

GEOS-5 Aerosol Modeling & Data Assimilation: *Update on Recent and Future Development*

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(1) Global Modeling and Assimilation Office, NASA/GSFC

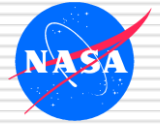
(2) Atmospheric Chemistry and Dynamics Branch, NASA/GSFC

(3) GESTAR

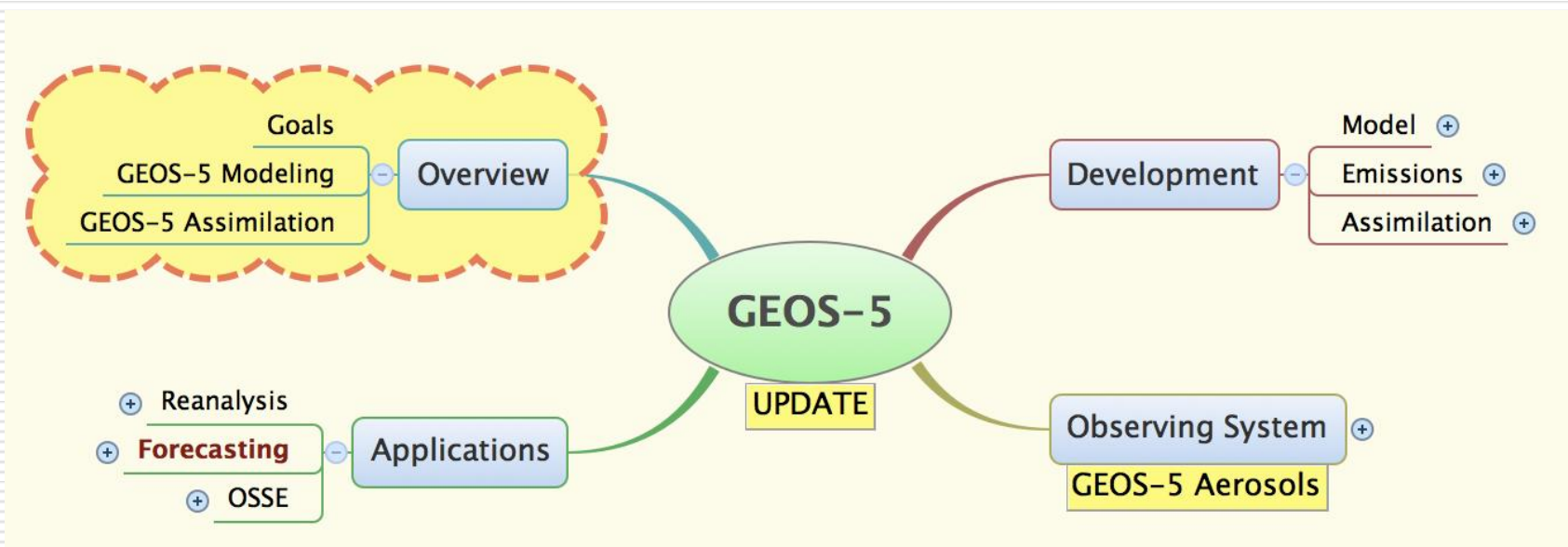
(4) Science Applications International Corp.

(5) Earth Resource Technology

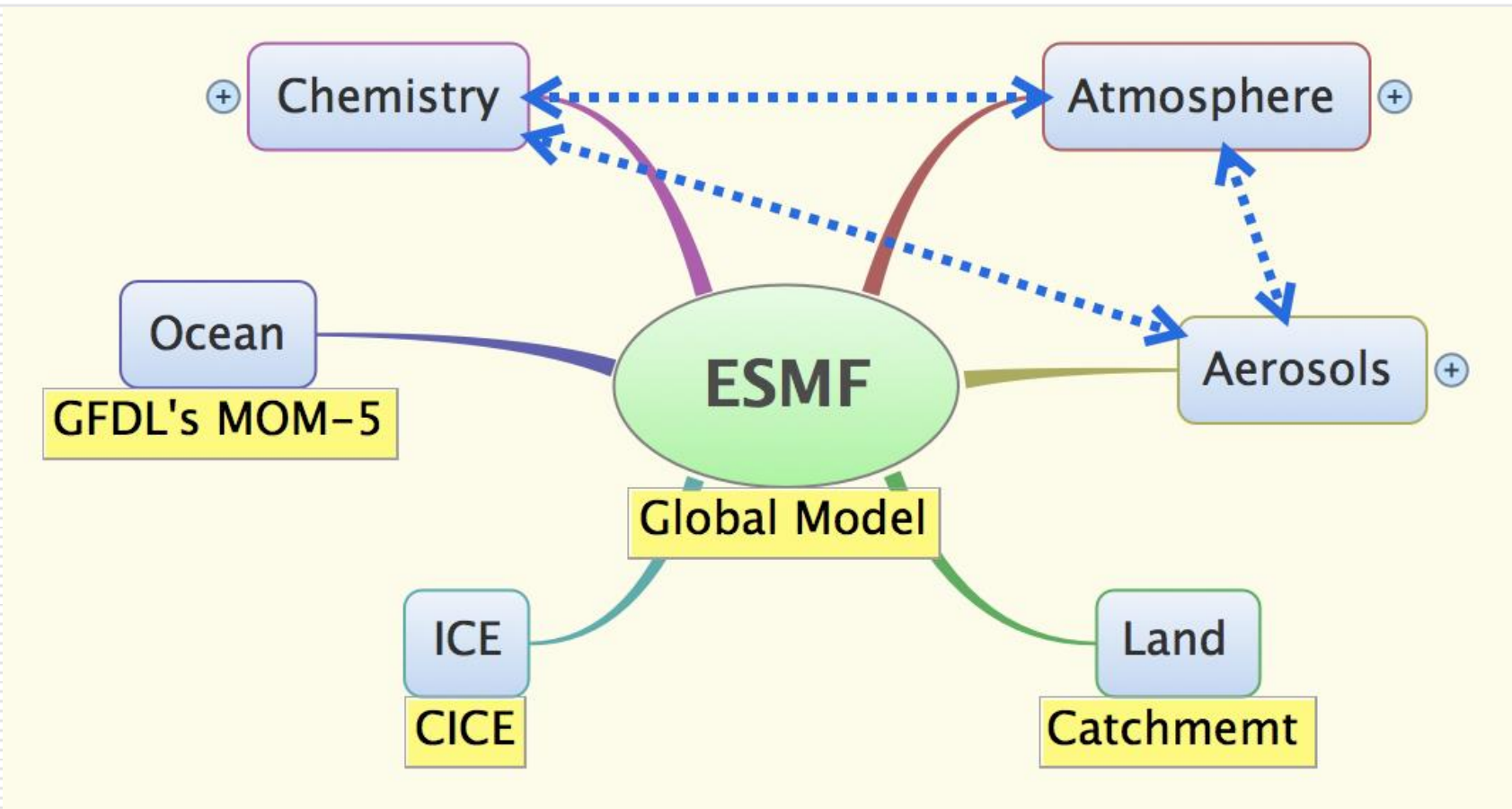
*ICAP 5th Working Group Meeting
Tsukuba, Japan
5-8 November 2013*



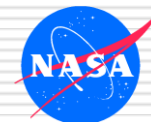
Outline



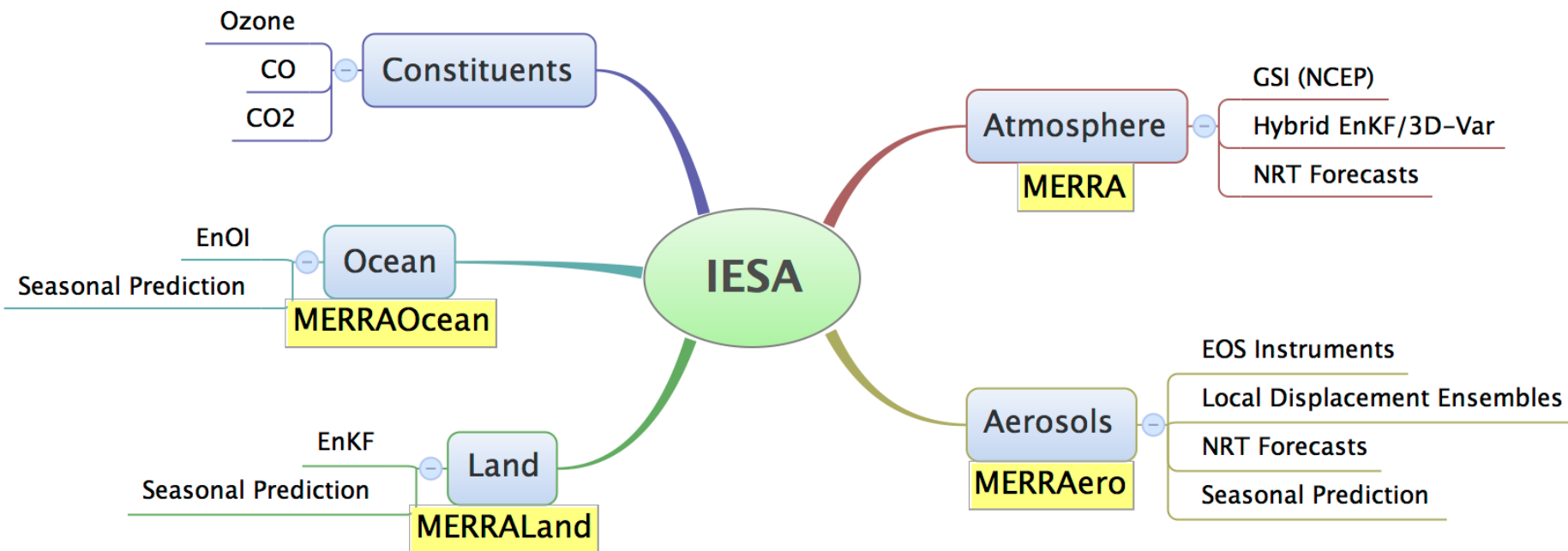
GEOS-5 Earth System Model



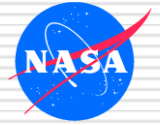
From weather to seasonal to decadal time scales



