GMAO Modeling and OSSE Capabilities in Support of PBL Mission Science

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Introduction

Boundary layer uncertainty is a key part to numerical modeling
- Many of the underlying processes are generally unresolved
- Therefore there is a need for parameterizations

In modern systems, however, there is still skill in these parameterizations
- How they interact with the large scale forces that are resolved

The Global Modeling and Assimilation Office is a NASA resource that aims to link observations with earth system models
- While we consider numerical weather prediction, it is certainly not our only driver

This talk aims to present our capabilities and with the aim of linking back to the mission science goals, primarily through two key capabilities
- Ensemble-based prediction
- Observing System Simulation Experiments (OSSEs)

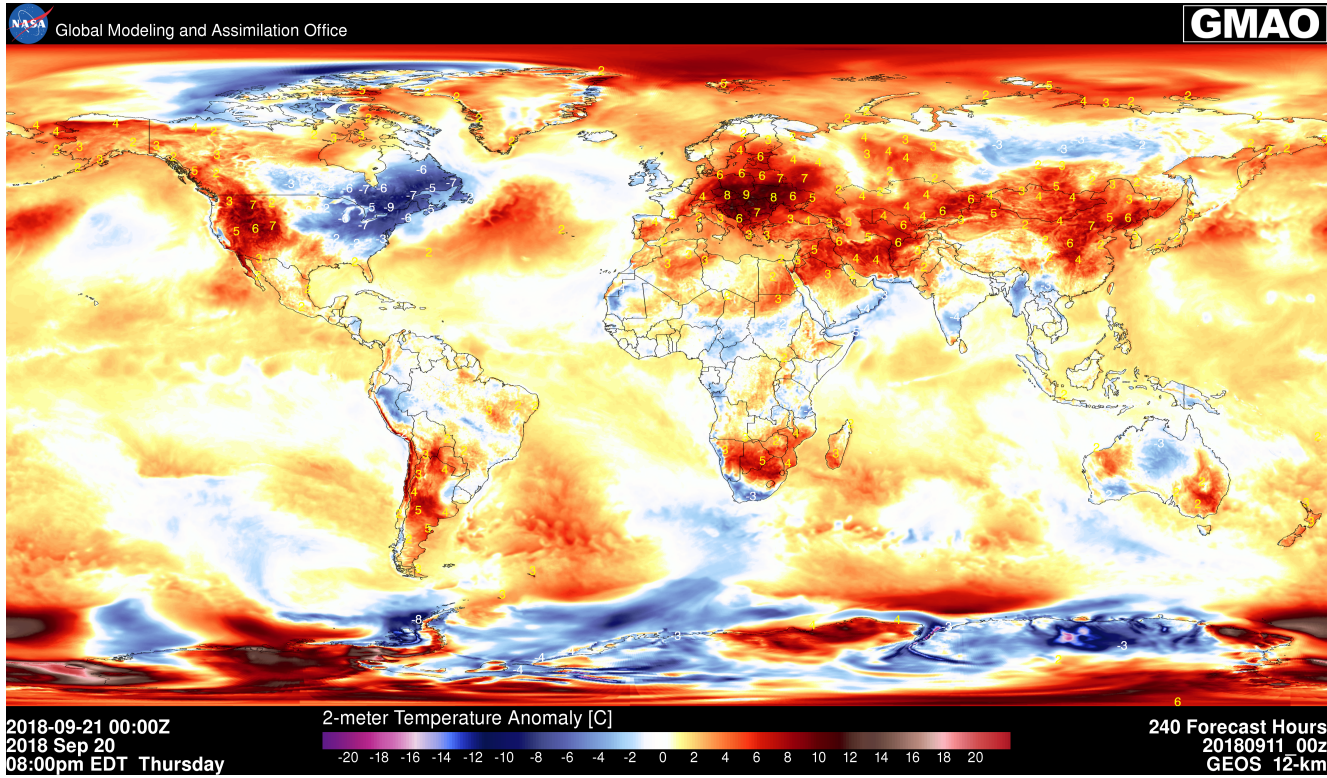
Routine Production – Forward Processing

Forward Processing (FP) is the GMAO nomenclature for our near-real-time 'operational' system

- 4 assimilation cycles per day (6 hour observation windows, centered at 00, 06, 12, 18 UTC)
- 10-day forecasts @ 00 UTC, 5-day forecasts @ 12 UTC
- 24 hour Forecast Sensitivity Observations Impact (FSOI) metric calculated once daily (@ 00 UTC)

