Observation-Driven Studies Using GEOS-5 Earth System Modeling and Analysis: Some Examples

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GMAO: Themes

Weather Analysis and Prediction

Seasonal-to-Decadal Analysis and Prediction

Global Mesoscale Modeling

Observing System Science

Reanalysis

- These (non-orthogonal) themes decribe GMAO's main activities
- GEOS-5 is a modular system, encompassing much of the Earth System
- All themes include multiple components of the Earth System
- Strong emphasis on NASA's Earth Observations

GEOS-5: An Overview

Modular Earth System Model:

- Atmosphere, land, ocean, cryosphere (physics, chemistry, biology)
- Aerosols, chemistry, carbon cycle, …
- Early adopter of a modular infrastructure (ESMF)
- Used at resolutions of about 100km to a few km

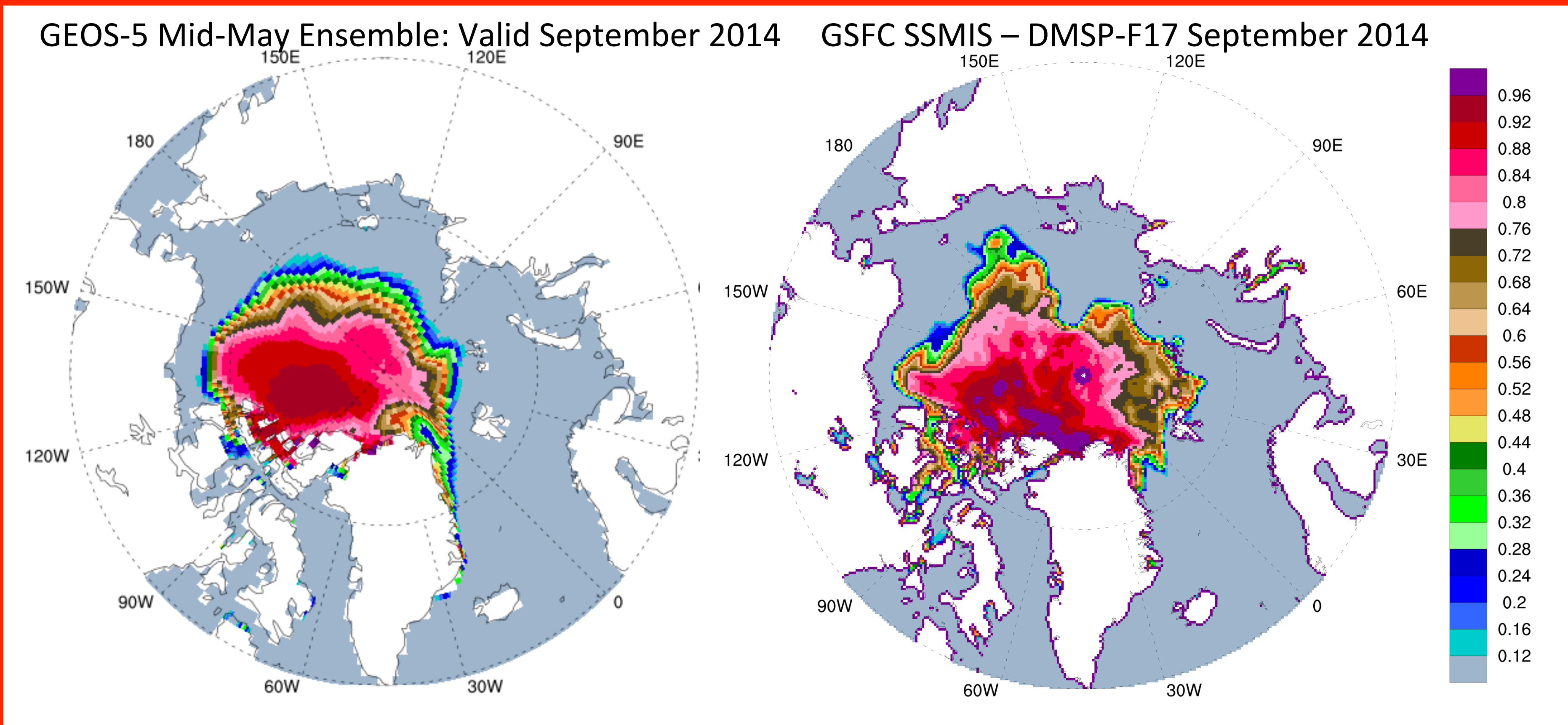
Data Assimilation:

- Atmospheric assimilation developed jointly with NCEP
- Ocean and land are developed in house

Observations:

- Use a broad range of NASA and non-NASA data
- Ability to synthesize observing systems from model fields

Sea-Ice Prediction from Seasonal Forecasts



Relevance for this Meeting

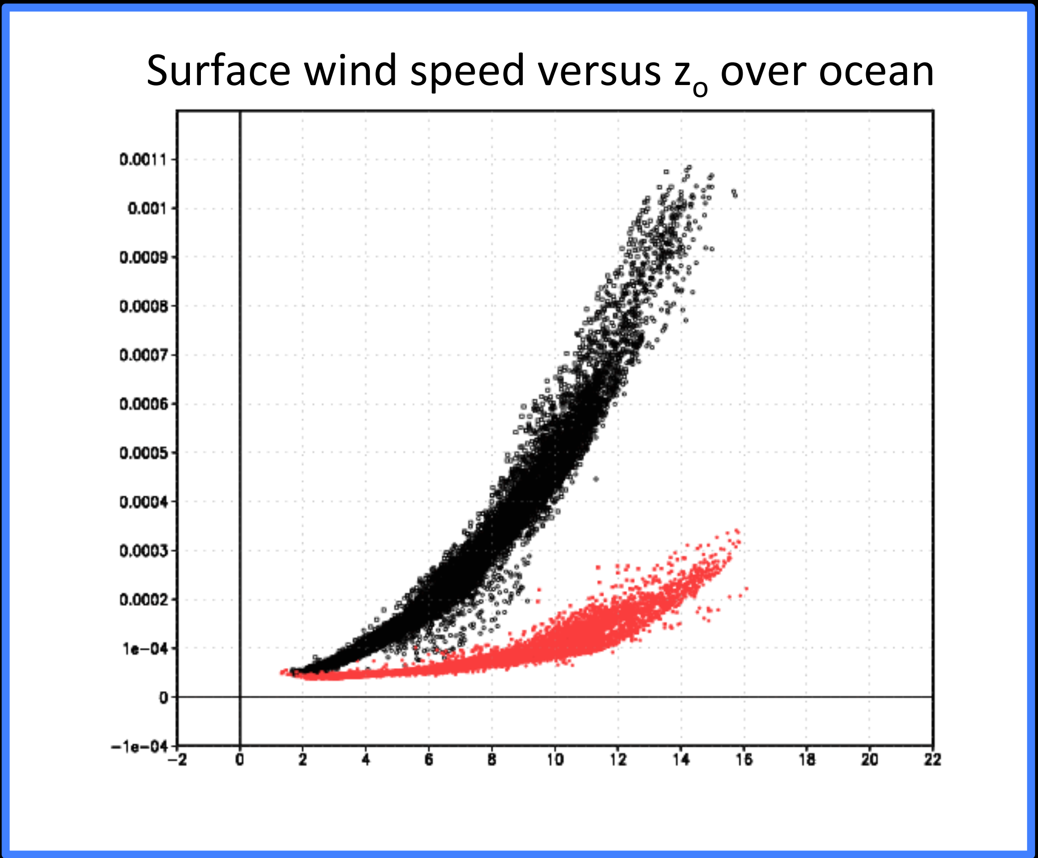
Data Assimilation:

