

# Overview and Status of MODIS Aerosol and Cloud Data Assimilation in GEOS-5

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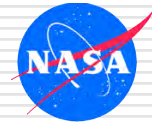
*(2) Atmospheric Chemistry and Dynamics Branch, NASA/GSFC*

*(3) GESTAR*

*(4) Science Applications International Corp.*

*(5) Earth Resource Technology*

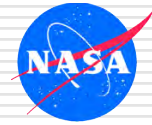
*MODIS Science Team Meeting  
Atmosphere Team Breakout Session  
Silver Spring, MD, 16 April 2013*



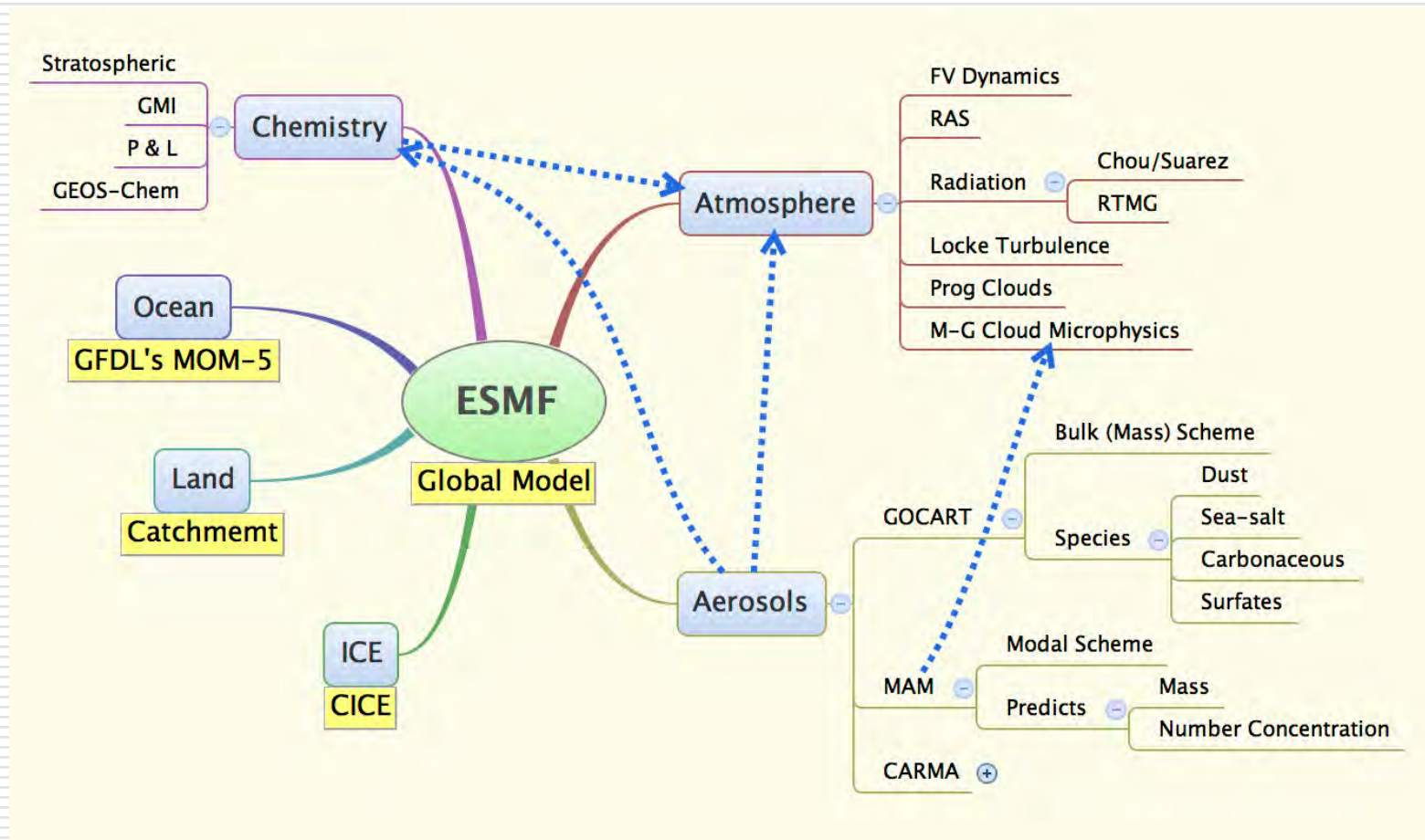
# Talk Overview

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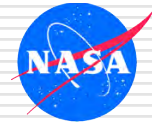
- GEOS-5 overview
  - Model and data assimilation
- QFED Biomass Emissions
- Aerosol Data Assimilation
- Cloud Data Assimilation
- Concluding Remarks