FP Configuration

- Model: Goddard Earth Observing System (GEOS) Atmospheric Model
  - C720 (12 km) resolution, 72 vertical levels to 0.01 hPa
- Assimilation: Gridpoint Statistical Interpolation (GSI) procedure
  - 0.25° x 0.3125° lat-lon grid, 72 levels
  - Hybrid 4D-EnVar assimilation based on 32 ensemble members
- Ensembles: GEOS Atmospheric Model
  - C180 (1/2°) resolution, 72 levels



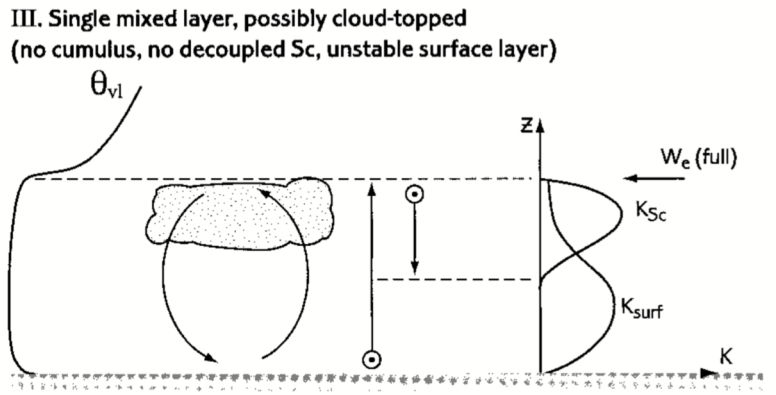
GEOS PBL Physics

In unstable layers, we use the K-Profile diffusion scheme of Lock et al. (2000), with two plumes driven by surface fluxes and cloud-top radiative cooling.

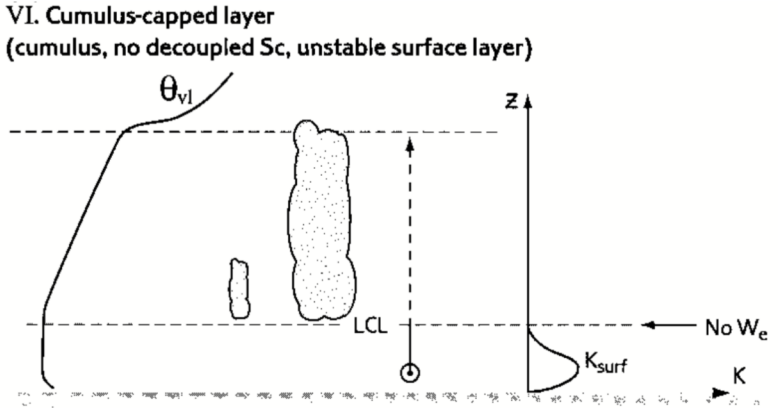
In stable layers, we use the Richardson-number based scheme of Louis (1982).

Shallow convection is based on Park and Bretherton (2009), a single plume buoyancy-sorting mass flux scheme, with closure based on CIN and TKE in the Lock surface layer.

Under development: An Eddy Diffusivity Mass Flux (EDMF) approach with prognostic TKE and multi-plume mass flux scheme with stochastic entrainment.



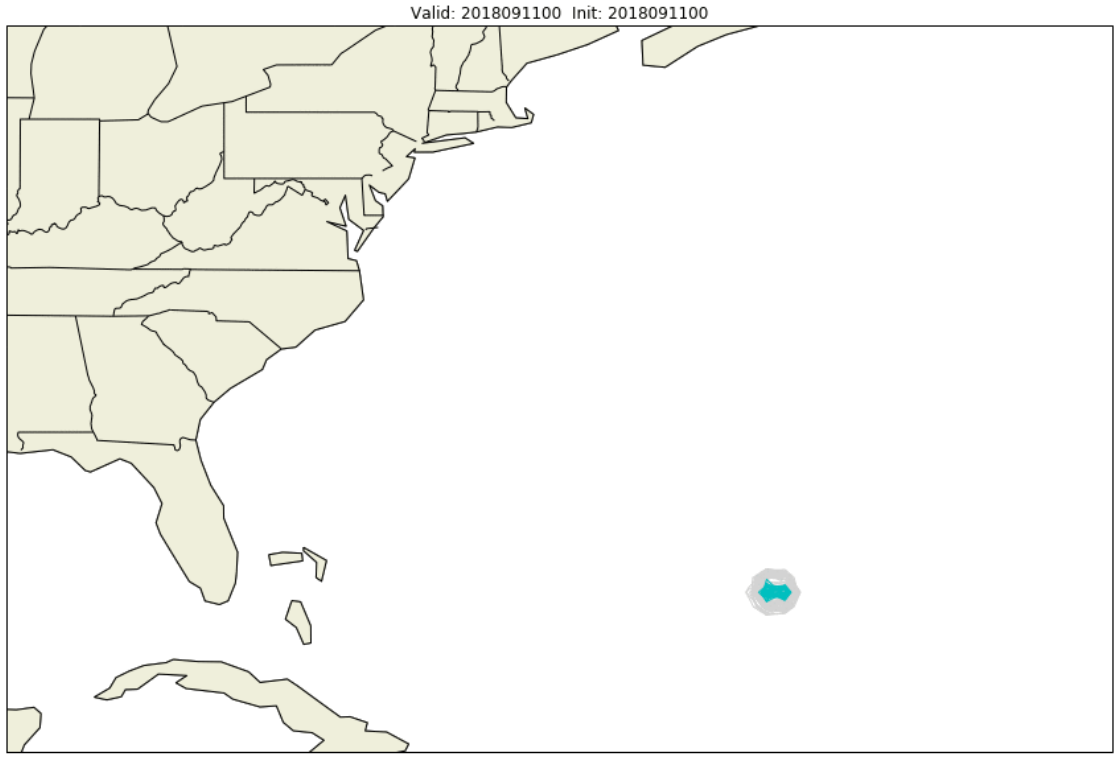
Lock et al. (2000) surface and cloud mixing profiles



