



Near Real-Time Sub/Seasonal Prediction of Aerosol at NASA Global Modeling and Assimilation Office

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Near Real-Time Sub/Seasonal Prediction of Aerosol at GMAO

- **Global Modeling and Assimilation Office – scope of activities, focus on sub/seasonal prediction**
- **Sub/Seasonal Prediction – sources of predictability and skill**
- **Why interactive aerosol?**
- **GMAO aerosol forecasts: Bias and skill of AOD, PM2.5**
- **Future Plans (hint: fire prediction model!)**



Major Activities in GMAO: from Research to Products

Weather Analysis and Prediction

Seasonal-to-Decadal Analysis and Prediction

Reanalysis

Global Multiscale Modeling

Observing System Science

- These (non-orthogonal) themes span GMAO's main activities
- Guiding principle: NASA's Earth Observations (use, support, planning).
- Overall intent: to demonstrate added value of NASA's unique observations for weather analysis and prediction, reanalysis, and subseasonal-to-seasonal prediction.
- All themes include multiple elements of the Earth System



GMAO uses coupled Earth-System models and analyses, in conjunction with satellite and *in situ* observations, to study and predict phenomena that evolve on seasonal to decadal timescales. A central motivation for GMAO is the innovative use of NASA satellite data to improve forecast skill

- **Atmosphere/Ocean Coupled Model Development**
- **Ocean Analysis Development**
- **Development of Initialization Strategy for ensembles of Sub/Seasonal Forecasts**
- **Coupled Assimilation Strategy Development**

- **Production of Coupled Data Assimilation (Re)Analysis**
- **Production of Sub/Seasonal Forecasts**
- **Dissemination of Sub/Seasonal Forecasts**

- **Validation/Assessment of Forecast Fidelity**
- **Validation/Assessment of Assimilated Ocean State**

- **Predictability Studies**



GMAO's Near Real-Time Sub/Seasonal Prediction Suite

GMAO's GEOS S2S coupled Ocean Data Assimilation system runs in near real time and is used to initialize our sub/seasonal forecasts. Results are generally examined in terms of anomaly from some climatology, derived from a series of retrospective forecasts.

	Subseasonal	Seasonal
Length of Forecast	45 days	9-12 months
Frequency of forecasts	Every 5 days	Every 5 days
Number of Ensembles	4 per start date	Total of 10 per month
Frequency of submission	Once per week	Once per month
Availability	~3 days after real time	Once per month
Initial Conditions from	GEOS ODAS	GEOS ODAS
Retrospective forecasts	1999-2016	1981-2016

File Specification: <https://gmao.gsfc.nasa.gov/pubs/docs/Nakada1033.pdf>



Current Seasonal Prediction System - GEOS S2S Version 2

Model

- AGCM: Post MERRA-2 generation, cubed sphere grid at $\sim 0.5^\circ$, 72 hybrid sigma/pressure levels; **GOART interactive aerosol model**, cloud indirect effect (2-moment cloud microphysics); MERRA-2 generation cryosphere;
- OGCM: MOM5, $\sim 0.5^\circ$, 40 levels;
- Sea Ice: CICE-4.0.

Coupled Ocean Data Assimilation System

- atmosphere is “replayed” to “FPIT” (like MERRA-2); precipitation correction over land;
- NCEP-like LETKF code/system, with static statistics as in Ensemble OI;
- Forecasts: initialized from ODAS, perturbations from analysis differences;
- Retrospective forecasts: re-initialized from 5-day run of ODAS, perturbations from analysis differences;

Observations

- nudging of SST and sea ice fraction from MERRA-2 boundary conditions;
- assimilation of *in situ* Tz and Sz including Argo, XBT, CTD, tropical moorings;
- assimilation of satellite along-track ADT (Jason, Saral, ERS, GEOSAT, HY-2A, CryoSat-2);
- sea ice concentration from the National Snow and Ice Data Center (NSIDC).

A Word (or Two) about Seasonal Prediction

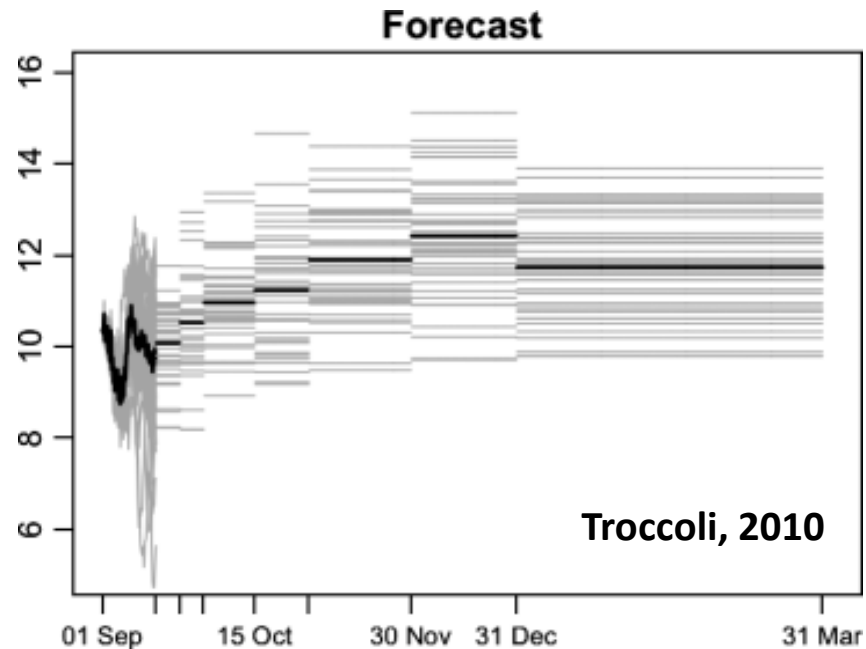
What is predictable at Seasonal Lead Times?