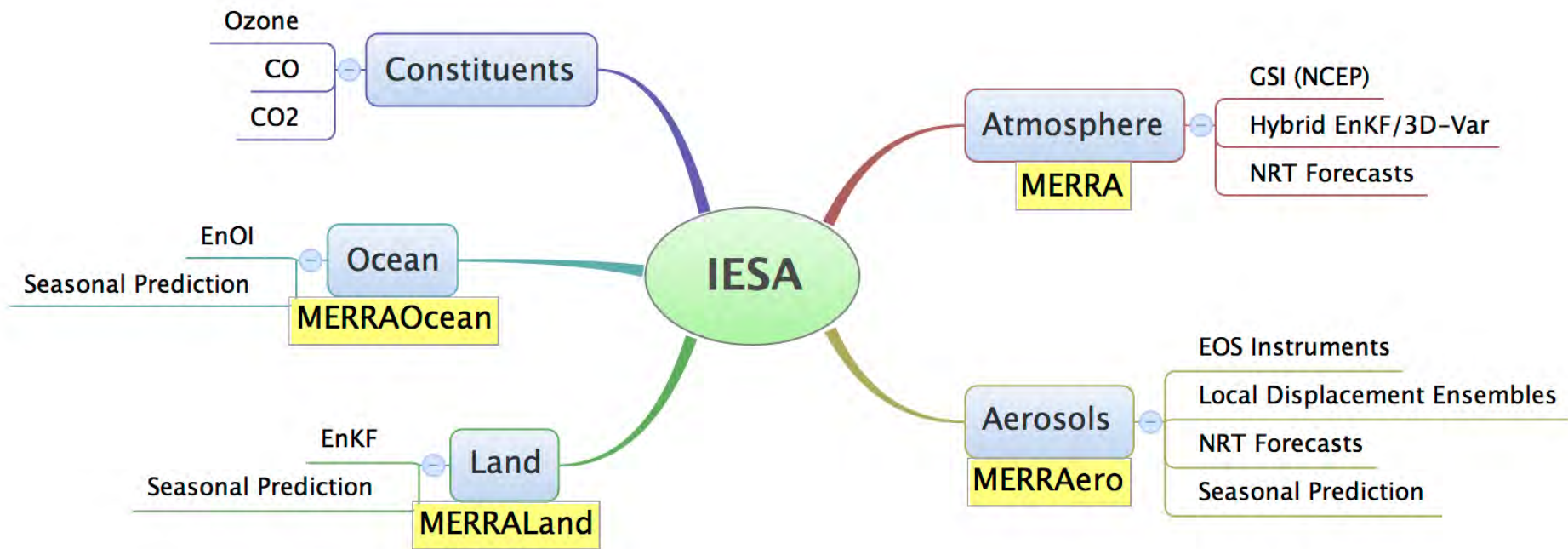
# GEOS-5 Earth-System Model



From weather to seasonal to decadal time scales



# Integrated Earth System Analysis



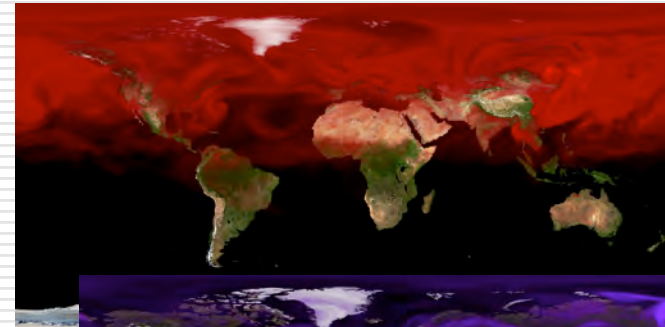
Data Assimilation in GEOS-5



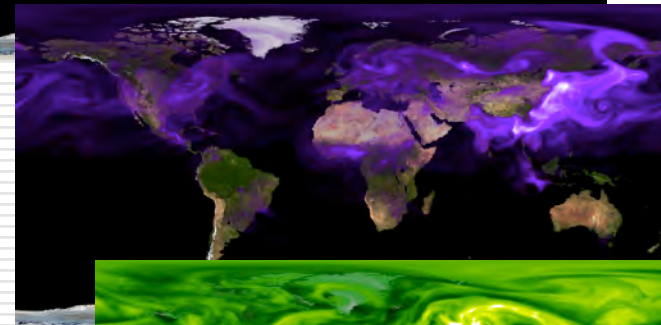
# GEOS-5 Forecasting Support

DISCOVER-AQ

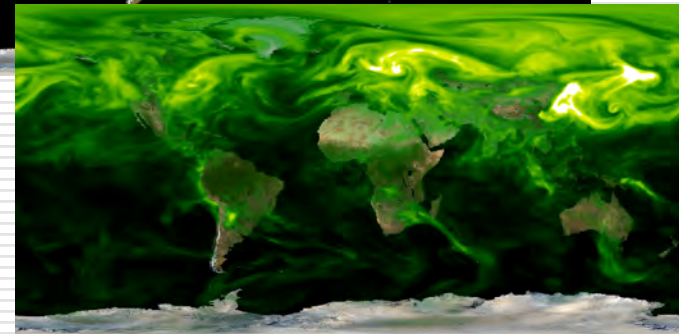
- ❑ Global 5-day chemical forecasts customized for each campaign
  - O<sub>3</sub>, aerosols, CO, CO<sub>2</sub>, SO<sub>2</sub>
  - Resolution: Normally 25 km
- ❑ Driven by real-time biomass emissions from MODIS
- ❑ Assimilated aerosols interacts with circulation through radiation



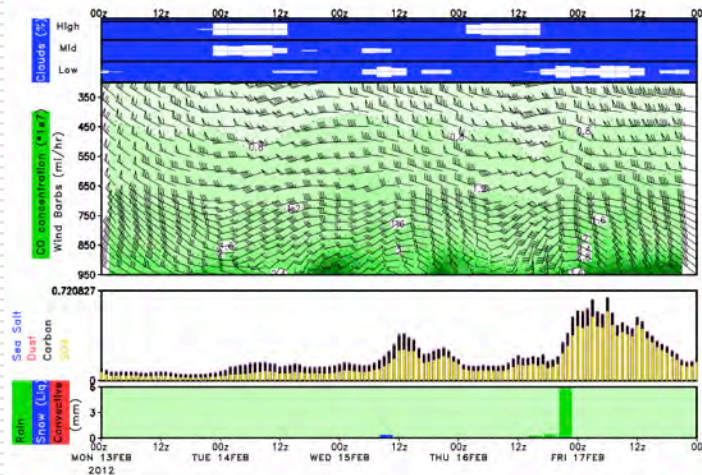
CO



Smoke

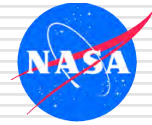


SO<sub>4</sub>

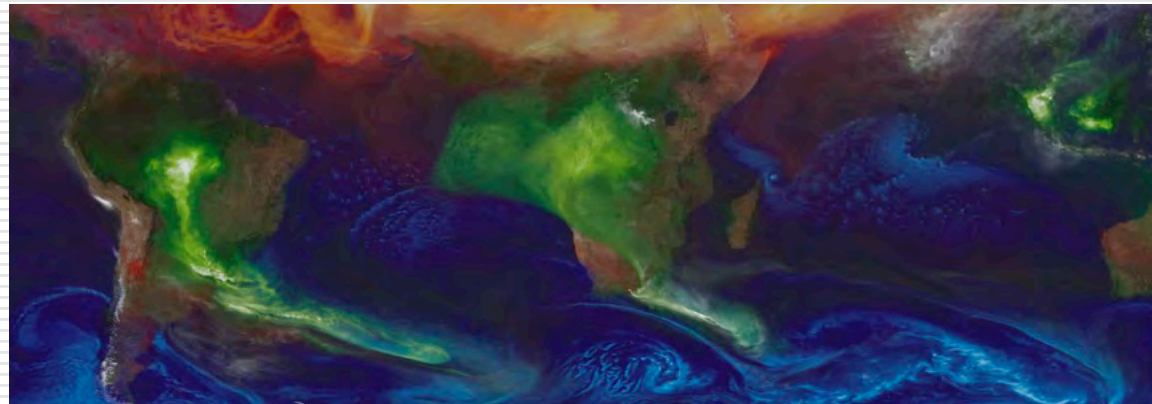


<http://gmao.gsfc.nasa.gov/forecasts/>

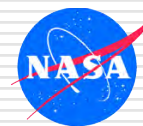
# QFED: Quick Fire Emission Dataset



- ❑ 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 v2 – Fire Radiative Power

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- Assumes simple linear relationship for each biome

$$E(x,y,t) = C_{\text{biome}} * FRP(x,y,t)$$

- Only 4 global constants to estimate (boreal, tropical fires, savannah, grasslands)
- Spatial structure determined by satellite data
- Accounts for pixels obscured by clouds
- Emission factor parameters determined using inverse modeling techniques.

# Gridding Biomass Burning Emissions

- “Observed” Emissions

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

- “Obscured” Emissions:  $E^*$

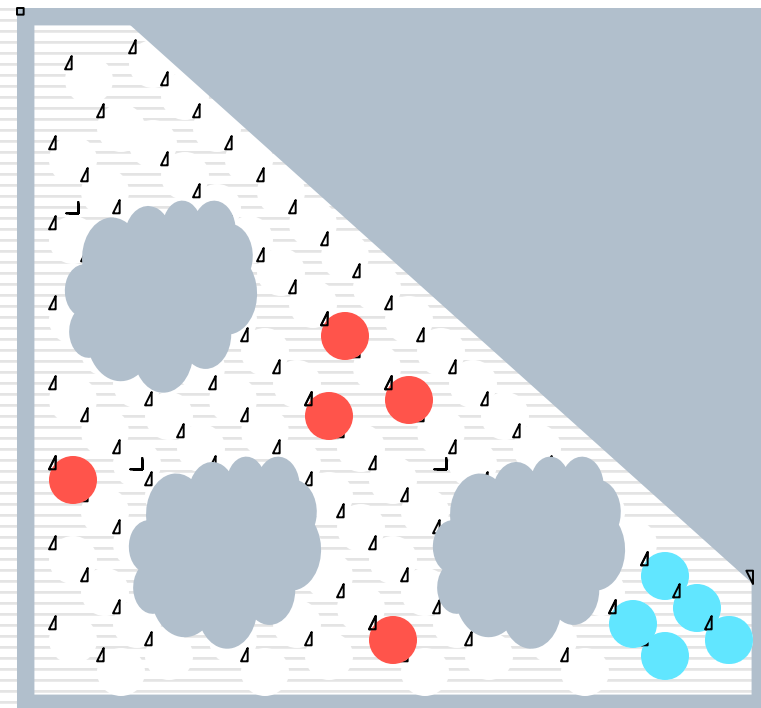
- A priori information
- Damped-persistency model

