The Global Observing System in the Assimilation Context

Atmosphere, Ocean, Land surface

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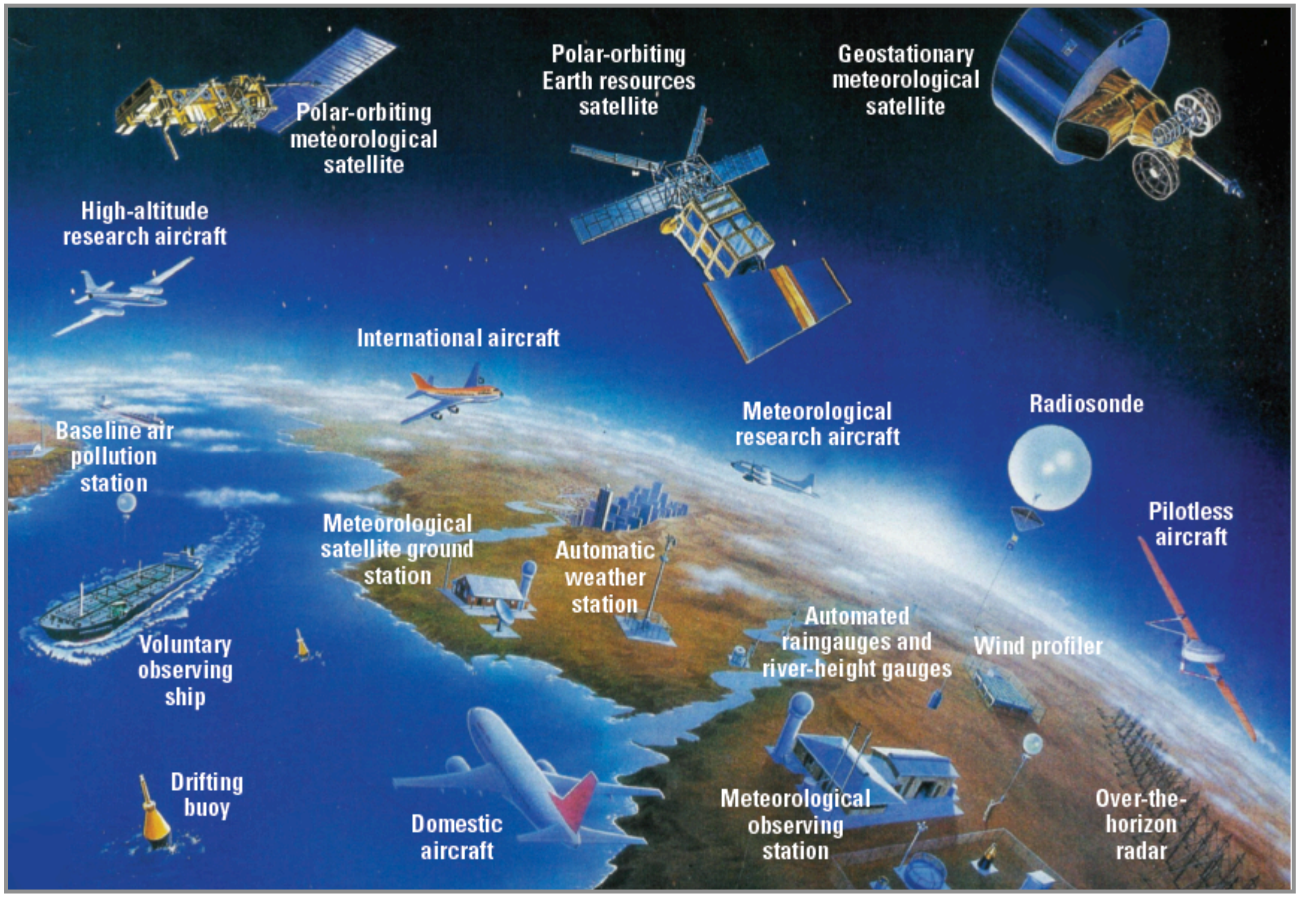
NASA Global Modeling and Assimilation Office

ECMWF Seminar
Data Assimilation for Atmosphere and Ocean
6-9 September 2011

Some of the components of the WMO Integrated Global Observing System



From WMO

From WIGOS flyer

Surface-based:

~11,000 land stations observing at least 3 hrly;

~4,000 VOS with ~ 1,000 reports daily, and

~1,200 drifting buoys (~14K SLP obs and 27K SST obs daily)

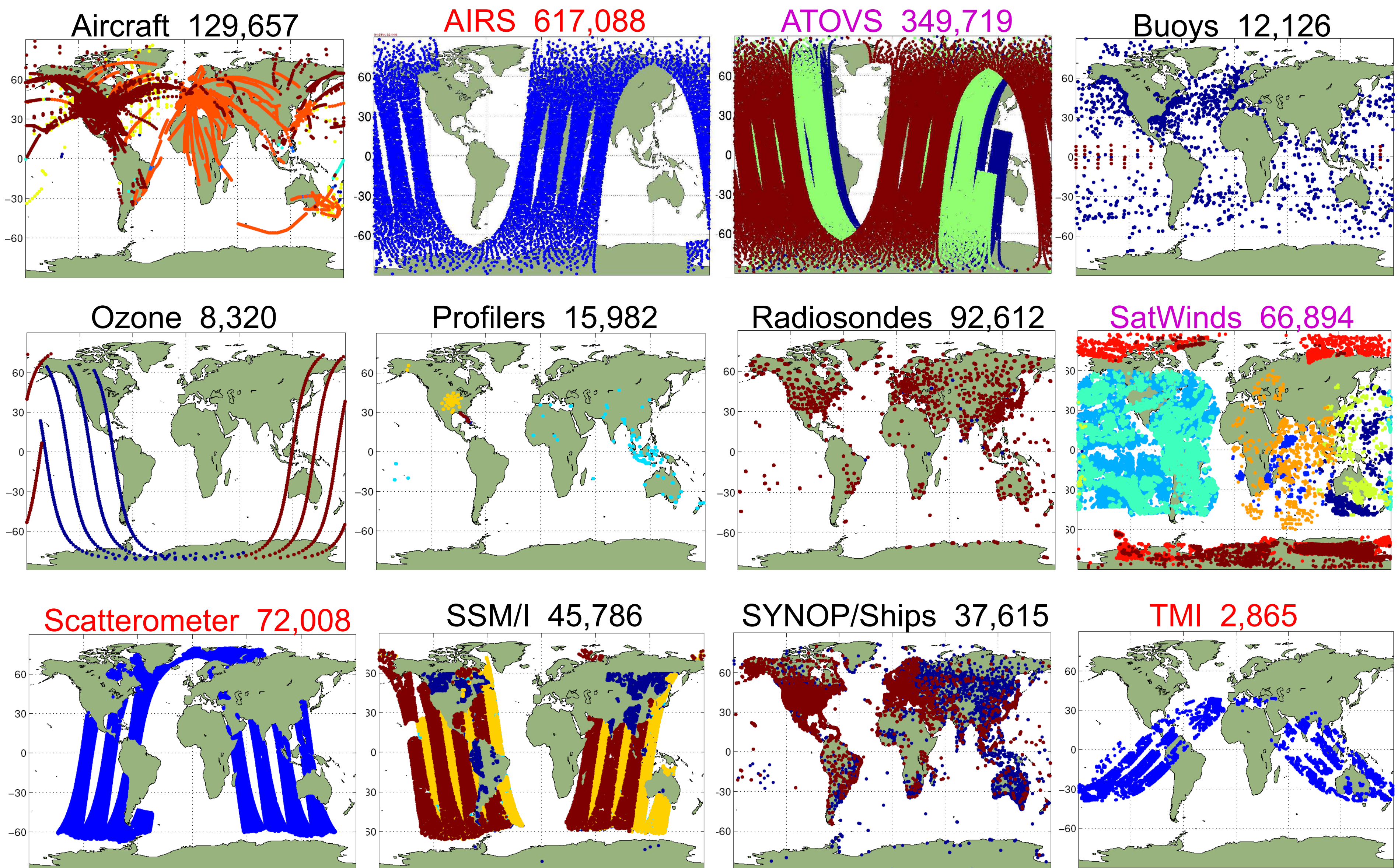
Upper air: ~1,300 stations with over 1,500 reports daily; ~ 300K aircraft reports

~ 268 Earth observation satellites with ~413 instruments

Main Observing Systems Assimilated in GEOS-5

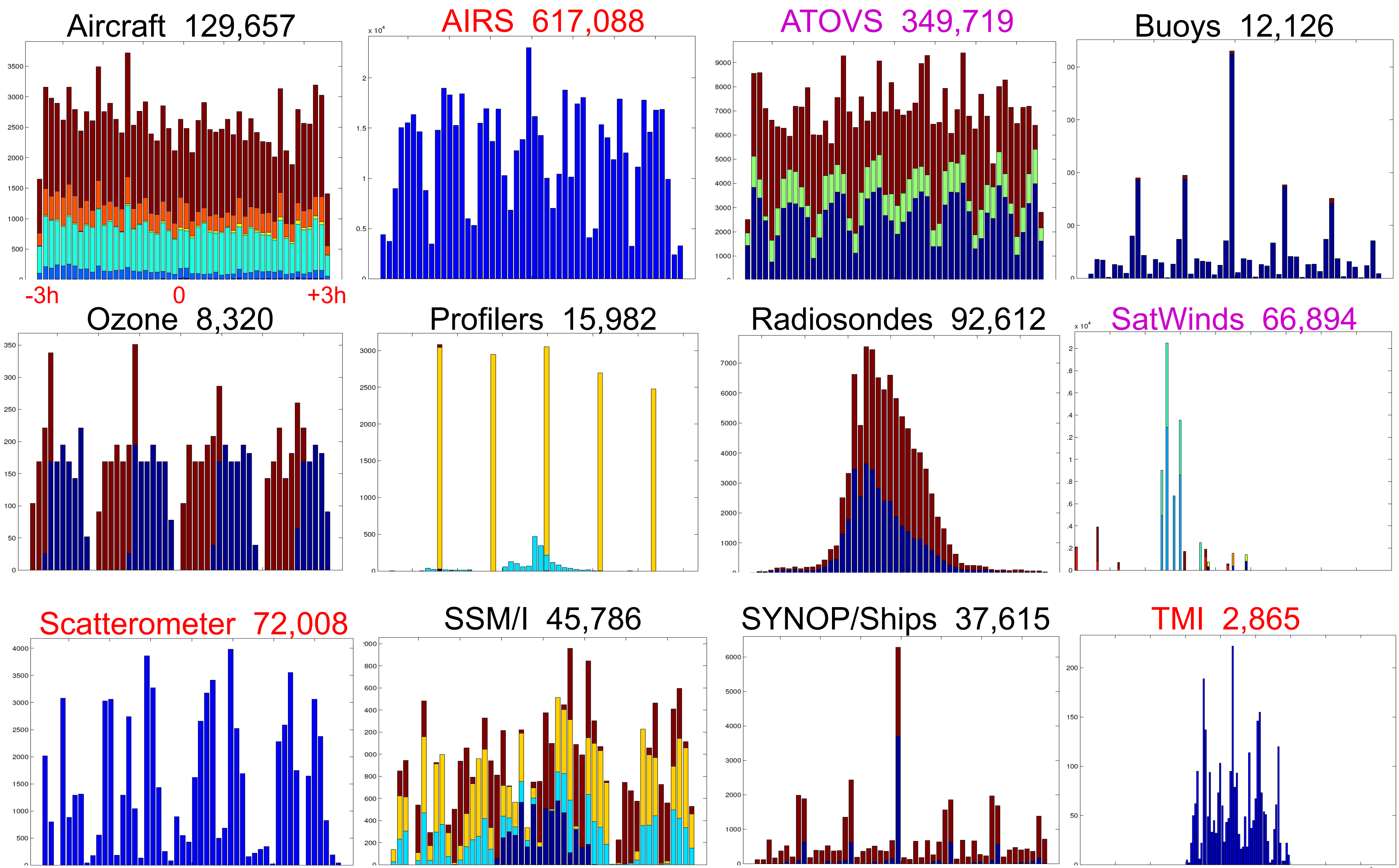
6-hr window centered at 00 UTC 11 Nov 2007

Operational
Research
Operational+Research



Temporal Distribution of Observations in the Assimilation Window

6-hr window centered at 00 UTC 11 Nov 2007



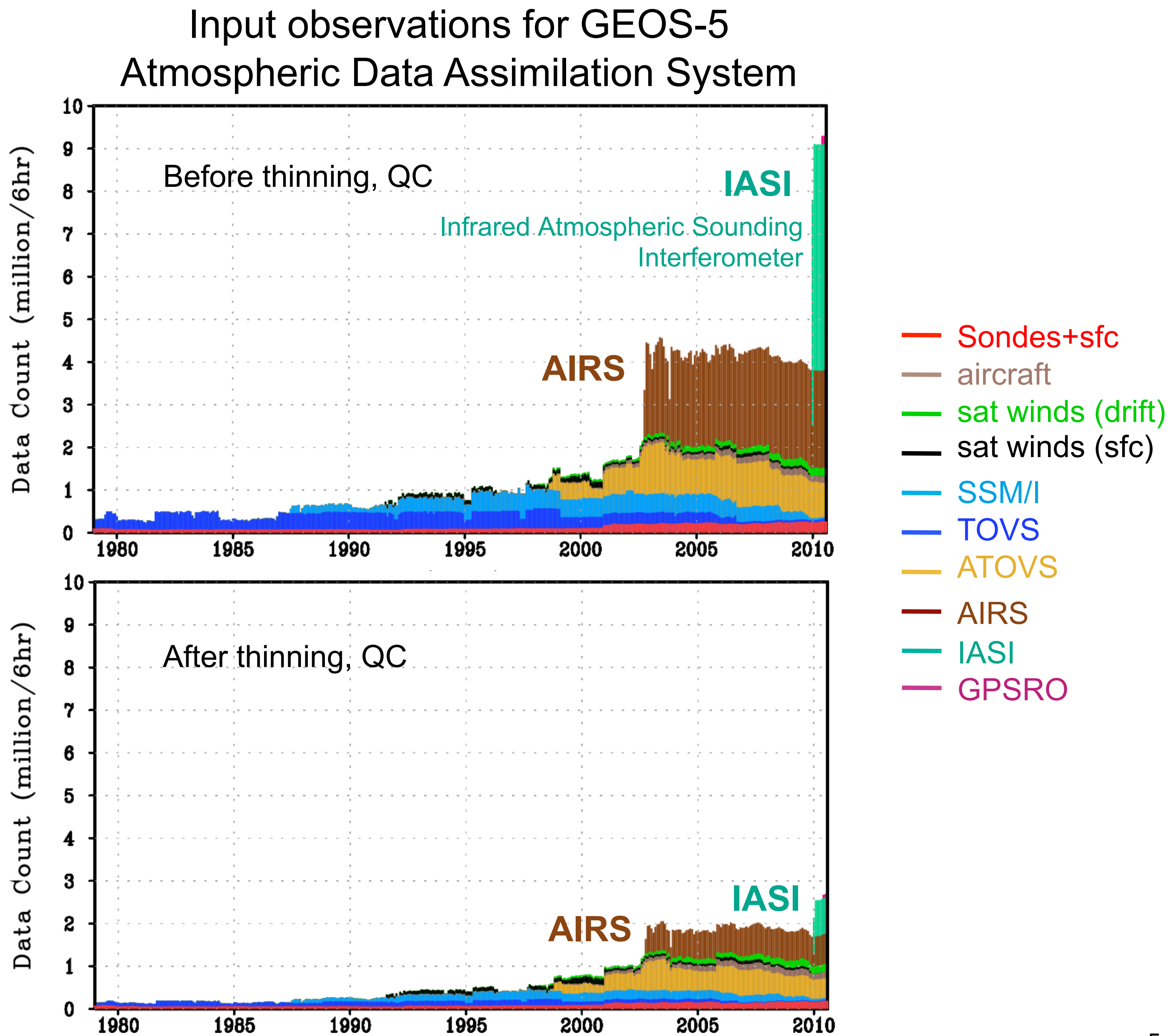
Data Assimilation in the Era of Hyper-Spectral Satellites

Observations processed per 6h

1979 – 2011

Observations used per 6h

1979 – 2011



From The Space-Based Global Observing System in 2011, B. Bizzarri, Sept 2011:

WMO: "Vision for the GOS in 2025"

The system of operational meteorological satellites in geostationary and sun-synchronous orbits should include:

- at least 6 geostationary satellites, separated by no more than 70°;
- satellites in 3 sun-synchronous orbital planes (AM, PM and Early Morning);
- comparable quality across systems through inter-calibration

The current operational meteorological *geostationary satellite system* includes:

European Meteosat
USA's GOES
Japanese Himawari (formerly GMS, currently MTSAT)
Russian Electro (formerly GOMS)
Chinese FY-2 to be replaced by FY-4
Indian INSAT and Kalpana (formerly MetSat)
Korean COMS.

