Atmospheric Data Assimilation at NASA/GMAO

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With thanks to many at NASA/GMAO and NOAA/NCEP/EMC

JCSDA Summer Colloquium on Data Assimilation
Stevenson WA, 15 June 2009

Outline

- Collaboration with NCEP/EMC
- Current (3D-Var) System and example applications
- 4D-Var development
- MERRA reanalysis
- OSSE development
- Plans

GMAO Assimilation Systems

Atmosphere

- GEOS-5 with GSI 3D-, 4D-Var, 6-hr assimilation window
- Meteorological analyses (u, v, T, q) for weather prediction, climate analysis
- Chemistry constituents: O_3 coupled to meteorology; CO, CO_2 under development
- Aerosols: transport, with source distributions from satellite

Ocean

- MOM4 with MvOI, EnKF, 5-day assimilation window
- Retrospective ocean analyses (u, v, T, S) for seasonal fcsts
- Assimilation in AOGCM coupled to atmospheric analysis
- Ocean color analyses: ocean time series, removing cross-satellite biases

Land Surface

- Catchment LSM with EnKF, 3-hr assimilation window
- Soil moisture, surface temperature and snow

GMAO Atmospheric Data Assimilation Mission

(i) **Maximize data usage, especially satellite data**, in modeling systems used for numerical weather prediction, short-term climate prediction, chemistry assessments

(ii) **Provide guidance on data development**, using assimilation-based tools to evaluate existing observations and identify new instruments that have the greatest potential for adding useful information to the observing network

(iii) **Produce research-quality assimilated datasets**, not limited to NWP, including trace gases, aerosol and climate products, with the aim of maximizing the return on NASA's investment in Earth observations

…the GMAO is <u>not</u> an operational NWP center, although we function like one in many respects

GMAO Atmospheric Data Assimilation Strategy

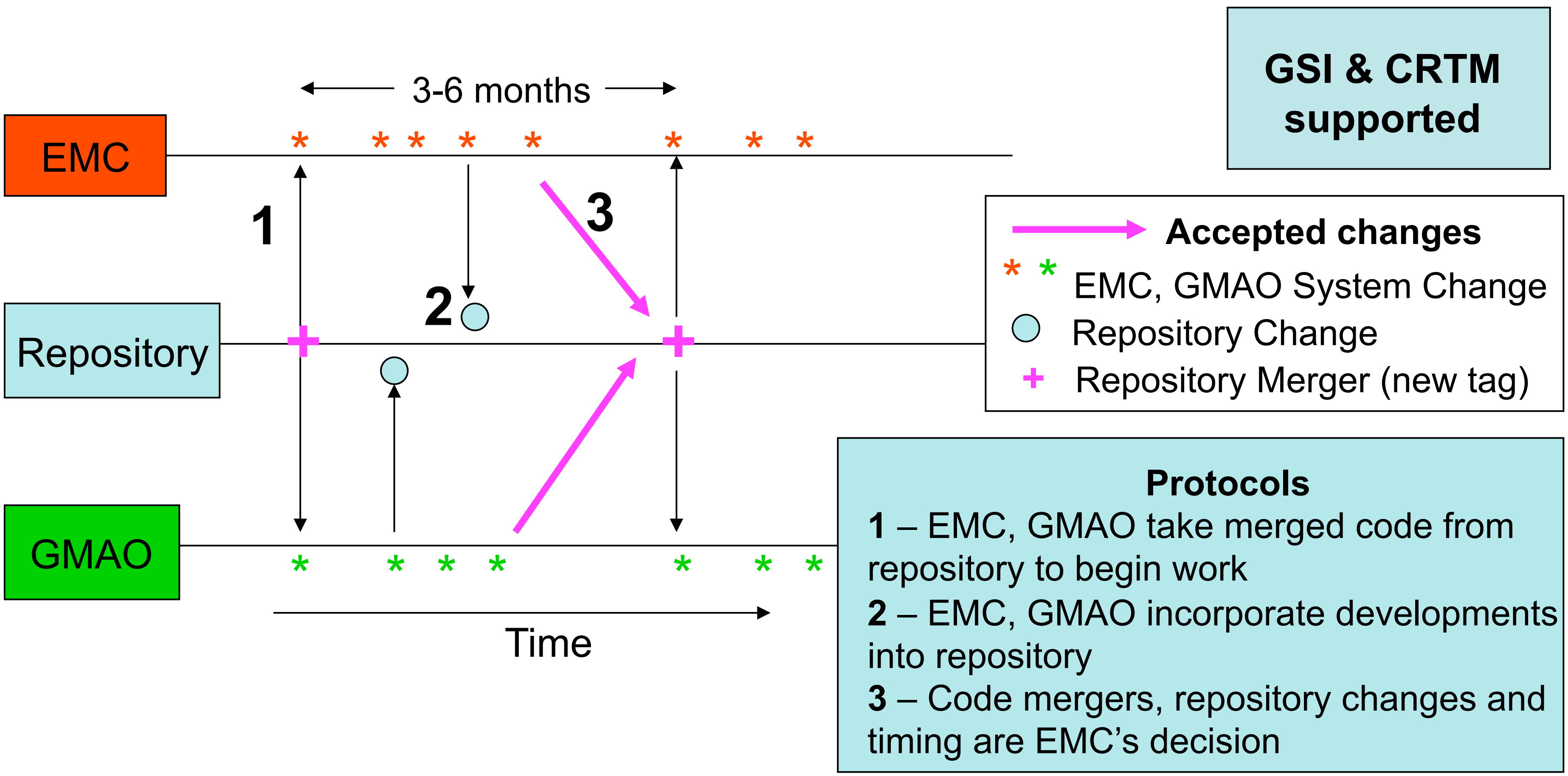
A joint development effort with NCEP/EMC:

- Brings the strength and maturity of operational systems to benefit NASA's research agenda
- Facilitates NASA's contribution to JCSDA goal of accelerating (improving) the use of satellite data in operations

    - NCEP's Gridpoint Statistical Interpolation (GSI) analysis scheme is the core infrastructure
    - Code reuse across organizations
    - Quasi-regular code merges*
    - Weekly meetings at the working level

* *Human resource limitations, major upgrades (e.g., 4D-Var) can delay regular mergers*

NCEP/EMC-GMAO Code Management for Atmospheric Data Assimilation

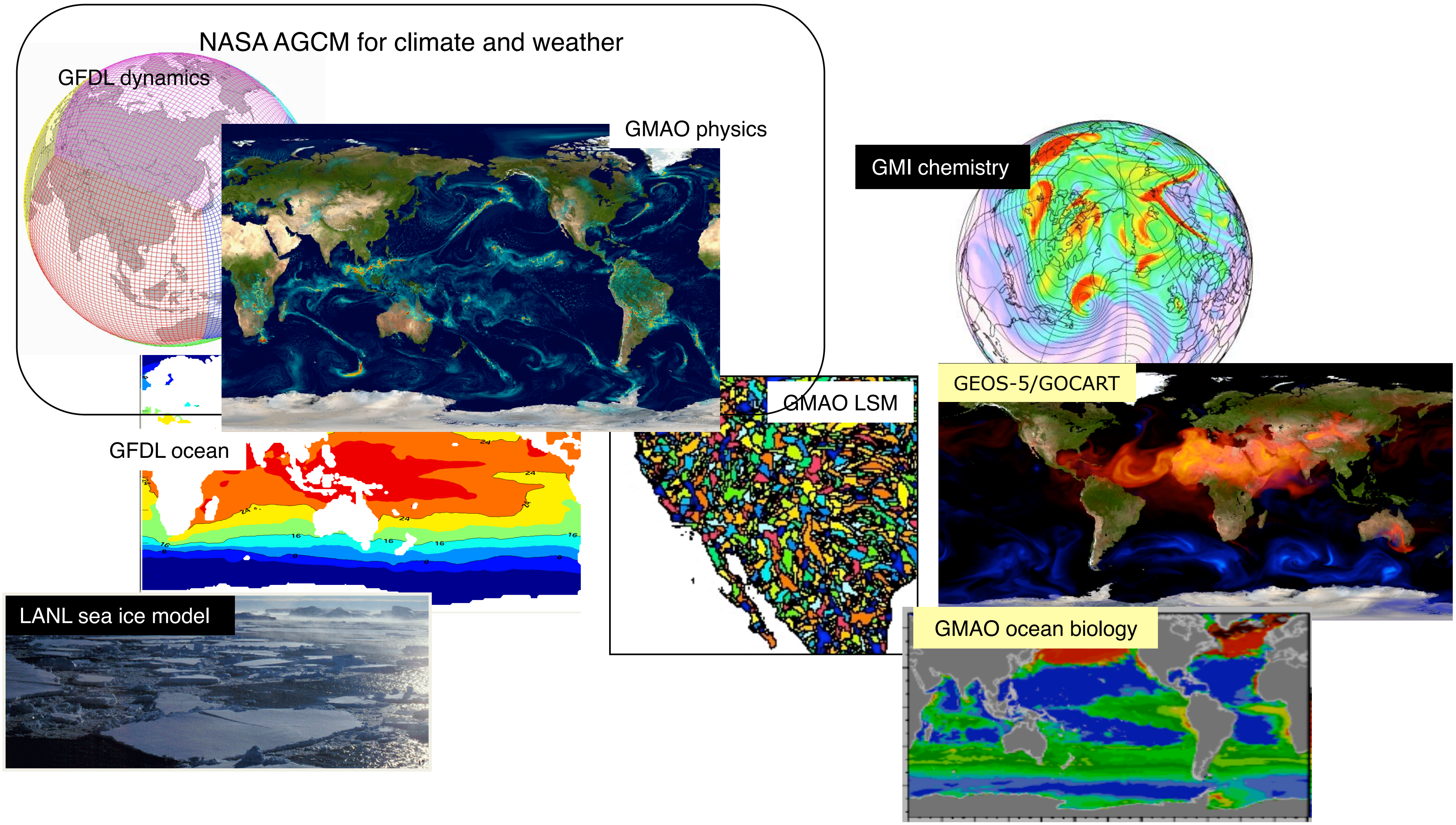


GMAO-NCEP Collaboration: Current Status

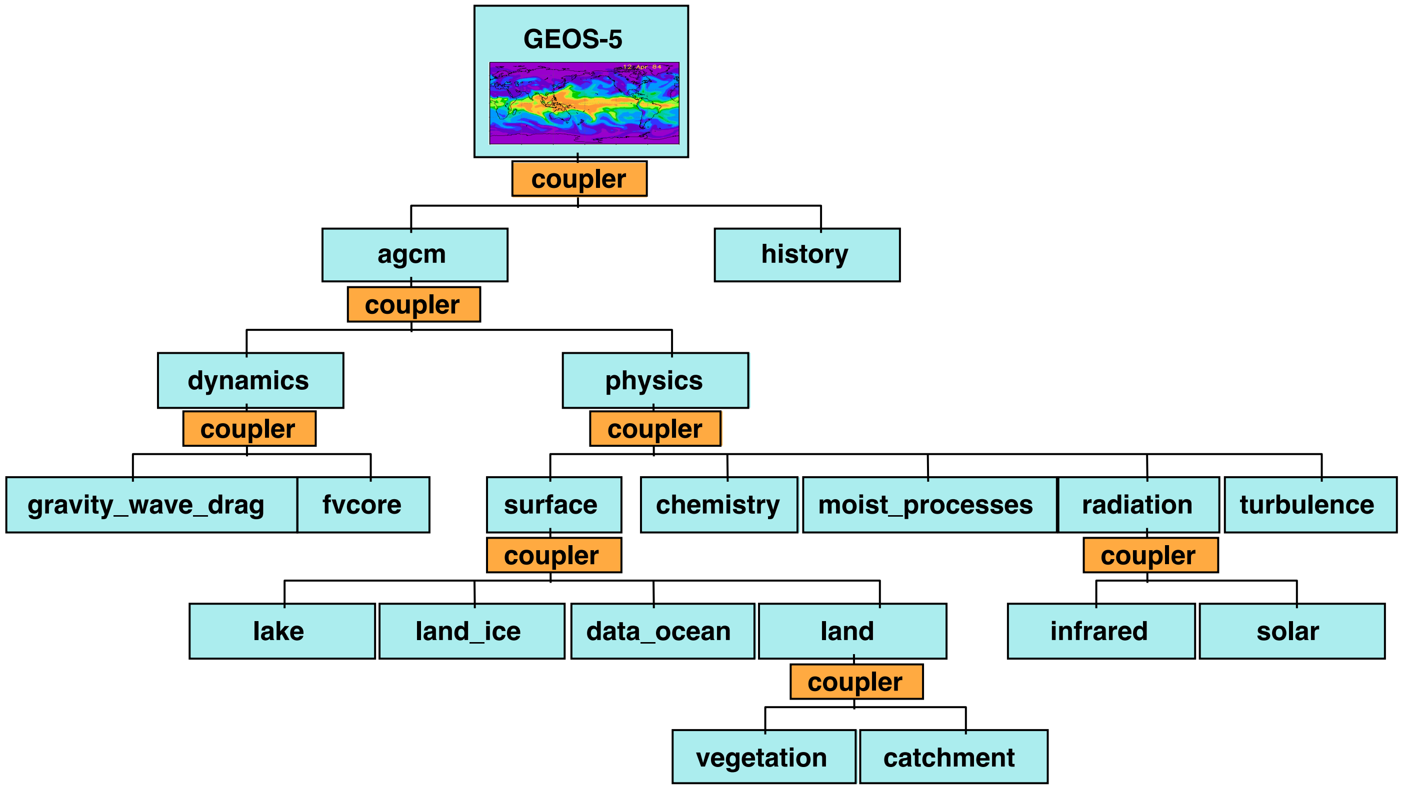
- GMAO and NCEP are developing 4D-Var systems using the same GSI code base
  - Major merge of 4D-Var code recently completed
  - Consistent use of <u>ESMF</u> to couple model-analysis
- Coordinated development foci for mutual benefit
  - NCEP: operational/RT data (GPS, MetOp, …), anisotropic background errors, balance, efficiency
  - GMAO: 4D-Var extension, observing system science tools, research data (MLS, AIRS, wind lidar)
- System diversity with some differences in approach
  - Forecast models differ for NASA research, NOAA operational priorities
  - AIRS channel selection, sampling
  - Data handling in 4D-Var

Earth System Modeling Framework – ESMF

Integrate components from a variety of sources
Facilitate shared codes, external developer contributions, interagency coordination
End-goal is a flexible Integrated Earth System Model and Analysis System



ESMF component graph for GEOS-5 AGCM



- Boxes are user-written ESMF components
- Every component has a standard ESMF interface **`Init()`**, **`Run()`**, **`Finalize()`**. These drive the components.
- Data in and out of components are packaged in **`ESMF_state`** types
- New components can be added to the hierarchical system
- Coupling tools include parallel regridding and redistribution methods

Max Suarez, Atanas Tryanov

GEOS-5 Atmospheric Data Assimilation System (ADAS)

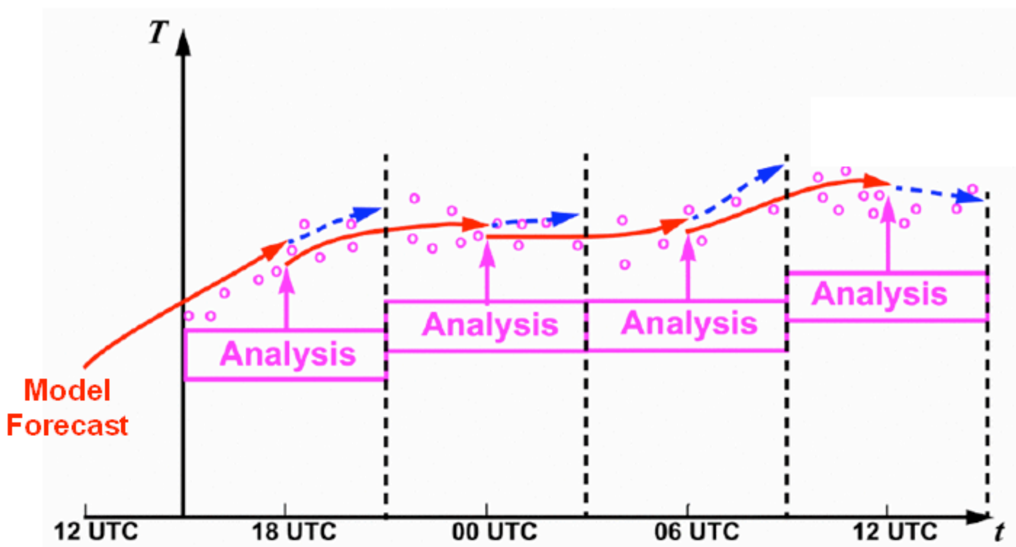
3D-Var system for current reanalysis (MERRA) and NRT forward processing

Atmospheric Model/AGCM

- Finite-volume dynamic core
- Bacmeister moist physics
- Physics integrated via ESMF
- Catchment land surface model
- Prescribed aerosols
- Interactive ozone

Atmospheric Analysis System

- Gridpoint Statistical Interpolation (GSI)
- Direct assimilation of satellite radiances
- JCSDA Radiative Transfer Model (CRTM)
- Variational bias correction for radiances
- Separate line-by-line adjoint GSI for observation impact studies



Graphic, ECMWF

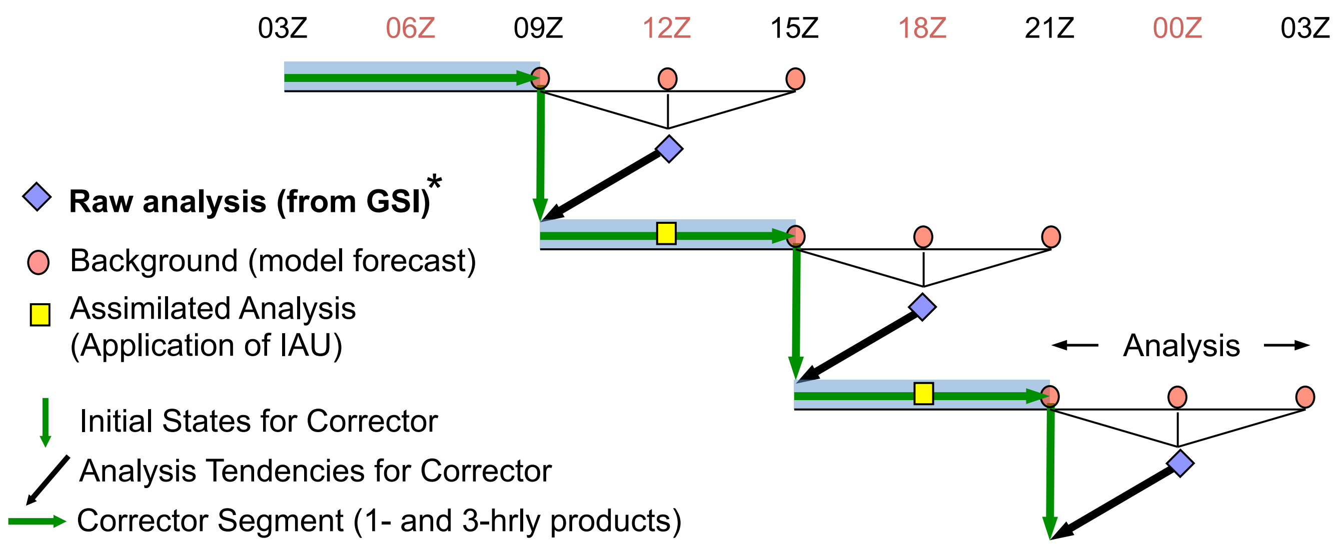
<u>3D-Var</u>

Compare the model forecast to observations ***assuming all information is valid at the analysis time****…..an approximation to 4D-Var*

GEOS-5 Incremental Analysis Update (IAU)

$$\left(\frac{\partial q^n}{\partial t}\right)_{total} = dynamics(adiabatic) + physics(diabatic) + \Delta q$$

Total "observed change" **Model predicted change** **Correction from DAS**



* IAU framework allows "replay" capability from <u>any</u> existing analysis

Data Types Assimilated in GEOS-5 (NRT)

From NCEP streams, except GMAO AIRS

Conventional

• Raob	(u,v,T,q,p_s)
• Dropsonde	(u,v,T)
• Pibal	(u,v)
• Aircraft	(u,v,T)
• Marine Sfc	(u,v,T,q,p_s)
• Land Sfc	(p_s)
• Profiler	(u,v)
• NEXRAD	(u,v)

Satellite Radiance

• AMSU-A	(N-15,18, Aqua, MetOp)
• AMSU-B	(N-15,16,17,18)
• HIRS/3,4	(N-17, MetOp)
• AIRS	(Aqua)
• SSM/I	(F-13)
• Sounder	(GOES-11,12)
• AMSR-E	(Aqua)
• IASI	(MetOp)
• MHS	(MetOp)