- confrontation of the GEOS-5 model with observations is the central theme of GMAO's work

Spatio-temporal structure:

- the broad range of time (hours to decades) and space (few-km to 100-km grids) demands drives GMAO to use resolution-aware parameterizations

Example 1: Surface Drag over the Ocean



A change to the functional relationship between ocean roughness and wind stress was introduced into GEOS-5.

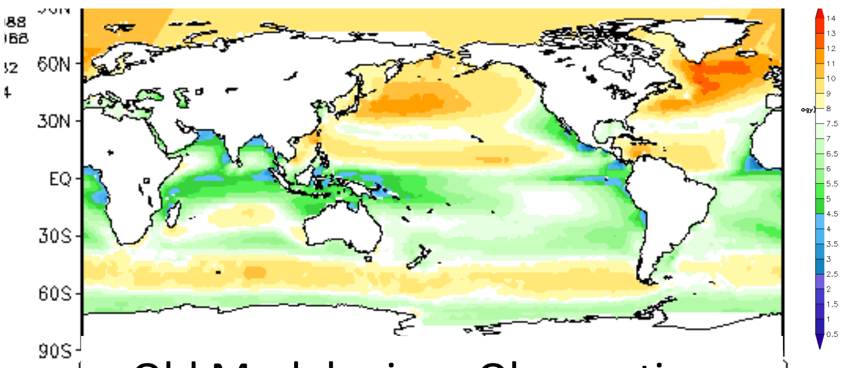
This was based on oceanic observations (Edson, 2011) implying that the drag in GEOS-5 was too weak.

Objective was to improve surface wind speeds over the oceans

Work led by Andrea Molod

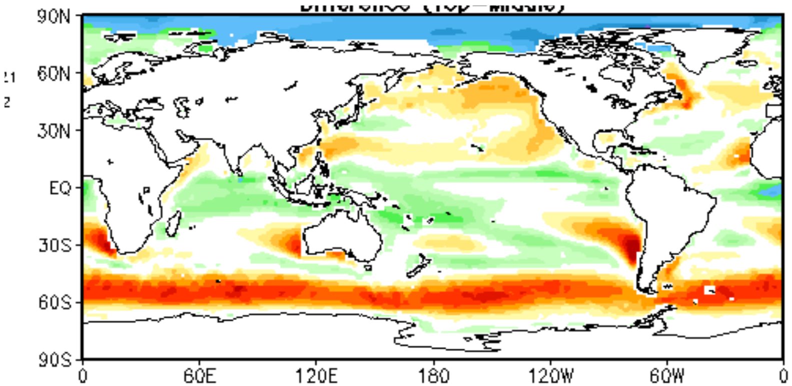
Impact on Simulated Surface Winds

Observation-derived surface wind speed

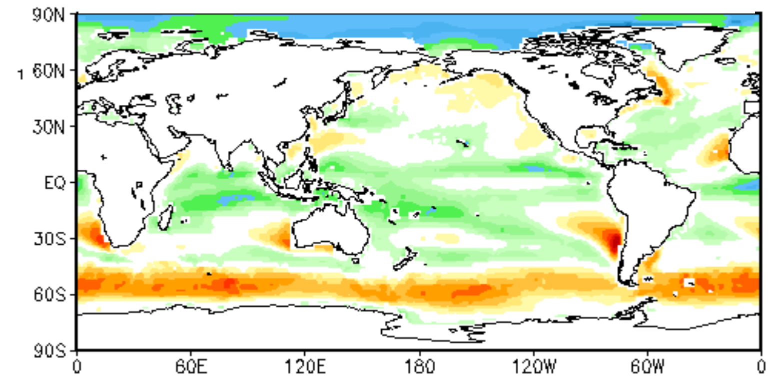


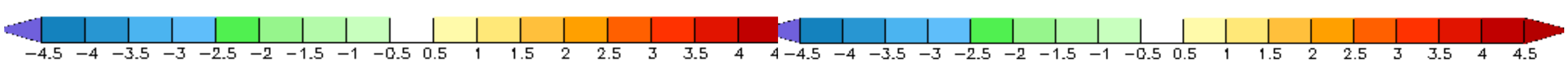
The increased surface roughness over oceans leads to a substantial improvement in surface winds in the DJF season (impact extends into the stratosphere). [Garfinkel et al., 2013)

