes in extreme precipitation over Britain using regional climate model integrations, *Int.J.Climatol*., **21(11),** 1337-1356. doi:10.1002/joc.677

Josey S, 2003: Changes in the heat and freshwater forcing of the Eastern Mediterranean and their influence on deep water formation, *J. Geophys. Res*., **108(C7),** doi :10.1029/ 2003JC001778.

Josey S, 2003: Changes in the heat and freshwater forcing of the Eastern Mediterranean and their influence on deep water formation, *J. Geophys. Res*., **108(C7),** doi :10.1029/ 2003JC001778.

Josey, S. and Kent, E. and Taylor, P., 1999: New insights into the ocean heat budget closure problem from analysis of the SOC air-sea flux climatology. *J. Clim.* **12, 2**,856-2,880

Josey, S., 2003: Changes in the heat and freshwater forcing of the eastern Mediterreanean and their influence on deep water formation. *J. Geophys. Res*., **108(C7),** 1-18.

Joss, J., and A. Waldvogel, 1990: Precipitation measurement and hydrology. *Radar in Meteorology: Battan Memorial and 40th Anniversary Radar Meteorology Conference*, D. Atlas, Ed., Amer. Meteor. Soc., 577-606.

Jeftic, L., Milliman, J.D. and Sestini, G., 1992: Climate change and the Mediterranean. Edward Arnord (publ.), London, 664 pp.

K

Kamburska, L., Fonda-Umani, S., in press. Long-term copepod dynamics in the Gulf of Trieste (Northern Adriatic Sea). Recent changes and trends. Climate Research, in press.

Kates, R. 2000: "Cautionary Tales: Adaptation and the Global Poor." *Climatic Change*, **45**, 5-17.

Khan, M.S., Coulibaly, P., Dibike, Y., 2006: Uncertainty analysis of statistical downscaling methods, *Journal of Hydrology,* **319,** 357–382

Kinder TH, Bryden HL, 1992: Hydraulic control in the Strait of Gibraltar, *Bulletin de l'Institut Océanographique*, Monaco, France, Special number 11.

Kinder, T., Parrilla, G., 1987. Yes, some of the Mediterranean outflow does come from great depths. J. Geophys. Res. 92, 2901–2906.

Kieffer Weisse, A., Bois, P., 2001: Topographic Effects on Statistical Characteristics of Heavy Rainfall and Mapping in the French Alps. Journal of Applied Meteorology, 40(4), 720–740.

Klein B, Roether W, Manca B, Bregant D, Beitzel V, Kovacevic V, Luchetta A, 1999: The large deep-water transient in the eastern Mediterranean, *Deep-Sea Research I*, **46**, 371-414.

Klein B, Roether W, Manca B, 2000: Is the Adriatic returning to dominate the production of Eastern Mediterranean Deep Water?, *Geophys. Res. Let.,* **27(20),** 3377-3380.

Kontoyiannis H, Theocharis A, Balopulos E, Kioroglou S, Papadopoulos V, Collins M, Velegrakis AF, Iona A, 1999: Water fluxes through the Cretan Arc Straits, Eastern Mediterranean Sea : March 1994 to June 1995, *Progress in Oceanography*, **44,** 511-529.

Köppen, W., 1936 : Das geographishe System der Klimate. In Köppen and Geiger Eds, Handbuch der Klimatologie 3. Gebrueder Borntraeger, Berlin, 46 pp.

Korres G, Pinardi N, Lascaratos, 2000: The ocean response to low frequency Interannual Atmospheric Variability in the Mediterranean Sea. Part I: Sensitivity Experiments and Energy Analysis, *J. Phys. Ocean*., **30,**705-731.

Kosmas, C., Danalatos, N., Cammeraat, L.H., Chabart, M., Diamantopoulos, J., Farand, R., Gutierrez, L., Jacob, A., Marques, H., Martinez-Fernandez, J., Mizara, A., Moustakas, N., Nicolau, J. M., Oliveros, C., Pinna, G., Puddu, R., Puigdefábergas, J., Roxo, M., Simao, A., Stamou, G., Tomasi, N., Usai, D. and Vacca, A., 1997: The effect of land use on runoff and soil erosion rates under Mediterranean conditions. *Catena*, **29,** 45-59.

Kouwenberg, J.H.M., 1998: Shift in copepod populations and long-term changes in the northwestern Mediterranean. An overview. Pelagic Biogeography ICOPB II. Proceedings of the 2nd International Conference. Final report of SCOR/IOC working Group 93 'Pelagic Biogeography'. Noordwijkerhout, The Netherlands, 9 July-14 July 1995. no. 142: 203-213. Workshop report. Intergovernmental Oceanographic Commission. Paris [workshop Rep. IOC]. Apr 1998.

Krichak, S. O., P. Alpert, M. Dayan, 2004: The role of atmospheric processes associated with hurricane Olga in the December 2001 floods in Israel. *J. Hydrometeorology*, **5**, 1259-1270.

Krinner, G., N. Viovy, N. De Noblet Ducoudré, J. Ogée, J. Polcher, P. Friedlingstein, P. Ciais, S. Sitch, and I. Prentice. 2005. A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system. Global Biogeochem. Cycles, 19, GB1015, doi:10.1029/2003GB002199.

Kutiel, P., Lavee, H., Segev, M., Benyamini, Y., 1995 : The effect of fire-induced surface heterogeneity on rainfall-runoff-erosion relationships in an eastern Mediterranean ecosystem, Israel. *Catena*, **25**, 77-87.

L

Lacombe H., P. Tchernia and L. Gamberoni, 1985. Variable bottom water in the Western Mediterranean basin. Prog. Oceanogr. 14, 319-338.

Lafore JP, Stein J, Asencio N, Bougeault P, Ducrocq V, Duron J, Fischer C, Héreil P, Mascart P, Masson V, Pinty JP, Redelsberger JL, Richard E, de Arellano VG, 1998: The Meso-NH atmospheric simulation system. Part 1: adiabatic formulation and control simulations, *Annales Geophysicae*, **16,** 90-109.

Lakkis, S., Zeidane, R., 2004: Exotic species and lessepsian migration of plankton in Lebanese waters, Levantine Basin, Eastern Mediterranean. Rapp. Comm. int. Mer Médit., 37, 384.

Lakkis, S., 1997 : Long-time series of hydrological and plankton data from Lebanese waters (the Eastern Mediterranean). NOAA Washington D.C. Technical Report NESDIS 87, 185-203.

Lakshmi, V., 2004: The role of satellite remote sensing in the Prediction of Ungauged Basins, *Hydrological Processes*, **18(5),** 1029-1034.

Lane, L.J., Diskin, M.H., Renard, K.G., 1971: Input-output relationships for an ephemeral streams channel system. *J. Hydrology*, **17**, 22-40.

Langlais C PhD Thesis

Lafuente JG, Delgado J, Vargas JM, Vargas M, Plaza F, Sarhan T, 2002: Low frequency variability of the exchanged flows through the Strait of Gibraltar during CANIGO, *Deep Sea Research II*, **49**,4051-4067.

Lascaratos A, Nittis K, 1998: A high resolution three-dimensional numerical study of intermediate water formation in the Levantine Sea, *J. Geophys. Res*., **103(C9),** 18497-18511.

Lascaratos, A. Roether, W., Nittis, K., Klein, B., 1999: Recent changes in deep water formation and spreading in the Mediterranean sea: a review. *Prog. Oceanog,* **44(1-2),** 36.

Lascaratos A, Williams RG, Tragou E, 1993: A mixed layer study of the formation of Levantine Intermediate water, *J. Geophys. Res*., **98**, 14739-14749.

Lastenet, R., Mudry, J., 1995 : Impact d'un événement pluvieux exceptionnel sur le fonctionnement d'un système karstique. Cas de l'orage du 22/9/1992 à Vaison-la-Romaine (Vaucluse, France). *Comptes Rendus de l'Académie des Sciences Paris*, t. 320, série II a, 953-959.

Lauvernet, C., Baret, F., Le Dimet, F.-X., 2003. Assimilating high temporal frequency SPOT data to describe canopy functioning: the ADAM project. In 2003 International Geoscience and Remote Sensing Symposium, IGARSS'03, 5, 3184-3186, Toulouse, 2003.

Lavabre, J., Sempere-Torres, D., Cernesson, F., 1991 : Etude du comportement hydrologique d'un bassin versant méditerranéenaprès la destruction de l'écosystème forestier par un incendie. *Hydrologie Continentale,* **6(2),** 121-132.

Lavabre, J., C. Fouchier, N. Folton, and Y. Grégoris, 2003: SHYREG : une méthode pour l'estimation régionale des débits de crue, application aux régions méditerranéennes. *Ingénierie EAT***,** 97-111.

Leaman KD, Schott F, 1991: Hydrographic structure of the convection regime in the Gulf of Lions : Winter 1987, *J. Phys. Ocean*., **21**, 575-598.

Lebeaupin, C., Ducrocq, V., Giordani, H., 2006: Sensitivity of torrential rain events to the sea surface temperature based on high-resolution numerical forecasts, *J. Geophys. Res*., **111**, D12: 1211010.1029/2005JD006541.

Leblois, E., 2002: Evaluation of the possible impacts of climatic change by distributed models (Gewex-Rhone et Gicc-Rhone projects), *La Houille Blanche*, **8**, 78-83

Legg S and J. Marshall, 1993: A heton model of the spreading phase of open-ocean deep convection, *J. Phys. Ocean.,* **23,** 1040-1056.

Le Lay and Saulnier, 2007: Exploring the signature of climate and landscape spatial variabilities in flash-flood events: case of the 8-9 September 2002 Cévennes-Vivarais catatastrophic event, submitted to GRL.