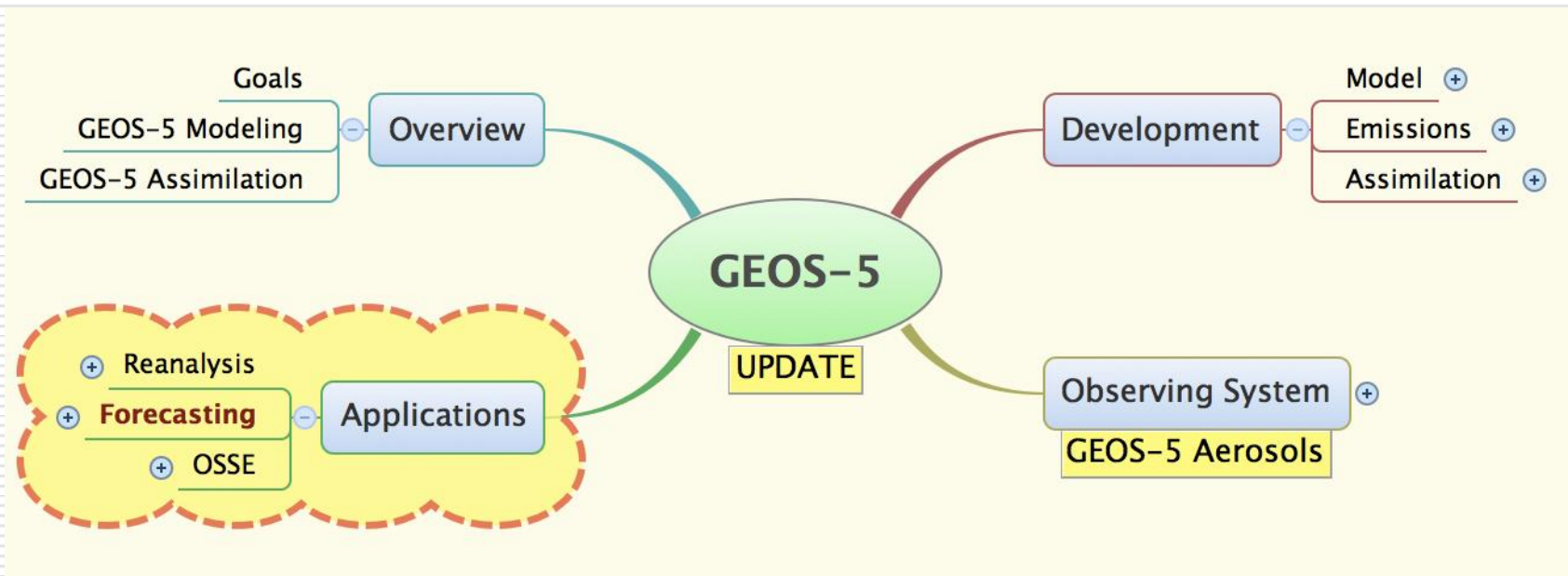
Integrated Earth System Analysis



Data Assimilation in GEOS-5



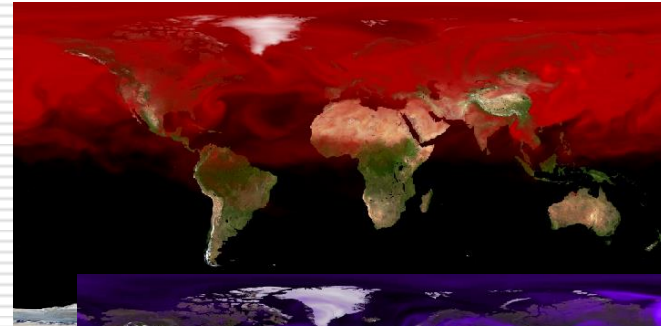
Applications



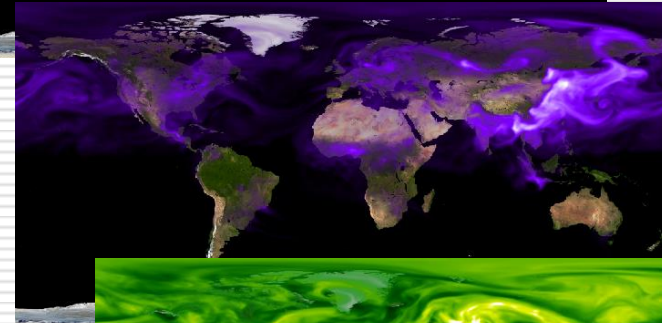
GEOS-5 Forecasting Support

DISCOVER-AQ

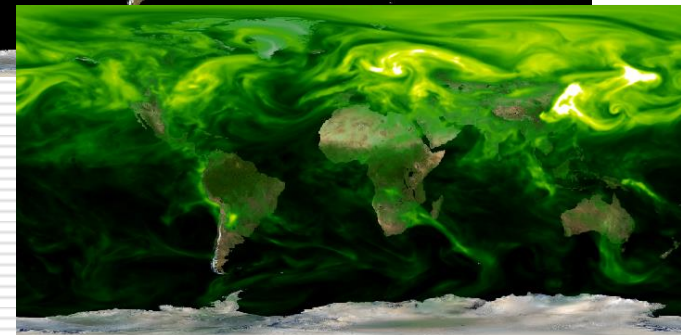
- Global 5-day chemical forecasts customized for each campaign
 - O₃, aerosols, CO, CO₂, SO₂
 - Resolution: **Nominally 25 km**
- Driven by real-time biomass emissions from MODIS
- Assimilated aerosols interacts with circulation through radiation



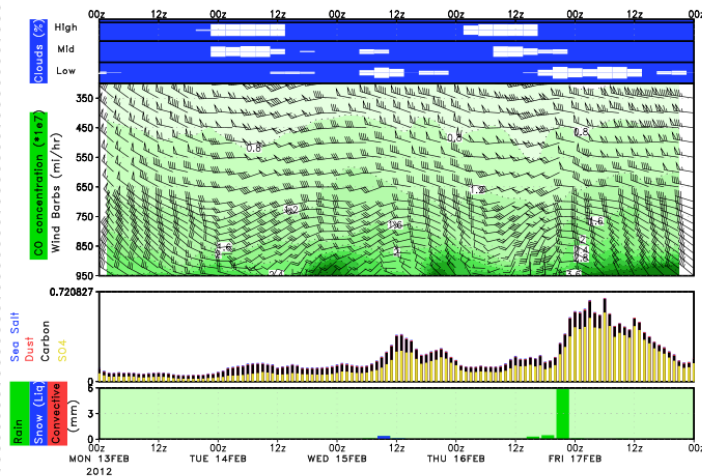
CO



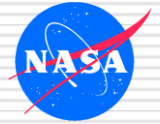
Smoke



SO₄



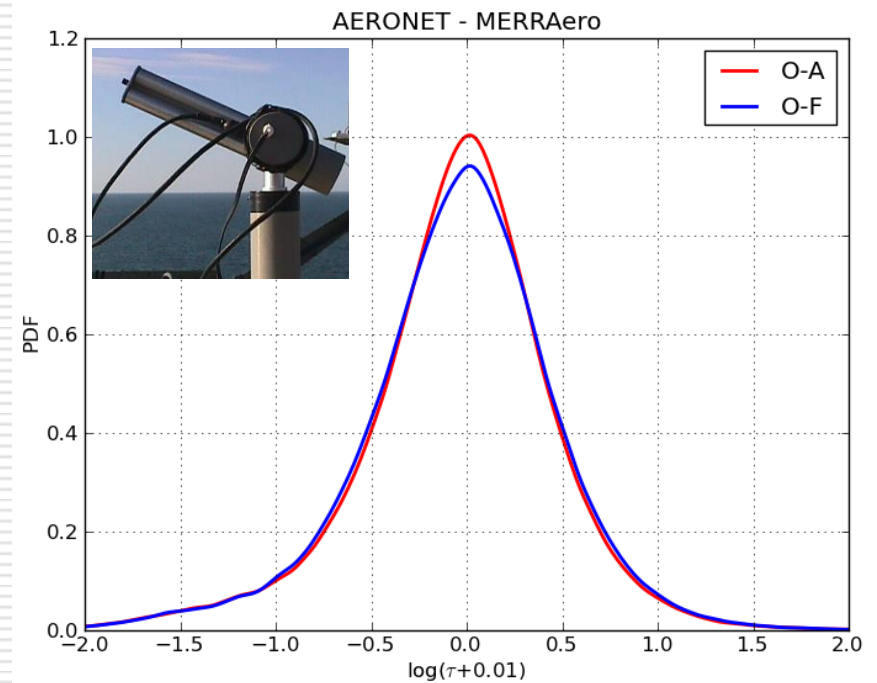
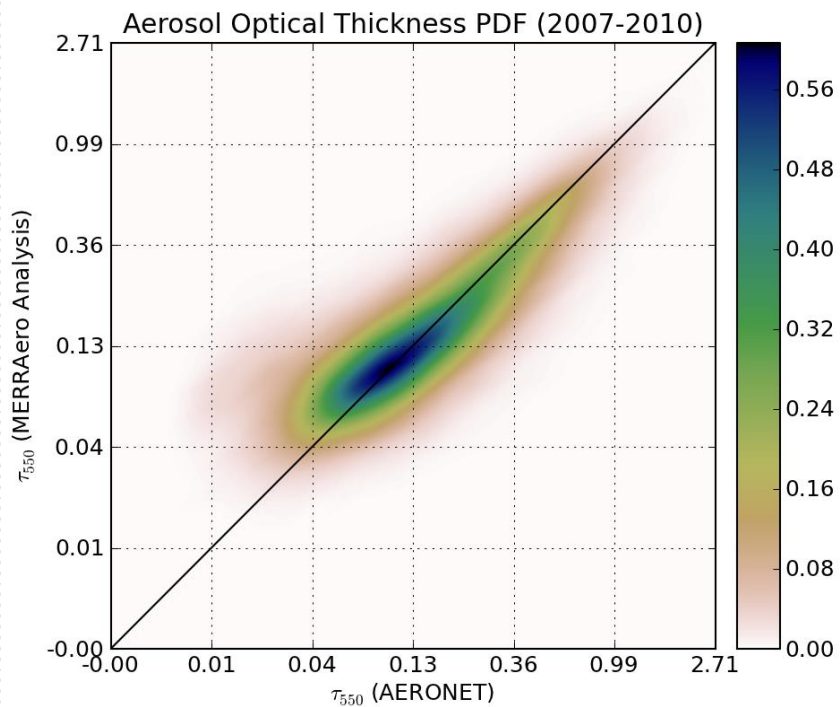
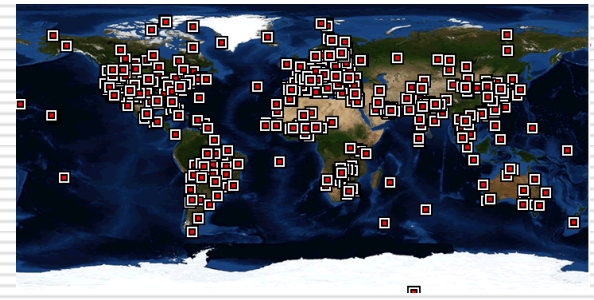
<http://gmao.gsfc.nasa.gov/forecasts/>



GEOS-5 Reanalysis Activities

Name	Nominal Resolution	Period	Aerosol Data	Available
MERRA-1	50 km	1979-present	NONE	now
MERRAero	50 km	2002-present	MODIS C5	now
FP for Inst. Teams	50 km	1997-	MODIS C5	In progress
NCA	25 km	2010-11	MODIS C5, MISR	Now
MERRA-2	50 km	1979-present	AVHRR, MODIS C5, MISR	Q2 2014

