HAMSR

HAMSR (High Altitude MMIC Sounding Radiometer)

The airborne HAMSR technology demonstration instrument is a 25 channel cross-track microwave sounder originally developed by NASA/JPL (Jet Propulsion Laboratory) under the IIP-98 (Instrument Incubator Program-1998) program. At the start of the 21st century, the instrument design introduced the first receivers based entirely on the newly developed MMIC (Monolithic Microwave Integrated Circuit) technology to enable substantial reductions in size and mass while at the same time achieve improved measurement sensitivity and accuracy. [1] [2] [3] [4] [5]

The remote-sensing HAMSR instrument analyzes the heat radiation (brightness temperature) emitted by oxygen and water molecules in the atmosphere to determine their density and temperature. The instrument operates at microwave frequencies that can penetrate clouds, enabling it to determine temperature, humidity and cloud structure under all weather conditions. This capability is critical for studying atmospheric processes associated with bad weather, like the conditions present during atmospheric river events.

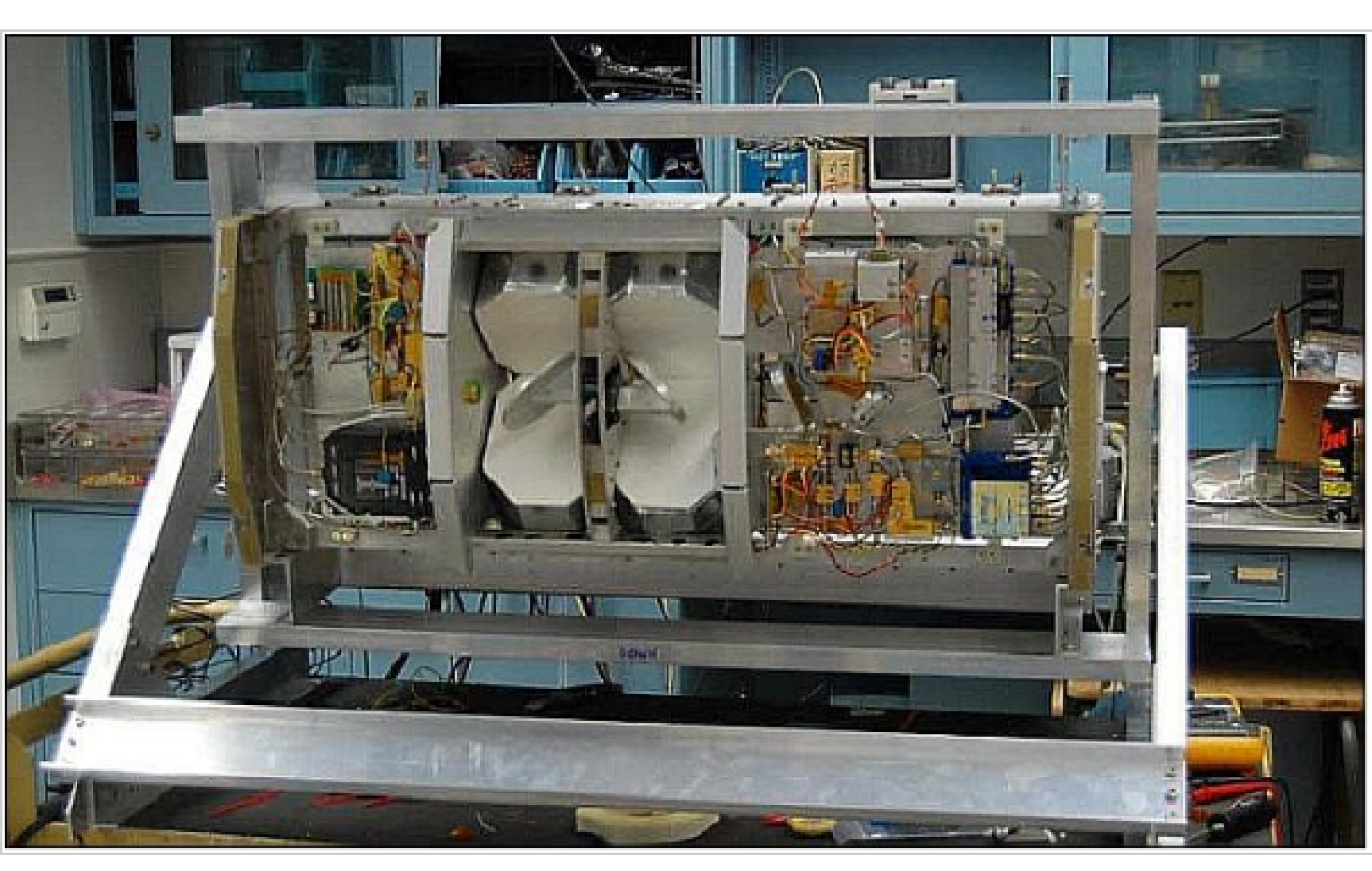

Figure 1: Photo of the HAMSR instrument (image credit: NASA/JPL)

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Directory Home
Satellite Missions
Airborne Sensors
Airbus A310 Zero-G
AMCW-LAS
APEX
ASIRAS
AToMS
ATOMMS
ATTREX
AVIRIS
AVIRIS-NG
CHARM
D2P
DBSAR
EcoSAR
FIRST
GeoSAR
GIFS
Global Hawk
GLORIA
GRASS
HAMSR
HIWRAP
HSRL
HUT-2D
HyMAS
HyTES
MABEL
MFLL
MicroASAR
NAST
PAMIR
PARIS
Pi-SAR2
PRISM
PSR
SIMPL
SPIRA
TIMS
TWiLiTE
UAVSAR
Wavemill
Observation of the Earth

Instrument:

HAMSR is a passive microwave radiometer, a self-calibrating cross-track scanning instrument, which measures the thermal radiation emitted from the atmosphere and the surface below the aircraft. It measures microwaves in two air temperature-sounding bands and one water-vapor sounding band to provide calibrated temperatures.