- 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

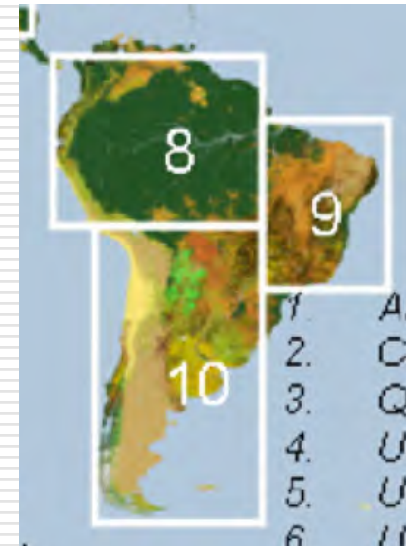
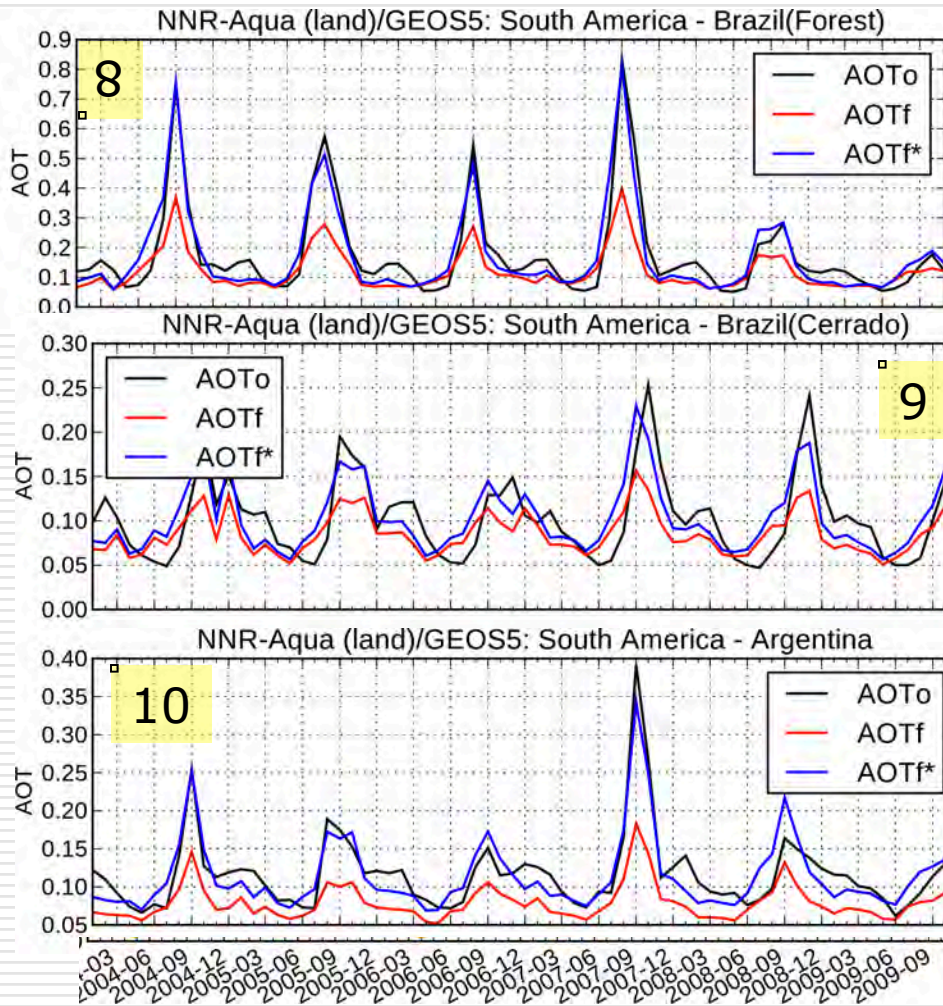
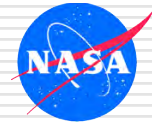
## Model grid-box



● burning    ● not burning    ● obscured    ● water

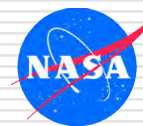


# QFED Calibrated by MODIS AOD



GEOS-5 Aerosol Optical Depth

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



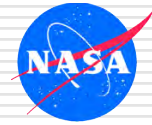
# More QFED intercomparison

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□ Poster:

Ellison, Luke, and Charles Ichoku:

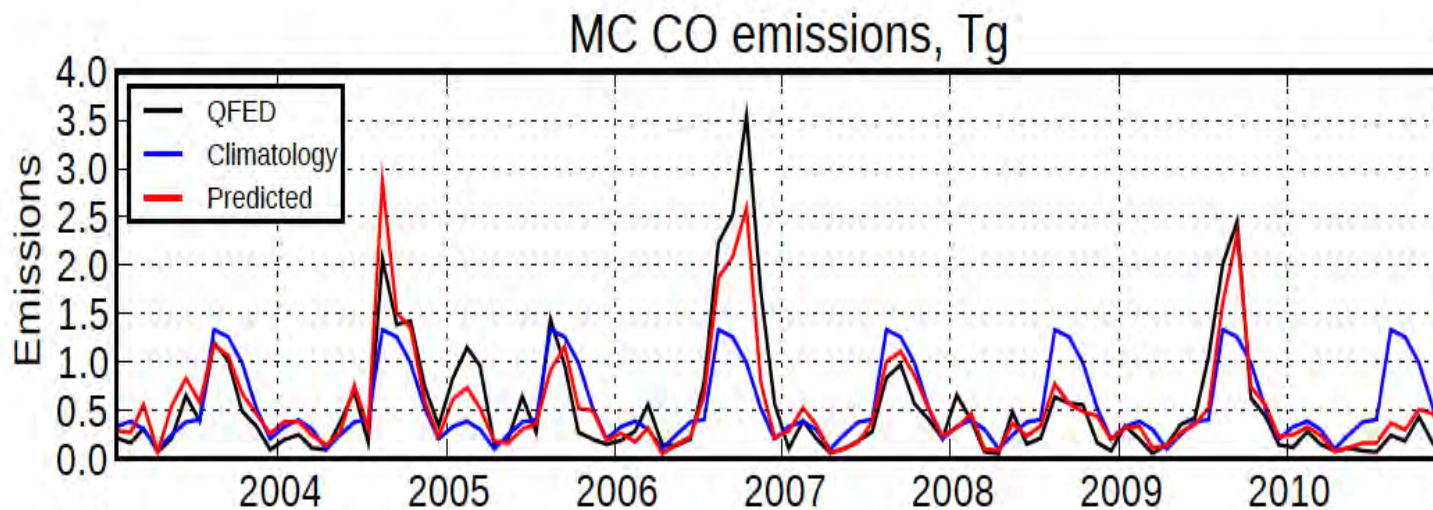
*The FEER coefficient of emission (Ce) product and a comparison to other common emission inventories.*



# Modeling Interannual Variability of Biomass Burning Emissions

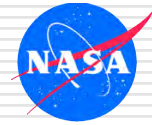
- BB emission anomalies respond directly to precipitation and surface humidity conditions
- The normalized Canadian Fire Weather Index captures the *fammability* conditions as a function of surface meteorology
- Parameterization:

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



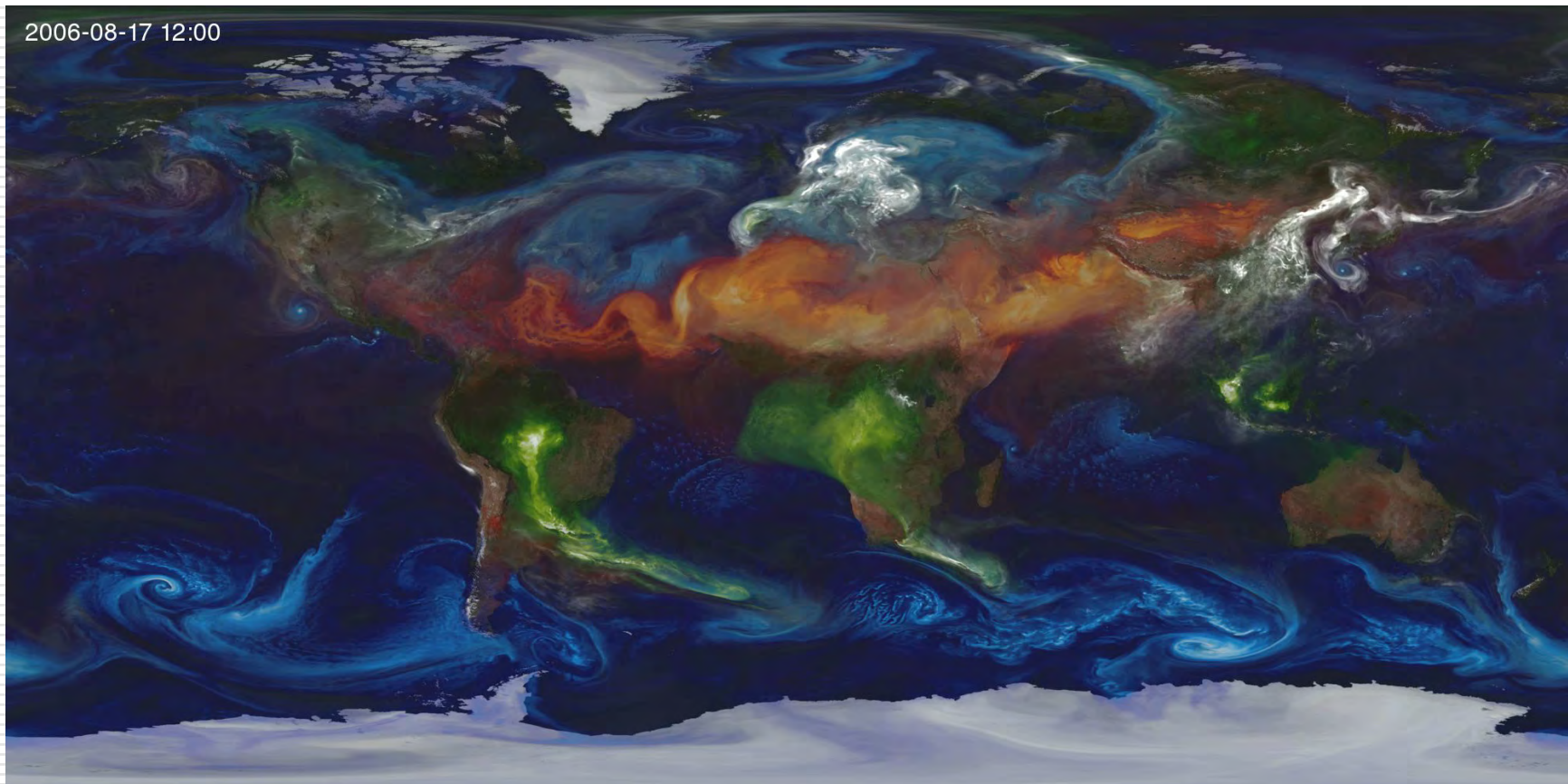
Maritime Continent Example



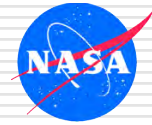


# GEOS-5 *Nature Run* for OSSEs

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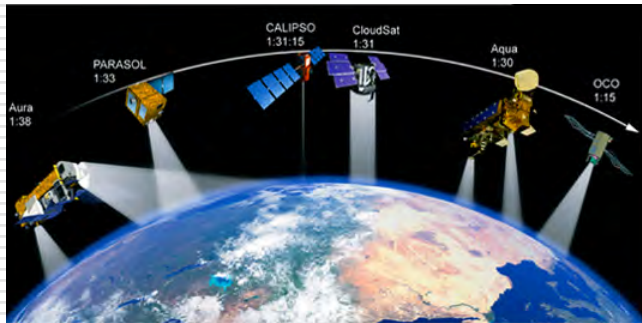


GEOS-5 10km Global Mesoscale Simulation: SST, aerosol emissions<sup>12</sup>



# Aerosol Data Assimilation

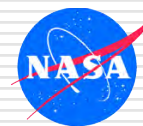
- Focus on NASA EOS instruments, MODIS for now



- 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





# NRL Empirical AOD Corrections

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 111, D22207, doi:10.1029/2005JD006898, 2006

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**MODIS aerosol product analysis for data assimilation:  
Assessment of over-ocean level 2 aerosol optical  
thickness retrievals**

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doi:10.5194/amt-6-949-2013  
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**Critical evaluation of the MODIS Deep Blue aerosol optical depth  
product for data assimilation over North Africa**

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Atmospheric  
Measurement  
Techniques



**An over-land aerosol optical depth data  
set for data assimilation by filtering,  
and aggregation of MODIS  
optical depth retrievals**

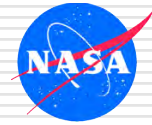
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Accepted: 14 August 2010 – Published: 14 September 2010  
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Publications on behalf of the European Geosciences Union.



# 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

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

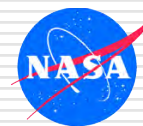
## Land Predictors

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

## Target: AERONET

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

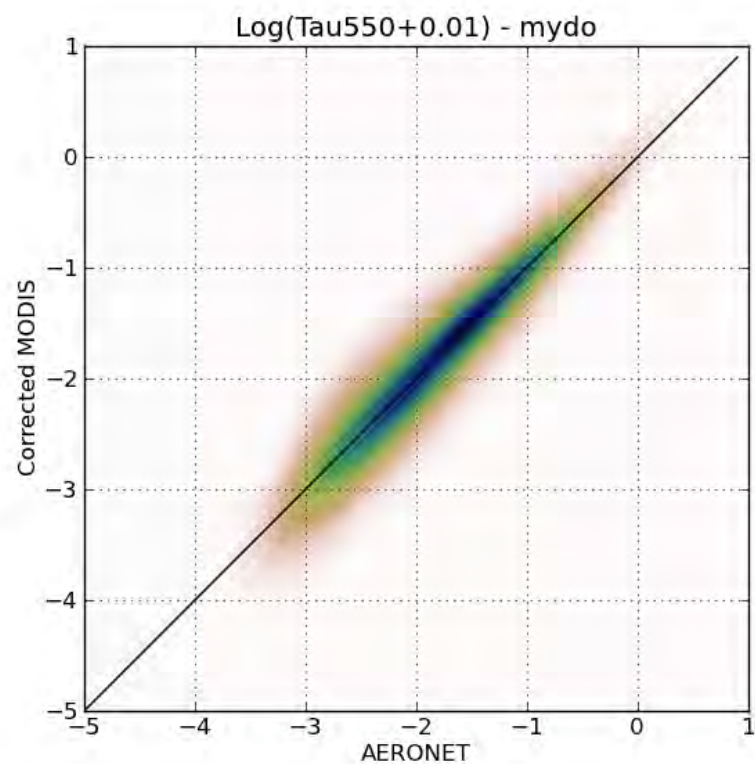
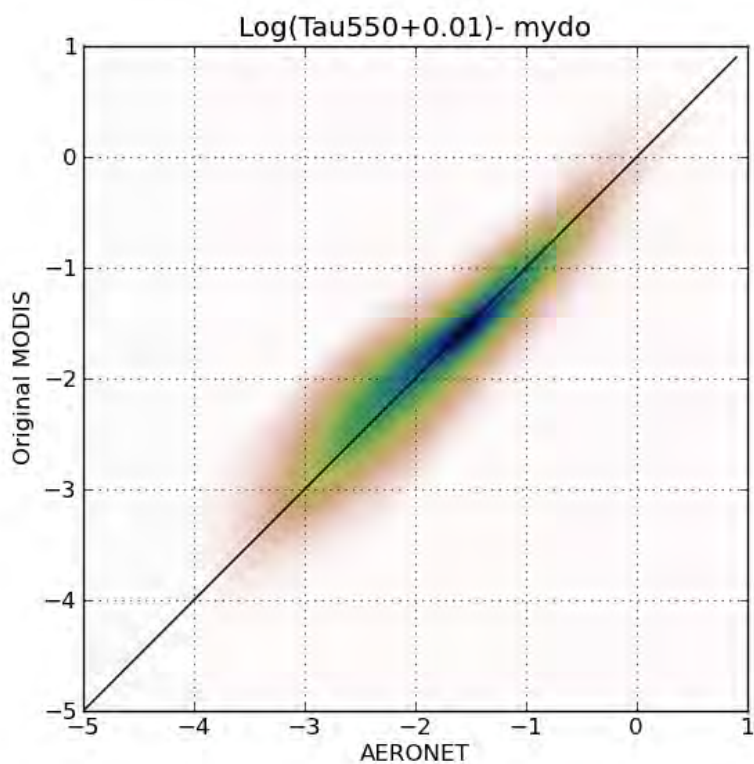