Lelieveld J, Berresheim H, Borrmann S, et al., Global air pollution crossroads over the Mediterranean, *Science*, **298 (5594),** 794-799

Leon, J. G., Calmant, S., Seyler, F., Bonnet, M. P., Cauhope, M., Frappart, F., and Filizola, N., 2006: Rating curves and estimation of average water depth at the Upper Negro River based on satellite altimeter data and modelled discharges, *J. Hydrol*., in press

Lermusiaux PFJ, 1999: Estimation and study of mesoscale variability in the Strait ofSicily, *Dynamics of Atmospheres and Oceans,* **29**, 255-303.

Lermusiaux PFJ, Robinson AR, 2001: Features of dominant mesoscale variability, circulation patterns and dynamics in the Strait of Sicily. *Deep-Sea Research I*, **48**, 1953-1997.

Le Vourch J., C. Millot, N. Castagné, P. Le Borgne and J.P. Olry, 1992. Atlas of Thermal Fronts of the Mediterranean Sea Derived From Satellite Imagery. Mémoires de l'Institut Océanographique, Monaco, 16, 146p.

Li L., Bozec A., S. Somot, K. Béranger, P. Bouruet-Aubertot, F. Sevault, M. Crépon, 2006: Regional atmospheric, marine processes and climate modelling (chapter 7). *In: Mediterranean Climate Variability, Lionello, P. and Malanotte, P. and Boscolo, R.(eds), Elsevier B.V.,* pp. 373-397

Lin, L.-Y., S. Chiao, T. Wang, M.L. Kaplan, R. P. Weglarz, 2001: Some common ingredients for heavy orographic rainfall. *Wea. Forecasting*, **16**, 633-660.

Liniger, M.A. and H.C. Davies, 2003: Substructure of a MAP streamer, *Q.J.R. Metorol. Soc*., **129**, 633-651.

Lionello, P., F. Dalan, and E. Elvini, 2002: Cyclones in the Mediterranean region : the present and doubled CO2 climate scenarios, *Clim. Res.,* **22**, 147-159.

Lionello et al, 2006 : MEDITERRANEAN CLIMATE VARIABILITY, Elsevier, 438 pp.

Liston, G.E., Elder, K., 2006. A distributed snow-evolution modeling system (SnowModel). Journal Of Hydrometeorology 7 (6): 1259-1276.

Lleonart, J. and Maynou, F., 2003: Fish stock assessments in the Mediterranean: state of the art. *Scientia Marina,* **67(suppl. 1),** 37-49.

Llorens, P., Gallart, F., 1992: Small basin response in a Mediterranean mountainous abandoned farming area: research design and preliminary results. *Catena*, **19**, 309-320.

Lloret, J. Lleonart, J., Solé, I. and Fromentin, J.M., 2001: Fluctuations of landings and environmental conditions in the north-western Mediterranean Sea. *Fisheries Oceanography,* **10(1),** 33-50.

Lloret, J., Palomera, I., Salat, J. and Solé, I., 2004: Impact of freshwater input and wind on landings of anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*) in shelf waters surrounding the Ebre River delta (northwestern Mediterranean). *Fisheries Oceanography***, 13(2),** 102-110.

Loaiciga, H. A., D. R. Maidment and J. B. Valdes, 2000: Climate-change impacts in a regional karst aquifer, Texas, USA, *J. Hydrology*, **227(1-4),** 173-194.

Lopez-Garcia M. J., C. Millot, J. Font and E. Garcia-Ladona, 1994. Surface circulation variability in the Balearic Basin. J. Geophys. Res., 99, C2, 3285-3296.

Lorenz P. and Jacob D., 2005: Influence of regional scale information on the global circulation: a two-way nesting climate simulation. *Geophys Res Lett*., **32**, doi: 10.1029/2005GL023351

Loukas, A., L. Vasiliades and N. R. Dalezios, 2002: Climatic impacts on the runoff generation processes in British Columbia, Canada, *Hydrol. Earth. Syst. Sci*., **6**, 211-227.

Loÿe-Pilot, M. D., J. M. Martin, and J. Morelli, 1986: Influence of Saharan dust on the rain acidity and atmospheric input to the Mediterranean, *Nature,* **321(6068),** 427 – 428.

Lüdi, A., Beyrich, F., Mätzler, C., 2005. Determination of the Turbulent Temperature–Humidity Correlation from Scintillometric Measurements, Boundary Layer Meteorology, 17(3), 525-550.

Ludwig, W., Meybeck, M., 2003: Riverine transport of water, sediments and pollutants to the Mediterranean sea. UNEP/MAP/MED POL, MAP Technical Reports Series No. 141.

Ludwig, W., Serrat, P., Cesmat, L. and Garcia-Esteves, J. 2004. Evaluating the impact off the recent temperature increase on the hydrology of the Têt River (Southern France), Journal of Hydrology, 289, 204-211.

Luterbacher J, Dietrich D, Xoplaki E, et al., xxxx: European seasonal and annual temperature variability, trends, and extremes since 1500, *Science*, **303 (5663),** 1499-1503

Lutherbacher, J. and et al., 2006: Chapter 1: Mediterranean Climate Variability over the Last Centuries: A Review (chapter 1) *In: Mediterranean Climate Variability, Lionello, P. and Malanotte, P. and Boscolo, R.(eds), Elsevier B.V.,* pp. 27-148

M

Madec G, Delecluse P, Imbard M, Levy C., 1997: OPA, release 8, Ocean General Circulation reference manual, Technical report 96/xx, LODYC/IPSL, France, February 1997.

Madec G, Lott F, Delecluse P, Crépon M, 1996: Large-scale preconditioning of deep-water formation in the northwestern Mediterranean Sea, *J. Phys. Ocean.,* **26,** 1393-1408.

Madec G, Chartier M, Delecluse P, Crépon M, 1991a: A three dimensional numerical study of deep-water formation in the northwestern Mediterranean Sea, *J. Phys. Ocean*., **21**, 1349-1371.

Madec G, Chartier M, Crépon M, 1991b: Effect of thermohaline forcing variability on deep-water formation in the western Mediterranean Sea : A high resolution 3D numerical study, *Dynamics of Atmospheres and Oceans*, **15,** 301-332.

Manalotte-Rizzoli P, Hecht A, 1988: Large scale properties of the Eastern Mediterranean: a review, *Oceanologica Acta*, **11**,323:335.

Malanotte-Rizzoli, P., Eremeev, N. 1999: The eastearn Mediterranean as a laboratory basin for the assessment of contrasting ecosystems. *NATO Science Series,* 2. Environmental Security, Vol. 51, 503 p.

Malanotte-Rizzoli, P., Manca, B.B., Ribera d'Alcala, M., Theocharis, A., Bergamasco, A., Bregant, D., Budillon, G., Civitarese, G., Georgopoulos, D., Michelato, A., Sansone, E., Scarazzato, P., and Souvermezoglou, E., 1997. A synthesis of the Ionian Sea hydrography, circulation and water mass pathways during POEM-Phase I. Prog. Oceanogr., 39, 153 -204.

Manca B, Kovacevic V, Gacic M, Viezzoli D, 2002: Dense water formation in the Southern Adriatic Sea Manca B, Kovacevic V, Gacic M, Viezzoli D, 2002: Dense water formation in the Southern Adriatic Sea and spreading into the Ionian Sea in the period 1997 – 1999, *J. Marine Sys*., **33-34**, 133-154.

Manca B, Budillon G, Scarazzato P, Ursella L, 2003: Evolution of dynamics in the eastern Mediterranean affecting water mass structures and properties in the Ionian and Adriatic Seas. *J. Geophys. Res*., 108, 8102, doi:10.1029/2002JC001664.

Manziafou A, Lascaratos A, 2005: An eddy resolving numerical study of the general circulation and deep-water formation in the Adriatic sea, *Deep-Sea Research Part I*, in press.

Marc, V., Travi, Y., Pichon, A., 1996 : Reconnaissance des mécanismes hydrologiques sur un petit bassin versant méditerranéen. Approche par le traçage chimique et isotopique naturel de l'eau. *Comptes Rendus de l'Académie des Sciences Paris*, t. 323, série II a, 57-64.

Maréchal J.C., Dörfliger N., Lachassagne P., Ladouche B. (submitted).- A method for the interpretation of pumping tests performed on drains in karstic aquifers.- *Water Resources Research*.

Margoum M., Oberlin G., Lang M., Weingartner R., 1994: Estimation des crues rares et extrêmes : principes du modèle Agregee. *Hydrologie Continentale*, vol.9 (1), 85-100.

Mariotti, A. and Struglia, M.V. and Zeng, N. and Lau, K.-M., 2002: The hydrological cycle in the Mediterranean region and implications for the water budget of the Mediterranean Sea. *J. Clim*, **15**, 1674-1690.

Marofi S., 1999 : Rôle des échanges nappes-fossés dans le fonctionnement hydrologique d'un bassin versant en milieu méditerranéen cultivé. *Thèse de doctorat de l'Ecole Nationale Supérieure Agronomique de Montpellier*, 240 p.

Marshall J, Schott F, 1999: Open ocean deep convection: observations, models and theory, *Review of Geophysics,* **37**, 1-64.

Marsigli C, Boccanera F, Montani A, Paccagnella T, 2005: The COSMO-LEPS mesoscale ensemble system: validation of the methodology and verification, *Nonlinear Processes in Geophysics***,** **12**, 527-536.

Marty, J. C., J. Chiaverini, M. D. Pizay, and B. Avril, 2002: Seasonal and interannual dynamics of nutrients and phytoplankton pigments in the western Mediterranean Sea at the DYFAMED time-series station (1991-1999), *Deep-Sea Res. II*, **49**, 1965-1985.

Marullo S, Santoleri R, Malanotte-Rizzoli P, Bergamasco A, 1999: The sea surface temperature field in the eastern Mediterranean from AVHRR data. Part I: Seasonal variability, *J. Marine Sys*., **20(1-4)**, 63-81.

Massacand, A.C., H. Wernli, and H.C. Davies, 1998: Heavy precipitation on the Alpine southside: An upper-level precursor, *Geophys. Res. Lett*., **25,** 1435-1438.

