Diminishing Returns: How Many GNSS-RO Observations are Enough?

25 July 2022

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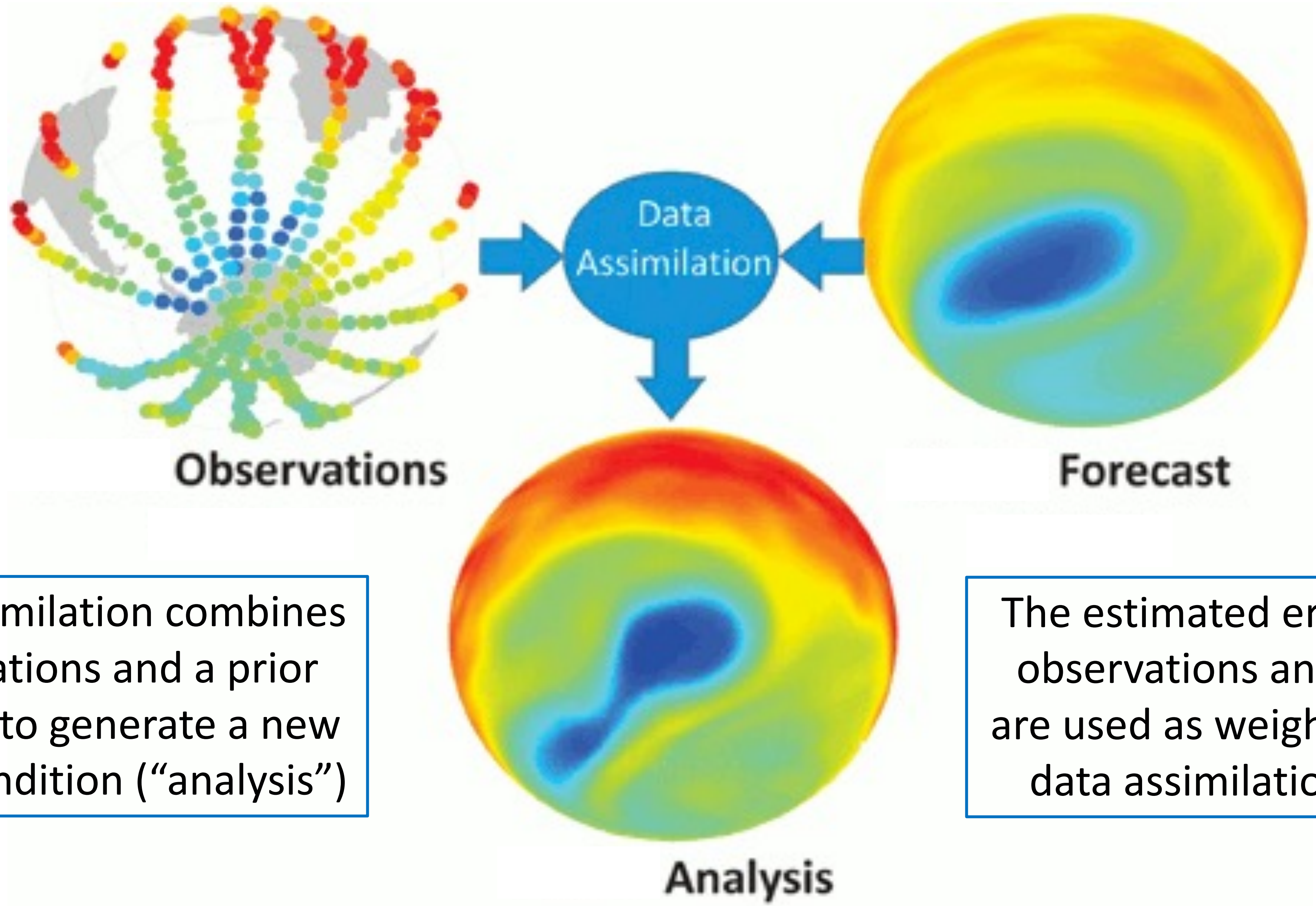
Thanks to: Ron Errico, Amal el Akkraoui, Hui Shao, Francois Vandenberghe, and Sean Healy

GMAO
Global Modeling & Assimilation Office

GNSS Radio Occultation

- GNSS (GPS) radio occultations generate soundings of temperature and humidity.
- The bending of signals between satellites that pass through the atmosphere (occultation) is measured.
- There is community interest in launching large numbers of GNSS satellites – how many are useful?

How NWP Uses Observations



Data assimilation combines observations and a prior forecast to generate a new initial condition ("analysis")

The estimated errors of the observations and forecast are used as weighting by the data assimilation system

Image: Lahoz, W. and P. Schneider, Front. Environ. Sci., 2014, with permission

What is an Observing System Simulation Experiment?

An OSSE is a modeling experiment used to estimate the impact of new observing systems on numerical weather prediction when actual observational data is not available.

