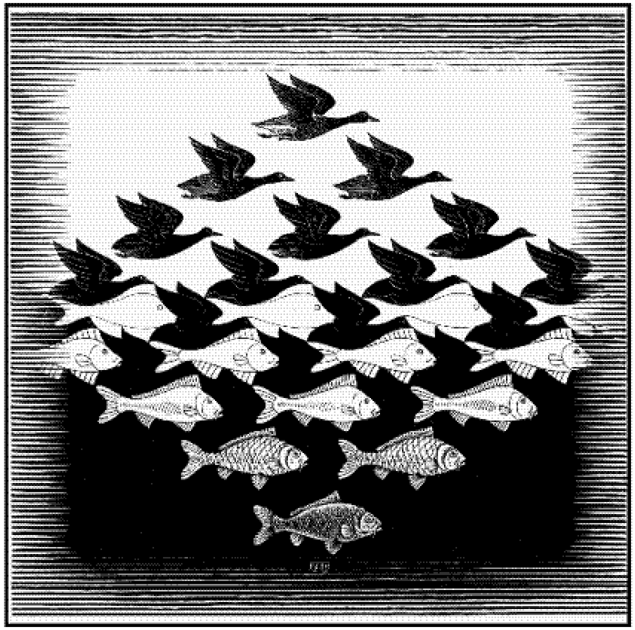
Weather-(Climate?) Data Assimilation

...can we get there from here?



"Sky and Water I",
M.C. Escher

Ron Gelaro et al.

NASA Global Modeling and Assimilation Office

MAP Meeting 7-9 March 2007

Data Assimilation Systems at the GMAO
…not quite seamless

- **Atmosphere:**

  Variational (3D-, 4D-VAR); GEOS-5/GSI, 0.5^{O} resolution;
  6-hr assimilation window

- **Ocean:**

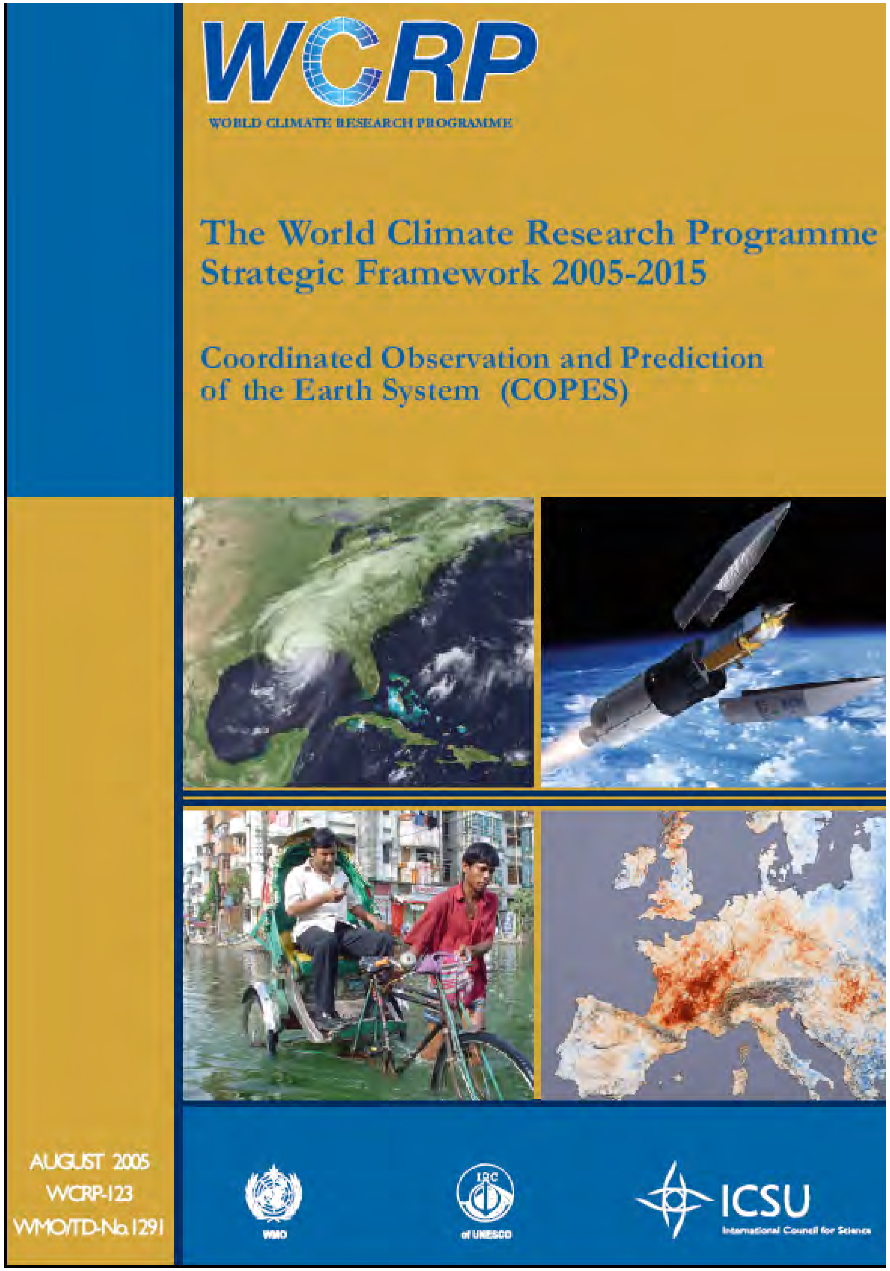
  Ensemble Kalman Filter (EnKF); Poseidon, 0.67^{O}x0.33^{O} resol;
  5-day assimilation window

- **Atmos-Ocean Coupled:**

  Optimal Interpolation (OI); GEOS-5/Poseidon, 2.0^{O} / 0.67^{O}x0.33^{O}
  5-day assimilation window

- **Land Surface:**

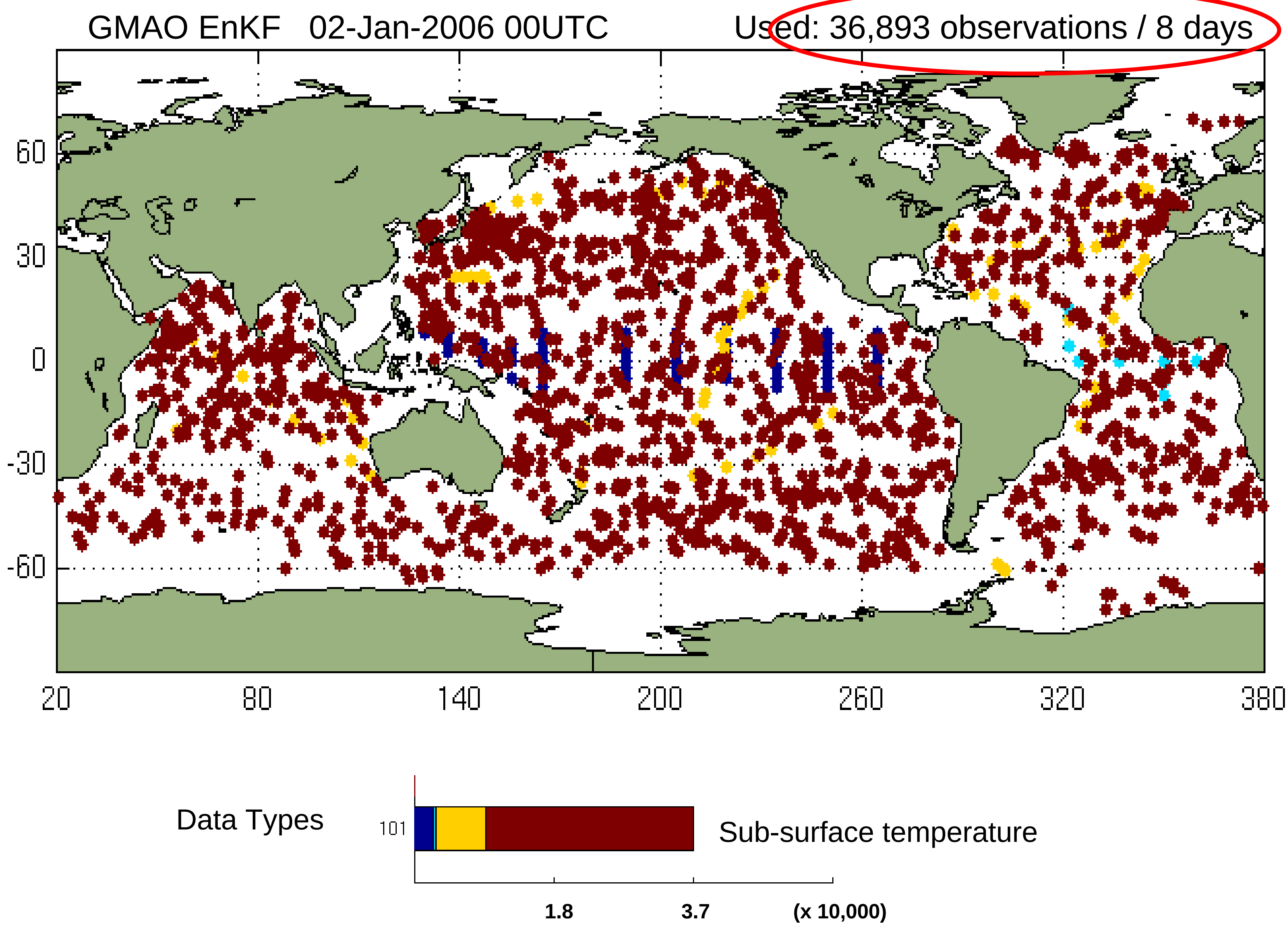
  EnKF; Catchment Model, $O(10^{1})$ members, 0.5^{O} resolution;
  3-hr assimilation window