Masson, V., Bougeault, P., 1996: Numerical simulation of a low-level wind created by complex orography: a cierzo case study, *Mon. Weather Rev*., **124**, 701-715.

Masson V, Grimmond CSB, Oke TR, 2002: Evaluation of the Town Energy Balance (TEB) Scheme with Direct Measurements from Dry Districts in Two Cities, J. *Appl. Meteorol*., **41**, 1011-1026.

Masson, V., J.-L. Champeaux, F. Chauvin, C. Meriguet, R. Lacaze, (2003) A global database of land surface parameters at 1-km resolution in meteorological and climate models. J. Climate 16(9): 1261-1282.

Mazzocchi, M.G., Nervegna, D., D'Elia, G., Di Capua, I., Aguzzi, L., Boldrin, A., 2003: Spring mesozooplankton communities in the epipelagic Ioanian Sea in relation to the Eastern Mediterranean Transient. *J. Geophys. Res.,* **108**, 8114.

Mearns L.O., R.W. Katz and S.H. Schneider, 1984: Extreme high temperature events: changes in their probabilities with changes in mean temperature*, J. Climate Appl. Meteor.,* **23**, 1601-1613.

Medail, F., 2005 : Mise en pace et organisation de la biodiversité: l'exemple de la flore méditerranéenne. In: Les biodiversities: objets, theories, pratiques, P. Marty et al. (eds). CNRS Editions, Paris, 97-112.

MEDAR/MEDATLAS Group, 2002: MEDAR/MEDATLAS 2002 Database. Cruise inventory, observed and analysed data of temperature and bio-chemical parameters. (4 CD-ROMs).

Medina, S. And R.A Houze, 2003: Air motions and precipitation growth in Alpine storms, *Q. J. R. Meteorol. Soc.,* **129**, 345-372.

Medoc Group, 1970: Observations of formation of deep water in the Mediterranean sea, 1969, *Nature,* **227**, 1037-1040.

Meigh, J. R., A. A. McKenzie and K. J. Sene, 1999: A Grid-Based Approach to Water Scarcity Estimates for Eastern and Southern Africa, *Water Resour.Manage*., **13(2),** 85-115. doi:10.1023/A:1008025703712

Meijninger, W. M. L., Beyrich, F., Lüdi, A., Kohsiek, W., De. Bruin, H. A. R., 2006. Scintillometer-Based Turbulent Fluxes of Sensible and Latent Heat Over a Heterogeneous Land Surface – A Contribution to Litfass-2003, Boundary Layer Meteorology, 121(1), 89-110.

Meloni G, Zou P, Klippenstein SJ, et al., 2006: Energy-resolved photoionization of alkylperoxy radicals and the stability of their cations, *J. Am.Chem. Soc*., **128 (41),** 13559-13567
Mendelsohn, R. and Williams, L., 2004: Comparing Forecasts of the Global Impacts of Climate Change, Mitigation and Adaptation Strategies for Global Change 9 (4), 315-333.
Merlin, O., Chehbouni, A., Kerr, Y. H., Goodrich, D. C., 2006. A downscaling method for distributing surface soil moisture within a microwave pixel : Application to the Monsoon'90 data. Remote Sensing of Environment, 101, 379-389.
Merritt, W. S., Y. Alila, M. Barton, B. Taylor, S. Cohen and D. Neilsen, 2006: Hydrologic response to scenarios of climate change in sub watersheds of the Okanagan basin, British Columbia, *J. of*. Hydrology, **326(1-4),** 79-108. doi:10.1016/j.jhydrol.2005.10.025
Mertens C, Schott F, 1998: Interannual variability of deep water formation in the North Western Mediterranean, *J. Phys. Ocean*., **28**, 1410-1424.
Mestre, O., 2000 : Méthodes statistiques pour l'homogénéisation de longues séries climatiques. PhD Thesis, 229 pp. Université Paul Sabatier, Toulouse, septembre 2000 (in french)
Miller, N. L., K. E. Bashford and E. Strem., 2003: Potential impacts of climate change on California hydrology, *J.Am.Water Resour.Assoc*., **39**,771-784
Milliman, J., 2001 : Delivery and fate of fluvial water and sediment to the sea: a marine geologist's view of European rivers. *Scientia marina*, **65(suppl. 2),**121-132.
Millot C., 1979. Wind induced upwellings in the Gulf of Lions. Oceanol. Acta, 2, 3, 261-274.
Millot C., 1985. Some features of the Algerian Current. J. Geophys. Res., 90, C4, 7169-7176.
Millot C, 1987: Circulation in the western Mediterranean Sea, *Oceanologica Acta,* 10, 143-149.
Millot C., 1990. The Gulf of Lions' hydrodynamics. Continental Shelf Res., 10, 9-11, 885-894
Millot C., 1991. Mesoscale and seasonal variabilities of the circulation in the western Mediterranean. Dyn. Atm. Oceans, 15, 179-214.
Millot C., 1992. Are there major differences between the largest Mediterranean seas? A preliminary investigation. Bulletin de l'Institut Océanographique, Monaco, 11, 3-25.
Millot C, 1999: Circulation in the western Mediterranean Sea, *J. Mar. Syst.,* **20**, 423-442.
Millot C. and A. Monaco, 1984. Deep intense currents and sedimentary transport in the northwestern Mediterranean Sea. Geo-Marine Letters, 4, 1, 13-17.
Millot C., I. Taupier-Letage and M. Benzohra, 1997. Circulation off Algeria inferred from the Médiprod-5 current meters. Deep-Sea Res., 44, 9-10, 1467-1495.
Millot C, Taupier-Letage I, 2005b: Additional evidence of LIW entrainment across the Algerian Basin by mesoscale eddies and not by a permanent westward-flowing vein. *Progr. In Oceanogr.,* 66, 231-250.Millot C, Taupier-Letage, 2005a: Circulation in the Mediterranean Sea. The Handbook of Environmental Chemistry, Volume 5 Part K, Alain Saliot volume Ed., Springer-Verlag, 29-66. DOI: 10.1007/b107143.
Millot C., Fuda, J.L., Candela, J., Tber, Y., 2006: Warming and salting of the Mediterranean outflow due to shifts in dense water formation zones. *Deep Sea Res.,* I, 53, 656-666.
Moisselin J M, 2002 : Les précipitations en France au XXème siècle. *Lettre pigb-pmrc*, **13**, p. 57-62.
Moisselin, J.M. and Schneider, M. and Canellas, C. and Mestre, O., 2002 : Les changements climatiques en France au XX siècle : Etudes des longues séries homogénéisées de données de température et de précipitations. *La Météorologie,* **54**, 33-42.
Moisselin, J.M. and B. Dubuisson, 2006 : Evolution des valeurs extremes de temperature et de precipitations au cours du Xxe siècle en France. *La Météorologie* 38:45-56
Molcard A, Gervasio L, Griffa A, Gasparini GP, Mortier L, Özgökmen TM, 2002: Numerical investigation of the Sicily Channel dynamics: density currents and water mass advection. *J. Marine Sys*., **36 (3-4)**, 219-238.
Molteni F, Buizza R, Palmer TN, Petroliagis T, 1994: The ECMWF Ensemble Prediction System : methodology and validation, *ECMWF Technical Memorandum,* **202,** 56 pp.
Montanari A., 1998: Storm structure variability in historical rainfall data observed in Italy. *Ann. Geophysicae*, **16(2),** 456.
Montginoul M., Rinaudo J.D., Lunet DelajonquièreY., Garin P., Marchal J.P., 2005: Simulating the impact water pricing on household behaviour: the temptation of using untreated groundwater, *Water Policy*, **7**, 523-541
Mora RD, Bouvier C, Neppel L, Niel H, 2005: Regional approach for the estimation of low-frequency distribution of daily rainfall in the Languedoc-Roussillon region, France, Hydrological Sciences Journal, 50 (1),
Moran X., I.Taupier-Letage, E. Vasquez-Dominguez, S. Ruiz, L. Arin, P. Raimbault and M. Estrada, 2001: Physical-biological coupling in the Algerian Basin (SW Mediterranean): influence of mesoscale

instability on the biomass and production of phytoplankton and bacterioplankton. *Deep-Sea Res.* I, 48 (2): 405-437.

Morgenstern, O. and H.C. Davies, 1999, Disruption of an upper-level PV-streamer by orography and cloud-diabatic effects. *Contrib. Atmos. Phys*., **72**,173-186.

Morin, G. and M. Slivitzky, 2002: Impacts des changements climatiques sur le régime hydrologique: le cas de la rivière Moisie, *Revue des Sciences de l'Eau*, **5**, 179-195

Mortier L, 1992 : Les instabilités du Courant Algérien. Ph. D. thesis, University of Aix-Marseille-II, France.

Moulin C, Lambert CE, Dayan U, et al., 1998: Satellite climatology of African dust transport in the Mediterranean atmosphere, *J. Geophys. Res.,* **103 (D11),** 13137-13144

Moussa, R. 1991 : 'Variabilité spatio-temporelle et modélisation hydrologique. Application au bassin du Gardon d'Anduze', PhD dissertation, University of Montpellier II, France, 314 pp.

Moussa R, Bocquillon C. 1996. Criteria for the choice of flood-routing methods in natural channels. *Journal of Hydrology* **186**(1-4) : 1-30.

Moussa R. 1997. Geomorphological transfer function calculated from digital elevation models for distributed hydrological modelling. *Hydrological Processes,* **11**(5), 429-449.

Moussa R, Voltz M, Andrieux P. 2002 : Effects of spatial organization of agricultural management on the hydrological behaviour of farmed catchment during flood events. *Hydrological Processes,* **16**, 393-412.

Moussa R., Chainian N. Bocquillon C. , 2007. Distributed hydrological modelling of a Mediterranean mountainous catchment - Model construction and multi-site validation, J. of Hydrology, doi:10.1016/j.jhydrol.2007.01.028

Moussa R, Chahinian N, Bocquillon, C. 2007. Distributed hydrological modelling of a Mediterranean mountainous catchment - model construction and multi-site validation. *Journal of Hydrology 337*: 37-51 (doi:10.1016/j.jhydrol.2007.01.028).

