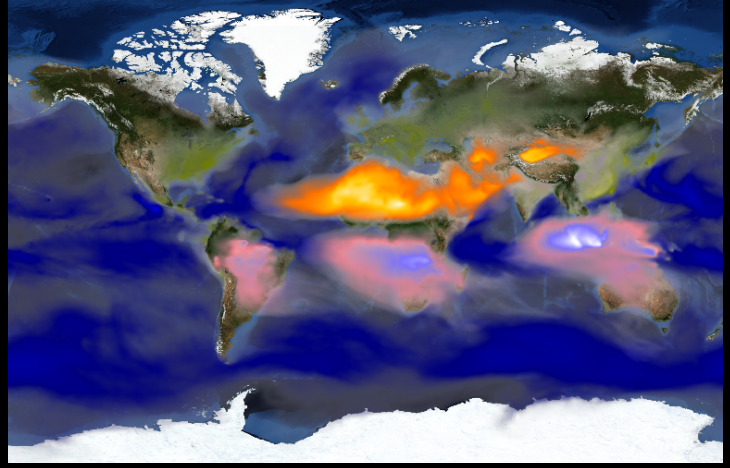


MERRA-2: Aerosol Reanalysis 1980 - Onward

Cynthia A. Randles

With thanks and contributions from:

Arlindo da Silva, Virginie Buchard, Anton Darmenov, Peter R. Colarco, Valentina Aquila, Huisheng Bian, Ed Nowottnick, Xiaohua Pan, Alexander Smirnov, Hongbin Yu, and R. Govindaraju

AeroCom/AerChemMIP/CCMI, October 7, 2015

GESTAR MORGAN STATE UNIVERSITY

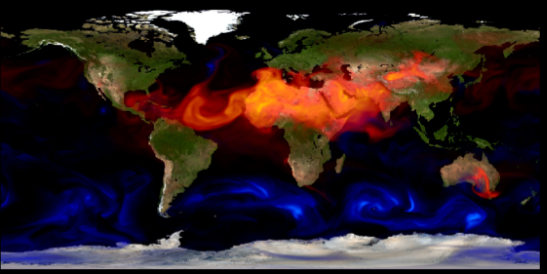
NASA

Why make a reanalysis?

A consistent reprocessing of Earth system observations using a modern, unchanging data assimilation system

- Relies on models to interpret, relate and combine many different observations from multiple sources
- Produces multi-decadal gridded data sets that estimate a large variety of Earth system variables, including ones that are not directly observed
- Has become fundamental to research and education in the Earth Sciences

*A successful reanalysis **requires** a good forecast combined with bias-corrected/quality controlled observations!*



MERRA-2 Advances

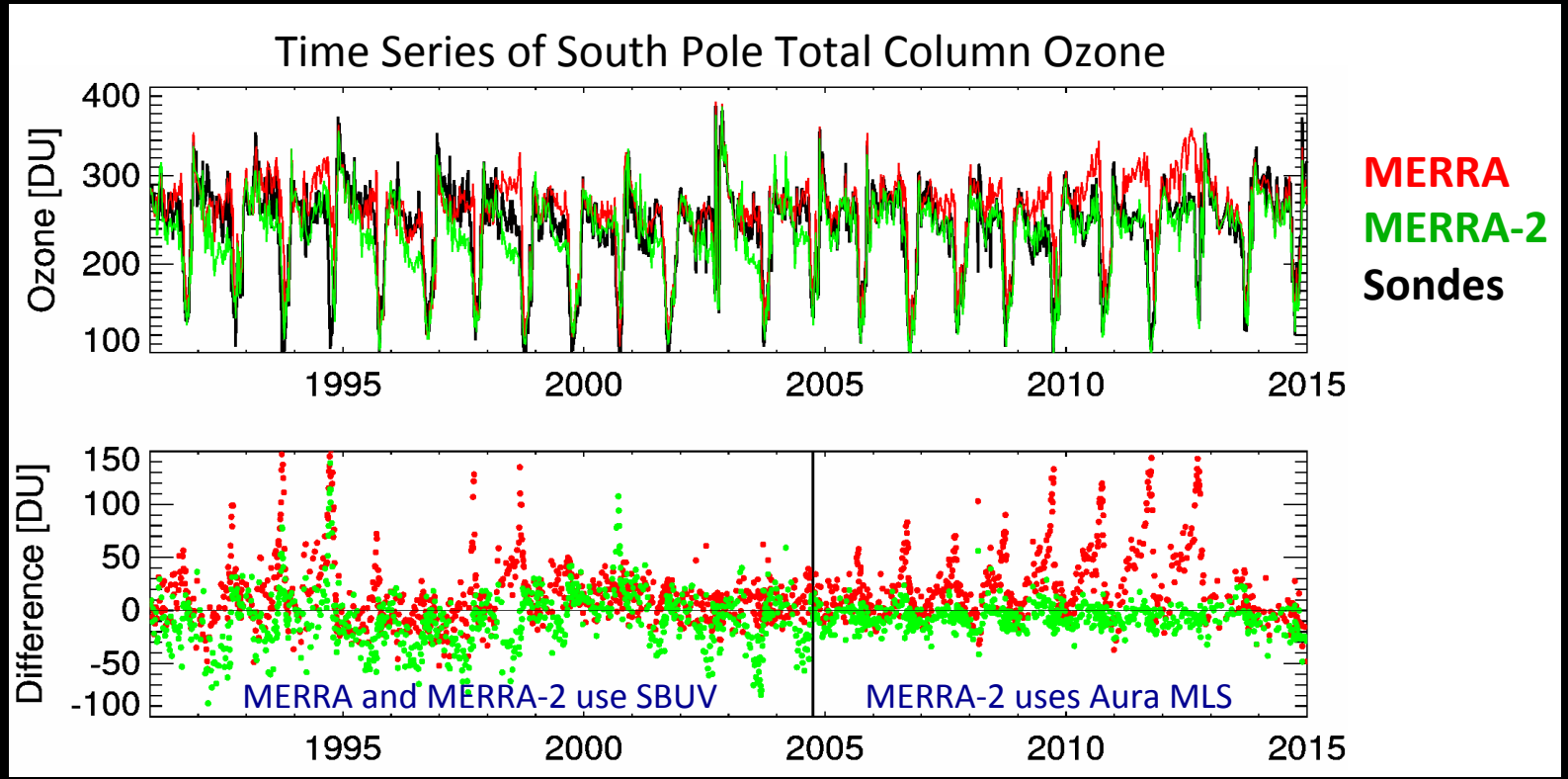
Building on the successes of MERRA by updating the GEOS-5 model, analysis code, and observing system:

- ✧ Include modern satellite observation types not available to MERRA
- ✧ Reduce spurious trends and jumps related to changes in the observing system
- ✧ Reduce biases and imbalances in the water cycle

Steps towards a full Earth System Reanalysis:

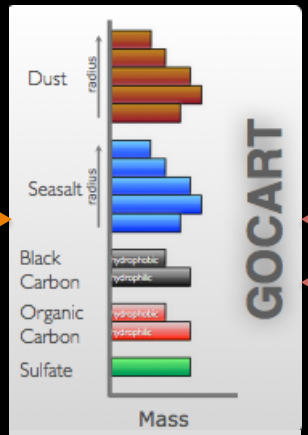
- ✓ Improved representation of cryospheric processes
- ✓ Improved representation of the stratosphere, including ozone
- ✓ **For the first time, a coupled aerosol-meteorological reanalysis for the entire satellite era (1980 – onward)**

MERRA-2: Improved representation of ozone



MERRA-2 shows close agreement with ozone sonde observations throughout, but especially when Aura MLS data are assimilated

GEOS-5: The MERRA-2 Modeling System

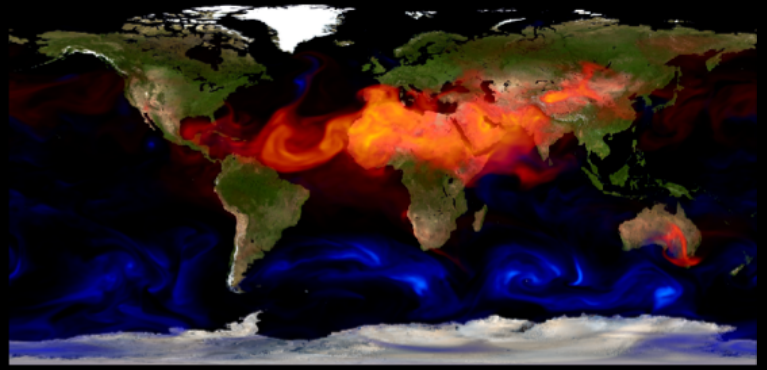


P&L: CO, CO_2, RATS

Biomass Burning Emissions (QFEDv2)

AeroChem

Anthropogenic Emissions Inventories



Atmospheric Data Assimilation (ADAS): Meteorological Assimilation

GAAS (AOD Assimilation)

Advection

Hydro-Dynamics

FV Dynamics

Forecast Model

GEOS-5

- Chou/Suarez Radiation
- RAS Convection
- SST/Sea Ice
- Catchment Land
- Prognostic Clouds
- Etc.