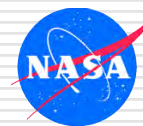


# MODIS AOD over Ocean

## Collection 5 (Aqua)

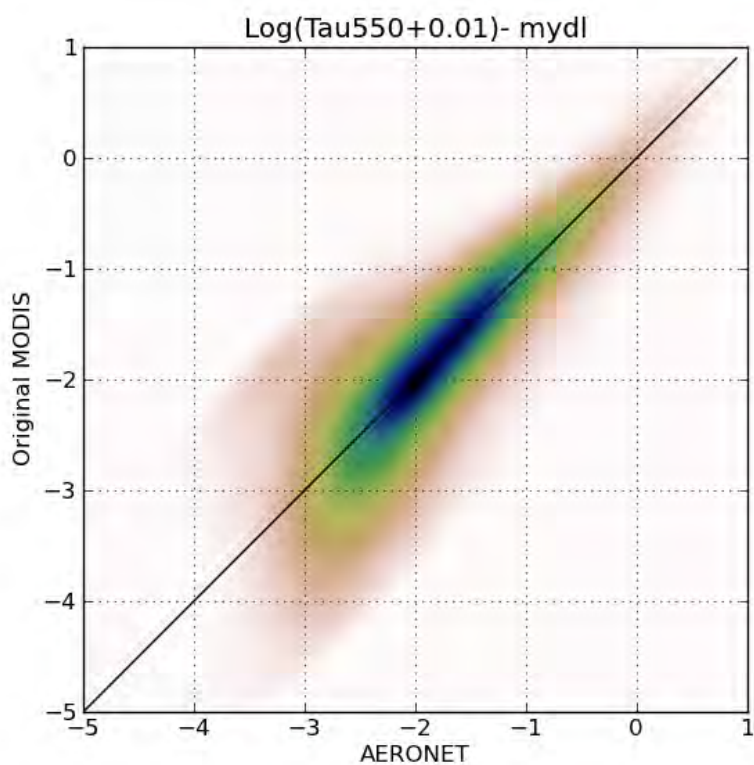
## NNR Retrieval



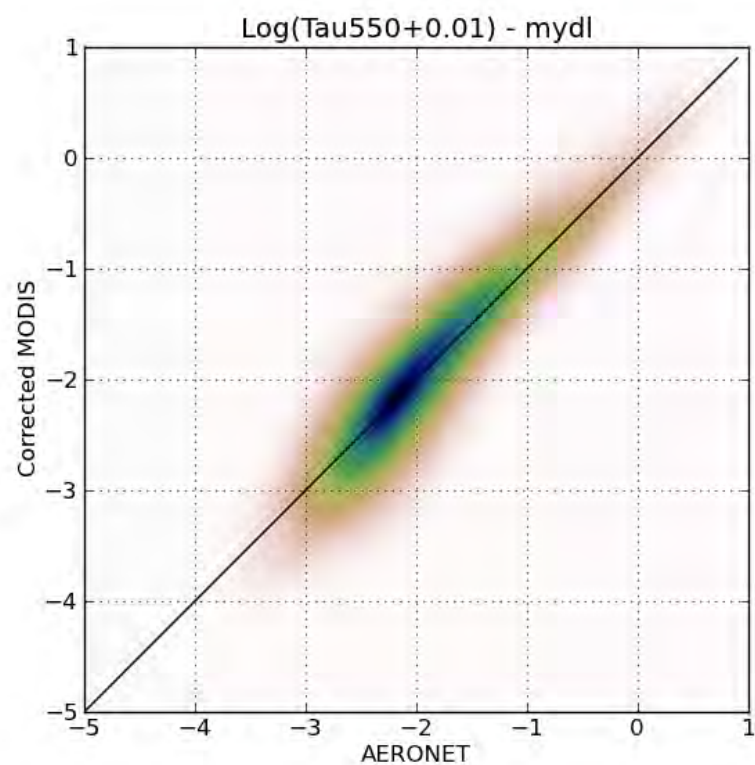


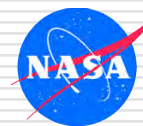
# MODIS AOD over Land

## Dark Target Coll. 5



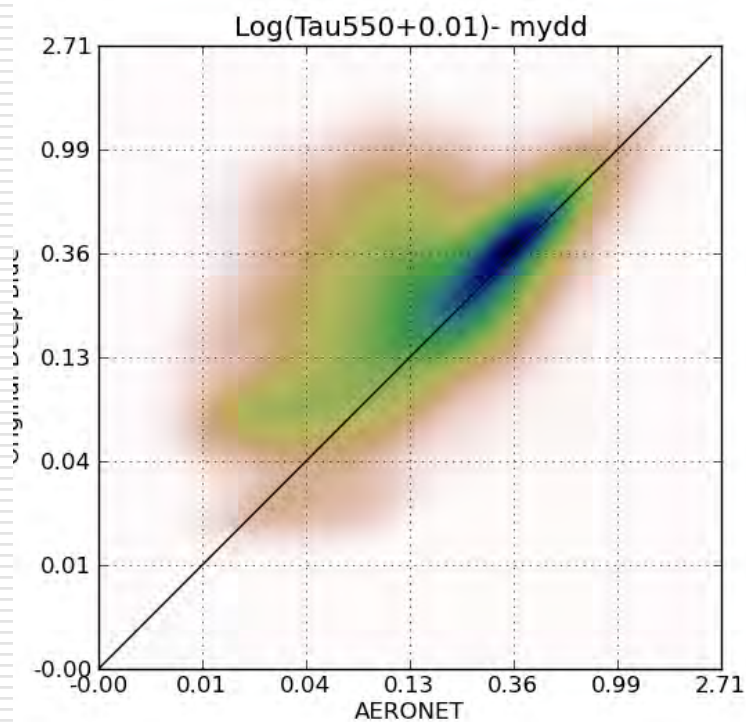
## NNR Retrieval



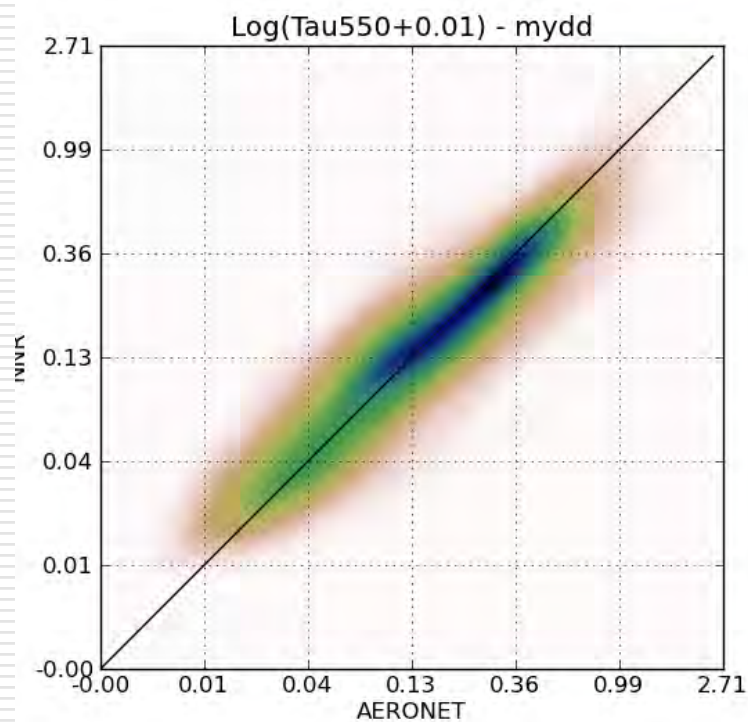


# MODIS AOD over Land

## Deep Blue Coll. 5



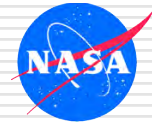