Mroczowski M, Raper GP, Kuczera G. 1997: The quest for more powerful validation of conceptual catchment models. *Water resources Research,* **30**(10), 2325-2335.

Muller A., Arnaud P., Lang M., Lavabre, J., 2007: Uncertainties in extreme rainfall distribution using a stochastic rainfall model. Hydrological Sciences Journal (submitted).

Muller, A., 2006: Comportement asymptotique de la distribution des pluies extrêmes en France. Doctorat Université Montpellier II, Cemagref Lyon et Aix, 246 p.

N

Nakicenovic N. and R. Swart, 2000: Emissions Scenarios. A Special Report of Working Group II of the Intergovernmental Panel on Climate Change, 570 pp.

Naulet R., Lang M., Ouarda T., Coeur D., Bobée B., Recking A., Moussay D., 2005: Flood frequency analysis on the Ardèche river using French documentary sources from the two last centuries. *Journal of Hydrology,* Special Issue "Applications of palaeoflood hydrology and historical data in flood risk analysis », Guest Editors G. Benito, T.B.M.J. Ouarda and A. Bárdossy , 312, 58-78.

Neal C., Jarvie H.P., Neal M., Love A.J., Hill L., Wickam H., 2005. Water quality of treated sewage effluent in a rural area of the upper Thames basin, southern England, and the impacts of such effluents on riverine phosphorus concentrations. *Journal of Hydrology*, 304: 477-490.

Neppel L., Bouvier C., Vinet F., Desbordes M., 2003 : Sur l'origine de l'augmentation des inondations en région méditerranéenne. *Revue des Sciences de l'Eau*, **16/4**, 475-494.

Neppel L, Bouvier C. 2003. Abattement spatial des precipitations en Languedoc Roussillon. *IAHS Publ*. no. 278, 2003, pp. 276–283.

New M, Hulme M, Jones PD, 2002: A high-resolution data set of surface climate over global land areas. *Climate Res*, **21**, 1-25

Nicholls, R. J. and Hoozemans, F.M.J., 1996: The Mediterranean: vulnerability to coastal implications of climate change. *Ocean & coastal Management,* **31(2-3)**,105-132.

Nicolau J, 2000: Short-range ensemble forecasting, WMO Workshop on use of ensemble prediction, Beijing, 16-20 October 2000, 6 pp. (http://www.wmo.ch/web/www/DPS/Reports/Wshop-EPS_Beijing2000/Proceedings/Introduction.htm)

Nittis K, Lascaratos A, 1998: Diagnostic and prognostic numerical studies of LIW formation, *J. Marine Sys.,* **18**,179-195.

Nixon S., Trentt Z., Marcuello C., Lallana C., 2003: Europe's water : an indicator-based assesment. European Environment Zgency report, 1/2003.

Nuissier, O., V. Ducrocq, D. Ricard, C. Lebeaupin, S. Anquetin, 2007 : A numerical study of three catastrophic precipitating events over Southern France. Part I: Numerical framework and synoptic ingredients, *Q. J. R. Meteorol. Soc*., (revised)

O

Obaton D., C. Millot, G. Chabert D'Hieres and I. Taupier-Letage, 2000: The Algerian Current: comparisons between in situ and laboratory data. *Deep-Sea Res.*, 47: 2159-2190.

Okuyama, Y., 2004: Modeling spatial economic impacts of an earthquake: input-output approaches. *Disaster Prevention and Management* ,**13 (4),** 297-306.

Olioso, A., I. Braud, A. Chanzy, J. Demarty, Y. Ducros, J. C. Gaudu, E. Gonzalez-Sosa, E. Lewan, O. Marloie, C. Ottlé, L. Prévot, J. L. Thony, H. Autret, O. Bethenot, J. M. Bonnefond, N. Bruguier, J. P. Buis, J. C. Calvet, H. Chauki, R. Goujet, R. Jongschaap, Y. Kerr, C. King, J. P. Lagouarde, J. P. Laurent, P. Lecharpentier, J. Mc Anneney, S. Moulin, E. Rybio, M. Weiss, and J. P. Wigneron. 2002. Monitoring energy and mass transfer during the Alpilles-ReSeDA experiment. Agronomie 22:597-610.

Olioso, A., Inoue, Y., Ortega-Farias, S., Demarty, J., Wigneron, J.-P., Braud, I., Jacob, F., Lecharpentier, P., Ottlé, C., Calvet, J.-C., Brisson, N., 2005. Future directions for advanced evapotranspiration modeling: Assimilation of remote sensing data into crop simulation models and SVAT models. Irrigation and Drainage Systems, 19(34), 355-376, 2005.

Ovchinnikov I., Y. Popov and I. Gertman, 1990. Investigation of the formation of deep waters in the eastern Mediterranean sea during the 36^{th} cruise of the R/V Ya. Oceanology, 30, 6, 769-771

Özsoy E, Hecht A, Ünlüata Ü, Brenner S, Sur HI, Bishop J, Latif MA, Rozentraub Z, Oguz Y, 1993: A synthesis of Levantine basin circulation and hydrography,1985-1990, *Deep-Sea Research II,* **40,**1075-1119.

Özsoy E, Hecht A, Ünlüata Ü (1989) Circulation and hydrography of the Levantine Basin-Results of POEM co-ordinated experiments 1985-1986, *Progress in Oceanography*, **22**, 125-170.

P

Pace G, di Sarra A, Meloni D, et al., 2006: Aerosol optical properties at Lampedusa (Central Mediterranean). 1. Influence of transport and identification of different aerosol types, *Atm. Chem. And Phys*., **6**, 697-713

Pan Z., E. Takle, M. Segal and R. Turner, 1996, Influences of Model Parameterization Schemes on the Response of Rainfall to Soil Moisture in the Central United States, *Mon. Wea. Rev*., **124,** 1786—1802.

Pan, M., et al. 2003. Snow process modeling in the North American Land Data Assimilation System (NLDAS): 2. Evaluation of model simulated snow water equivalent, J. Geophys. Res., 108(D22), 8850, doi:10.1029/2003JD003994.

Pardé, M., 1961: Sur la puissance des crues en diverses parties du monde. *Geographica*, **8,** 293.

Pellarin, T., G. Delrieu, G. M. Saulnier, H. Andrieu, B. Vignal, and J. D. Creutin, 2002: Hydrologic visibility of weather radar systems operating in mountainous regions: Case study for the Ardèche catchment (France). Journal of Hydrometeorology, **3,** 539-555.

Pellenq, J., Kalma, J., Boulet, G., Saulnier, G.-M., Wooldridge, S., Kerr, Y., Chehbouni, A., 2003. A disaggregation scheme for soil moisture based on topography and soil depth. Journal of Hydrology, 276, 112-127.

Pellenq, J., Boulet, G., 2004. A methodology to test the pertinence of remote-sensing data assimilation into vegetation models for water and energy exchange at the land surface. Agronomy for Sustainable Development, 24, 197-204.

Peyrille, P., and J-P. Lafore, 2006: An idealized two-dimensional framework to study the West African monsoon, Part II: role of large scale forcing and characterization of the diurnal cycle. J. Atm. Sci., in press

Perrin C, Michel C, Andréassian V. 2003: Improvement of a parsimonious model for streamflow simulation. *J. Hydrology*, **279**(1-4), 275-289.

Petterssen, S., 1956: Weather analysis and forecasting. McGraw-Hill, New-York, 428p.

Petit R.J., Brewer, S., Bordács, S., Burg, K., Cheddadi, R., Coart, E., Cottrell, J., Csaikl, U.M., Deans, J.D., Fineschi, S., Finkeldey, R., Goicoechea, P.G., Jensen, J.S., König, A.O., Lowe, A.J., Madsen, S.F., Mátyás, G., Munro, R.C., Oledska, I., Popescu, F., Slade, D., Tabbener, H., van Dam, B., Ziegenhagen, B., de Beaulieu, J.-L., Kremer, A., 2002: Identification of refugia and postglacial colonisation routes of European white oaks based on chloroplast DNA and fossil pollen evidence. *Forest Ecology and Management*, **156 (1-3),** 49-74.

Petrenko A, Leredde Y, Marsaleix P, 2005: Circulation in a stratified and wind-forced Gulf of Lions, NW Mediterranean Sea: in situ and modeling data, *Continental Shelf Research*, **25**, 7-27.

Pichevin T, Nof D, 1996: The eddy cannon, *Deep-Sea Research*, **43(9),**1475-1507.

Pilgrim, D.H., Chapman, T.G., Doran, D.G., 1988: Problems of rainfall-runoff modelling in arid and semiarid regions. *Hydrological Sci. J.,* **33,** 379-400.

Pinardi N, Navarra A, 1993: Baroclinic wind adjustment processes in the Mediterranean Sea, *Deep-Sea Research II*, **40(6),** 1299-1326.

Pinault, J.-L., V. Plagnes, L. Aquilina, M. Bakalowicz, 2001: Inverse modeling of the hydrological and the hydrochemical behavior of hydrosystems: Characterization of karst system functioning, Water Resour. Res., 37(8), doi:10.1029/2001WR900018.

Pinault J.-L., N. Doerfliger, B. Ladouche, M. Bakalowicz, 2004: Characterizing a coastal karst aquifer using an inverse modeling approach: The saline springs of Thau, southern France, Water Resour. Res., **40**, W08501, doi:10.1029/2003WR002553.

Piñol, J., Lledó, M.J., Escarré, A., 1991: Hydrological balance of two Mediterranean forested catchments (Prades, northeast Spain). *Hydrological Sci. J.,* **36 (2**), 95-107.

Piñol, J., Ávila, A., Rodà, F., 1992 : The seasonal variation of streamwater chemistry in three forested Mediterranean catchments. *J. Hydrology*,**140,** 119-141.