Old Model minus Observations



New Model minus Observations

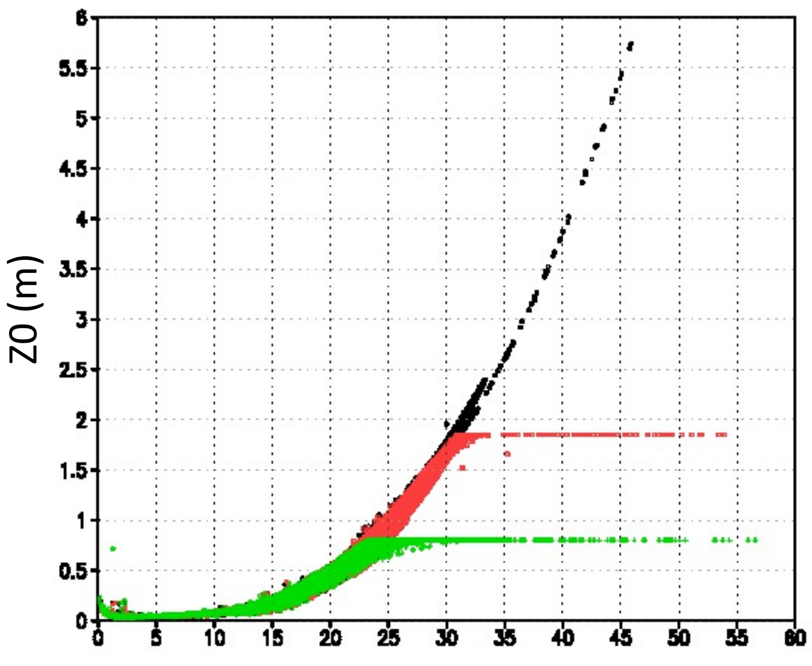


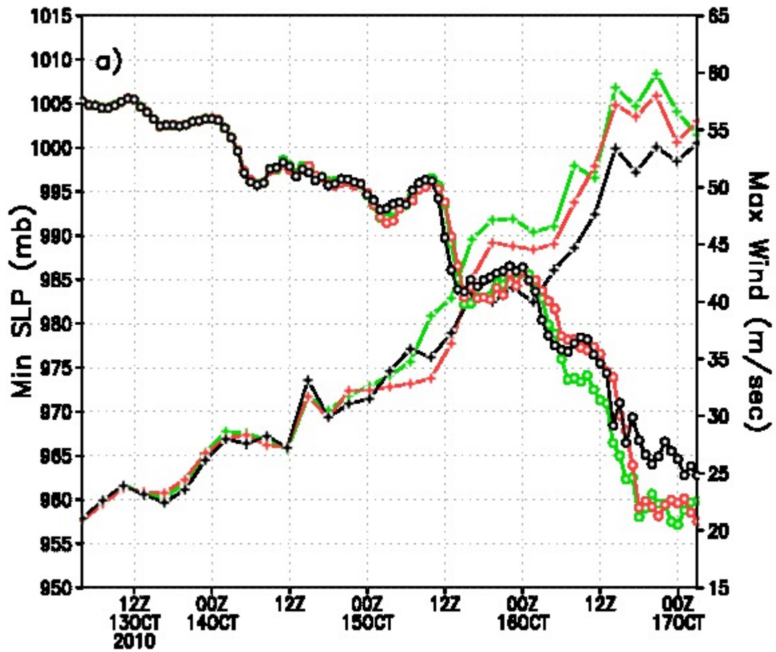


An Additional Improvement

Few observations of surface roughness exist in the vicinity of tropical storms. In GEOS-5, the roughness increased with wind speed, reaching unrealistic values. An upper bound was imposed, following work by Emanuel (1996, 2003), Donelan (2004), and others.

Surface wind speed versus z_o over ocean

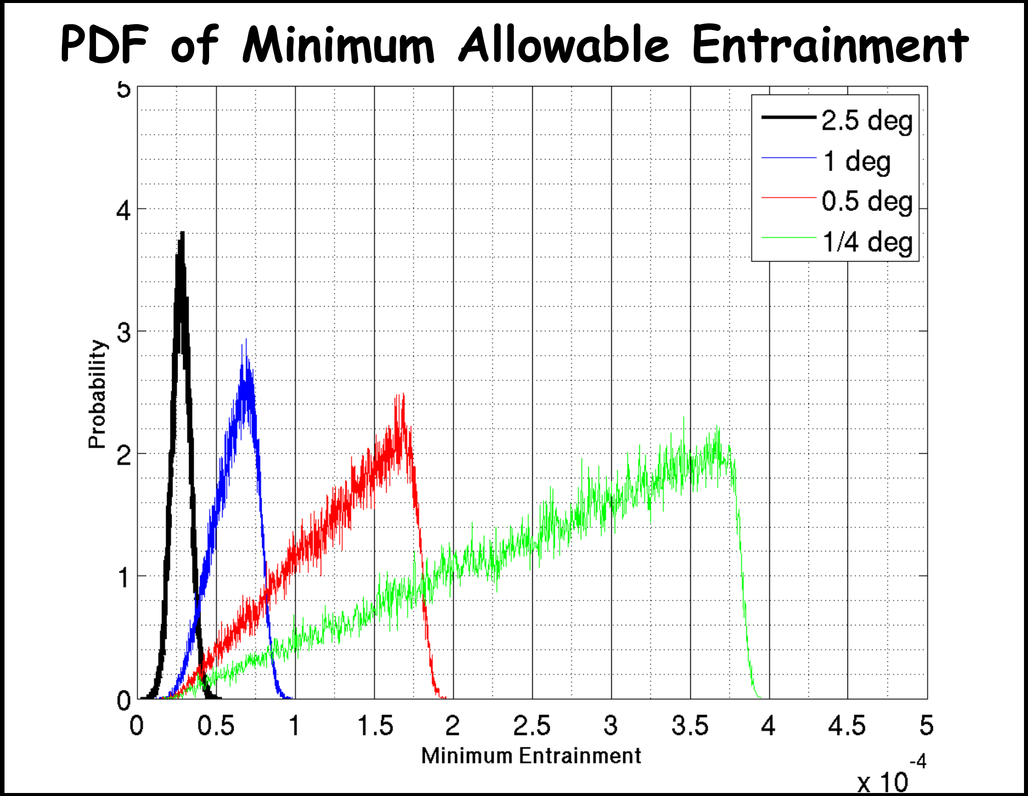




Impact: Typhoon Megi in 2010 was more realistic with capped drag (Molod, 2012)