## NNR Retrieval



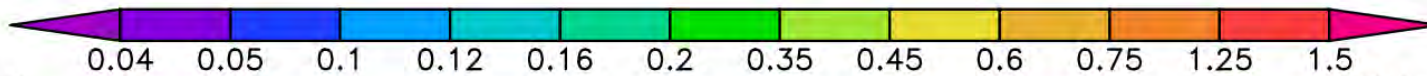
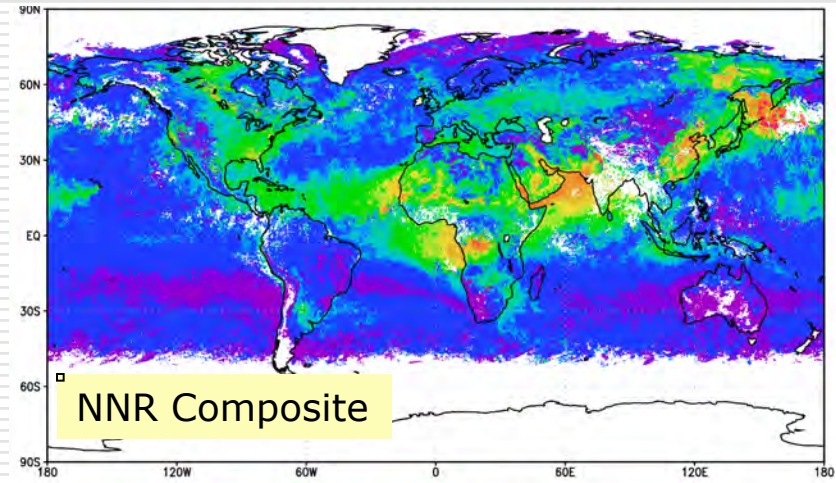
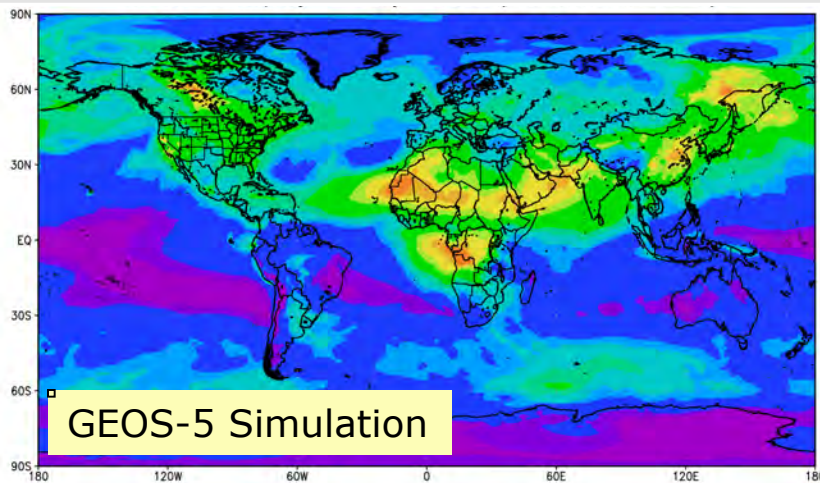
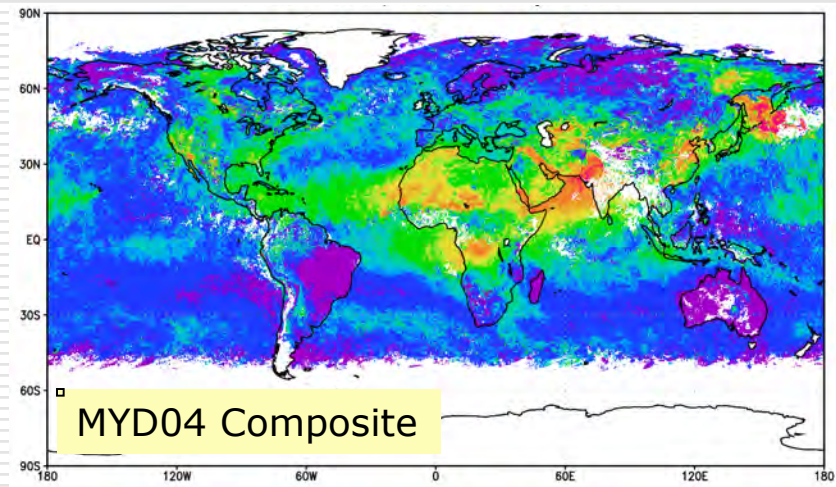
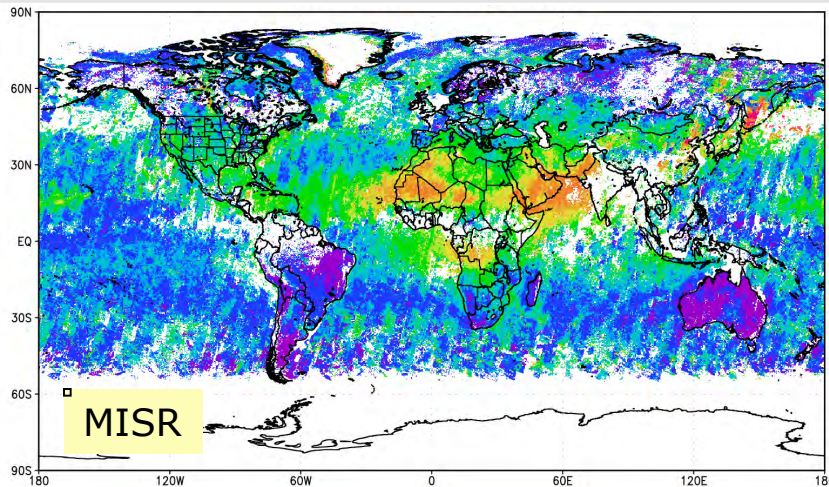
Bright Surfaces (albedo > 0.15)

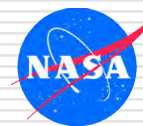


# Challenge: AOD Spatial Coherence



July 2008



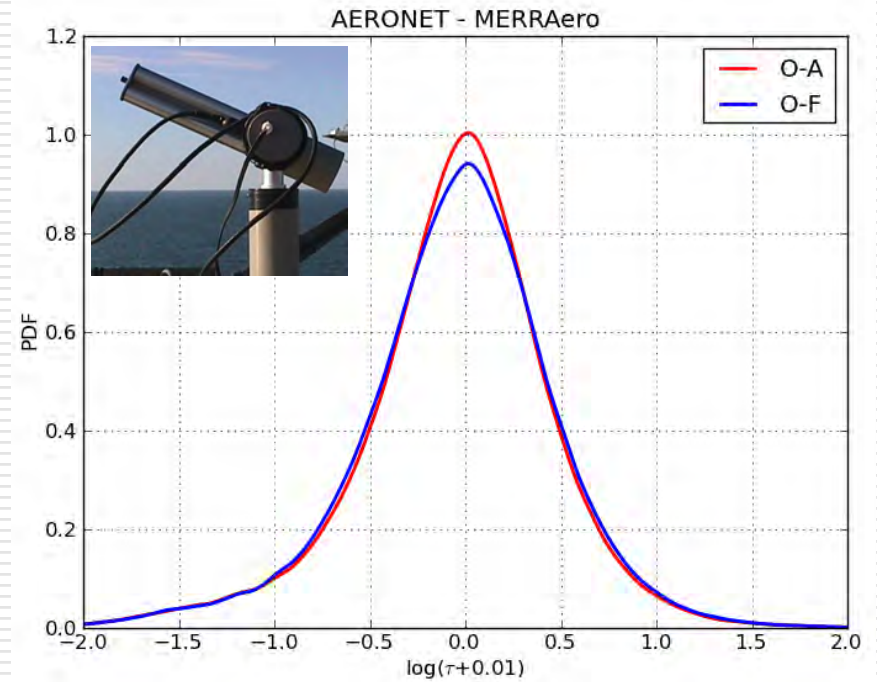
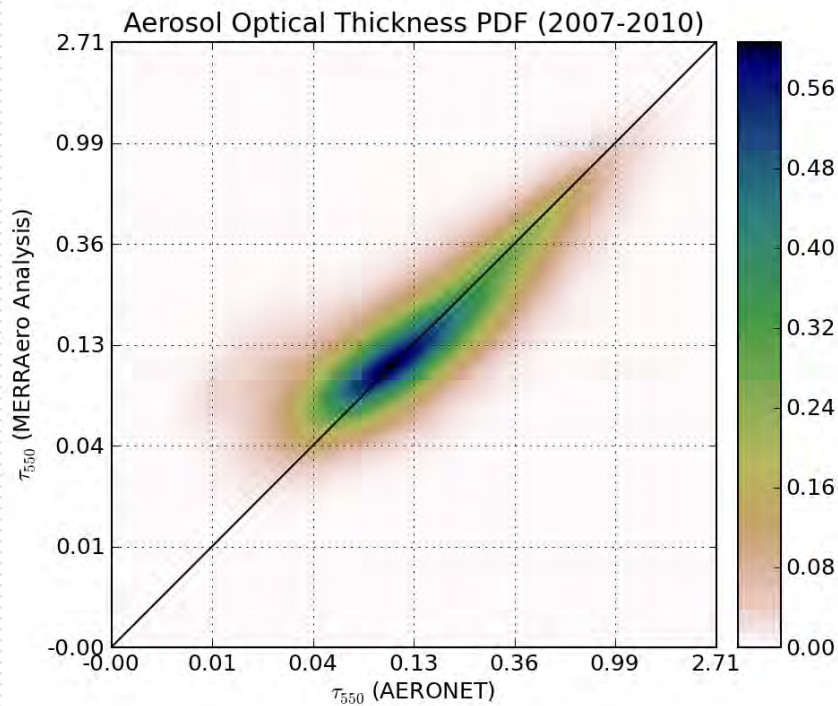