Leveraging Ensembles for Uncertainty Estimates

Though there is no official GEOS-Ensemble Prediction System (EPS) product, there is no reason why ensemble forecasts cannot be run from the Ensemble-based DAS

- The system has been run as an EPS before
- Hurricane Florence renewed the desire to exercise this capability
- Though not PBL-related, the figure to the right illustrates the central pressure from 32 global forecasts
- The models are identically configured, so the sensitivity in forecast is a function of the initial conditions
  - For forecasting problems, this may be suboptimal, but for observing system science, this may be a strength



Leveraging Ensembles for PBL Uncertainty Estimates

Typically, we've mainly looked at model prognostic variables within our ensemble system

- T, q, uv, p_s, O_3, cloud water, cloud ice, *rain, snow*
- These are what are used in our 4D-EnVar solution, which is the primary use of our ensembles

Many additional model diagnostics can be written, however

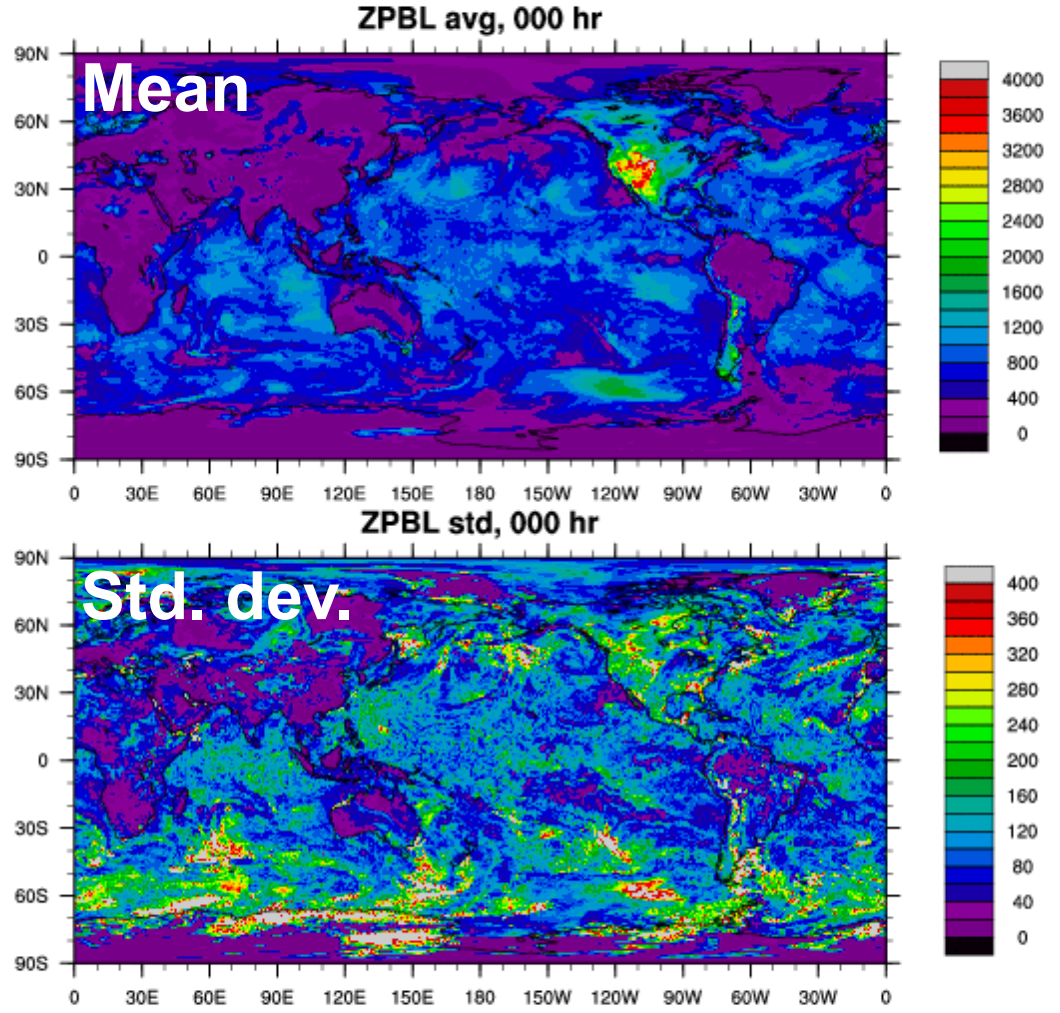
- For today's audience: PBL Height

3-Day EPS Forecast of PBL Height

Mean and standard deviation of PBL Height from a single set of ensemble forecasts

- Initialized at 0000 UTC on 11 Sept 2018
- 32 Members
- 3 day forecast integration

Over land, spread is correlated with PBLH and thus solar insolation. Over ocean, spread is largest over Southern Ocean.



OSSEs for PBL Studies

Observing System Simulation Experiments (OSSEs) are a theoretical framework from which many data assimilation and modeling science questions can be addressed

– Traditionally, a quantified impact of a theoretical observing system

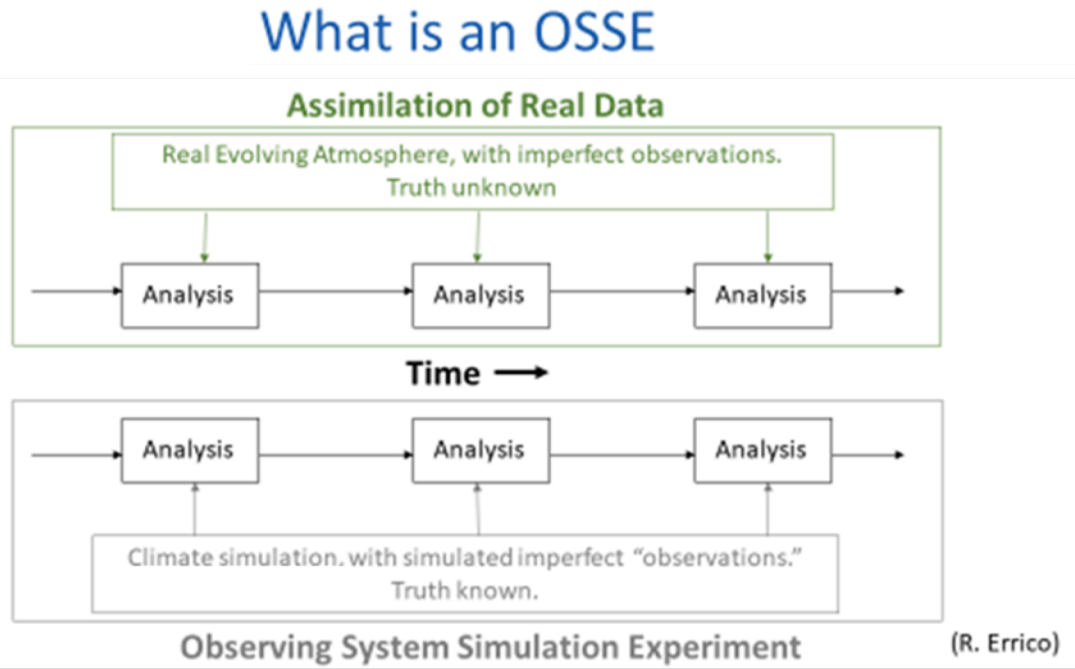
OSSEs use a free-running model (Nature Run) at the 'true atmosphere'

Observations & their errors are simulated from the NR (calibration)

Those observations are then assimilated like real observations into a DAS

Core to this is that *the true atmosphere is known*

– For this talk, we consider the changes to the forecasted PBL height by the addition of a new observing system