WCRP "Seamless prediction"

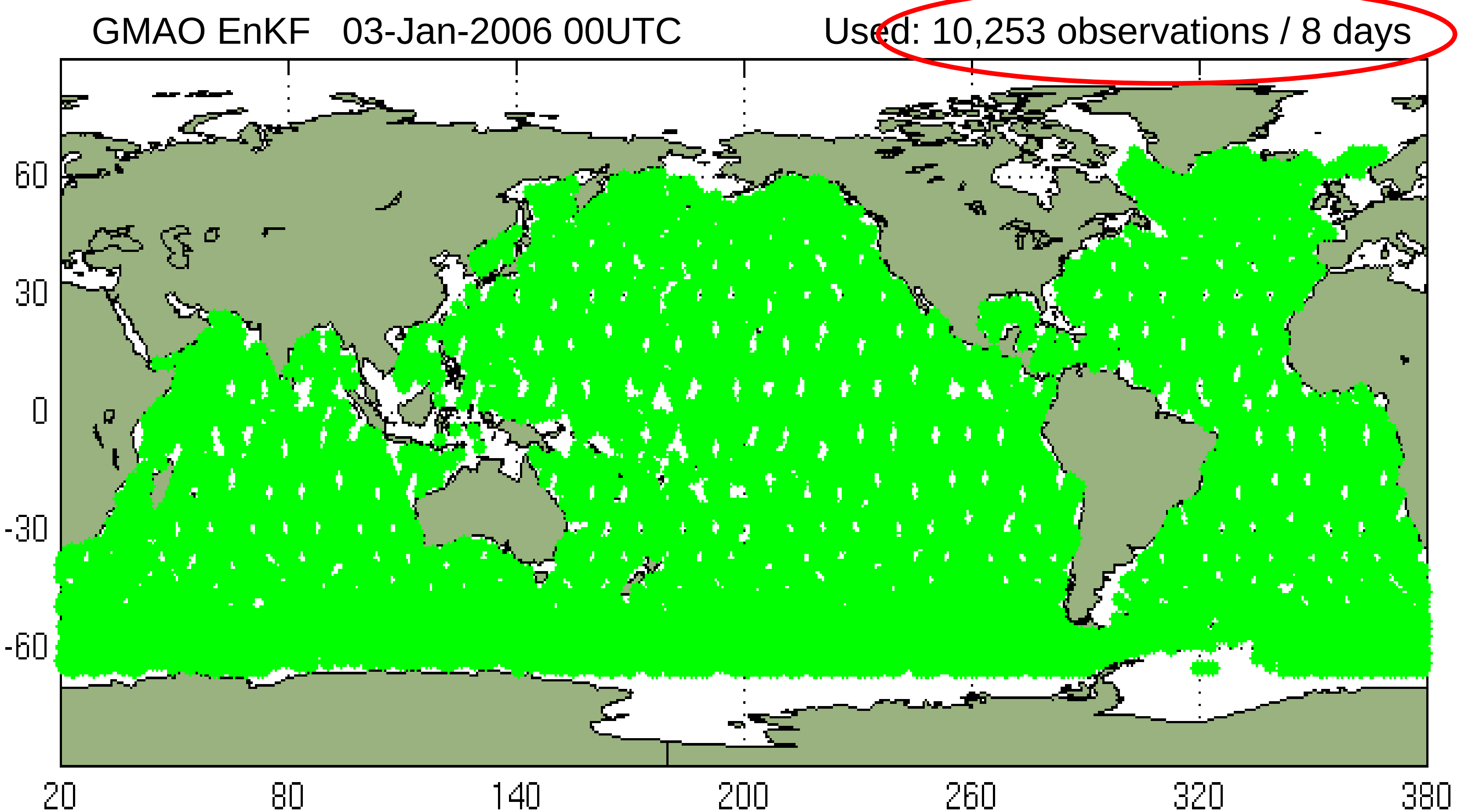
…climate models are being run with the highest possible resolutions, resolutions that were employed in the best weather forecast models only a few years ago. There is also increasing emphasis on traceability, the ability to relate the structure, parameterizations and performance of models used on different time-scales. Even though the prediction problem itself is seamless, the best practical approach to it may be described as unified: models aimed at different time-scales and phenomena may have large commonality but place emphasis on different aspects of the system.