Satellite Non-Radiance

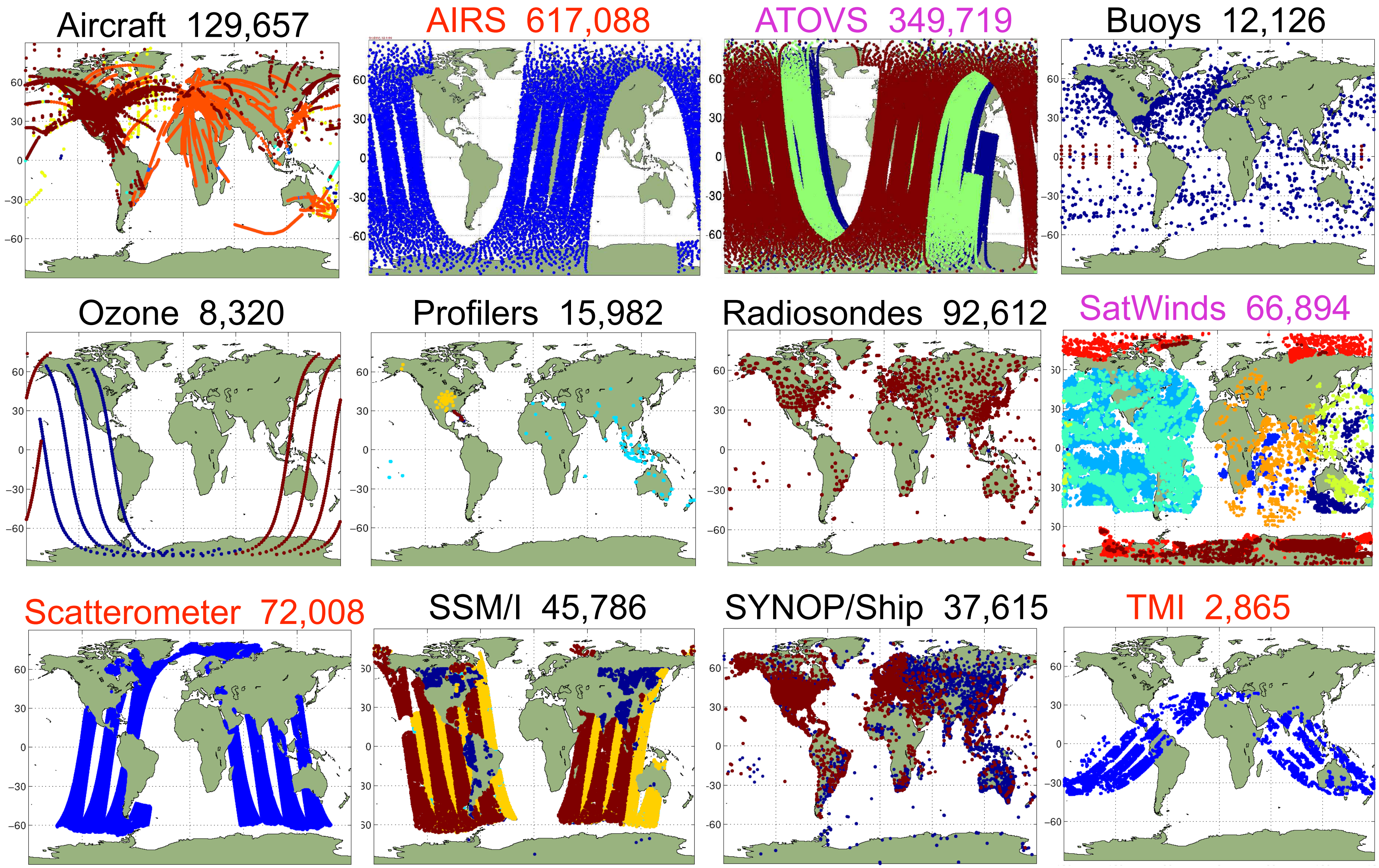
• AMVs	(GMS, GOES, MODIS, METEOSAT Vis, IR, WV)
• Scat Wind	(QuikSCAT)
• Wind Speed	(SSM/I)
• Rain Rate	(SSM/I, TRMM/TMI)
• Ozone	(N-17 SBUV/2 Level and total column)
• GPS RO	(COSMIC)

~1.5/2.4 million obs assimilated/6 hrs

Main Observing Systems Assimilated in GEOS-5

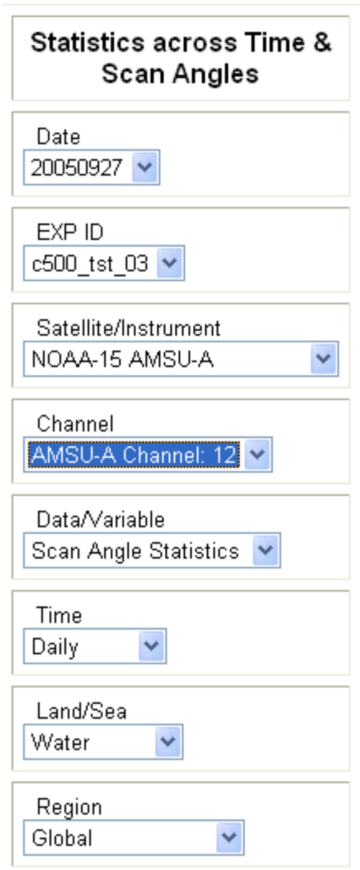
6-hr window centered at 00 UTC 11 Nov 2007

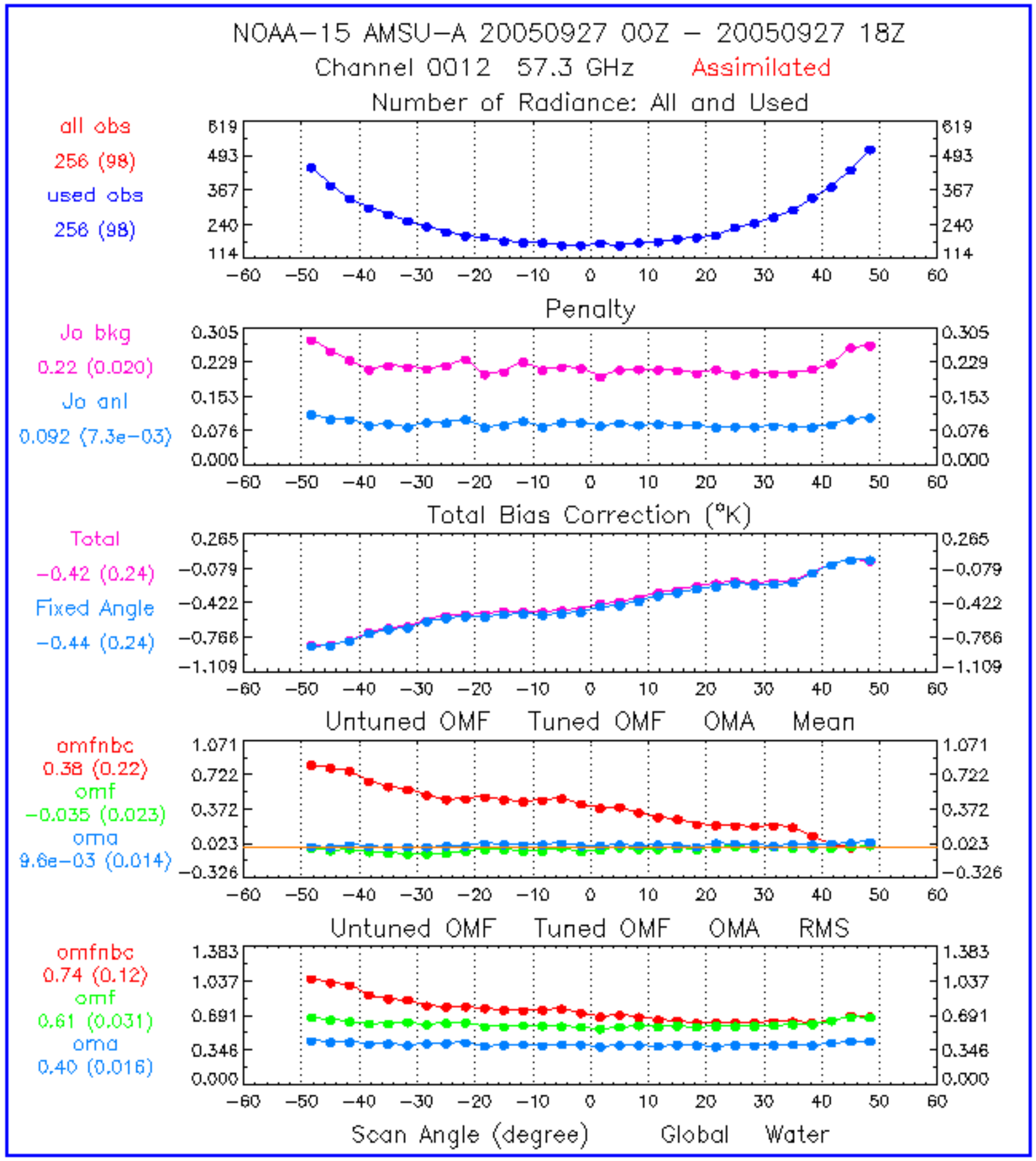
Operational
Research (NASA)
Operational+Research



Monitoring of Satellite Radiamces

Screen-shot of GMAO radiance monitoring package





Accounting for instrument characteristics & related biases is critical to successful use of the data!

Observation count

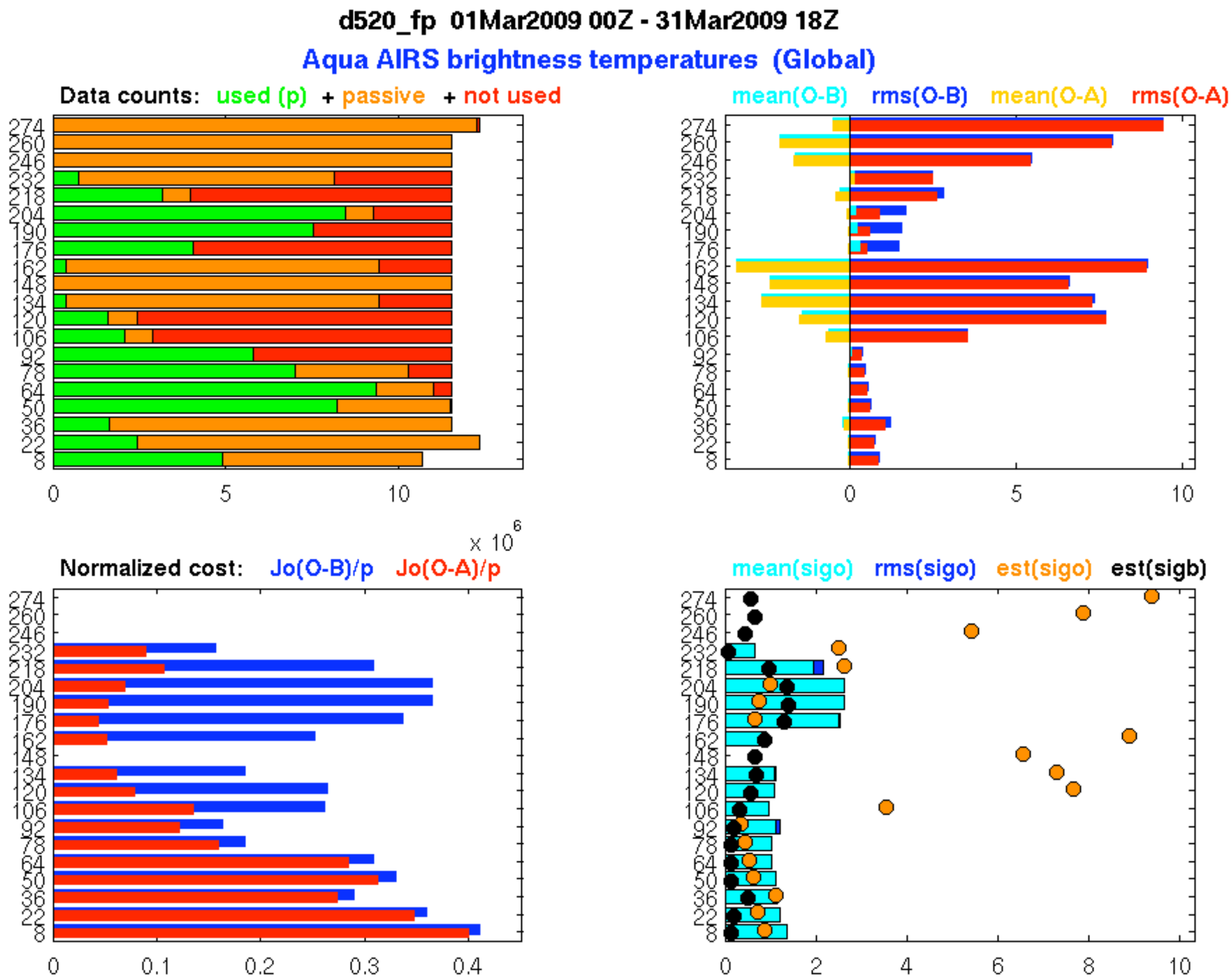
Obs penalty (fit) before and after analysis solution

Adaptively estimated obs bias

Mean and RMS obs departures before and after bias correction, & after analysis solution

On-Line Observing System Monitoring

Screen-shot of GMAO DOLMS monitoring package



Desroziers diganostics

GEOS-5 DAS Products in Support of NASA Missions and Related Research

Instrument Teams

- ✓ *MLS, TES, HIRDLS on Aqua*
- ✓ *MODIS Land on Terra, Aqua*
- ✓ *CERES on Terra, Aqua, TRMM*
- ✓ *CALIPSO*
- ✓ ***MLS Real-Time***

✓ *= use GEOS-5 real time products*

Field Campaigns

- ✓ *INTEX-NA*
- ✓ *NAMMA*
- ✓ *TC4*
- ✓ *ARCTAS*
- ✓ *TIGERZ*
- ✓ *GLOPAC*

Projects

- ✓ *Power*
- ✓ *Flash Flux*
- ✓ *SRB*
- ✓ *GEWEX/CEOP*
- ✓ *YOTC*
- ✓ *Flood/Landslide potential*
- ✓ *GLDAS*
- ✓ *JAXA/SMILES*

Science Support

- ✓✓ *GMI-CTM*
- ✓✓ *Harvard GEOS Chem*
- ✓ *Universities…*

GEOS-5 Production Streams

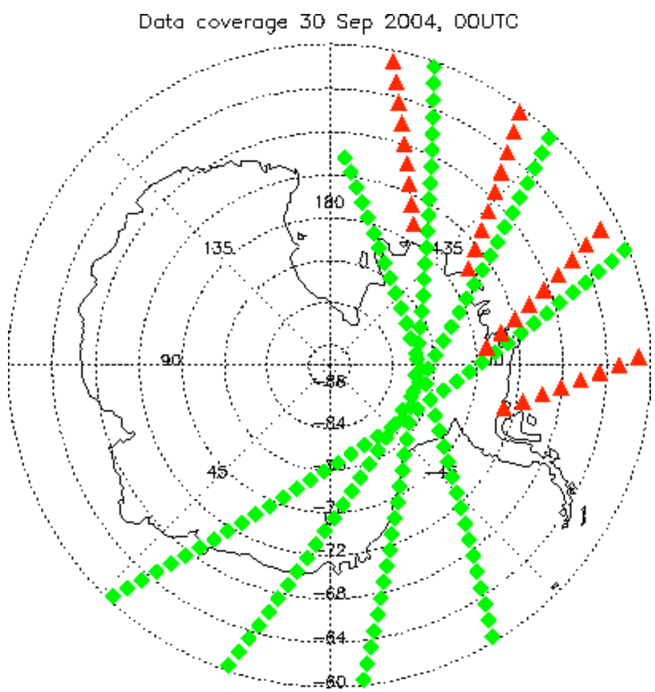
Production	Stream	Frequency	Distribution	Status as of 7/9/2009
Forward Processing	DAS	00z, 06z, 12z and 18z every day	Sent to GSFC MDISC for instrument teams On NCCS data portal for field campaigns	Running NRT
	Fcst	5-day fcsts at 00z and 12z every day	On NCCS data portal for field campaigns	Running NRT
YOTC Support (V5.3.0 at ¼°)	DAS	00z, 06z, 12z and 18z every day	On NCCS data portal, & field campaign use	Running NRT
	Fcst	5-day fcst at 00z every day	On NCCS data portal, & field campaign use	Running NRT
MERRA Re-analysis	Stream 1 (79–88)	Continuous at 10 dd/d	GSFC MDISC	Running 12/1988
	Stream 2 (89–97)			Running 7/1997
	Stream 3 (98-present)			Running 10/2005
	Scout 79 (79-present)	Continuous at 30 dd/d	Internal use	Running 05/2009
G5-NCEP	Fcst	5-day fcst at 00z every day	Internal use	Running NRT
CERES Support	V5.3.0 Reprocessing (97–12)		To be sent via GSFC MDISC	Under validation
	V5.2.0 Forward	Continuous from September 2007, then ~2 wks behind RT	Sent via GSFC MDISC	Running 05/2009

Assimilation of AURA/MLS Ozone in GEOS-5

Data not (yet) available in real time

SBUV daytime only – no data near South Pole due to high solar zenith angle

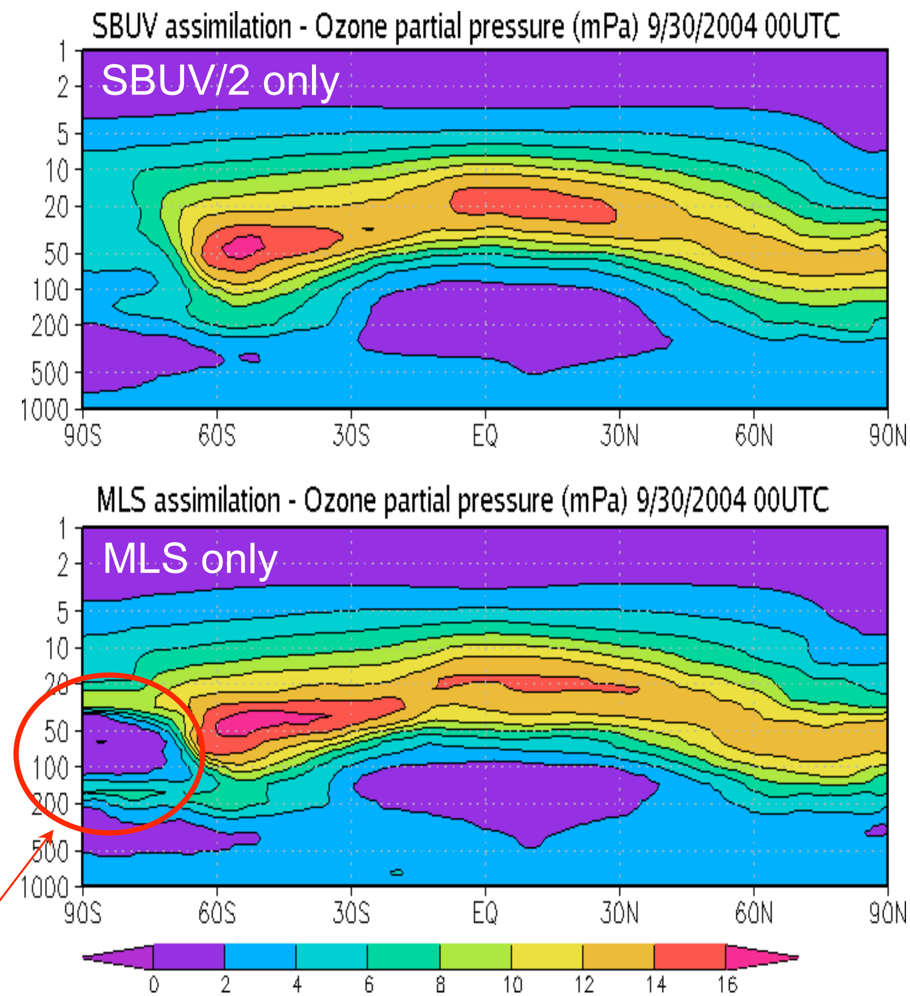
MLS orbital limit ±82º



▲ NOAA 16 SBUV

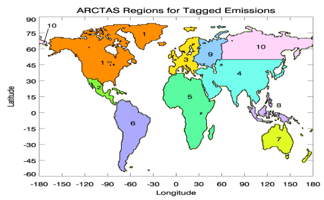
◆ MLS

Zonal mean ozone 9/30/2004 00UTC



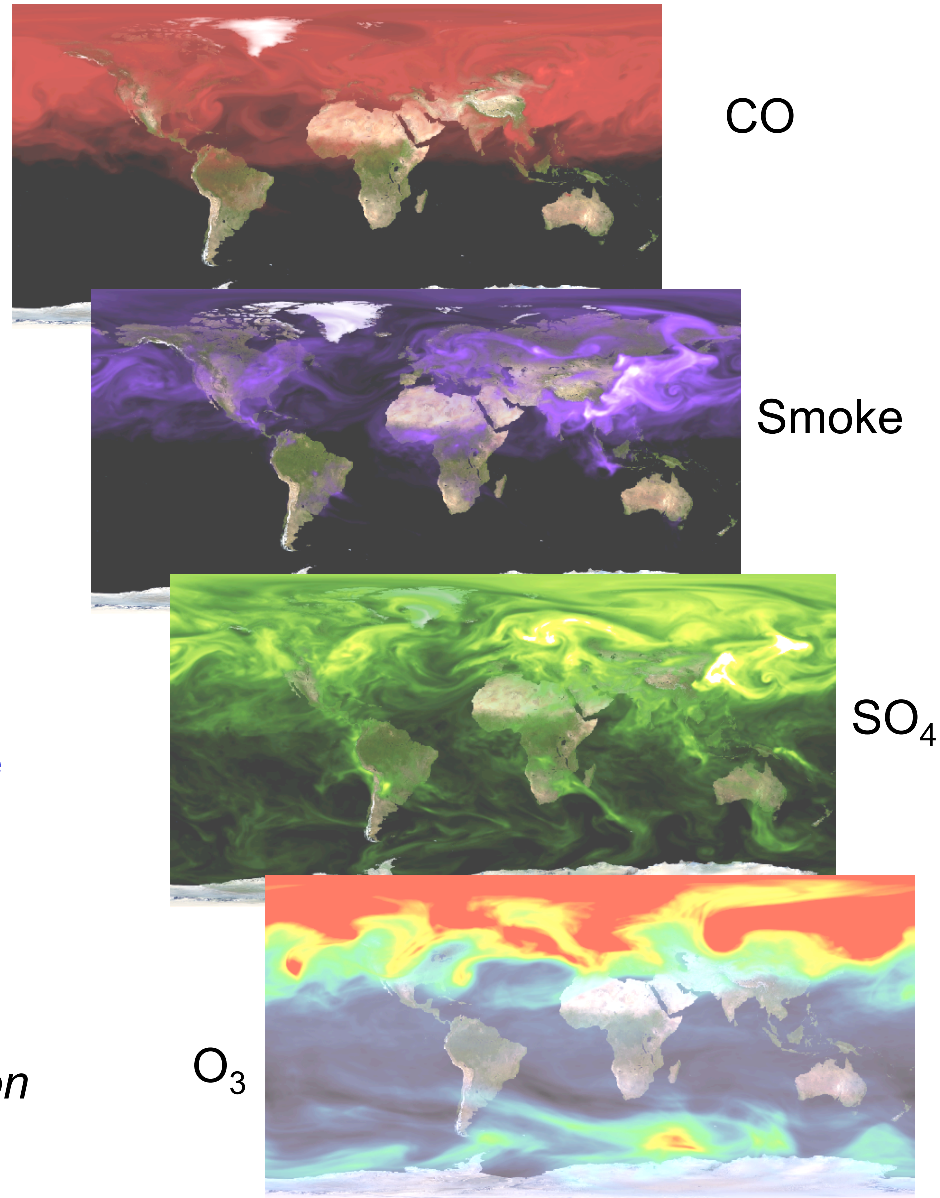
Ozone hole develops in MLS assimilation

Meta Sienkiewicz and Ivanka Stajner



GEOS-5/GOCART Forecasts for Field Campaigns

- Global 5-day chemical forecasts customized for each campaign
  - O_3, Aerosols, CO, CO_2,..
  - Tagged tracers
- Driven by real-time biomass emissions from MODIS
- During-mission
  - Web visualization, data delivery
  - In-field forecasting support
  - Comparison to aircraft data
- Post-mission:
  - Gridded datasets available online for post mission analysis
  - In depth evaluation, model tuning