The current operational meteorological *sun-synchronous satellite system* includes:

USA's civilian POES
USA's military DMSP
EUMETSAT Polar System
Russian Meteor
Chinese FY-1 being replaced by FY-3.

How well are we using existing observations? What observations should be made for NWP…?

Assimilation systems provide input to observing system investments:

Observing System Experiments (OSEs) – data denial experiments

Observation impacts using Assimilation Adjoint tools

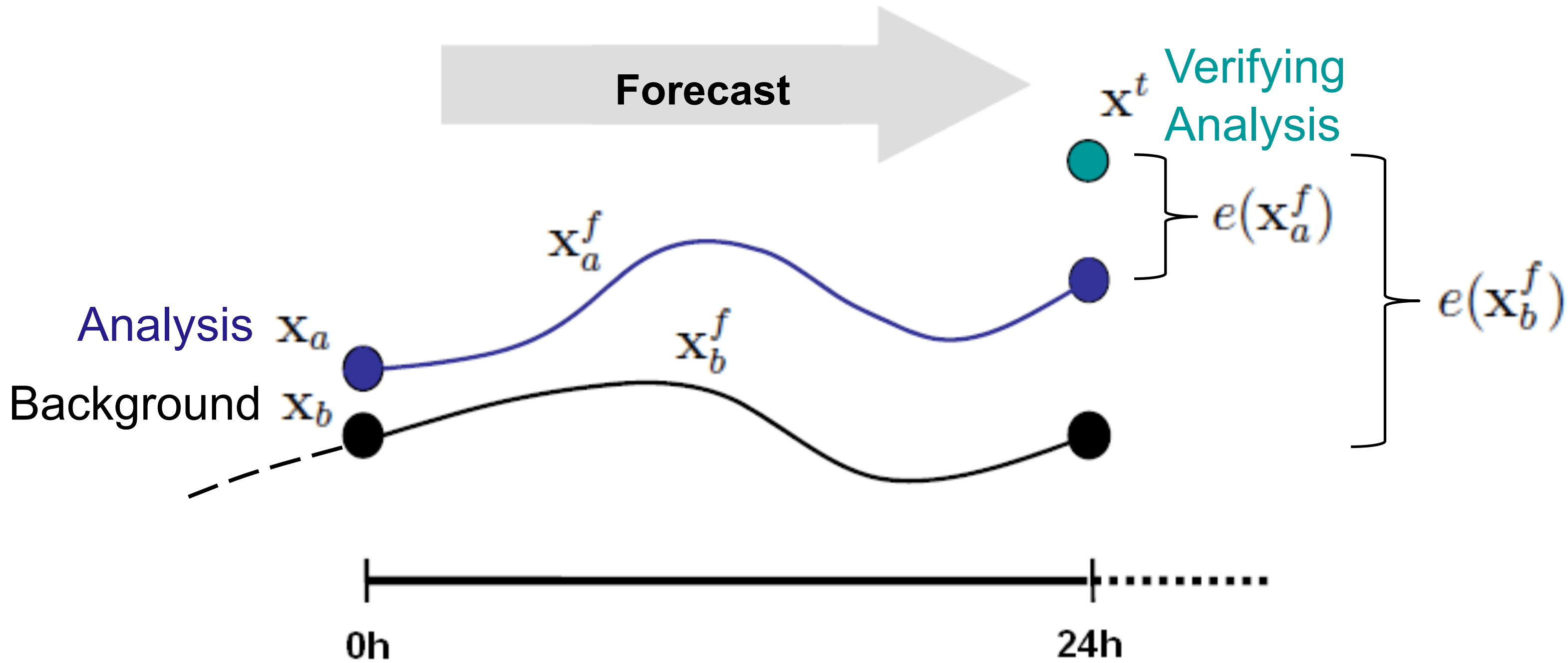
Observing System Simulation Experiments (OSSEs) – for new instruments

Assimilation Adjoint Tools are very powerful:

- evaluate impacts of all observations on a selected measure of short-range forecast error
- impact observation by observation, channel by channel
- provides information on the assimilation system as well as the observations
- can be run routinely as part of the operational system

Definition of Observation Impact

following Langland and Baker (2004)



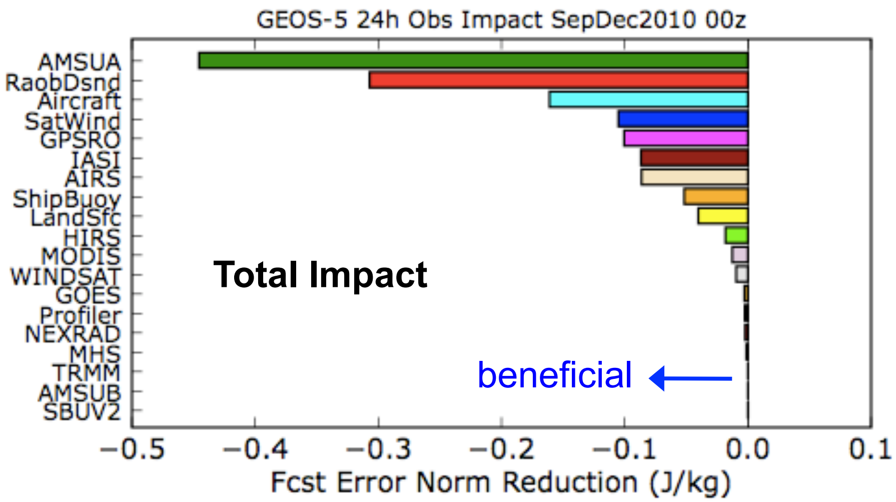
Forecast Error Measure: $e = (\mathbf{x}^f - \mathbf{x}^t)^{\mathrm{T}}\mathbf{C}(\mathbf{x}^f - \mathbf{x}^t)$

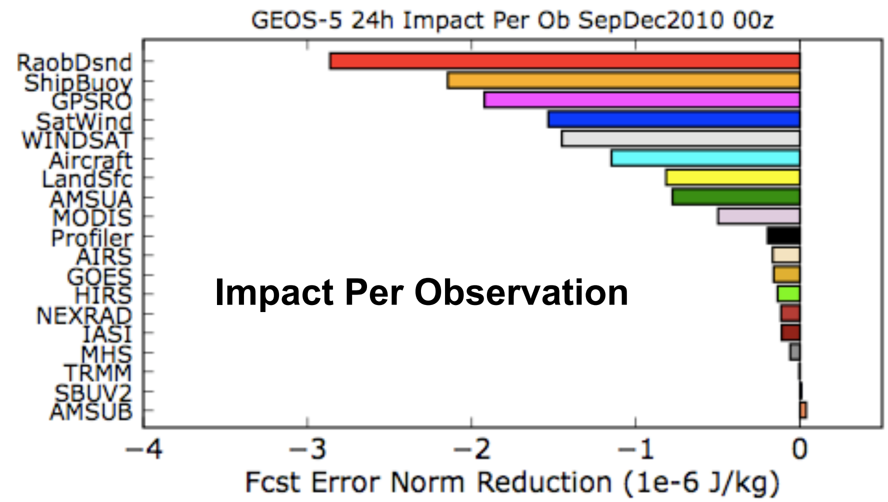
Observation Impact: $\delta e = e(\mathbf{x}_a^f) - e(\mathbf{x}_b^f)$

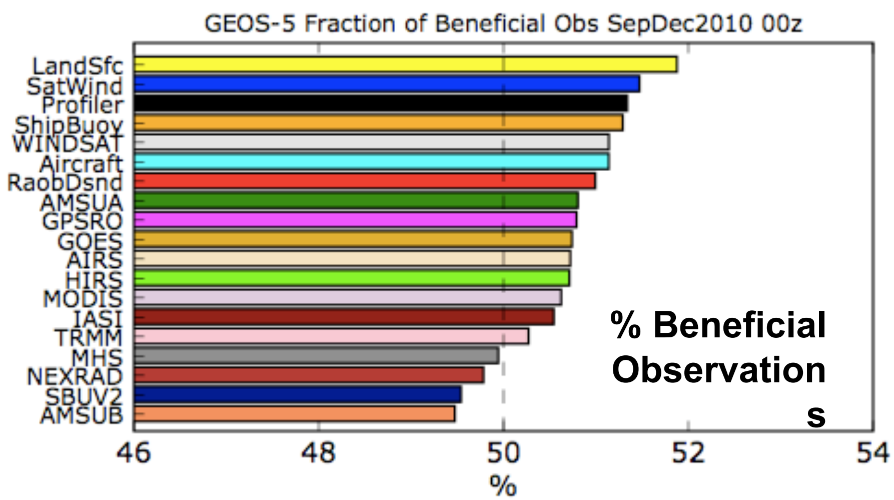
- **Global 24-h forecast error measure, sfc-150 hPa**
- **Dry total energy norm** (u, v, T, p_s ➙ J/kg)
- **Dry adjoint model physics ⇒** *impacts of moisture observations likely under-represented in current results and should be interpreted with proper caution*

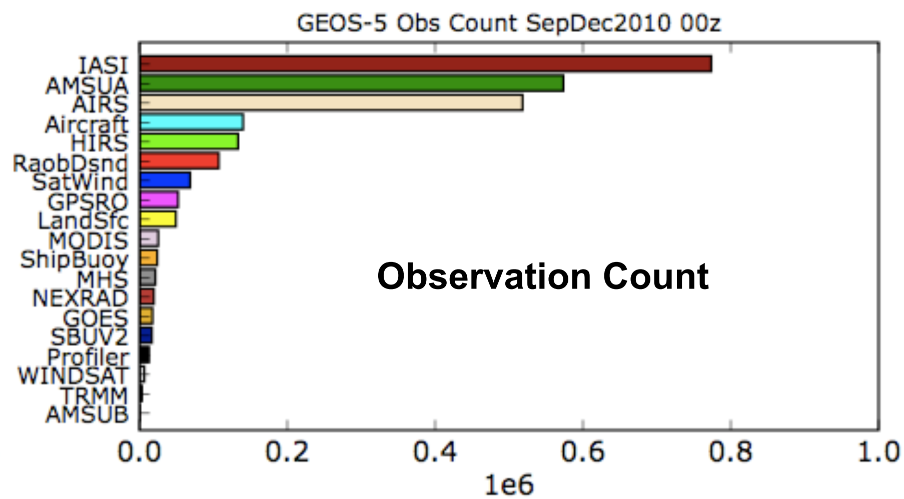
Daily Average Impacts of Various Observing Systems in GEOS-5