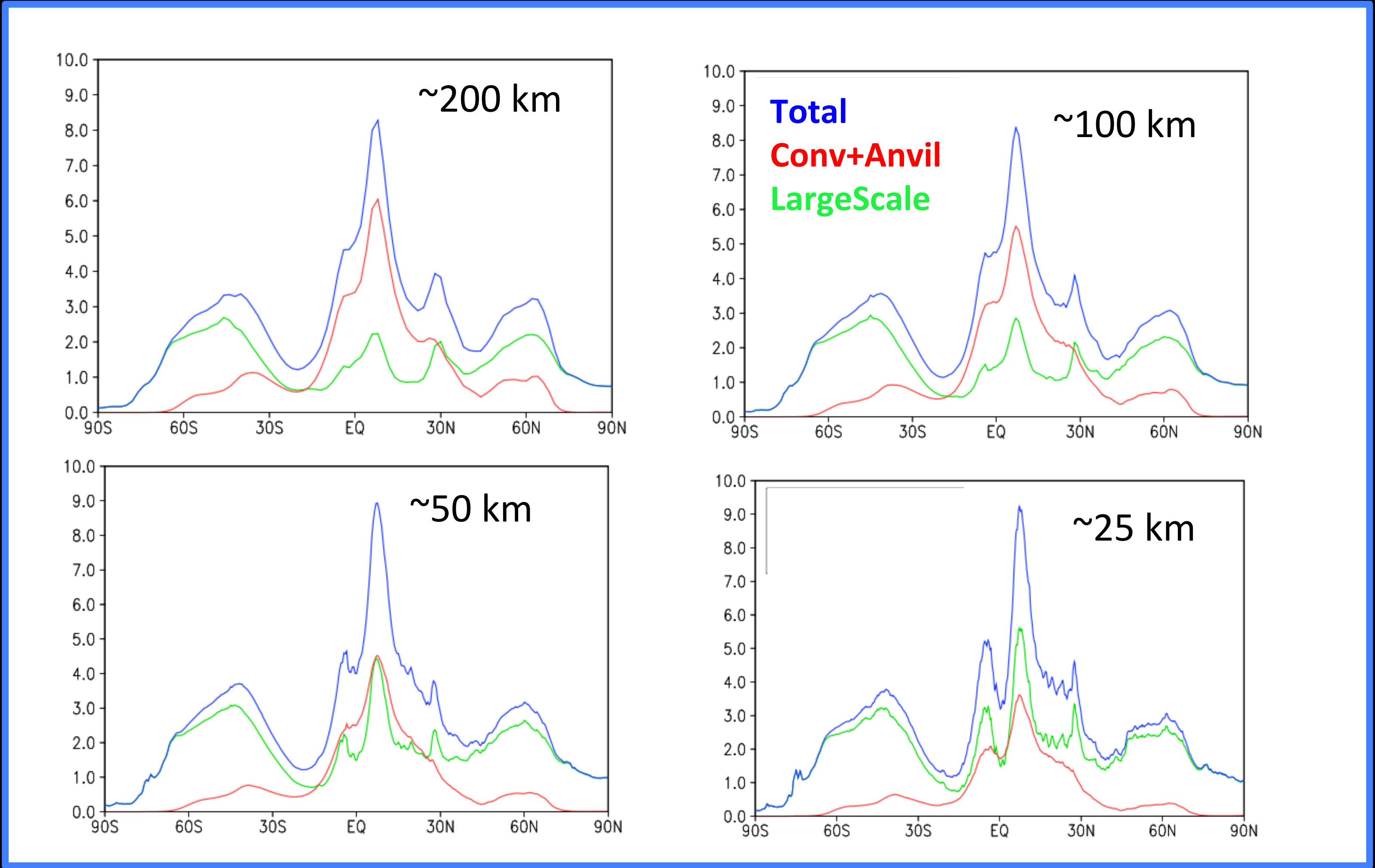
GEOS-5 AGCM: Resolution-Aware Cumulus Convection

Approach adopted by Molod et al. (2015) in GEOS-5 builds on the "Stochastic Tokioka" model by using introducing a limit that depends on resolution of the GCM. (See also Lim et al., 2015.)



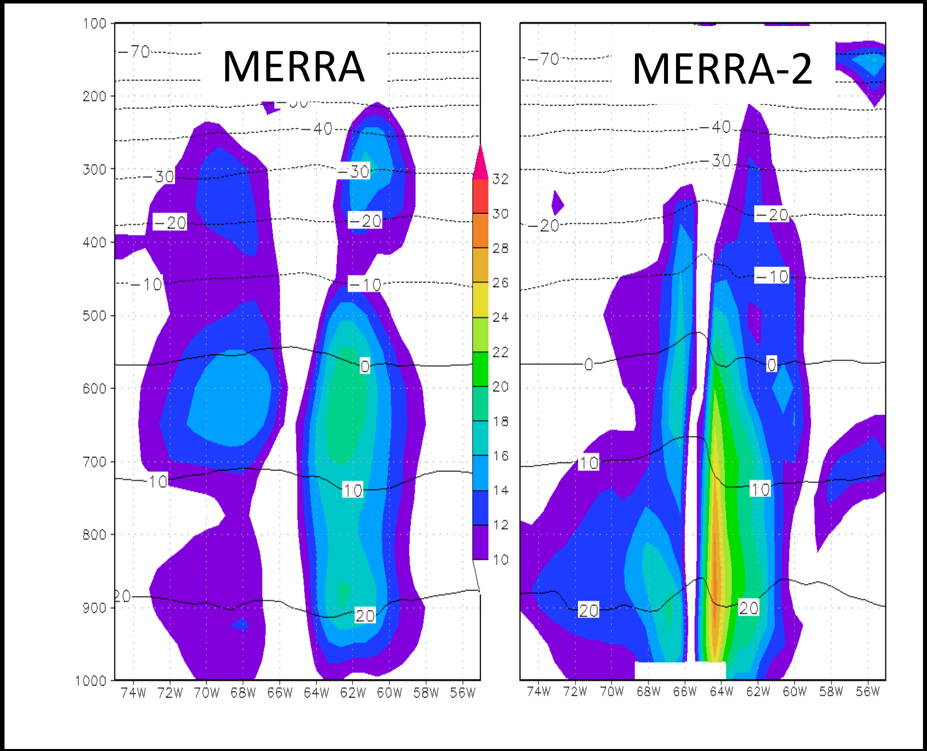
"Stochastic Tokioka" (Bacmeister and Stephens, 2011) describes the use of a variable Tokioka (1988) parameter, which places a minimum on the entrainment into deep convective clouds. Tallest (non-entraining) large mass flux convective events are eliminated, and total cumulus mass flux for deep convection is restricted. Values are sampled from a PDF with prescribed parameters).