- A long free model run is used as the "truth" - the Nature Run

- The Nature Run fields are used to back out "synthetic observations" from all current and new observing systems

- Realistic errors are added to the synthetic observations

- The synthetic observations are assimilated into a different operational model

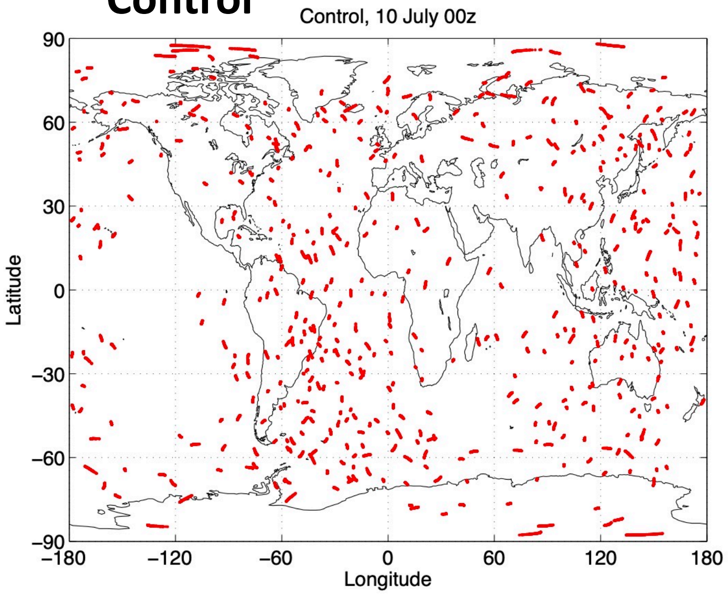
- Forecasts are made with the second model and compared with the Nature Run to quantify improvements due to the new observing system

GMAO OSSE Setup

- Nature Run: GEOS 2 year run, 7 km, 72 levels, 30 minute output
- Simulated Observations: conventional, radiance based on 2015
  - Radiance types: advanced microwave sounders, hyperspectral infrared sounders, microwave humidity sounders
  - Conventional types: rawinsondes, atmospheric motion vectors, aircraft, surface, scatterometer
  - Random correlated and uncorrelated errors added to match real var(O-F)
  - GNSS-RO simulated with ROPP operator – 2-D ray tracing below 10 km
    - GNSS-RO assimilated with 1-D GSI operator
    - Vertically correlated GNSS-RO errors added
- DAS: Hybrid 4DEnVar Gridpoint Statistical Interpolation
- Forecast model: 25 km GEOS 5.17 (fraternal twin)
- Experiments: July – August

GNSS-RO Saturation OSSE Experiments

Control



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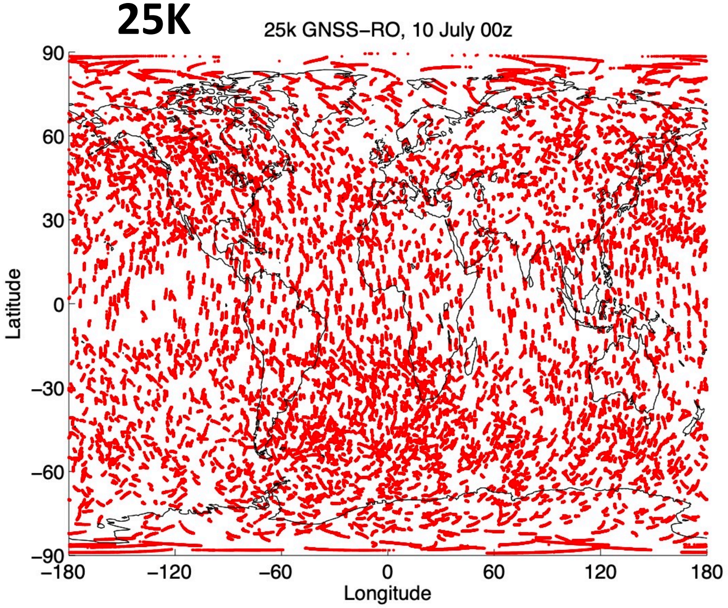

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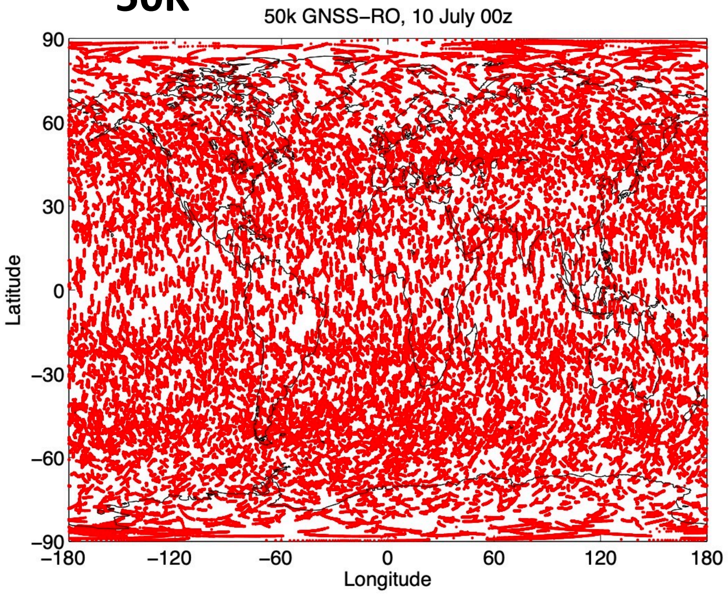

Snapshot of GNSS-RO locations on 10 July 00z for all experiment configurations

GNSS-RO locations simulated by combining multiple days of real observations from 2009