- **Time averages**
- **Spatial averages**
- **Probabilistic Measures (PDFs)**

Ensemble forecasts needed to predict PDFs, must assess reliability

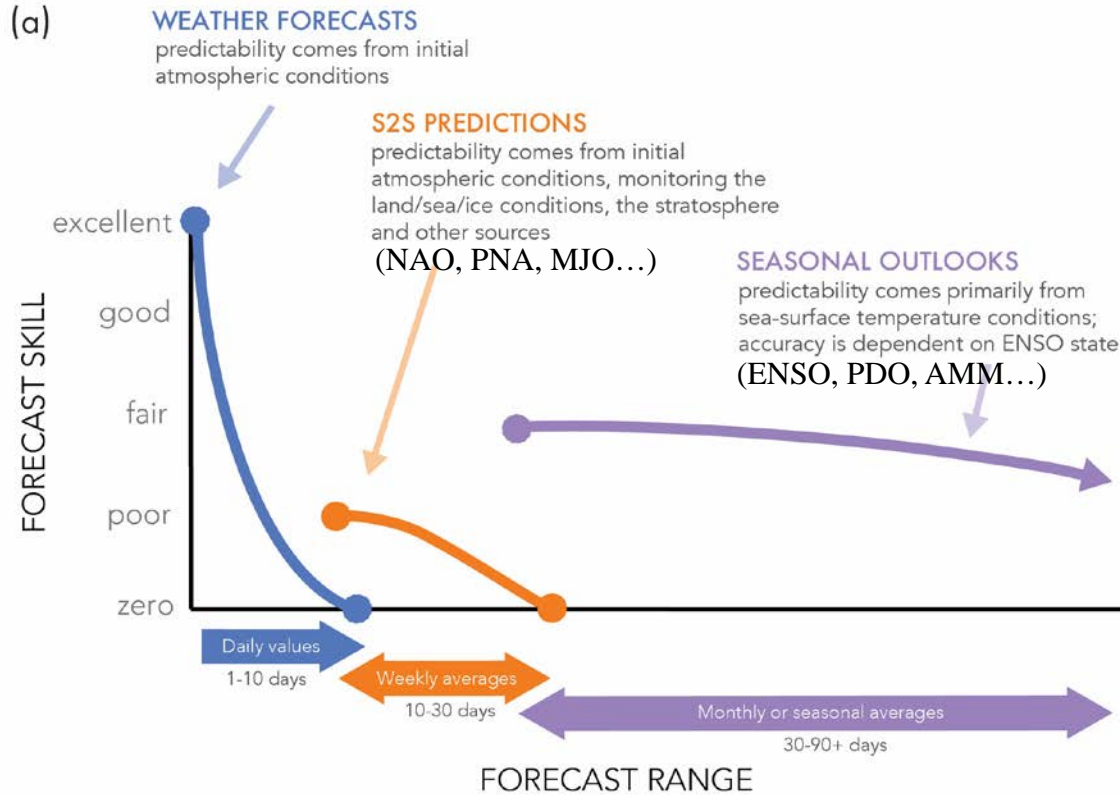
Forecasts require calibration, or removal of mean bias or of mean bias and variance (standardization). For this we need reforecasts. Calibrated forecasts are more reliable.

Multi model ensembles help (Krishnamurti et al., 1999; Palmer et al., 2004) skill, but not clear why. It does reduce overconfidence.



The longer the lead time, the longer the period of time average needed. This increases the signal to noise ratio enough to obtain reliable forecasts.

A Word (or Two) about Seasonal Prediction



<https://www.weadapt.org>



A Word (or Two) about Seasonal Prediction

The issues related to seasonal prediction (of aerosol, constituents, air quality):

What exactly is predictable/being predicted?

Bias/drift – Will impact the skill of a forecast

Anomaly Correlation – The critical metric for assessing the skill of a forecast. Will next month/seasonal be characterized by higher/lower than “normal” conditions? How much? With what probability?

AOD vs PM2.5 – AOD is better initialized, PM2.5 more useful

Other possible options for air quality:

Example: The number of exceedance days in a month/season (need full chemistry or CTM driven with seasonal forecast meteorology)



Why Interactive Aerosol Model?