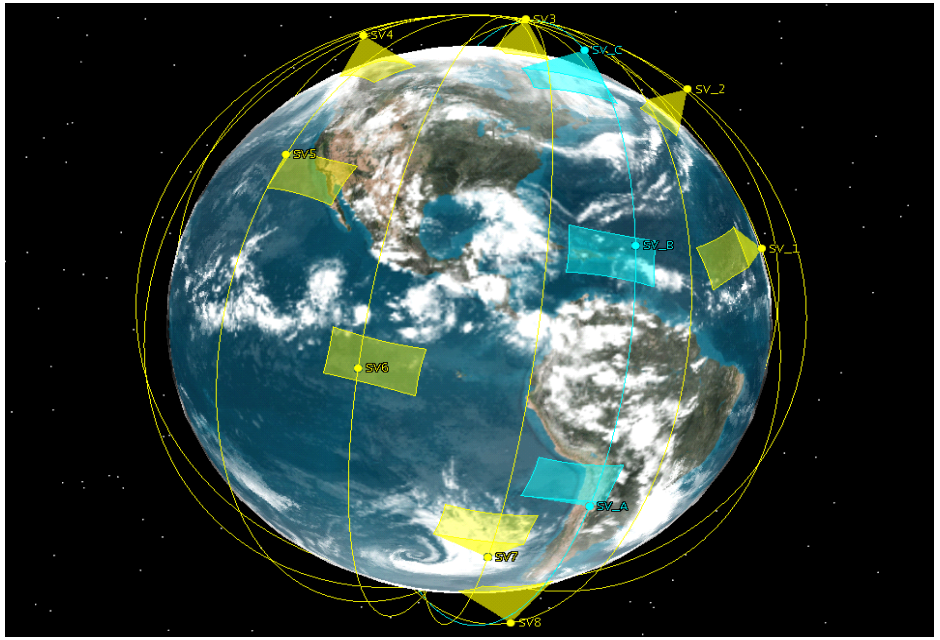


Brief Project Overview

Results presented based on an OSSE for MISTiC™ Winds
- MISTiC™ Winds provide High Spatial/Temporal Resolution Temperature and Humidity Soundings of the Troposphere
- The observing strategy is to retrieve atmospheric state and motion via LEO Constellation of MicroSats
  - Infrared spectrometer sampling the midwave
  - With the constellation approach, temporally subsequent sets of retrievals can then be used to perform feature tracking and retrieve atmospheric motion vectors (AMVs)
- Main goal of the study is to investigate the potential impact of these observations of both the *wind and radiance* information from the constellation

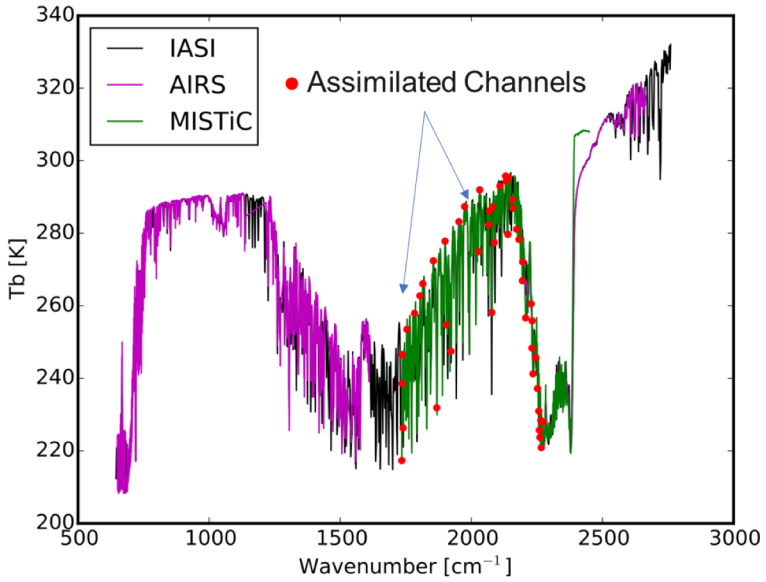
Study is performed on top of GMAO OSSE system
- Full 2016 Observing System
- Simulated from 7 km GEOS-5 Nature Run