Pinto J. G., M. Klawa, U. Ulbrich, R. Rudari, and P. Speth, 2001: Extreme precipitation events over southwestern Italy and their relationship with tropical-extratropical interactions over the Atlantic Mediterranean storms. Proc. Third Plinius Conf., Baja Sardinia, Italy, European Geophysical Society, GNDCI Publication 2560, 327-332.

Pinty J-P, Jabouille P, 1998: A mixed-phase cloud parameterization for use in a mesoscale non-hydrostatic model: simulations of a squall line and of orographic precipitation, In Conf. on Cloud Physics, Everett, WA. Amererican Meteorological Society, 217-220.

Pytharoulis I., G. C. Craig and S. P. Ballard, 2000 : The hurricane-like Mediterranean cyclone of January 1995. *Meteor. Applications*, **7**, 261-279.

Portney, P. R. and Weyant, J.P., 1999: Discounting and Intergenerational Equity, Resources for the Future, 202 pp.

Poulos, S.E and P.G. Drakopoulos, 2001: A reassessment of the Mediterranean river run-off, Rapp. Comm. Int. Mer. Medit. 36, 76.

Prentice, I. C., J. Guiot, S. P. Harrison, 1992: Mediterranean vegetation, lake levels and paleoclimate at the Last Glacial Maximum, *Nature*, **360**, 658-660.

Prévot, L., Chauki, H., Troufleau, D., Weiss, M., Baret F., Brisson, N., 2003. Assimilating optical and radar data into the STICS crop model for wheat. Agronomy for Sustainable Development, 23, 297-303.

Price, C., L. Stone, B. Rajagopalan and P. Alpert, 1998: A possible link between El Nino and precipitation in Israel, Geophys. Res. Lett., 25, 3963-3966. Price, J.F., Baringer, M., 1994. Outflows and deep water production by marginal seas. *Prog. Oceanog.*, 33, 161-200

Prieur, L., 2002. Physical historical data in the Ligurian Sea from the Observatory of Villefranche sur mer. In '*Tracking long term hydrological change in the Mediterranean Sea'*, CIESM Workshop Monographs n° 16, Monaco –22-24th, April 2002.

Puillat I., I. Taupier-Letage and C. Millot. Algerian eddies lifetimes can near 3 years, 2002. J. Mar. Sys., 31, 4, 245-259.

Q

Quereda Sala J, Gilolcina A, Perez Cuevas A, S3, Olcina Cantos J, , Rico Amoros A, Monton Chiva QR, 2000. Climatic warming In The Spanish Mediterranean: Natural Trend Or Urban Effect(Cicyt Project, National Climate Plan). *Climatic Change,* **46**, 473–483.

Quintana-Seguí P., P. Le Moigne, Y. Durand, E. Martin, F. Habets, M. Baillon, L. Franchisteguy, S. Morel, J. Noilhan The SAFRAN atmospheric analysis. Description and validation. Accepted by Journal of applied meteorology.

Qiu S., Mc Comb A. J., 2002. Interrelations between iron extractability and phosphate sorption in reflooded air-dried sediments. *Hydrobiologia*, 472: 39-44.

R

Rabier F., 2006: Overview of data assimilation developments in Numerical Weather Prediction Centres, Submitted to Q. J. R. Meteorol. Soc., Special Issue

Rabiet, M., Togola, A., Brissaud, F., Seidel, J.L., Budzinski H., Elbaz-Poulichet, F., 2006. Consequence of wastewater disposal on the contamination of the water ressource by pharmaceuticals in a Mediterranean basin. *Env. Sci Technol*., **40**, 5282-5288.

Raimbault, P., Rodier, M., Taupier-Letage I., 1988: Size fraction of phytoplankton in the Ligurian Sea and the Algerian Basin: size distribution versus total concentration. *Mar. Microb. Food Webs*, 3(1):1-7.

Raimbault, P., Rodier M., Taupier-Letage, I., 1988 : Size fraction of phytoplankton in the Ligurian Sea and the Algerian Basin: size distribution versus total concentration. *Mar. Microb. Food Webs*, 3(1):1-7.

Rambal, S. 2002. How do Mediterranean trees face the unpredictability of water resources?, *La Houille Blanche*- Revue Internationale de l'Eau, 3, 33-37.

Reale, O., Feudale, L., Turato, B., 2001 : Evaporative moisture sources during a sequence of floods in the Mediterranean region, *Geophys. Res. Lett*., **28**, 2085-2088.
Reiter, E.R., 1975: Handbook for Forecasters in the MediterraneanTech. Pap. N05-75, 344pp. Environmental Prediction Research Facility, Naval Postgraduate School, Monterey, CA 93940.
Refsgaard JC. 1997:Parameterisation, calibration and validation of distributed hydrological models. *J. Hydrology,* **198,** 69-97.
Renard, B. - 2006. Détection et prise en compte d'éventuels impacts du changement climatique sur les extrêmes hydrologiques en France. Doctorat INP Grenoble, Cemagref Lyon. 361 p.
Renard, B., Lang, M., Bois, P., Dupeyrat, A., Mestre, O., Niel, H., Gaillard, J., Laurent, C., Neppel, L., Sauquet, E. - 2006. Evolution des extrêmes hydrométriques en France à partir de données observées. *La Houille Blanche*, vol. 6, p. 48 - 54
Reynaud T, LeGrand P, Mercier H, Barnier B, 1998: A new analysis of hydrographic data in the Atlantic and its application to an inverse modelling study, *International WOCE Newsletter*, **32**, 29-31.
Rhein M, Send U, Klein B, Krahmann G, 1999: Interbasin deep-water exchange in the western Mediterranean, *J. Geophys. Res*., **104(C10),** 23495-23508.
Riandey V., Champalbert G., Carlotti F., Taupier-Letage I., and Thibault-Botha D. 2005: Mesoscale variability of the zooplankton distribution related to the hydrodynamic features of the Algerian Basin (Western Mediterranean Sea). *Deep Sea Res.* I 52 (2005), 2029-2048.
Ricard, D., 2002 : Initialisation et assimilation de données à méso –échelle pour la prévision à haute résolution des pluies intenses de la région Cévennes – Vivarais. PhD (in French) Université Paul Sabatier – Toulouse III.
Ricard, D., 2005: Modélisation à haute resolution des pluies intenses dans les Cévennes: le système convectif des 13-14 octobre 1995. *La Météorologie*, **48**, 28-38.
Richard, E., S. Cosma, P. Tabary, J.-P. Pinty and M. Hagen, 2003, High-resolution numerical simulations of the convective system observed in the Lago Maggiore area on 17 september 1999 (MAP IOP 2a), Q. *J. R. Meteorol. Soc*., **129**, 543-564.
Ridame C., Guieu C. & Loye-Pilot M-D.,1999: Trend in total atmospheric deposition fluxes of aluminium, iron and trace metals in the north-western Mediterranean, over the past decade (1985-1997), *J. Geophys. Res*., **104**, N°D23, 30127-30138.
Riosalido, R. , 1990: Chararcterization of mesoscale convective systems by satellite pictures during PREVIMET MEDITERRANEO-89. Proc. Segundo Simposio National de Prediction, Madrid, Spain,Instituto Nacional de METEOROLOGIA, 135-148.
Risk Management Solutions, 2005: Hurricane Katrina: Profile of a Super Cat: Lessons and Implications for Catastrophe Risk Management
Rivrain, C. , 1997 : Les épisodes orageux à précipitations extrêmes sur les régions Méditerranéennes de la France. *Phénomènes remarquables* N°4, publication of Météo-France.
Rixen M, Beckers JM, Levitus S, Antonov J, Boyer T, Maillard C, Fichaut M, Balopoulos E, Iona S, Dooley H, Garcia MJ, Manca B, Giorgetti A, Manzella G, Mikhailov N, Pinardi N, Zavaratelli M, 2005: The Western Mediterranean Deep Water: A proxy for climate change, *Geophys. Res. Let*., **32**, LI12208, doi:10.1029/2005 GL022702.
Robinson AR, Golnaraghi M, Leslie WG, Artegiani A, Hecht A, Lazzoni E, Michelato E, Sansone E, Theocharis A, Ünlüata Ü, 1991: The eastern Mediterranean general circulation: features, structure and variability, *Dynamics of Atmospheres and Oceans*, **15**, 215-240.
Robinson AR, Sellschopp J, Warn-Varnas A, Leslie WG, Lozano CJ, Haley PJJr, Anderson, LA, Lermusiaux PFJ, 1999: The Atlantic Ionian Stream. *J. Marine Sys*., **20**, 129-156.
Robinson, A.R., and M. Golnaraghi, 1993. Circulation and dynamics of the Eastern Mediterranean Sea; quasi-synoptic data-driven simulations. Deep Sea Res., 40 (6), 1207-1246.
Robinson, D. A., A. Binley, N. Crook, F. D. Day-Lewis, T. P. A. Ferré, V. J. S. Graush, R. Knight, M. Knoll, V. Lakshmi, R. Miller, J. Nyquist, L. Pellerin, K. Singha, and L. Slater, 2006: A vision for geophysics instrumentation in watershed hydrologic research, 52 pp.
Rodier, J. A. and M. Roche, 1984: World catalogue of maximum observed floods. IAHS Publication N. 143, *IAHS* Press.
Rodo X., Baert E., Comin F.A., 1997: Variations in seasonal rainfall in Southern Europe during the present century: relationships with the NAO and the ENSO. *Clim. Dyn*., **18**, 203-217.
Rodo X., 2001 : Reversal of three global atmospheric fields linking changes in SST anomalies in the Pacific, Atlantic and Indian oceans at tropical latitudes and midlatitudes. *Clim. Dyn*., **18**, 203-217
Rodriguez-Fonseca, B., and M. De Castro, 2002: On the connection between winter anomalous precipitation in the Iberian Peninsula and North West Africa and the summer subtropical Atlantic sea surface temperature. *Geophys. Res. Let.*, **29**, 10.1029/2001GL014421.

Rodwell, M. J., and B. J. Hoskins, 1996: Monsoons and the dynamics of deserts, *Q. J. Roy Met. Soc*., **122**, 1385-1404.