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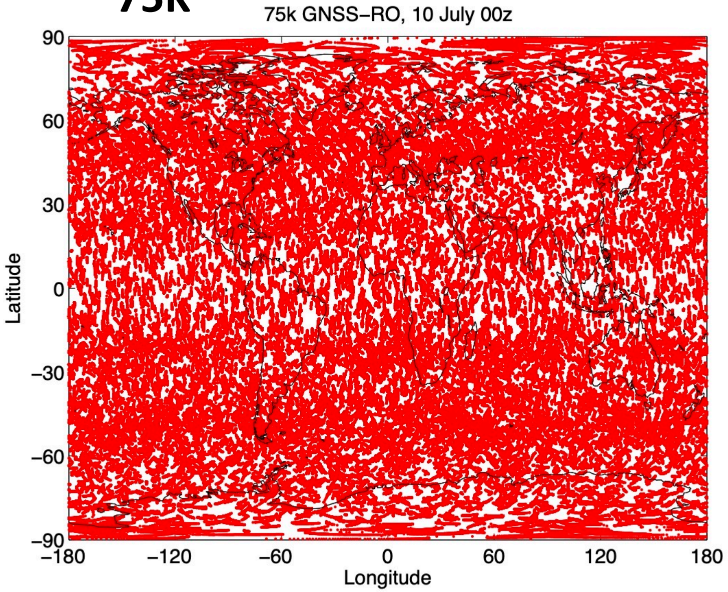

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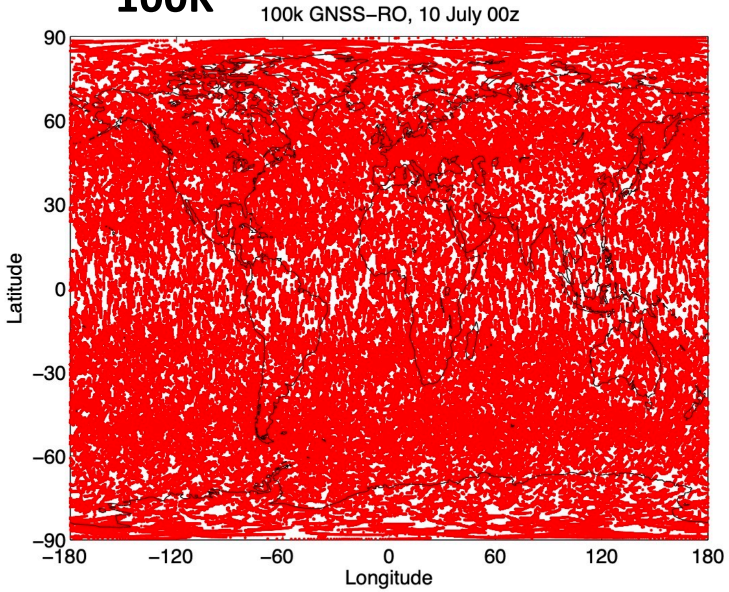