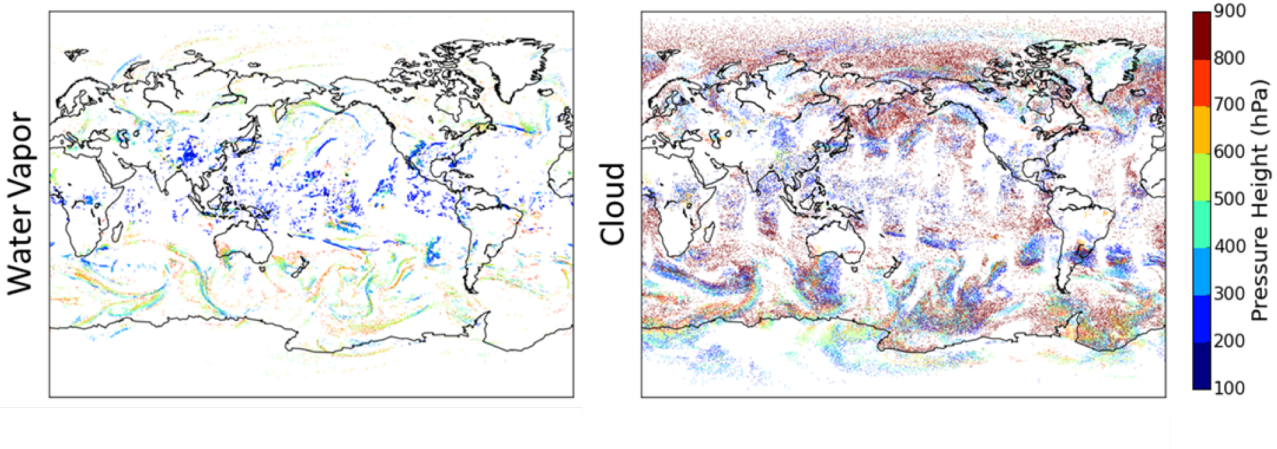
PBL was not the main focus of this OSSE



MISTiC Winds = Midwave Infrared Sounder for Temperature and humidity in a Constellation for Winds

MISTiC Radiances and Winds





MISTiC spectral information is about 1/3 of AIRS, CrIS, IASI

- Simulated MISTiC spectrum shown in green, based on BAE-provided specs
- 590 channels ranging from 1735-2450 cm^{-1}
- All cases perform a channel selection, down-selecting to 46 channels

Nature run clouds used in simulation to produce realistic yields

Increase of spectral coverage equates to more vertical information

- Typically, winds are measured from geostationary instruments with 1-3 water vapor channels and limited vertical temperature information

Winds were also included, generated from a probabilistic model based on NR fields