# MERRA*Aero* Overview

Feature	Description
<b>Model</b>	GEOS-5 Earth Modeling System (w/ GOCART) Constrained by MERRA Meteorology (Replay) Land sees obs. precipitation (like MERRA <i>Land</i> ) Driven by QFED daily Biomass Emissions
<b>Aerosol Data Assimilation</b>	Local Displacement Ensembles (LDE) MODIS reflectances AERONET Calibrated AOD's (Neural Net) Stringent cloud screening
<b>Period</b>	mid 2002-present (Aqua + Terra) 2000-mid 2002 (Terra only)
<b>Resolution</b>	Horizontal: nominally 50 km Vertical: 72 layers, top ~85 km
<b>Aerosol Species</b>	Dust, sea-salt, sulfates, organic & black carbon

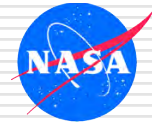


# AERONET Validation

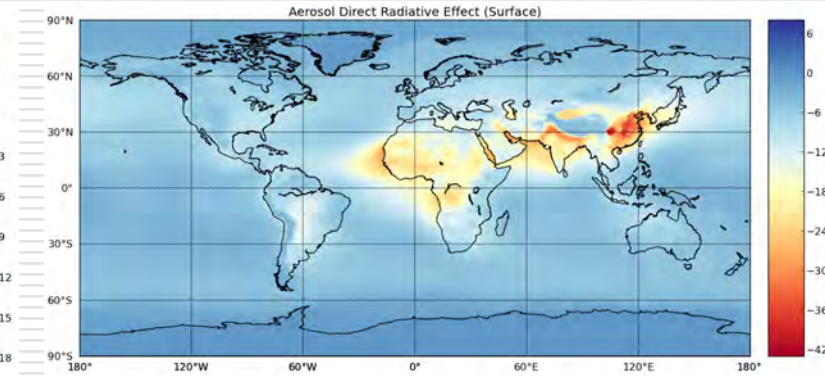
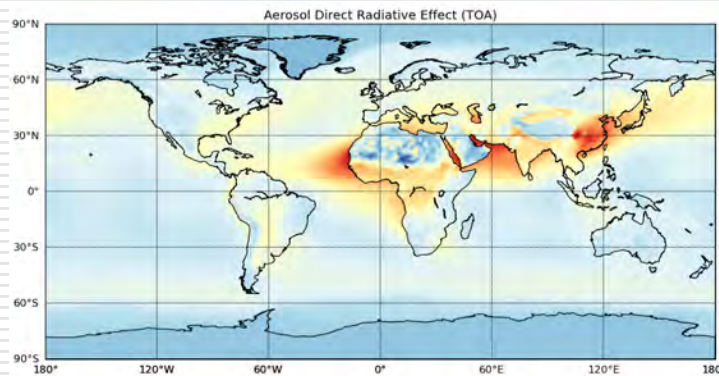


$$\eta = \log(\tau + 0.01)$$

# Clear-Sky



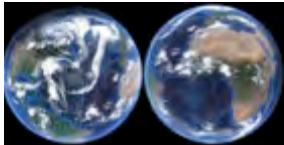
# Aerosol Direct Radiative Effect



Source	TOA SW DRE Ocean (Land)		Atmos. Ocean (Land)		Surface SW DRE Ocean (Land)	
<b>MERRAero</b>	-3.8	(-4.3)	2.8 (6.8)		-6.6	(-11.1)
Other Observational Yu <i>et al.</i> (2006)	-5.5 ± 0.2	(-4.9 ± 0.7)	3.3 (6.8)		-8.8 ± 0.7	(-11.8 ± 1.9)
Multi-model Ensemble Yu <i>et al.</i> (2006)	-3.4 ± 0.6	(-2.8 ± 0.6)	1.4 (4.4)		-4.8 ± 0.8	(-7.2 ± 0.9)
GEOS-5 (Free)	-3.4	(-2.7)	0.5 (2.8)		-3.9	(-5.5)