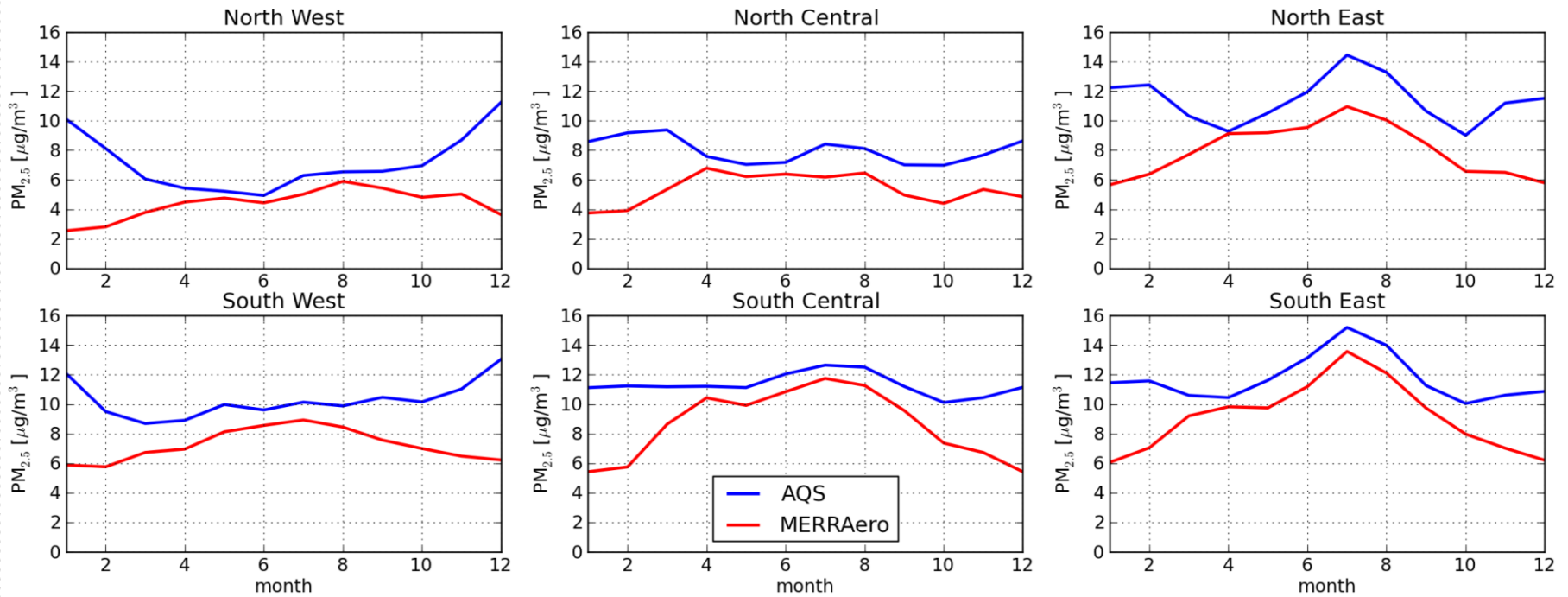
AERONET MERRAero Validation



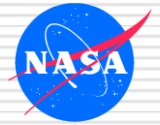
$$h = \log(t + 0.01)$$



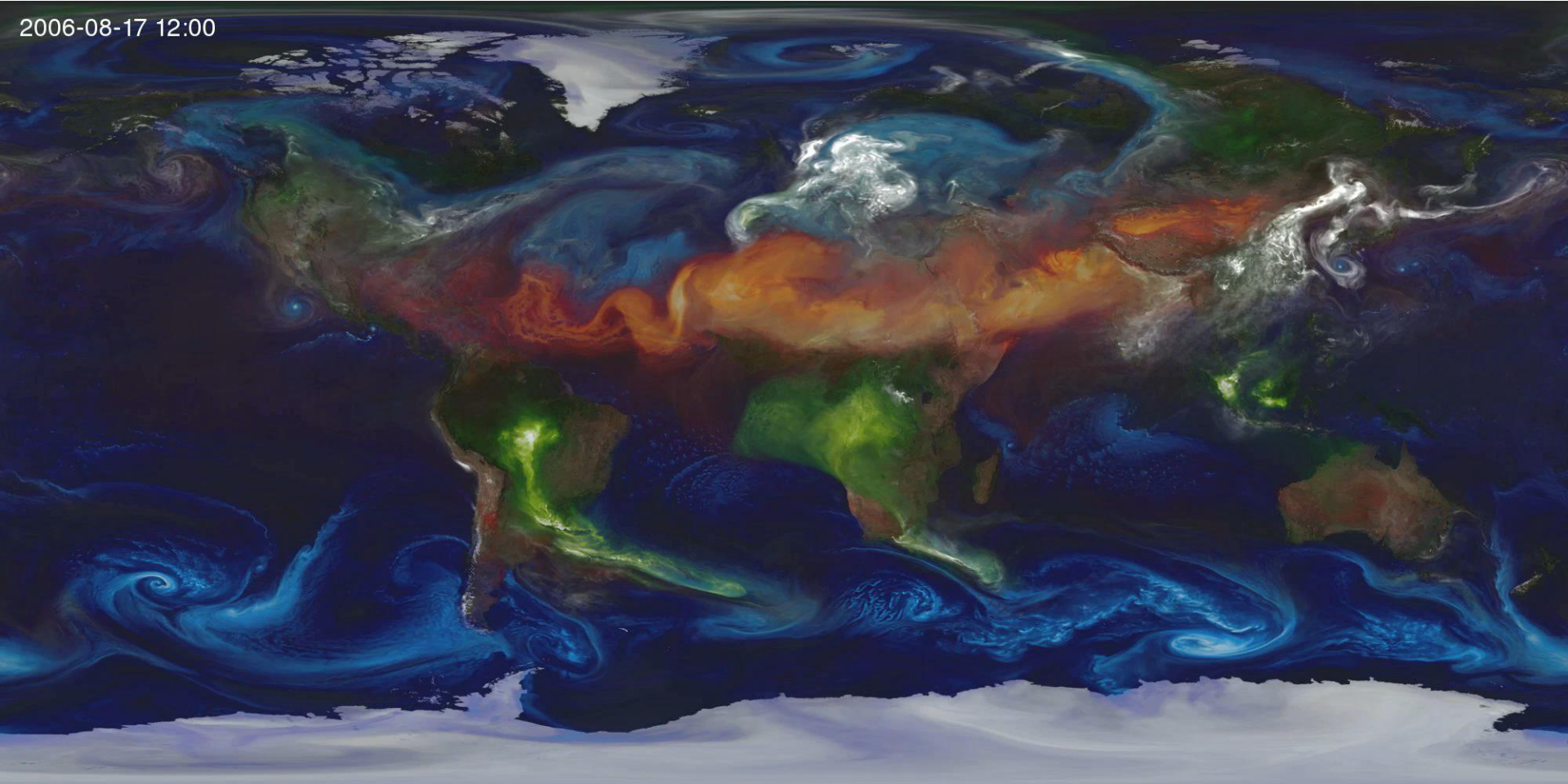
PM_{2.5} Regional Climatology



GEOS-5 Global 10 km Nature Run



2006-08-17 12:00



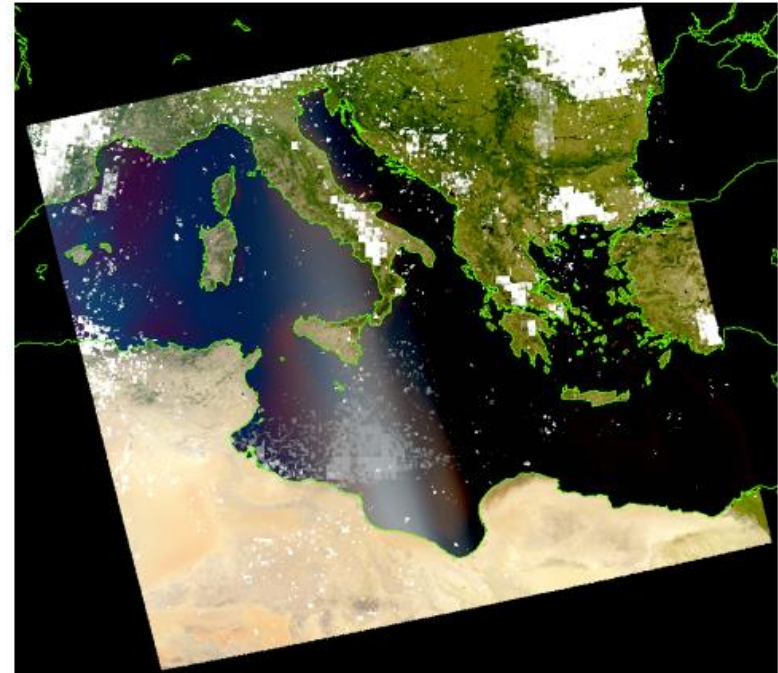
GEOS-5 10km Global Mesoscale Simulation: SST, aerosol emissions¹⁰

MODIS Level 1 & 2 Simulators

a) Actual RGB composite



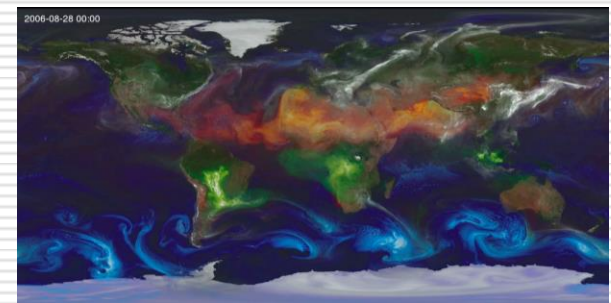
b) Simulated RGB composite



Example: no aerosols

Wind et al., 2013, GMD

GEOS-5 Global 7 km Nature Run



□ Components

- Atmospheric GCM on cubed-sphere, **non-hydrostatic**
- Prescribed SST, sea-ice
- Constituents
 - Radiatively coupled aerosols
 - Carbon species
 - GMI Combo Chemistry (*)

□ Emissions

- Prescribed daily biomass-burning emissions (QFED)
- New dust source function from Ginoux
- Anthropogenic inventories downscaled to 10km

□ GEOS-5 2013 NR

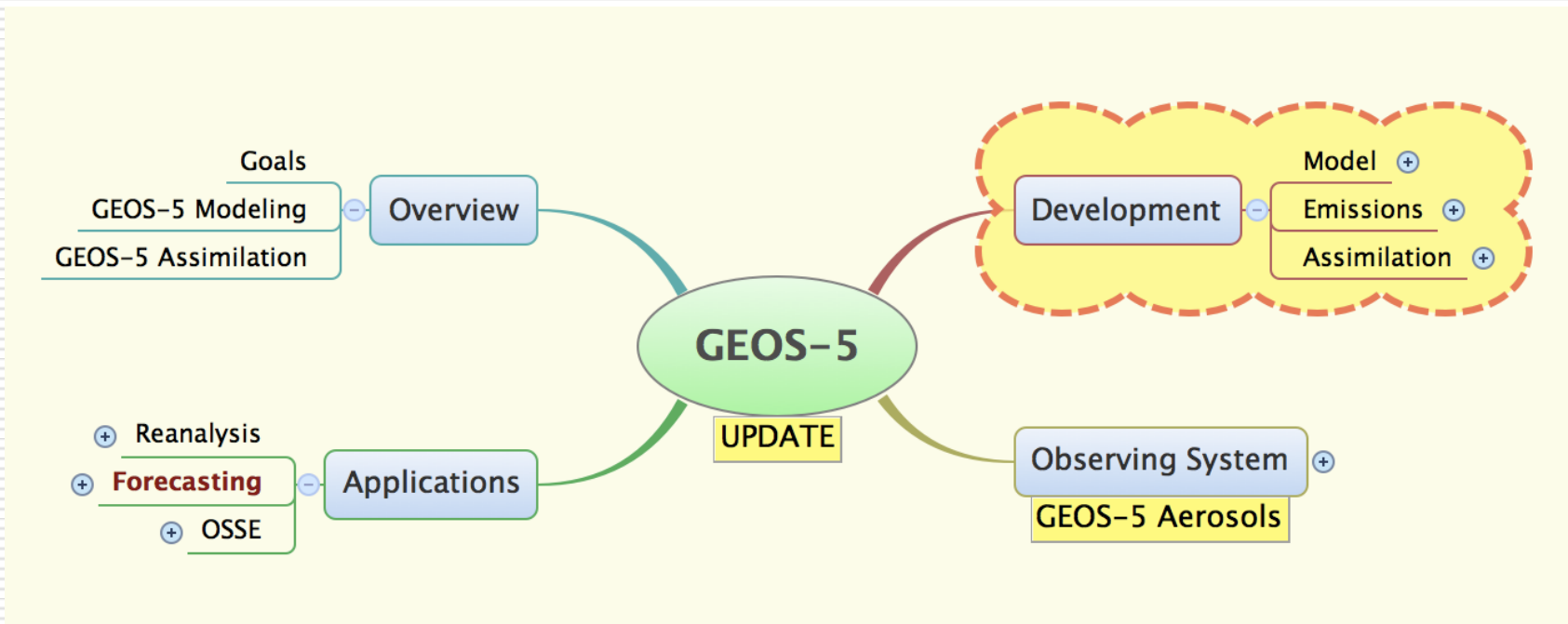
- Global, 7 km
- Aerosol, parameterized Chemistry
 - ~2 years **simulation**
 - May 2005 – May 2007
- Aerosol, full chemistry
 - ~ 1 month (TBD)
- Availability
 - Free, on-line
 - ~ August 2013

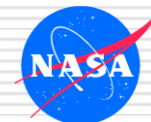
□ GEOS-5 2016+ NR

- Global, 3.5 km
- Improved model
- Cloud-aerosol microphysics, etc.

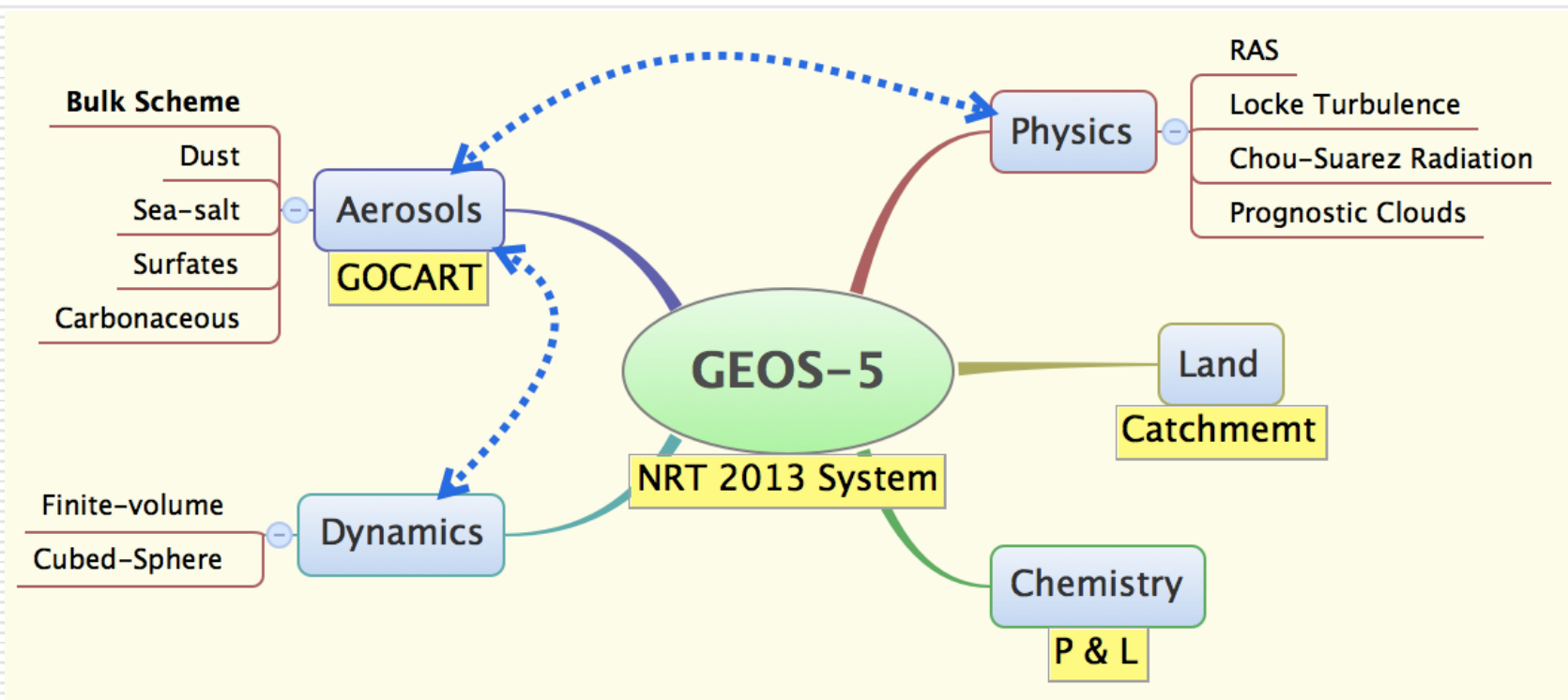
(*) GMI combo chemistry used for short experiments only.