The HAMSR instrument was built around a core of miniaturization technology developed under the short-lived IMAS (Integrated Multispectral Atmospheric Sounder) program, and it uses a flexible design that makes it easily reconfigurable. This makes it ideally suited as a testbed for new components. It also implemented dual-band temperature sounding, similar to the AMSU on NOAA spacecraft, which results in greater retrieval accuracy as well as a broader measurement scope.

HAMSR scans cross-track below the airplane and has a ± 60° field of view. The scan system consists of two reflectors mechanically connected to a common scanning mechanism with both beams pointing along the same boresight direction. One reflector is a flat mirror for **118** and **183** GHz and the other is a parabolic mirror for **55** GHz. The size of the beam at each band is 5.7° HPFW (Half Power Full Width), and the sidelobes for all beams are well below 30 dB with a beam efficiency of > 95%, providing a minimal footprint contamination. The polarization of the beams rotates as the reflectors scan, with pure V-polarization at nadir. A table of the HAMSR passband characteristics including center frequency (f_c), BW (bandwidth) and side-band weighting ratios are shown in Table 1. The 25 sounding channels are accommodated in three bands: 50-60 GHz, 118 GHz, and 183 GHz.

Each reflector scans across two calibration targets during each scan. One target is at the ambient air temperature (about -10°C at altitude) and the other is heated to about 70°C. The reflectivity of the targets has been designed to be less than -50 dB. The temperature of each target is measured with four temperature sensors. The targets are constructed of heavy aluminum and are insulated to keep gradients across them to < 0.25 K. The integration time on each target is about 10 times the integration time for the atmospheric measurements. The absolute accuracy of the HAMSR TBs (Brightness Temperature) has been demonstrated in flight to be better than 1.5 K using dropsonde and radiosonde comparisons.

Channel No	f_c – LSB [GHz]	BW – LSB [MHz]	W$_1$	f_c – USB [GHz]	BW – USB [MHz]	W$_2$
1	50.30	185.34	-	-	-	-
2	51.81	456.26	-	-	-	-
3	52.82	444.60	-	-	-	-
4	53.46	151.29	0.58	53.69	155.73	0.42
5	54.41	446.50	-	-	-	-
6	54.94	442.91	-	-	-	-
7	55.46	374.80	-	-	-	-
8	55.99	279.05	0.90	56.61	235.84	0.10
9	113.27	1062.11	-	-	-	-
10	115.19	1060.03	-	-	-	-
11	116.18	506.09	-	-	-	-
12	116.70	504.33	-	-	-	-
13	117.13	432.13	-	-	-	-
14	117.54	418.95	-	-	-	-
15	117.93	450.60	0.54	119.56	424.56	0.46
16	118.30	319.84	0.54	119.19	302.38	0.46
17	118.50	117.19	0.47	118.98	140.74	0.53
18	118.61	100.86	0.42	118.86	105.95	0.58
19	166.95	3812.82	-	-	-	-
20	173.22	3298.97	0.54	192.88	2926.96	0.46
21	176.26	2409.16	0.34	190.23	2472.45	0.66
22	178.74	2133.24	0.23	187.95	2162.90	0.77
23	180.39	1093.10	0.29	18632	1119.17	0.71
24	181.44	1157.75	0.36	185.09	1109.80	0.64
25	182.30	536.28	0.27	184.31	539.22	0.73

Table 1: HAMSR passband characteristics (upgraded version)

The scan mirror makes a full revolution in a little more than 1 second. During that period it obtains a number of overlapping spatial samples of the scene below and several views of two internal calibration targets. From an altitude of 20 km the scan width is about 40 km wide on the ground with a single field of view of 2 km at nadir. The sampling intervals are 1 km in cross-track.