01 Sep – 31 Dec 2010 00z



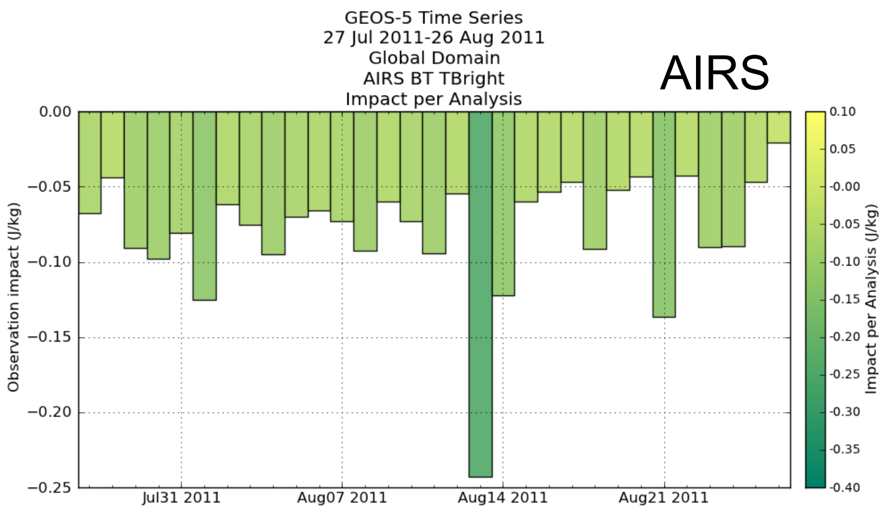


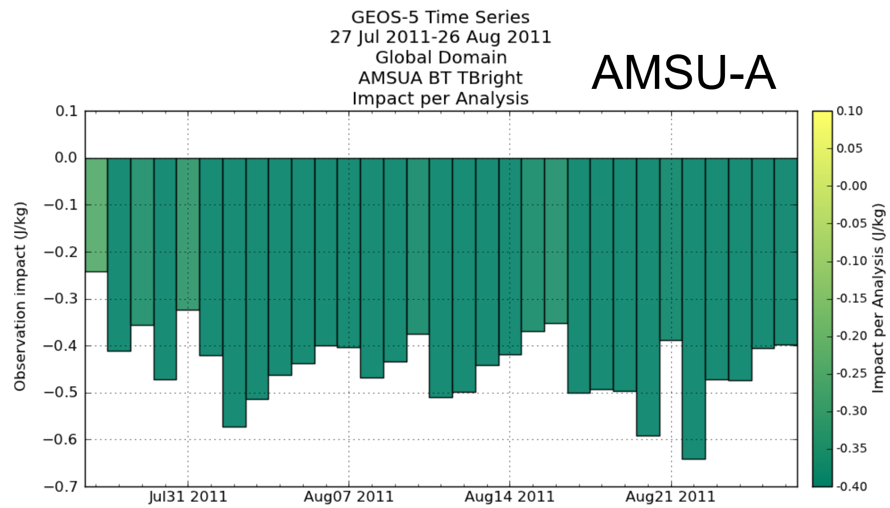


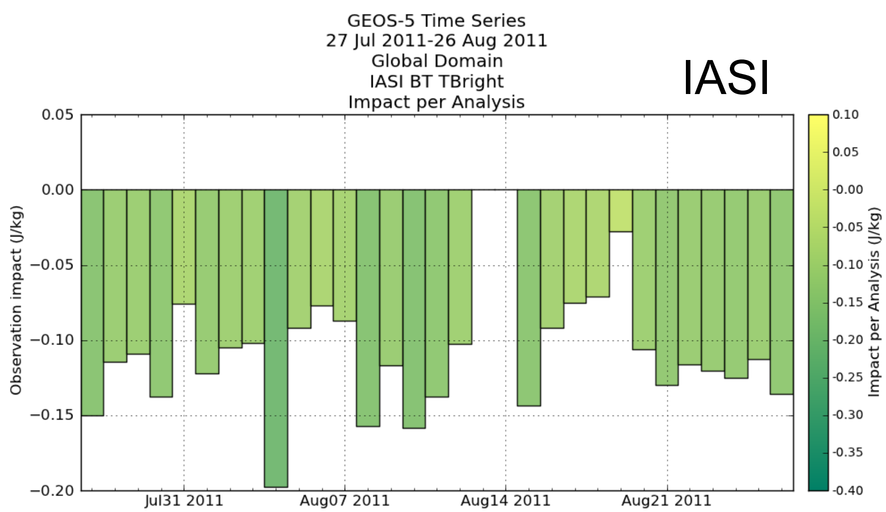


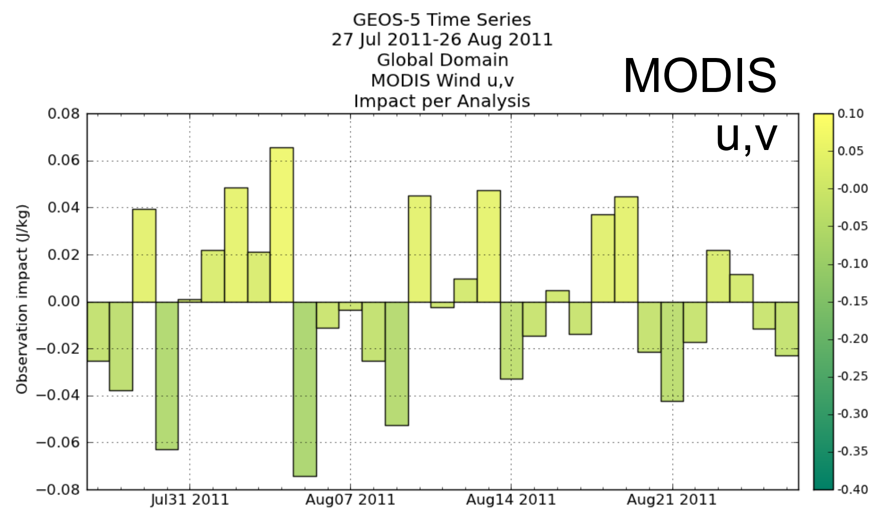
NRT Monitoring of Observation Impact

Current <u>1-Month</u> Time Series of 24-h Global Forecast Error Reduction





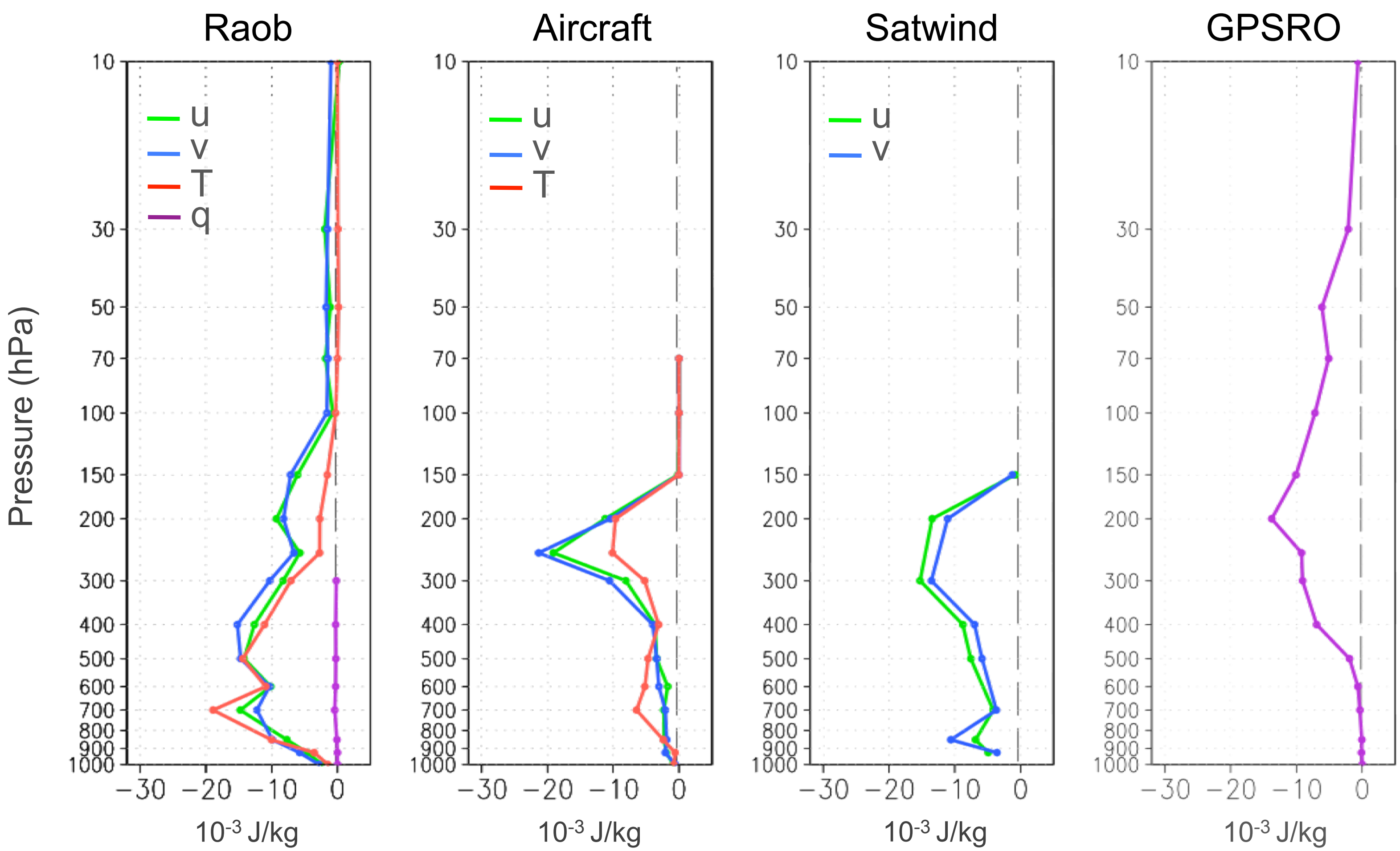




- *Negative values indicate beneficial impact*
- *Color coding denotes magnitude*

Impact of Selected **Non-Radiance Data Types by Level**

GEOS-5 01 Sep – 31 Dec 2010 00z



GPSRO data in the lower stratosphere (150 – 50 hPa) provide substantial benefit in terms of the tropospheric impact measure δe used here

SOME GAPS

Gap analysis for post-2020 observing system – Vol. 3 of The Space-Based Global Observing System in 2011, B. Bizzarri, Sept 2011.

also

Statement of Guidance for Global Numerical Weather Prediction (updated by J. Eyre, Dec 2008):

The critical atmospheric variables that are not adequately measured by current or planned systems are (in order of priority):

- wind profiles at all levels;
- temperature and humidity profiles of adequate vertical resolution in cloudy areas;
- precipitation;
- snow equivalent water content.

- Satellite sounding data are currently under-utilised over land
- Surface pressure is not observed by present or planned satellite systems (RO, OCO-2?)
- NWP centres would benefit from more timely availability of all observations, in particular satellite data, and from several types of in situ measurement that are made but not currently disseminated globally (e.g., soil moisture).

OSSE for Doppler Wind Lidar

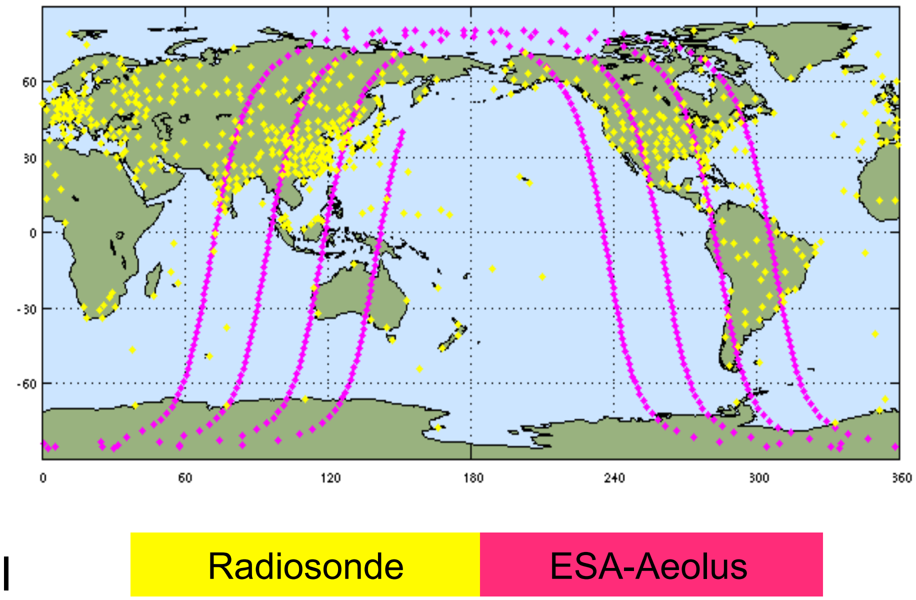
First investigation of new data type using GMAO's GEOS-5 OSSE capability

Doppler Wind Lidar Concept

- Lidar backscatter is Doppler-shifted by a scattering agent
- Improved accuracy in height assignment

Spaceborne Doppler Wind Lidar

- Global wind measurements, 3D
- ESA **Aeolus** (2013) single horizontal wind component
- NASA **3D-Winds** (NRC Decadal Survey recommendation) full horizontal wind



Observation Locations

Assimilation Results: OSSE Baseline + Wind Lidar

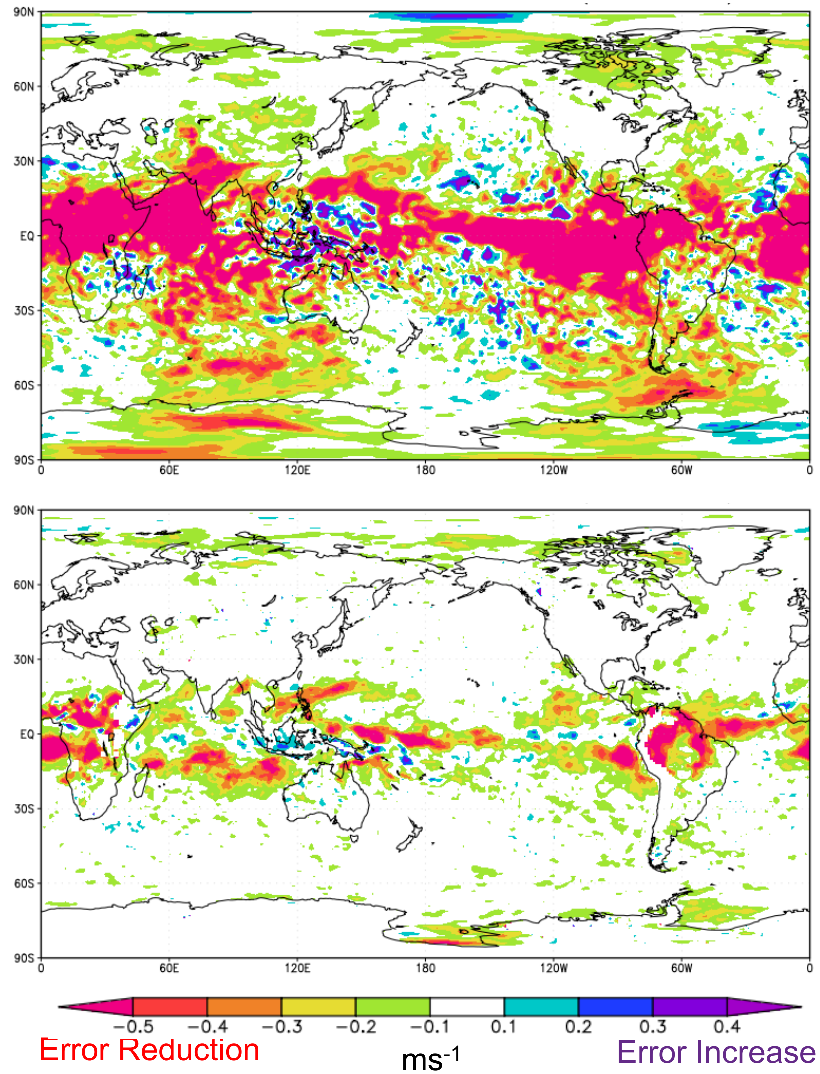
Simulated ESA-Aeolus Observations

- ECMWF nature run plus GOCART aerosols
- LIPAS Aeolus simulator developed at KNMI

Impact on zonal wind RMS analysis error (vs. nature run)

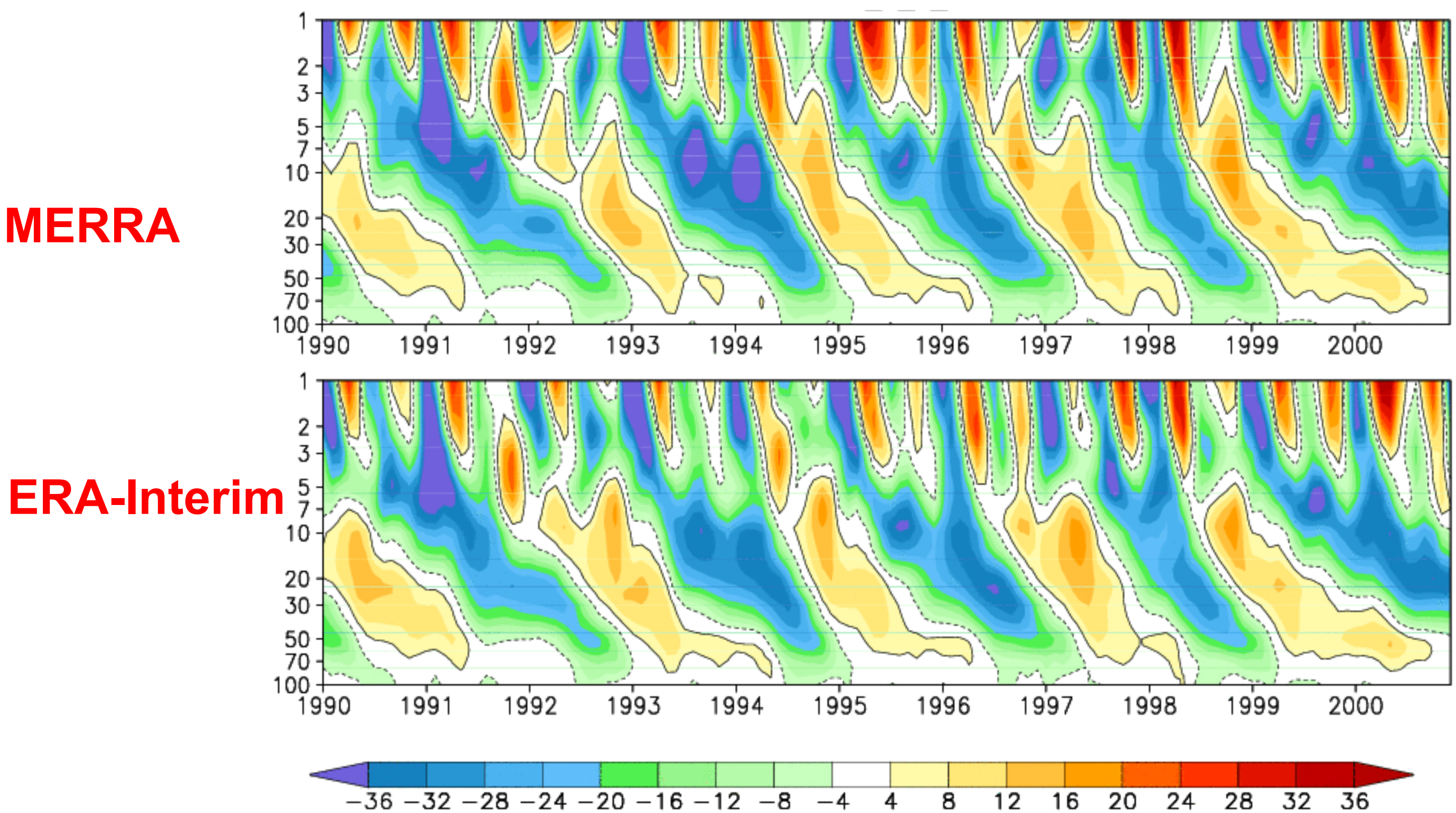
- Assimilation of wind lidar retrievals has overall modest positive impact, especially in the tropics and SH
- Largest impacts at upper levels
- Rayleigh (clear-sky) channel dominates aloft, both Rayleigh and Mie (aerosol) contribute in lower atmosphere

Zonal Wind RMS Difference (DWL-CTL)