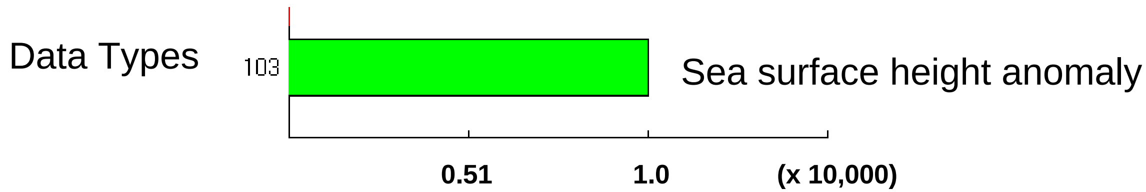
The oceanic observing system…temp



Courtesy R. Kovach, GMAO

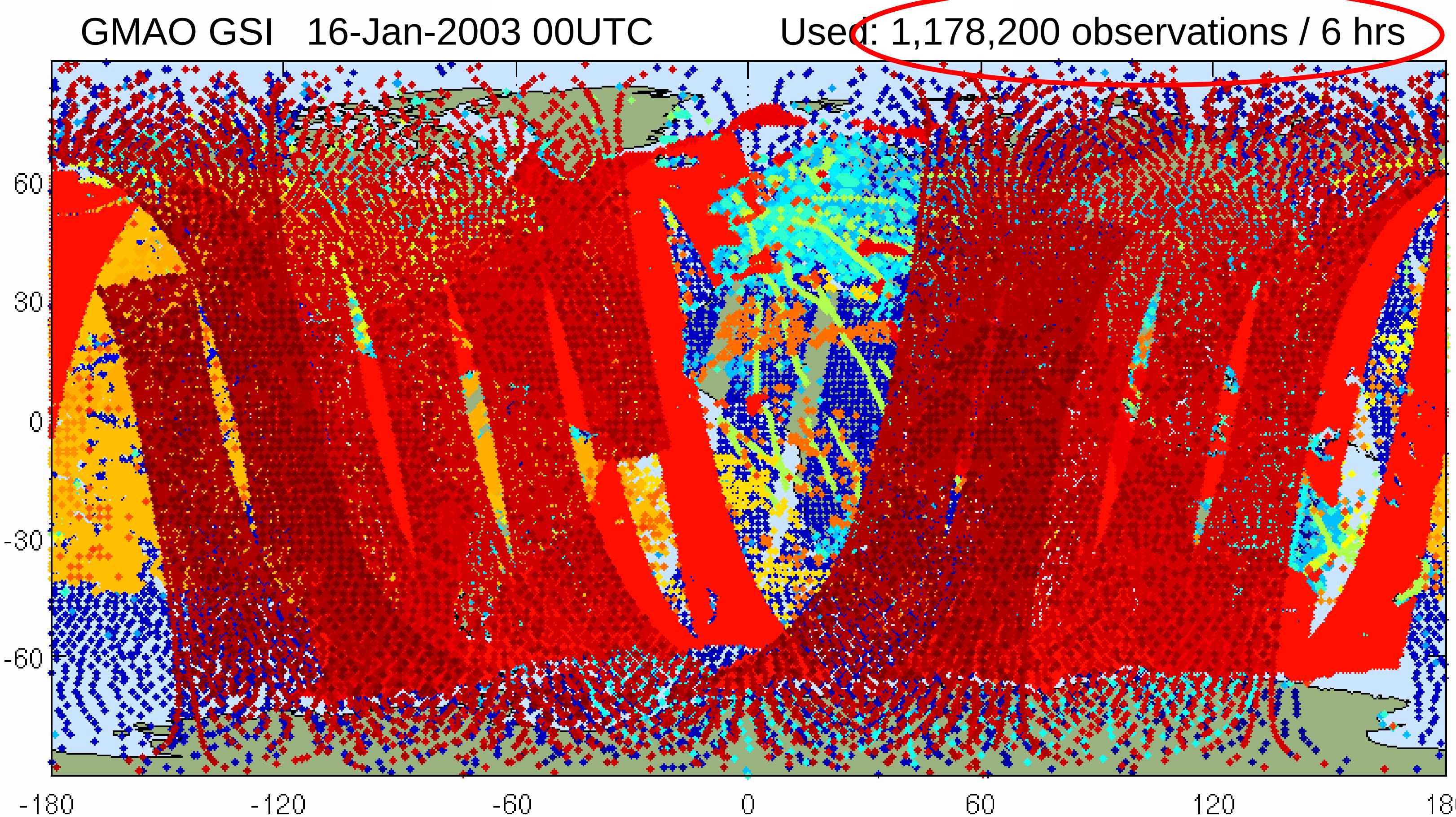
The oceanic observing system…sea surface height

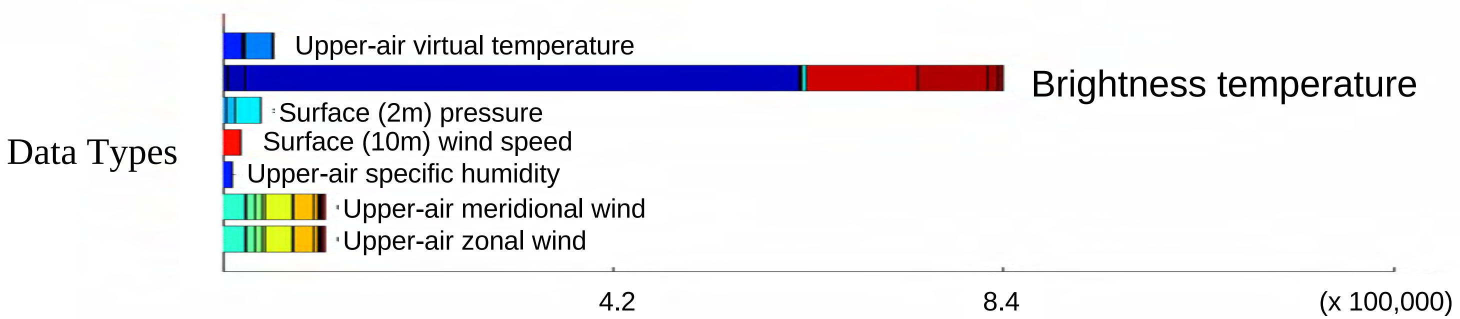




Courtesy R. Kovach, GMAO

The atmospheric observing system

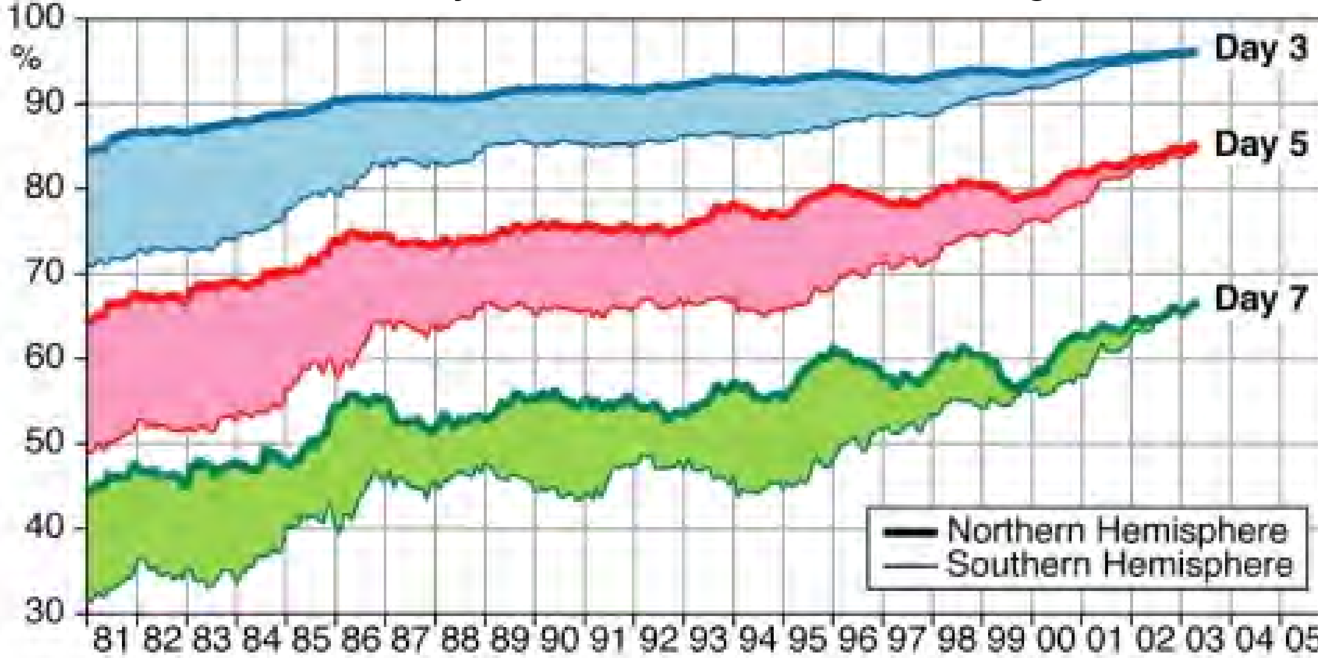




Data Assimilation for Weather

Forecasts have improved substantially over the last decade due to better models, analysis techniques and observations $\Rightarrow$ *satellite data*

ECMWF Anomaly correlation of 500hPa height forecasts



Graphic courtesy ECMWF

Data Assimilation for Weather

- Involves life-cycles of well-characterized waves in the initial conditions
- Quasi-linearity exploited with great success: incremental variational formulations, adjoint tools, EnKF (some flavors)
- Clouds, other moist processes accounted for crudely or ignored
- Assume that errors are random and normally distributed, even though not necessarily true (largest biases removed/reduced, but others ignored)
- Model error largely ignored up to now: this is slowly changing, but cost is high and knowledge of required error covariance lacking
- Consistency/balance between physical quantities…not so much
- Forecast viewed as an “amplifier” of analysis error (quality)

Data Assimilation Beyond Weather

Interaction between waves and mean flow becomes important, consistency between small and large, fast and slow scales of motion required $\Rightarrow$ *e.g., residual circulation*

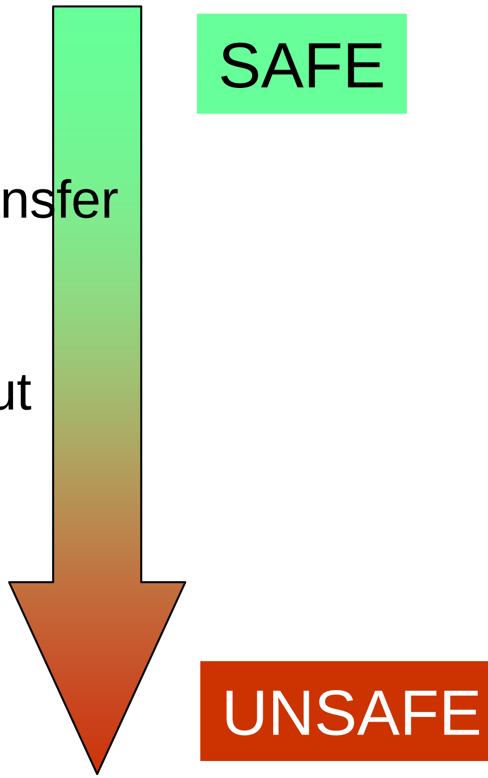
- Improved estimates of waves in terms of prognostic variables does not necessarily lead to improved physical consistency:
  - Link to general circulation is through dissipation of waves
  - Link includes gravity waves (mostly filtered in NWP)
- Insertion of information from observations may introduce inconsistencies that are a significant part of the budget
- Clouds-precipitation, other physical processes become critical part of balance at longer time scales
- Breakdown of usual assumptions re: Gaussian, uncorrelated errors may become problematic … affect means?
- Accounting for model error likely to be critical

Adapted from Rood 2006, EGU Vienna

What are the applications we seek to address?