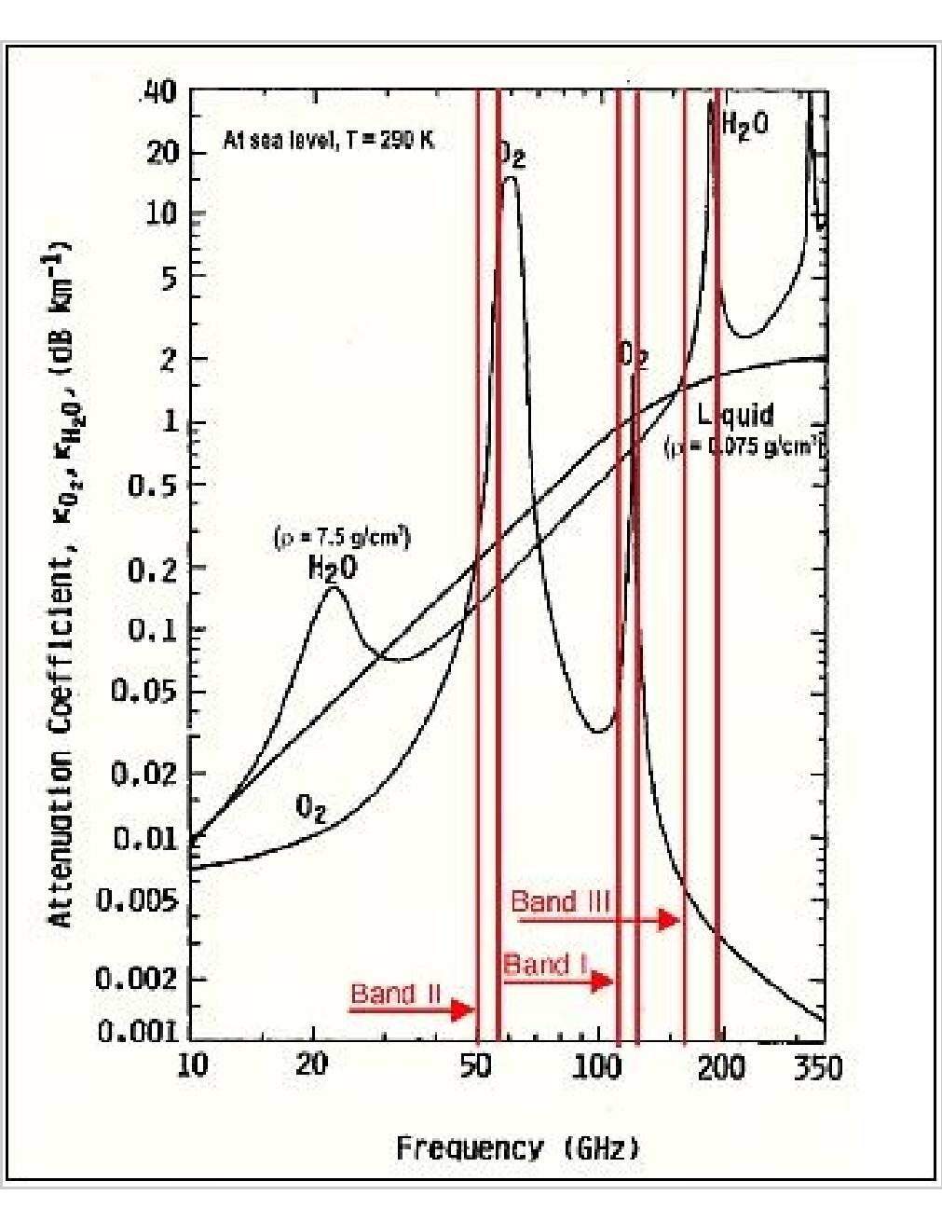

Figure 2: Illustration of the microwave absorption spectrum (image credit: NAS/JPL)

The HAMSR instrument consists of an open-frame sensor module and an electronics and power module, connected with cables. These can be packaged together in a single enclosure.

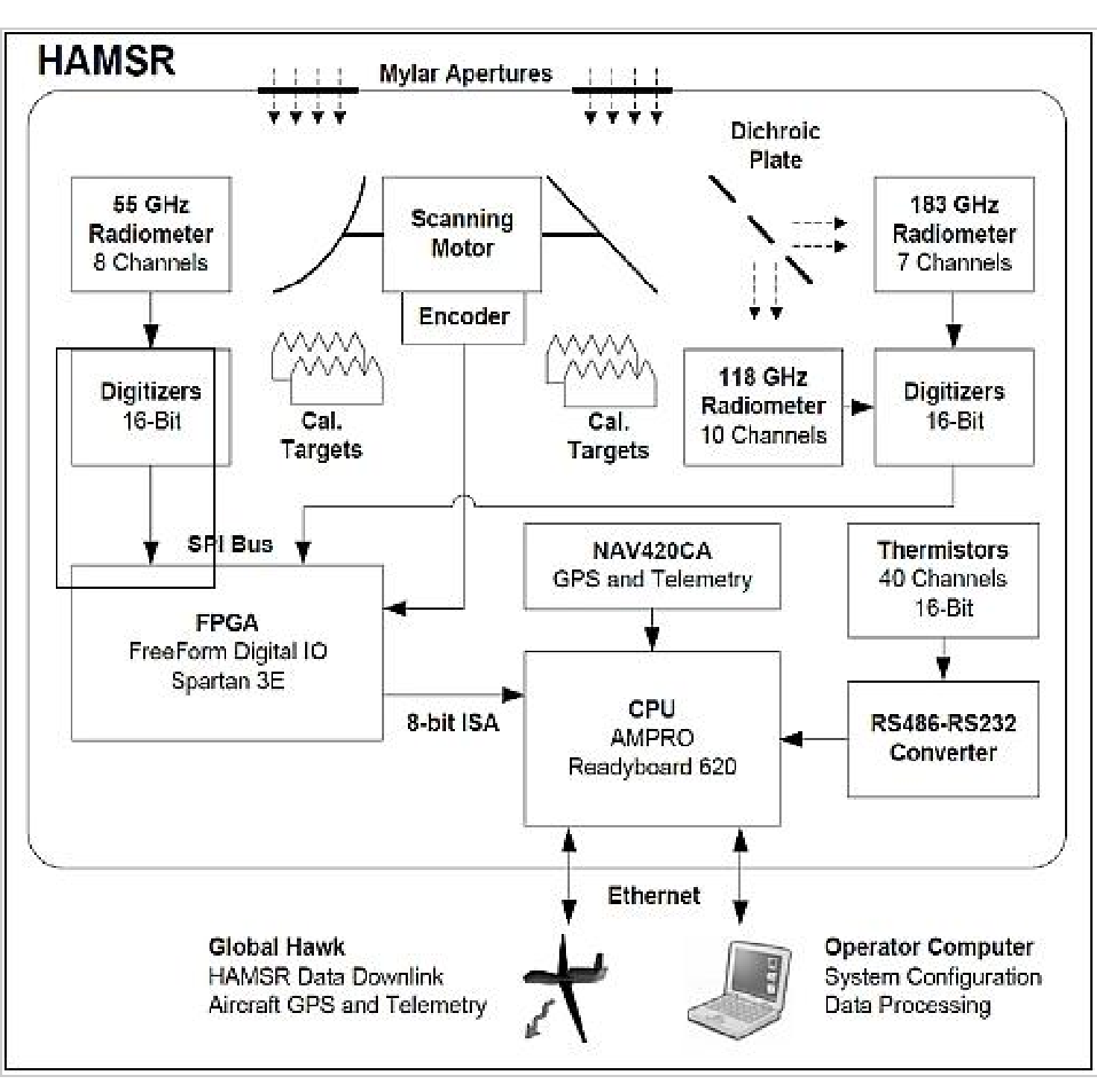

Figure 3: System diagram of the upgraded HAMSR assembly (image credit: NASA/JPL)