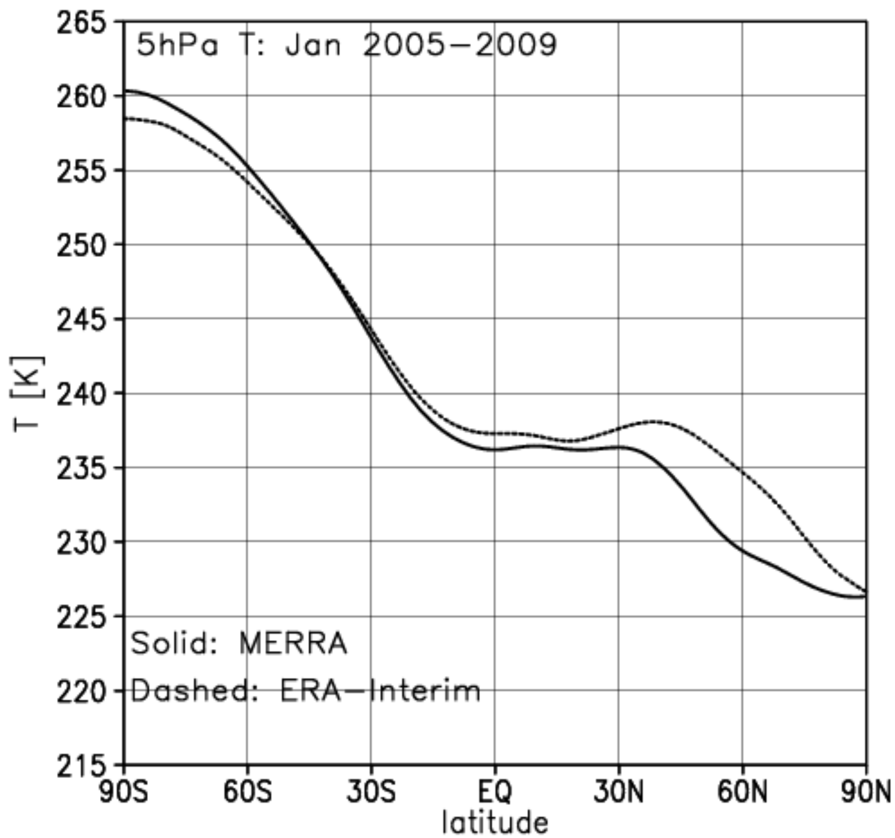
From Will McCarty, GMAO

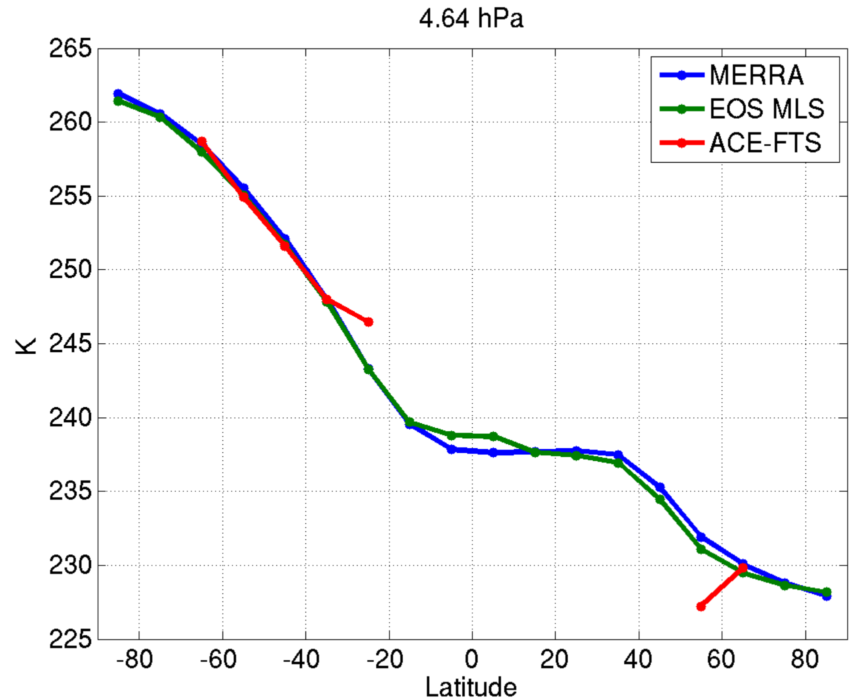
QBO and SAO from zonal mean zonal wind (10°S-10°N)



QBO well-constrained, but the SAO is not.
⇒ Upper stratospheric wind observations are needed in the tropics.

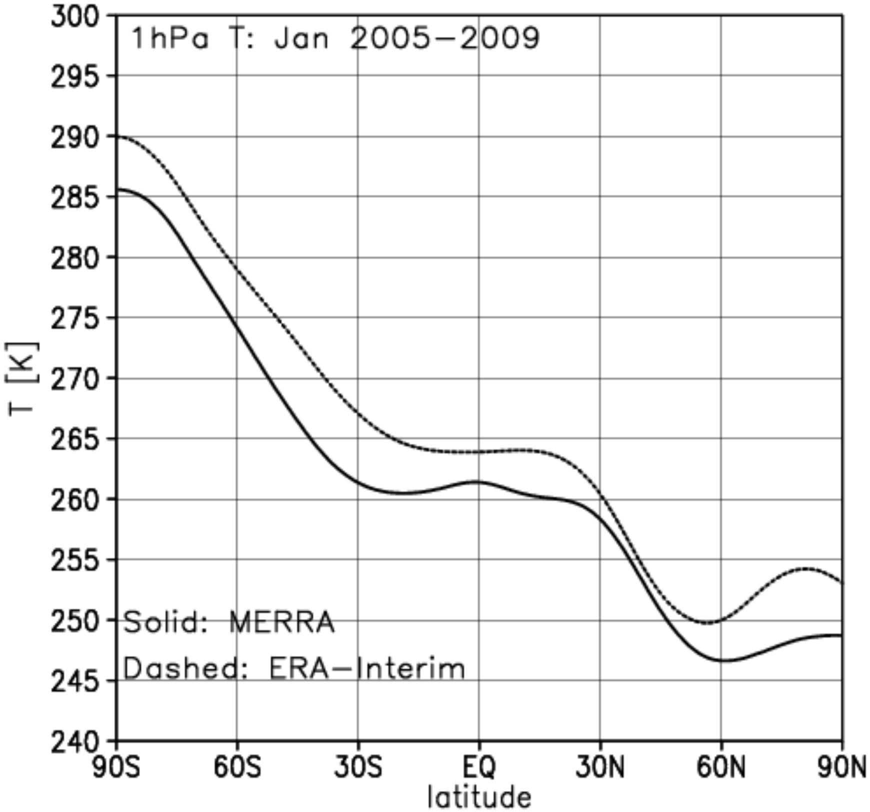
5 hPa T (2005-2009)
Comparison of MERRA and ERA-Interim with independent data

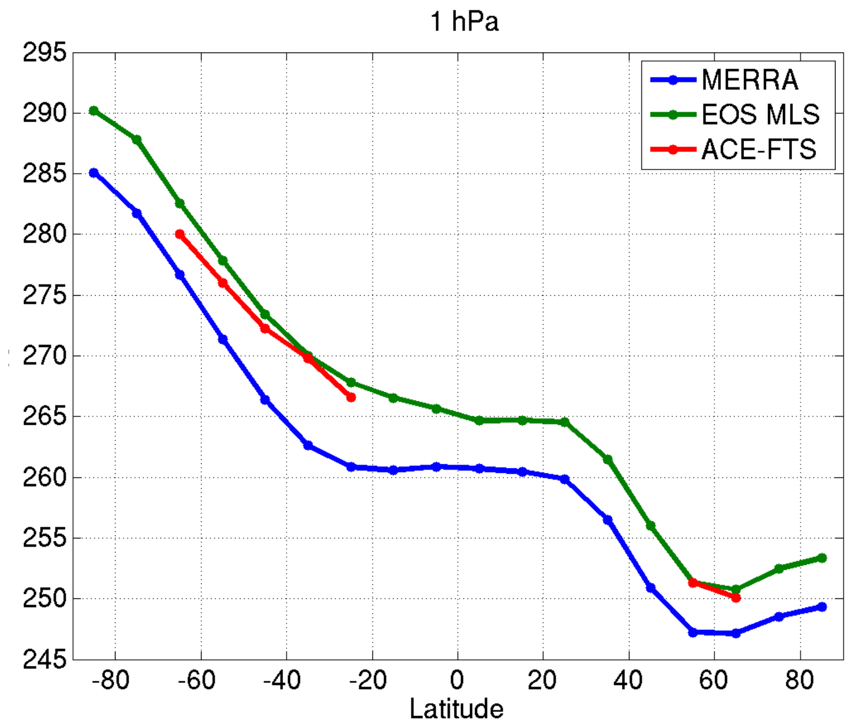




MERRA and ERA-Interim differ by several K (left).
Independent observations show a favorable comparison with MERRA (right).

1 hPa T (2005-2009)
Comparison of MERRA and ERA-Interim with independent data





ERA-Interim is in better agreement with independent data (EOS MLS and ACE FTS) at 1 hPa.

MLS provides detailed temperature (and ozone) structure from ~316 hPa to ~0.001 hPa with 3-14 km vertical resolution and would improve analyses in the upper atmosphere. After MLS? RO data not useful above 10 hPa.

ConcordIASI

A multi-year, multi-faceted international project for improving analysis and prediction in polar regions

Field Phase Sep-Dec 2010

• 30,000+ dropsondes deployed, many coincide with MetOp overpass + A-train

• Calibration/validation of IASI assimilation

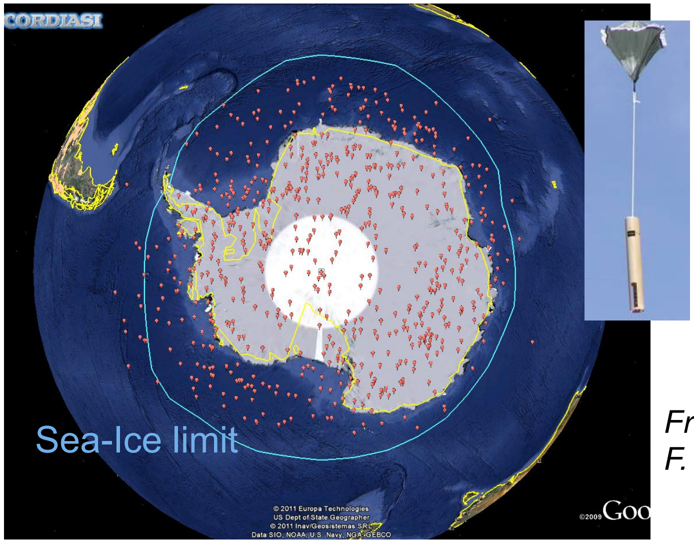
• Model validation

• **Comparison of monitoring statistics**

• **Data impact studies**

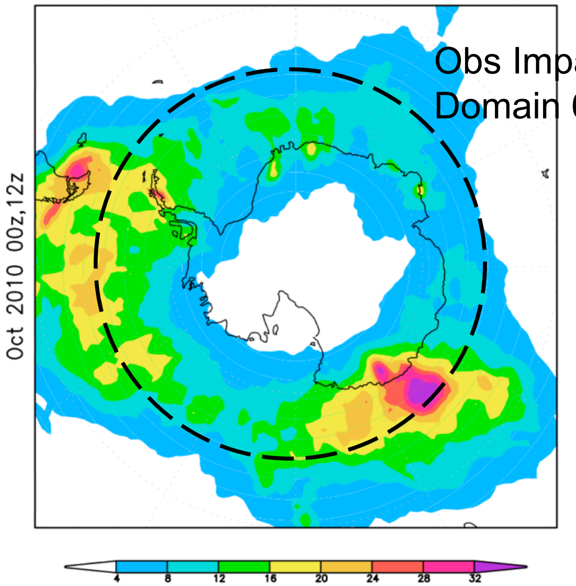
• **Intercomparison of sensitivity to observations**

ConcordIASI Dropsondes Sep-Dec 2010



From F. Rabier

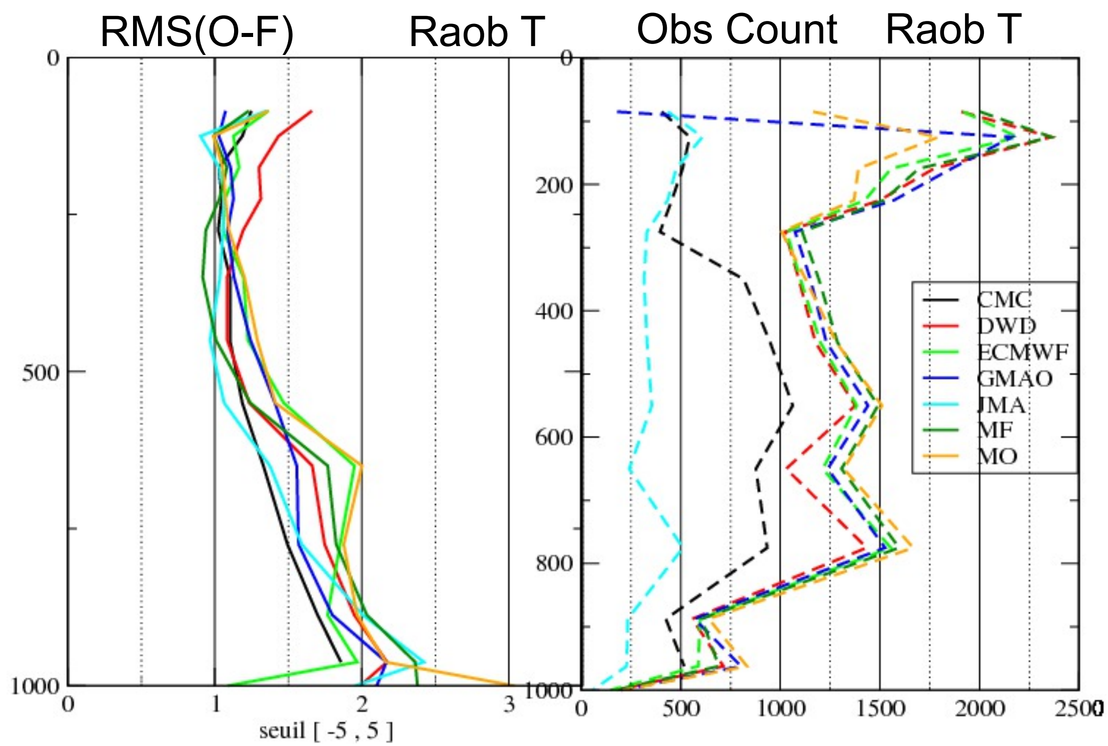
GEOS-5 24h Fcst Sensitivity



DAS Monitoring Statistics over the Antarctic

Radiosonde Background Temperature Departures (O-F)

Participants
CMC
DWD
ECMWF
GMAO
Météo-France
Met Office
JMA



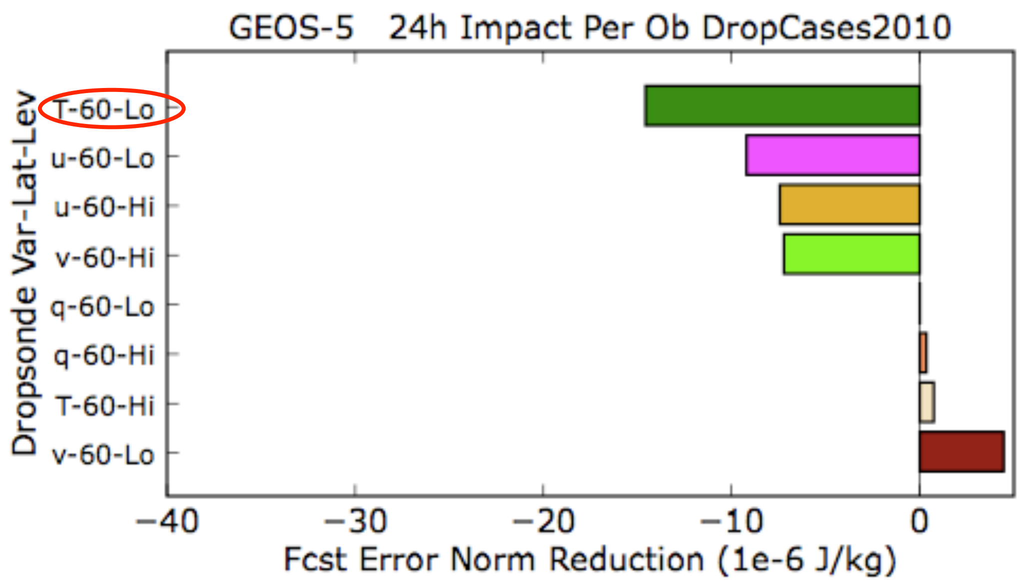
Courtesy F. Rabier, Météo-France

Models have difficulty predicting lowest-level temperatures

GEOS-5 Observation Impacts for Concordiasi

Dropsonde u,v,T,q – Averages for All Drop Cases

Impact Per-Observation: 60°-70°S



- 24-h forecasts at 00z and 12z (89 Drop cases)
- Dry total energy norm: **60°S-90°S, sfc – 50 hPa**
- Dry adjoint model physics