…and what is the level of confidence in our analyses?

- Short-term forecasting
- Observing system monitoring
- Mapping
- Better information for calculation of radiative transfer
- Better information for data use (and retrieval)
- Benefits from multivariate analysis
  - One observed variable has information about another observed variable
- Model and observation evaluation
- Estimates of unobserved quantities
- Unified data sets
- Estimates of budgets terms / transport
- Trends



After Rood 2006, EGU Vienna

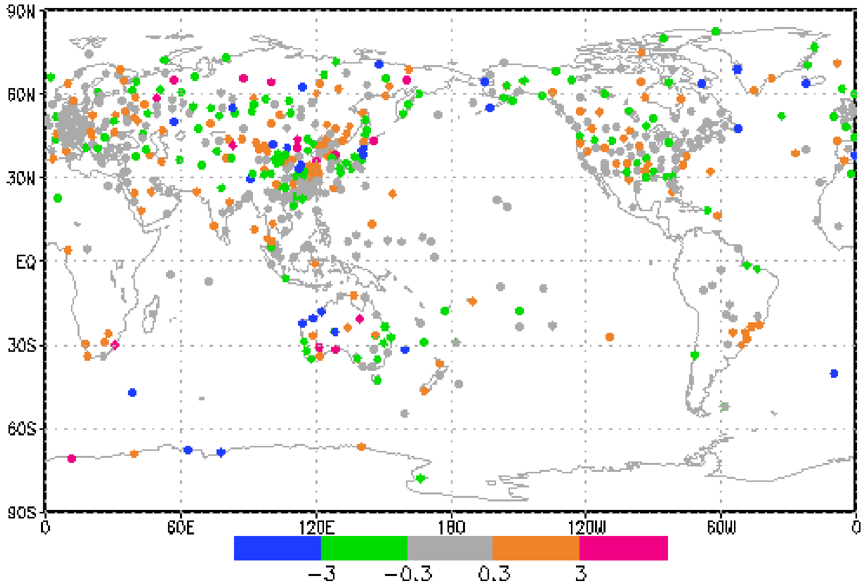
Some things we have learned from the use of observations in GEOS-5…

…does any of it help us with weather↔climate?

Observation Impact on GEOS-5 24h Forecast Error

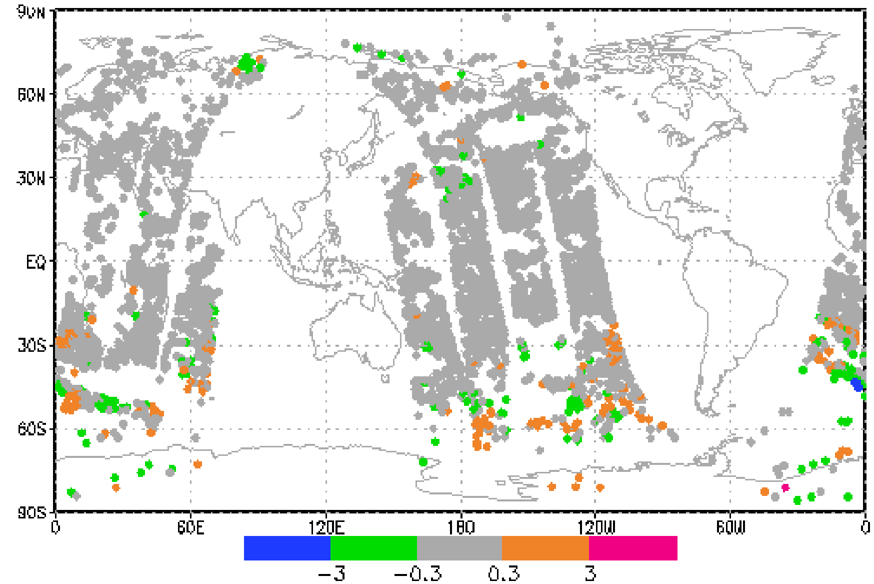
GEOS-5 Adjoint Data Assimilation System

Impact of 500mb RAOB Temps
10 July 2005 00z



Error Reduction   Error Increase

Impact of AIRS Ch.221 Radiances
10 July 2005 00z



Error Reduction   Error Increase

- Observations that reduced the 24h forecast error
- Observations that increased the 24h forecast error
- Observations that had small impact on 24h forecast error

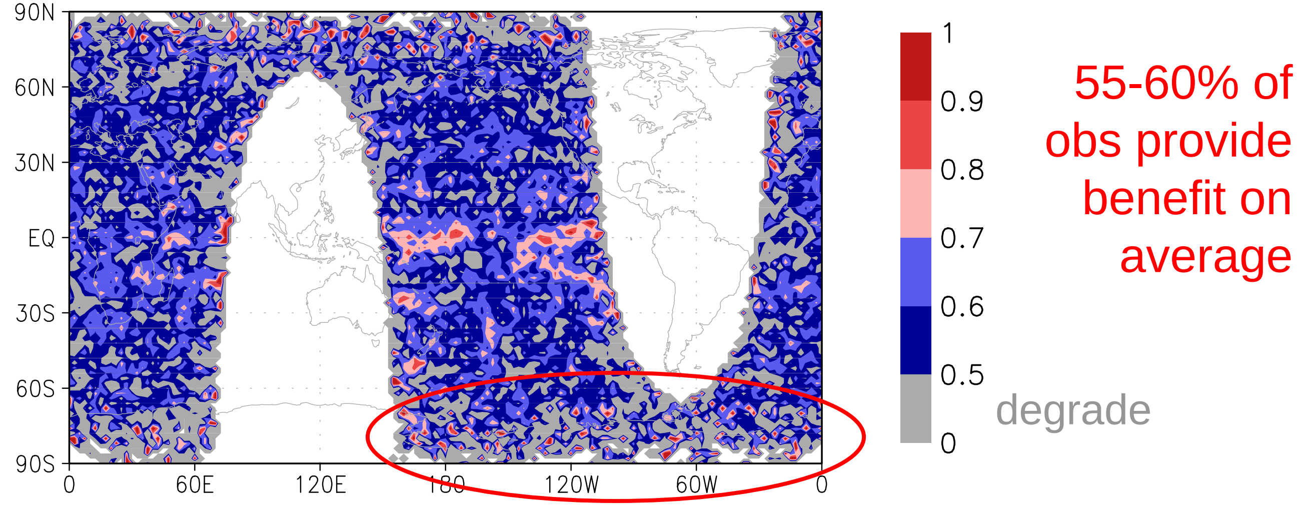
…a lot of the observations degrade the forecast (analysis)