Development Activities

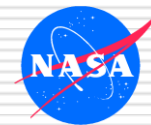




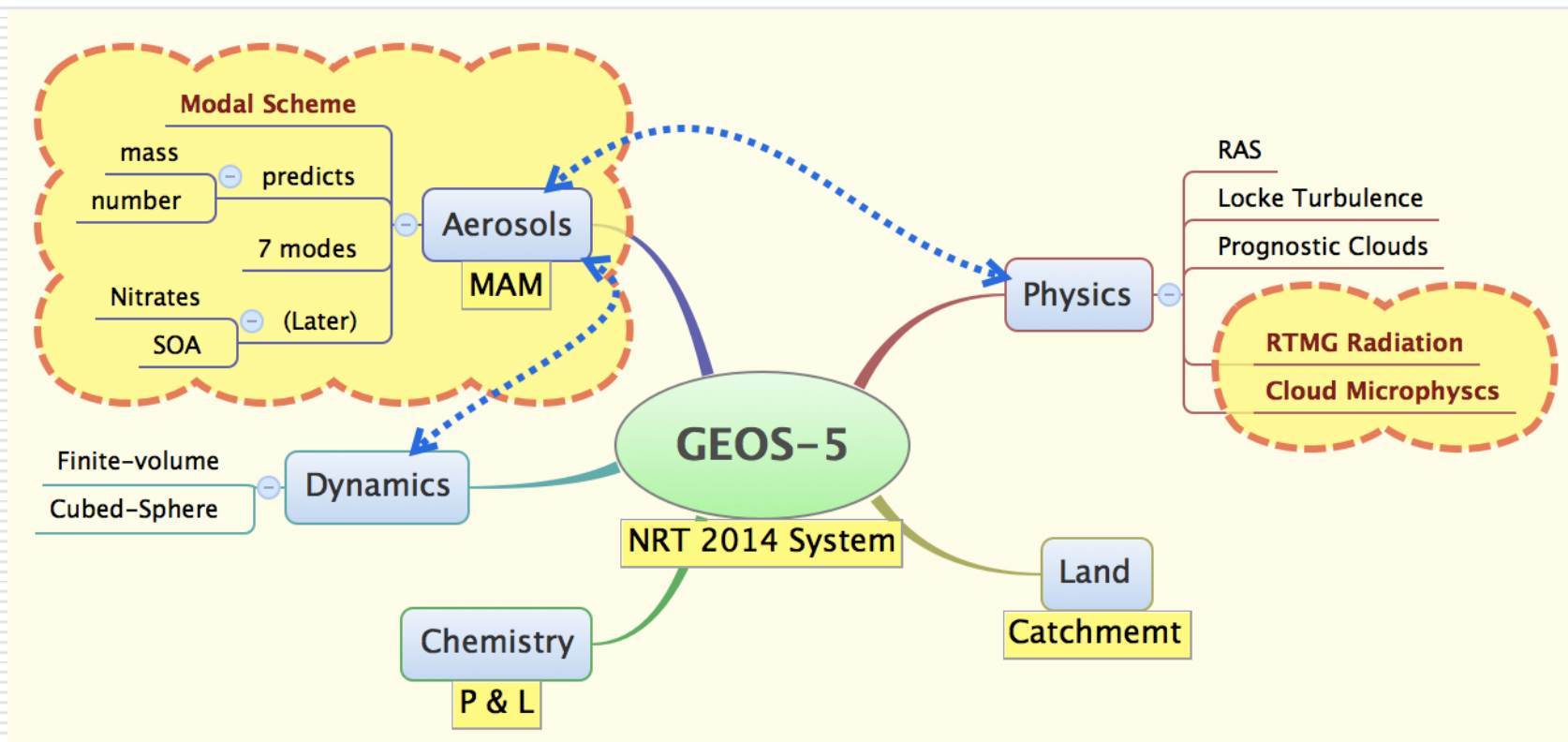
2013 NRT GEOS-5 Configuration



Global, 25 km, 72 Levels, top at 0.01 hPa



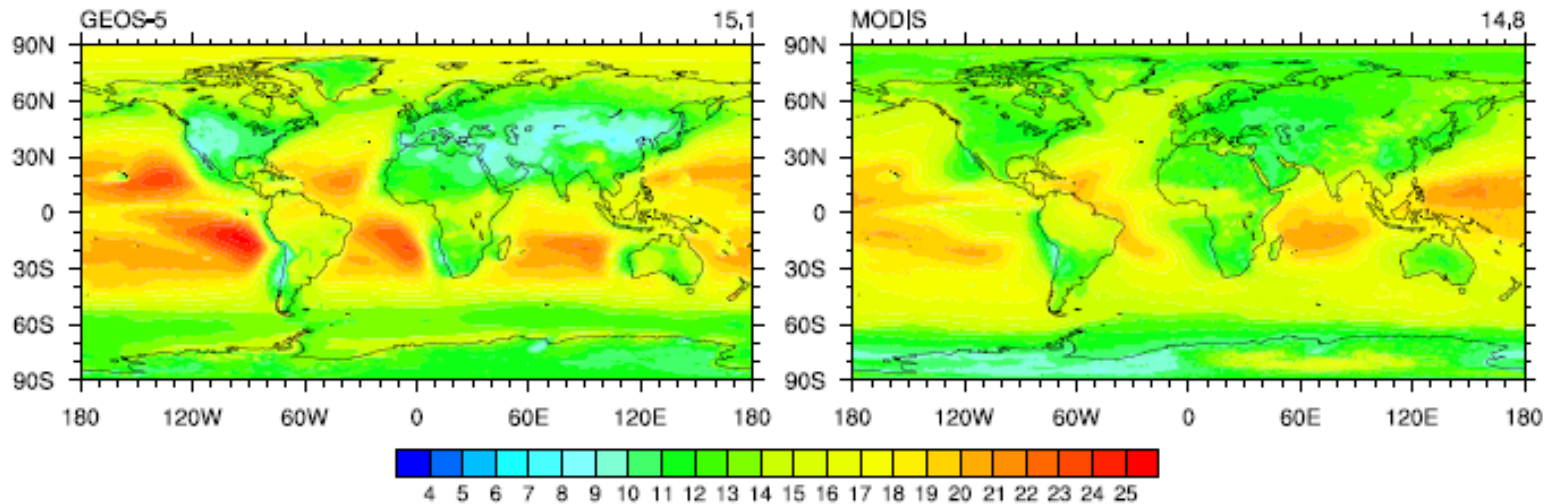
2014/15 NRT GEOS-5 Configuration



Global, **14 km**, 72 Levels, top at 0.01 hPa

New Cloud Microphysics

- Two-moment cloud microphysics for stratus and convective clouds (Morrison and Gettelman, 2008, Barahona et al. 2013).
- Explicit ice nucleation (Barahona and Nenes, 2009) and CCN activation (Fountoukis and Nenes, 2005) coupled to GOCART aerosol.
- New cloud fraction scheme.



Annual Mean Cloud Droplet Effective radius (μm)

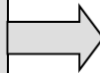
- Great improvement in the representation of liquid and ice water content.
- Effective sizes are explicitly calculated accounting for aerosol effects.
- More realistic cloud fields (cloud water path, cloud fraction, optical thickness).

7-Mode Modal Aerosol Module (MAM)

ESMF Component Derived from CAM5 Implementation
In Collaboration with Xiaohong Liu, Steve Gahn (PNNL)

Aitken

number
sulfate
ammonium
secondary OM
sea salt



Accumulation

number
sulfate
ammonium
secondary OM
hydrophobic OM
BC
sea salt

coagulation
condensation



Fine Soil Dust

number
soil dust
sulfate
ammonium

Fine Sea Salt

number
sea salt
sulfate
ammonium

All modes log-normal
with prescribed width.

Total transported
aerosol tracers: 31

Cloud-borne aerosol
and aerosol water
predicted but not
transported.

Primary Carbon

number
hydrophobic OM
BC

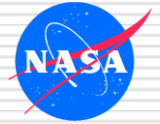
Coarse Soil Dust

number
soil dust
sulfate
ammonium

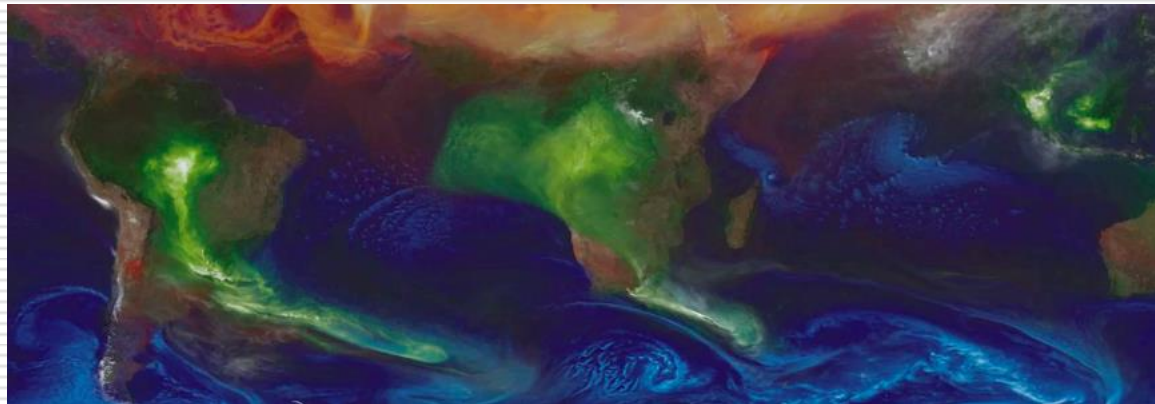
Coarse Sea Salt

number
sea salt
sulfate
ammonium

QFED: Quick Fire Emission Dataset

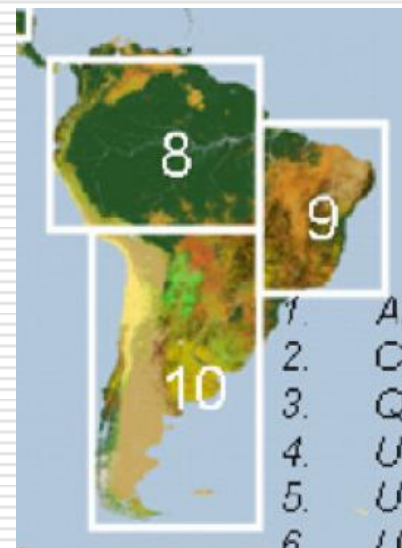
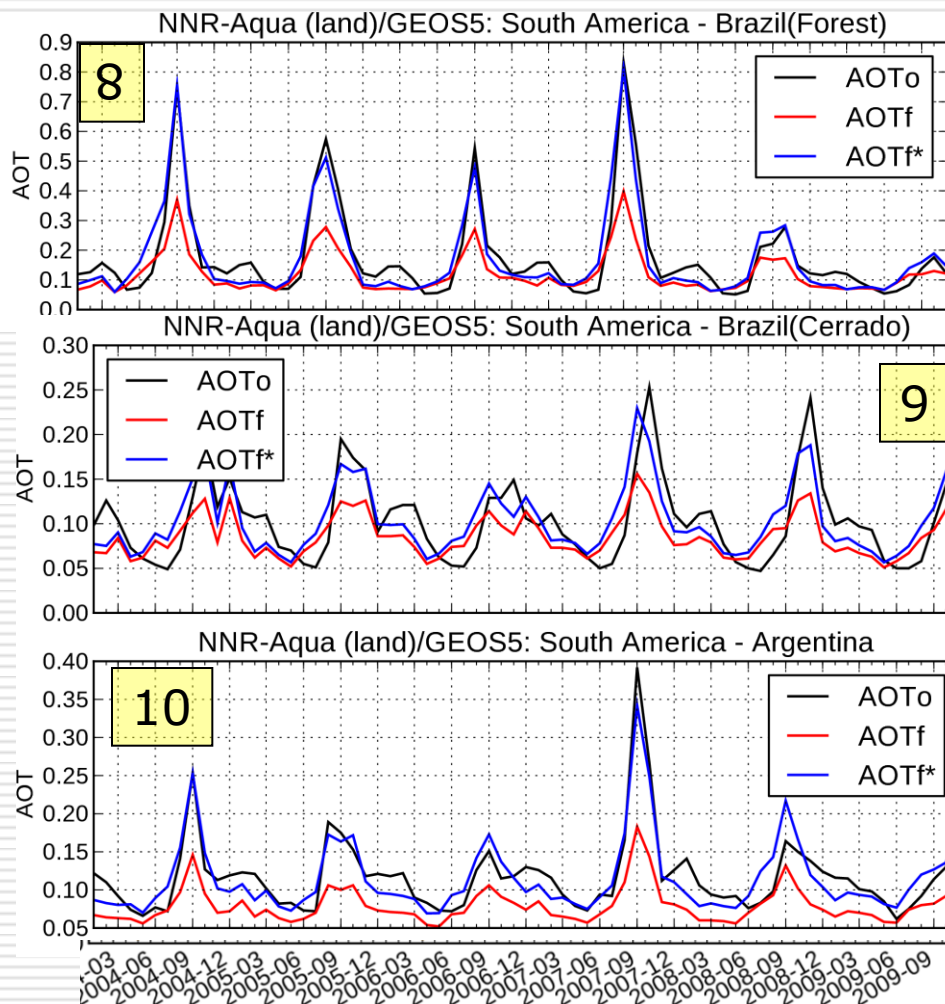


- ❑ Top-down algorithm based on MODIS Fire Radiative Power (AQUA/TERRA)
- ❑ FRP Emission factors tuned by means of inverse calculation based on MODIS AOD data.
- ❑ Daily mean emissions, NRT (thanks to LANCE)
- ❑ Prescribed diurnal cycle