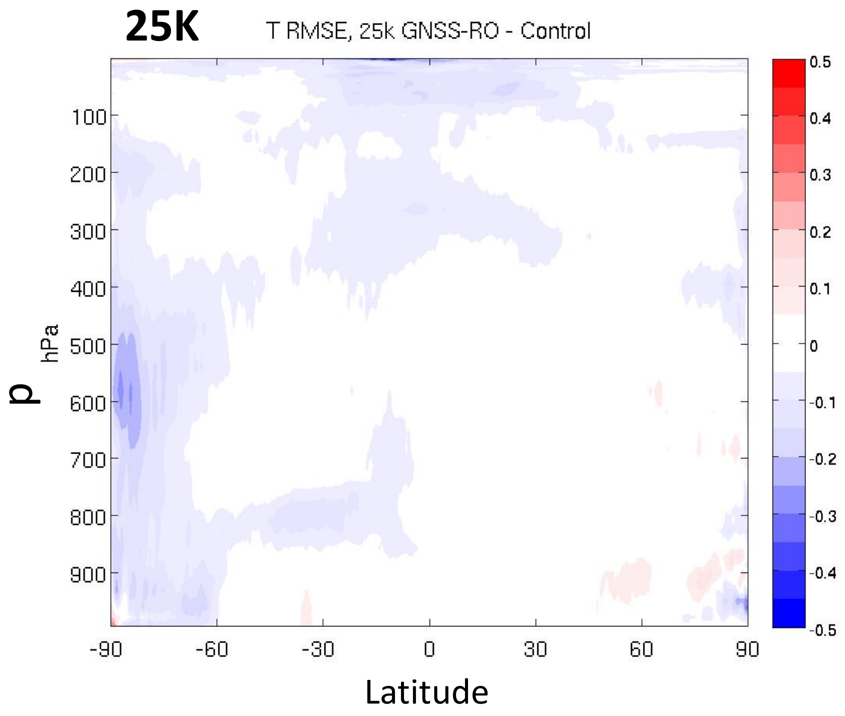
Analysis Impact

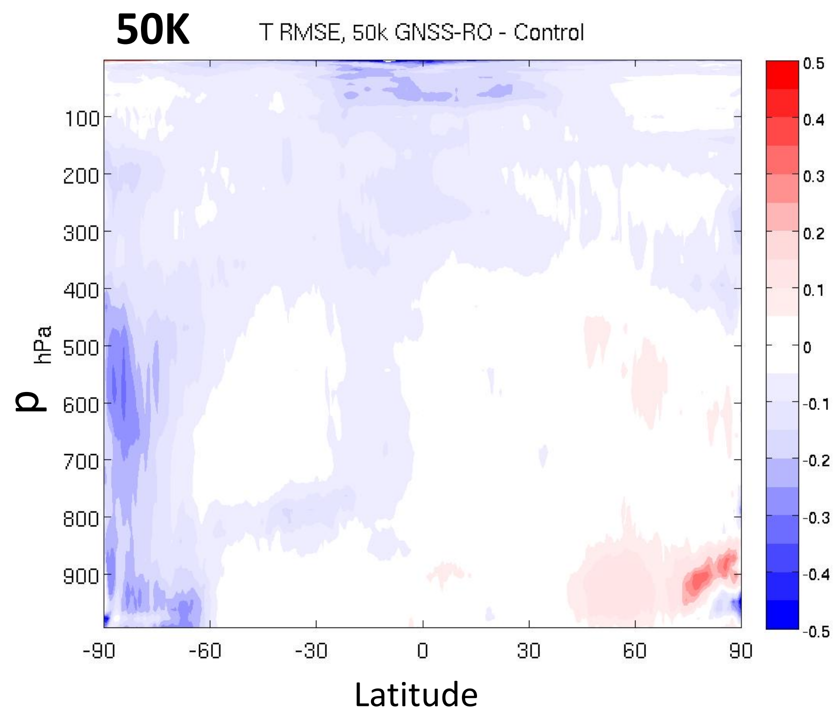
Zonal Mean RMS Temperature Analysis Error vs Control

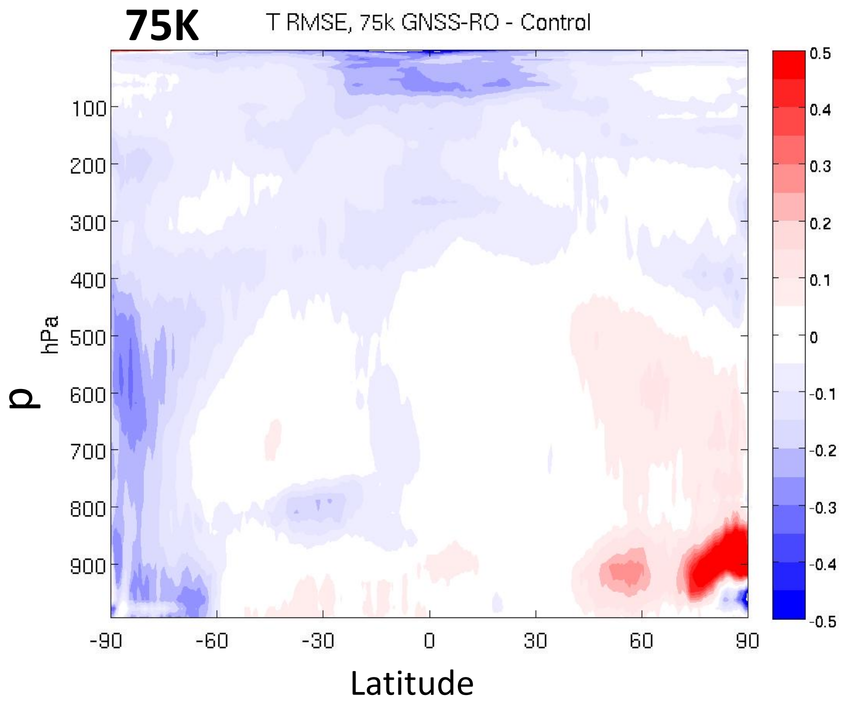
Blue = reduction in error vs Control

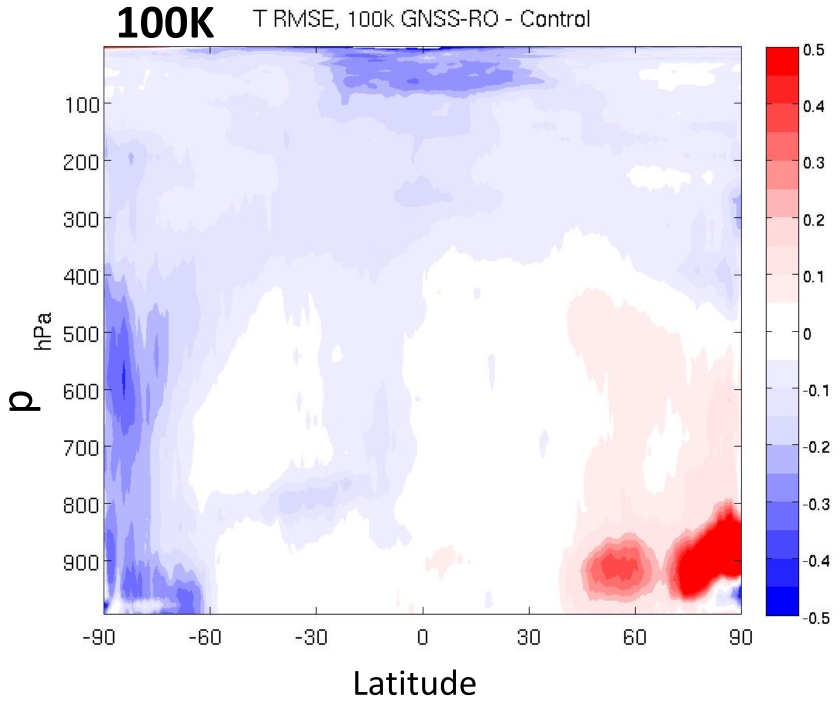
Progressive changes to analysis error with increased GNSS-RO data