Plot Legend: **T – 80 – Lo**

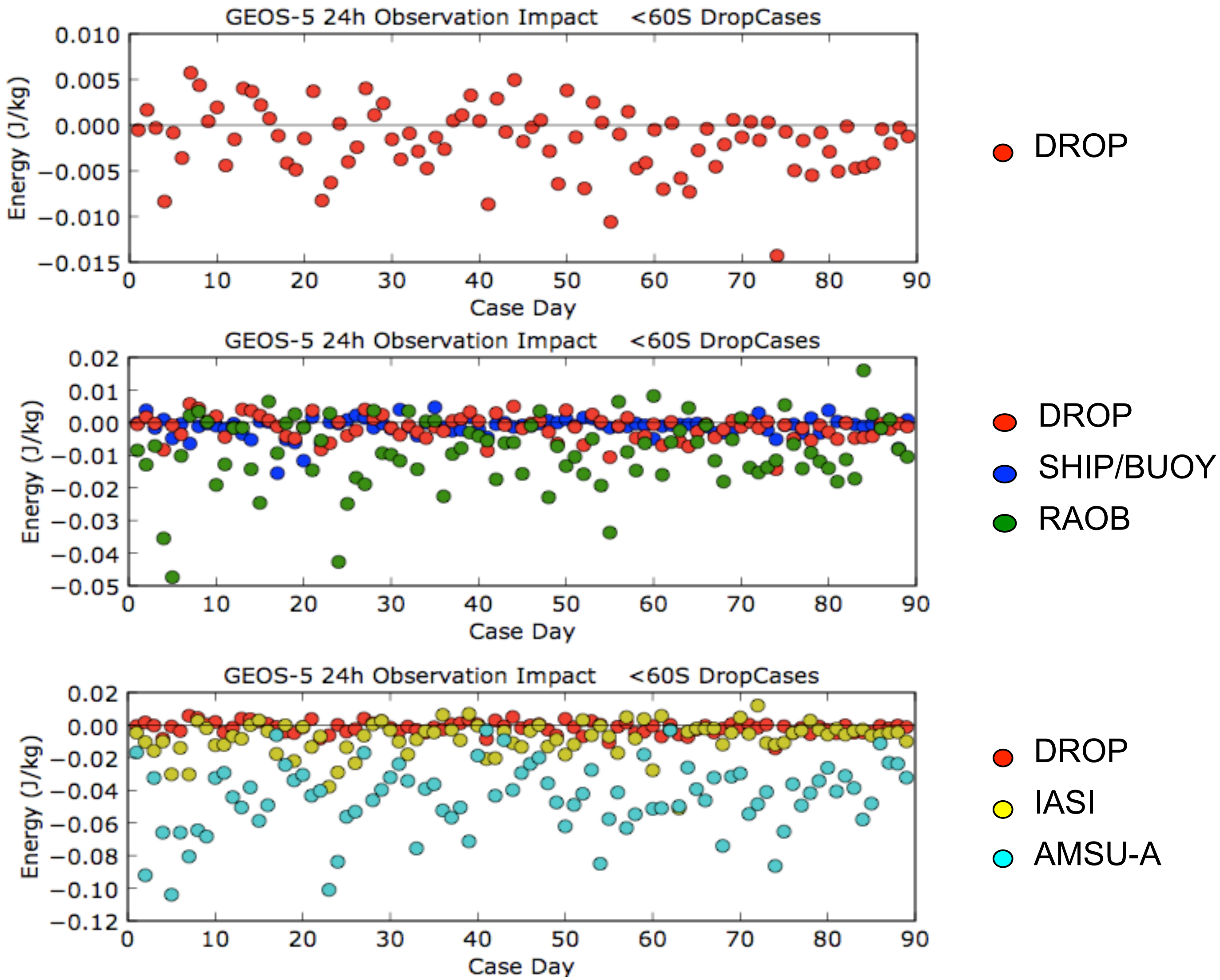
Data Type	Latitude Band	Pressure Layer
Raob	60 – 70°S (60)	≤ 400 hPa (Hi)
Drop	70 – 80°S (70)	> 400 hPa (Lo)
u, v, T, q	80 – 90°S (80)	

GEOS-5 24-h Observation Impacts for Concordiasi

Time Series of All Drop Cases – 60°S-90°S Observations

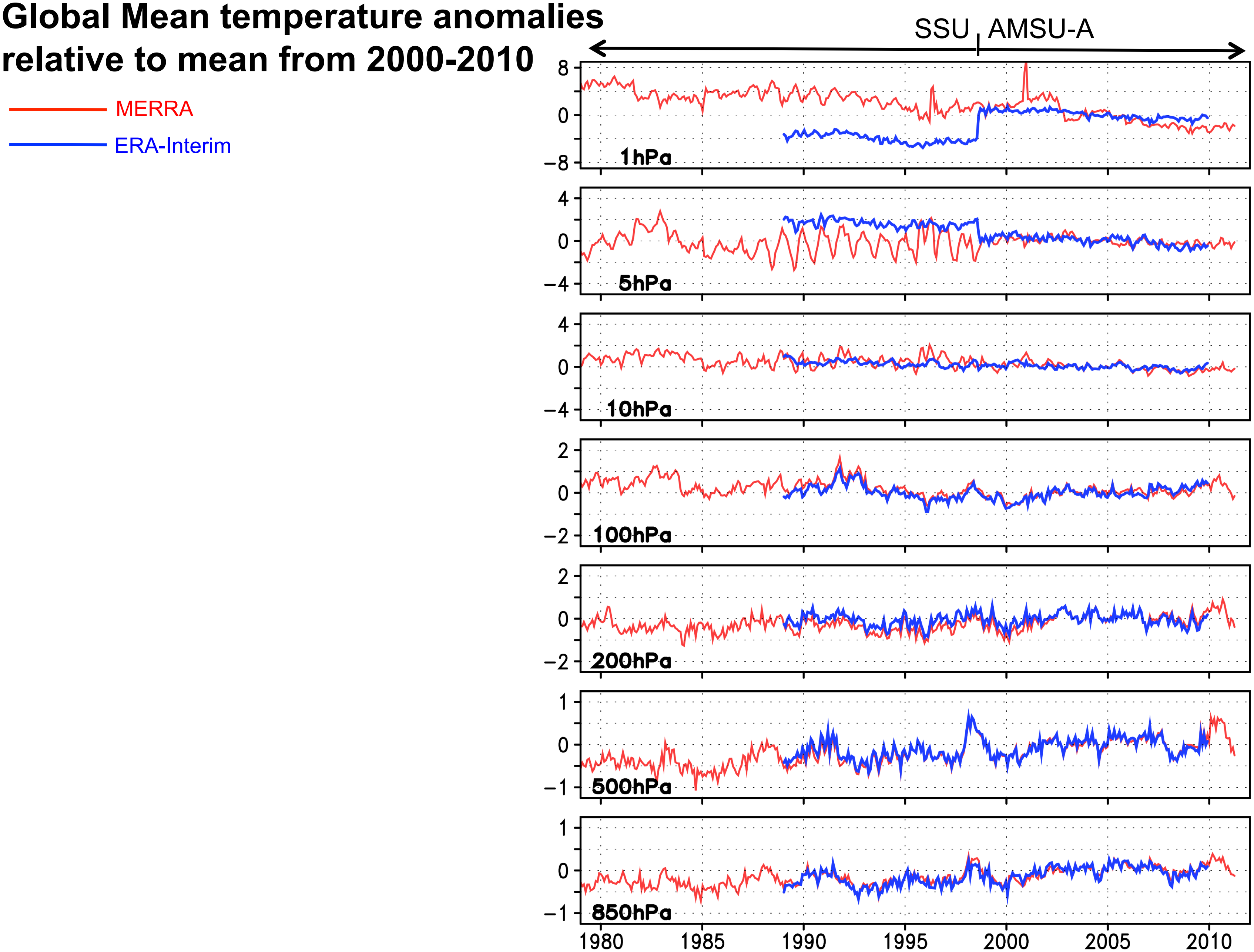
<u>Improved cases</u>

AMSUA	100%
IASI	85%
RAOB	79%
SHIP/BUO	72%
DROP	67%



ISSUES AS SEEN THROUGH REANALYSES

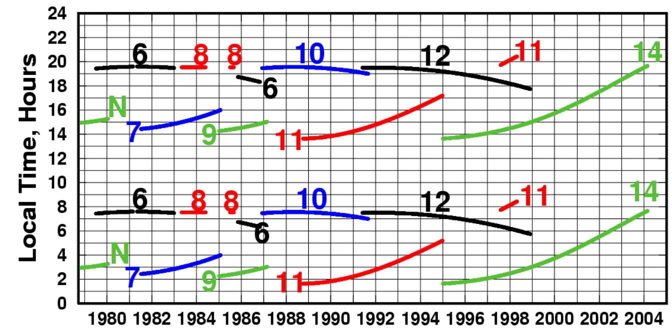
Global Mean temperature anomalies relative to mean from 2000-2010

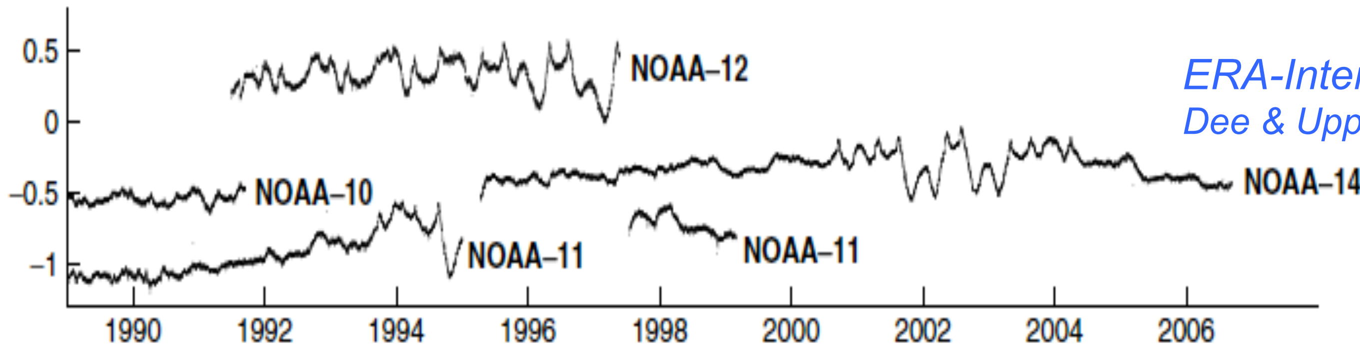


Variational Bias estimates for MSU Channel 2

Does cross-calibration have an impact in assimilation?

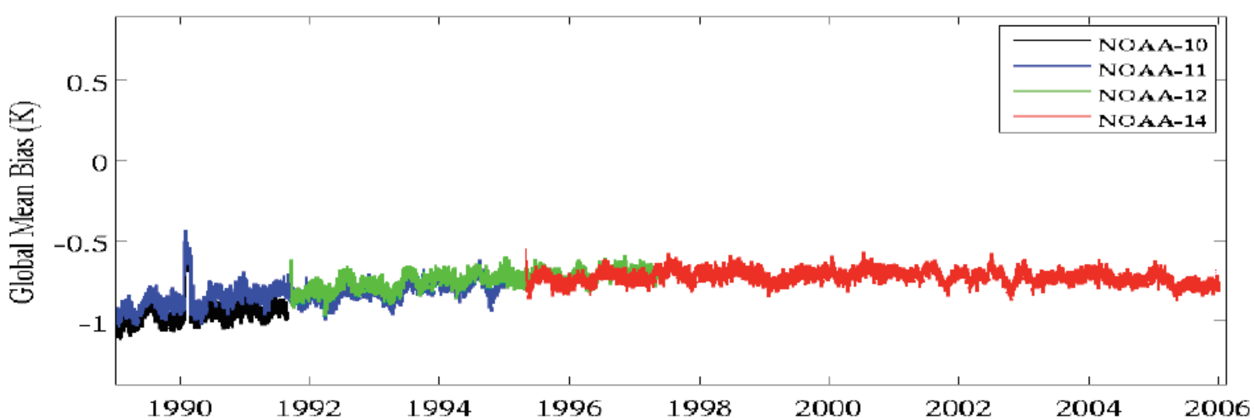
- Orbital drift leads to variations in the warm target
- VarBC is able to correct the resulting calibration errors





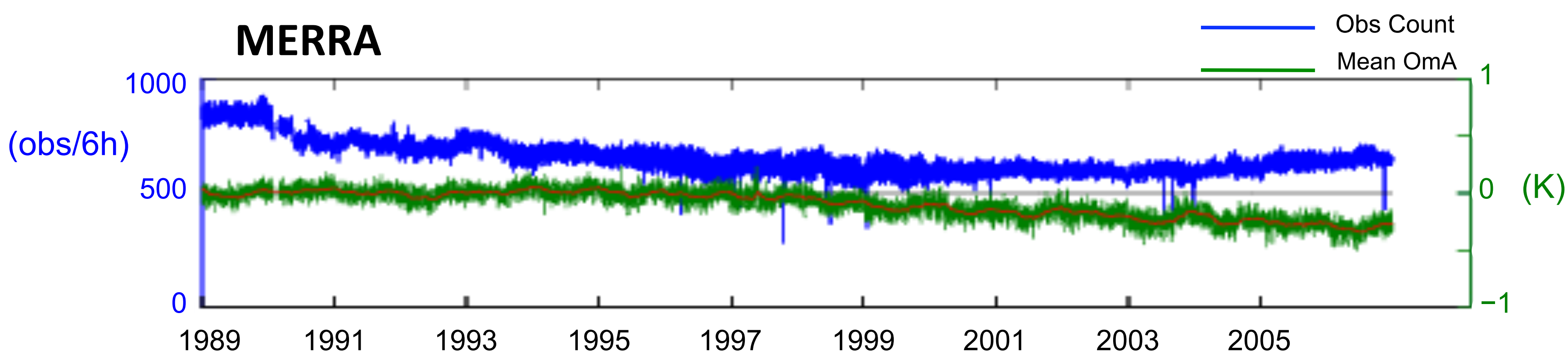
ERA-Interim

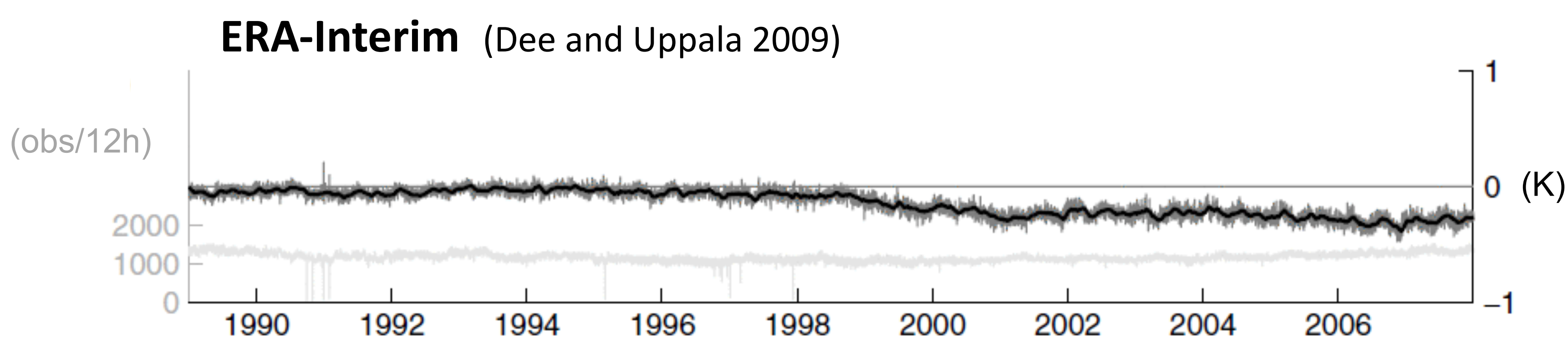
Dee & Uppala 2009



MERRA system used intercalibrated data from NESDIS (SNO matchups, Zou et al. 2006)