Gelaro and Zhu, GMAO

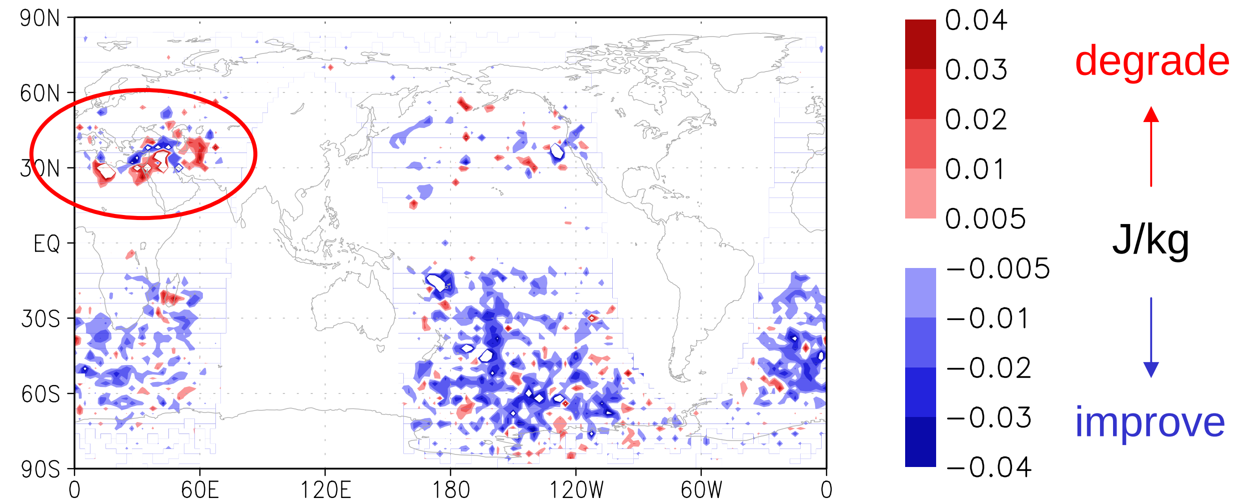
Larger samples show regional patterns…processes?