Mid and lower tropospheric degradation due to GNSS-RO





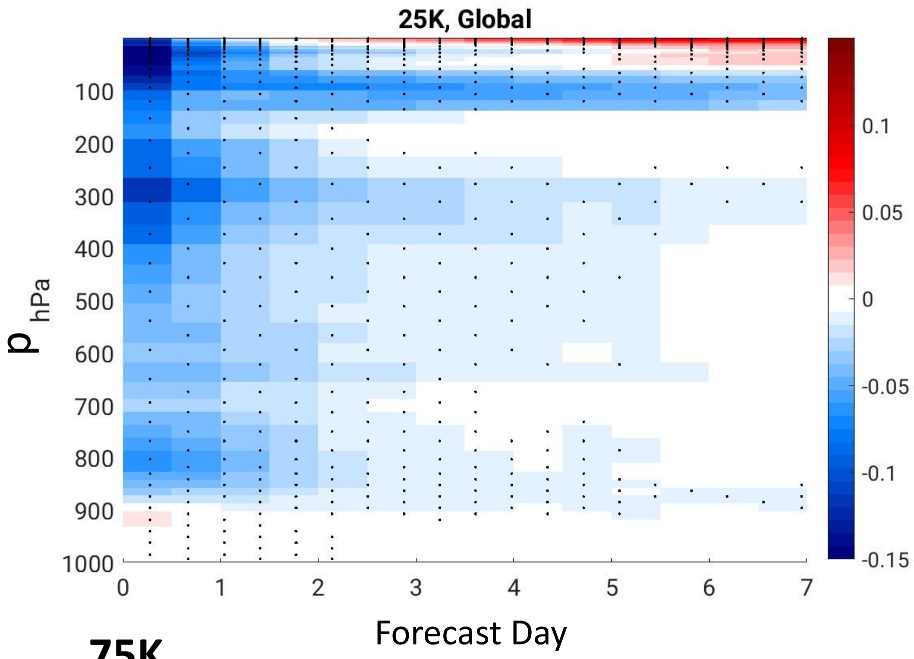




Forecast Impact

Largest forecast impact (>10 %) seen in the first 48-72 hours. Some small impact retained to day 7.

25K



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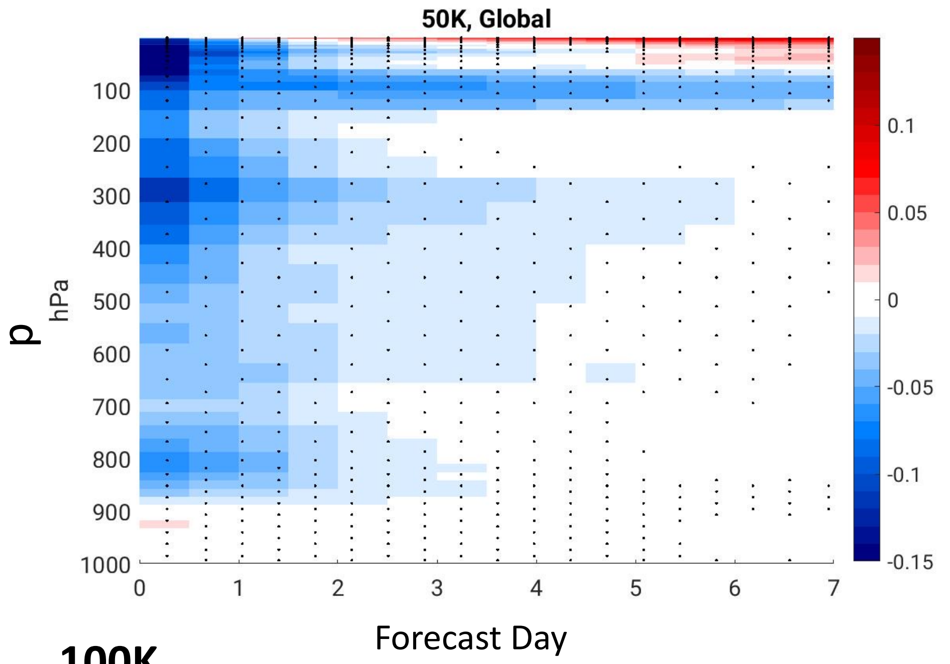