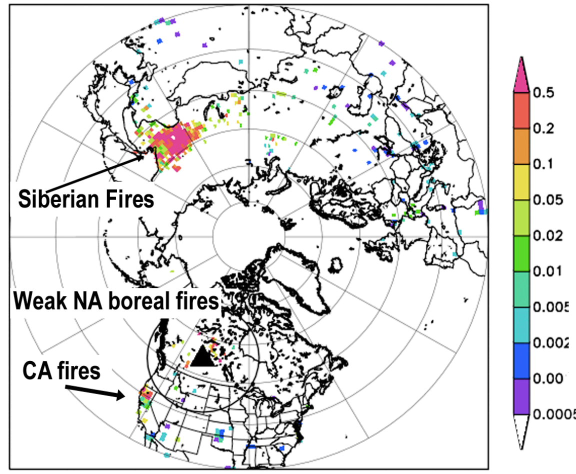


***Go**ddard **C**hemistry **A**erosol **R**adiation and **T**ransport model*

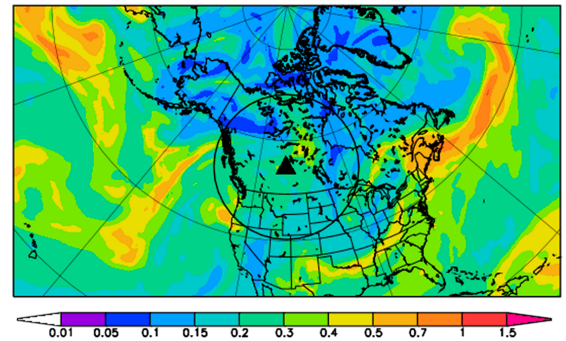
ARCTAS support

Arctic **R**esearch of the **C**omposition of the **T**roposphere from **A**ircraft and **S**atellites

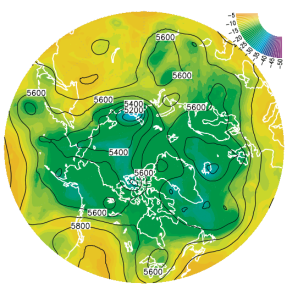
GEOS-5/GOCART analyses and forecasts used for DC8 flight planning June 2008



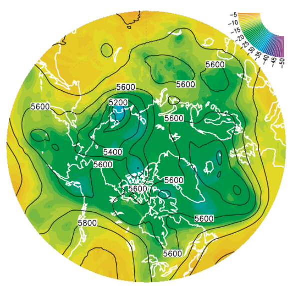
Total AOD (550 nm)



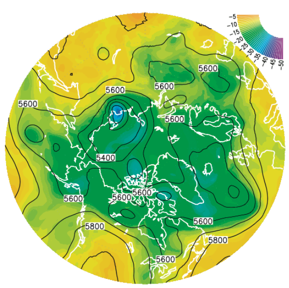
500 hPa Temperature and height



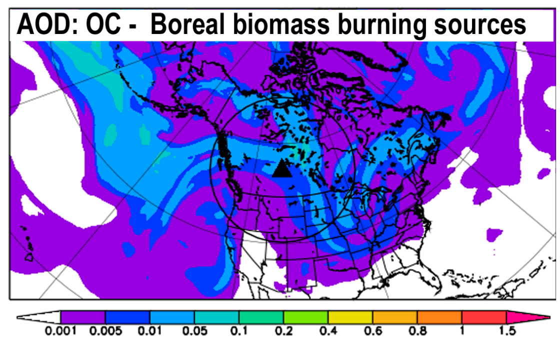
Analysis
12Z Jun 29

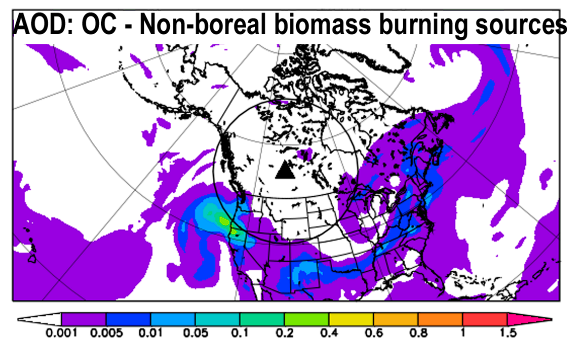


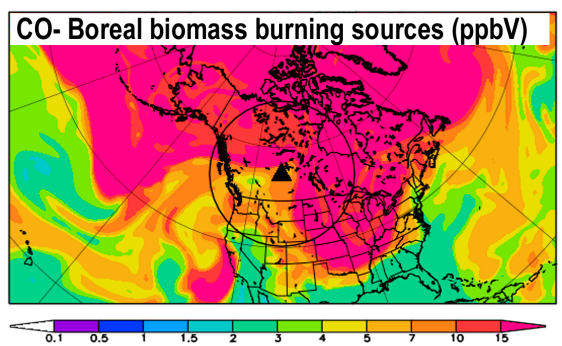
24-hr forecast

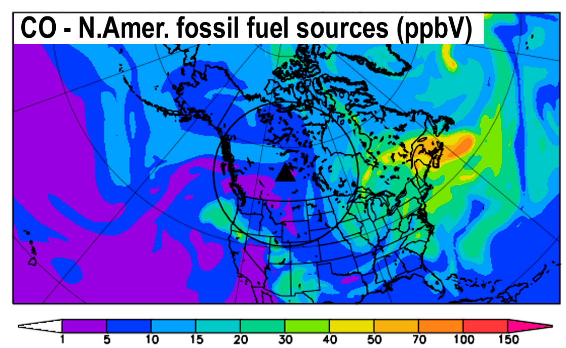


Analysis
12Z Jun 30









Da Silva & Colarco

YOTC: Year of Tropical Convection
1 August 2008 – 31 July 2011
WCRP and WWRP-THORPEX

*A Year of **coordinated observing, modeling and forecasting of organized tropical convection** and its influences on predictability (an 'IOP' every day concept). This is intended to exploit the vast amounts of existing and emerging observations and computational resources becoming available in conjunction with the development of new/high-resolution modeling frameworks, in order to better characterize, diagnose, model and forecast multi-scale convective/dynamic interactions and processes, including the two-way interaction between tropical and extra-tropical weather and climate circulations.*

Analyses and forecasts from ECMWF, GMAO and NCEP

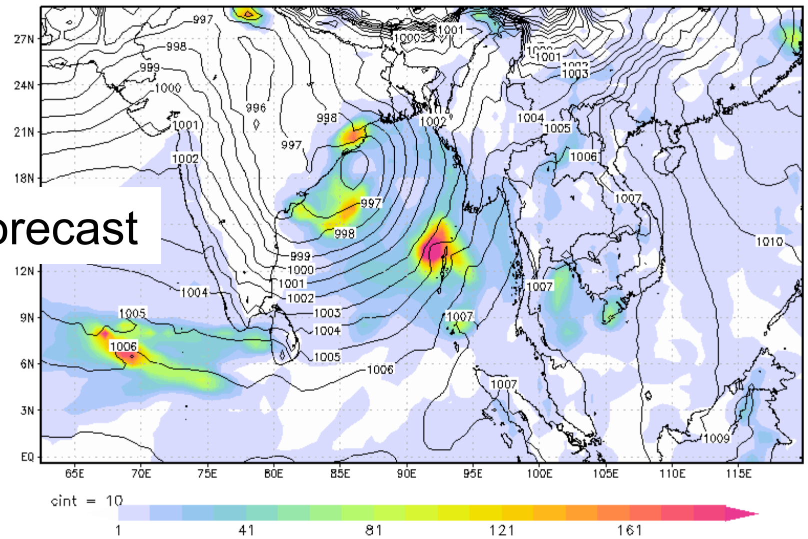
- GEOS-5.3.0 – interactive aerosols
- Analyses and 5-day forecasts from 0Z analysis, January 2009 onwards
- 1/4° × 1/3°
- Collections of 3D fields at 3-hourly intervals
- 2D fields, hourly
- Collections follow MERRA collections
- http://gmao.gsfc.nasa.gov/projects/yotc
- Data distributed from NCCS data portal

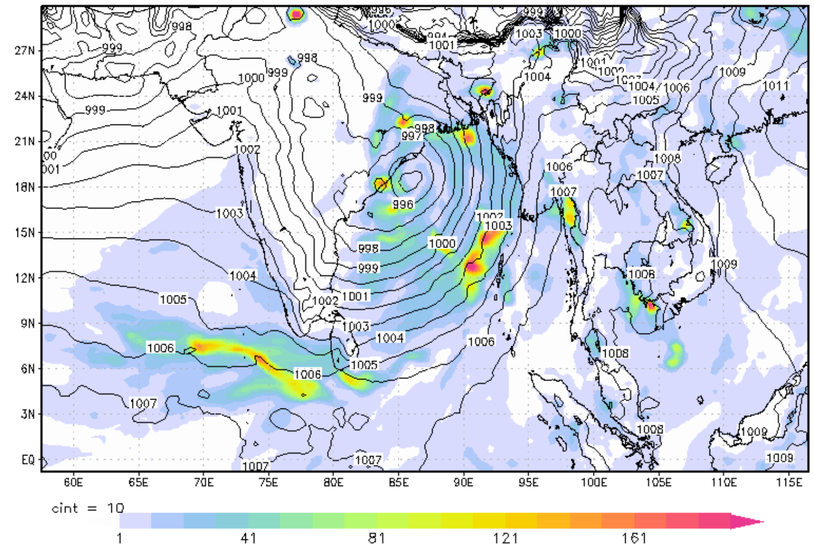
Forecasts of TC Aila on May 25 2008 00UTC
SLP and precipitation

½° GEOS-5.2.0 system

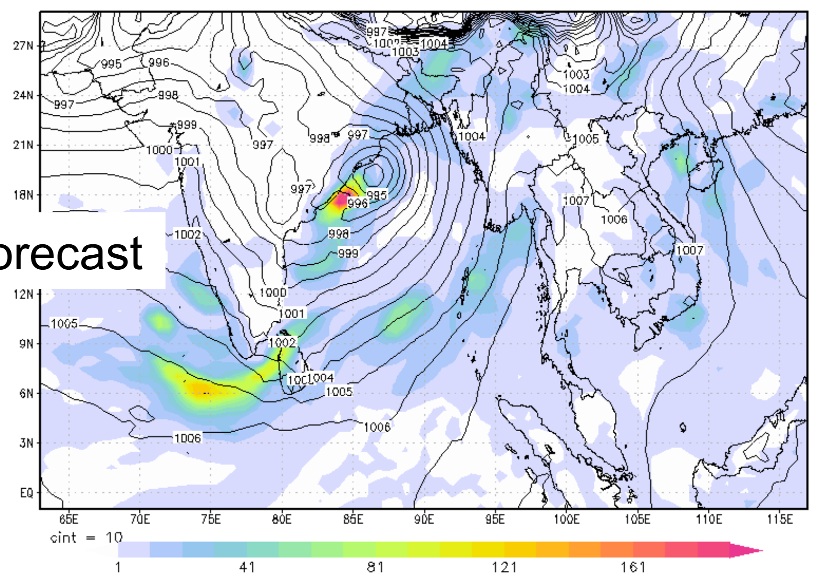
¼° GEOS-5.3.0 system (YOTC)

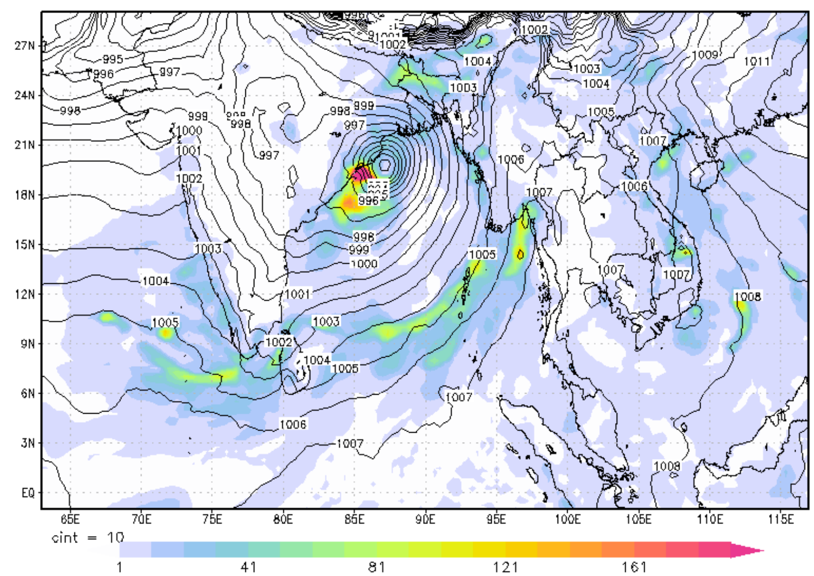
4-day forecast





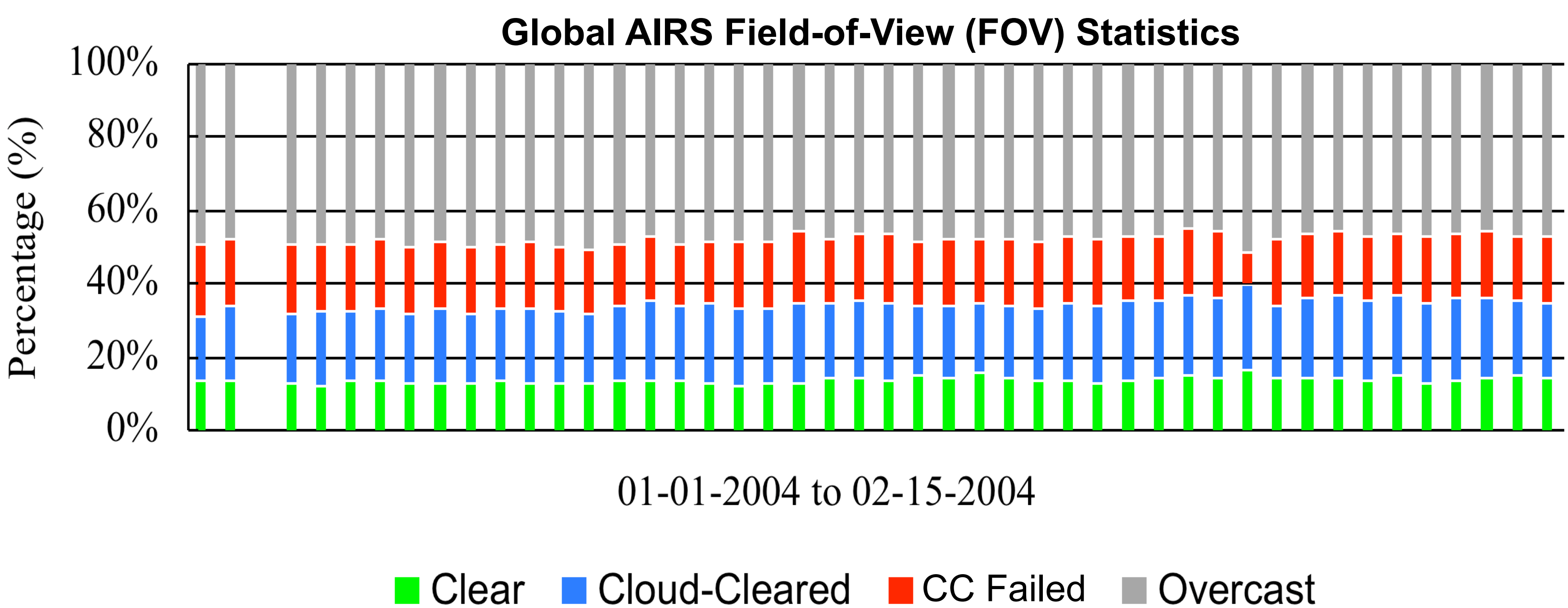
2-day forecast





Limited use of satellite radiances due to clouds

- Direct use of cloudy data is currently hindered by complexity and computational expense of IR cloudy radiative transfer calculation
- Currently, only clear-sky radiances are used in most data assimilation systems
  - *GEOS-5: <1% of AIRS considered (thinning), < 0.1% used (after QC)*
- Roughly 13% of considered AIRS FOVs are clear, and another 20-30% can be cloud-cleared successfully



Development of 4D-Var

The model contains information about the evolution of the atmosphere. It is information that should be used.