Physics

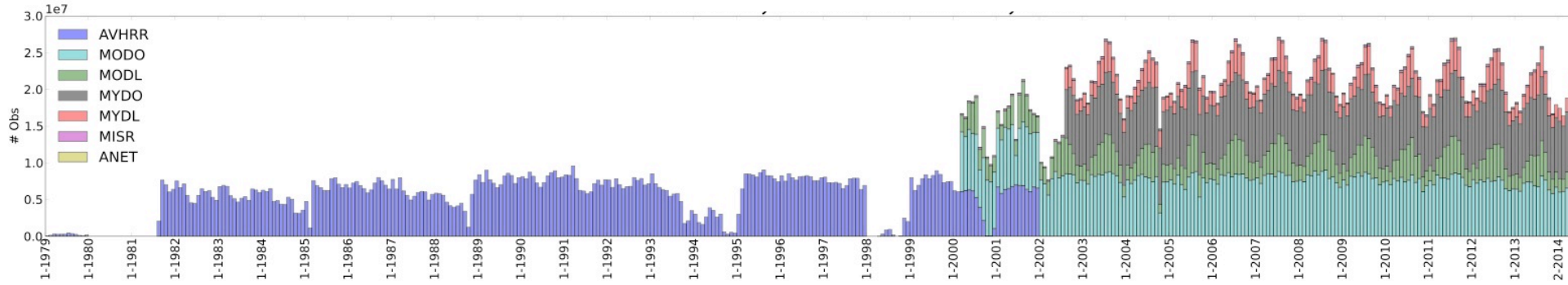
Global, ~50 km, 72 levels, top 0.01 hPa

NASA

MERRA-2: Global AOD Observing System

Sensor	Time Period	Description
AVHRR*	1979 – 2002	PATMOS-x; NNR; Ocean Only
AERONET	1999 – Onward	Ground-based stations
MODIS Terra*	2000 – Onward**	C5; NNR; Separate land & ocean
MODIS Aqua*	2002 – Onward**	C5; NNR; Separate land & ocean
MISR	2000 – Onward	Bright surfaces (albedo > 0.15)

Total Global Monthly Number of AOD Observations (× 10^7) by Sensor



* NNR: QC AOD retrievals from observed reflectance using neural net trained on AERONET

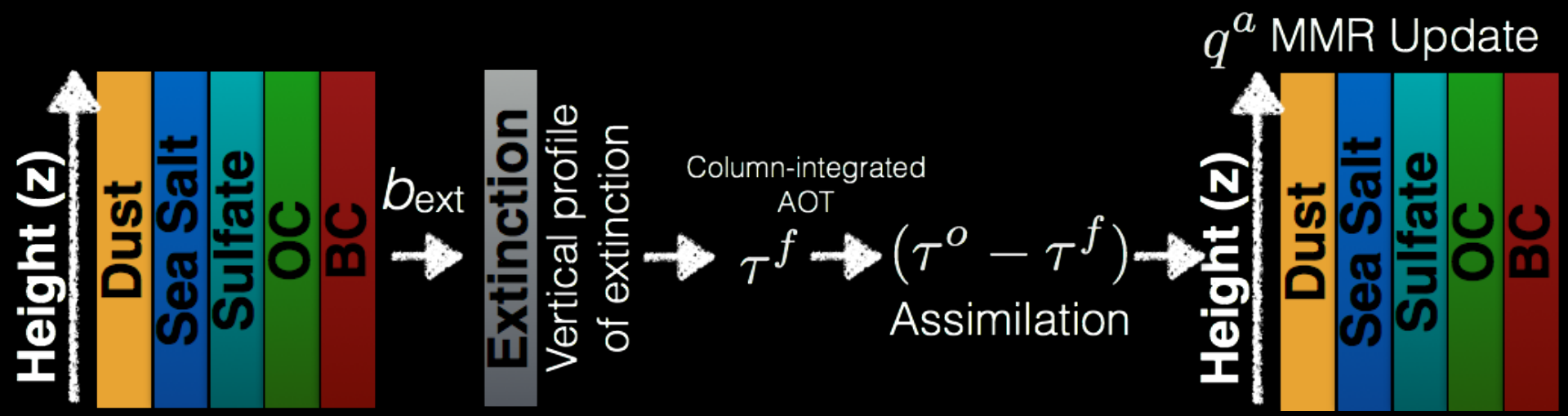
** Available in near real time (NRT)

Aerosol Assimilation: Forecast and Updates/Increments

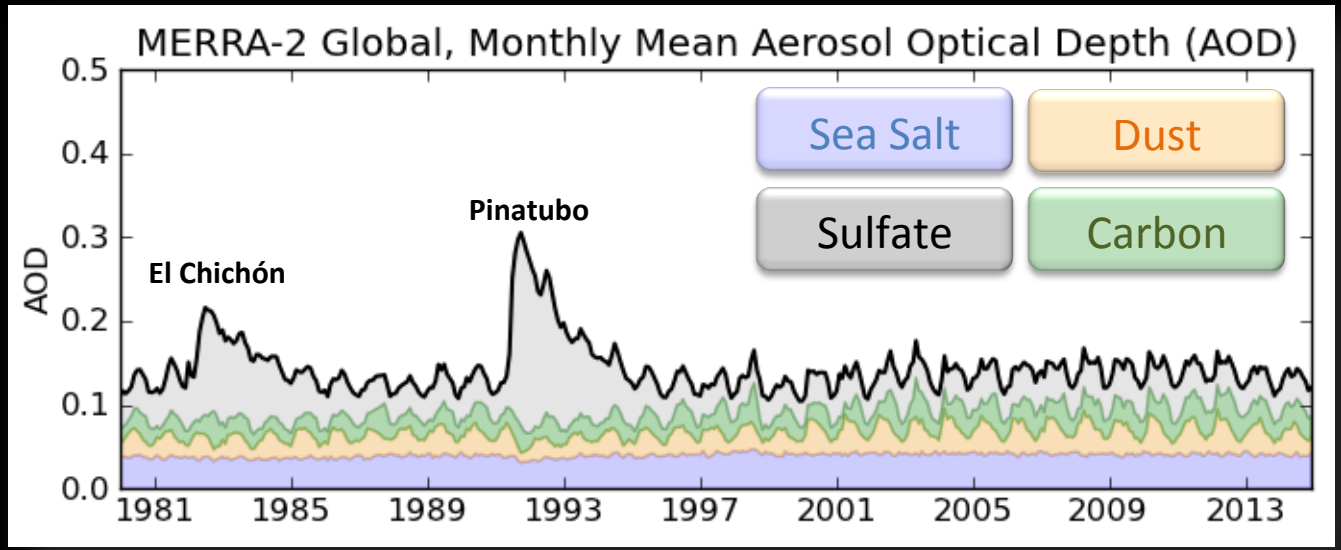
The Aerosol Analysis (every 3 hours) takes 2 steps:

① **2D AOD Analysis:** Observable AOD is two-dimensional and constrains the *total column optics* of aerosol, NOT the aerosol speciation or vertical distribution.

② **Relate analysis increments to 3D aerosol concentrations:** GOCART simulates aerosol *mass*, so AOD analysis increment must be translated from an optical quantity to mass using the relative speciation, vertical distribution, parameterizations *etc.* from the model.



Aerosol Analysis: Global Mean AOD 1980 - Onward

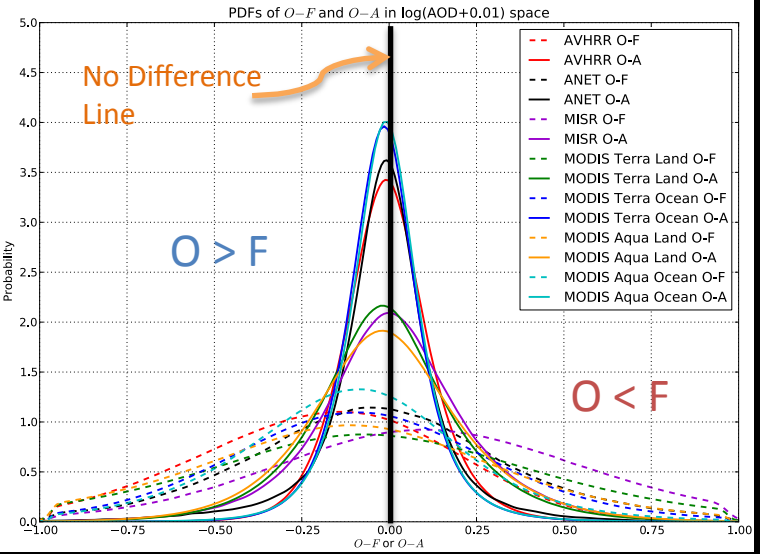


- Unique amongst its peers, the MERRA-2 reanalysis now includes an aerosol reanalysis for the modern satellite era (1980 – onward).
- Aerosols are *coupled* to the meteorological reanalysis (both radiatively and through emissions/loss processes).
- Constrained by observed aerosol optical depth (AOD), MERRA-2 simulates major aerosol events (i.e. volcanic eruptions) as well as the temporal and spatial variability of major aerosol species.

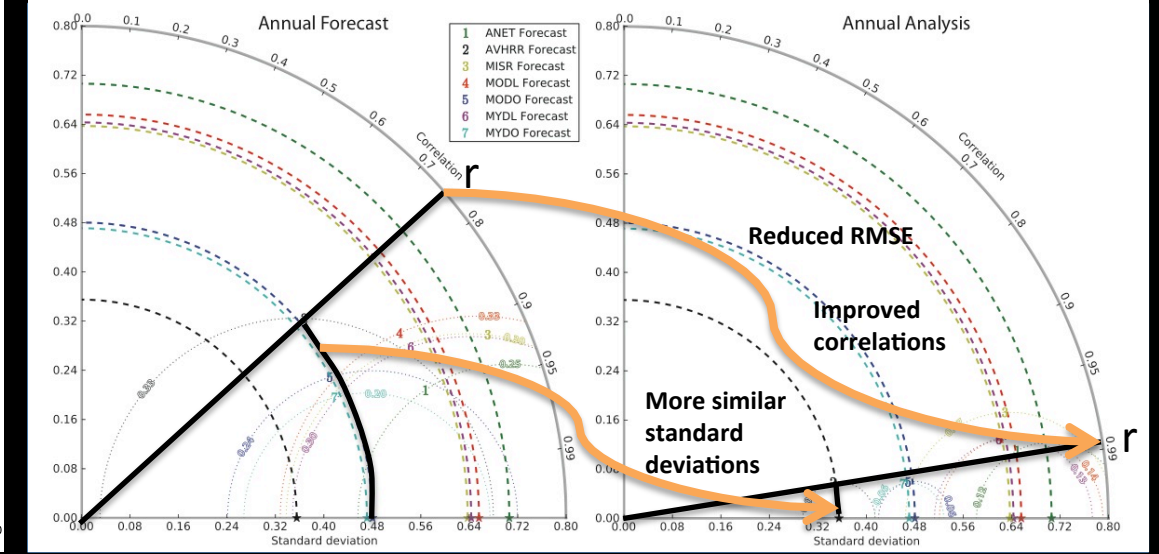
Aerosol Analysis Performance

- The MERRA-2 aerosol analysis performance can be evaluated by examining the differences between the observations and model forecast (O - F) and between the observations and the AOD analysis (O - A).
- Prior to assimilating AOD, co-locating the model and each sensor, the forecast generally underestimates observed AOD; after the assimilation the model bias is reduced.
- For each sensor, Taylor diagrams show improved performance of analysis compared to forecast (standard deviation, correlation, root mean square error).