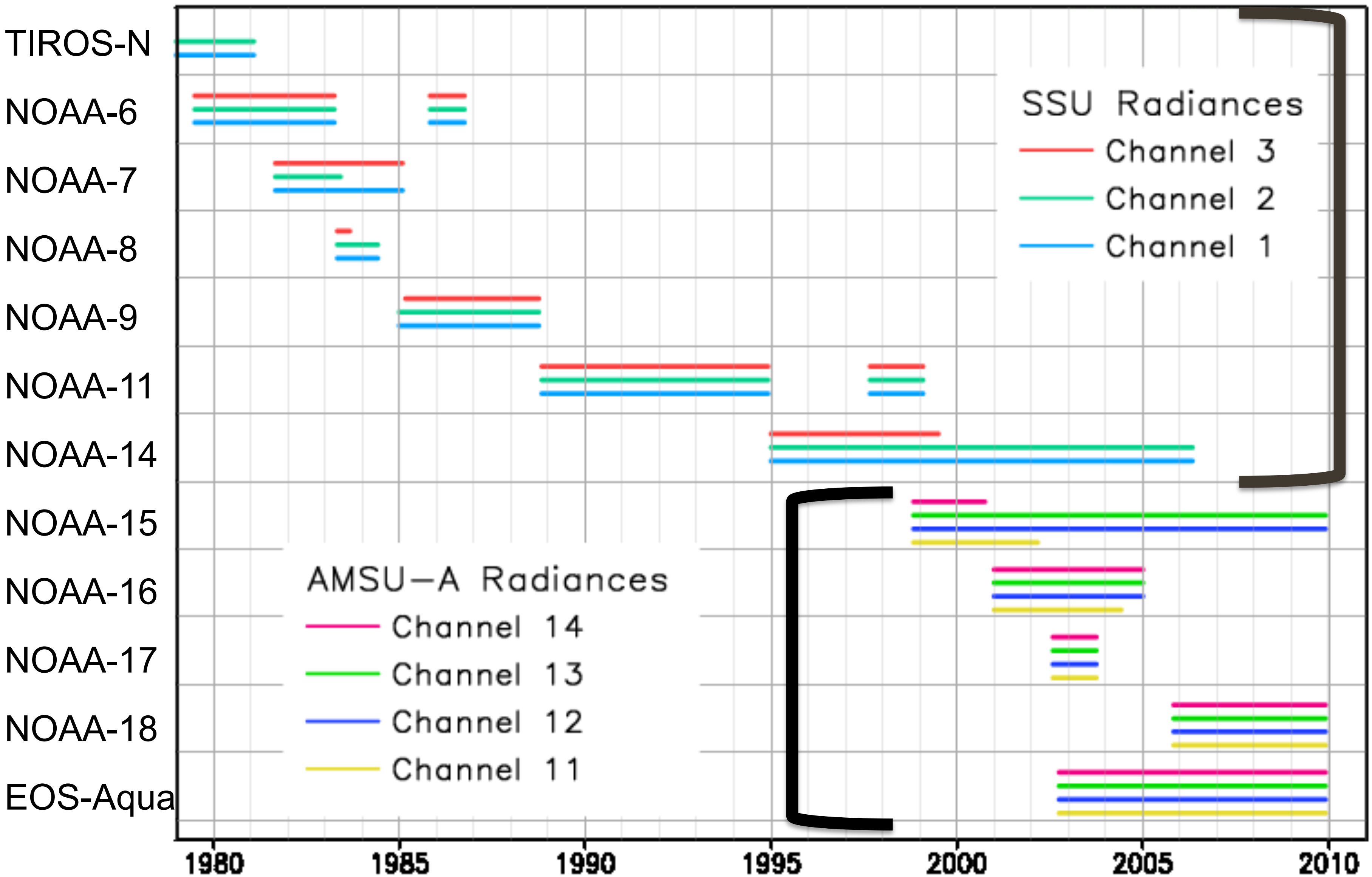
200 hPa Global Mean Analysis Departures (O-A) and Observation Counts for Radiosonde Temps



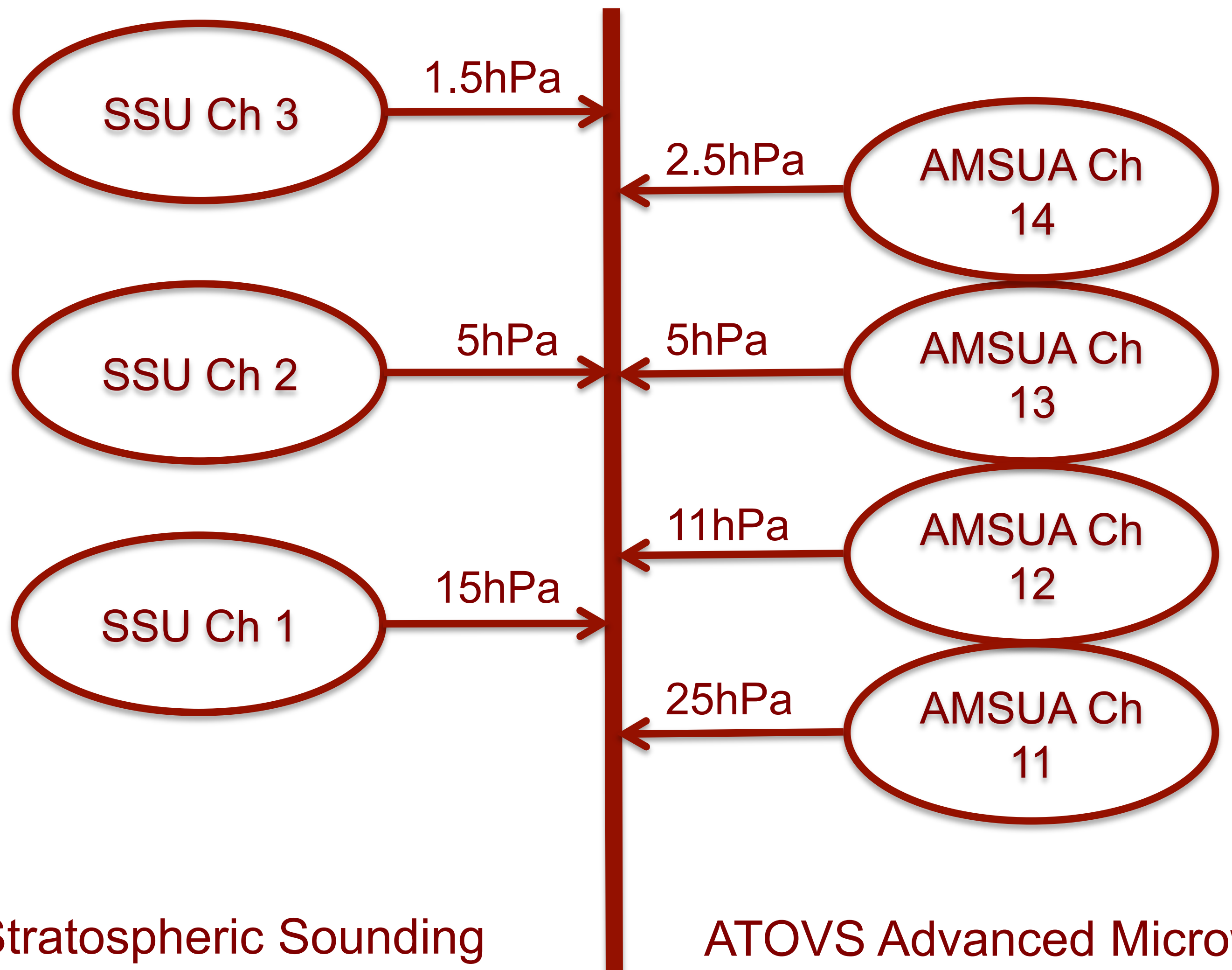


Influence of aircraft obs – known warm bias
Cardinali et al. (2003); Ballish & Kumar (2008)

Upper Stratospheric Observations



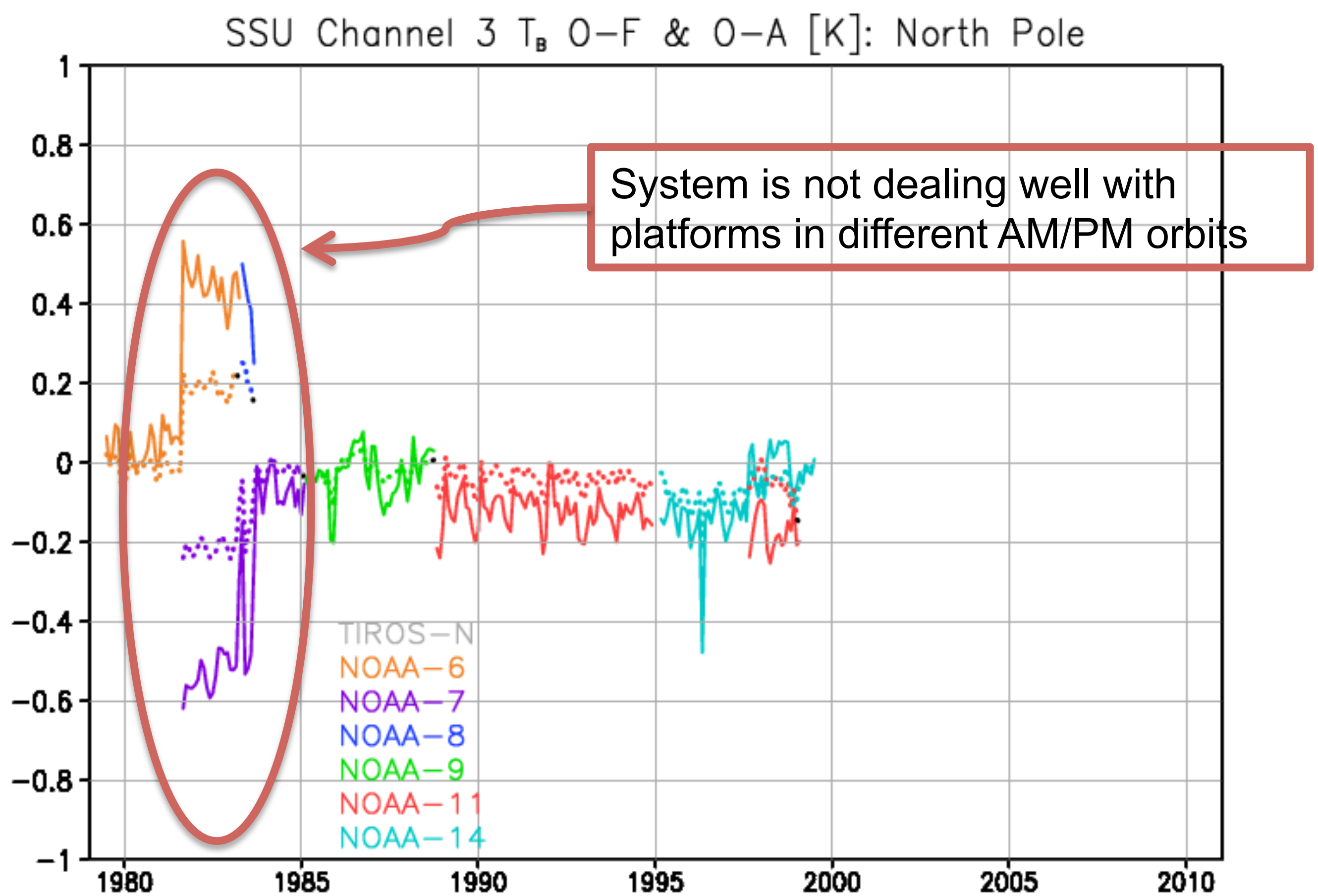
Upper Stratospheric Temperature Information



TOVS Stratospheric Sounding Units Measure Infrared Emission by CO_2

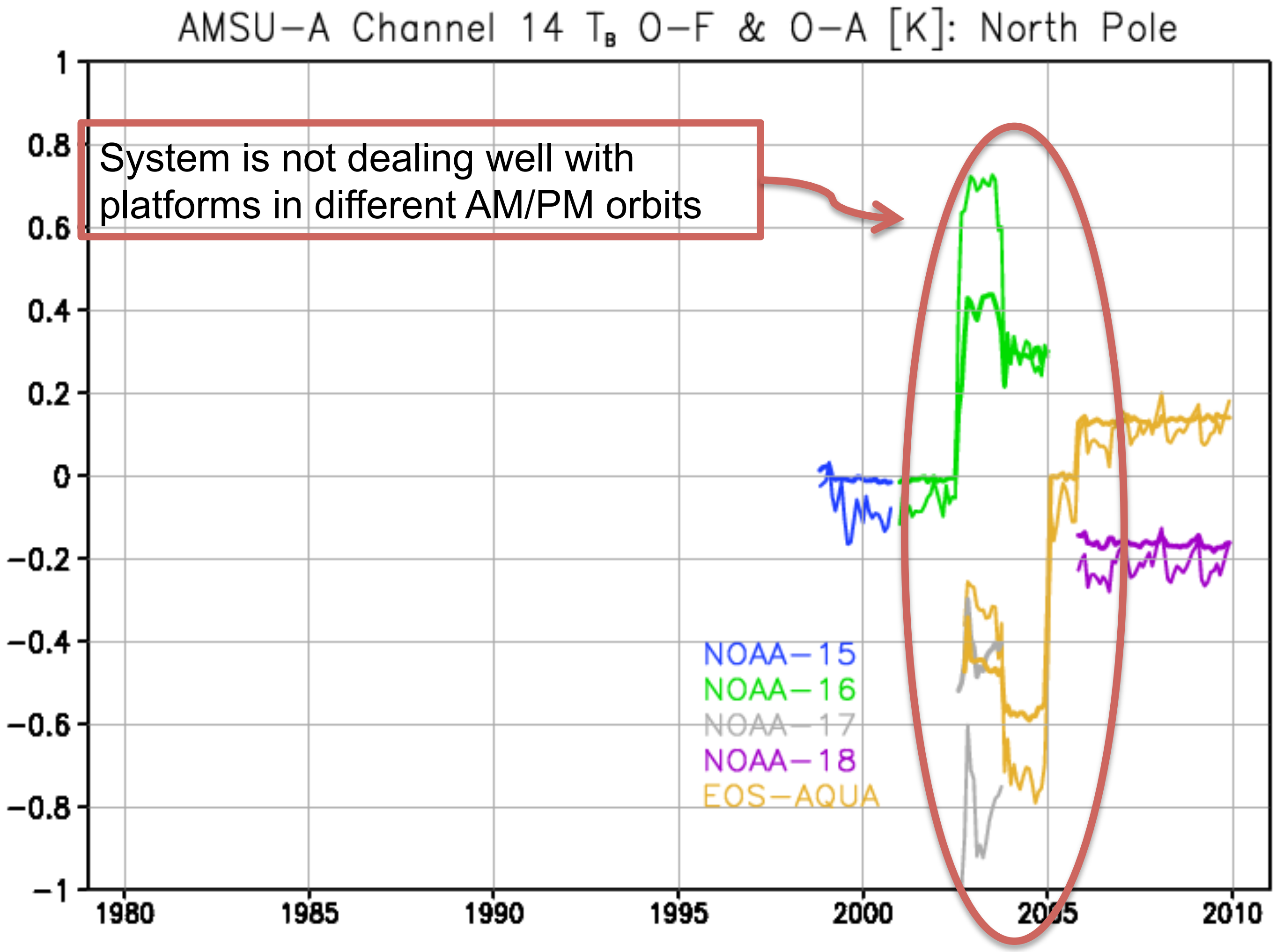
ATOVS Advanced Microwave Sounding Units Measure Microwave Emission by O_2

SSU Channel 3: Peak Sensitivity at 1.5hPa



O-Fs are generally weak and negative (forecast biased warm)
NOAA-6 & -8 are the only two of these in an 0730 AM orbit
No bias correction applied