HAMSR upgrades:

The HAMSR instrument was extensively upgraded beginning in 2008 under the AITT (Airborne Instrument Technology Transition) program of NASA to deploy on the Global Hawk UAV. In the timeframe 2010/11, the instrument has state-of-the-art radiometric performance and the capability to process and display both brightness temperature imagery and derived products in real time. The improved performance of the instrument is demonstrated through retrievals of temperature and water vapor.

One of the major upgrades was the addition of a front-end LNA, developed by JPL through the MIMRAM ACT (Advanced Component Technology) project, to the **183 GHz channel** which reduces the noise in this channel to < 0.1 K at the sensor resolution (~2 km) and enabling HAMSR to observe much smaller scale water vapor features. The 118 GHz receiver was also upgraded using the state-of-the-art ACT developed LNA (Low Noise Amplifier), lowering the noise figure of this receiver significantly. Another major upgrade was an enhanced data system that provides on-board science processing capability and real-time data access (Ref. 1).

The radiometric sensitivity in the 183 GHz band improved by an order of magnitude as a result, as shown in Figure 4, where the right panel shows the thermal noise level of the new receiver (green line) vs. the original receiver (blue curve). HAMSR is now (2011) the most sensitive and accurate microwave sounder in existence. This receiver was flown for the first time in the NASA GRIP (Genesis and Rapid Intensification Processes) hurricane experiment in late summer of 2010 and is now field tested.

Parameter	Old HAMSR	New HAMSR
Receiver noise temperature	9000 K	580 K
NEDT (7 ms, 3 GHz BW channel)	2 K	0.2 K

Table 2: Parameters of the 183 GHz receiver

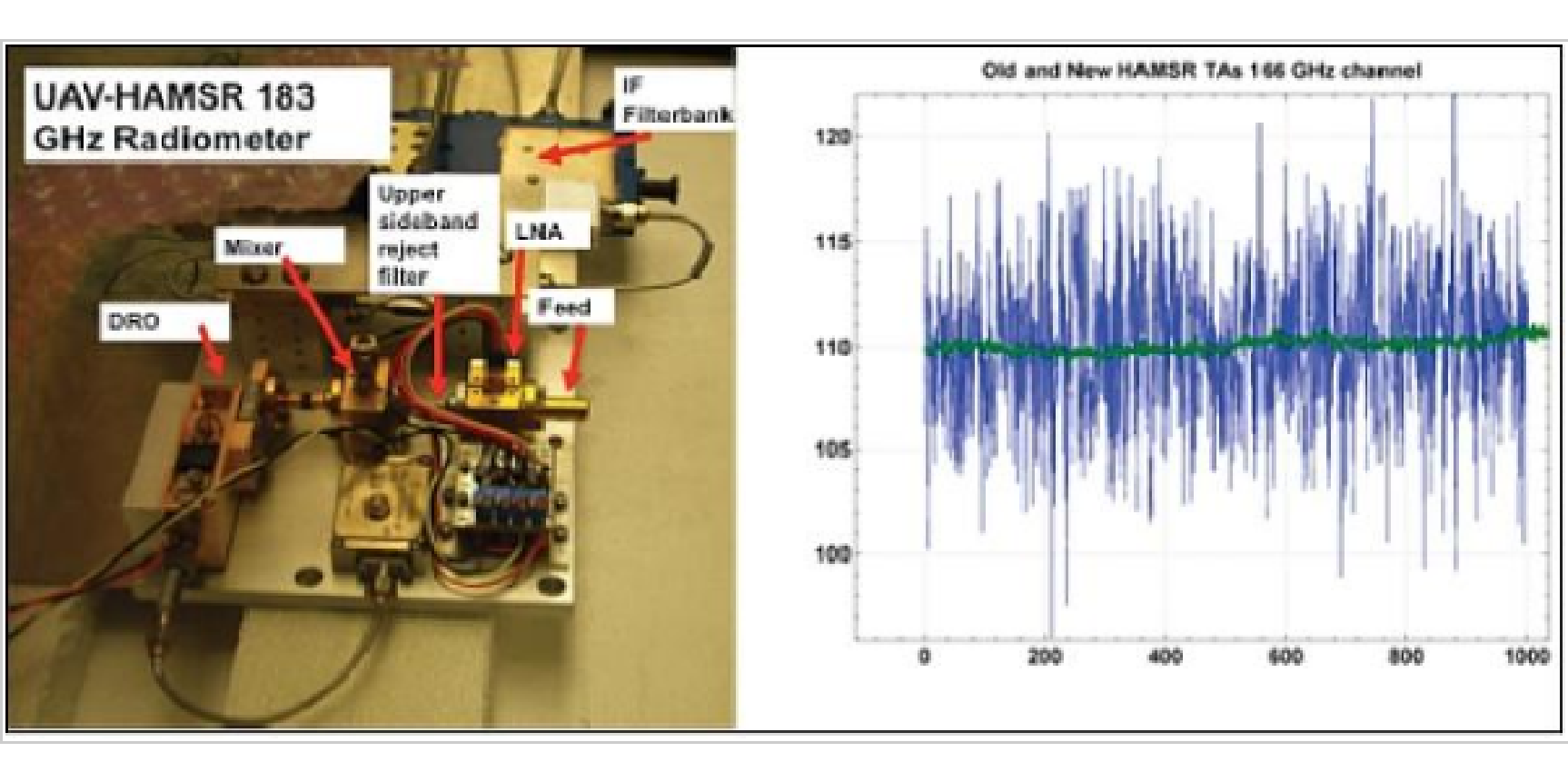

Figure 4: HAMSR/GeoSTAR 183 GHz receiver (left); noise level (right), image credit: NASA/JPL