JCSDA: inclusion of geo-stationary information

QFED Calibrated by MODIS AOD



GEOS-5 Aerosol Optical Depth

- QFED (GFED Calibrated)
- QFED (MODIS Calibrated)
- MODIS Retrievals

Gridding Biomass Burning Emissions

- “Observed” Emissions

$$E^o = \frac{\alpha_s}{A^o} \sum_b C_b R_b$$

- “Obscured” Emissions: E^*

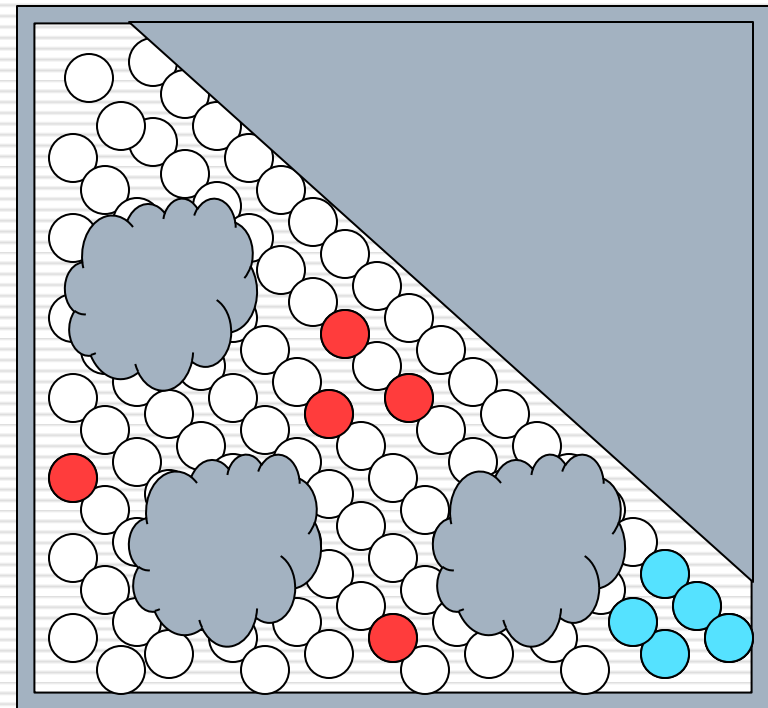
- A priori information
- Damped-persistency model

- Grid-box estimate:

$$E = E^* + \frac{A^o}{A^o + A^*} (E^o - E^*)$$

- It is important to have information about **obscured** and **not-burning** pixels

Model grid-box

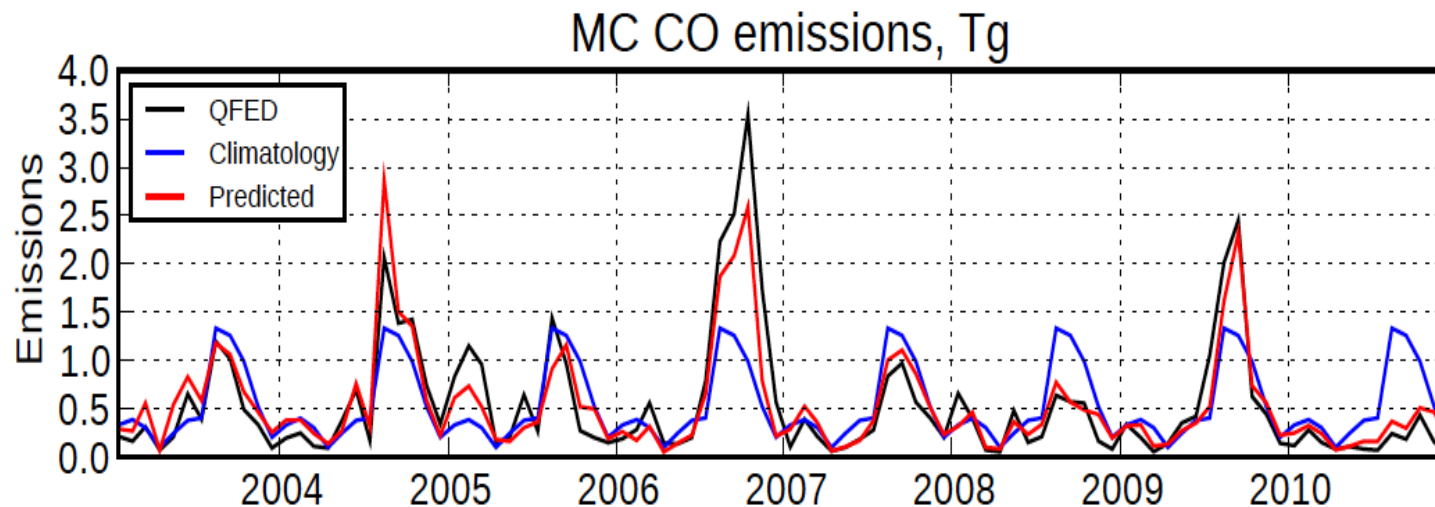


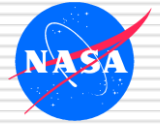
Modeling Interannual Variability of Biomass Burning Emissions

- BB emission anomalies respond directly to precipitation and surface humidity conditions
- The normalized Canadian Fire Weather Index captures the *fammability* conditions as a function of surface meteorology

- Parameterization:

$$E = \varepsilon \left(\frac{I}{I_{clm}} \right)^{\alpha_b} E_{clm}$$





Advancing emissions

□ **QFED v3**

- Incorporating GEO information for delineating diurnal cycle
- Revisit Plume Rise

□ **Over land**

- Formulation of emissions in land surface space
- Implement latest MEGAN for biogenic
- Better account of diurnal and weekly cycles
- Update anthropogenic inventories
- Update to Ginoux's latest dust source function

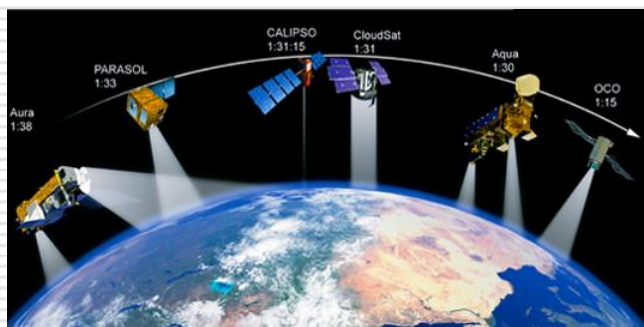
□ **Sea-salt emissions**

- Couple to Wave Watch 3
- Couple to new ocean-surface parameterization in GEOS-5
- Physically-based sea-spray model

Aerosol Data Assimilation

2013 NRT Configuration

- Focus on NASA EOS instruments, MODIS for now

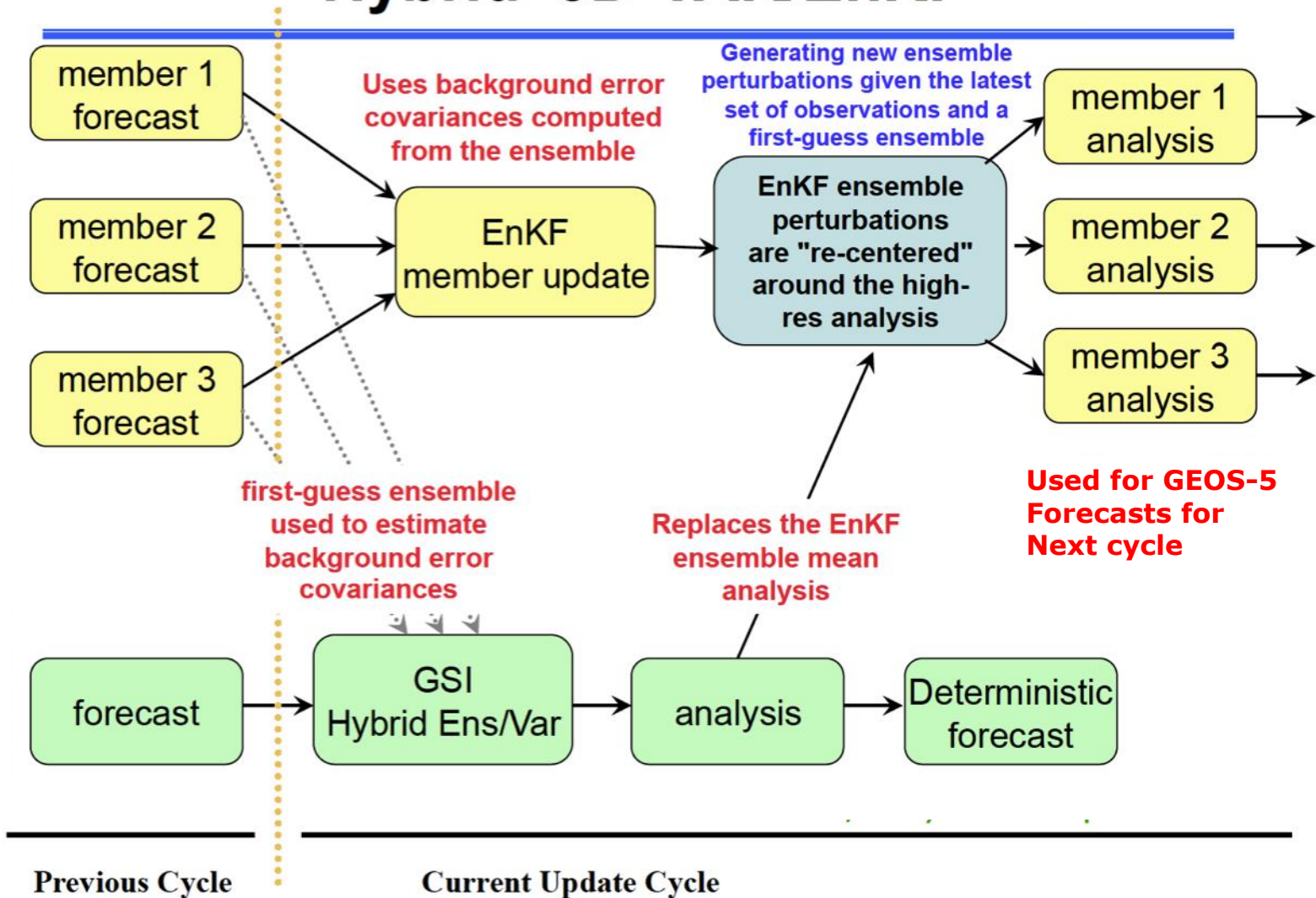


- Global, high resolution 2D AOD analysis
- 3D increments by means of Local Displacement Ensembles (**LDE**)

- Simultaneous estimates of background bias (*Dee and da Silva 1998*)
- Adaptive Statistical Quality Control (*Dee et al. 1999*):
 - State dependent (adapts to the error of the day)
 - Background and Buddy checks based on log-transformed AOD *innovation*
- Error covariance models (*Dee and da Silva 1999*):
 - Innovation based
 - Maximum likelihood