- There may be more useful skill in AOD/PM2.5 seasonal forecasts than from a statistical model or climatology (Benedetti and Vitart, 2018 for AOD)
- May increase weather/subseasonal skill under certain conditions (forecasts of opportunity) such as the impact of dust on tropical cyclone development. (eg., Reale et al., 2011 using GMAO NWP system)
- May increase seasonal skill in the aftermath of a large volcanic event (eg., Aquila et al 2019 using GMAO-S2S-2 system).
- May increase subseasonal forecast skill (Benedetti and Vitart, 2018)
- Postulated to have an impact on decadal prediction skill (Bellucci et al., 2015)



Community Activity/Interest in Interactive Aerosol Models

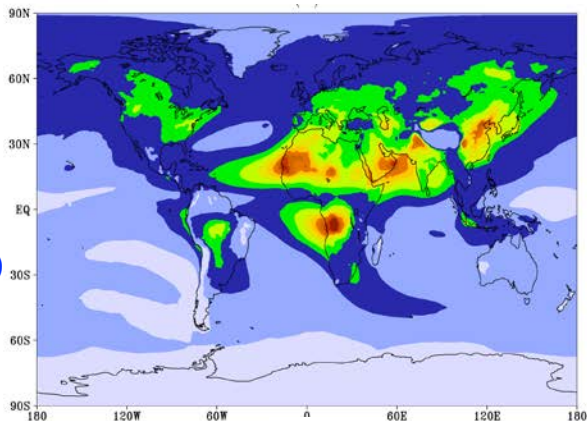
WGNE-S2S-GAW (WCRP Working Group on Numerical Experimentation-Subseasonal to Seasonal Project-Global Atmospheric Watch) Phase 2 will ask models to run retrospective forecasts with interactive aerosols. GMAO will participate.

GMAO is the only model participating in either NMME or SubX or WCRP S2S (ie., near real-time forecasts on sub/seasonal scale) that has been running with interactive aerosol model and 2-moment microphysics that includes the direct, semi-direct and indirect aerosol effect.

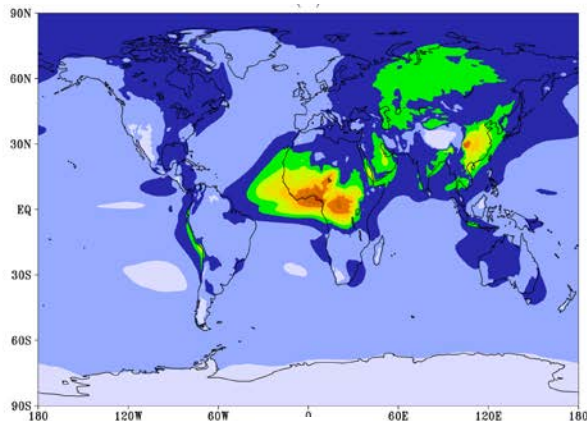
A few other groups (ECMWF) have run retrospective forecasts to assess the impact of an interactive aerosol model on sub/seasonal forecasts, but include the direct effect only, no semi- or indirect.

Bias: Aerosol Optical Depth (2000-2015)

**GEOS-S2S-2
(1-month lead)**

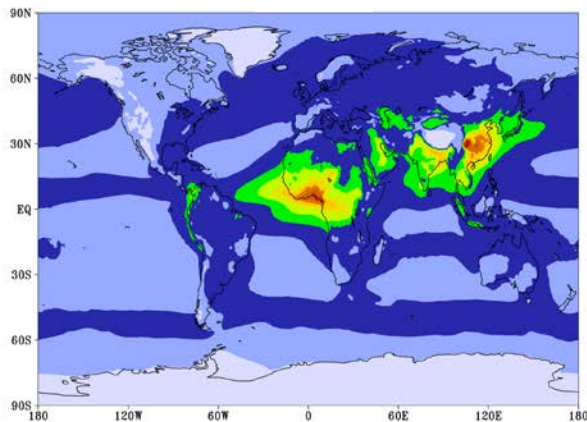
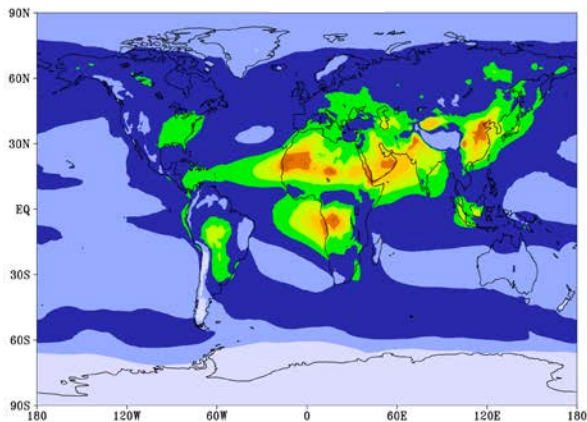