Roether W, Manca B, Klein B, Bregant D, Georgopoulos D, Beitzel V, Kovacevic V, Luchetta A, 1996: Recent changes in the eastern Mediterranean deep waters, *Science*, **271**, 333-335.

Roether W, Klein B, Beitzel V, Manca B, 1998: Property distributions and transient-tracer ages in Levantine Intermediate Water in the Eastern Mediterranean, *J. Marine Sys.,* **18**, 71-87.

Romero, R., Doswell, C.A., and Ramis, C., 2000: Mesoscale numerical study of two cases of long-lived quasi-stationary convective systems over Eastern Spain. *Mon. Wea. Rev*., **128,** 3731-3752.

Rose, A., Liao, S.-Y., 2005. Modeling regional economic resilience to disasters: a computable general equilibrium analysis of water service disruptions. *J. Regional Sci.,* **45 (1),** 75-112.

Rosenberg, N. J., D. J. Epstein, D. Wang, L. Vail, R. Srinivasan and J. G. Arnold., 1999: Possible Impacts of Global Warming on the Hydrology of the Ogallala Aquifer Region, *Clim.Change,* **42(4),** 677-692.

Rotunno, R., and R. Ferretti, 2001: Orographic effects on rainfall in MAP cases IOP 2b and IOP 8. *Q. J. R. Meteorol. Soc.*, **129,** 373-390.

Roussenov V, Stanev E, Artale V, Pinardi N, 1995: A seasonal model of the Mediterranean Sea general circulation, *J. Geophys. Res*., **100(C7),**13515-13538.

Rowell, D.P. 2003: The Impact of Mediterranean SSTs on the Sahelian Rainfall Season., *J. Clim.,* **16**, 849-862

Rowell, D., 2005: A scenario of European climate change for the late twenty-first century: seasonal means and interannual variability, *Clim.Dyn*., **25(7-8),** 837-849, 10.1007/s00382-005-0068-6

Roy, L., R. Leconte, F. P. Brisstte and C. Marche, 2001: The impact of climate change on seasonal floods of a southern Quebec River Basin, *Hydrol.Process.,* **15(16),** 3167-3179.

Rudari, R., D. Entekhabi, G. Roth, 2004: Terrain and multiple-scale interactions as factors in generating extreme precipitation events. *J. Hydrometeorology*, **5**, 390-404.

Ruiz S., J. Font, M.Emelianov, J. Isern-Fontanet, C. Millot and I. Taupier-Letage, 2002. Deep structure of an open sea eddy in the Algerian Basin. J. Mar. Sys., 33-34, 179-195.

S

Sabatier, P., Dezileau, L., Condomines, M., Briqueu, L., Colin, C., Bouchette, F., Le Duff, M. and Blanchemanche P., 2007: Reconstitution of paleostorms events about 300 years ago, recorded in a coastal lagoon (Hérault, South of France). *Marine Geology*, submitted.

Sala, O. E., Chapin, III F.S., Armesto ,J. J., Berlow, E., Bloomfield, J., Dirzo, R., Huber-Sanwald, E., Huenneke, L. F., Jackson, R. B., Kinzig, A., Leemans, R., Lodge, D. M., Mooney, H. A., Oesterheld, M., Leroy Poff, N., Sykes, M. T., Walker, B. H., Walker, M., & Wall D. H., 2000: Global biodiversity scenarios for the year 2100. *Science*, 287, 1770-1774.

Salas J., C. Millot, J. Font and E. García-Ladona, 2002. Analysis of mesoscale phenomena in the Algerian Basin observed with drifting buoys and infrared images. Deep-Sea Res., 49, 2, 245-266.

Salat, J. and Pascual, J., 2002: The oceanographic and meteorological station at l'Estartit (NW Mediterranean). In: Tracking long-term hydrological change in the Mediterranean Sea (ed: F. Briand). CIESM Workshop series 16, 134p.

Salinger M J, Stigter CJ, Das HP, 2000: Agrometeorological adaptation strategies to increasing climate variability and climate change. *Agricultural and Forest Meteorology*, **103**, 167–184

Sammari, C., C. Millot, I. Taupier-Letage, A. Stefani and M. Brahim, 1999: Hydrological characteristics in the Tunisia-Sicily-Sardinia area during spring 1995. *Deep-Sea Res.,* 46, 1671-1703.

Sanchez-Goñi, M. F., Turon, J-L., Eynaud, F. & S. Gendreau, 2000: European climatic response to millennial-scale changes in the atmosphere-ocean system during the last glacial period. *Quaternary Research*, **54**, 394-403.

Sannino G, Bargagli A, Artale V, 2002: Numerical modelling of the mean exchange through the Strait of Gibraltar. *J. Geophys. Res*., **107(C9),** 1-24.

Sannino, G., Carillo, A. and V. Artale. 2007. Threelayers view of transport and hydroulics in the Strait of Gibraltar: A 3D model study. J. Geophys. Res., (C3), C03010, doi 10.1029/2006JC003717.

Sheffer N. A., Enzel Y., Benito G., Grodek T., Poart N., Lang M., Naulet R., Cœur D., 2003. Paleofloods and historical floods of the Ardèche river, France. Water Resources Research, 39 (12), 1376, 13p.

Scheidereit, M. And C. Schär, 2000, Idealised numericcal experiments of Alpine Flow regimes and southside precipitation events. *Meteorol. Atmos. Phys*., **72**, 233-250.

Schott F. and K. Leaman, 1991. Observations with moored acoustic Doppler current profilers in the convection regime in the Golfe du Lion. J. Phys. Oceanogr., 21, 558-574

Schott F, Visbeck M, Send U, Fischer J, Stramma L, Desaubies Y, 1996: Observations of deep convection in the Gulf of Lions, Northern Mediterranean, during the winter of 1991/1992, *J. Phys. Ocean*., 505-524.

Schuurmans, J.M., Troch, P.A., Veldhuizen, A.A., Bastiaanssen, W.G.M. & Bierkens, M.F.P. 2003. Assimilation of remotely sensed latent heat flux in a distributed hydrological model. Advances in Water Resources 26: 151-159.

Schumacher, R.S., and Johnson, R.H., 2006: Characteristics of U.S. extreme rain events during 1999-2003. *Weather and Forecasting,* **21**, 69-85.

Sciare J, Oikonomou K, Cachier H, et al., 2005:Aerosol mass closure and reconstruction of the light scattering coefficient over the Eastern Mediterranean Sea during the MINOS campaign, *Atmos. Chem. And Phys*., **5,** 2253-2265

Scofield, R.A., 1985, Satellite convective categories associated with heavy precipitation. In Sixth Conf. On Hydrometeorology, Indianapolis, Amer. Meteor. Soc. ,42-51

Send U, Font J, Krahmann G, Millot C, Rhein M, Tintoré J, 1999: Recent advances in observing the physical oceanography of the western Mediterranean Sea, *Progress in Oceanography,* **44,** 37-64.

Servat, E., Najem, W., Leduc, C., Shakeel, A., 2003: Hydrology of Mediterranean and semiarid regions. Publication AISH 278, 498 p.

Sheffield, J., et al. 2003. Snow process modeling in the North American Land Data Assimilation System (NLDAS): 1. Evaluation of model-simulated snow cover extent, J. Geophys. Res., 108(D22), 8849, doi:10.1029/2002JD003274.

Siccardi, F., 1996 : Rainstorm hazards and related disasters in the Western Mediterranean region, *Remote Sens. Rev*., **14**, 5-21.

Sivapalan, M. 2003. Process complexity at hillslope scale, process simplicity at the watershed scale: is there a connection? Hydrological Processes 17:1037-1041.

Skliris, N. and Lascaratos, A., 2004: Impacts of the Nile River damming on the thermohaline circulation and water mass characteristics of the Mediterranean Sea*. J Mar. Syst.,* **52**, 121-143

Skirlis, N. Sofianos, S. and Lascaratos, A., 2007. Hydrological changes in the Mediterranean Sea in relation to changes in the freshwater budget: A numerical modelling*. J. Mar. Systems***, 65,** 400-416

Slater, A.G. and Clark, M.P., 2006. Snow data assimilation via an ensemble Kalman filter. Journal of Hydrometeorology, 7 (3): 478-493.

Somot S., 2005 : Modélisation climatique du bassin méditerranéen: variabilité et scénarios de changement climatique. *Ph-D thesis. Université Paul Sabatier,* Toulouse, 333 pp.

Somot S., F. Sevault, M. Déqué, 2006: Is the Mediterranean Sea Thermohaline Circulation Stable in a Climate Change Scenario? Climate Dynamics

Somot, S. and Sevault, F. and Déqué, M., 2006: Transient climate change scenario simulation of the Mediterranean Sea for the 21st century using a high-resolution ocean circulation model. *Clim Dyn,* 27(7-8), 851-879

Somot, S. and Sevault, F. and Déqué, M. and Crépon, M., 2007: 21st century climate change scenario for the Mediterranean using a coupled Atmosphere-Ocean regional Climate Model. *Global and Planetary Change* (submitted)

Sorriso-Valvo, M., Bryan, R.B., Yair, A., Iovino, F., Antronico, L., 1995. Impact of afforestation on hydrological response and sediment prodction in a small Calabrian catchment. *Catena*, **25**, 89-104.

Sotillo, M.G. and Ratsimandresy, A. W. and Carretero, J.C. and Bentamy, A. and Valero, F. and Gonzàlez-Rouco, F.et al, 2005: A high-resolution 44-year atmospheric hindcast for the Mediterranean Basin: contribution to the regional improvement of global reanalysis *Clim Dyn,* **25(2-3),** 219-236

Sparnocchia S, Gasparini GP, Astraldi M, Borghini M, Pistek P, 1999: Dynamics and mixing of the Eastern Mediterranean outflow in the Tyrrhenian basin, *J. Marine Sys*., **20(1-4),** 301-317.