Experiment Configuration

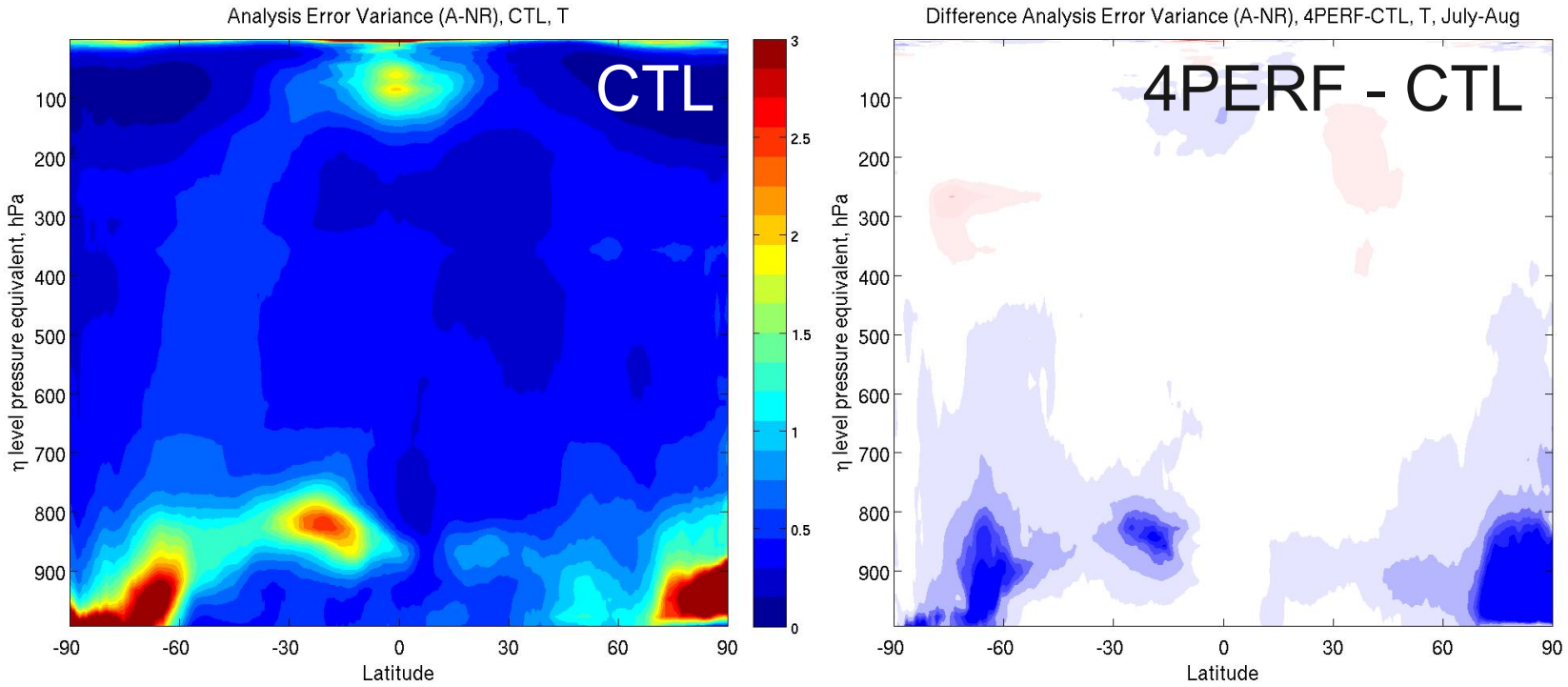
Control – GMAO OSSE System

- Full Observing System circa 2016
  - Conventional: RAOB, surface, aircraft
  - Satellite Retrieved: GEO AMVs (GOES/ Himawari/MeteoSat), Polar LEO AMVs (MODIS Aqua/Terra)
  - Radiance:
    - IR: AIRS, IASI (Metop-A/B), CrIS, HIRS (Metop-A)
    - Microwave T: AMSU-A (NOAA-15/18/19, Metop-A/B, Aqua), ATMS, SSMIS F17