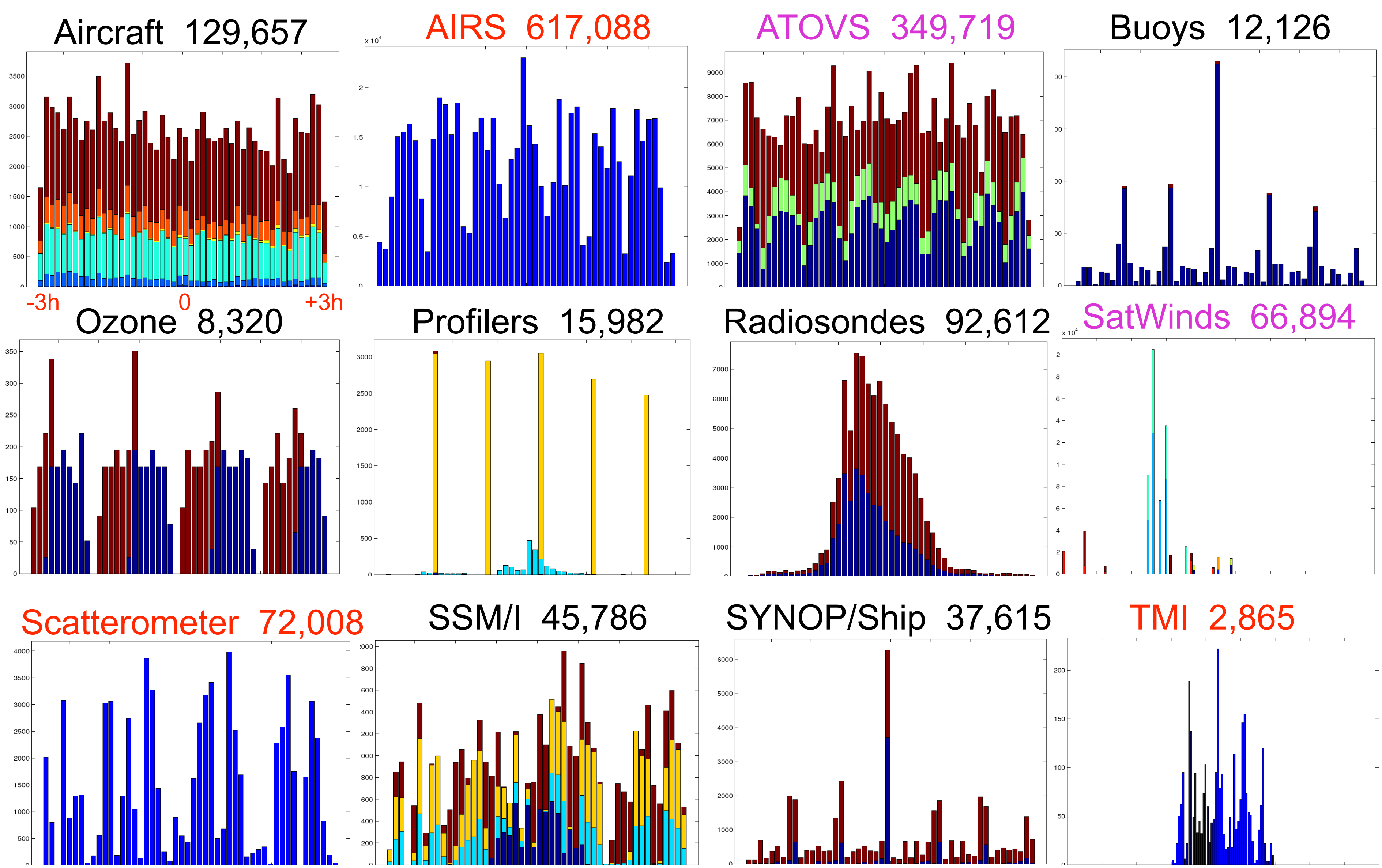
- Proper account of the time dimension is required to get the full benefit of **asynoptic satellite measurements**
- Accurate simulation of observations is necessary to extract tendency information from the data

…and…

- Proven track record of improvement over 3D-Var; gains by Europeans and Japanese attributable at least in part to 4D-Var

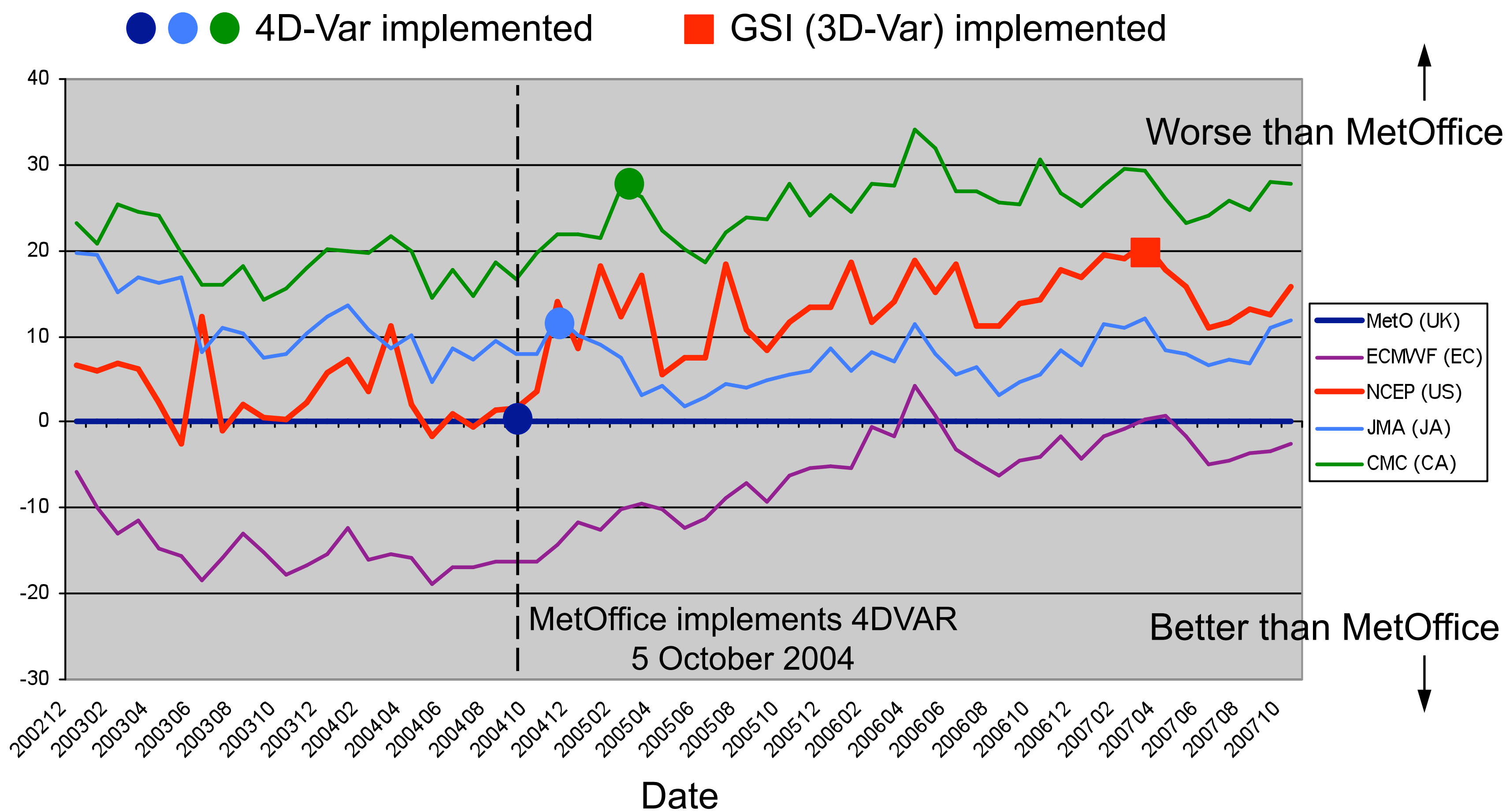
Temporal Distribution of Observations in the Assimilation Window

6-hr window centered at 00 UTC 11 Nov 2007



Global Forecast Performance Relative to (UK) Met Office

Based on Met Office Multi-parameter Skill Metric



A. Lorenc, MetOffice

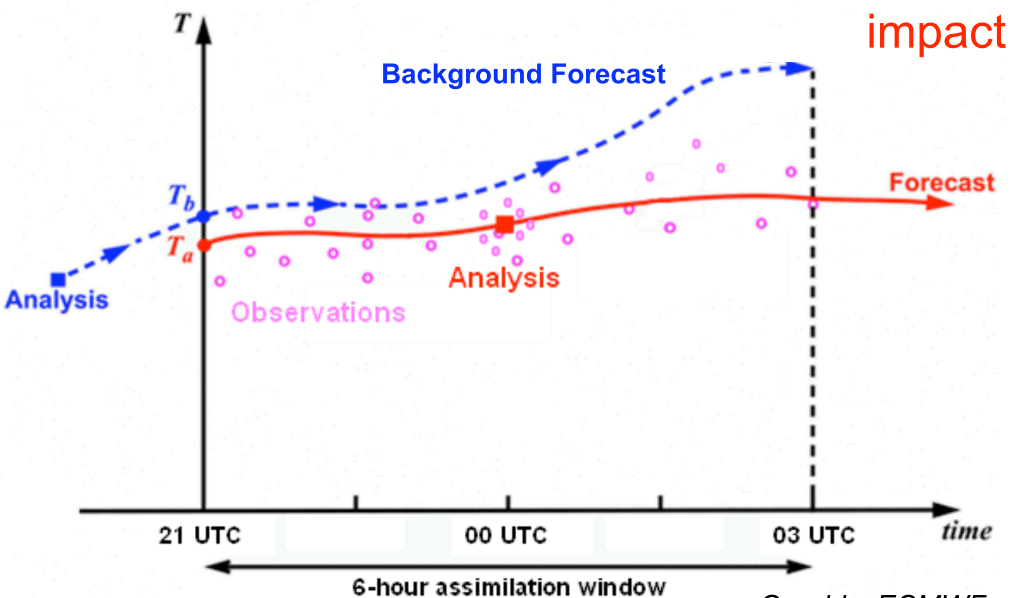
GEOS-5/6 Prototype 4D-Var ADAS

Atmospheric Model/AGCM

- Finite-volume dynamic core
- Bacmeister moist physics
- Physics integrated via ESMF
- Catchment land surface model
- Prescribed aerosols
- Interactive ozone
- Observation operator interface to GSI via ESMF

Atmospheric Analysis System

- 4D-Var GSI, weak constraint capable
- TLM/ADM of FV core + simple physics
- Multiple preconditioners ($B^{1/2}$, Lanczos)
- Multiple minimizations (CG, QN, Lanczos)
- Direct assimilation of satellite radiances
- JCSDA Radiative Transfer Model (CRTM)
- Variational bias correction for radiances
- Embedded adjoint GSI for observation impact (maintenance free)



Graphic, ECMWF

<u>4D-Var</u>

Compute the (starting point of the) ***forecast trajectory*** *that best fits all available observations in space and time*

Summary of 4D-Var Status I

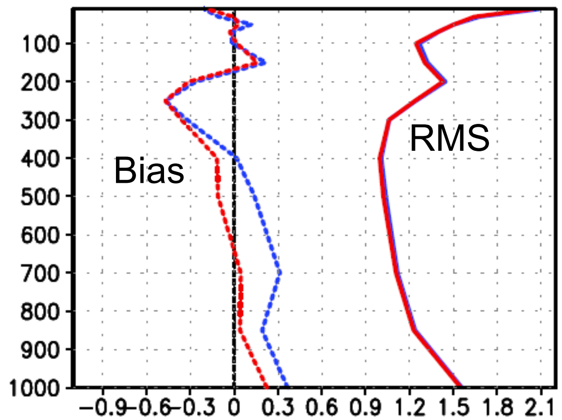
- Prototype NASA GEOS DAS 4DVAR now available
- Encouraging preliminary results with prototype 6-hr 4DVAR
  - mixed results in observation-minus-forecast residuals
  - neutral to positive impact on forecast skills
  - neutral to positive impact on monthly means
- Preliminary results with 12-hr 4DVAR similarly encouraging
- Various adjoint-based diagnostic tools in GEOS DAS
  - Forecast sensitivity
  - Singular vectors
  - Observation impact

R. Todling (GMAO) and Y. Trémolet (ECMWF)

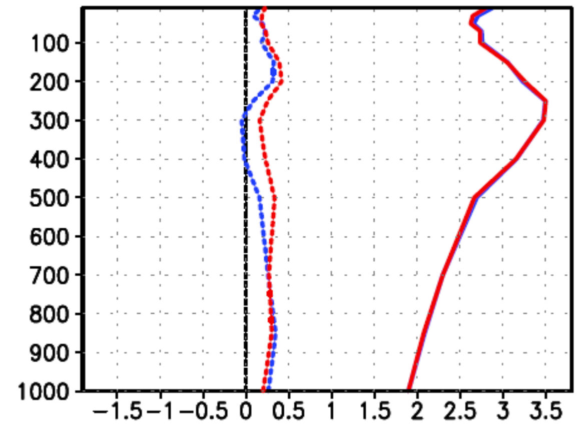
Early Results Comparing 3D-Var with 6h 4D-Var

Raob observation-minus-background residuals

Global Temperature Raob Residual



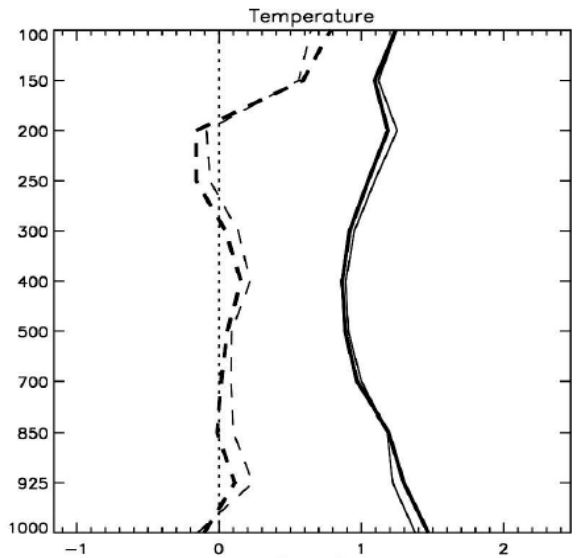
Global U-wind Raob Residual

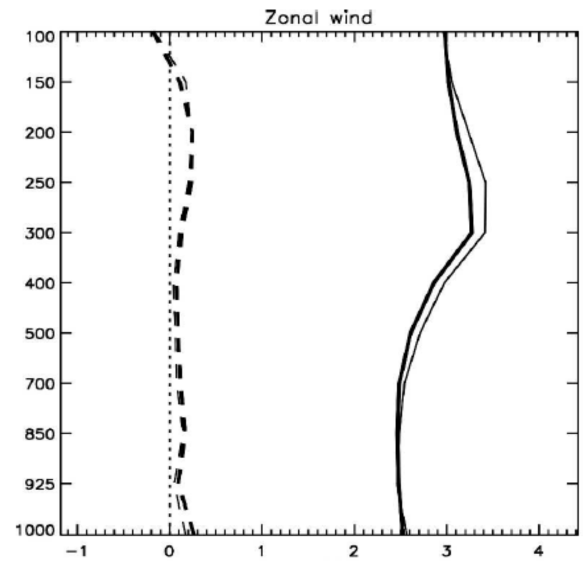


GMAO prototype 4D-Var Winter 2006

3D-Var

4D-Var





MSC 4D-Var Winter 2004

Gauthier et al. 2007

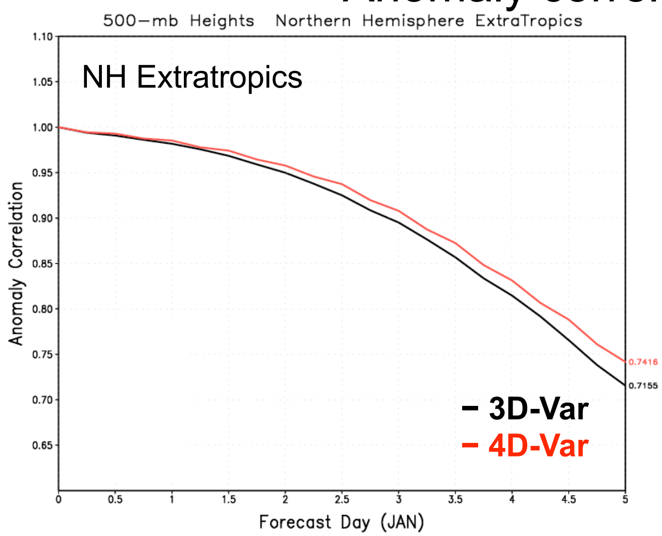
3D-Var

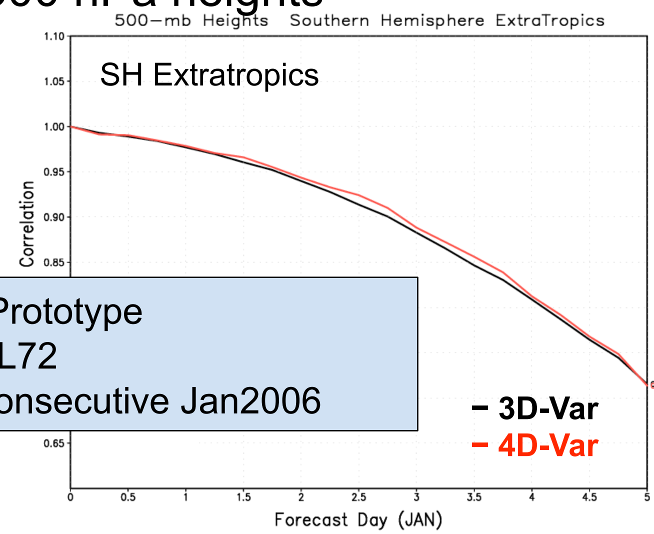
4D-Var

Note that comparison periods differ, but early results are qualitatively similar

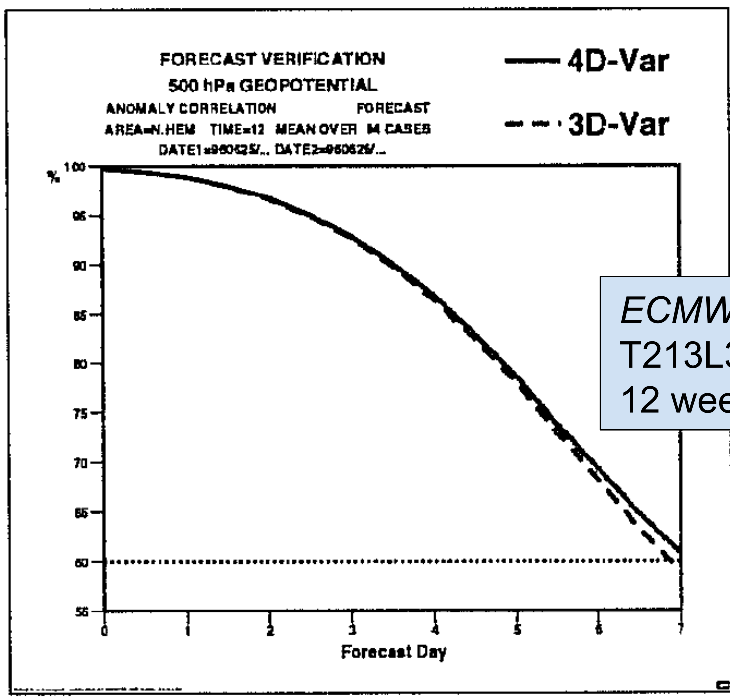
Early Results Comparing 3D-Var with 6h 4D-Var

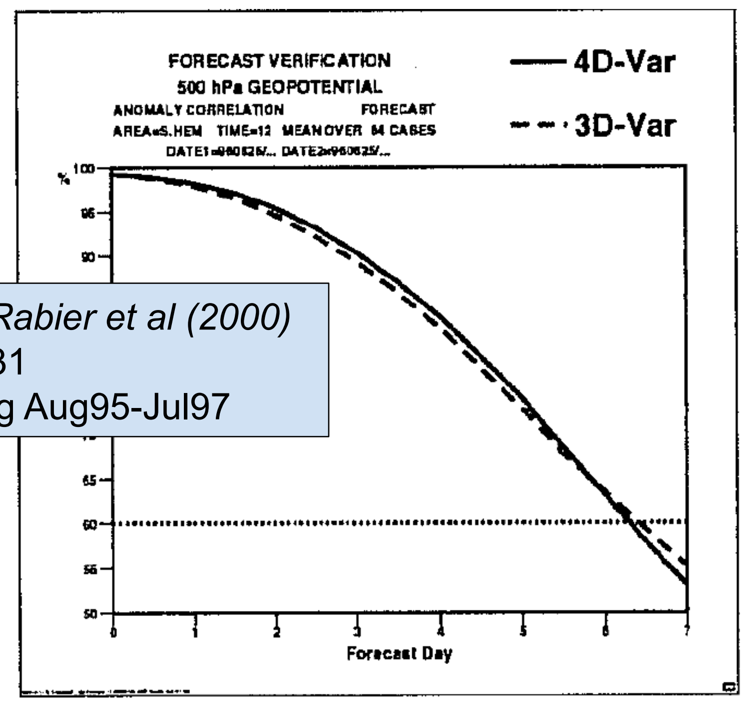
Anomaly correlation for 500 hPa heights





GEOS-5 Prototype
2.0°x2.5° L72
31 days consecutive Jan2006

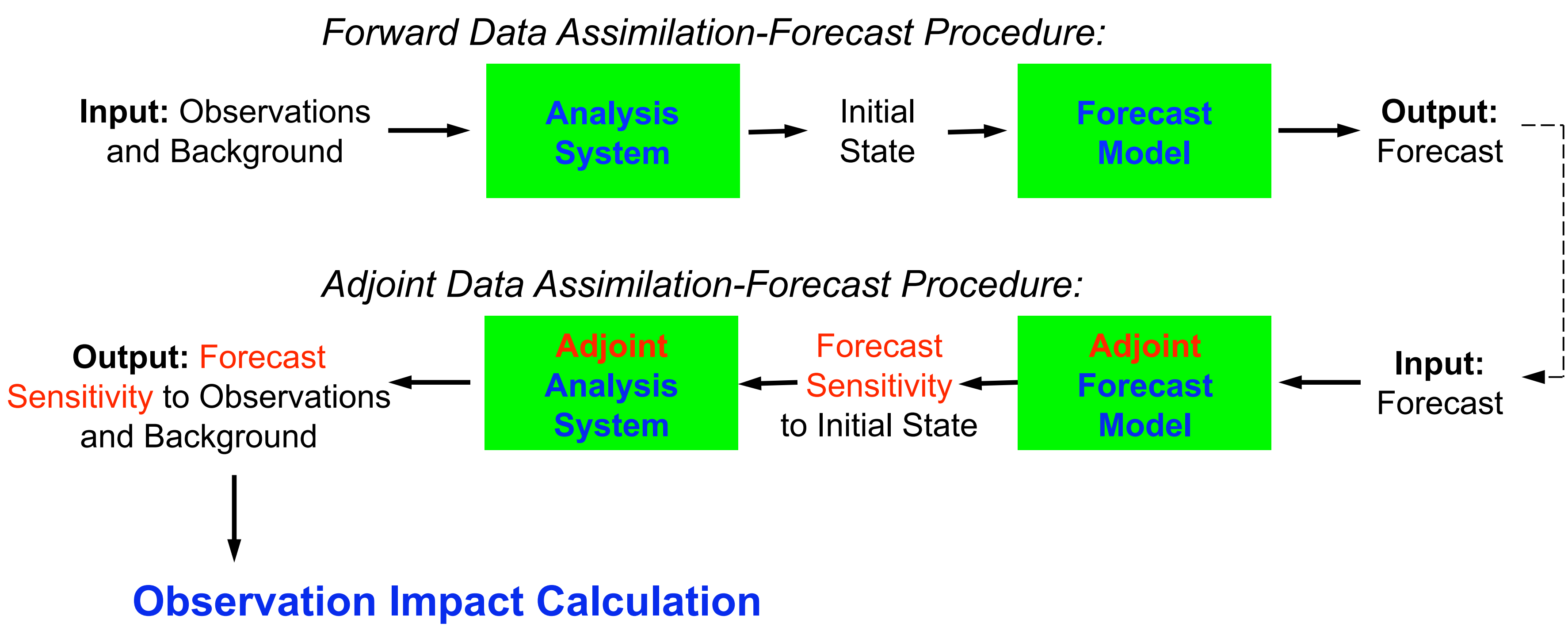




ECMWF, from Rabier et al (2000)
T213L31/T63L31
12 weeks during Aug95-Jul97

Adjoint Tools for Observation Impact Studies

*The adjoint of a data assimilation system allows accurate and efficient estimation of the impacts of **all** assimilated observations simultaneously on analyses and short-range forecasts*