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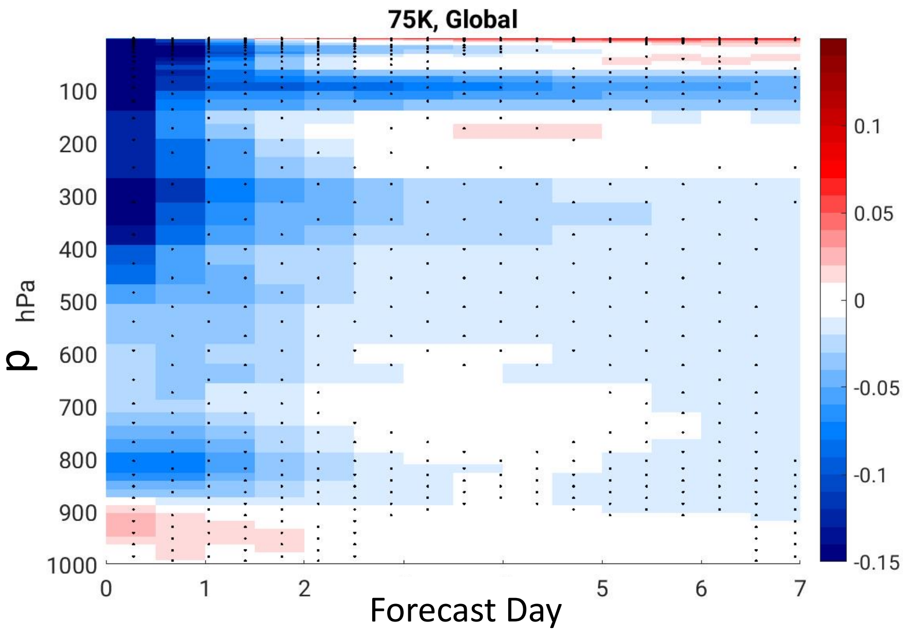

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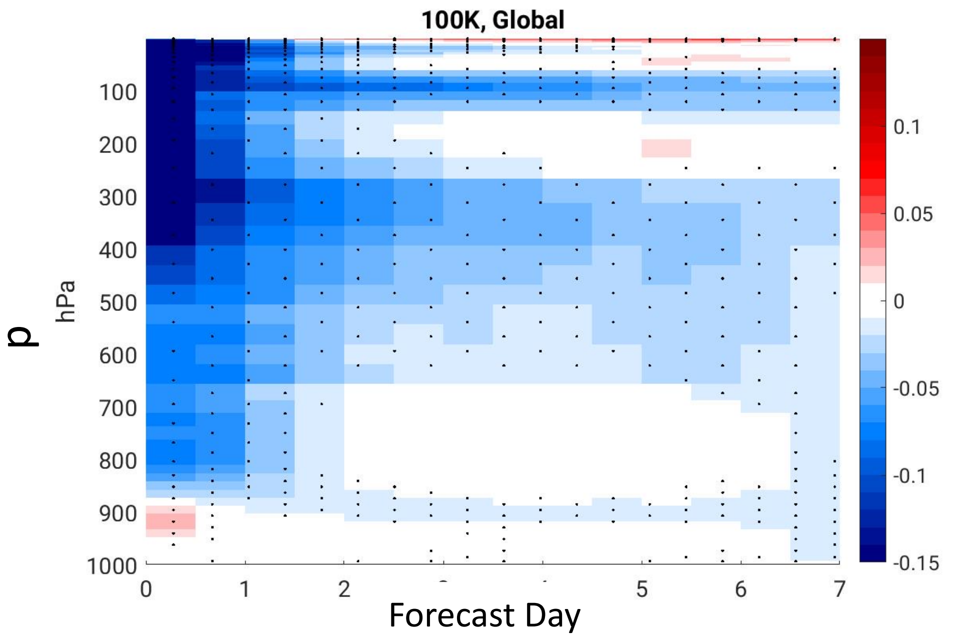