Data system upgrades: Because the HAMSR instrument was originally built as a laboratory demonstration instrument, the data system was not optimized for an operational scenario. The data system was upgraded to accommodate real time data transfer to the GH platform as well as to have the ability to perform on-board processing. Because the main advantage of the Global Hawk is its long duration, it is essential that data can be transmitted to the ground during the flight. The data system consists of an FPGA that is used to read the digitized radiometer counts from the analog-to-digital converters and receive the reflector position from the scan motor encoder, which are then sent to a microprocessor and packed into data files.

The microprocessor additionally reads telemetry data from 40 on-board housekeeping channels (containing instrument temperatures) and receives packets from an on-board navigation unit, which provides GPS time and position, as well as independent attitude information (e.g. heading, roll, pitch and yaw). The raw data files are accessed through an Ethernet port and are stored on-board the instrument using a removable flash memory card. The HAMSR full data rate is relatively low, at 75 kbit/s, allowing for real time access over the Global Hawk high data rate downlink. The instrument also broadcasts a low data rate stream providing swath imagery over the iridium data link to the Global Hawk, which is limited to 2 kbps. The main difference between the high and low data rate steams is that the full data steam is over sampled by a factor of 12 and the low data rate stream only includes one observation per beamwidth and does not include the 118 GHz channels.

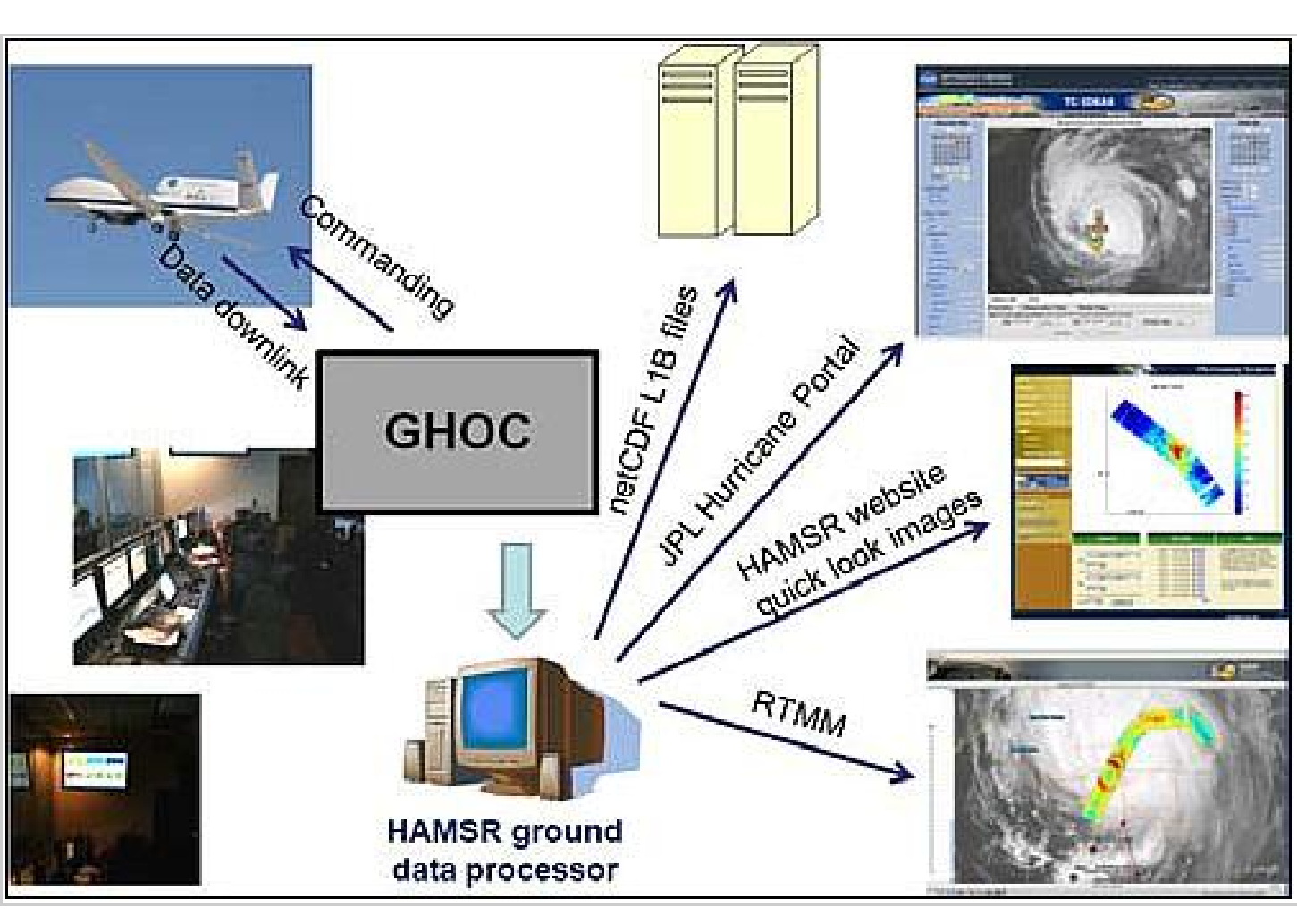

Figure 5: HAMSR ground data system on the Global Hawk (image credit: NASA/JPL)

The HAMSR upgrade initiative included a re-packing of the instrument into the light-weight compact housing for deployment in the forward bay of the Global Hawk UAS. The combined upgrades of HAMSR made the system a reliable operational instrument with state-of-the-art performance.