    - Microwave Q: MHS (NOAA-18, Metop-A/B)
  - All observations have error models applied

Experiment – 4PERF

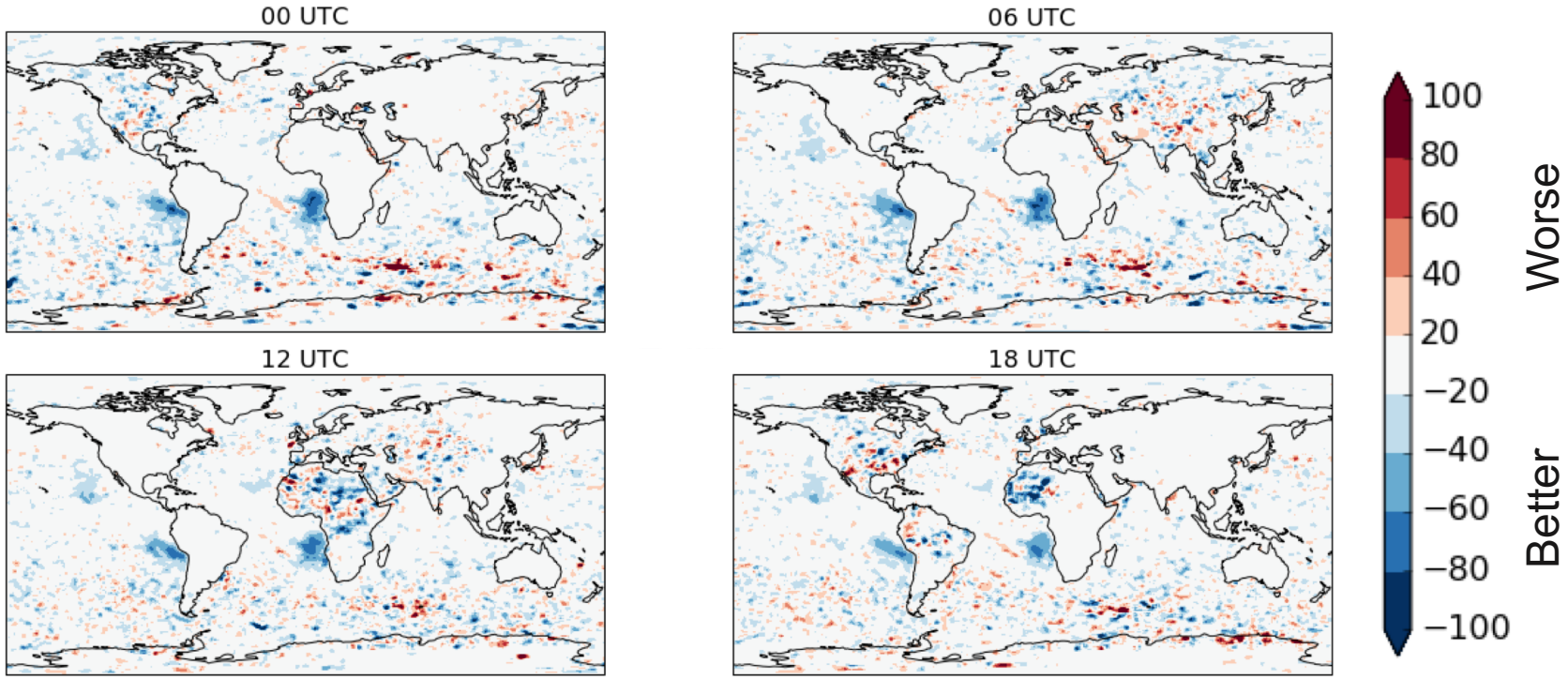
- Control + 4 Orbit Configuration
  - MISTiC Radiances (*46 channel selection*)
    - Channel selection performed to reduce interchannel correlations
  - MISTiC AMVs (Cloud & WV)
  - No additional errors applied to either radiances or AMVs