Normalized Global RMS T forecast error vs Control

Blue = reduction in error vs Control

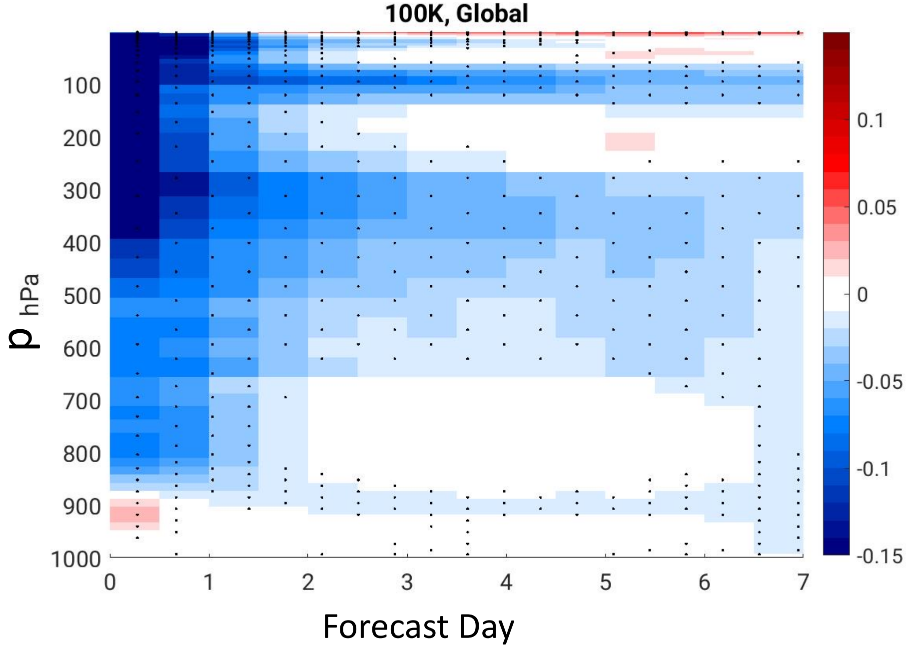
Forecast Impact

Different impacts seen in different regions: different error growth regimes

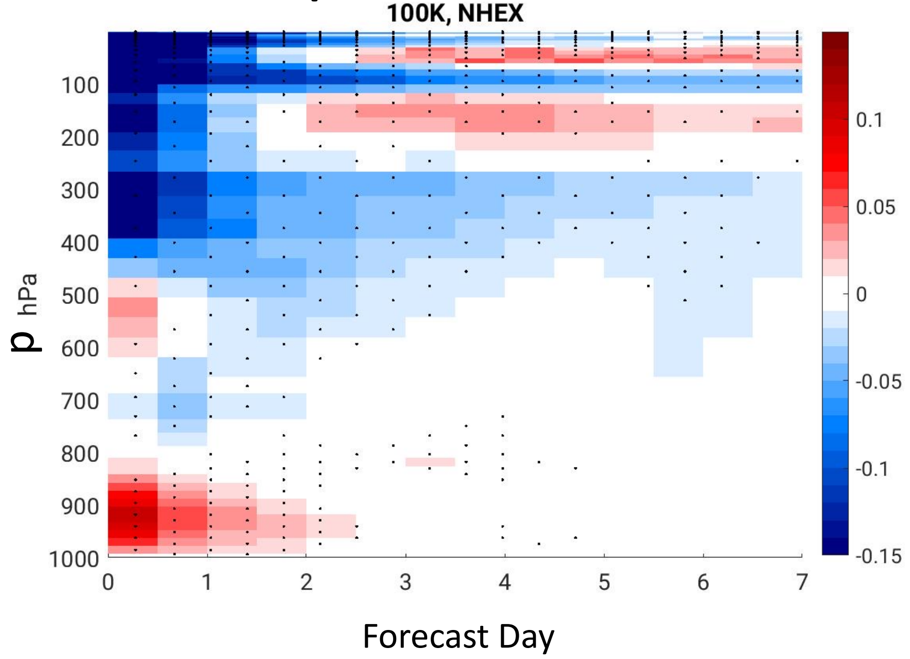
Normalized **Regional** RMS T forecast error