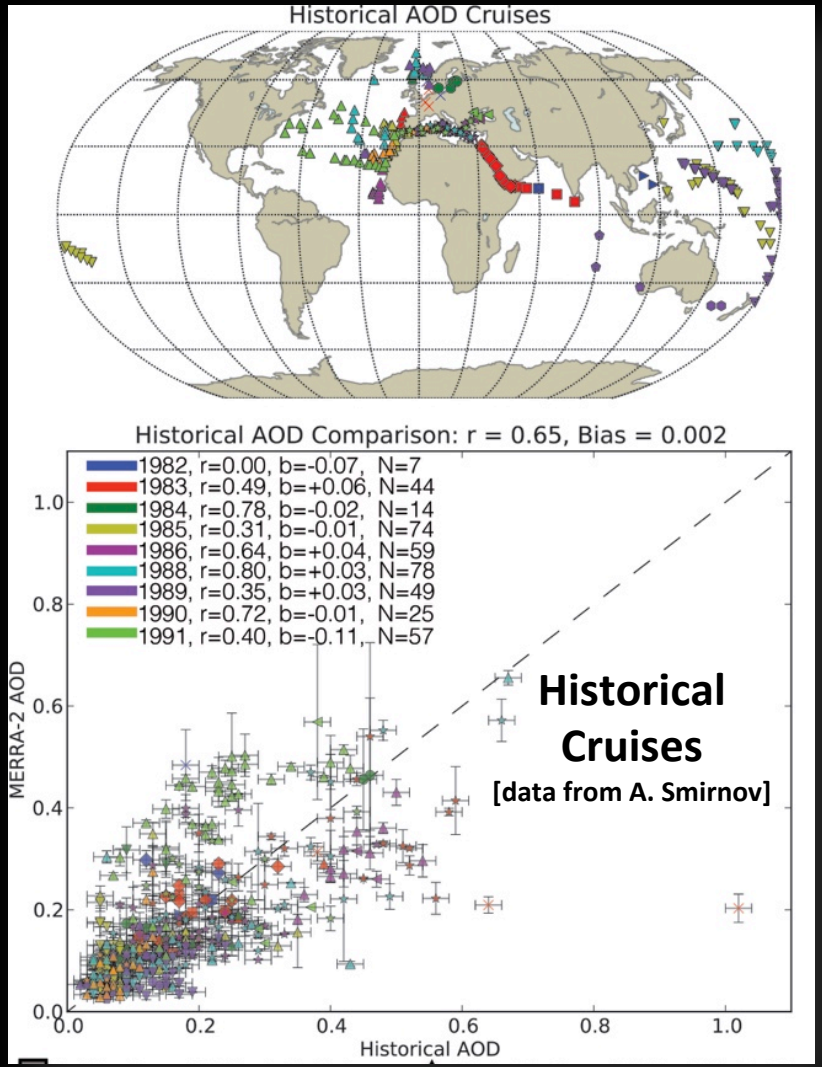
PDFs of *O – F* (dashed) and *O – A* (solid)