July 2005 00z Totals

Fraction of **AIRS** observations that improve forecast

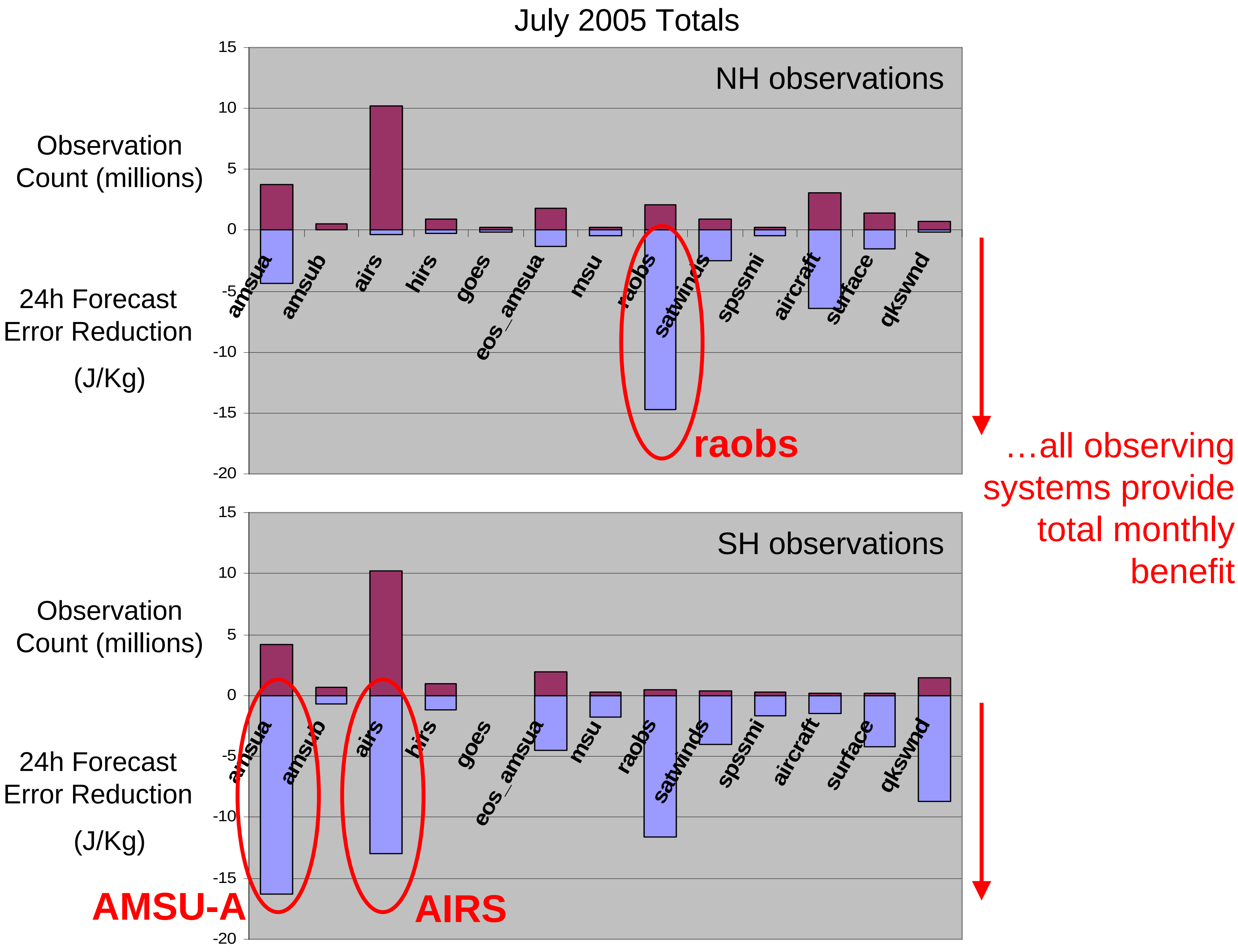


Impact of **AIRS** observations on forecast



GEOS-5 Adjoint Data Assimilation System

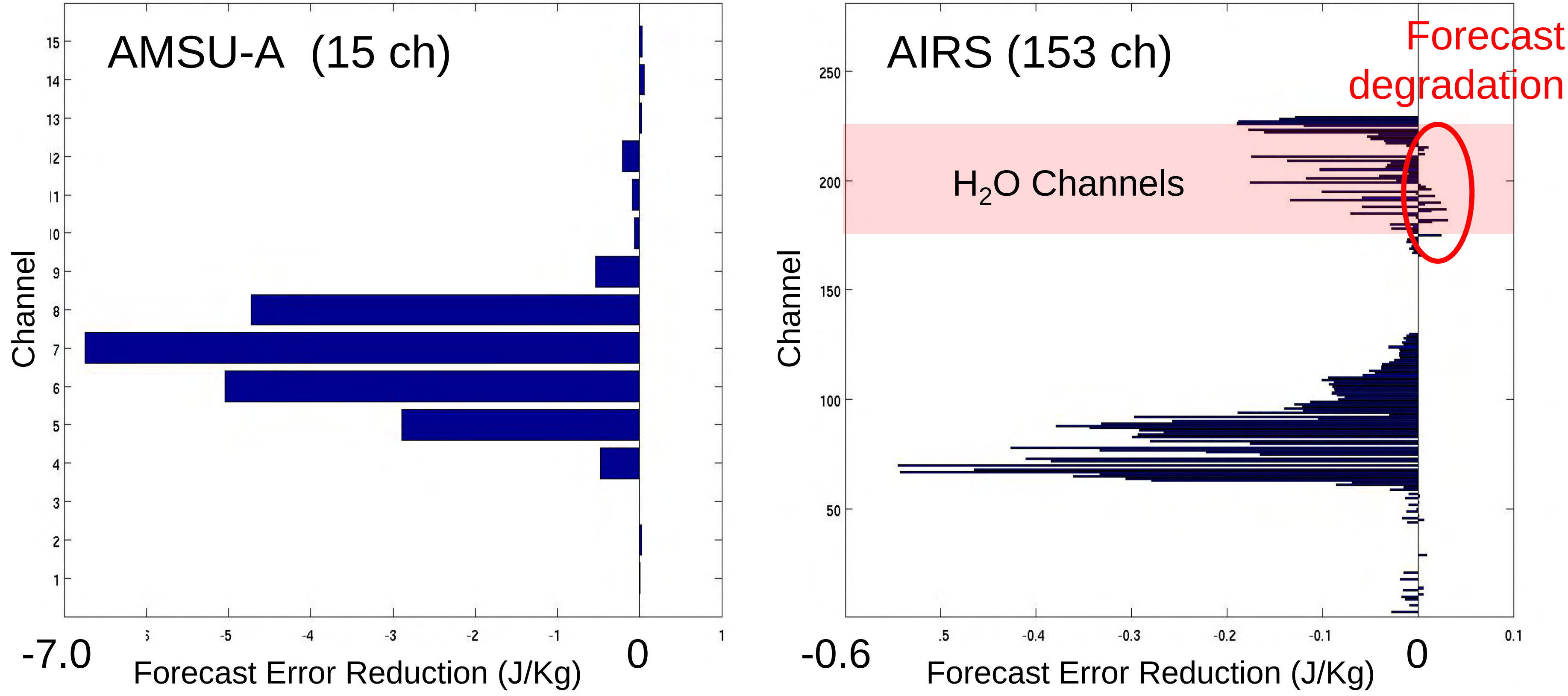
Impacts of various observing systems



Impacts of hyper-spectral observing systems

GEOS-5 Adjoint Data Assimilation System

July 2005 00z Totals

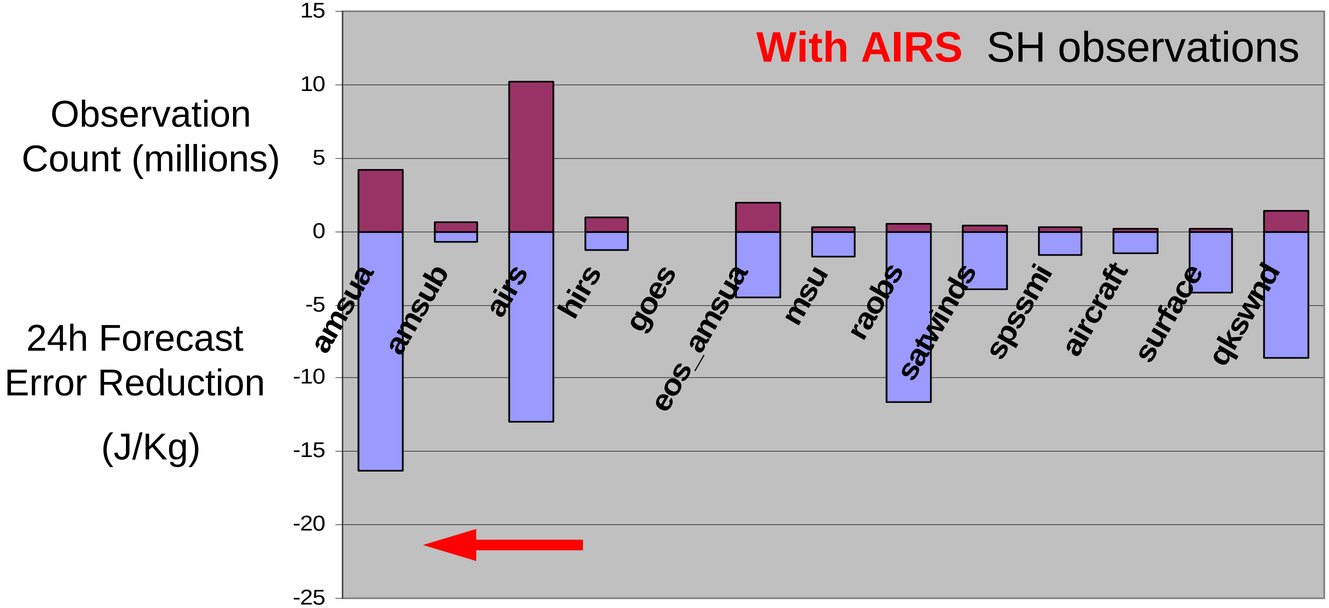


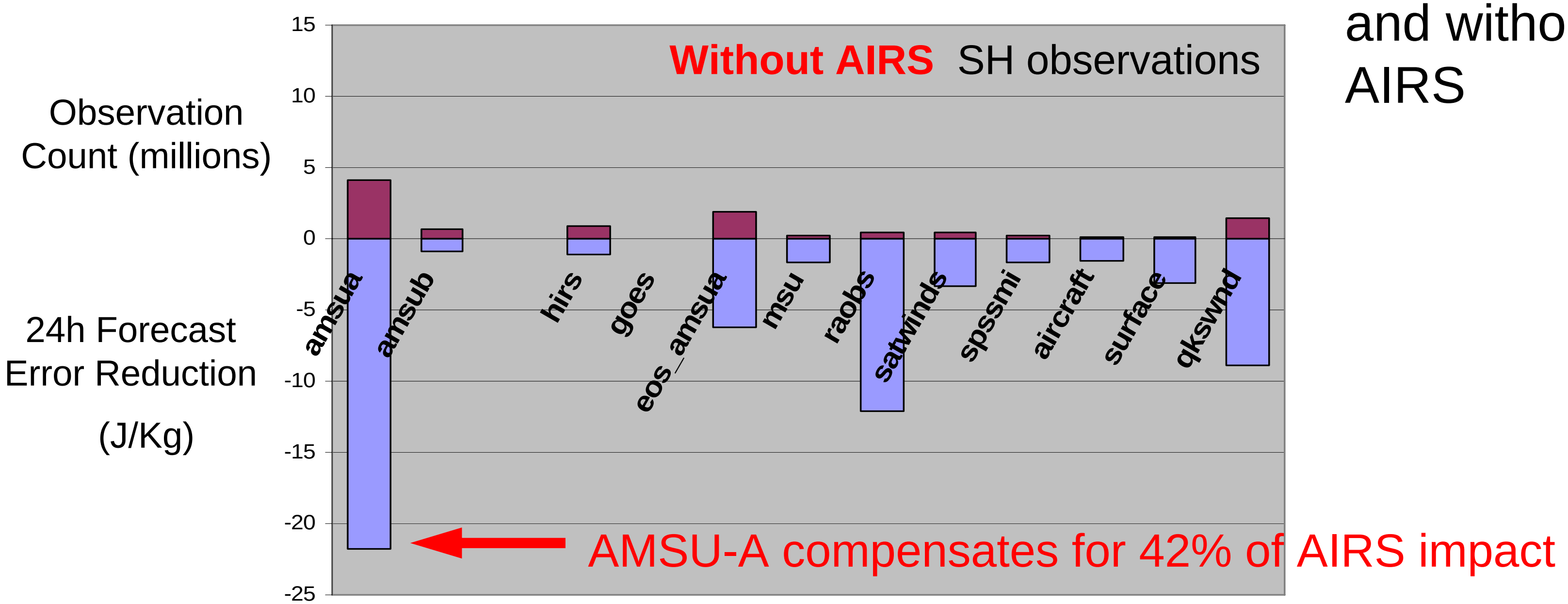
…a significant fraction of AIRS water vapor channels currently degrade the 24h forecast in GEOS-5…

Gelaro and Zhu, GMAO

Data Redundancy…how much is too much?