Sparnocchia, S., Manzella, G.M.R., La Violette, P.E., 1994: The interannual and seasonal variability of the MAW and LIW core properties in the Western Mediterranean Sea. *Coast. estuar. Stud*., **46**, 177-194.

Speranza, A., A. Buzzi, A. Trevisan, and P. Malguzzi, 1985: A theory of deep cyclogenesis in the lee of the Alps. Part I : modifications of baroclinic instability by localized topography, *J. Atmos. Sci*., **42,** 1521-1535.

Stanev EV, Le Traon P-Y, Peneva EL, 2000: Sea level variations and their dependency on meteorological and hydrological forcing: Analysis of altimeter and surface data for the Black Sea, *J. Geophys. Res*., **76(24),** 5877-5892.

Stansfield K, Gasparini GP, Smeed DA (2003) High-resolution observations of the path of the overflow from the Sicily Strait, *Deep-Sea Research I* , **50(9),** 1129-1149.

Stansfield K, Smeed DA, Gasparini GP, 2001: Deep-Sea, high resolution, hydrography and current measurement using an autonomous underwater vehicle: The overflow from the Strait of Sicily, *J. Geophys. Res*., **28(13),** 2645-2648.

Stein, J., E. Richard, J.P. Lafore, J.P. Pinty, N. Asencio, and S. Cosma, 2000: High-resolution non-hydrostatic simulations of flash-flood episodes with grid-nesting and ice-phase, *Meteor. Atmos. Phys*., **72**, 203-221.

Stemmann L., L. Prieur, I. Taupier-Letage, M. Picheral, L. Guidi and G. Gorsky, 2006: Effect of frontal processes on marine aggregate dynamics and fluxes: an interannual study in a permanent geostrophic front (NW Mediterranean). *Journal of Marine Syst., in press*

Suc, JP. 1984. Origin and evolution of the Mediterranean vegetation and climate in Europe. *Nature,* **307**, 429-432.

Sultan B., Janicot S., Drobinski P., 2007: Characterization of the Diurnal Cycle of the West African Monsoon around the Monsoon Onset. *J. Climate*, in press

Svenning, J.C., 2003: Deterministic Plio-Pleistocene extinctions in the European cool-temperate tree flora. *Ecological Letters*, **6**, 646-653.

Swallow JC, Gaston GF, 1973: The preconditioning phase of MEDOC 1969-I, *Deep-Sea Research*, **20**, 429-448.

T

Tabary, P., 2007: The new French operational radar rainfall product: Part I, methodology. *Weather and forecasting*, **22,** 393-408.

Tabary, P., J. Desplats, K. Dokhac, F. Eideliman, C. Guéguen, and J.-C. Heinrich, 2007: The new French operational radar rainfall product. *Weather and forecasting*, **22,** 409-427.

Tapley, B. D., Bettadpur S., Watkins, M. M., and Reigber C., 2004: The Gravity Recovery and Climate Experiment: Mission Overview and Early Results, *Geophys. Res. Lett*., **31**, L09607, doi:10.1029/2004GL019920.

Taupier-Letage I. and C. Millot, 1986. General hydrodynamical features in the Ligurian Sea inferred from the DYOME experiment. Oceanol. Acta, 9, 2, 119-131.

Taupier-Letage I. and C. Millot, 1988. Surface circulation in the Algerian Basin during 1984. Oceanol. Acta, sp. n° 9, 119-131.

Taupier-Letage, I., I. Puillat, P.Raimbault and C.Millot, 2003: Biological response to mesoscale eddies in the Algerian Basin. *J. Geophys. Res.,* VOL. 108, NO. C8, 3245-3267, doi:10.1029/1999JC000117

Tennekes, H., 1978: Turbulent flow in two and three dimensions. *Bull. Amer. Meteor. Soc*., **59**, 22-28.

Testor P, Gascard JC, 2003: Large scale spreading of deep waters in the western Mediterranean Sea by sub-mesoscale coherent eddies, *J. Phys. Ocean.,* **33**, 75-87.

Testor P, Gascard J-C, 2005: Observation of a Levantine intermediate water eddy in the Algerian basin, Progress in Oceanography, REF.

Testor P, Gascard JC, Millot C, Taupier-Letage I, 2005: The mean circulation of the southwestern Mediterranean Sea: algerian gyres. J. Geophys. Res., 110, C11017, doi:10.1029/2004JC002861.

The POEM Group, 1992: General circulation of the Eastern Mediterranean, Earth Science Reviews 32:285-30.

The THETIS Group, 1994: Open-ocean deep convection explored in the Mediterranean. EOS Transactions of the American Geophysical Union 75(19): 217-221.

Theocharis A, Klein B, Nittis K, Roether W, 2002: Evolution and status of the Eastern Mediterranean Transient (1997-1999), *J. Marine Sys*., **33-34**, 91-116.

Theocharis A, Balopoulos E, Kioroglou S, Kontoyiannis H, Iona A (1999) A synthesis of the circulation and hydrography of the South Aegean Sea and the Straits of the Cretan Arc (March 1994 – January 1995), *Progress in Oceanography*, **44**,469-509.

Thornes, J.B., Shao, J.X., Diaz, E., Roldan, A., McMahon, M., Hawkes, J.C., 1996: Testing the MEDALUS hillslope model. *Catena*, **26**, 137-160.

Thornes, J.B., Wainwright, J. 2003. Environmental Issues in the Mediterranean. Environmental Studies, Routledge (UK), 368 p.

Thorpe, R.B. and G.R. Bigg, 2000: Modelling the sensitivity of Mediterranean Outflow to anthropogenically forced climate change, *Clim. Dyn*. **16**, 355-368.

Todini E. 1996: The Arno rainfall-runoff model. *Journal of Hydrology,* 175, 339-382

Torrecilla N.J., Galve J.P., Zaera L.G., Retamar J.F., Alvarez A.N.A., 2005. Nutrient sources and dynamics in a Mediterranean fluvial regime (Ebro river, NE Spain) and their implications for water management. *Journal of Hydrology*, 304: 166-182.

Tournoud, MG, Perrin JL, Gimbert F, Picot B, 2005: Spatial evolution of nitrogen and phosphorus loads along a small Mediterranean river: implication of bed sediments. *Hydrological Processes*, **19**, 3581-3592.

Trigo, I.F., T.D. Trevor, and G. R. Bigg, 2000: Decline in the Mediterranean rainfall caused by weakening of Mediterranean cyclones, *Geophys. Res. Lett*., **27**, 2913-1916.

Trigo R. M., I. F. Trigo, C. DaCamara, T. J. Osborn, 2004: Climate impact on the European winter blocking episodes from the NCEP/NCAR reanalyses, *Clim. Dyn*., **23**, 17-28, doi :10.1007/s00382-004-0410-4.

Trigo, I. F., G. R. Bigg and T. D. Davies, 2002: Climatology of cyclogenesis mechanisms in the Mediterranean. *Mon. Wea. Rev*., **130(3),** 549-569.

Tripathi, S., Srinivas, V.V., Nanjundiah, R.S., 2006: Downscaling of precipitation for climate change scenarios: A support vector machine approach, Journal of Hydrology, 330, 621– 640.

Troch, P. A., C. Paniconi, and E. E. van Loon. 2003. Hillslope-storage Bossinesq model for subsurface flow and variable source areas along complex hillslopes: 1. Formulation and characteristic response. Water Resources Research 39:1316, doi:1310.1029/2002WR001728.

Tropeano, D., 1983: Soil erosion on vineyards in the tertiary piedmontese basin (northern Italy). Studies on experimental areas. Catena supplement 4, "Rainfall simulation, Runodd and Soil Erosion, edited by J. de Ploey, Braunschweig, 115-127.

Tsimplis MN, Bryden HC, 2000: Estimation of the transports through the Strait of Gibraltar, *Deep-Sea Research I,* **47**,:2219-2242.

Tsimplis, M.N., Zervakis, V., Josey, S.A., Peneva, E.L., et al., 2006: Changes in the oceanography of the Mediterranean sea and their link to climate variability. *In: Mediterranean Climate Variability*, Lionello P., Malanotte-Rizzoli P. and R. Boscolo *eds*., Elsevier; Chap. 4, pp226-282.

Tsimplis, M., Marcos, M., Somot, S., 2007. 21st century Mediterranean sea level rise. Regional model predictions. *Global and Planetary Change* (in revision).

Turato, B., O. Reale and F. Siccardi, 2004: Water vapour sources of the October 2000 Piemont Flood. *J. Hydrometeorology*, 5, 693-712.

Tzedakis, P.C., J. F. McManus, H. Hooghiemstra, D. W. Oppo, and T. A. Wijmstra, 2003: Comparison of changes in vegetation in northeast Greece with records of climate variability on orbital and suborbital frequencies over the last 450,000 years. *Earth and Planetary Science Letters*, **21**2, 197-212.

Tziperman, E., Speer, K., 1994. A study of water mass transformation in the Mediterranean Sea : analysis of climatological data and a simple three-box model*, Dyn. Atm. Oceans*, **21**, 53–82.

U

Ulbrich U., W. May, P. Lionello, J.G. Pinto, S. Somot, 2006: The Mediterranean Climate Change Under Global Warming (chapter 8). *In: Mediterranean Climate Variability, Lionello, P. and Malanotte, P. and Boscolo, R.(eds), Elsevier B.V,* pp. 399-415

V

VanderKwaak, J. E., and K. Loague. 2001. Hydrologic-response simulations for the R-5 catchment with a comprehensive physics-based model. Water Resources Research 37:999-1013.

Van Haren H., C. Millot and I. Taupier-Letage, 2006: Fast deep sinking in Mediterranean eddies. Geophys. Res. Let., 33, L04606, doi: 10.1029/2005GL025367. Vargas-Yáñez M, Plaza F, García-Lafuente J, Sarhan T, Vargas JM, Vélez-Belchi P (2002) About the seasonal variability of the Alboran Sea circulation. *J. Marine Sys.,* **35(3-4),** 229-248.