JAS

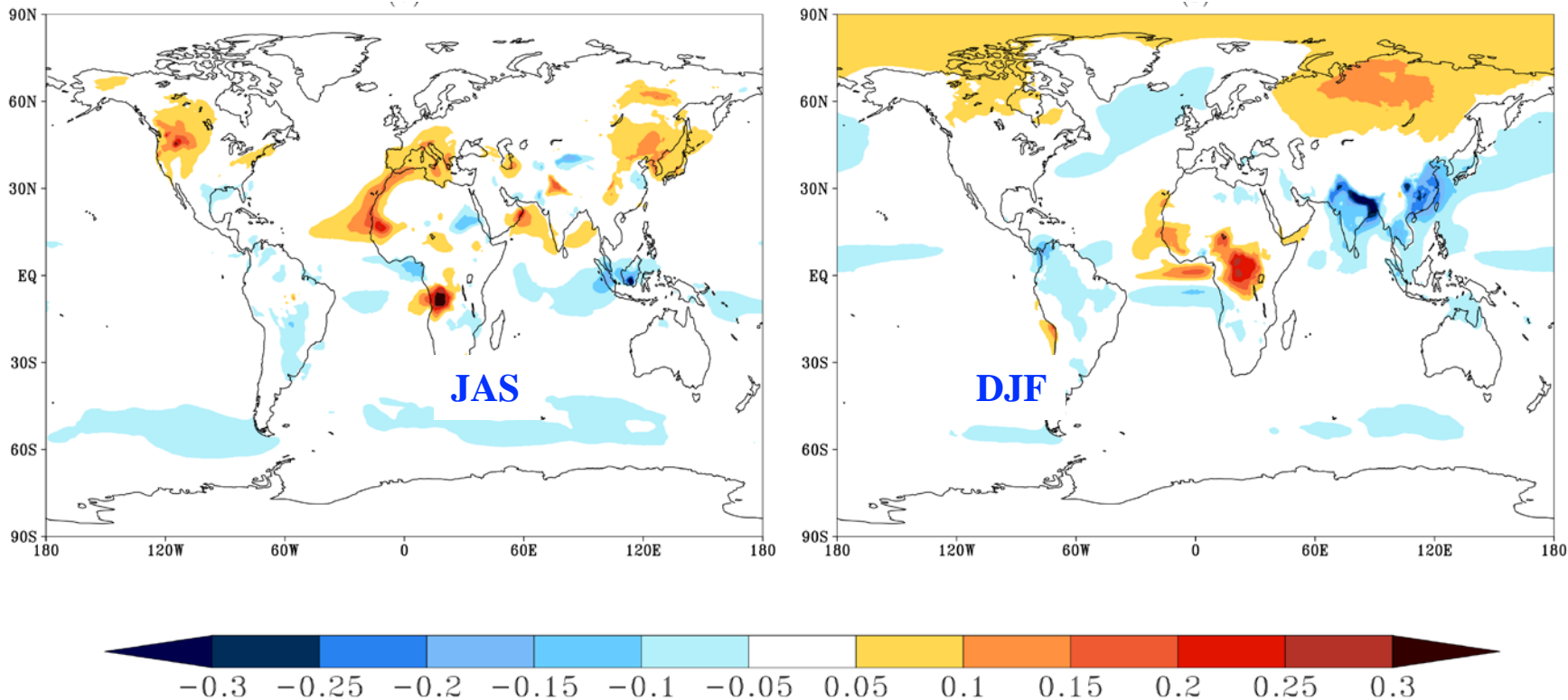


DJF

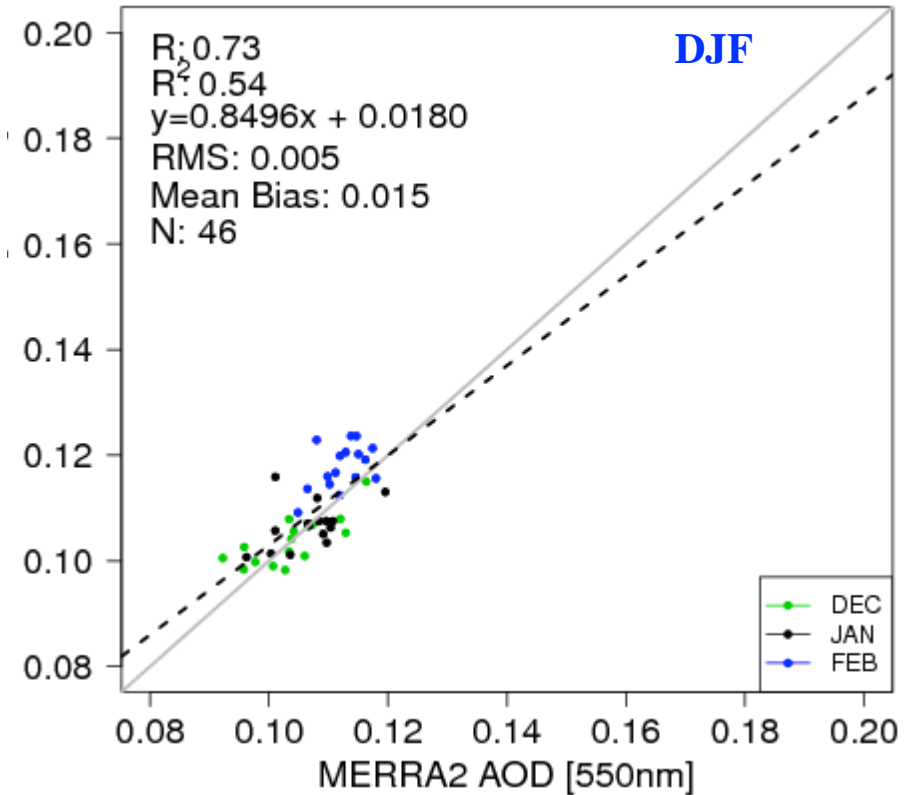
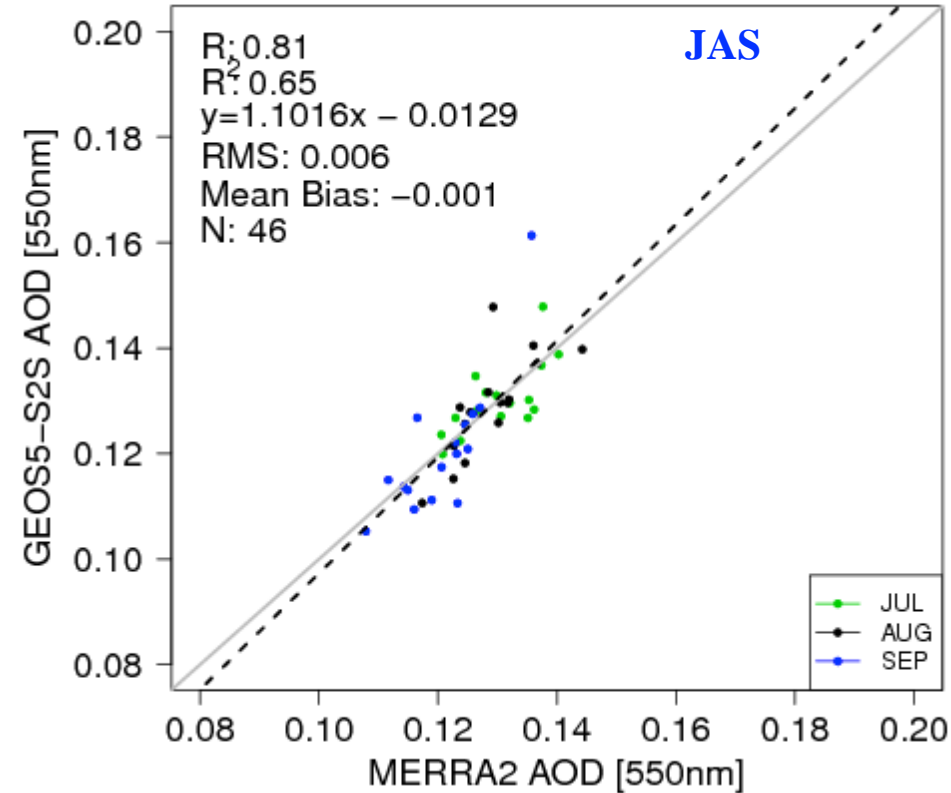
MERRA-2