Campaigns with the HAMSR instrument:

- **CAMEX-4** Convection and Moisture Experiment), the fourth campaign of the CAMEX series in 2001 from Aug. 16 to Sept. 24: HAMSR was first deployed in the field in CAMEX-4 - a hurricane field campaign organized jointly by NASA and the HRD (Hurricane Research Division) of NOAA in Florida. CAMEX-4 was focused on the study of tropical cyclone (hurricane) development, tracking, intensification, and landfalling impacts using NASA-funded aircraft and surface remote sensing instrumentation. HAMSR flew aboard the ER-2.

A number of tropical convective systems – large and small – were studied during CAMEX-4. The HAMSR observations exhibited often very large brightness temperature depression over intense convective cells, particularly in the most transparent water vapor channels. This depression could reach 100-150 K. [6]

Figure 6: Photo of the HAMSR assembly installed in the ER-2 aircraft (image credit: NASA/JPL)

- **TCSP** (Tropical Cloud Systems and Processes) campaign, conducted during the period July 1-27, 2005 out of the Juan Santa-Maria Airfield in San Jose, Costa Rica. The TCSP field experiment flew 12 NASA ER-2 science flights, including missions to Hurricanes Dennis and Emily, Tropical Storm Gert and an eastern Pacific mesoscale complex that may possibly have further developed into Tropical Storm Eugene. HAMSR again flew aboard the NASA ER-2 aircraft. [7]

- **NAMMA** (NASA African Monsoon Multidisciplinary Analyses) campaign. This mission was based in the Cape Verde Islands, ~ 600 km off the coast of Senegal in west Africa. Commencing in August 2006, NASA scientists employed surface observation networks and aircraft to characterize the evolution and structure of AEWs (African Easterly Waves) and Mesoscale Convective Systems over continental western Africa, and their associated impacts on regional water and energy budgets.

- **GRIP** (Genesis and Rapid Intensification Processes), a NASA Earth science field experiment, which was conducted from Aug. 15 to Sept. 30, 2010 with bases in Fort Lauderdale, FL using the DC-8, at Houston, TX, using the WB-57 aircraft, and at the NASA DFRF (Dryden Flight Research Facility), CA, using the Global Hawk UAS (Unmanned Airborne System). GRIP was conducted to better understand how tropical storms form and develop into major hurricanes. [8]

This campaign capitalized on a number of ground networks, airborne science platforms (both manned and unmanned), and space-based assets. The field campaign was executed according to a prioritized set of scientific objectives. In two separate science solicitations, NASA selected a team of investigators to collect NASA satellite and aircraft field campaign data with the goal of conducting basic research on problems related to the formation and intensification of hurricanes. HAMSR was one instrument set flying aboard the Global Hawk UAS during the GRIP campaign.

- **WISPAR** (Winter Storms and Pacific Atmospheric Rivers) campaign, flown on the Global Hawk in February and March 2011 over the Pacific Ocean between Hawaii and California. HAMSR participated with dropsondes in the NOAA-led WISPAR 2011 campaign. An objective of this campaign was to study atmospheric water vapor rivers. HAMSR precipitable water vapor data were used in real time during this campaign to locate the boundaries of the atmospheric river to time the release of dropsondes, which were the main payload on this mission. [9] [10] [11]

The improved system performance enabled high quality retrievals of vertical temperature and water vapor profiles. An example of the retrievals for an atmospheric river transect are shown in Figure 8. The atmospheric river is characterized by a marked increase in water vapor through the lower troposphere as well as a local temperature increase below about 900 mb (Ref. 1).