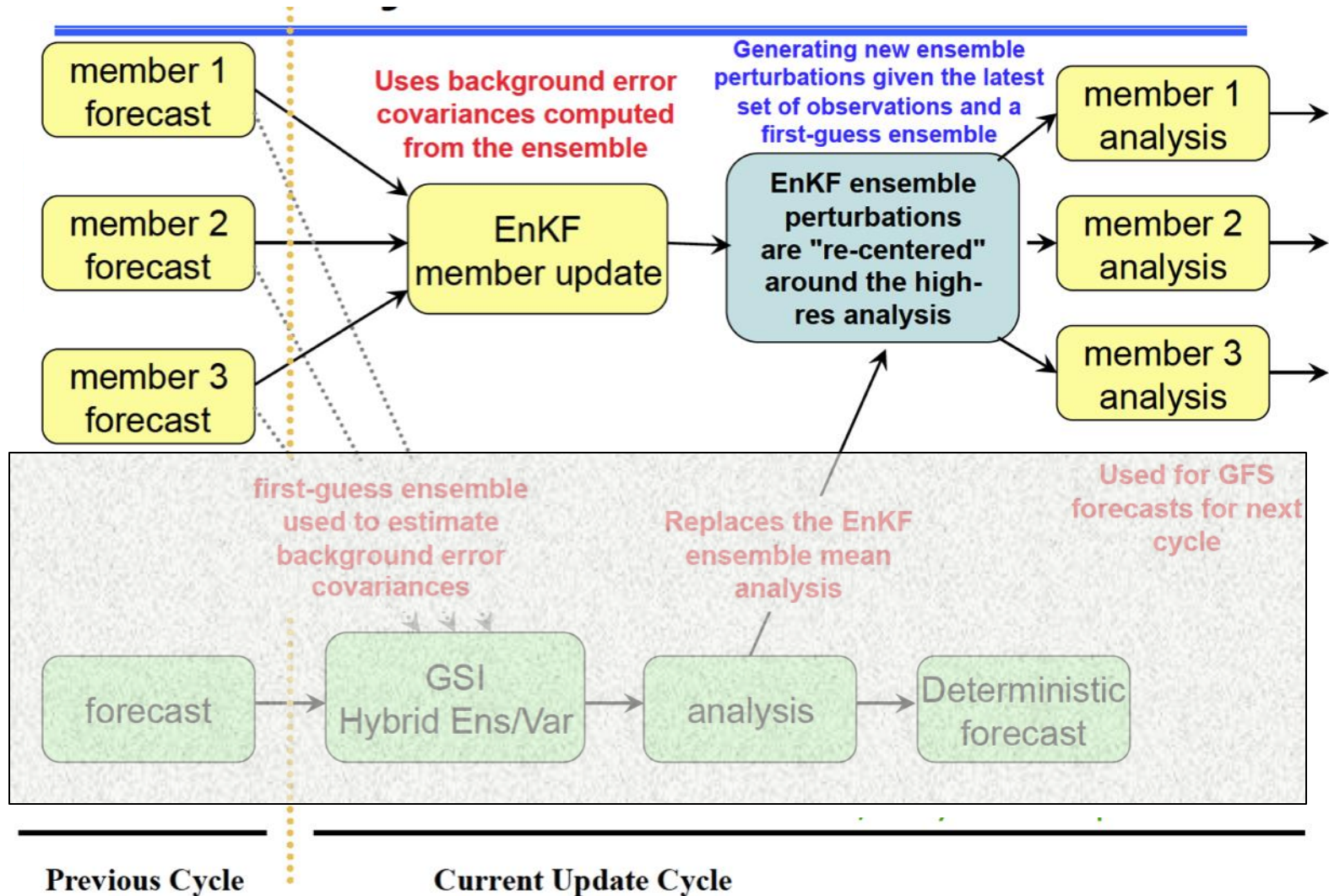
GEOS-5 Meteorological DAS

Hybrid 3D-VAR/EnKF

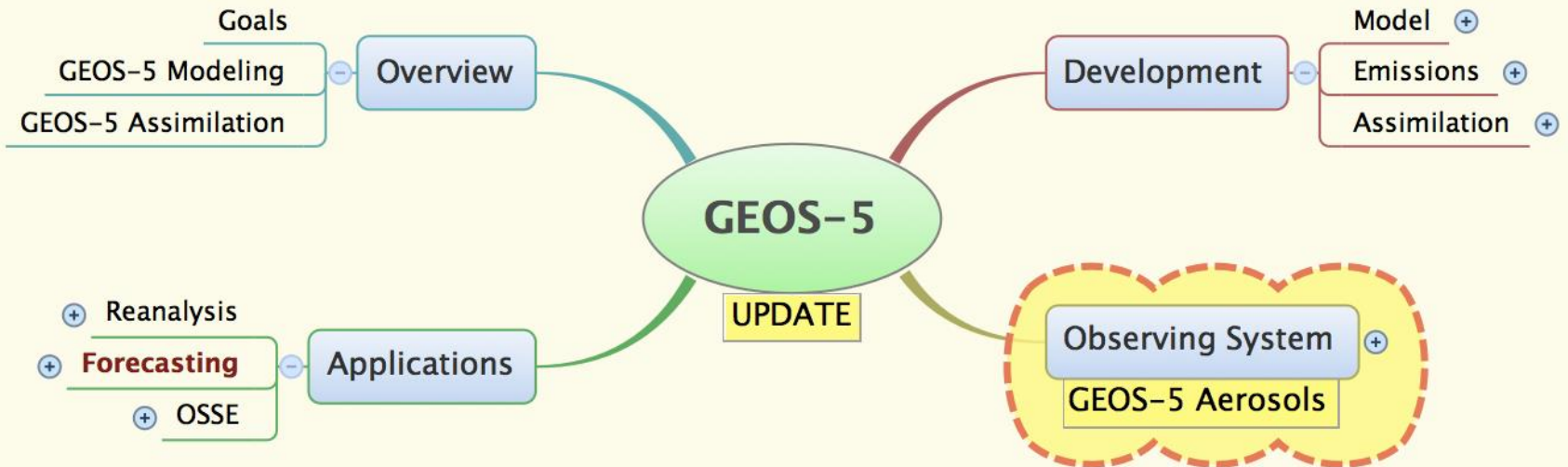


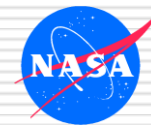
In collaboration with NOAA NCEP, ESRL

GEOS-5 **Aerosol** Assimilation EnKF Only

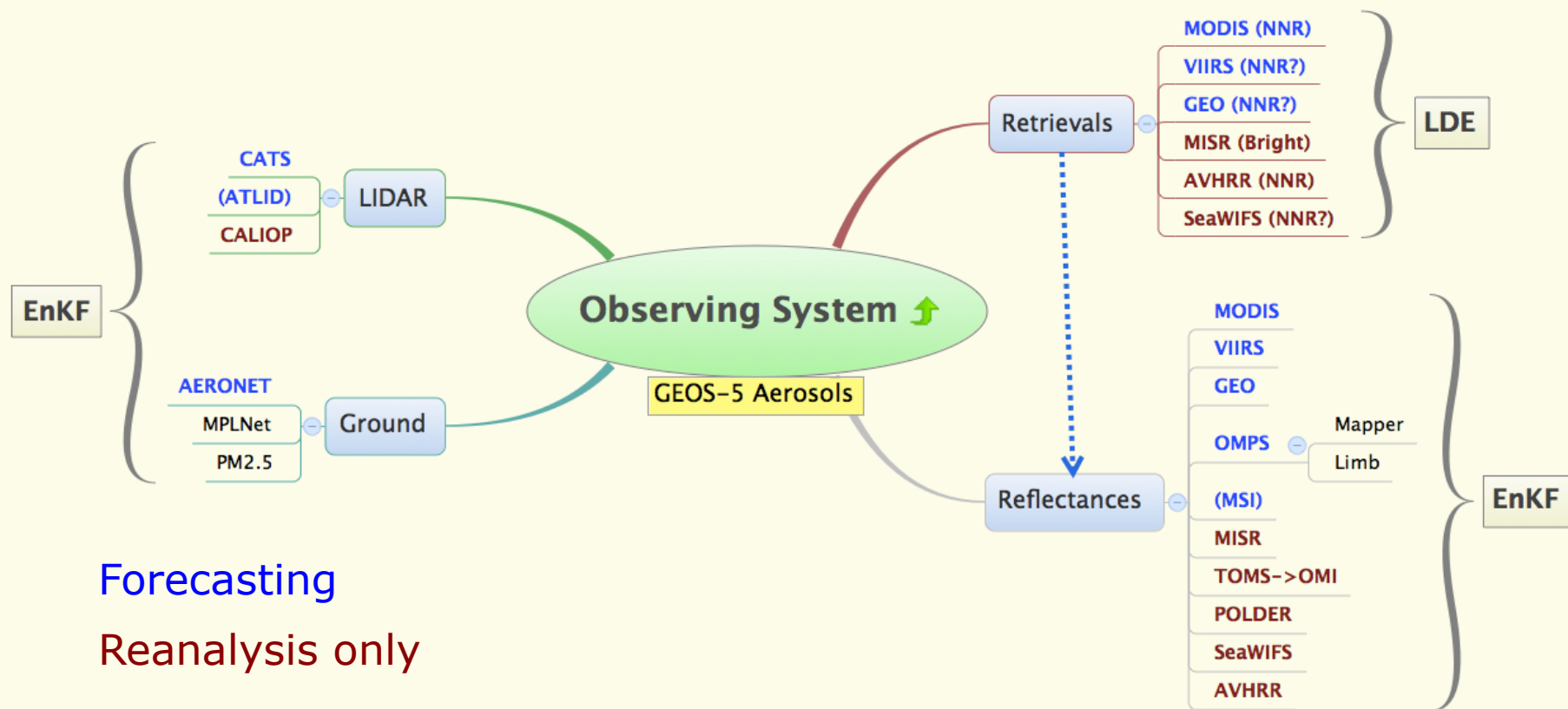


Observing System

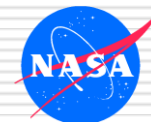




Aerosol Observing System



Aerosol Data Assimilation in GEOS-5



Neural Net for AOD Empirical Retrievals

Ocean Predictors

- Multi-channel
 - TOA Reflectances
 - Retrieved AOD
- Angles
 - Glint
 - Solar
 - Sensor
- Cloud fraction (<85%)
- Wind speed

Target: AERONET

- $\text{Log}(\text{AOD}+0.01)$

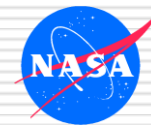
Land Predictors

- Multi-channel
 - TOA Reflectances
 - Retrieved AOD
- Angles
 - Solar
 - Sensor
- Cloud fraction (<85%)
- Climatological albedo
 - < 0.25

Target: AERONET

- $\text{Log}(\text{AOD}+0.01)$

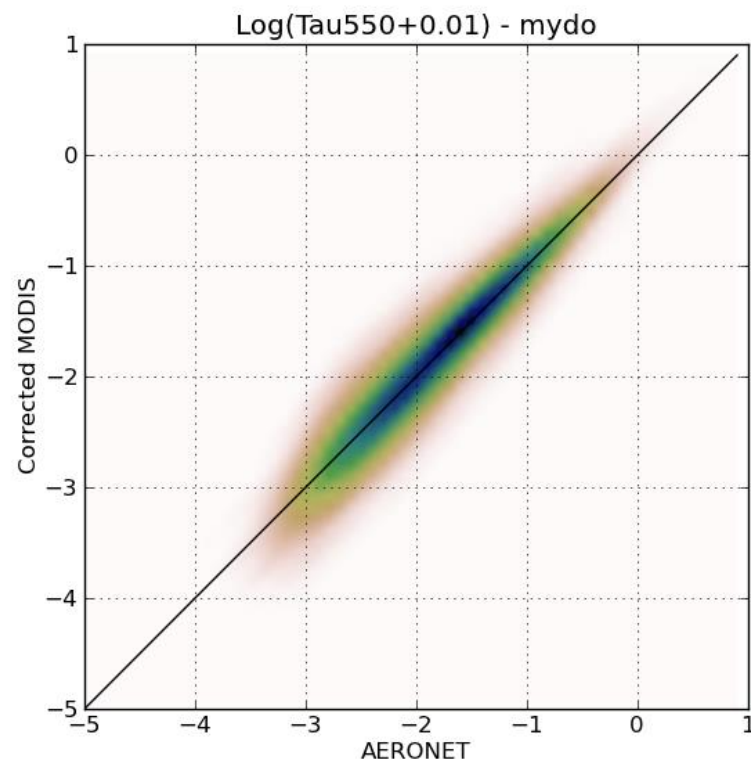
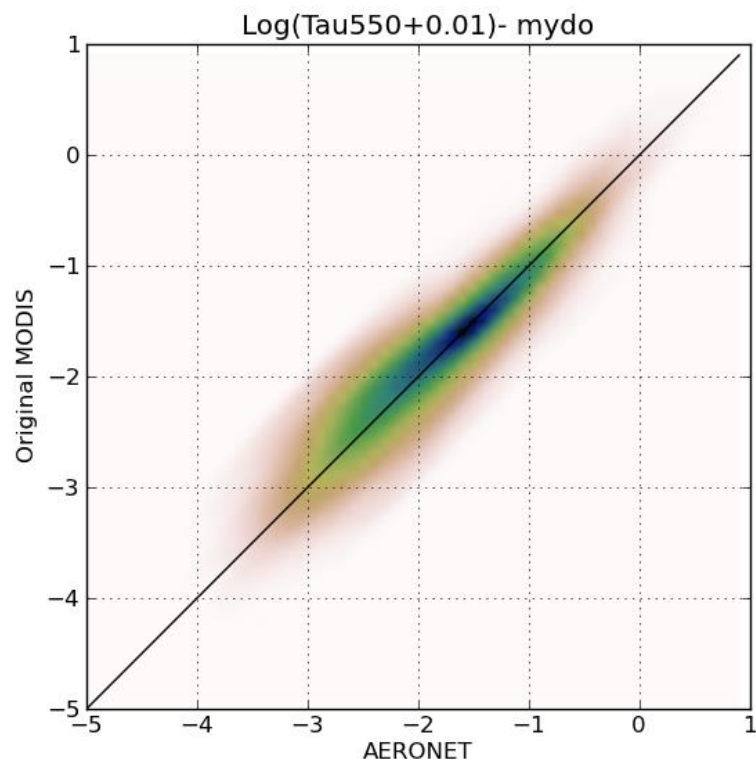


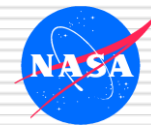


MODIS AOD over Ocean

Collection 5 (Aqua)