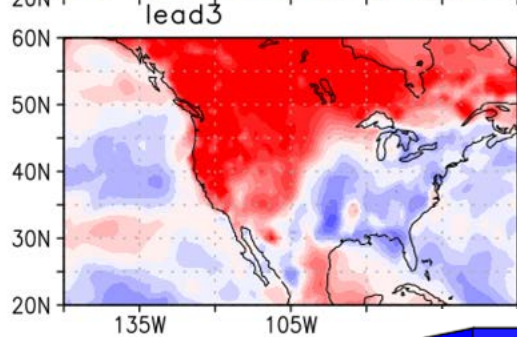
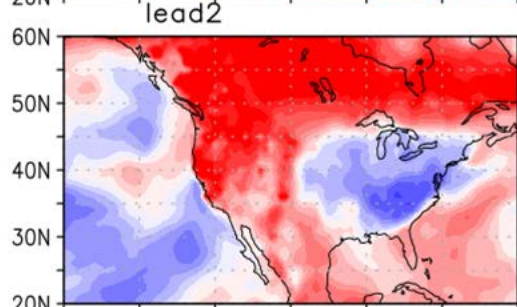
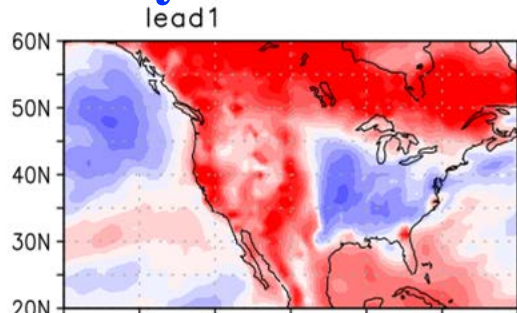
Bias: Aerosol Optical Depth difference (GEOS-S2S-2 – MERRA-2)



Bias and RMS: Global Mean Aerosol Optical Depth (2000-2015)