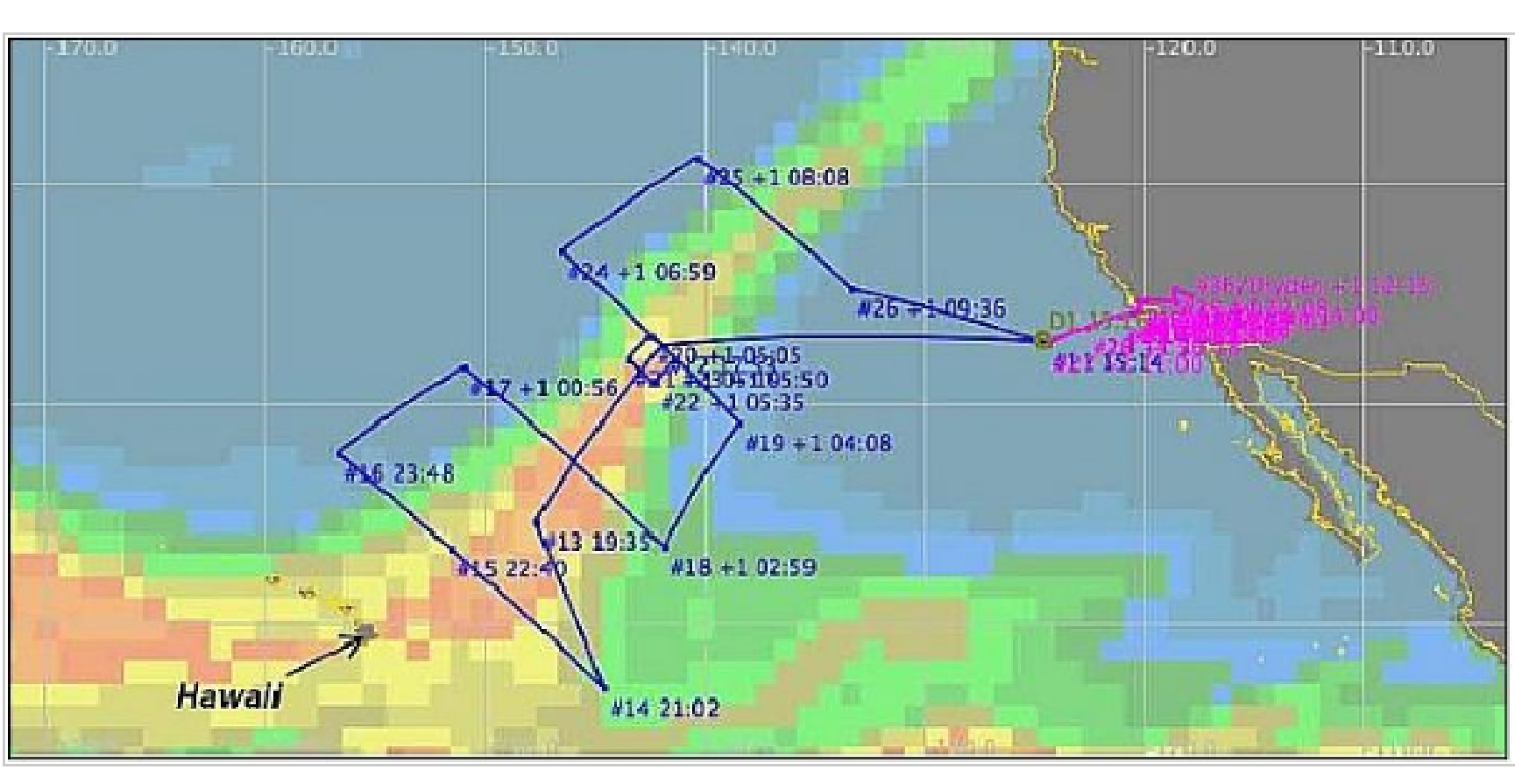

Figure 7: Flight path of the Global Hawk in the WISPAR campaign (image credit: NASA, Ref. 2)

- HS3 (Hurricane and Severe Storm Sentinel) campaign, planned to start in 2012. The overall science objective is to provide measurements to address key science questions related to storm formation and intensity change, including whether it is primarily a function of the storm environment or storm internal processes. [12]