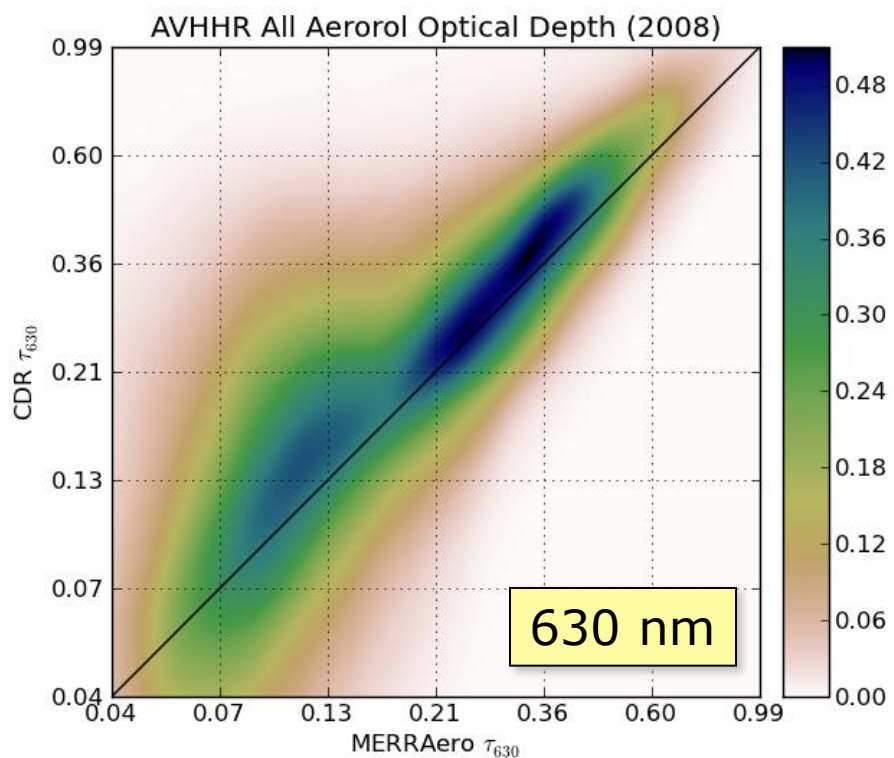
NNR Retrieval



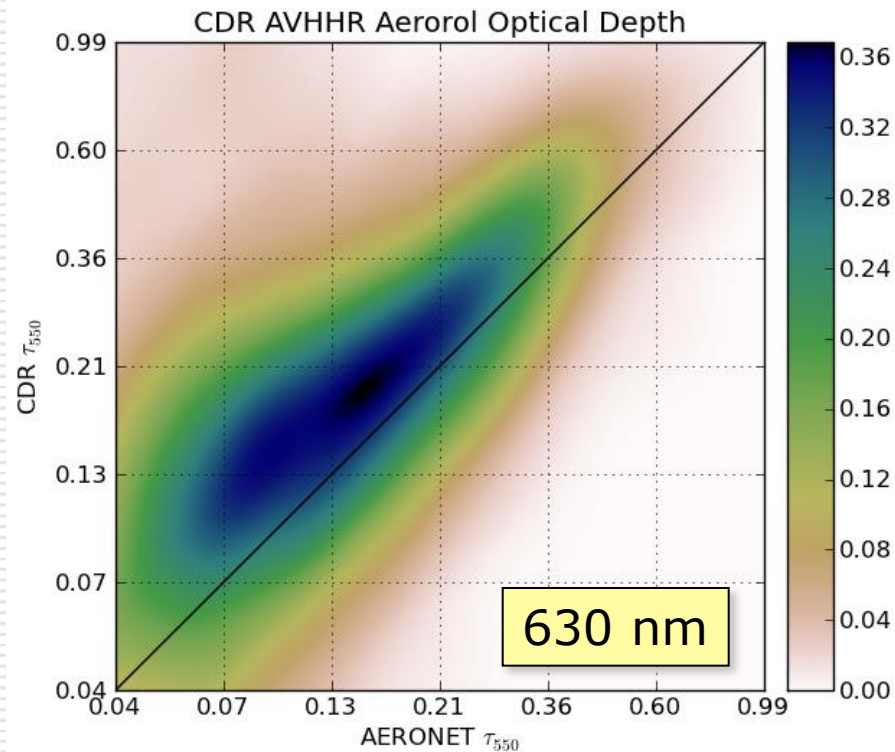


AVHRR NOAA CDR AOD

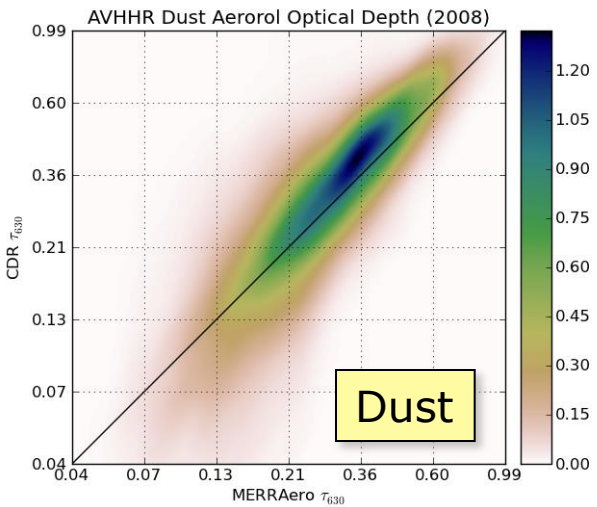
MERRAero, AERONET Comparison



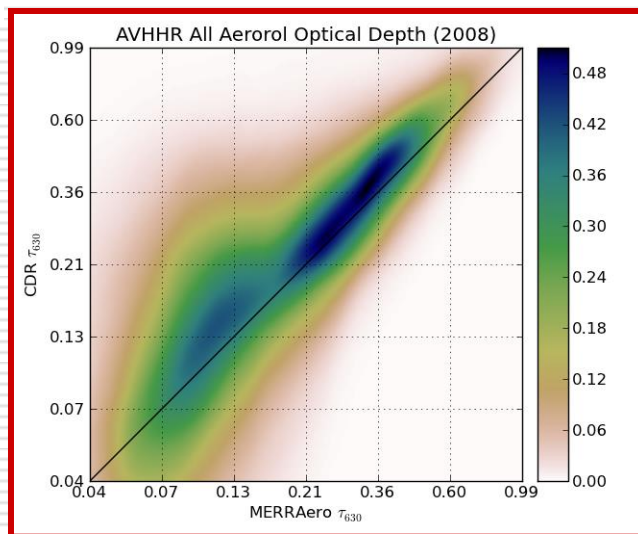
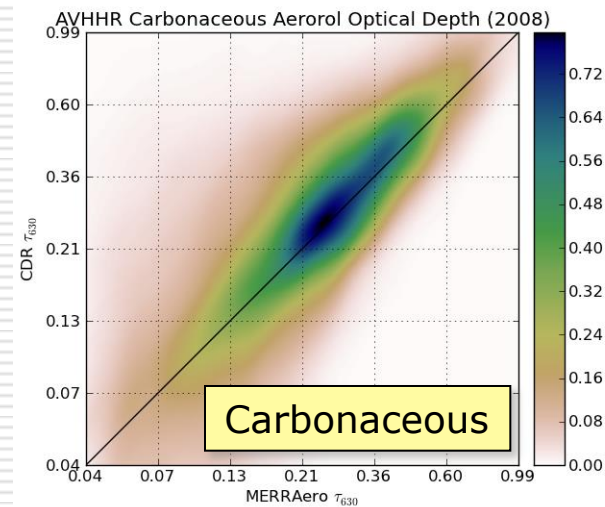
MERRAero



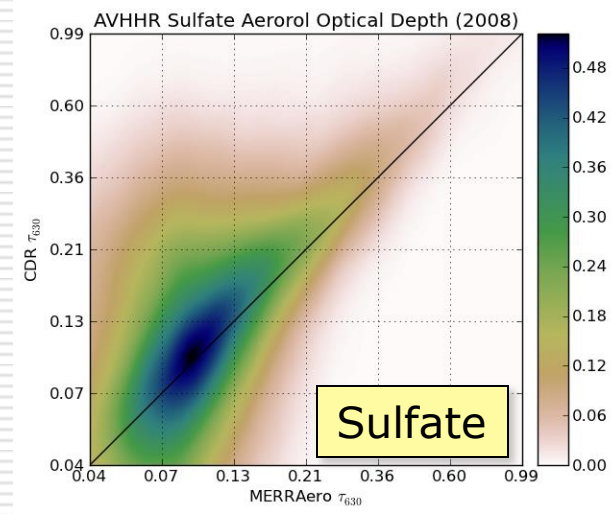
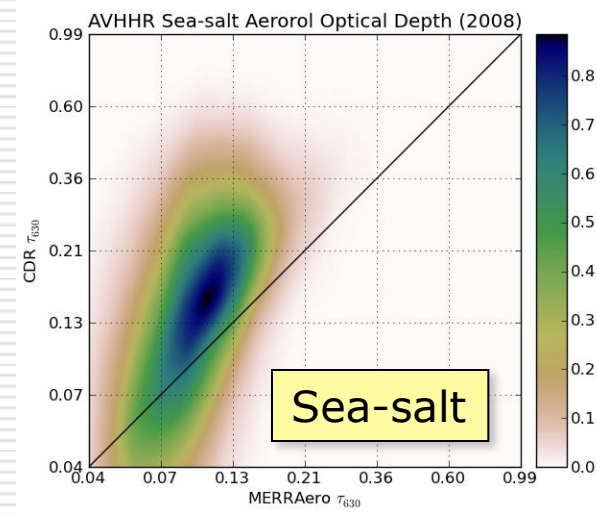
AERONET



CDR: 2008



Multiple Species



PATMOS-x

AVHRR Pathfinder Atmospheres - Extended



PATMOS-x Dataset

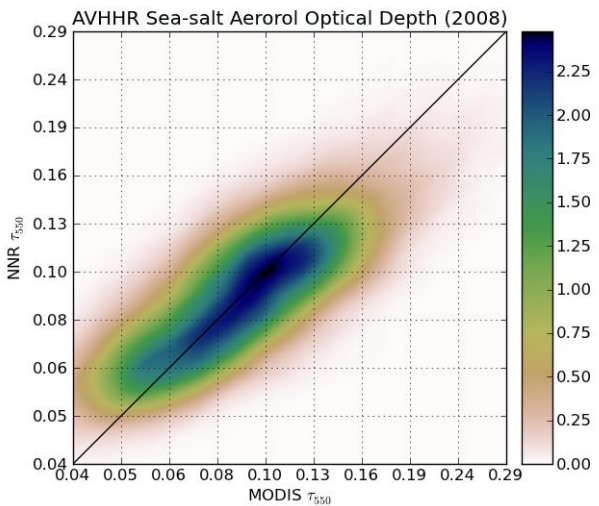
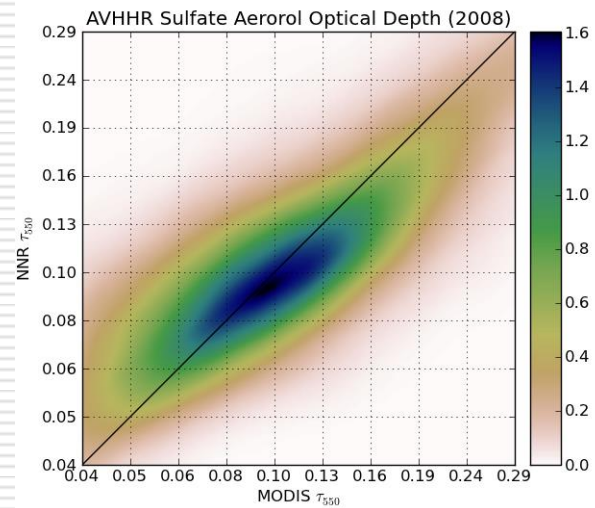
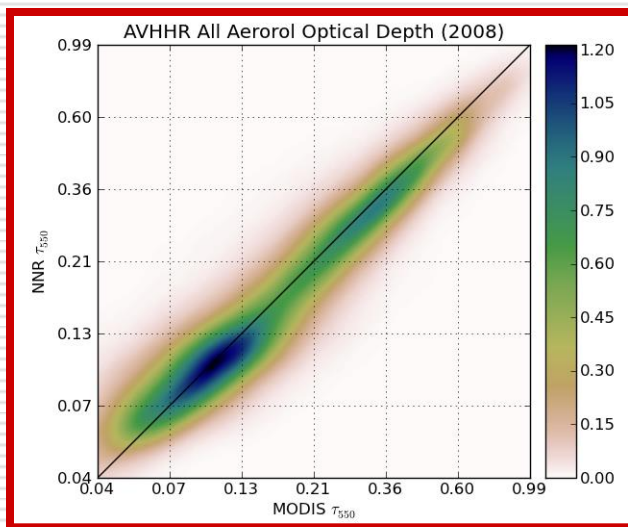
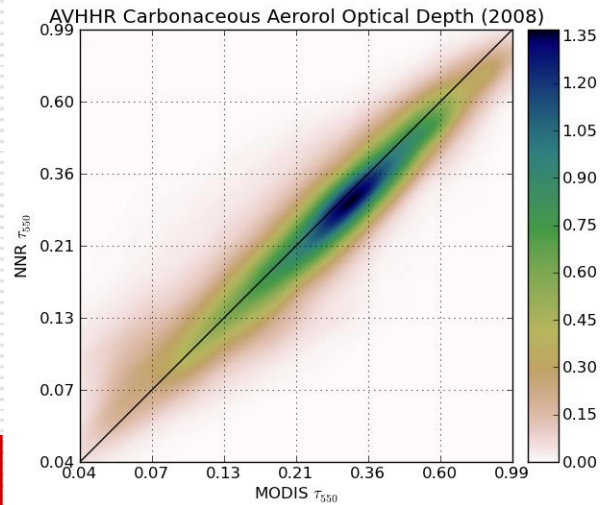
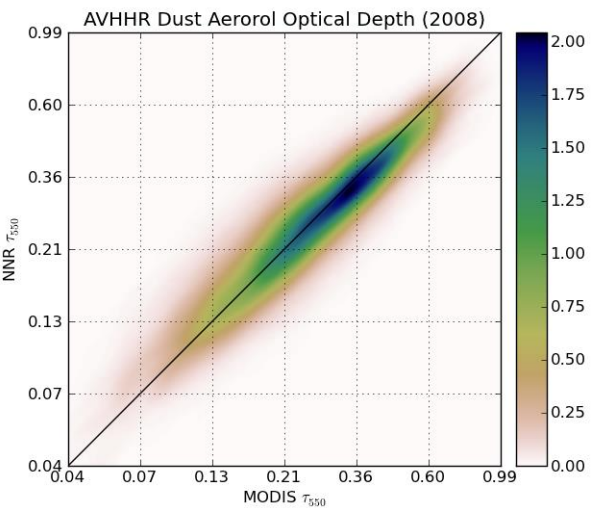
- ❑ Version 5 Level 2B
- ❑ 0.1 degree sampling (not average)
- ❑ Period: 1978-2009
- ❑ Inter satellite calibration (MODIS reference)
- ❑ Bayesian probabilistic cloud detection (CALIPSO reference)
 - **cpd <0.5%**