Blue = reduction in error vs Control

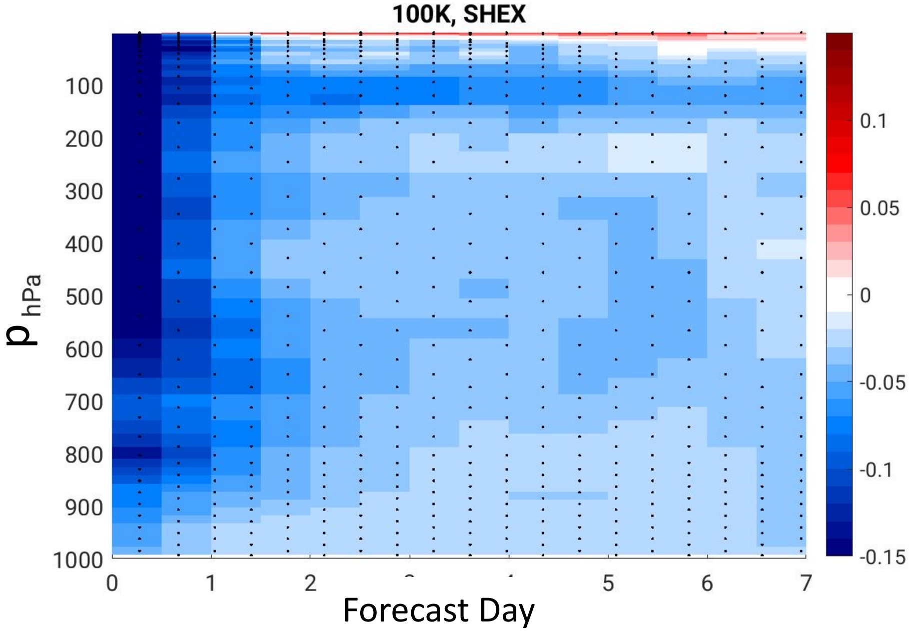
Global, 100 k



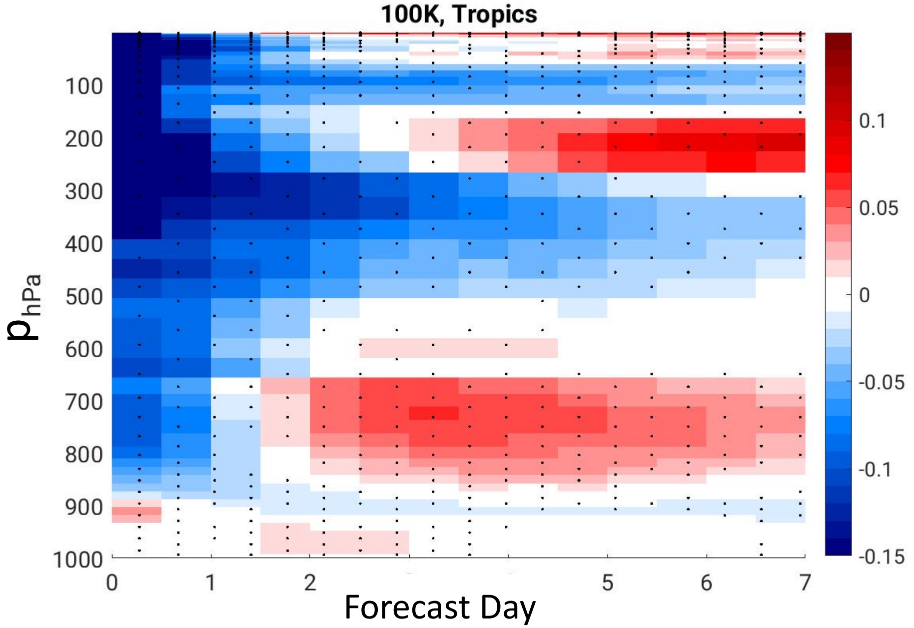
NH Extratropics, 100 k



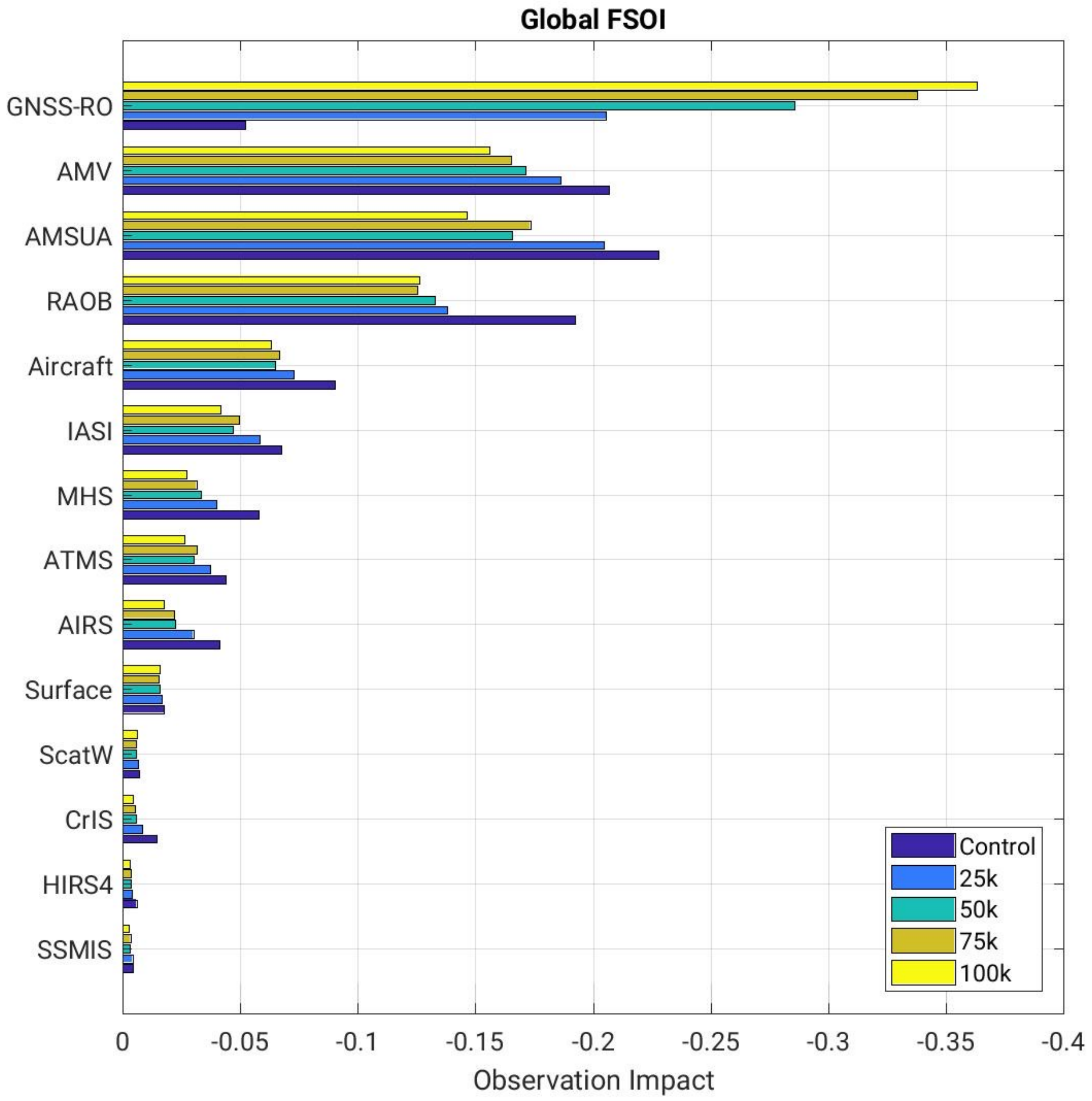
SH Extratopics, 100k



Tropics, 100k



Forecast Sensitivity – Observation Impact



FSOI estimate using global Total Wet Energy norm for 24 hour forecast error

Large increase in GNSS-RO impacts for 25k soundings/day

Diminishing returns from 50-100k

Increased GNSS-RO draws from most radiance and conventional types

Takeaway

- GNSS-RO impacts start to show leveling off beyond 50k soundings per day but saturation of information has not occurred at 100k
- Sensitivity to seasonal/humidity related observation errors in the troposphere can result in suboptimal impacts
- GSI weighting function for GNSS-RO may warrant improvement
- Recent publication: Privé, N. C., R. M. Errico, and A. El Akkraoui, 2022. **Investigation of the potential saturation of information from Global Navigation Satellite System Radio Occultation observations with an observing system simulation experiment** . *Monthly Weather Review*, **150** (6), 1293-1316. doi:10.1175/MWR-D-21-0230.1