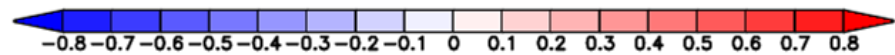
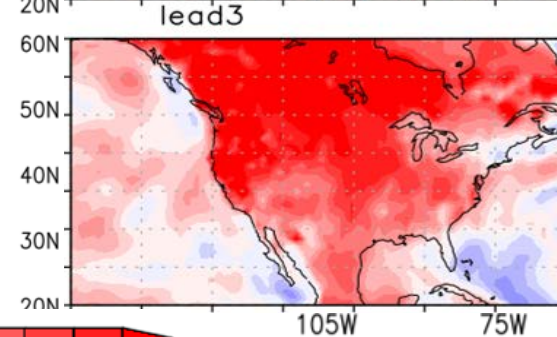
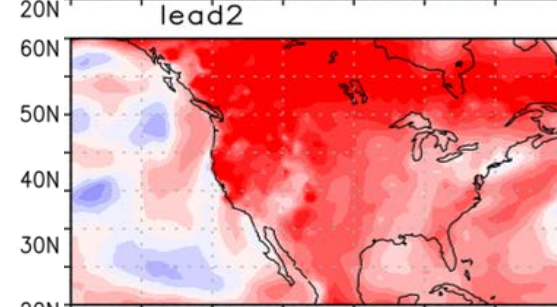
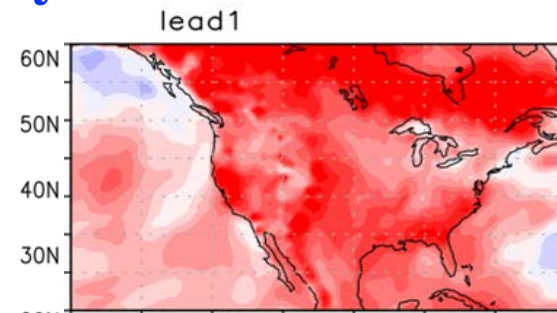
Anomaly Correlation (AC) : PM2.5 from May initial conditions



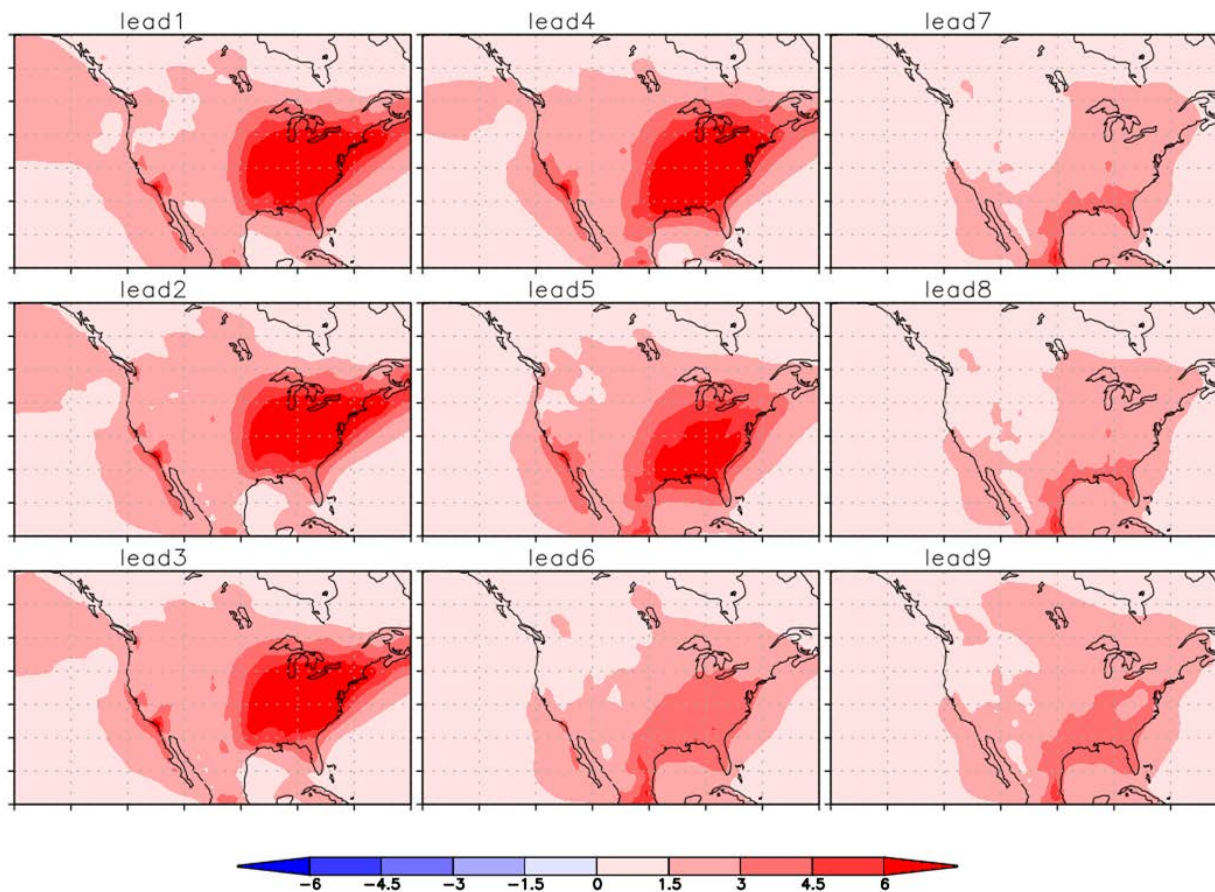
**“Naive” calculation of AC:
AC (sum of components of
PM2.5)**