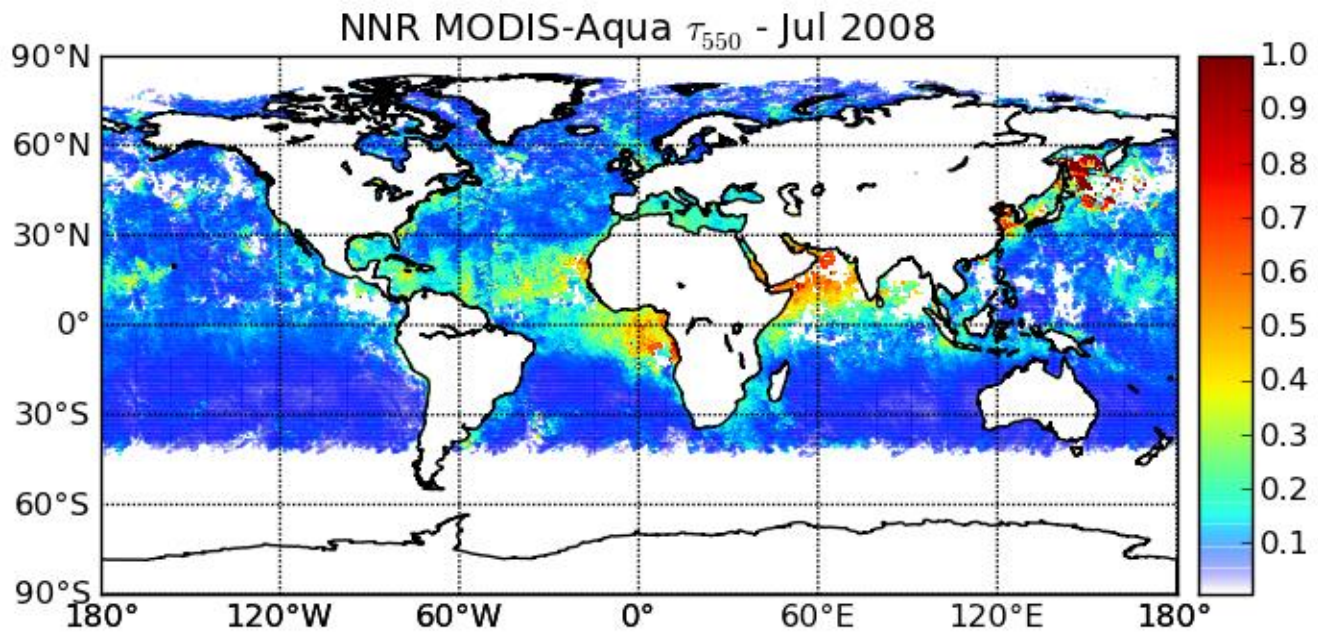
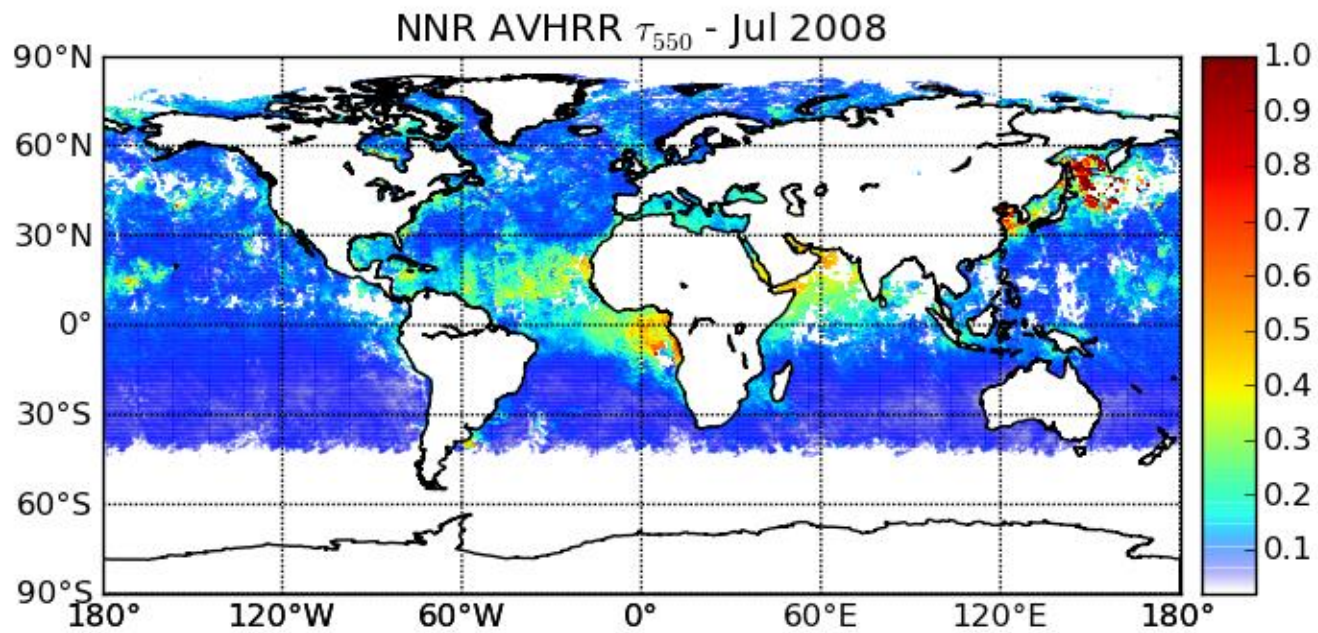
Neural Net Retrival

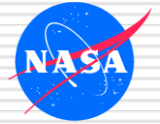
- ❑ Ocean Predictors
 - TOA Reflectances
 - **630 and 860 nm**
 - TPW
 - Ocean albedo (wind)
 - Solar and sensor angles
 - GEOS-5 fractional AOD speciation
- ❑ Target:
 - AOD at **550 nm**
 - Balanced MODIS NNR

2008

Multiple Species



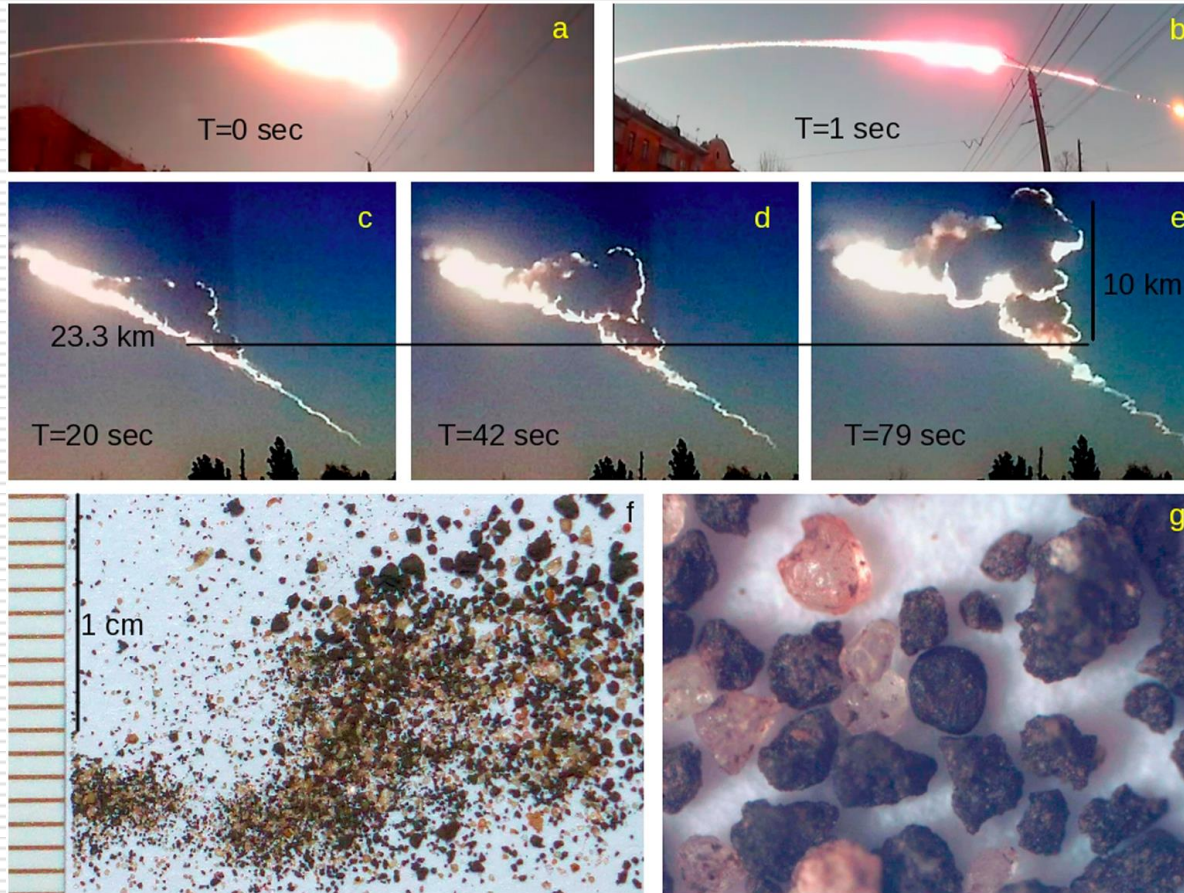




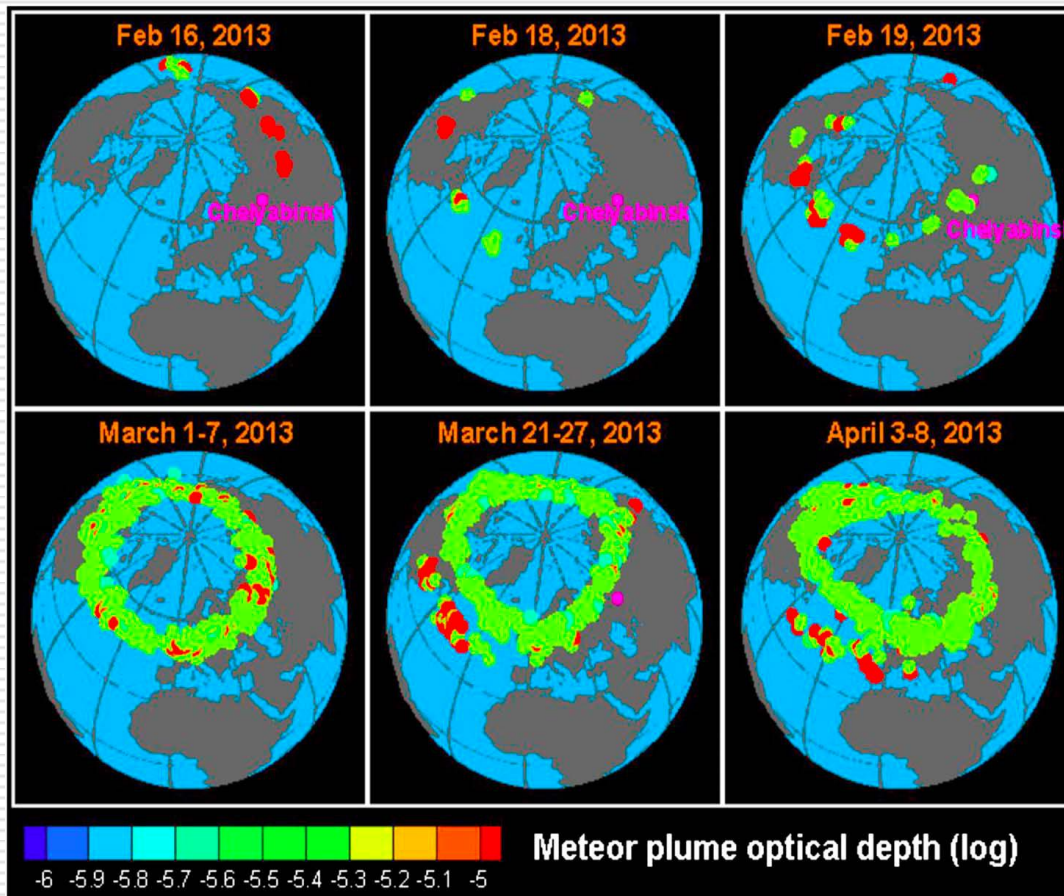
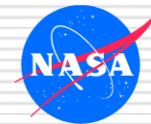
Summary

- ❑ Aerosols are an integral part of the GEOS-5 modeling and data assimilation systems
- ❑ General framework: *Integrated Earth System Analysis* (IESA)
- ❑ Capabilities
 - Prediction from weather to decadal scales
 - Assimilated datasets for synthesizing the information content of models and satellite data
 - OSSEs for supporting future NASA observing mission
- ❑ Close collaboration between modelers and data producers is key.

Russian Super Bolide of 2013



Chelyabinsk Meteor Dust Plume



Chelyabinsk Meteor Dust Plume