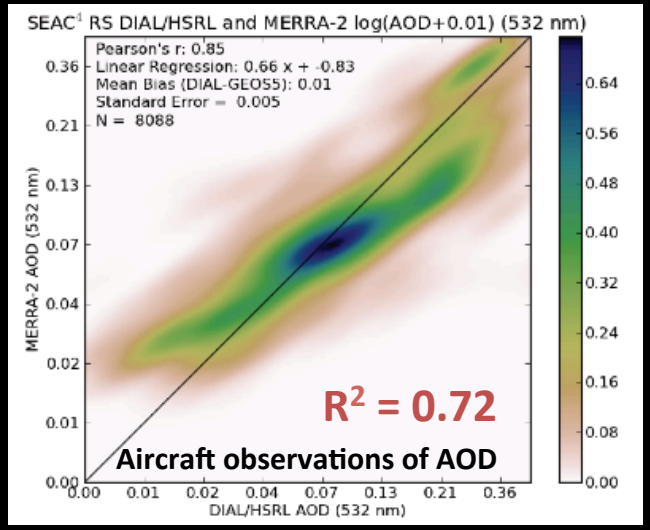


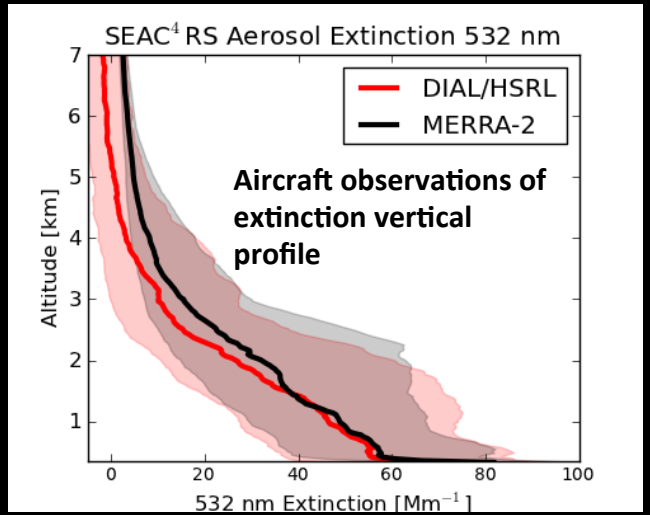
Taylor Diagrams for Forecast (left) and Analysis (right)



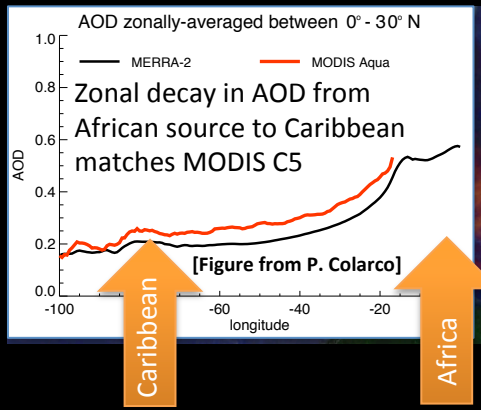
Aerosol Analysis: Independent Verification

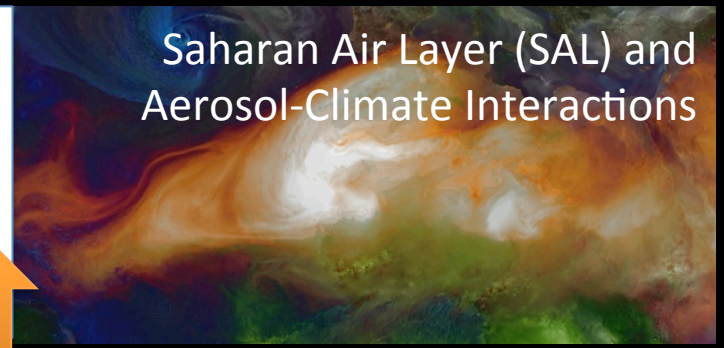


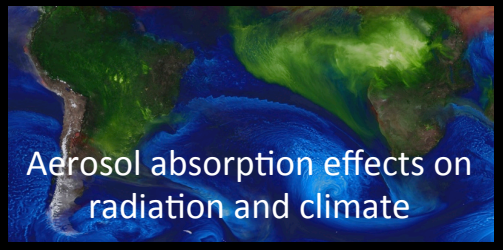


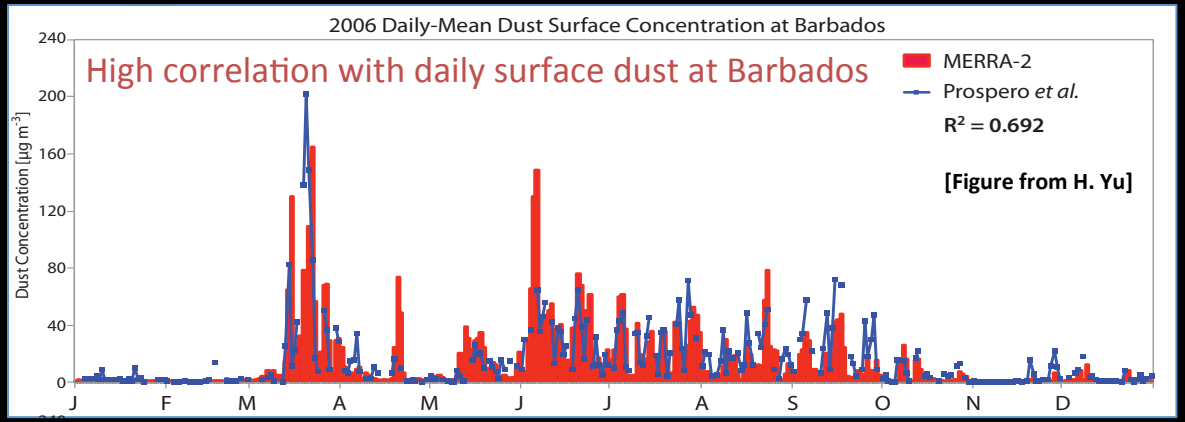


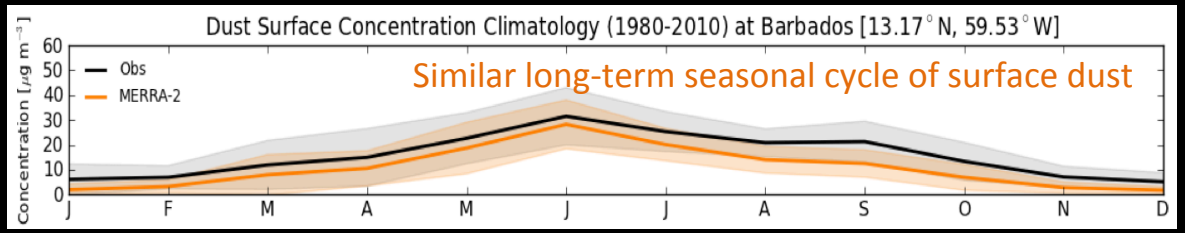
Aerosol Analysis Application: Climate Studies