AMSU-A Channel 14: Peak Sensitivity at 2.5hPa



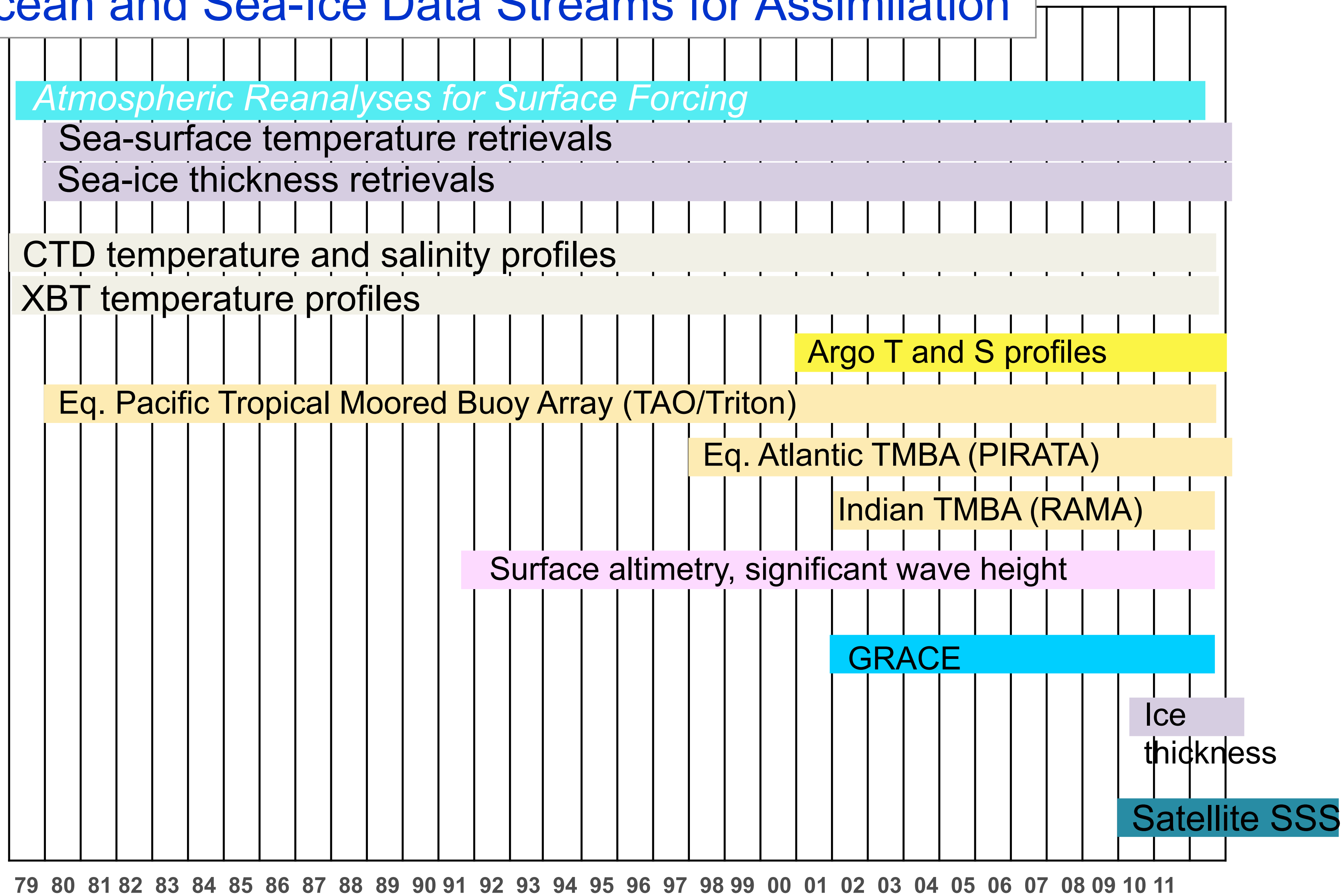
Generally slightly smaller O-Fs than for SSU.
Competition between platforms is quite severe!

Summary

- Satellite era brings a huge increase in data volumes to assimilation.
- AMSU ….is now the single most important source of observational information for global NWP, even in the Northern Hemisphere. (*SOG-Global NWP*).
- Radio-occultation measurements complement other systems in both temperature and moisture profile information for 10-200 hPa. (*SOG-Global NWP*).
- Many issues for real-time satellite data utilization (biases, QC, cloud- and rain-affected data) and even more for re-analyses.
- Satellite data are under-utilized over land and ice/snow-covered regions (surface emissivity; surface peaking channels;)
- Conventional data are not without issues … e.g., warm bias of aircraft data; radiosonde radiation corrections for reanalyses.
- Adjoint-based sensitivity approach is helpful for monitoring the observing system and for improving the use of data, particularly hyper-spectral sounders (channel selection, etc) …
- Observing system gaps remain:

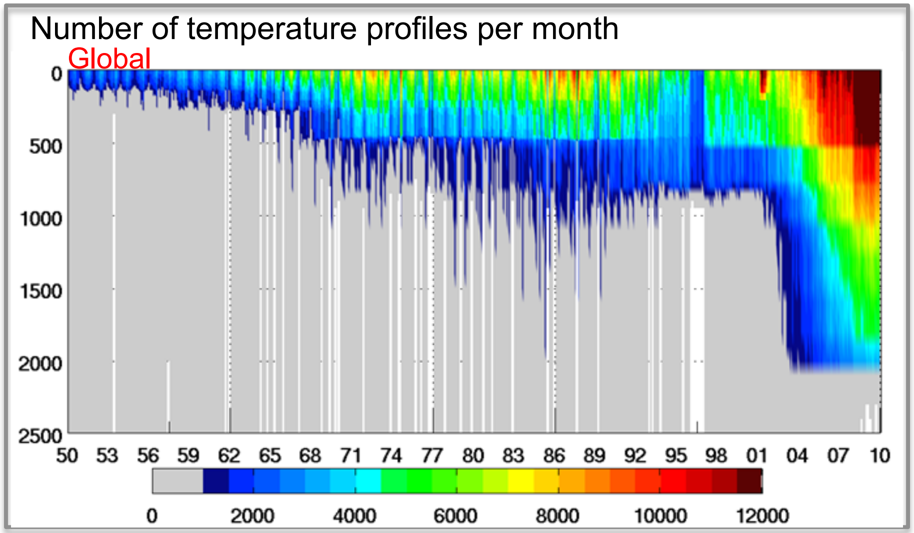
  winds
  polar latitudes
  upper stratosphere
  surface pressure

Ocean and Sea-Ice Data Streams for Assimilation



Issues:

In situ observing system



- Uneven observational coverage in space and time
- Deep ocean and ice covered regions are poorly observed.
- OS in marginal seas is declining
- OS in coastal areas needs attention

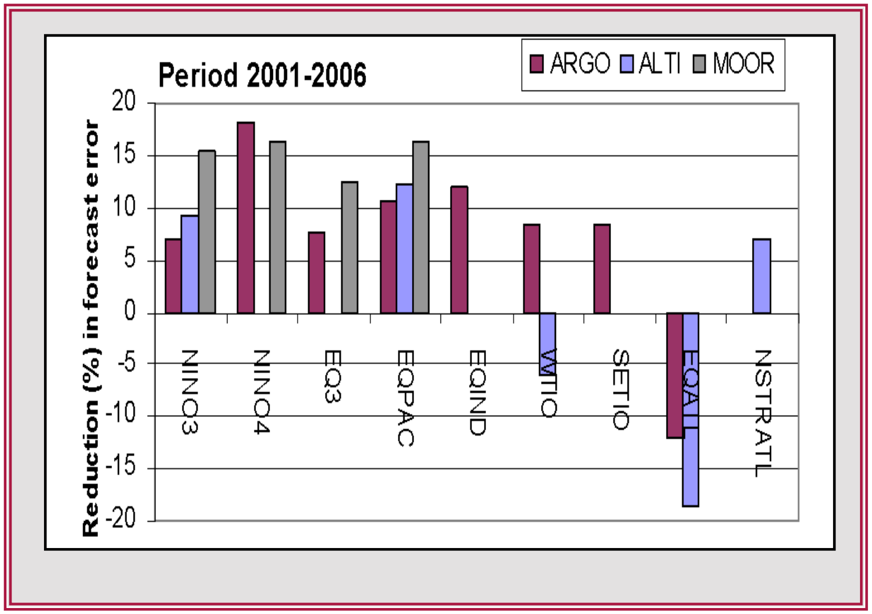
Surface forcing

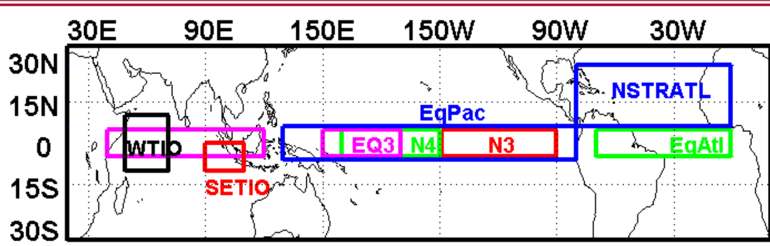
- Ocean community has tackled the task of improving surface forcing itself (CORE, DRAKKAR, OAFlux)
- Satellite observations – essential for air-sea fluxes (esp. scatterometer and precipitation)
- *In situ* surface measurements - calibration of satellite-derived fluxes; evaluation of NWP and reanalysis flux estimates

- NWP centres should continually improve analyses, reduce the impact of changing observing systems (reduce model biases), provide estimates of uncertainty.

Ocean Observing System impact assessments are from data-denial experiments (OSEs)

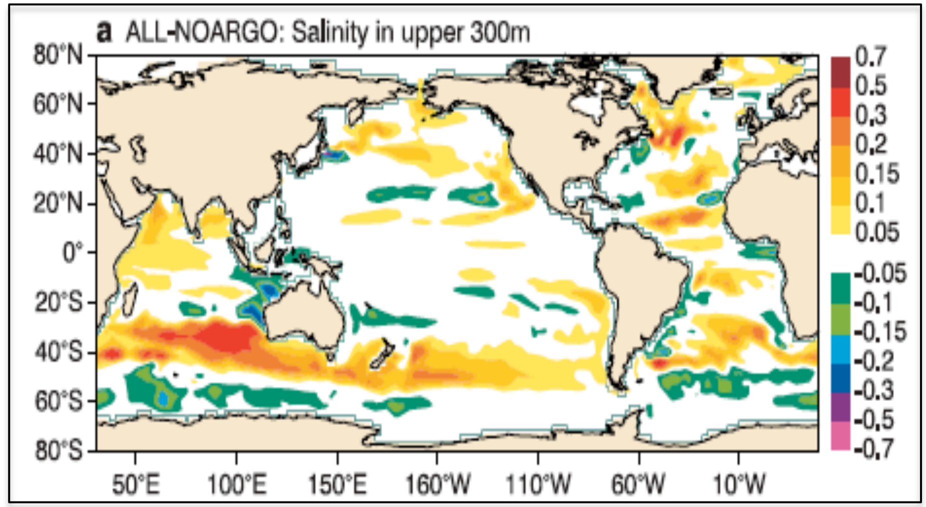
ECMWF S3
Impact of ocean observations on forecast SST (1-7 mon lead forecasts)
Balmaseda & Anderson, 2009





Altimetry data still pose a challenge: distributing height anomalies in depth and between T´(z), S´(z); bias relative to model mean.

ECMWF S3
Impact of Argo on av. salinity in upper 300m
Balmaseda et al., 2007



- Argo: Biggest impact in less well-observed regions (Indian, S. Atlantic, S. Pacific, Southern Ocean)
- Argo salinity also improves estimated temperature

Smith and Haines (2009)

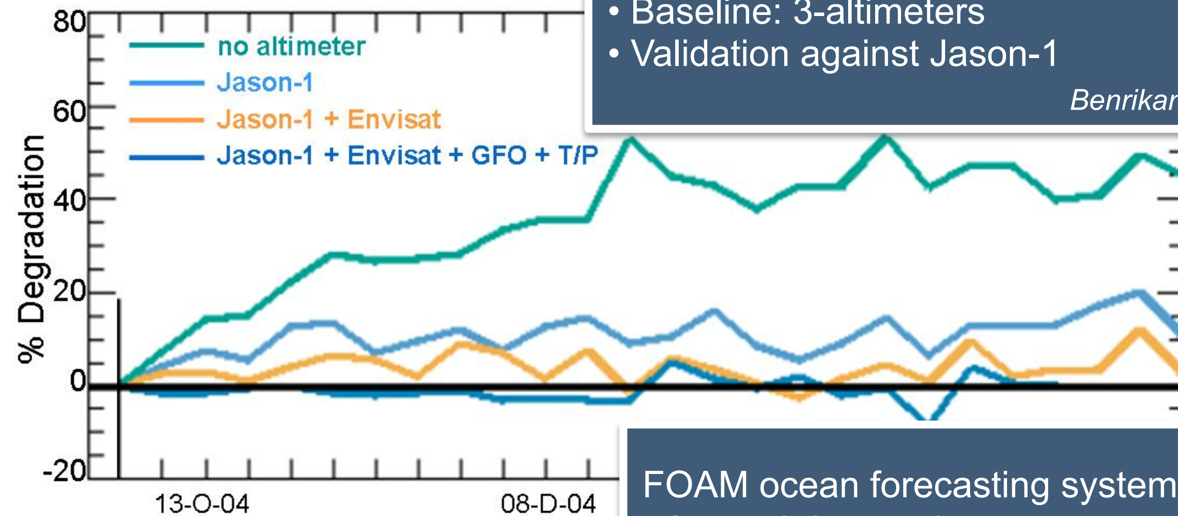
- T impact on S can differ from S data impact on S *Balmaseda et al. (2007)*

Assimilation: a contribution to observing system design for real-time ocean applications

- All 4 altimeters add to skill
- Impact from 1st altimeter is the largest
- Mesoscale dynamics in NE Atl constrained better by altimeters than in NW Atl
- NRT data from 4 altimeters ≡ delayed mode data from 2 altimeters
- Q: Will SWOT be able to replace 4 altimeters??
- Future: OSSEs (GODAE OceanView) & new diagnostic tools

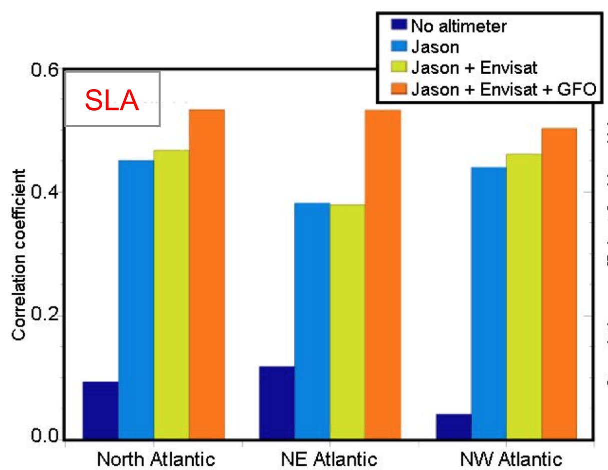
Mercator ocean forecasting system – N. Atl.
- 7-day forecasts using all available data
- Baseline: 3-altimeters
- Validation against Jason-1

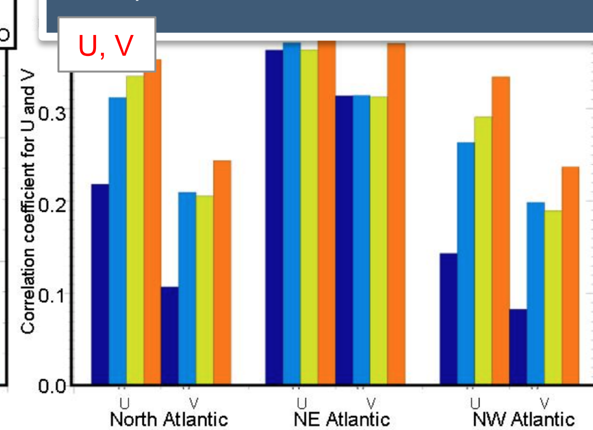
Benrikan et al., 2009



FOAM ocean forecasting system – N. Atl.
- 3-month integrations
- comparisons against assimilated SLA and velocities from drifting buoys (indept data)

Martin et al., 2007





SUMMARY

Operational ocean forecasting critically depends on altimeter, Argo and SST observations