Computation of the adjoint of GSI ($\mathbf{K}^T$) for 3D-Var and 4D-Var

Features recently added to GSI as part of 4D-Var development allow the adjoint to be computed in two ways for both 3D-Var and 4D-Var

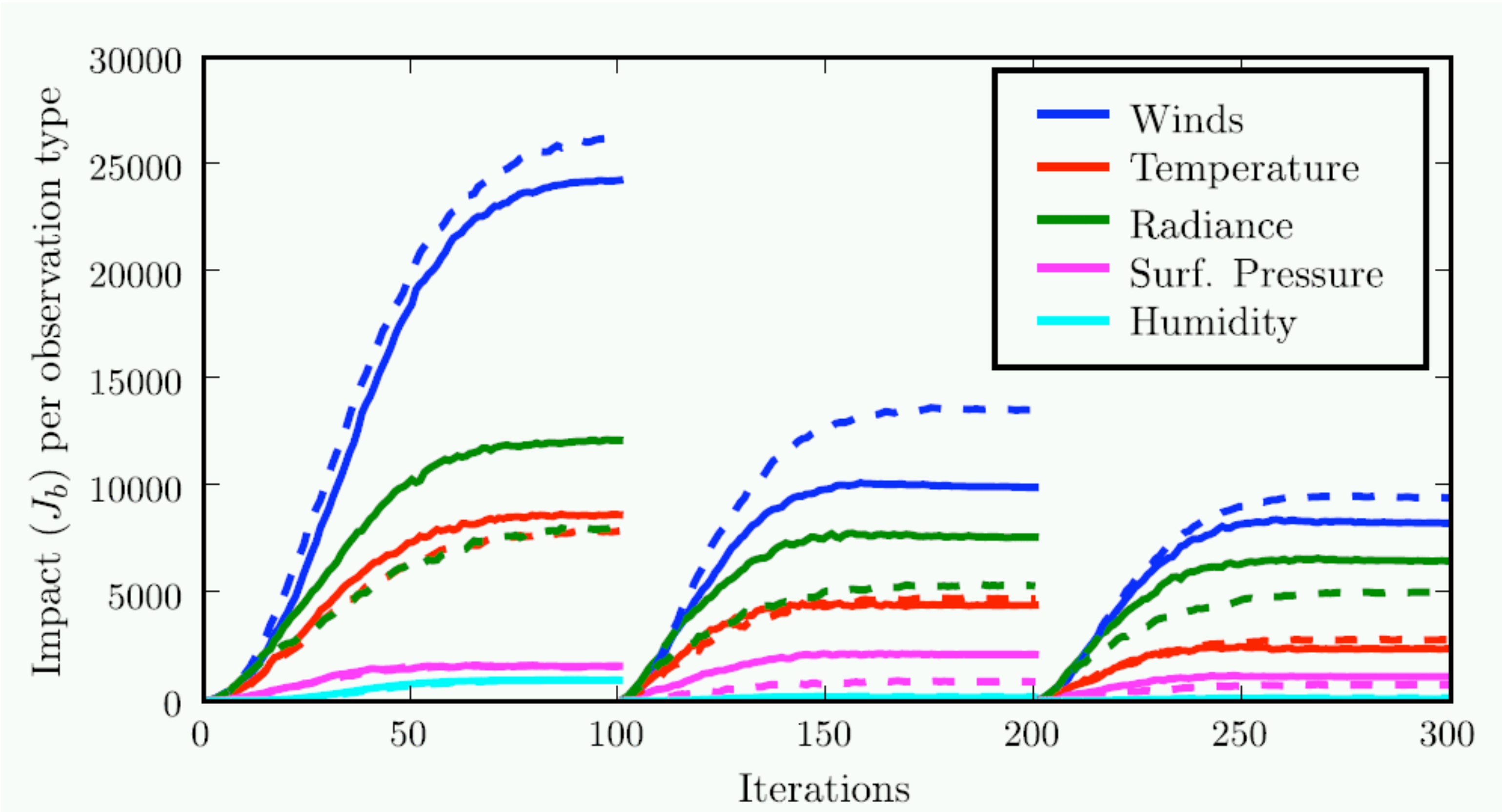
Method 1: *Use GSI minimization (CG or quasi-Newton) to solve modified linear system (input sensitivity vector instead of departures)*

- Adjoint costs the same as the analysis
- Minimal extra storage requirements (outer loops)
- Adjoint valid only at convergence

Method 2: *Use transposed Lanczos vectors (Lanczos minimization)*

- Adjoint is essentially free…big savings in 4D-Var
- Need to store Lanczos vectors
- Adjoint valid regardless of convergence…good diagnostic tool

Observation impact during the minimization using the Lanczos method

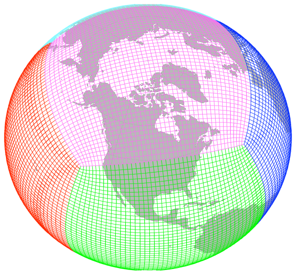


Partial impact of observations during the inner-loop iterations of **4D-Var (solid)** and **3D-Var (dashed)**

Summary of 4D-Var Status II

There is much left to do to bring prototype 4D-Var to operational readiness

- Replace TLM/ADM with **cubed-sphere** dynamical core
- Increase resolution
- Implement multi-incremental inner loop
- Tune digital filter initialization
- Re-tune background errors (**B**)
- Modify observer for efficiency
- Test, test, test…

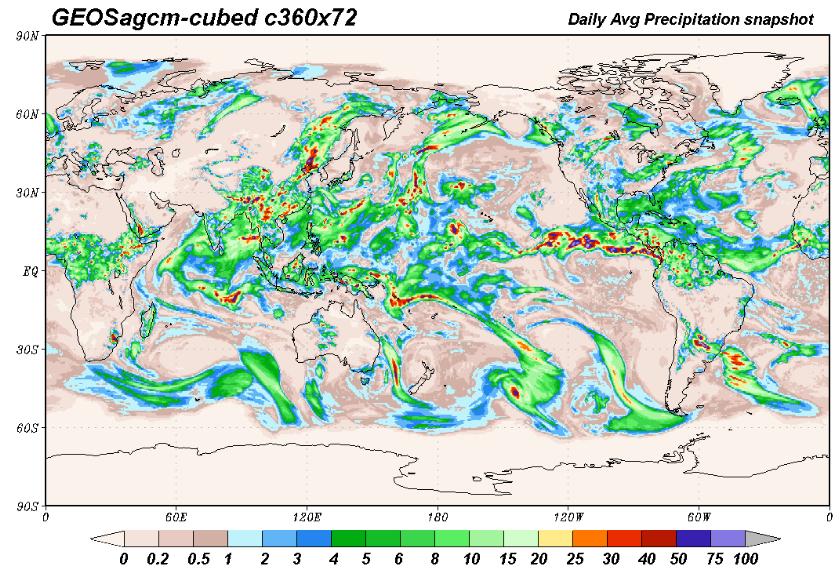


Finite Volume Cubed Sphere for GEOS-5/-6 & ModelE

S.J. Lin, W. Putman, M. Suarez, G. Schmidt, T. Clune and collaborators

- ✓ Cubed-Sphere dynamical core
- ✓ Non-hydrostatic capability
- ✓ Coupled to GEOS-5 physics
- ✓ Adjoint for 4D-Var GEOS ADAS
- ✓ Performance targets:

2009: 1/4 & 1/8° model with 1/2° 4DVar
60 tracers with GMI chemistry
2013: 1/8 & 1/16° non-hydro model with
1/4° 4DVar, Chemistry at 1/4°

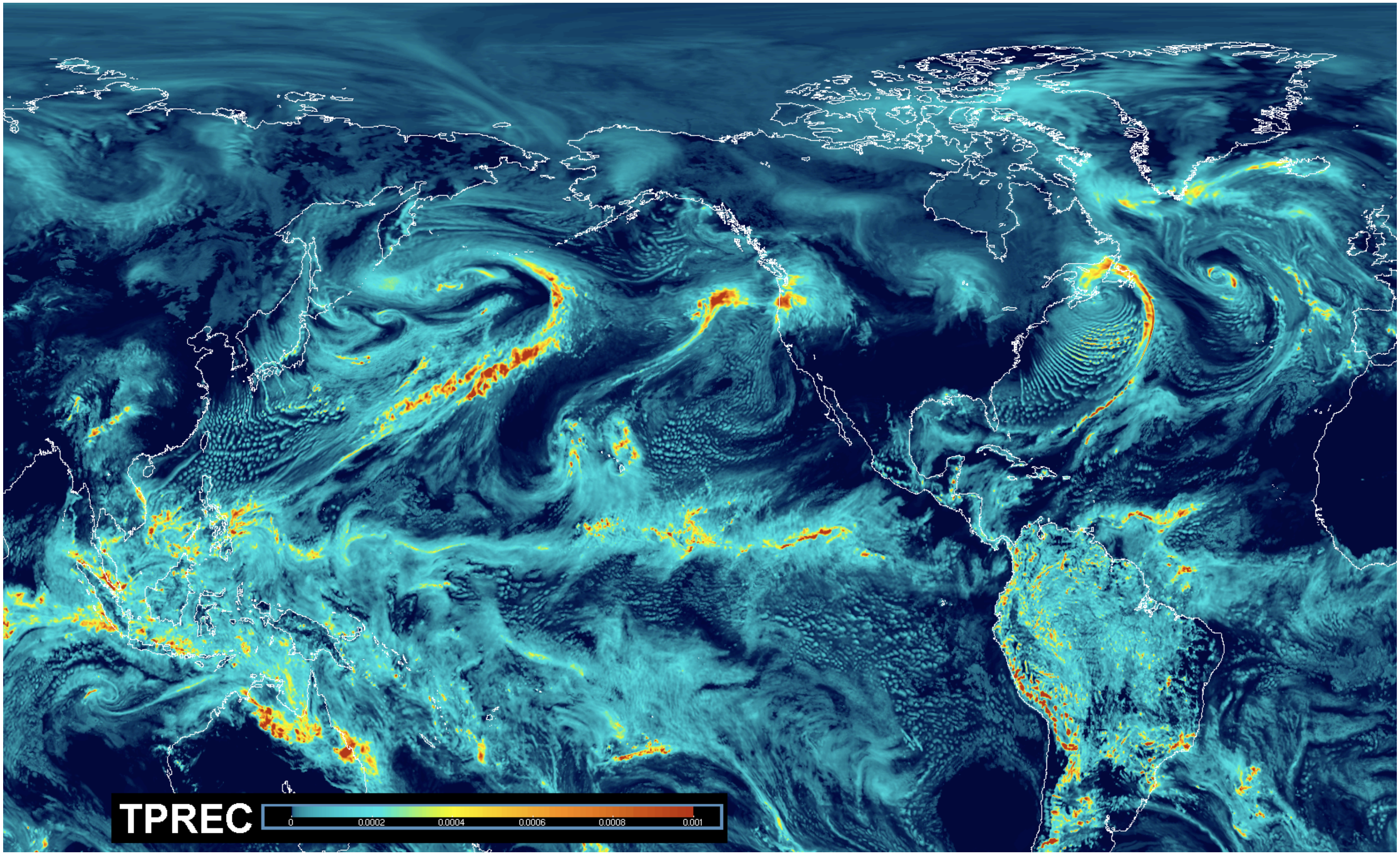


✓ Interagency collaboration on infrastructure challenges: running on 10’s of thousands of processors, I/O bottlenecks, etc.

- GEOS-5cs ported to NAS/Pleiades and ORNL/Jaguar
- Joint endeavor with NOAA/GFDL, DOE/ORNL/LLNL, NSF/NCAR
- GEOS-5 – WRF interactions to formulate GEOS-6 physics

GEOS-5 Cubed-Sphere: C720 (~1/8°)

24-h Forecast Precipitation initialized from ½° DAS in December 2008

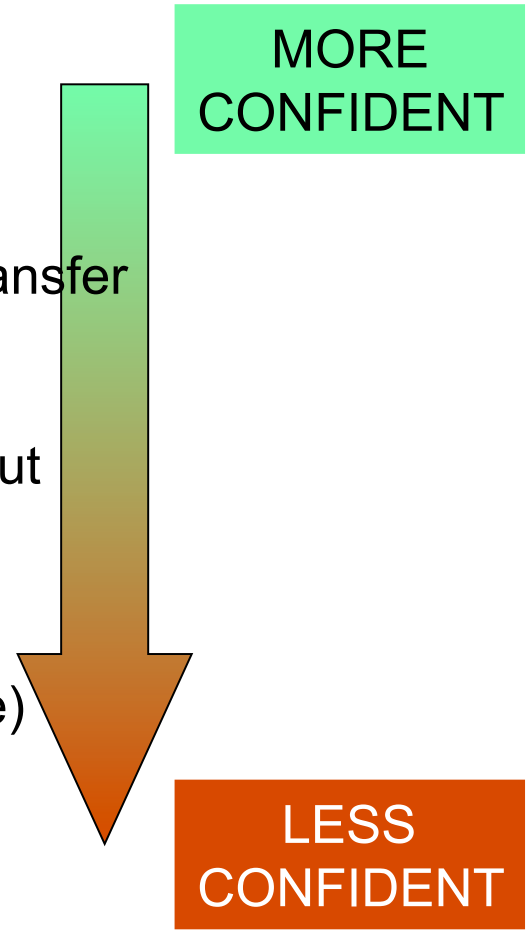


Run at DOE/ORNL on Cray XT5 Jaguar using **5,400 cores**

Data Assimilation Beyond Weather

What are the applications we seek to address?
…and what is the level of confidence in our analyses?

- Short-term forecasting
- Observing system monitoring
- Observation Impacts
- 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 physics evaluation / improvement
- Estimates of unobserved quantities
- Unified data sets (ocean, land, atmosphere, ice)
- Estimates of budget terms / transport
- Trends

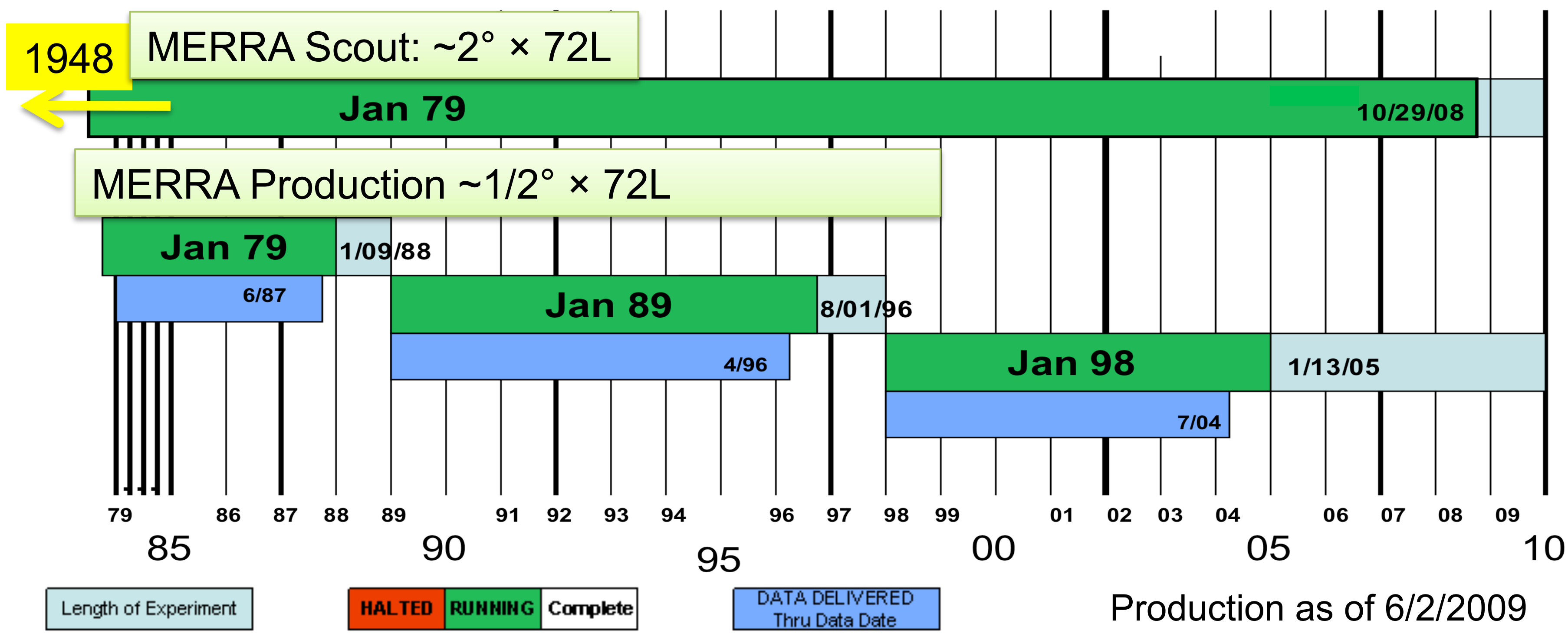


Adapted from Rood 2006, EGU Vienna

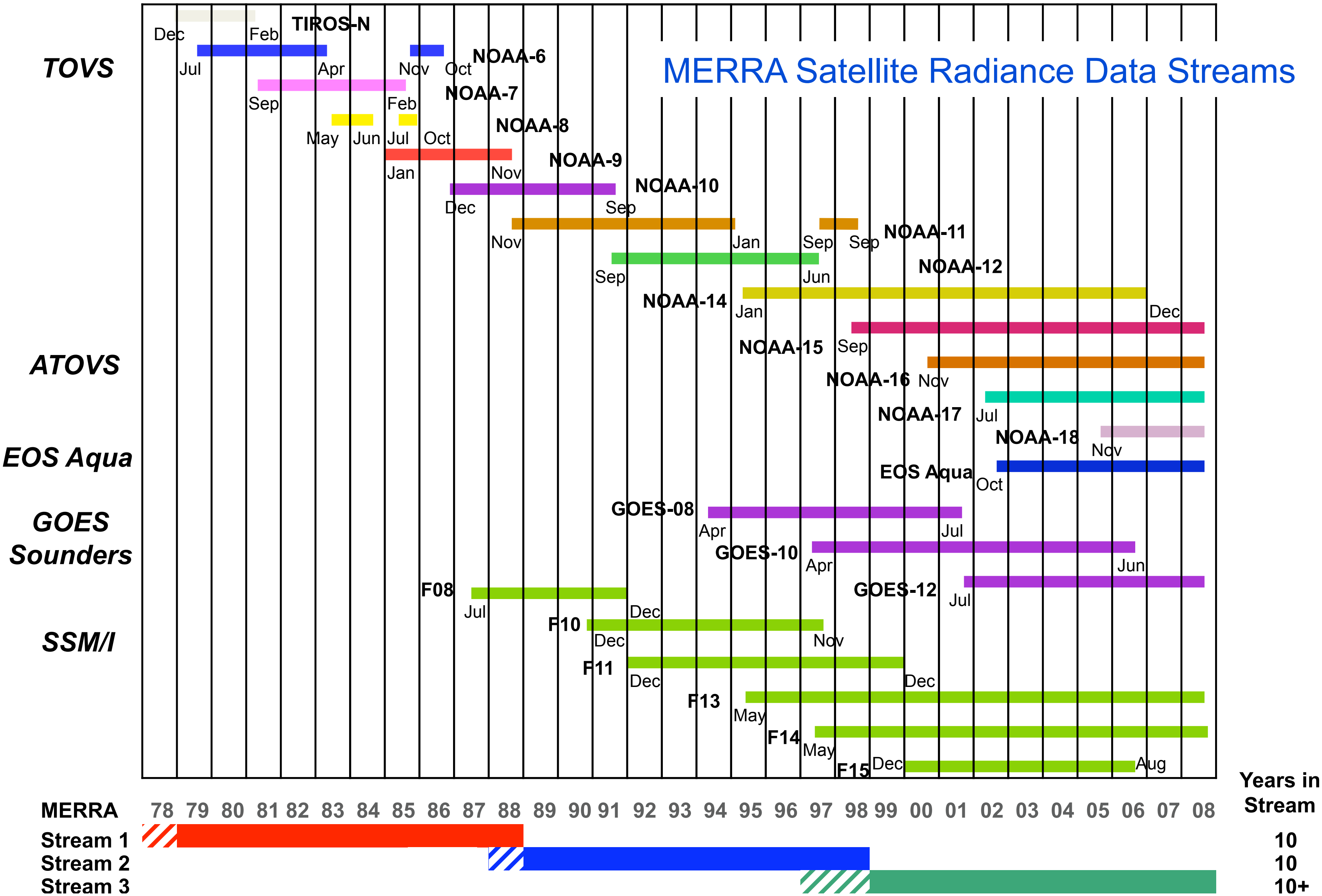
MERRA Modern Era Retrospective-analysis for Research and Applications