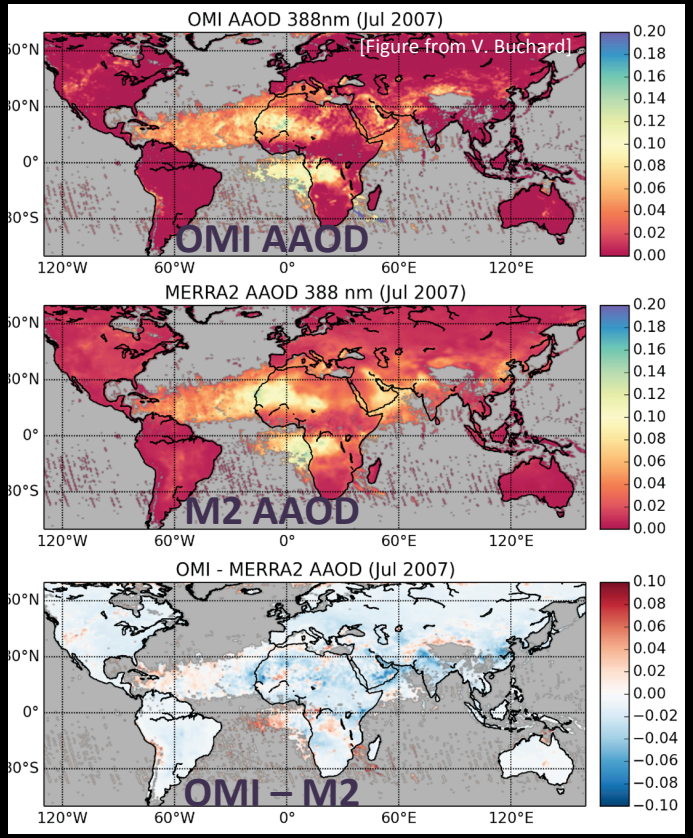




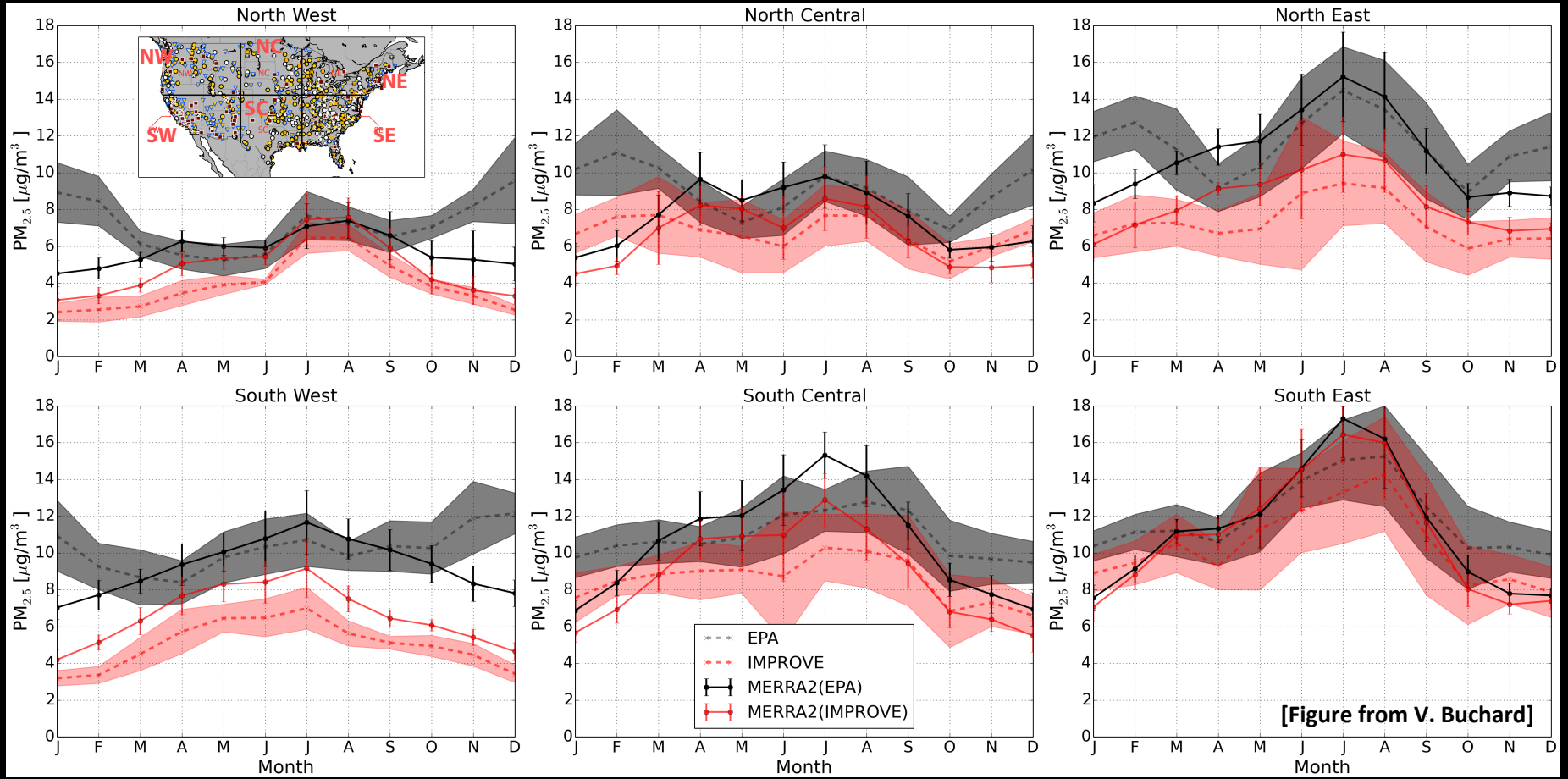






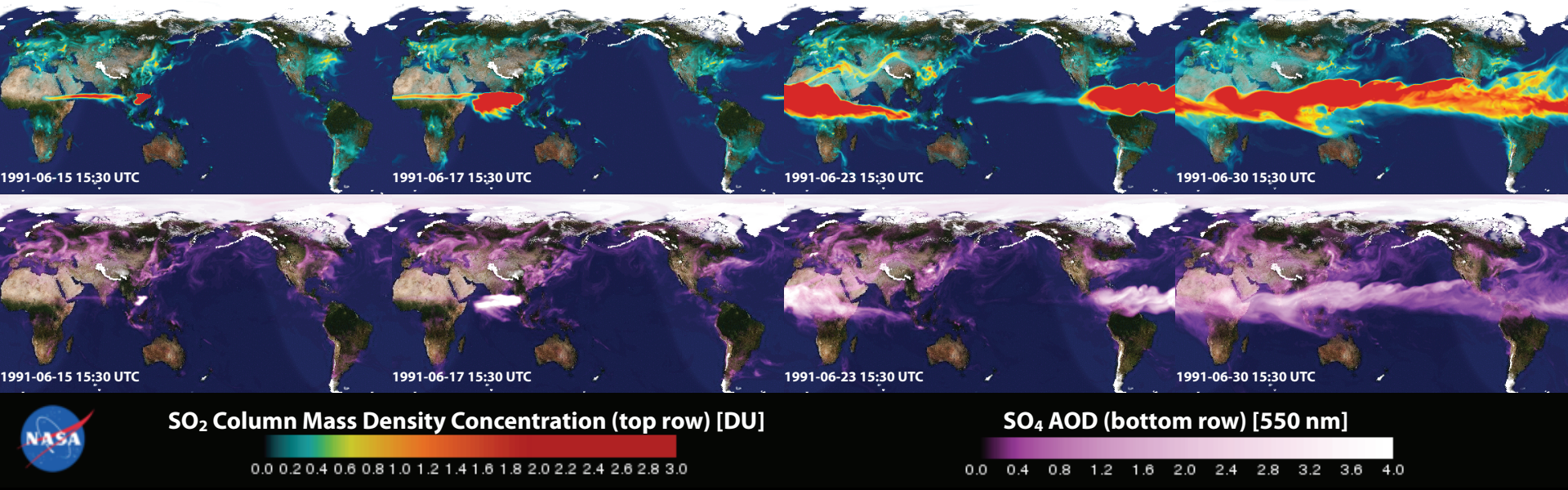


Aerosol Analysis Application: Air Quality (Surface PM2.5)



Good overall agreement with surface PM2.5 Observational Networks in United States

Aerosol Analysis Application: Events (Pinatubo Eruption)



- First aerosol assimilation to include major historic volcanic events like El Chichón (1982) and Pinatubo (June, 1991).
- Movie shows the co-evolution of gaseous SO_2 emissions from Pinatubo (left) and formation of the the sulfate aerosol plume (right) as SO_2 is converted into particles.
- SO_2 (g) is from emissions inventories and unconstrained by assimilation. Sulfate aerosol AOD (right), however, is impacted by the assimilation of total aerosol AOD.

MERRA-2 Production Status

Completed 1980 – present, now running as a continuing climate analysis with 2 – 3 week latency

Office-wide evaluation of MERRA-2 has been completed, with Tech Memos and refereed publications *in preparation*

File specification: http://gmao.gsfc.nasa.gov/pubs/office_notes/

Data released via the NASA Goddard Earth Sciences (GES) Data Information Services Center (DISC)

- **1-hourly surface and 2D fields**
- **3-hourly and 6-hourly 3D fields**
- **Daily Products ~25 GB/day** (9.1 TB/yr)
- **Monthly Products ~34 GB/mo** (408 GB/yr)