Impact on resolved/parametrized precipitation



Improved Tropical Cyclones in MERRA-2

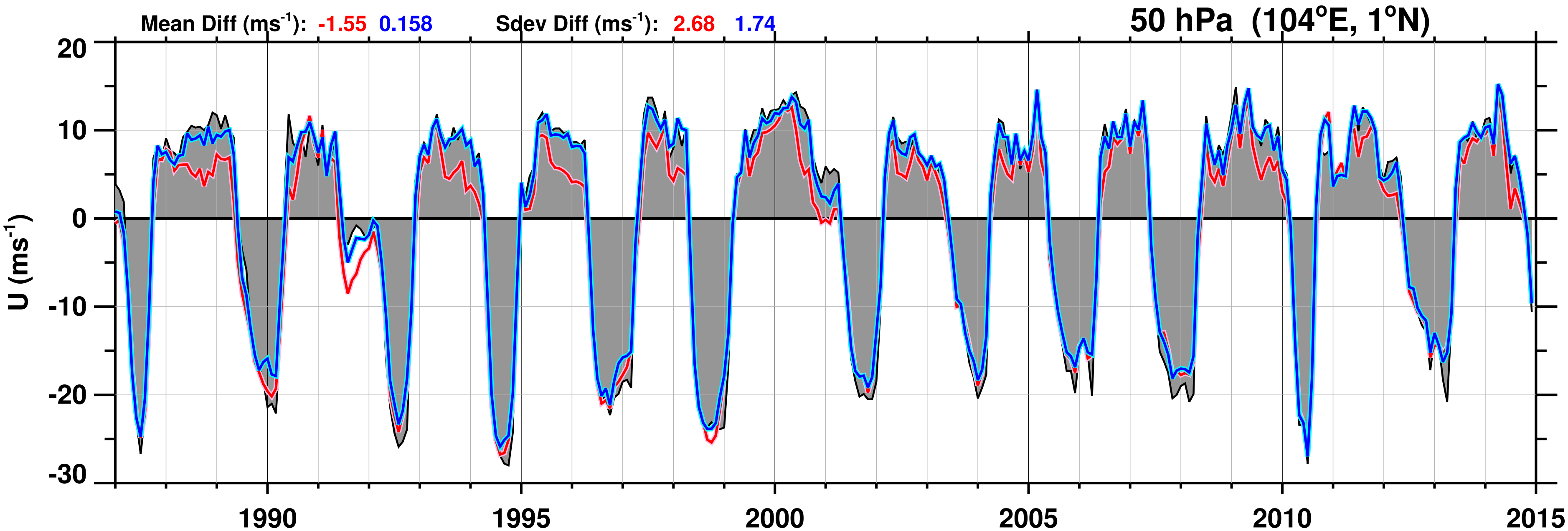
Category-5 Hurricane David (1979) caused widespread damage from the Caribbean to the U.S.. It was virtually undetected in models of the day. It is one of several historical hurricanes in ***MERRA-2*** that is realistically depicted for the first time in a gridded data set.



Even through the spatial resolution of MERRA-2 is not much better than that of MERRA (close to 50km), this plot shows that the hurricane is developed much more realistically in MERRA-2. Largely a consequence of the model improvements. (This is a height section through the core.)

Diagnosis led by Oreste Reale

Example 2: The Quasi-Biennial Oscillation

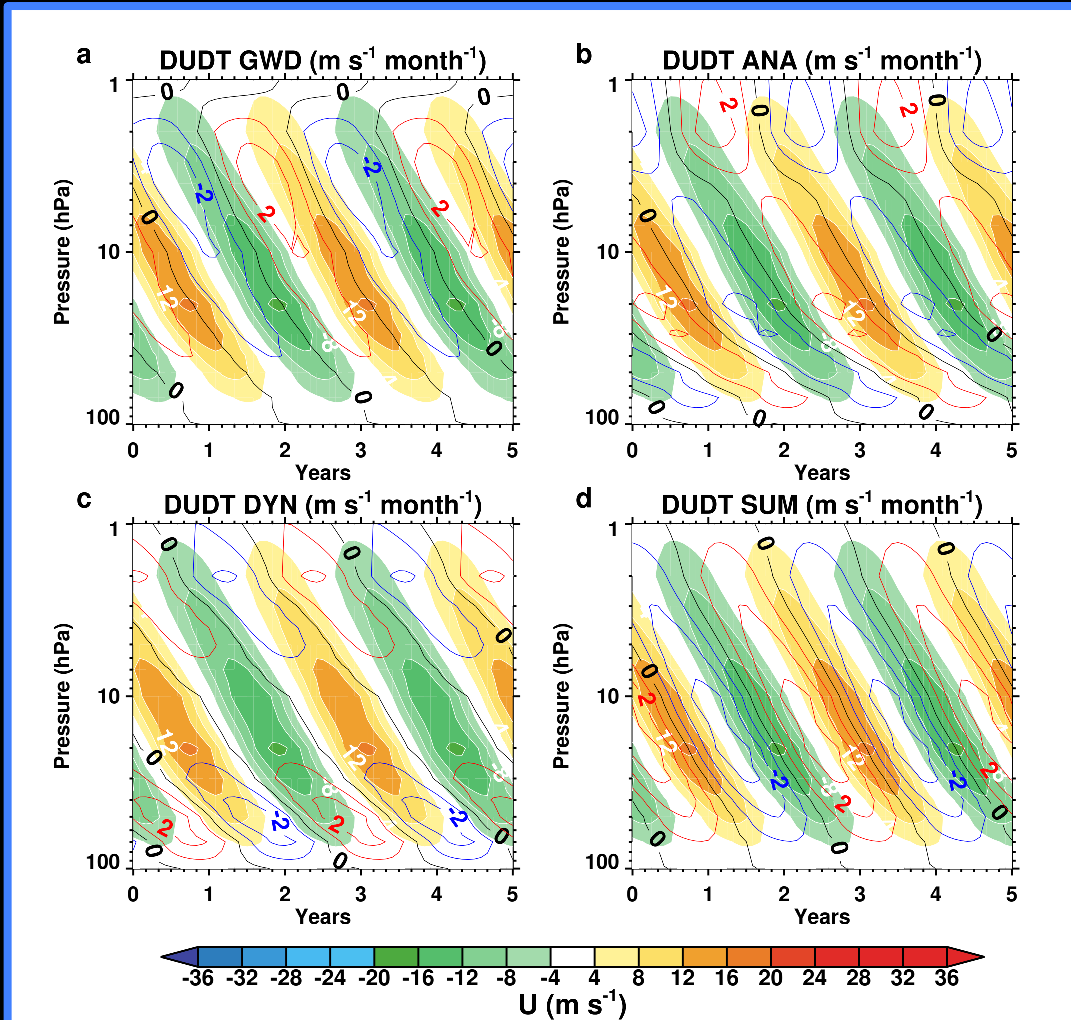


Singapore (gray shading)
MERRA
MERRA-2

MERRA-2 fits the Singapore observations better, especially during the westerly phase of the QBO.