- Atmospheric synthesis of historical satellite and conventional data records from 1979–present
- Place EOS satellite observations in a climate data context
- Focus on improved estimates of the hydrological cycle on a broad range of weather and climate time scales

System version GEOS-5.2.0 (3D-Var/IAU)
Production began 7 May 2008



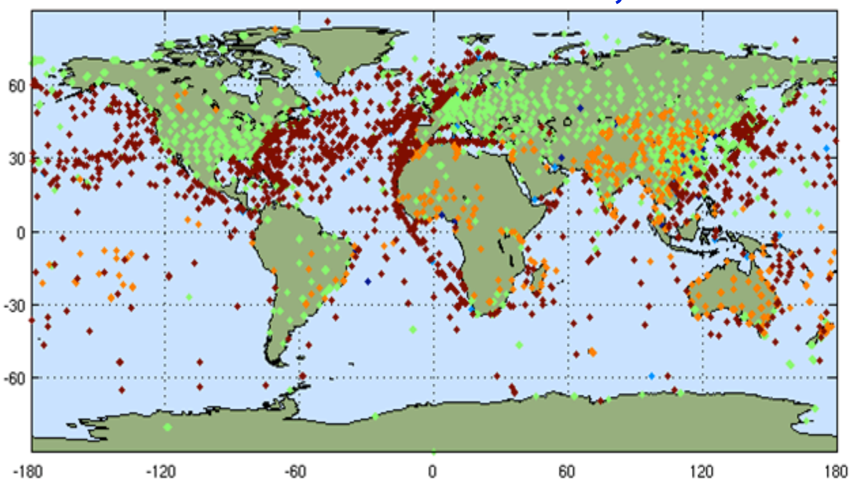
Production as of 6/2/2009


MERRA Satellite Radiance Data Streams
TOVS
ATOVS
EOS Aqua
GOES Sounders
SSM/I
TIROS-N
NOAA-6
NOAA-7
NOAA-8
NOAA-9
NOAA-10
NOAA-11
NOAA-12
NOAA-14
NOAA-15
NOAA-16
NOAA-17
NOAA-18
EOS Aqua
GOES-08
GOES-10
GOES-12
F08
F10
F11
F13
F14
F15
Dec Feb
Jul Apr Nov Oct
Sep Feb
May Jun Jul Oct
Jan Nov
Dec Sep
Nov Jan Sep Sep
Sep Jun
Jan Dec
Sep
Nov
Jul
Nov
Oct
Apr Jul
Apr Jun
Jul
Jul Dec
Dec Nov
Dec Dec
May
May
Dec Aug
MERRA
78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08
Stream 1
Stream 2
Stream 3
Years in Stream
10
10
10+

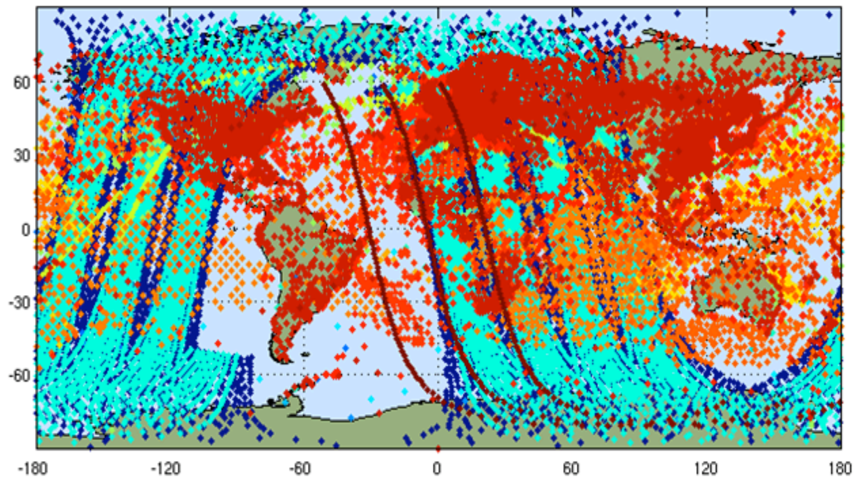
The Changing Observing System…6hr snapshots through time

GEOS-5 Data Assimilation System

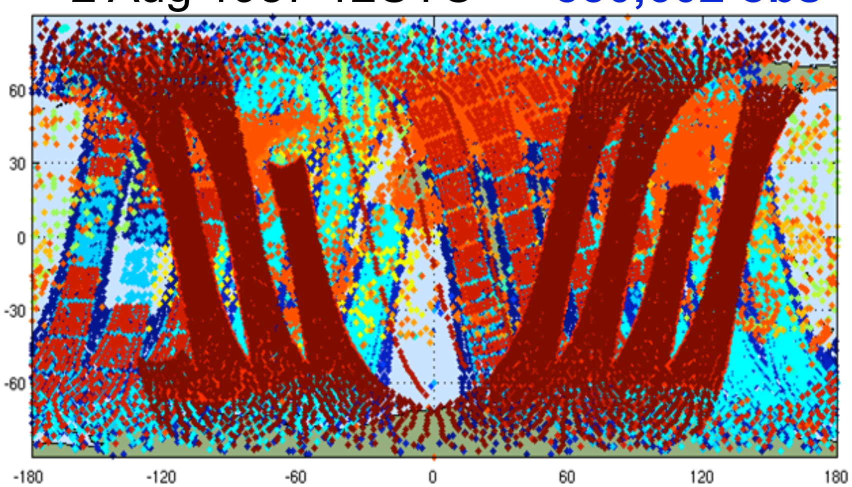
7 Jan 1973 12UTC **77,098 obs**



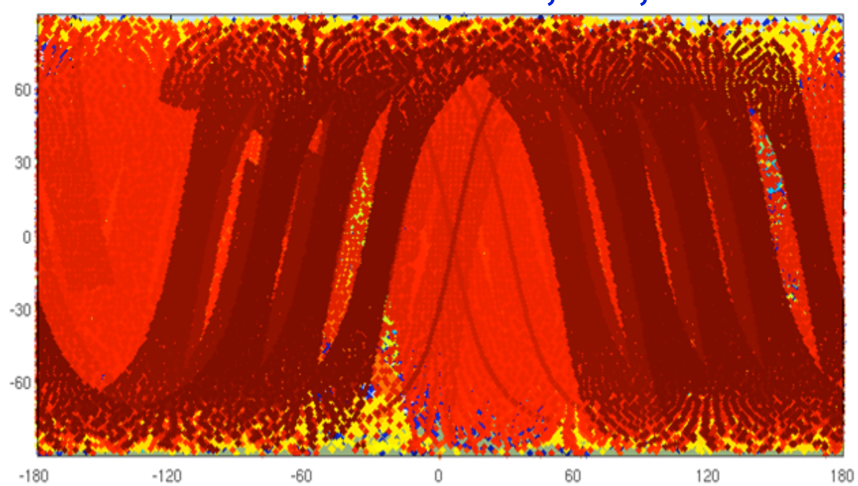
7 Jan 1979 12UTC **325,765 obs**



2 Aug 1987 12UTC **550,602 obs**

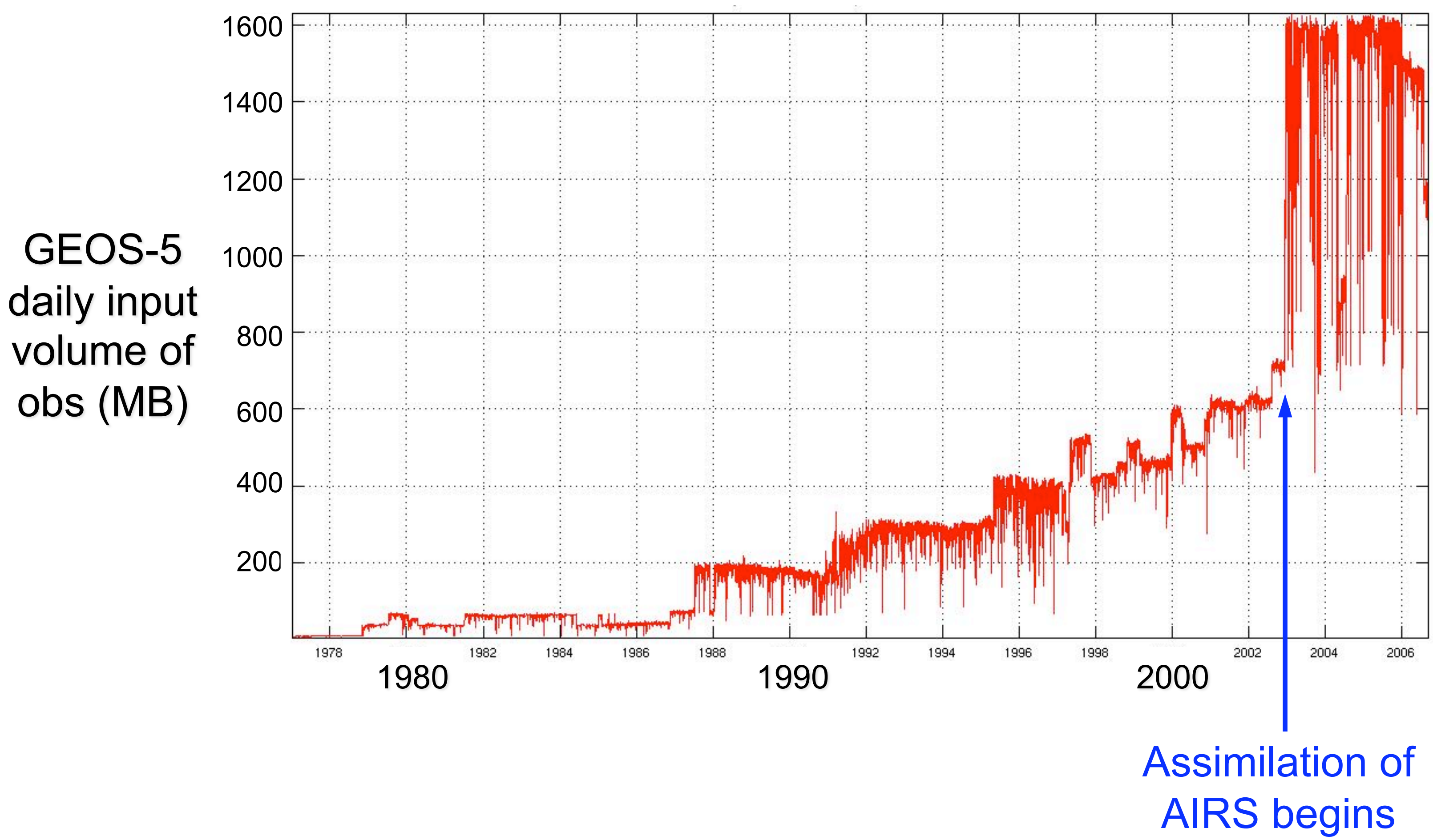


7 Jan 2006 12UTC **4,217,655 obs**



Data Assimilation in the Era of Hyper-Spectral Satellites

*Observation volume for NASA's **M**odern **E**ra **R**etrospective-analysis for **R**esearch and **A**pplications (MERRA): January 1977 to present*



MERRA Validation

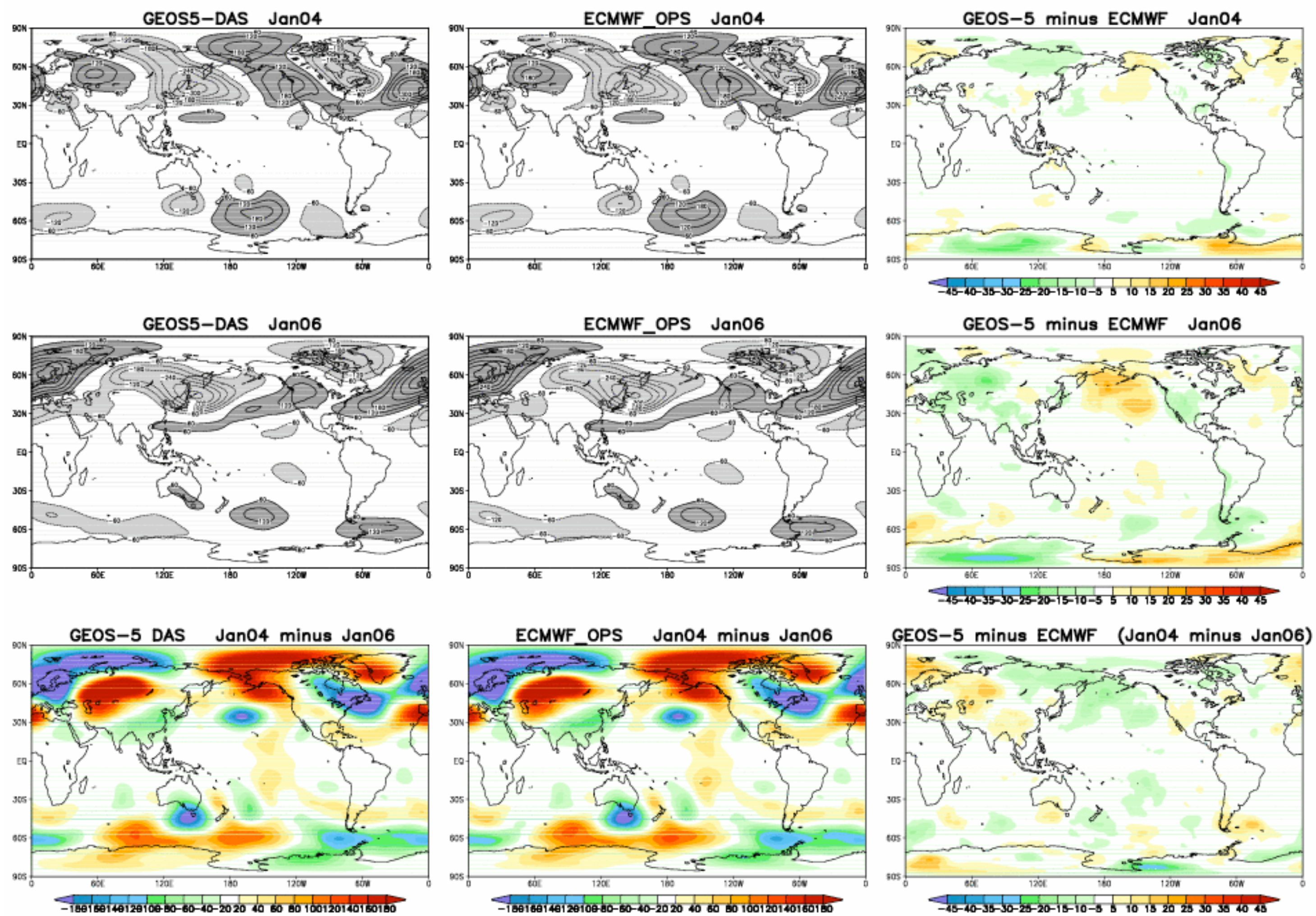
300 hPa Eddy Height vs ECMWF OPS

GEOS-5 | ECMWF OPS | GEOS5 - ECMWF

Jan 04 (neutral)

Jan 06 (weak La Nina)

'04 - '06



…for large-scale dynamic fields, at least, current analyses <u>are</u> the real world

MERRA Validation

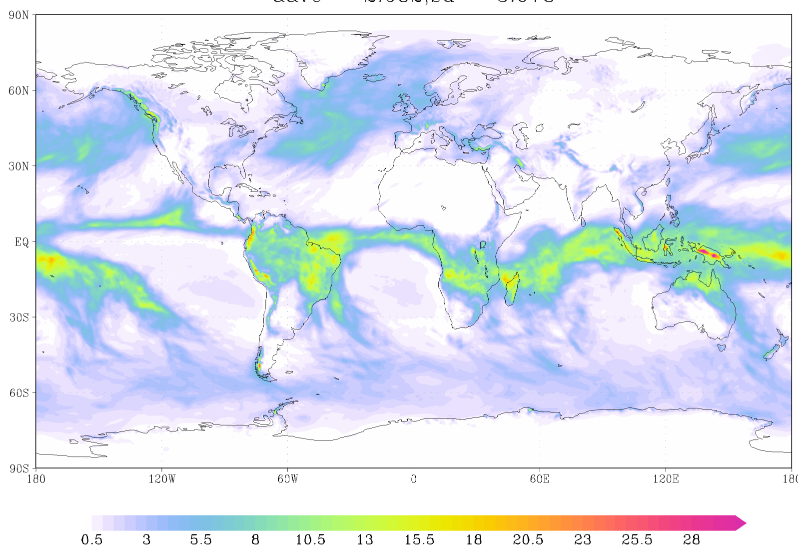
Precipitation (mm/day)