GEOS-5 July 2005

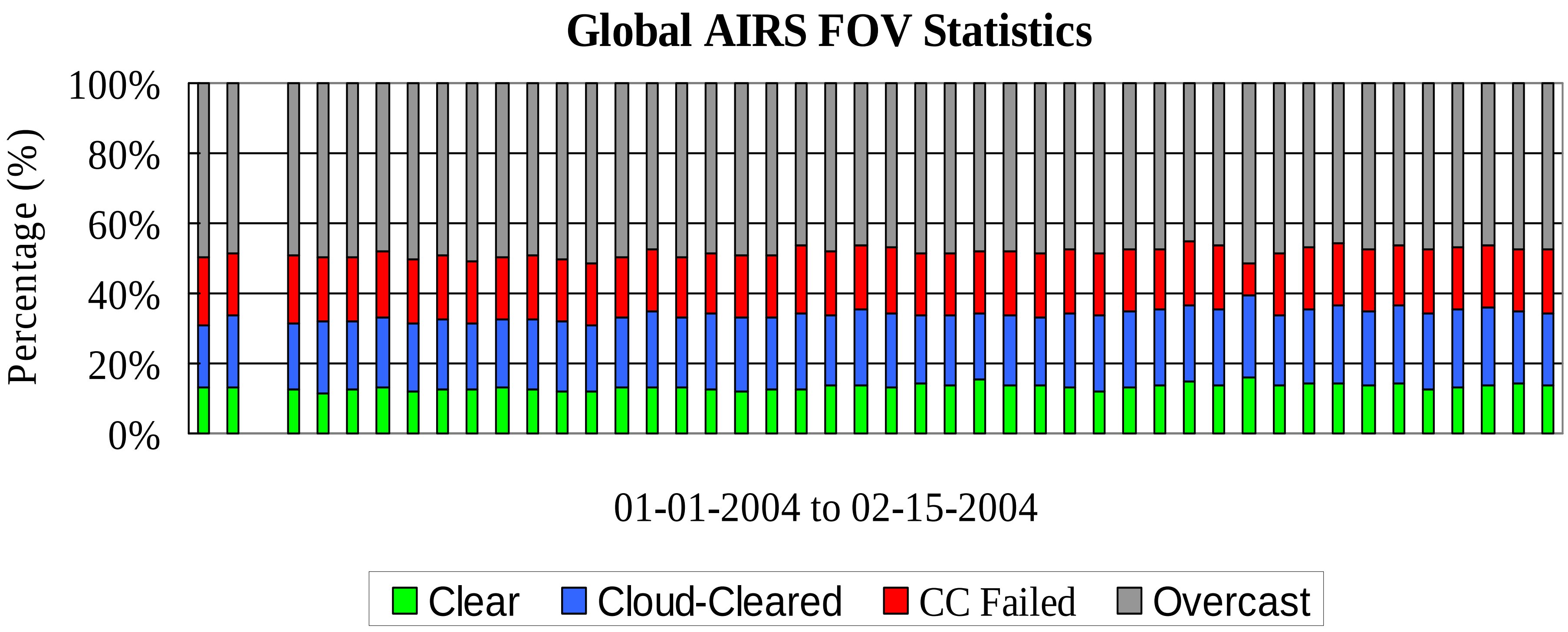




Adjoint DAS applied to OSEs with and without AIRS

Limited use of AIRS radiances due to clouds

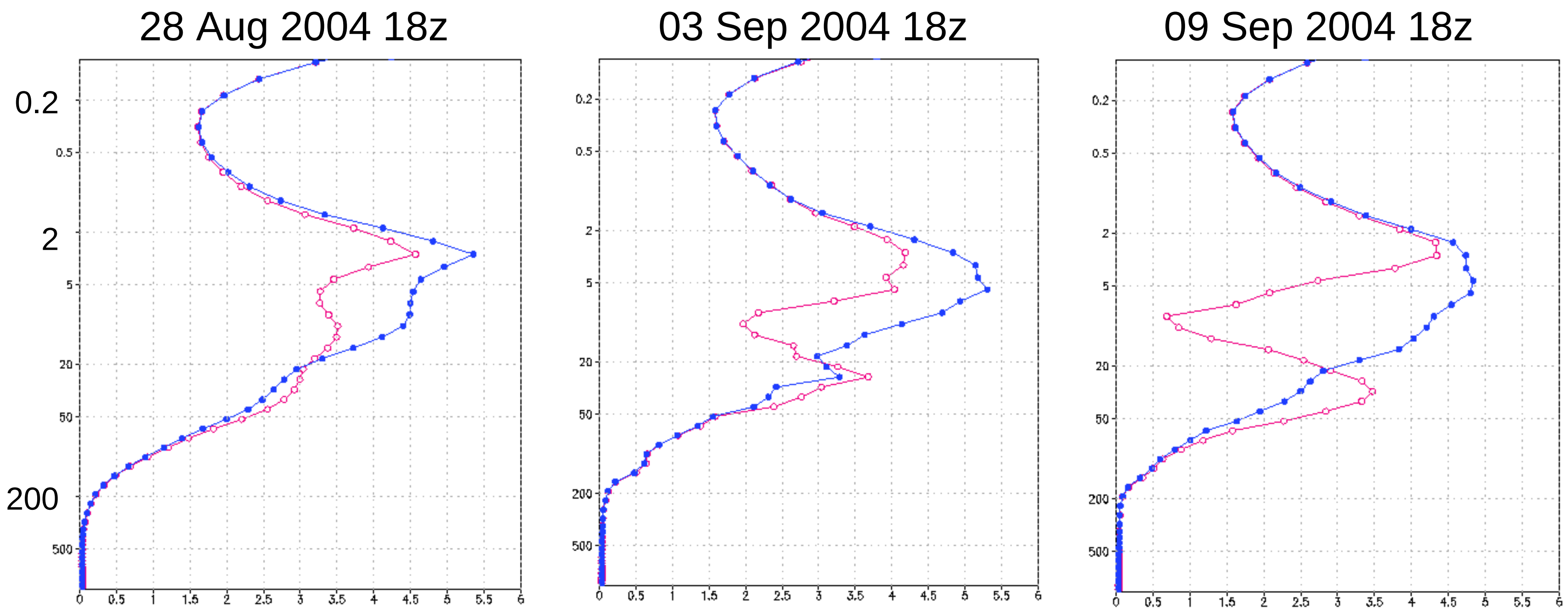
- Currently, only clear AIRS channels are used in most data assimilation systems.
- Direct use of cloudy data is currently prohibited by immense computational expense of infrared cloudy radiative transfer calculation
- Roughly13% of AIRS FOVs are clear, and another 21% can be cloud-cleared successfully,….and the rest?



Assimilation of clouds and precipitation: Evolution and challenges

- Currently, the assimilation of satellite information involves approximately only 20% of the globe (ECMWF, 2003)
- The ability of atmospheric models to describe clouds and precipitation is slowly improving
- Several satellite observing systems already launched, with other(s) to follow (GPM)
- Issues:
  - Non-smooth processes
  - Representativeness errors
  - Predictability of cloudy-rainy systems
  - Radiative transfer and background error modeling

AIRS and Polar Ozone (Polar Night)



GEOS-5 crashes in GCM on Sept. 10

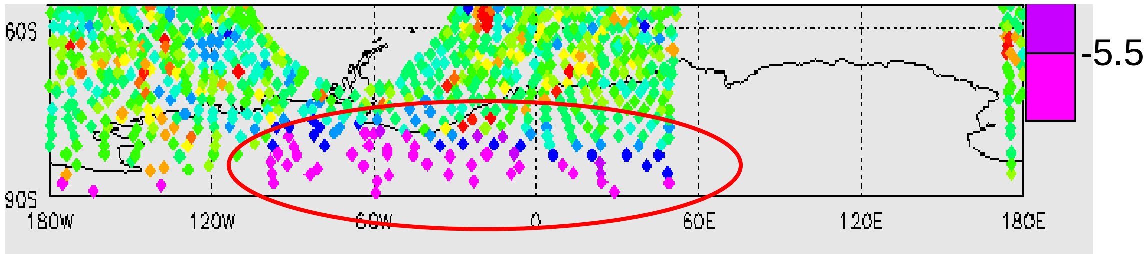
Runs start on August 27, 2004

- Ozone profiles at South Pole
- 152 AIRS channels used: **No ozone channels (1003-1285)**
- Red – other AIRS channels impact ozone
- Blue – impact of AIRS on ozone turned off

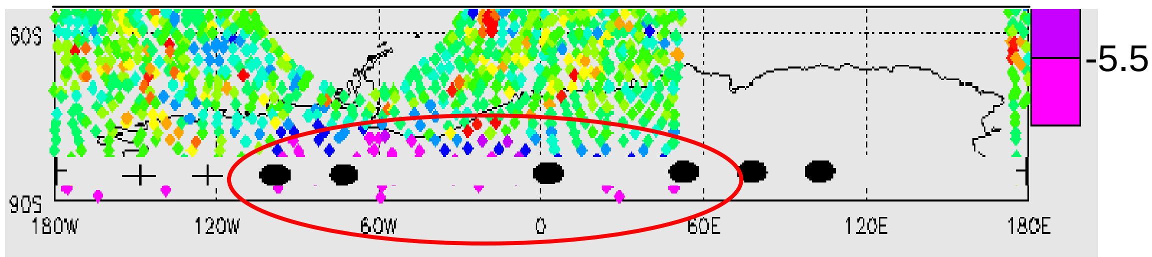
Stajner et al., GMAO

AIRS O-F residuals in channel 191 (6.79μm, Water Vapor) 08 Sep 2004 00z

Large-negative O-F residuals...