Work led by Larry Coy

Zonal wind forcing terms in MERRA

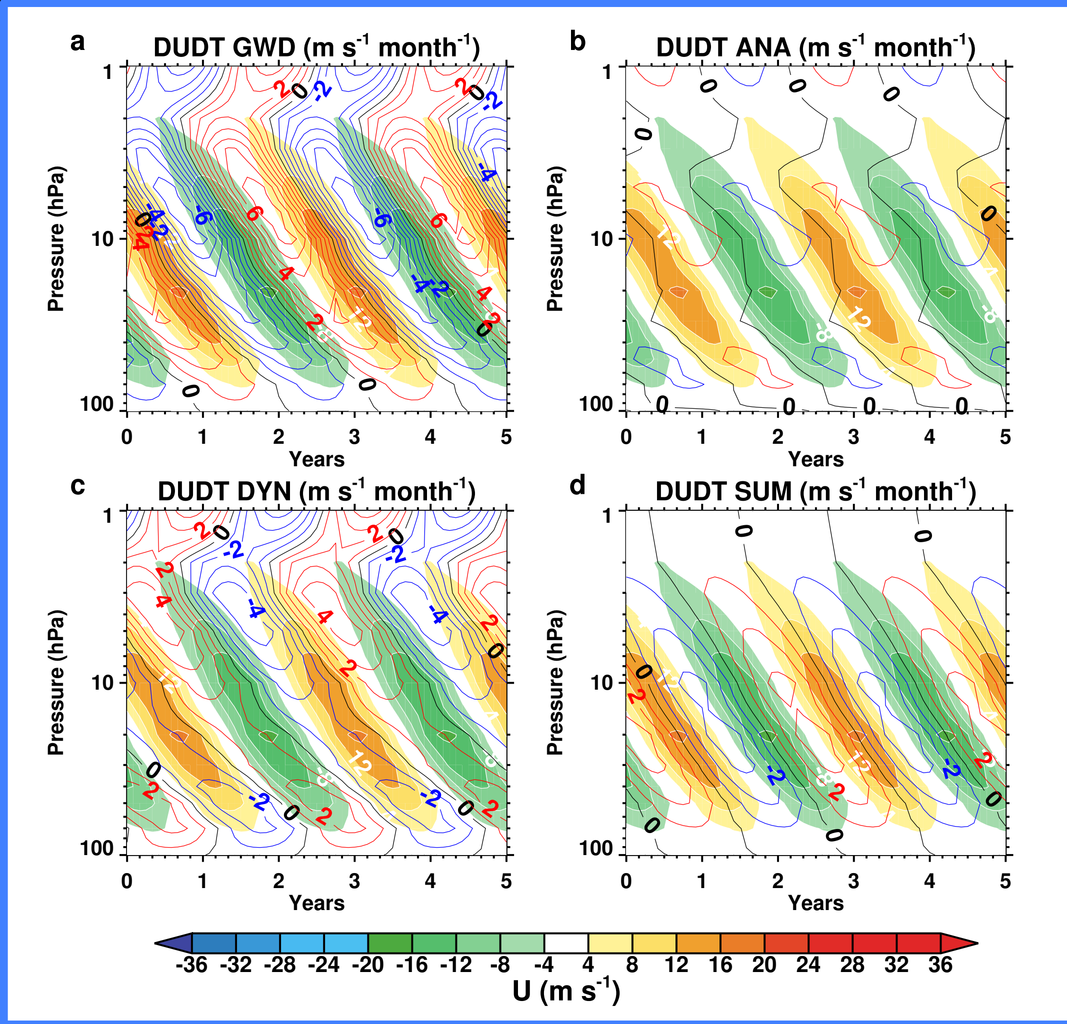


Tropical winds in MERRA are forced in roughly equal measure by resolved dynamics, gravity-wave drag, and analysis increments

Excessive reliance on analysis to force these winds suggests that a forcing term is missing

Developments of the GWD scheme (adding an extra wave spectrum in the Tropics) was a part of the development from MERRA to MERRA-2.

Zonal wind forcing terms in MERRA-2



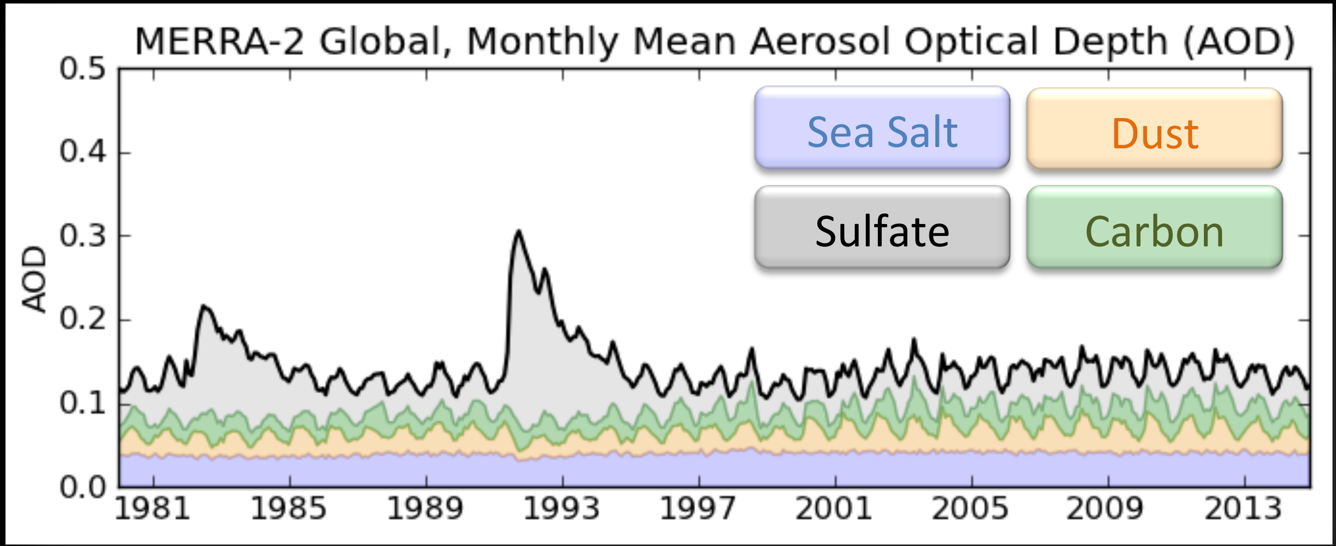
The impact of these changes to GWD is high