**Recompute AC:
Remove SO₄ from PM2.5**

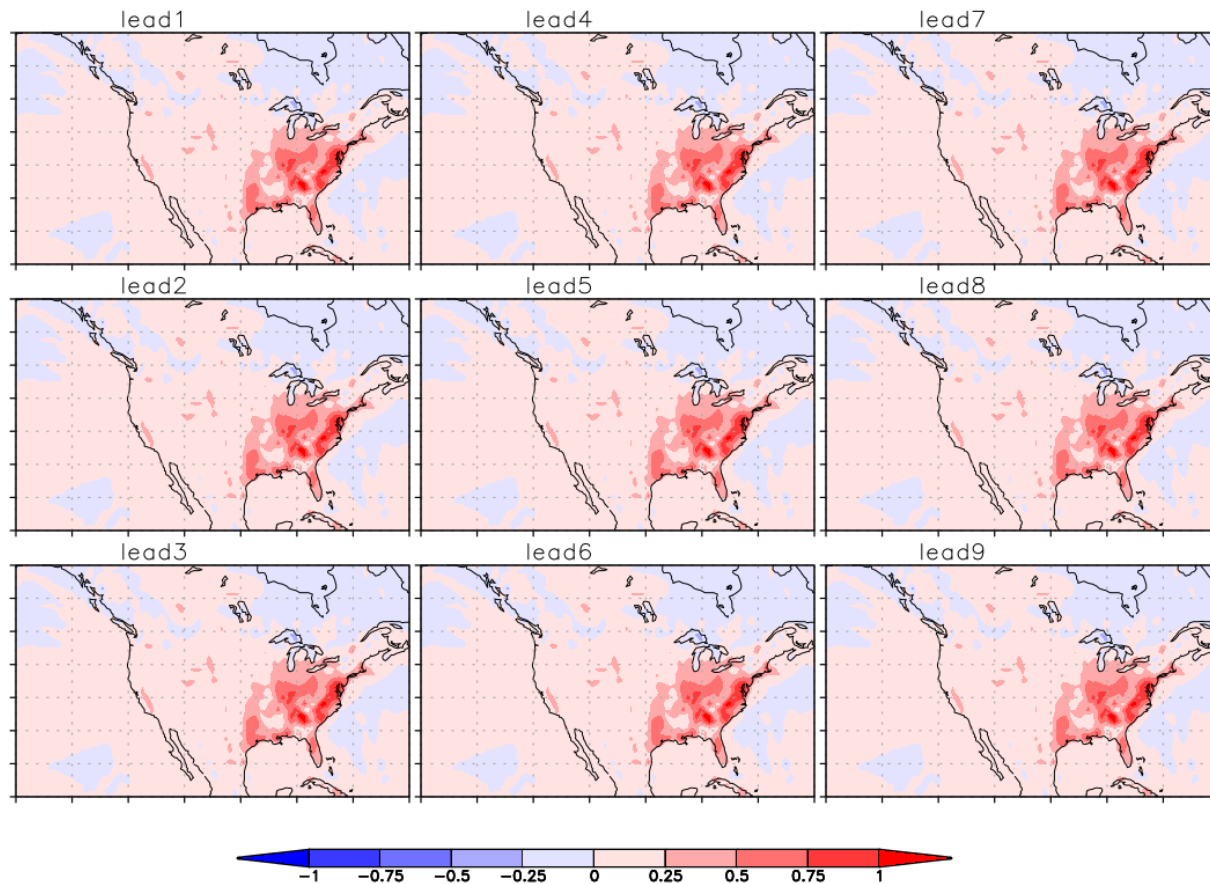


SO₄ Bias relative to MERRA-2



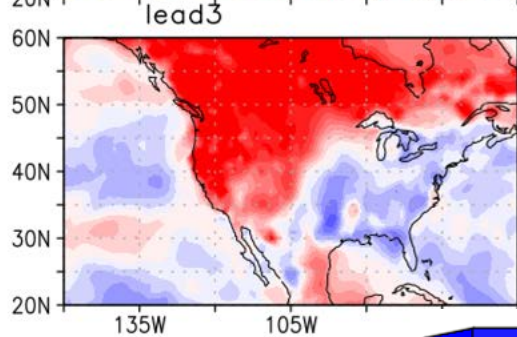
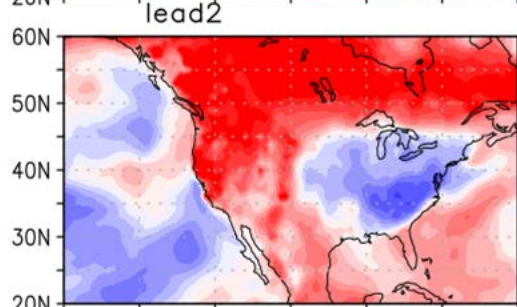
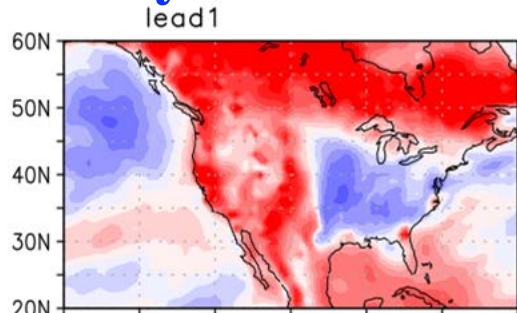
Systematic excess of SO₄ in seasonal forecast relative to MERRA-2 “overwhelms” the Anomaly Correlation, SO₄ anomaly dominates

SO₄ Bias and In-cloud Production



Systematic excess of SO₄ is due to an excess of in-cloud aqueous production (cloud fraction higher than in MERRA-2)