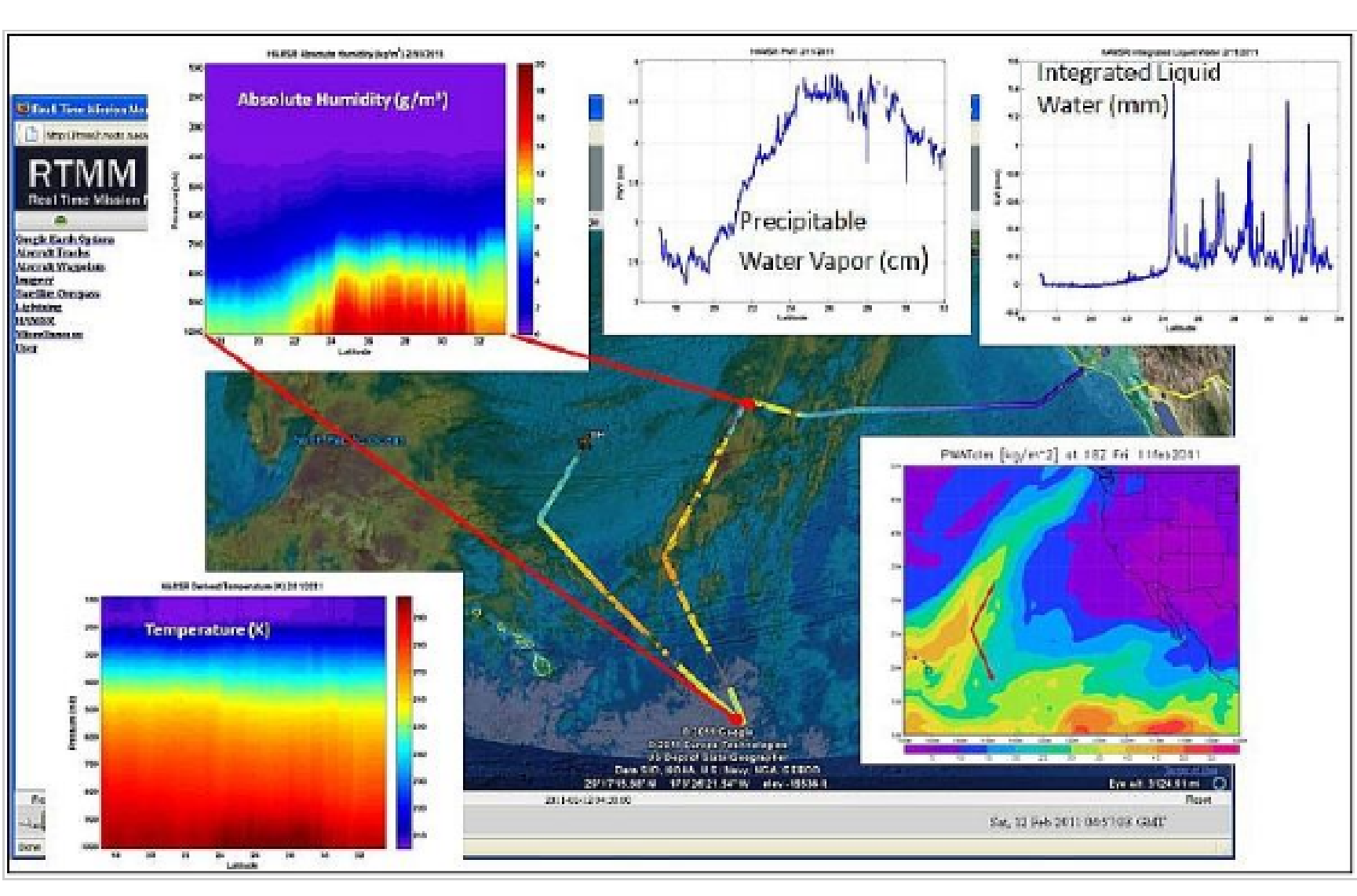

Figure 8: This image shows HAMSR retrievals of PWV (Precipitable Water Vapor), integrated cloud liquid water, vertical temperature profile and vertical moisture profile during an atmospheric river transect. The image on the bottom right shows the PWV from NCEP (National Centers for Environmental Prediction), image credit: NASA/JPL

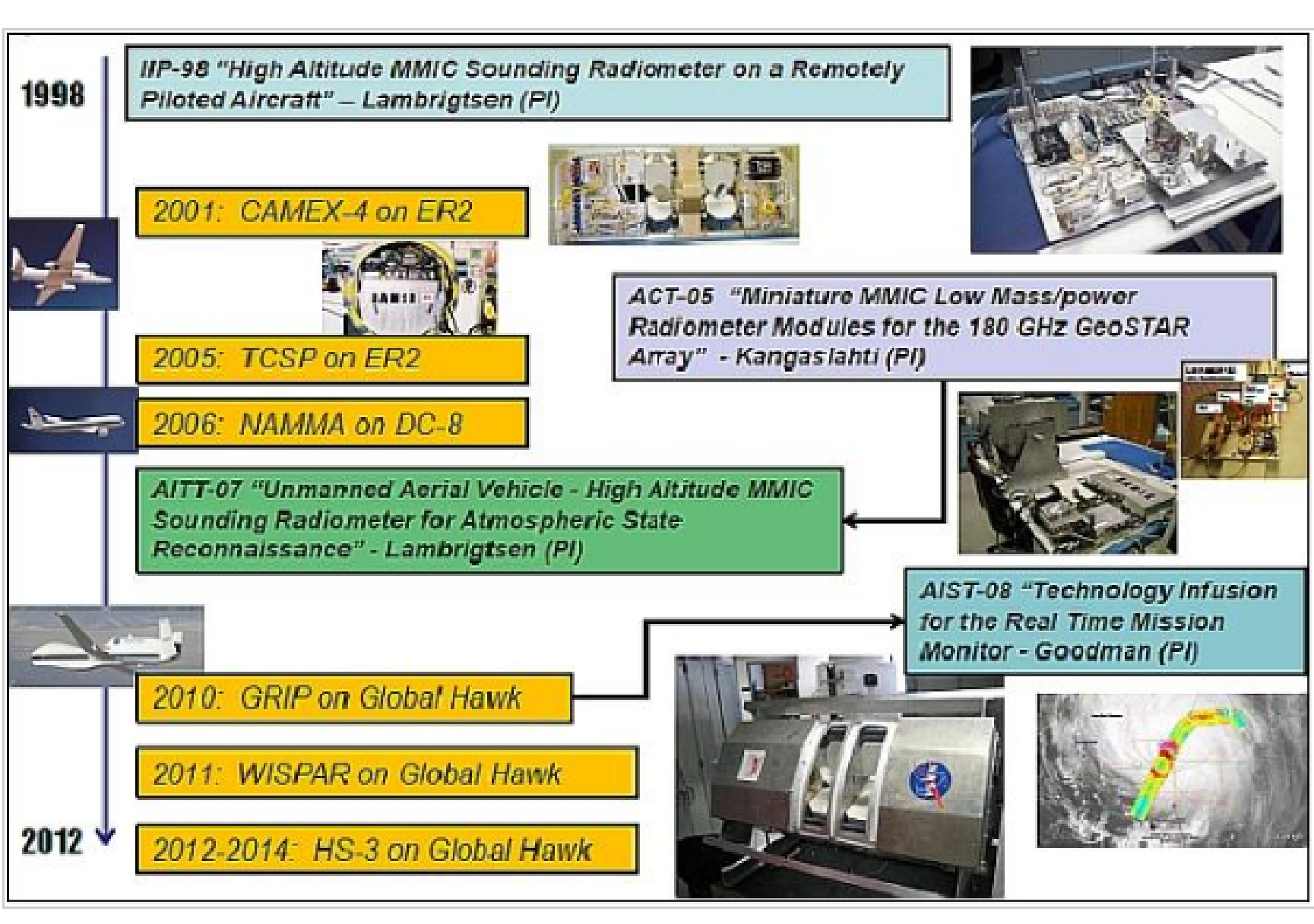

Figure 9: Overview with the HAMSR development timeline (image credit: NASA/JPL)

Figure 10: Photo of the Global Hawk UAS at DFRF (image credit: NASA/DFRF)

Figure 11: Photo of the upgraded HAMSR instrument flown on the Global Hawk (image credit: NASA/JPL)

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The information compiled and edited in this article was provided by Herbert J. Kramer from his documentation of: "Observation of the Earth and Its Environment: Survey of Missions and Sensors" (Springer Verlag) as well as many other sources after the publication of the 4th edition in 2002. - Comments and corrections to this article are always welcome for further updates.