Altimeter → **mesoscale variability**

Argo T/S → **stratification, heat content, <u>only</u> constraint on salinity**

SST → **mixed layer properties**

Oke et al. OceanObs'09

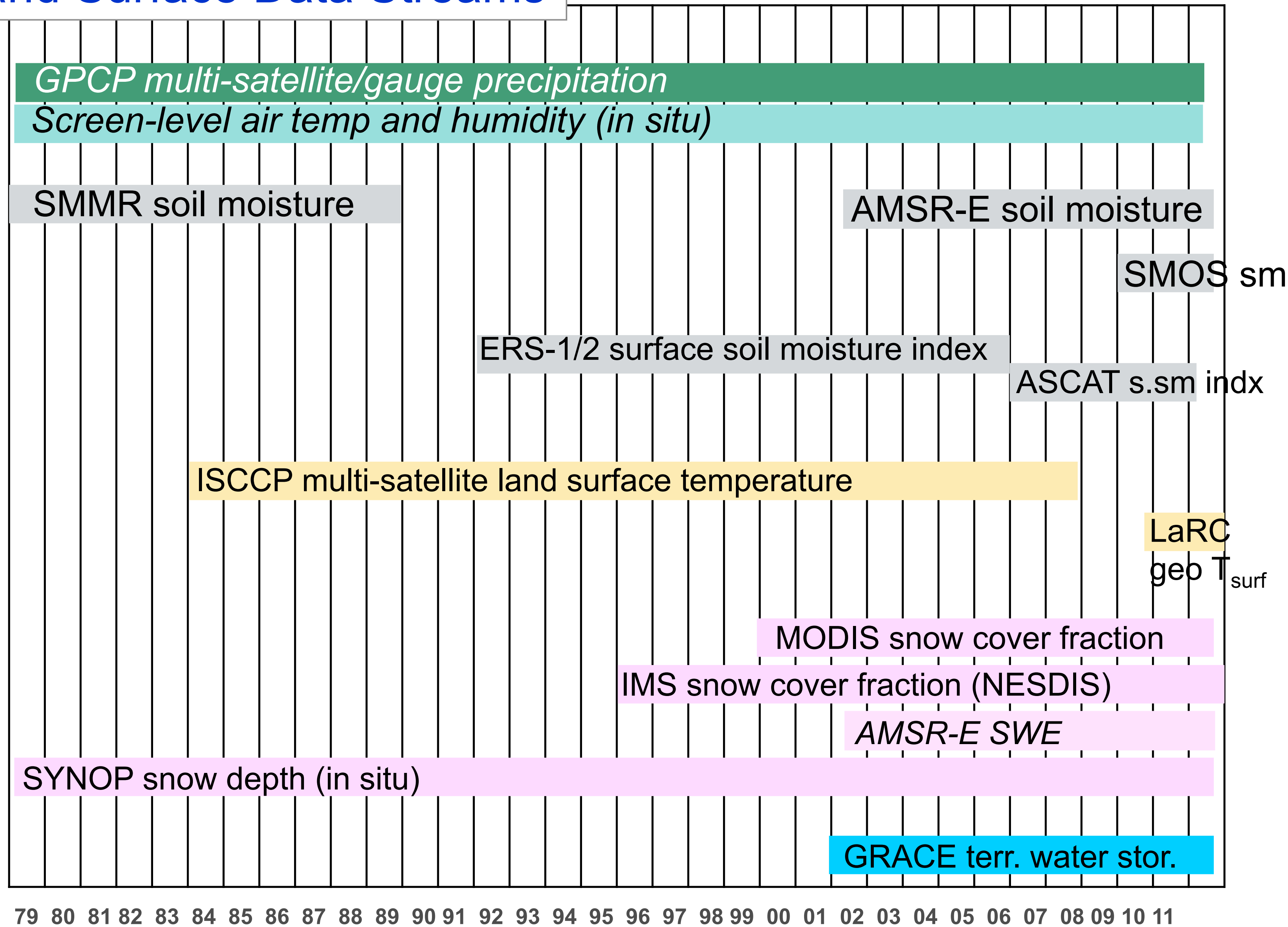
Seasonal Prediction

- Moorings, altimeter data, Argo are complementary
- GTMBA: the backbone; provide high frequency data; *continuity important for forecast calibration*
- Altimeter: the only OS contributing skill in the N. Subtrop. Atlantic skill; backbone away from TAO/ Triton – still a challenge to use (surface-only, bias relative to model guess)
- Argo is the only OS contributing skill in the Indian Ocean (in ECMWF system)
- SST: important for mixed layer and for AGCM

Decadal Prediction

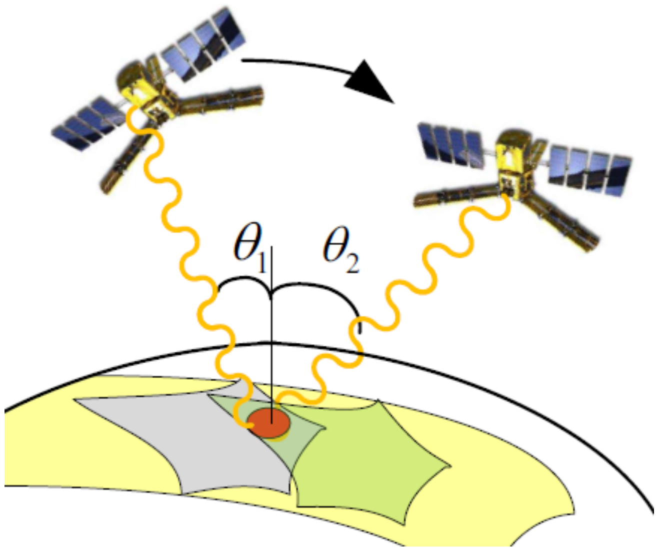
- Data outside the tropical oceans; deep data? homogeneous? Long time series important
- Sea-ice

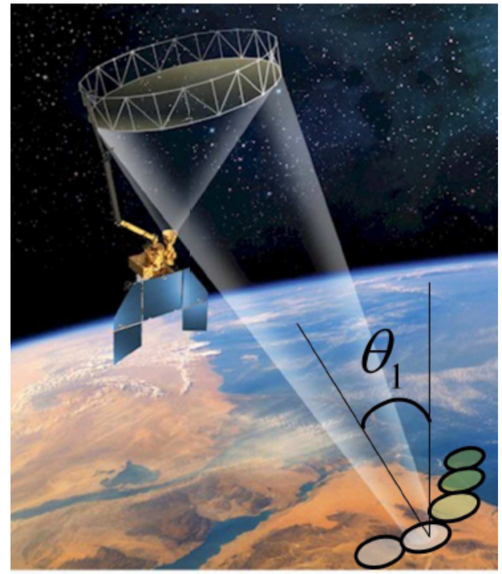
Land Surface Data Streams



SMOS and SMAP

SMOS (ESA)





SMAP (NASA)

Launched Nov 2009

L-band passive

40 km resolution

SMOS soil moisture retrievals based on Tb angular signature.

Launch ~2014

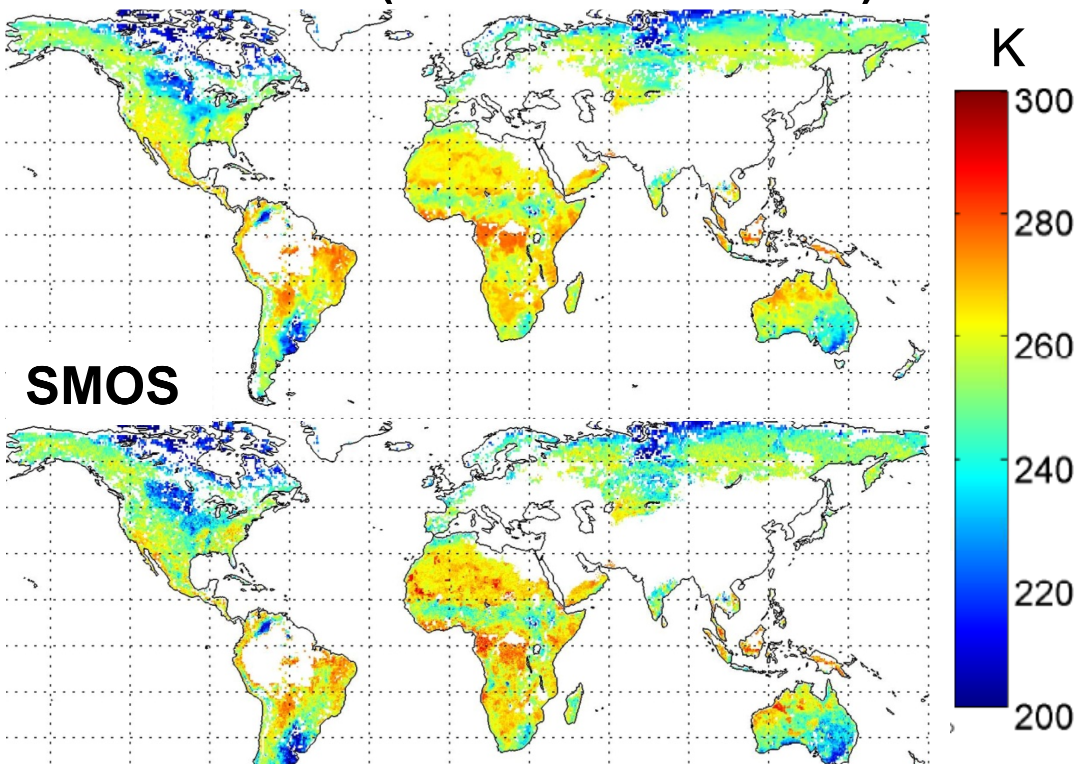
L-band **active**/passive

3-40 km resolution

- higher Tb accuracy at single incidence angle
- high-resolution radar

H-pol Tb at 42.5°: SMOS vs. GEOS-5

Mean (1/1/2010 – 1/1/2011)



GEOS-5 ***after*** calibration of L-band radiative transfer model (mean abs bias ~5 K).

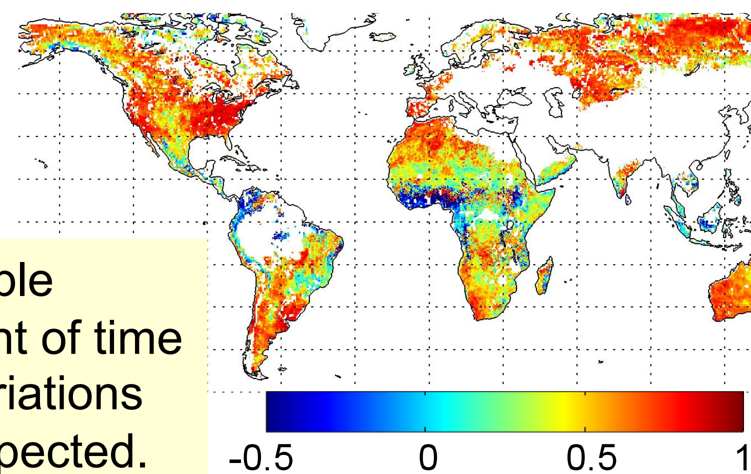
GEOS-5 L-band Tb has been calibrated to SMOS.

Challenge: RFI interference

Before calibration, mean absolute bias exceeded 50 K.

Similar for V-pol. and other incidence angles.

Time series correlation coeff.



Reasonable agreement of time series variations where expected.

Evaluation of near-real time Tskin from NASA/LaRC

GEOS-5 – LaRC
Jan – Jun 2011
Clear-sky

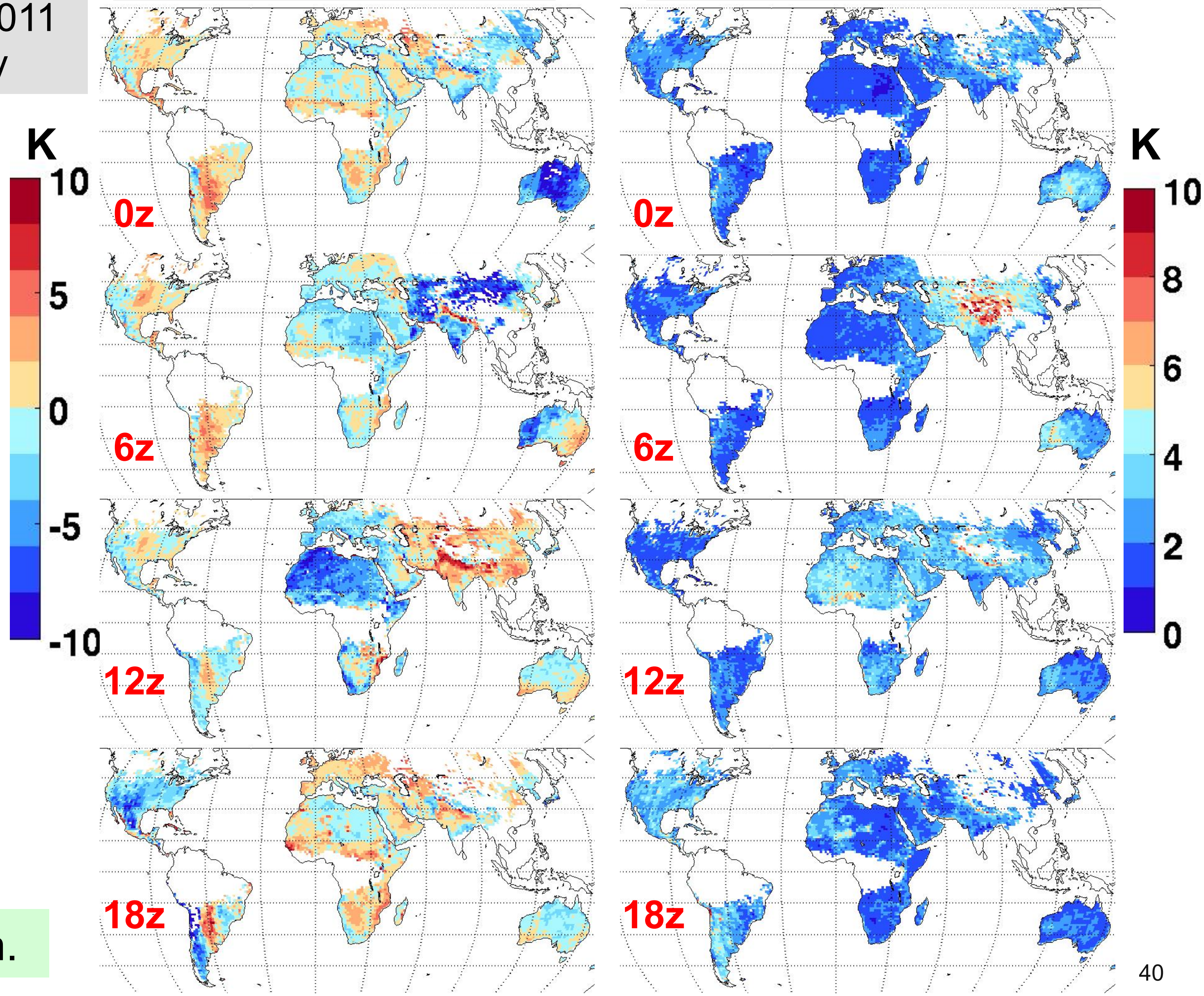
NRT Tskin retrievals from NASA/LaRC based on 5 geo-stat. satellites: MTSAT-2, FY2E, MET09, GOES-East/West.

Reasonable bias and RMSD under clear-sky conditions except for retrievals from FY2E.

Next: Assimilation.

Mean Difference

RMSD (bias removed)



Summary

Soil Moisture

Assimilation needs careful calibration of the data to the model, but then improves comparisons of both model and satellite retrievals (ASCAT, AMSR-E) with in situ observations.

Land surface skin temperature

- Satellite IR and MW imagers and sounders – retrieval accuracy is affected by cloud detection problems and surface emissivity uncertainties; interpretation is difficult because of the heterogeneous nature of the emitting surface for many surface types. (*SOG-NWP)*
- Reichle's work with NASA LaRC retrievals show that with a lot of care the data may be able to be assimilated.

Snow cover and SWE

- Surface station measurements: good temporal resolution but marginal horizontal resolution and accuracy (primarily because of spatial sampling problems).
- Visible / near IR imagery: good horizontal and temporal resolution and accuracy on snow cover (but not on its equivalent water content) in the day-time in cloud-free areas.
- MW imagery offers the potential of more information on snow water content. (*SOG-NWP)*
- De Lannoy's results with SWE show some promise but not in deeper snowpack areas.

Assimilation systems are integral to how we make decisions regarding the global observing system!

THANK YOU!