January 2004

July 2004

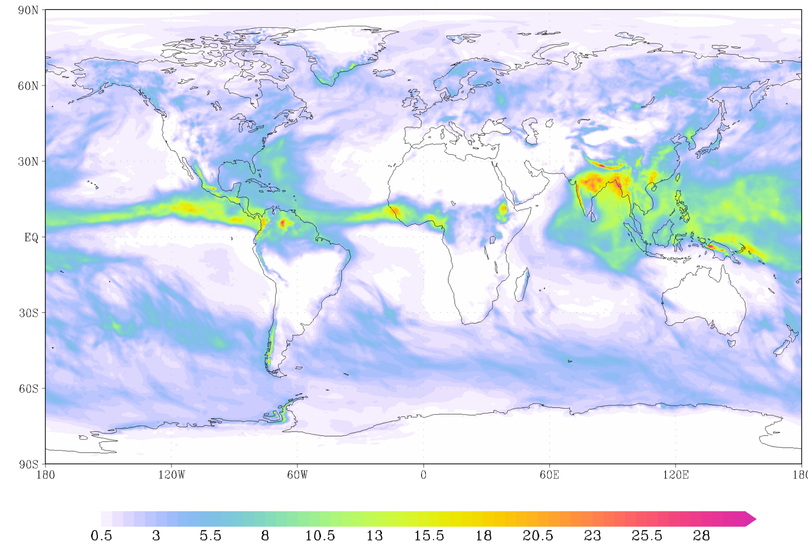
GEOS-5

aave = 2.682,sd = 3.078

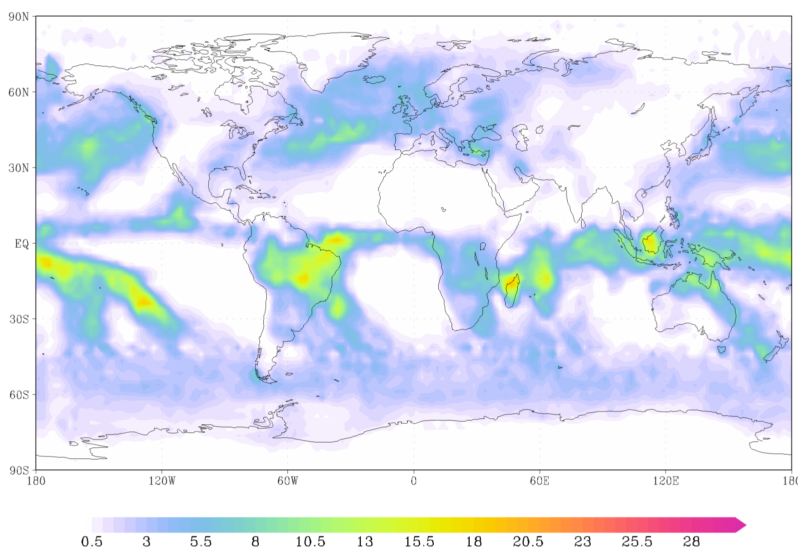


GEOS-5

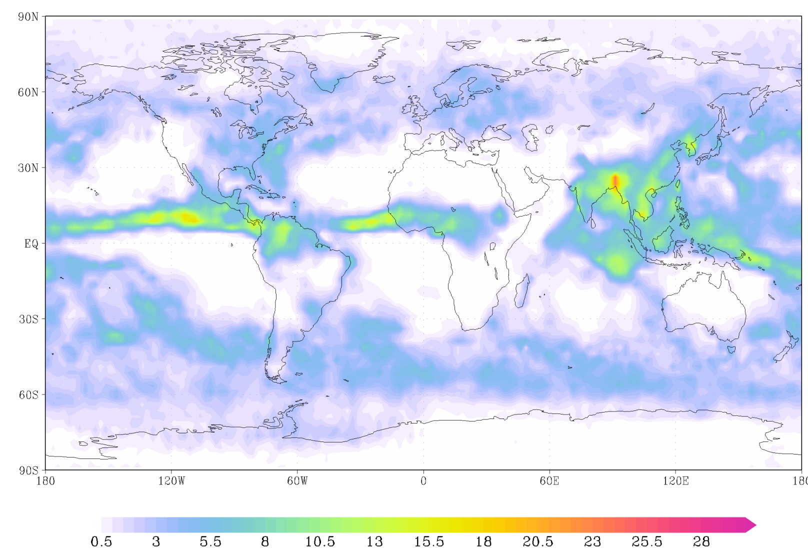
aave = 2.865,sd = 3.099



GPCP verification

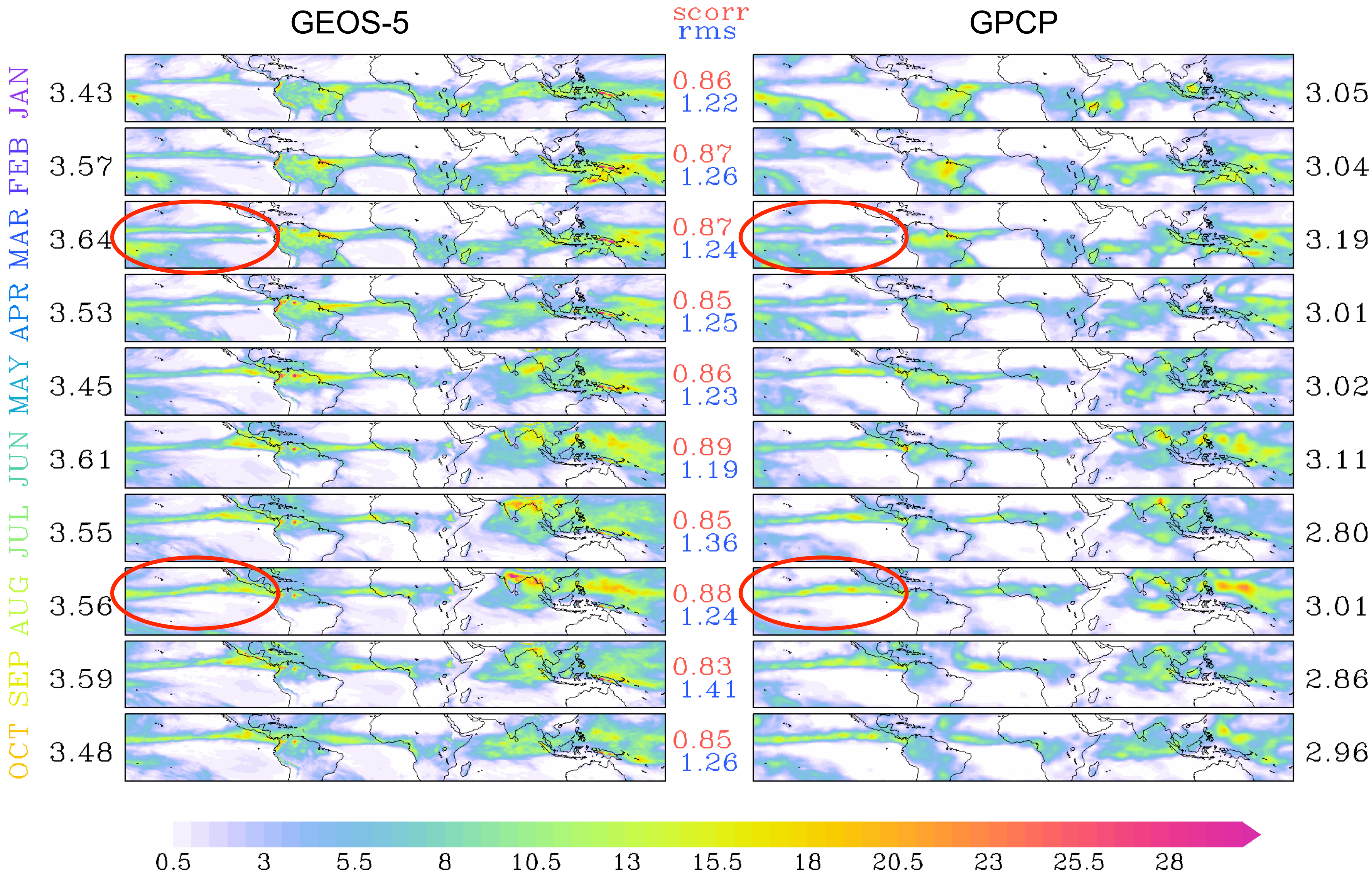


GPCP verification



MERRA Validation

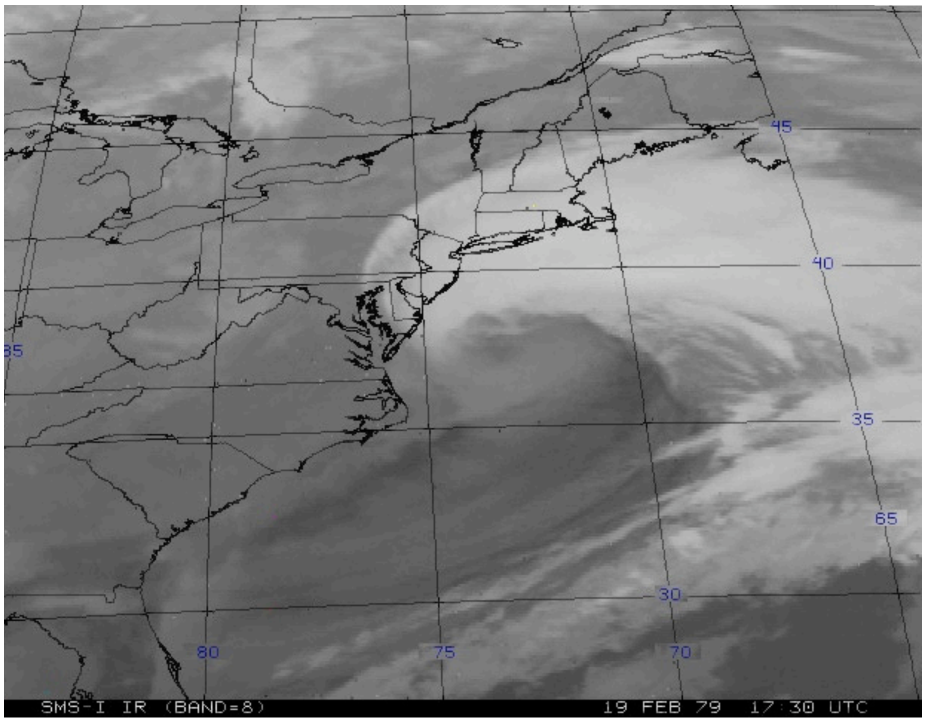
2004 Tropical Precipitation



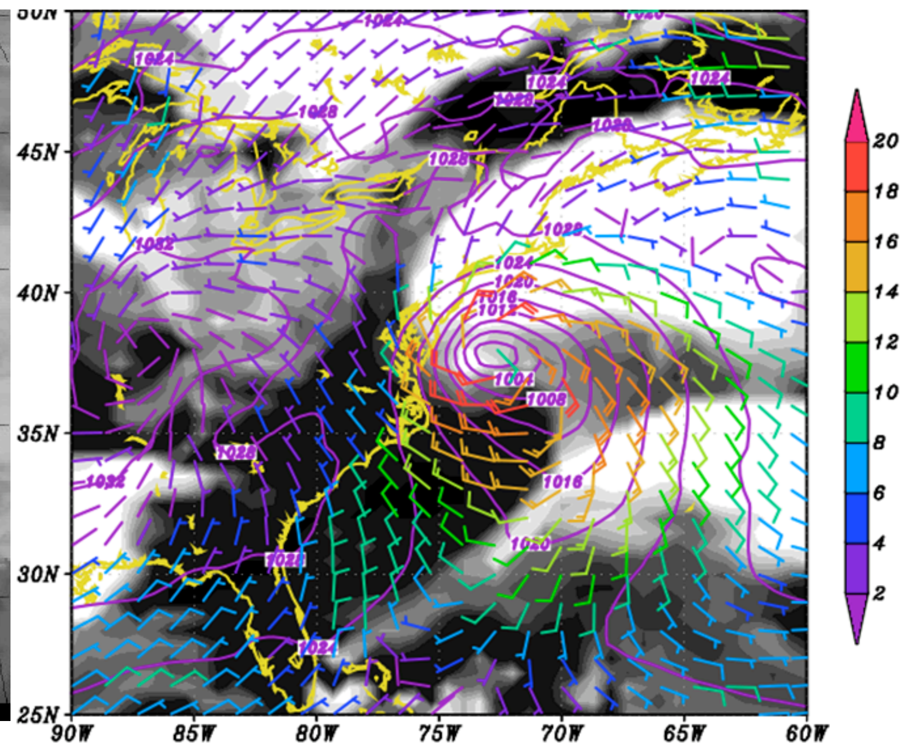
MERRA's depiction of the 1979 President's Day Snow Storm

17:30 UTC 19 FEB 1979

GOES Infrared Imagery



MERRA Clouds, Wind and SLP



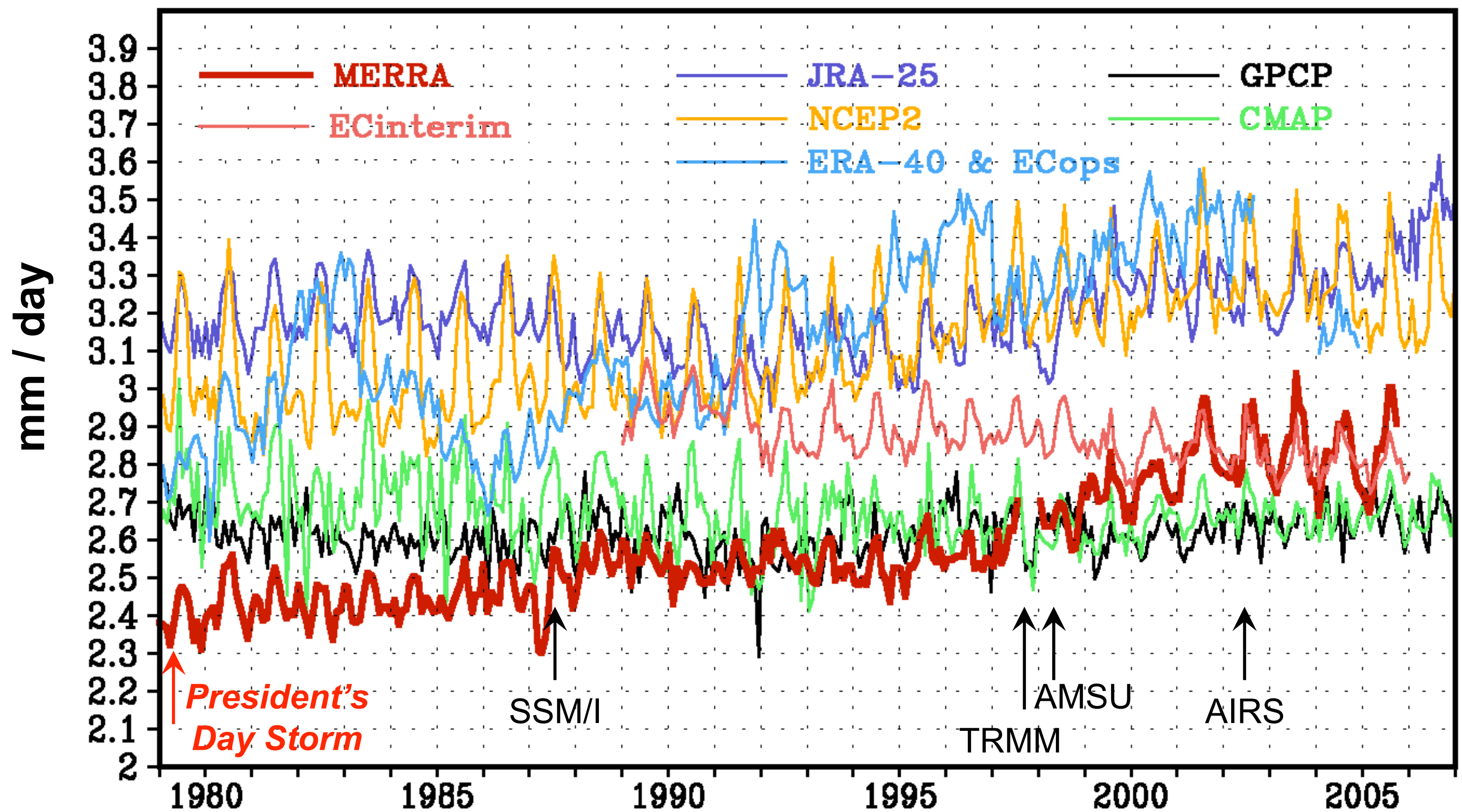
(Barbs every other grid space)

Many fewer observations early in the record, but 'weather' can be reasonably well depicted

Floral Street, Washington DC   20 February 1979

Washington DC: 18.7”   Baltimore MD: 20”   Upper Marlboro MD: 22”

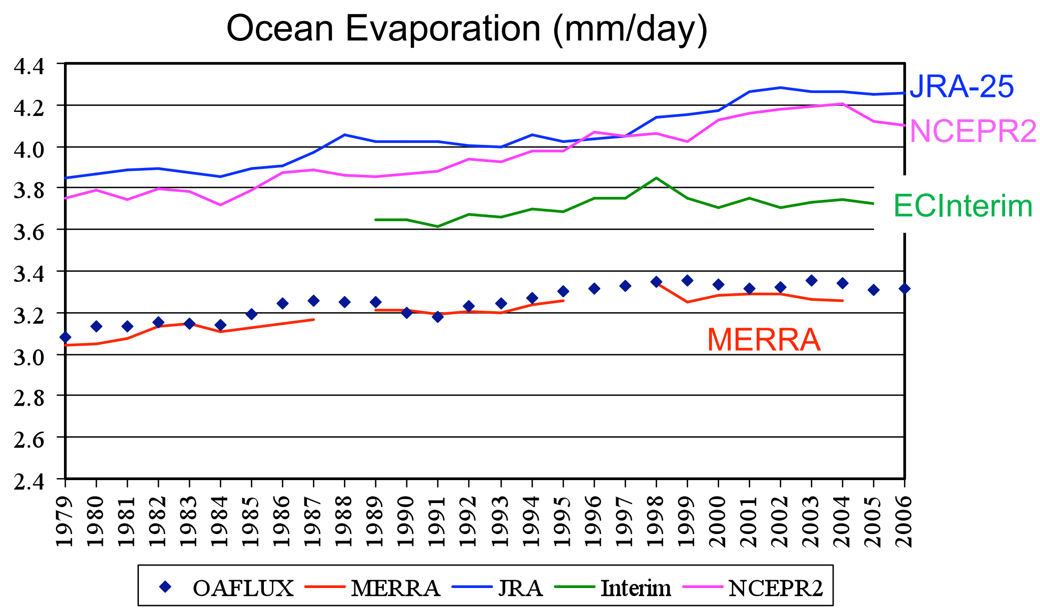
Time series of global mean precipitation from re-analyses and observations

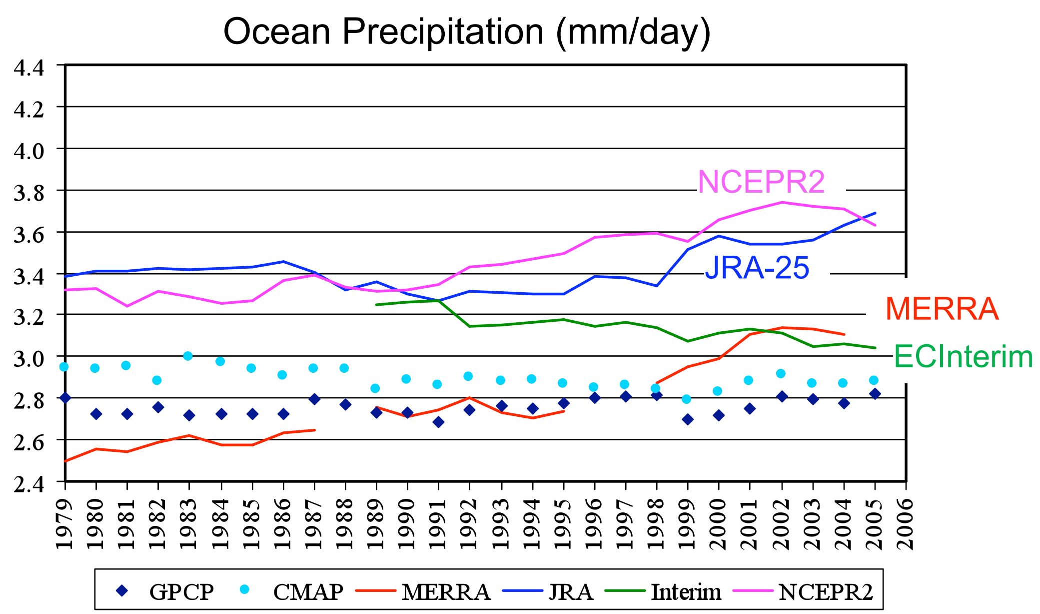


Representation of the hydrological cycle in a data assimilation system is extremely sensitive to how highly "tuned" models respond to a constantly changing global observing system

MERRA Production

Ocean-only Evaporation & Precipitation





Note that CMAP and OAFLUX have elements of reanalyses in their algorithms

Development of an Observing System Simulation Experiment (OSSE) Capability at NASA/GMAO

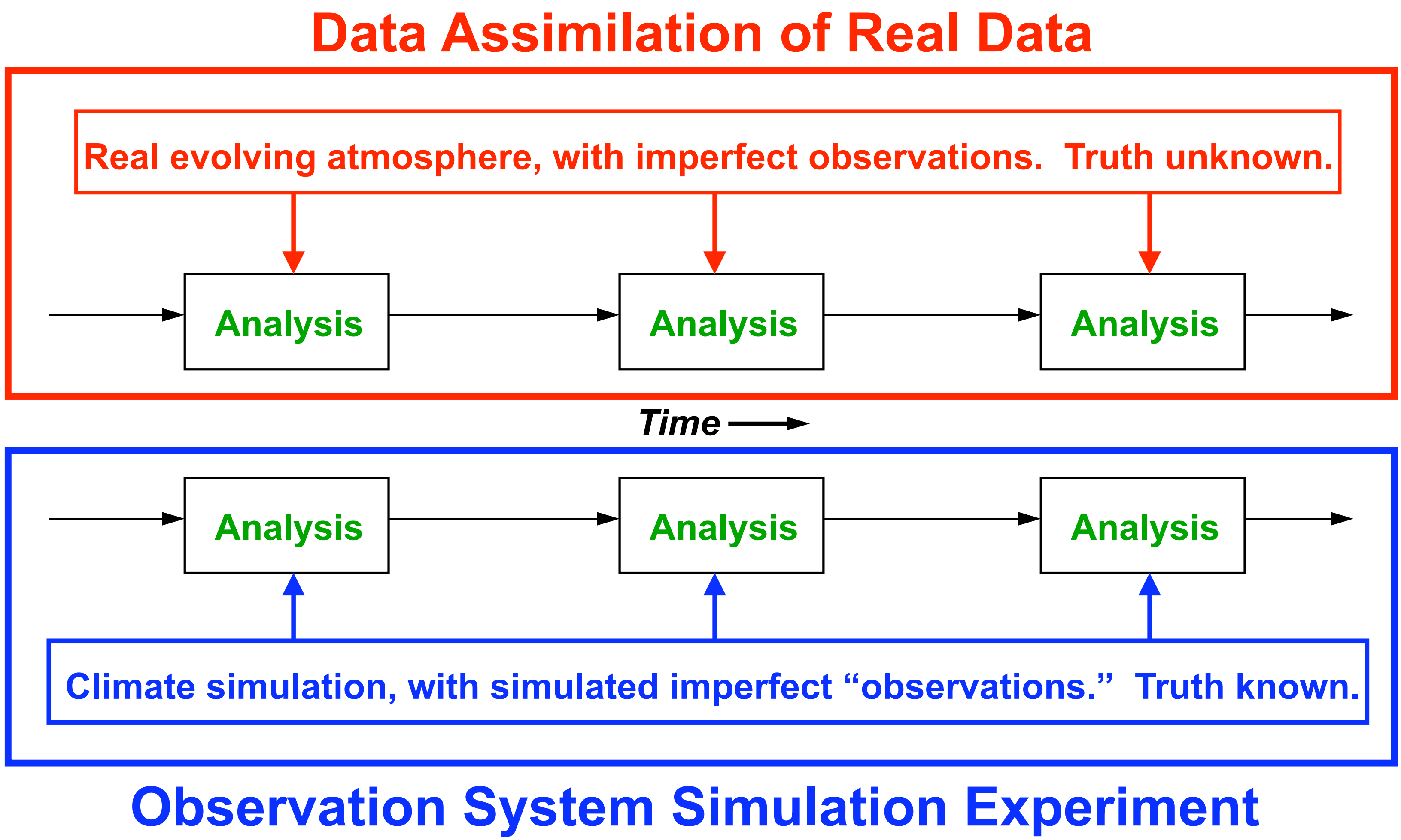
A framework for numerical experimentation in which observables are simulated from fields generated by an earth system model, including a parameterized description of the observational error characteristics

OSSE Concepts

- **Simulations** are derived from a '**nature run**' in support of a given experimental goal *(e.g., test impact of a proposed sensor)*

- **Calibration** is the process of tuning the experimental framework to reproduce some key behavior *(e.g., ensure that simulated existing observations behave statistically as in a real DAS)*

…see talk by Ron Errico this afternoon


Data Assimilation of Real Data
Real evolving atmosphere, with imperfect observations. Truth unknown.
Analysis
Analysis
Analysis
Time
Analysis
Analysis
Analysis
Climate simulation, with simulated imperfect "observations." Truth known.
Observation System Simulation Experiment

New ECMWF Nature Run

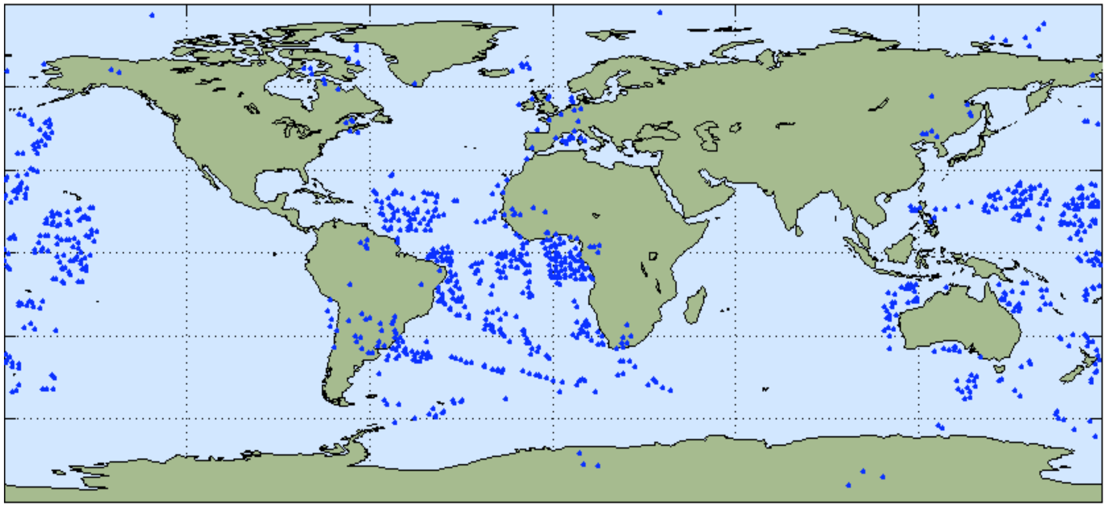
- 13-month "forecast" starting 10 May 2005
- Analyzed SST as lower boundary condition
- Operational model from 2006
- T511L91 reduced linear Gaussian grid (~35 km)
- 3-hourly output

Immediate Goal: Generate a prototype baseline set of simulated observations that, for various relevant statistics, produces values similar to real DAS.