Anomaly Correlation (AC) : PM2.5 from May initial conditions



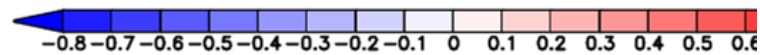
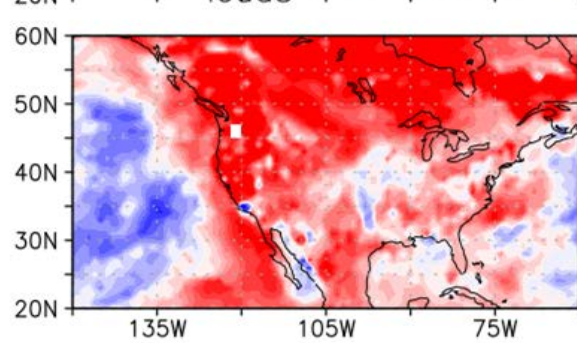
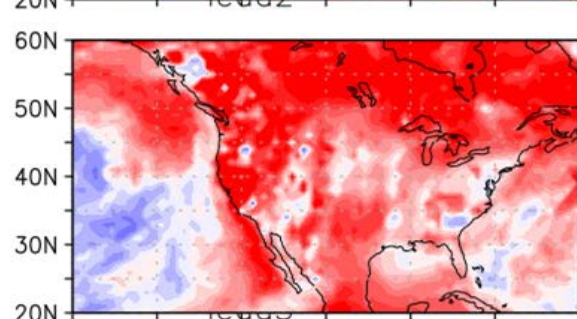
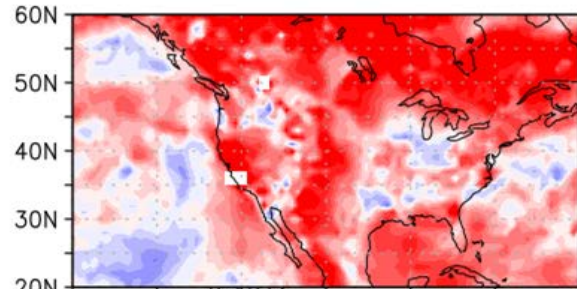
“Naïve” calculation of AC:

AC (sum of components of PM2.5)



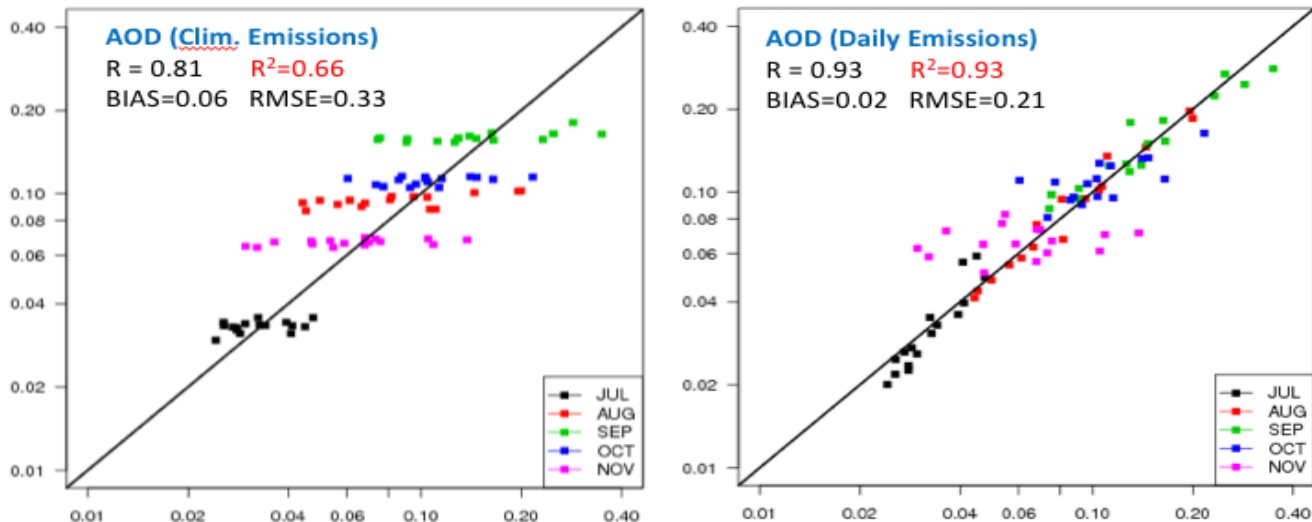
**Recompute AC:
Sum of AC of all
components**

**Must compute PM2.5
anomaly this way for skillful
forecast**



Impact of Fire Emissions on Seasonal AOD Hindcasts

Regionally averaged AOD skill in S. America (2000-2015)



Skill critically dependent on skill of biomass burning emissions, climatological emissions not adequate for predicting interannual variability of AOD. Interannual variability of transport/removal processes are second order

Predictive biomass burning algorithm needed for skillfull seasonal AOD forecast



Summary

- **Dynamical predictions of PM_{2.5} on sub/seasonal scale can be skillful**
- **Bias in one component of PM_{2.5} can adversely impact skill if care is not taken to provide the proper forecast**
- **Predictive biomass burning model is needed**
- **Future work: Assessment of impact of interactive aerosol model on meteorological forecast skill, and to identify “forecasts of opportunity”**