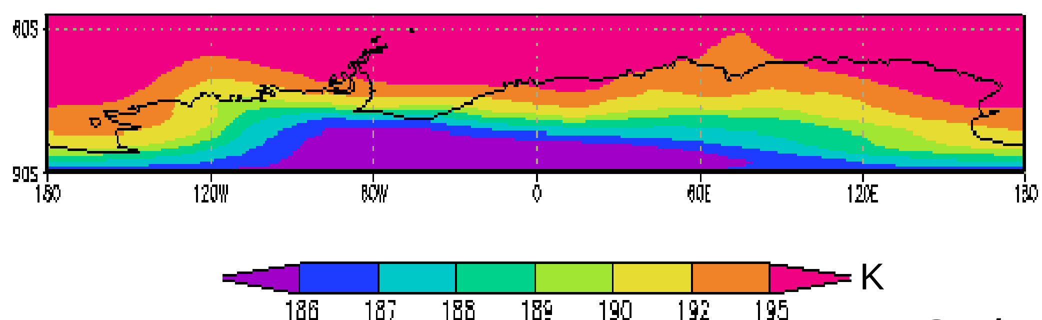


…may point to likely locations of PSCs



POAM observations: + no thick PSCs, ● thick PSCs

Temperature at 100 hPa on 07 Sep 2004 18z



Stajner et al., GMAO

General satellite data assimilation: Evolution and challenges

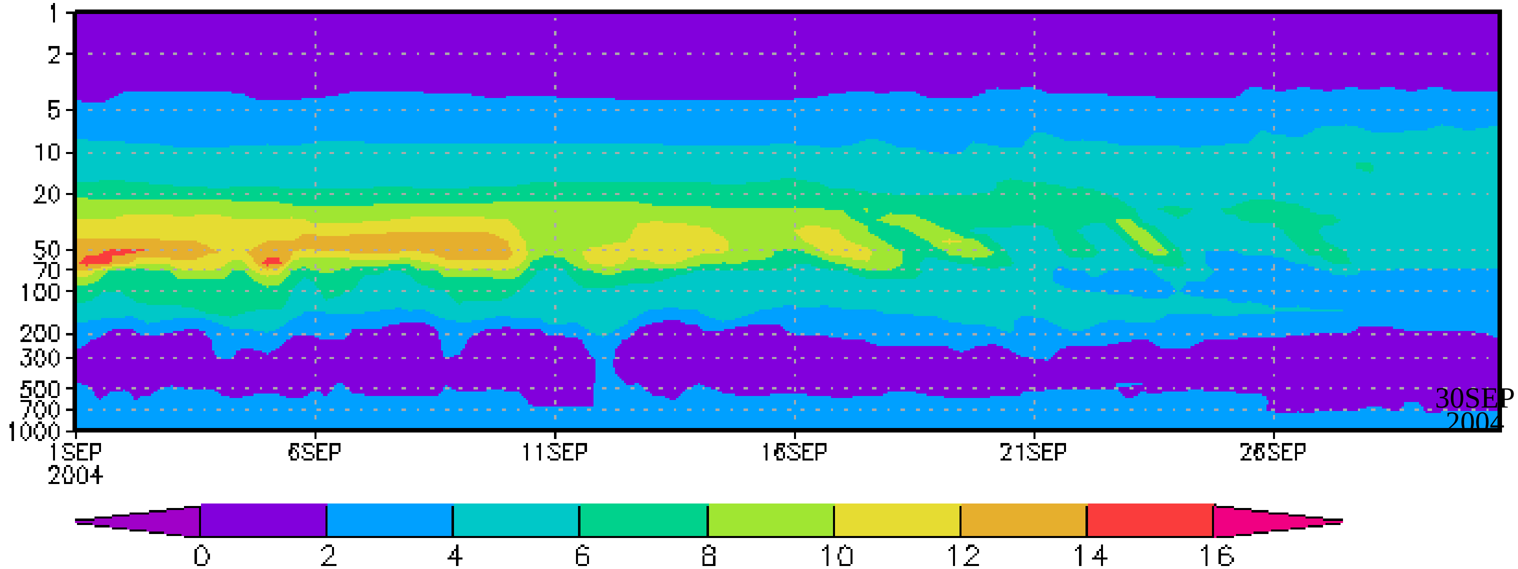
- Active technologies (lidars, radars) will provide detailed vertical information on hydrometeors (CloudSat, GPM), aerosols (Calipso), wind (ADM-AEOLUS) that data assimilation schemes should exploit

- Limb sounding techniques (MLS) raise new challenges for data assimilation. These should also contribute to improved vertical resolution of temperature, moisture, ozone

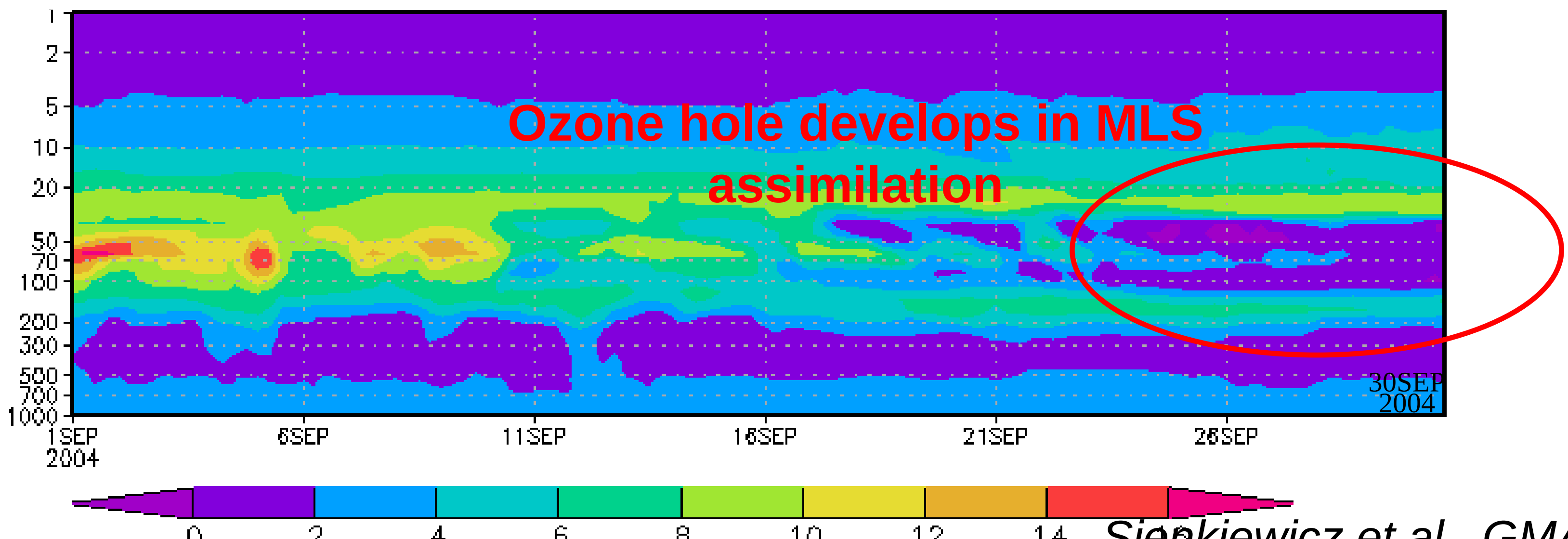
- Satellite data will become increasingly important for:
  - Land data assimilation
    - surface type, soil moisture…MODIS, AMSR, MSG, SMOS
  - Ocean data assimilation
    - SST, sea state, salinity, gravity, ocean color…TOPEX, JASON(2), ERS, SMOS…

Assimilation of MLS Retrieved Ozone in GEOS-5

SBUV assimilation   South Pole ozone partial pressure (mPa)



MLS assimilation   South Pole ozone partial pressure (mPa)



Sienkiewicz et al., GMAO

Some Weather↔Climate Data Assimilation Research Topics?

- Improved representation of moist physics and gravity waves
- Assimilation of cloud information (cloudy radiances)
- Inclusion of physical balances and constraints more appropriate for “climate” applications
- Improved radiative transfer/parameterizations over land and ice
- Need for stochastic physics / ensembles of analyses
- Inclusion of model error: weak constraint formulations, possibly over “long-windows”…20-30 days or longer?
- Assimilation system design modifications to mitigate shocks and improve/preserve propagation of information through the system
- Application/extension of NWP-derived diagnostic tools to other temporal and spatial scales. ...slow components?