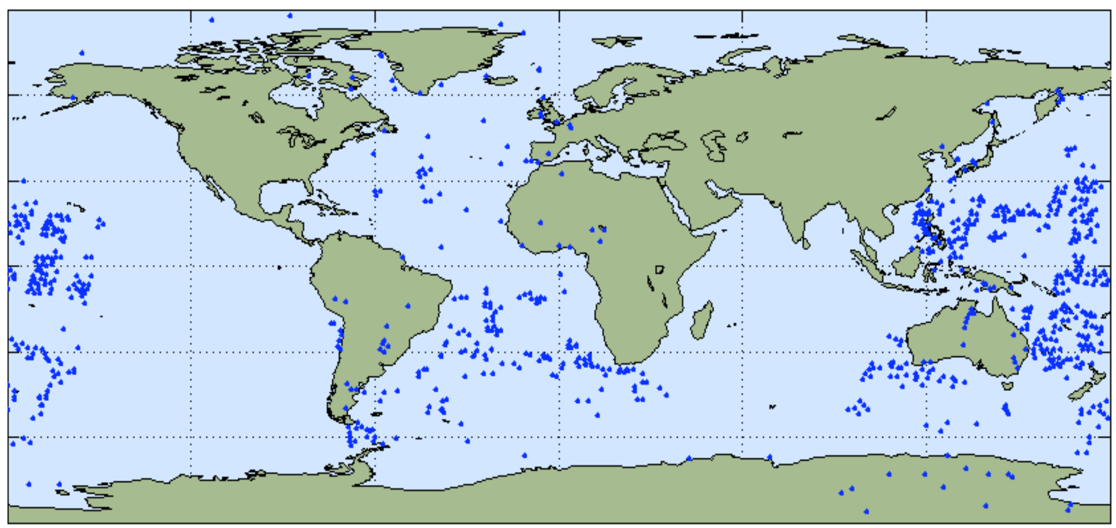
Account for:

1. Resources are somewhat limited
2. The nature run may be unrealistic in some important ways
3. Some issues are not very important compared to others
4. Some important issues may still have many unknown aspects

Locations of Brightness Temperature accepted by QC for NOAA-17 HIRS-3 Channel 7 1 Jan 2006 00 UTC +/- 3hrs



OSSE Data

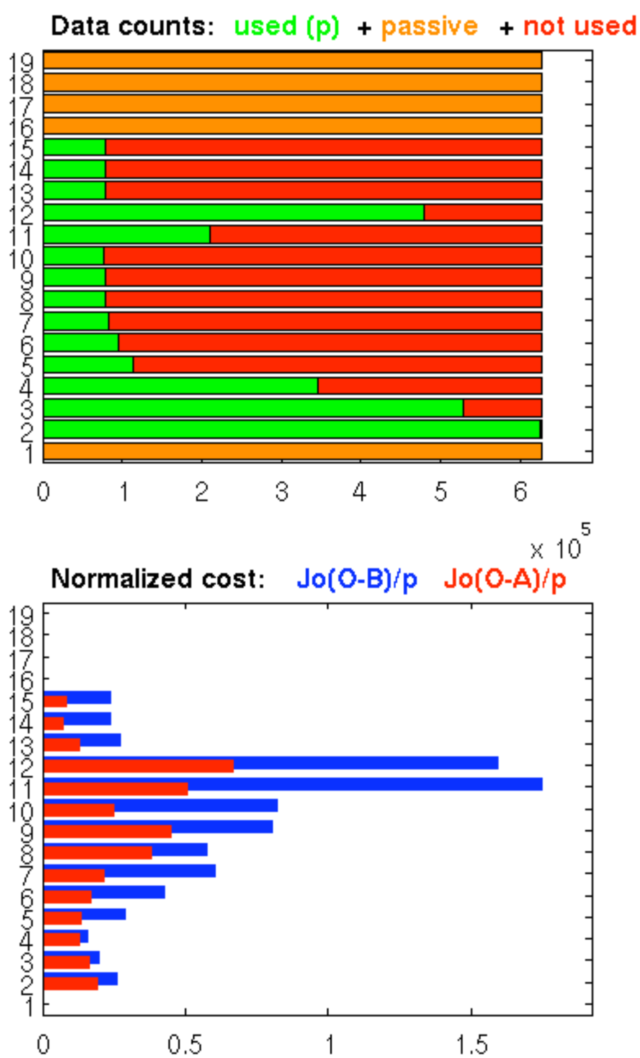


Real Data

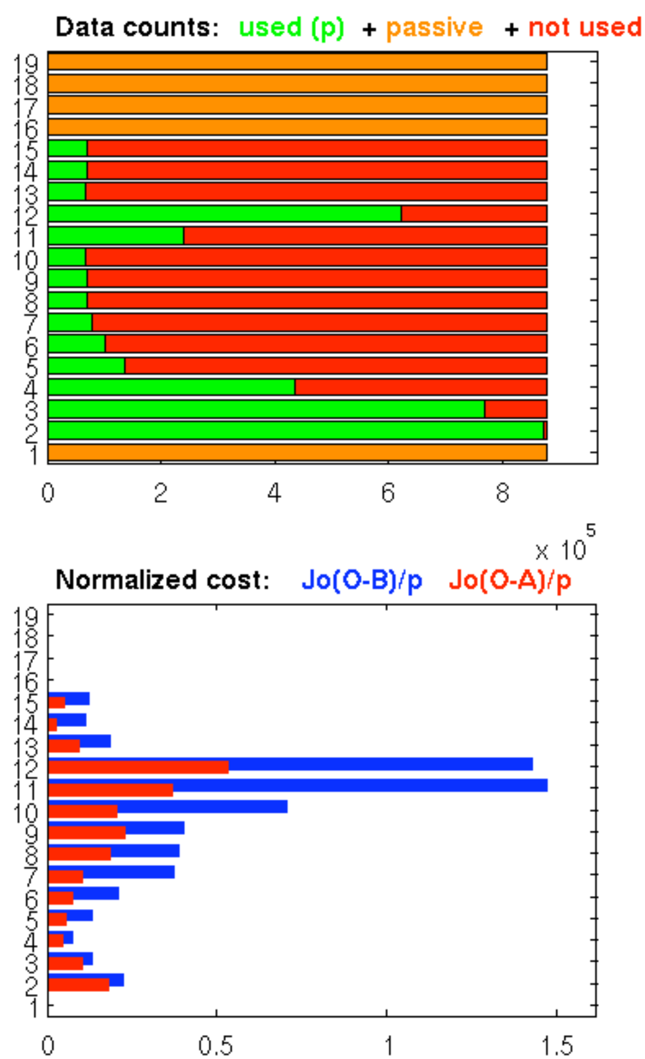
Assimilation of Simulated vs. Real Observations

NOAA-17 HIRS/3 Brightness Temps Jan 2006

OSSE

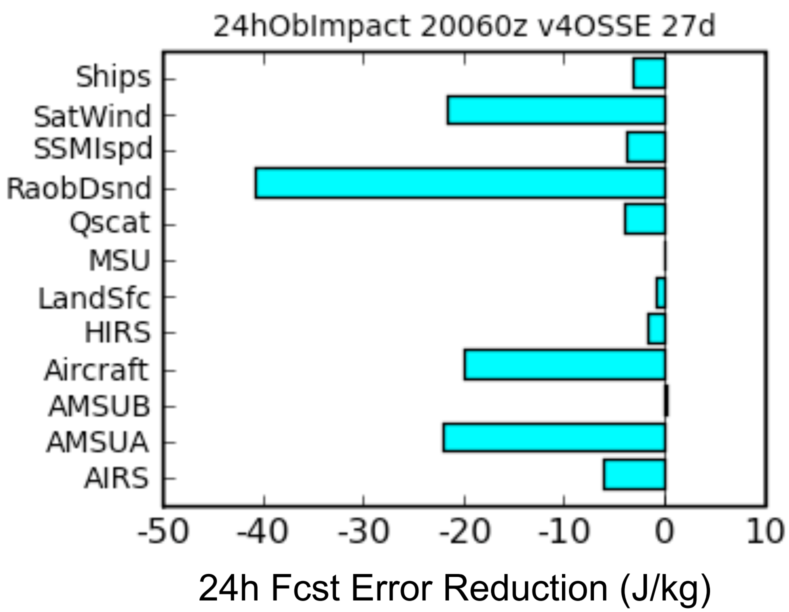


Real

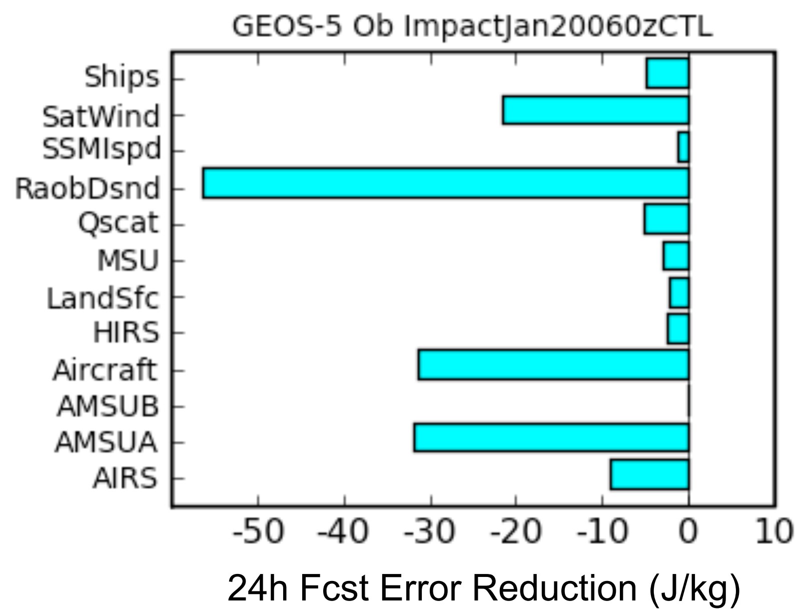


OSSE Calibration Using Adjoint Tools

OSSE



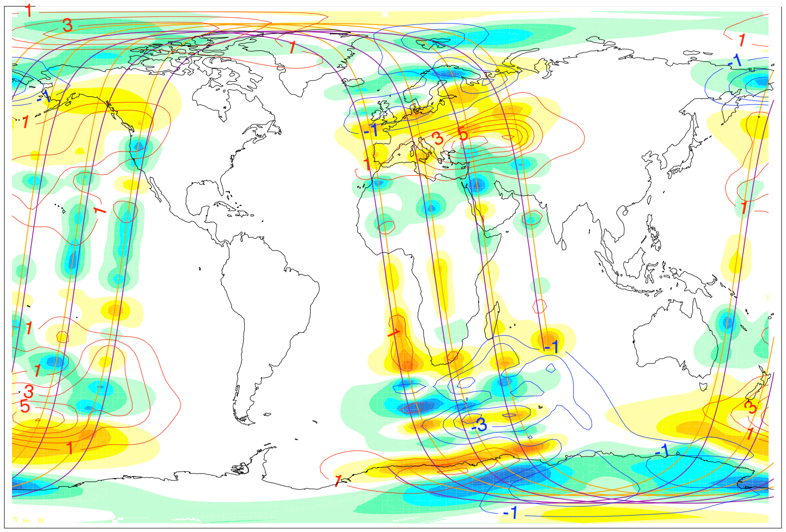
Real



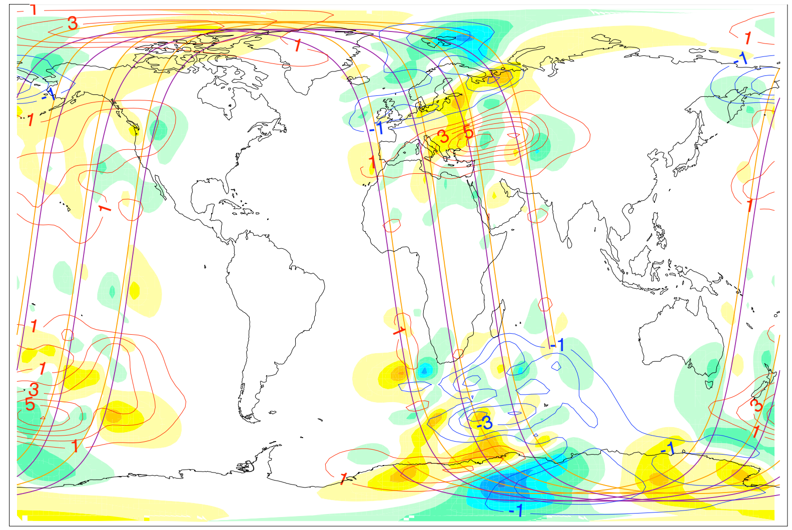
Bars show the reduction in 24-h global forecast error due to assimilation of **simulated** and **actual** observations for January 2006 in terms of an energy-based measure that combines winds, temperature and sfc pressure.

Assimilation of Simulated Doppler Wind Lidar Measurements in Preparation for ADM-Aeolus and 3D-Winds

Analysis Inc 200 hPa **u-comp** (shaded), T_v



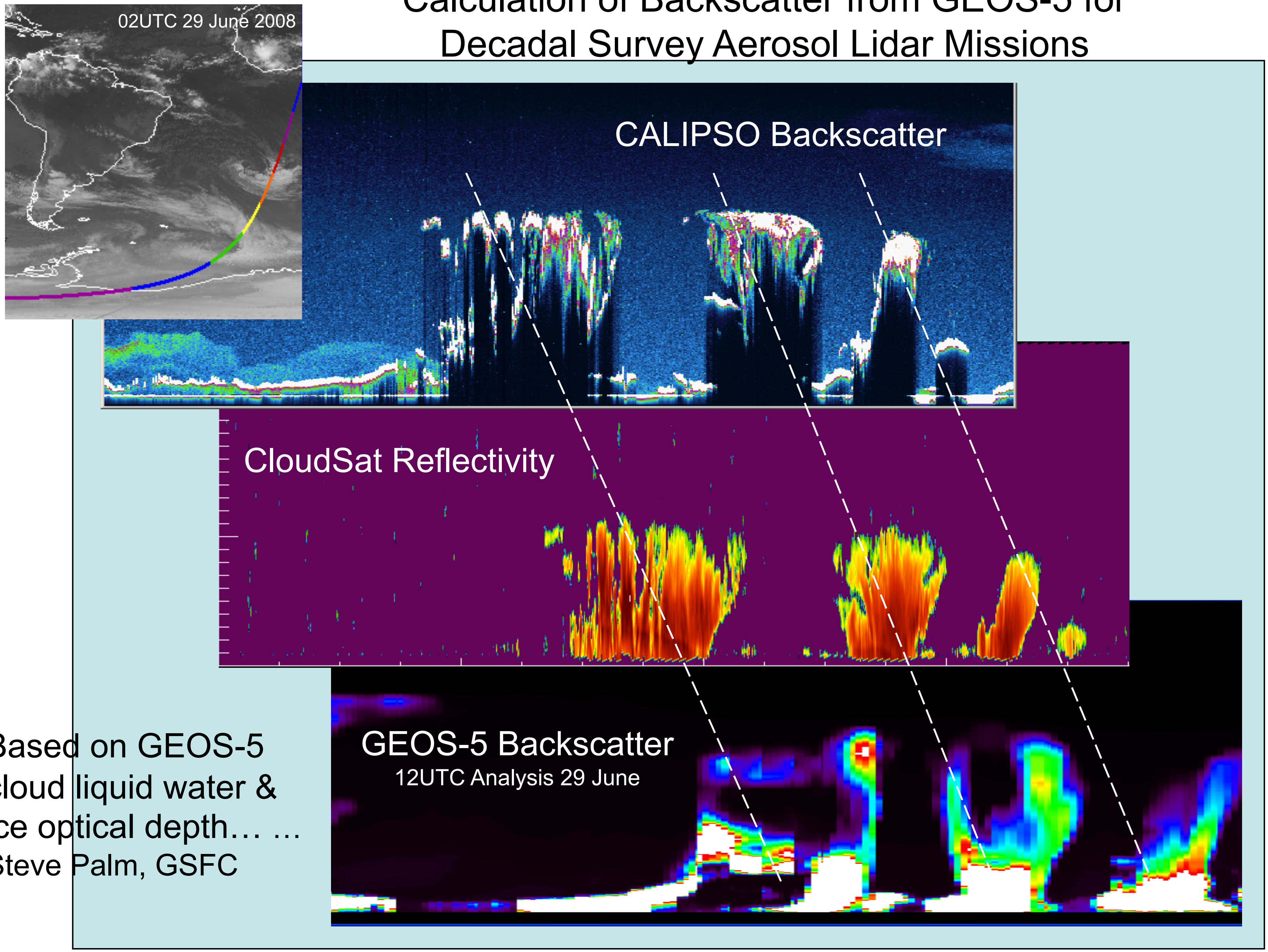
Analysis Inc 200 hPa **v-comp** (shaded), T_v



- Infra-structure developed to simulate LOS measurements from ECMWF Nature Run
- 1st step: ADM-like orbit, no addition of error, crude account of cloud structure
- GSI updated to assimilate these Level-2 measurements
- Test case underestimates LOS wind error

Will McCarty, GMAO

Calculation of Backscatter from GEOS-5 for Decadal Survey Aerosol Lidar Missions



Based on GEOS-5 cloud liquid water & ice optical depth… …
Steve Palm, GSFC

Near-Term Plans and Work In Progress

- Implement 4D-Var operational-test system at 0.5° resolution with adjoint tools for routine monitoring of observation impacts
- Begin development of the adjoint of moist physics processes for 4D-Var and related applications
- Begin development of cloud-, rain- and aerosol-affected radiances in collaboration with JCSDA partners
- Contribute to bringing MLS to real-time, with radiance assimilation for temperature
- Continue experimentation to increase/improve AIRS usage (especially H_2O, O_3 channels)

Near-Term Plans and Work In Progress

- Prepare GSI for ADM-Aeolus and OMPS (lead JCSDA effort)

- OSSE Infrastructure
  - Complete simulation of existing observations (IASI, GPSRO) and prepare for ADM-Aeolus, NPP (OMPS, CrIS, VIIRS), 3Dwinds
  - Account for aerosol effects in meteorological OSSEs, including aerosol absorption (3DWinds)
  - Extend capability for non-NWP instruments (initially ACE)…

Longer-Term Plans

- Develop weak constraint 4D-Var to account for model errors (implementation allows for incremental increases in complexity)

- Increase flow-dependent aspects of background error specification, working toward a hybrid 4D-Var with ensemble-based background errors (collaboration with NOAA/NCEP, NOAA/ESRL…see also *NCEP Advanced Data Assimilation Plan, April 2009*)

- Increase resolution of multi-incremental minimization ('inner-loop') in conjunction with increases in forecast model resolution

- Implement moist physics adjoints (convective and large-scale precipitation) in production 4D-Var system

- Extend assimilation window to 12 hrs