Temperature Analysis Error Variance – Zonal Average



– Error variance calculated relative to Nature Run truth
– Difference relative to CTL – Blue (red) indicates addition of MISTiC obs reduced (increased) error
– The OSSEs illustrated a clear signal in improved lower-tropospheric T
  • The polar improvements were lessened when realistic observation errors were used

PBL Height RMS Error Difference (4PERF – CTL)



PBL errors for forecast hours 0 (initialized @ 00 UTC), 6, 12, and 18 for a month of forecasts (NR Year 2006, July)

– Top-left is the direct affect of the MISTiC obs, other three are forecast error changes

Summary

There is a natural linkage between PBL & the GMAO's Earth System Modeling and Analysis

- GMAO is already actively coupled in terms of Land, Atmosphere, and Aerosols
- NRT Composition/Chemistry forecasting
  - Nearly ready for routine production (next few weeks)
  - Work of composition/aerosol OSSEs (P. Castellanos)
- Much of our focus is towards coupling all system in terms of modeling and assimilation
  - Atmosphere, ocean, ice, land, aerosol, chemistry, biogeochemistry

Increases in resolution (horizontal, vertical) will improve the resolution of processes

- The PBL will move from being a simple parameterization near the boundaries of the model to being essential to interacting with the cross-system interfaces

Summary

The decadal survey explicitly refers to the role of ‘observation-driven modeling’

- Recent missions have considered the ‘Level-4’ assimilated product as part of their suite
  - e.g. GMAO generates the SMAP L4 product
- Let modeling fill in the null space, consider assimilation as part of the full instrument product suite

Both ensembles and OSSEs can be used to test sensitivity of PBL schemes within the model to initial conditions

- Test response of the earth system to new observing types
- Idealized studies can be performed to target areas of uncertainty and their response

Assimilation improvements

- Modern ensemble-based systems (EnKF, Hybrid VAR) should be more readily able to assimilate PBLH
- Improved PBLH analysis, combined with improved aero/chem analysis, will result in better transport
  - Short-term, but what about the role of marine PBL in sub-seasonal to seasonal (S2S) prediction?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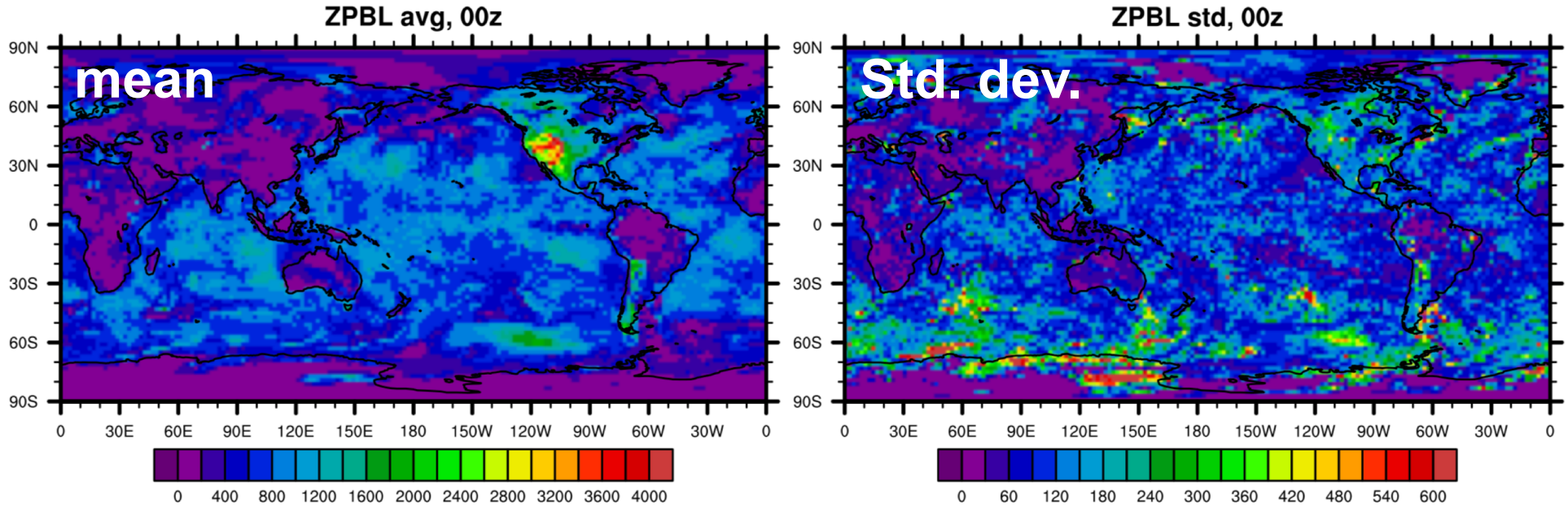
Initial Condition PBL Height Ensembles



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