The physical forcing (GWD driving) now dominates the QBO wind forcing in MERRA-2

Analysis increments play a much smaller role

Coy et al. (2015)

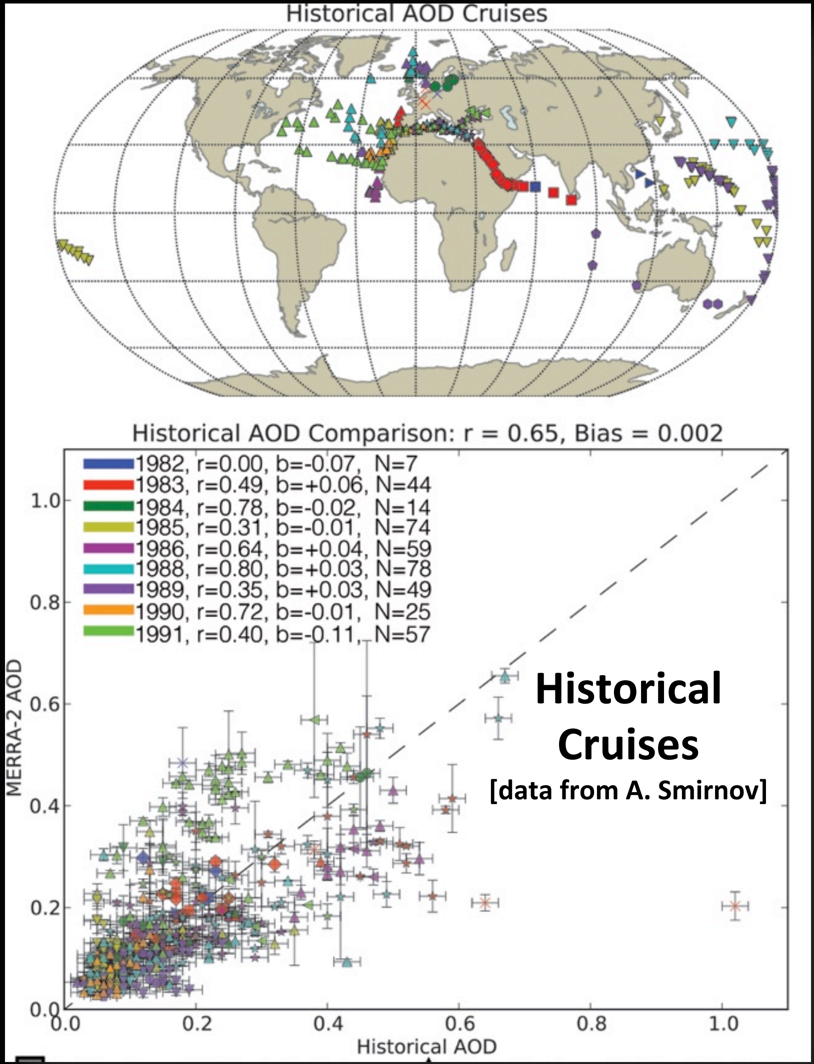
Example 3: Aerosol Analysis in MERRA-2

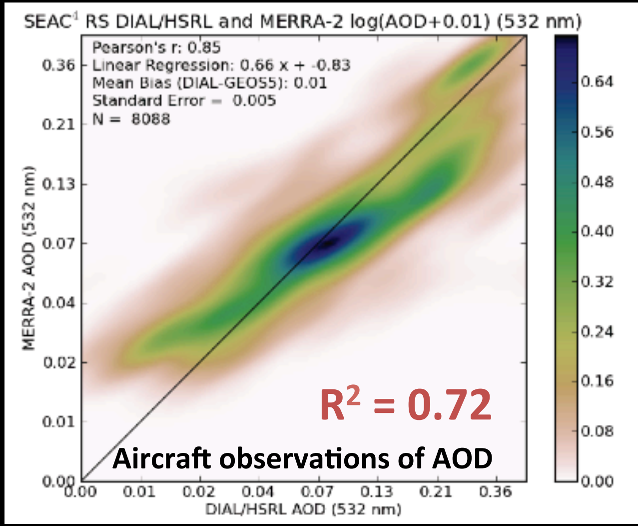


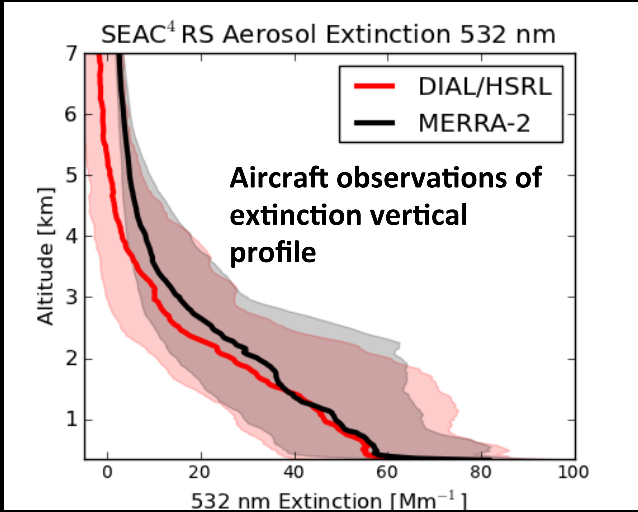
- Unique amongst its peers, the MERRA-2 reanalysis includes an aerosol reanalysis for the modern satellite era.
- Constrained by observed aerosol optical depth (AOD), MERRA-2 simulates major aerosol events (i.e. volcanic eruptions) as well as the temporal and spatial variability of major aerosol species.