Verhoef, W., Bach, H., 2003. Remote sensing data assimilation using coupled radiative transfer models. Physics and Chemistry of the Earth 28: 3-13.

Vignudelli S, Gasparini G-P, Astraldi M, Schiano ME, 1999: A possible influence of the North Atlantic Oscillation on the circulation of the Western Mediterranean Sea, *Geophys. Res. Let*., **26**, 623-626.

Voltz M, Andrieux P, 1995 : Etude des flux d'eau et de polluants en milieu méditerranéen viticole: le programme Allegro-Roujan. Bilan des travaux 1992 et 1993 AIP "Valorisation et Protection des ressources en eau", INRA Montpellier, 32 p.

Voltz M, Albergel J., 2002: OMERE: Observatoire Méditerranéen de l'Environnement Rural et de l'Eau. Impact des actions anthropiques sur les transferts de masse dans les hydrosystèmes méditerranéens ruraux. Proposition d'Observatoire deRecherches en Environnement, 18 p.

Vörösmarty CJ, Fekete BM, Tucker BA, 1996: Global river discharge database. RivDIS, Vol. 0 to 7, International Hydrological Programme, Global Hydrological Archive and Analysis Systems, United Nations Educational Scientific and Cultural Organization, Paris, France.

Voss, R., W. May and E. Roeckner, 2002: Enhanced resolution modelling study on anthropogenic climate change: changes in extremes of the hydrological cycle, *Int.J.Climatol*., **22(7),** 755-777. doi:10.1002/joc.757.

Vrugt, J. A., H. V. Gupta, L. A. Bastidas, W. Bouten, and S. Sorooshian. 2003. Effective and efficient algorithm for multiobjective optimization of hydrologic models. Water Resources Research **39**:1214, doi: 1210.1029/2002WR001746.

W

Wainwright, J., 1996: Infiltration, runoff and erosion characteristics of agricultural land in extreme storm events, SE France. *Catena,* **26**, 27-47.

Walin, G., 1982. On the relation between sea-surface heat flow and the thermal circulation in the ocean, Tellus, 34, 187-195.

Wang, G., 2005: Agricultural drought in a future climate: results from 15 global climate models participating in the IPCC 4th assessment, *Clim.Dyn.,* **25(7 - 8),** 739-753. DOI:10.1007/s00382-005-0057-9

Wang, X, Melesse, AM., 2005. Evaluation of the swat model's snowmelt hydrology in a northwestern Minnesota watershed Transaction of the American Society of Agricultural Engineers, 48 (4): 1359-1376.

Weiss, M., Baret, F., Smith, G. J., Jonckheere, I., Coppin, P., 2004. Review of methods for in situ leaf area index (LAI) determination. Part II. Estimation of LAI, errors and sampling. Agricultural and Forest Meteorology, 121, 37-53.

Wigneron, J.-P., Calvet, J.-C., Pellarin, T., Van de Griend, A.A., Berger, M., Ferrazzoli, P., 2003. Retrieving near-surface soil moisture from microwave radiometric observations: current status and future plans. Remote Sensing of Environment, 85, 489-506

Wigneron J. -P. et al., 2006. L-band Microwave Emission of the Biosphere (L-MEB) Model: Description and calibration against experimental data sets over crop fields. Remote Sensing of Environment, doi:10.1016/j.rse.2006.10.014.

Wilson, J. W., N. A. Crook, C. K. Mueller, J. Sun, and M. Dixon, 1998: Nowcasting Thunderstorms: A Status Report. *Bull. Amer. Meteor. Soc.*, **79,** 2079-2099.

Wu P, Haines K, Pinardi N, 2000: Toward and understanding of deep-water renewal in the Eastern Mediterranean, *J. Phys. Ocean*., **30**, 443-458.

Wu P, Haines K, 1996: Modeling the dispersal of Levantine Intermediate Water and its role in Mediterranean deep-water formation, *J. Geophys. Res*., **101(C3),**6591-6607.

X

Xoplaki, E., 2002: Climate variability over the Mediterranean, *PhD thesis, University of Bern*, Switezrland.

Xoplaki, E., Gonzales-Rouco F.J., Luterbacher J., Wanner H., 2003: Mediterranean summer air temperature variability and its connection to the large-scale atmospheric circulation and SSTs. *Clim Dyn*., **2**0, 723-739.

Xoplaki E., Gonzales-Rouco F.J., Luterbacher J., Wanner H., 2004: Wet season Mediterranean precipitation variability : influence of large scale dynamics. *Clim. Dyn*., **23**, 63-78, doi:10.1007/s00382-004-0422-0.

Y

Z

Zierl, B. and H. Bugmann, 2005: Global change impacts on hydrological processes in Alpine catchments, *Water Resour.Res.,* **41**,W02028, doi:10.1029/2004WR003447

Zribi, M., Baghdadi, N., Holah, N., Fafin, O., 2005. New methodology for soil surface moisture estimation and its application to ENVISAT-ASAR multi-incidence data inversion. Remote Sensing of Environment, 96, 485-496.

Glossary

ADCP: Acoustic Doppler Current Profiler
AdDW: Adriatic Deep Water
AeDW: Aegean Deep Water
Alpilles-ReSeDA:
AMMA: African Monsoon Multidisciplinary Analysis
AMSL: Above Mean Sea Level
AOGCM: Atmosphere-Ocean General Circulation Model
ATI: Atmospheric and Terrestrial Influx
AUV: Autonomous Underwater Vehicle
AW: Atlantic water
CAPE: Convective Available Potential Energy
CCN: Cloud Condensation Nuclei
CDW: Cretan Deep Water
CICLE: A compléter (ANR project**)**
CIRCE: A compléter (FP6)
CIW: Cretan Intermediate Water
COPS: Convective and Orographically-driven Precipitation Study
Corine: Coordination of information on the environment (map of land cover)
CRU: Climatic Research Unit
CYPRIM: French acronym for " Intense cyclogeneses and heavy precipitation in Mediterranean regions" . Project sponsored by the French research ministry.
DWF: Dense water formation
EC: Eddy Correlation
Ecoclimap: dataset of surface parameters
EMDW: Eastern Mediterranean Deep Waters
EMT: Eastern Mediterranean transient
ENSEMBLES: FP6 European Project
ENSO: El Niňo Southern Oscillation
ERA-15: ECMWF ReAnalysis - 15 years (1979-1993)
ERA40: ECMWF ReAnalysis – 45 years (mid-1957 to mid-2002)
FF: Flash-Flood
FORMOSAT: satellite program
GCM: Global Circulation Model
GEV: Generalized extreme values
GEWEX: Global Energy and Water Cycle Experiment
GHG: GreenHouse Gas
GPR: Ground Penetrating Radar
GPS: Global Positionning System
GSWP2: Global Soil Wetness Project
HPE: Heavy Precipitation Event
HYMEX: Hydrological cycle in Mediterranean Experiment
IN: Ice Nuclei
INSU: Institut National des Sciences de l'Univers
IMFREX: IMpact des changements anthropiques sur la FRéquence des phénomènes EXtrêmes de vent, de température et de précipitations (GICC project)
IPCC: Intergovernmental Panel on Climate Change
ISBA: Interactions Soil Biosphere Atmosphere
ISBA-A-gs: Interactions between Soil, Biosphere and Atmosphere, CO2-reactive
LAI: Leaf Area Index
LDW: Levantine Deep Water
LIW: Levantine Intermediate Water
LLJ: Low-Level Jet
OMERE: French acronyms for Research Observatory of the Environment "Mediterranean Observatory of Rural Environment and Water"
MADDW: Middle Adriatic Deep Water
MAP: Mesoscale Alpine Program
MCS: Mesoscale Convective System
MedClivar: Mediterranean CLImate VARiability

MEDEX: The Mediteranean Experiment on cyclones that produce high-impact weather in the Mediterranean
Mesan: Meso scale analysis (used in Sweden)
MOBHYDIC: French acronym for Distributed Hydrological Modeling and Observing within Cropped Areas
MODCOU: MODelisation COUplée (hydrogéological model)
MTHC: Mediterranean Thermohaline Circulation
MW: Mediterranean water(s)
NAO: North Atlantic Oscillation
NAdDW: Northern Adriatic Deep Water (formerly NADW)
NCEP: National Centers for Environmental Prediction
OGCM: Ocean Global Circulation Model
OHMCV: French acronyms for Research Observatory of the Environment " Hydrometeorological Observatory for the Mediterranean Cevennes-Vivarais region"
ORCHIDEE: a land-surface model (developed by IPSL)
PRUDENCE: Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects (European FP5 project)
PV: Potential Vorticity
QPE: Quantitative Precipitation Estimate
QPF: Quantitative Precipitation Forecast
RCM: Regional Climate Model
SADDW: Southern Adriatic Deep Water
SAF: Satellite Application Facility
SAFRAN: meteorological analysis system (Système d'analyse fournissant des renseignements à la neige)
SECHIBA: Land surface model of IPSL
SEVE: Sol eau végétation énergie (land surface model)
SiSPAT: Simple Soil Plant Atmosphere Transfer (land surface model)
SMOS: Soil Moisture and Ocean Salinity
SMOSMANIA: Soil moisture observing system – Meteorological network integrated application
SNOW17: Snow model
SRES: Special Report on Emission Scenarios
SSGF: Sea Spay Generation Function
SST: Sea Surface Temperature
STICS: Simulateur mulTIdisciplinaire pour les Cultures Standard
SVAT: Surface – Vegetation-Atmosphere Transfer
TDW: Tyrrhenian Deep Water
THC: Thermohaline Circulation
TR: Thermal Infrared
VENuS: Vegetation and Environment monitoring on a New Micro-Satellite
VIC: Variable infilatration capacity
WIW: Western Mediterranean Intermediate Water
WMDW: Western Mediterranean Deep Water
XBT: Expendable Bathythermograph

NB: for the water masses acronyms, see also https://www.ciesm.org/catalog/WaterMassAcronyms.pdf