Diagnosis led by Cynthia Randles

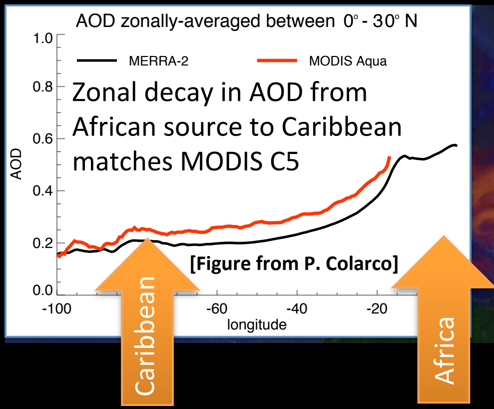
Aerosol Analysis: Independent Verification

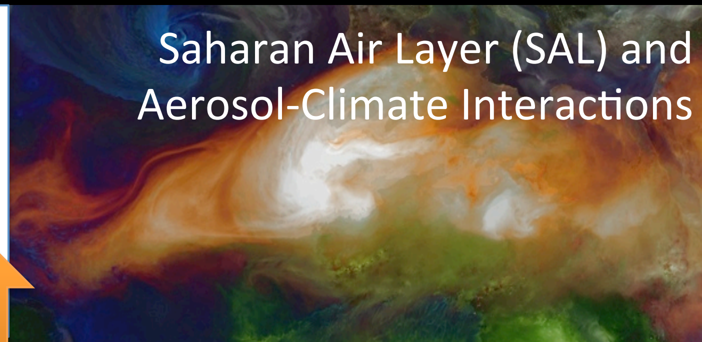


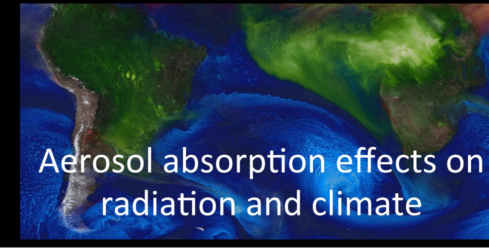


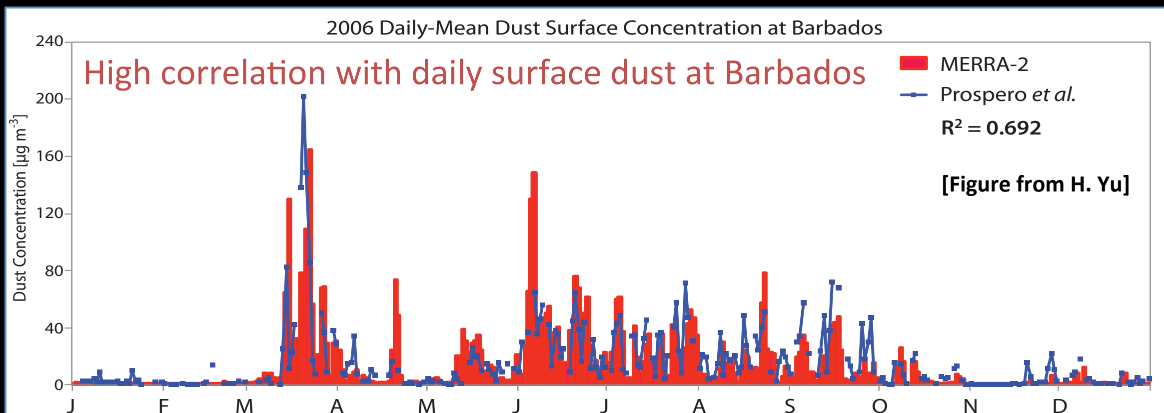


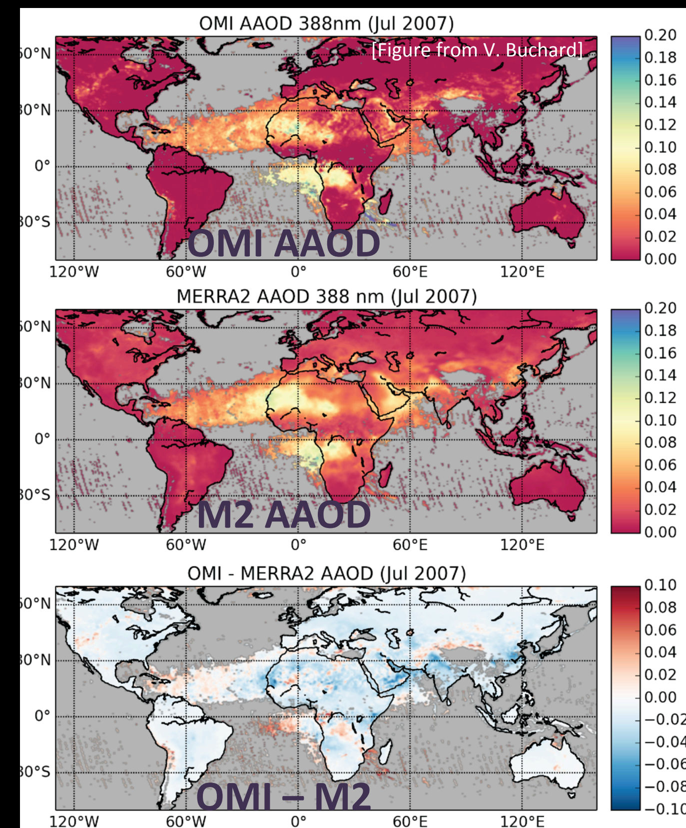
Emerging Application of MERRA-2 Aerosols to Climate Studies

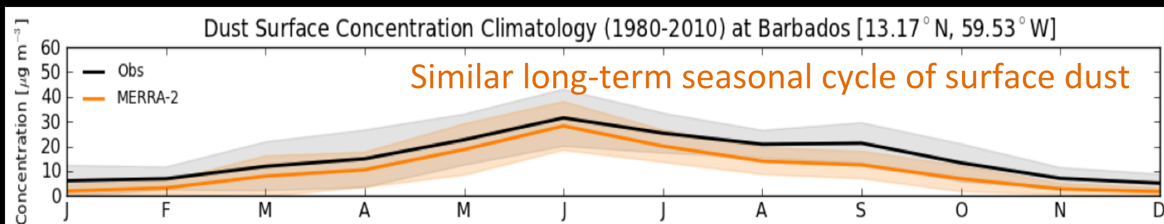












Summary

GEOS-5 modeling work is intimately linked to observations:

- Timescales of hours to decades, includes prediction of weather and seasonal-to-decadal variations
- Data assimilation, including reanalysis, is a core element

Three examples of model-data combinations, with a focus on the new GEOS-5 reanalysis, called MERRA-2:

- Observationally derived implementation of surface drag over oceans – beneficial impacts (when care is taken)
- Physical forcing of the QBO by gravity wave drag
- Emerging capabilities in aerosol assimilation – direct effects included in MERRA-2