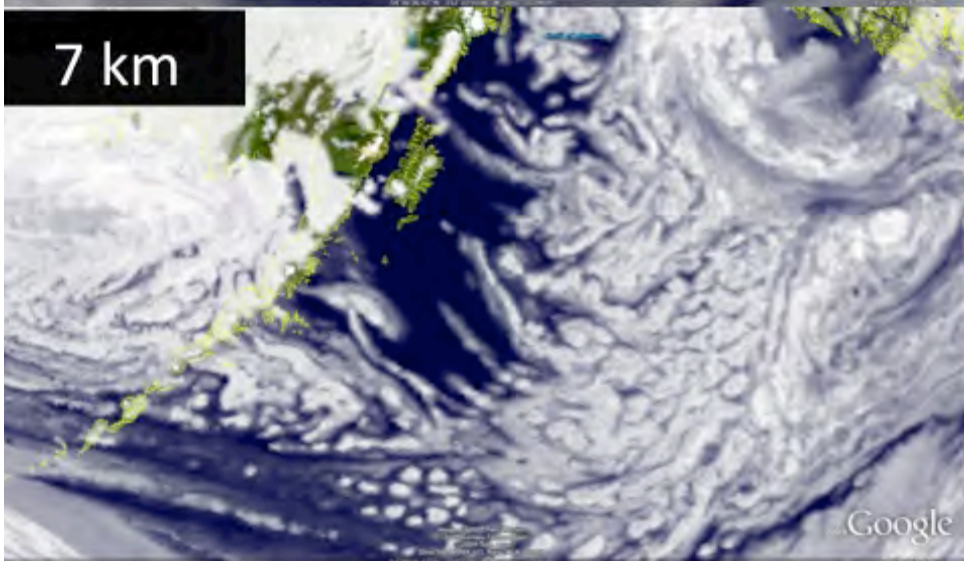
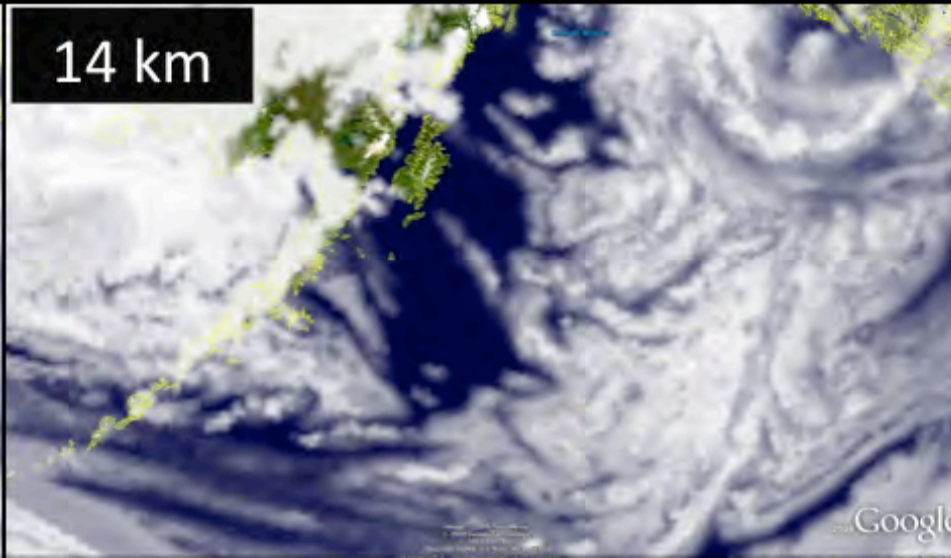
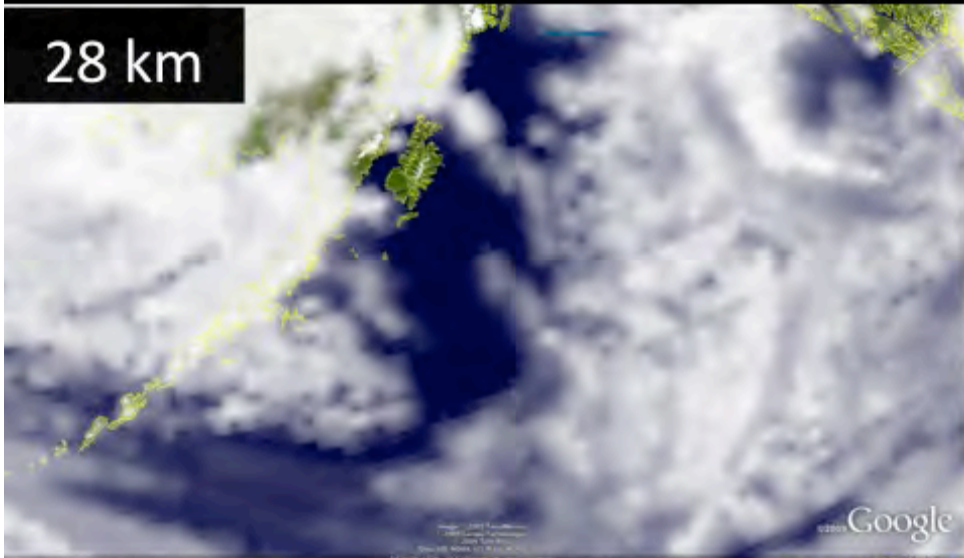
$$DRE_{sw} = \left( F_{SW}^{\downarrow} - F_{SW}^{\uparrow} \right)_{Aerosols} - \left( F_{SW}^{\downarrow} - F_{SW}^{\uparrow} \right)_{NoAerosols}$$



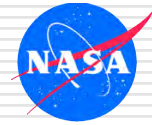


# Karman Vortex Streets

SCIENCE  
MISSION DIRECTORATE





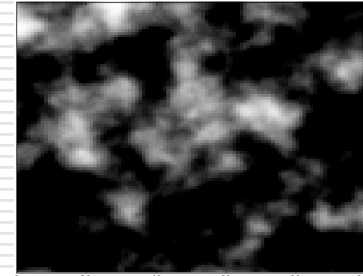


# Cloud Data Assimilation

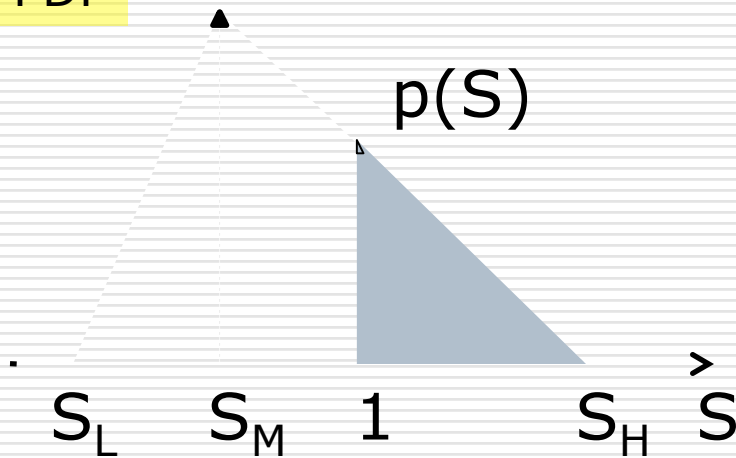
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- We cannot simply insert clouds in the model
  - We need to convince the model to make clouds
- Recent GCM cloud parameterizations are based on a PDF of total water (vapor+condensate)
  - much higher resolution satellite data can be used to constrain total water PDF
  - “Cloud relocater”
- Improved cloud distribution essential for effective assimilation of cloudy radiances in 3D/4D Var:
  - Microwave data used to constrain cloud liquid water
- Data retention requires high degree of consistency across GCM and assimilation algorithms.
- Validation: CloudSat, CERES, SRB

# Clouds & Sub-grid Variability

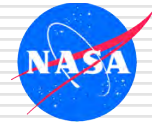


PDF



$$S = (q_v + q_L + q_I) / q_s(T)$$

- PDF-based cloud parameterizations provide very useful information about sub-grid variability
- Given a PDF of total water one can generate sub-columns consistent with that PDF
- Observation simulators can account for representativeness error by operating on these sub-columns



# Bayesian Parameter Estimation

- Within a grid column, consider a set of measurements

$$\mathbf{y} = (y_1, \dots, y_p)$$

say MODIS cloud top pressure, cloud optical depth

- Goal:

- estimate PDF parameters  $\alpha_k$
- Given the observations  $\mathbf{y}$

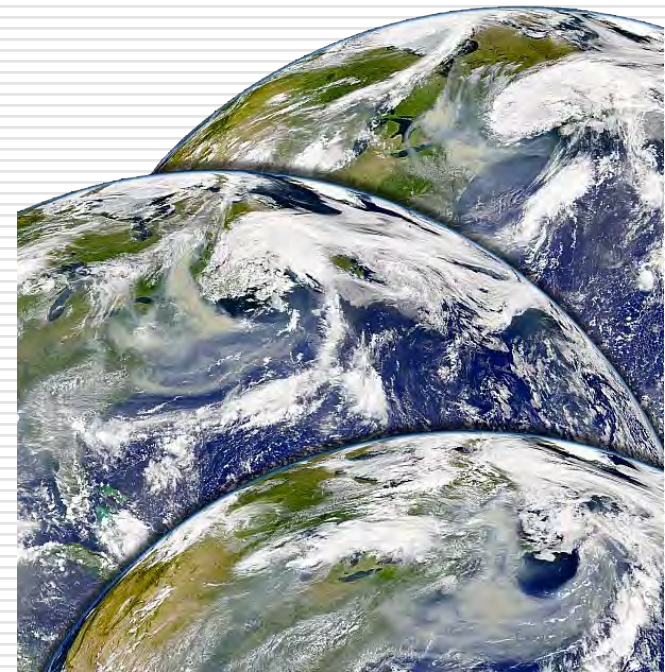
- Bayes theorem:

$$p(\alpha|\mathbf{y}) \sim p(\mathbf{y}|\alpha) p(\alpha)$$

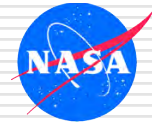
- Maximum-likelihood estimation

- Find  $\alpha$  that maximizes  $p(\alpha|\mathbf{y})$

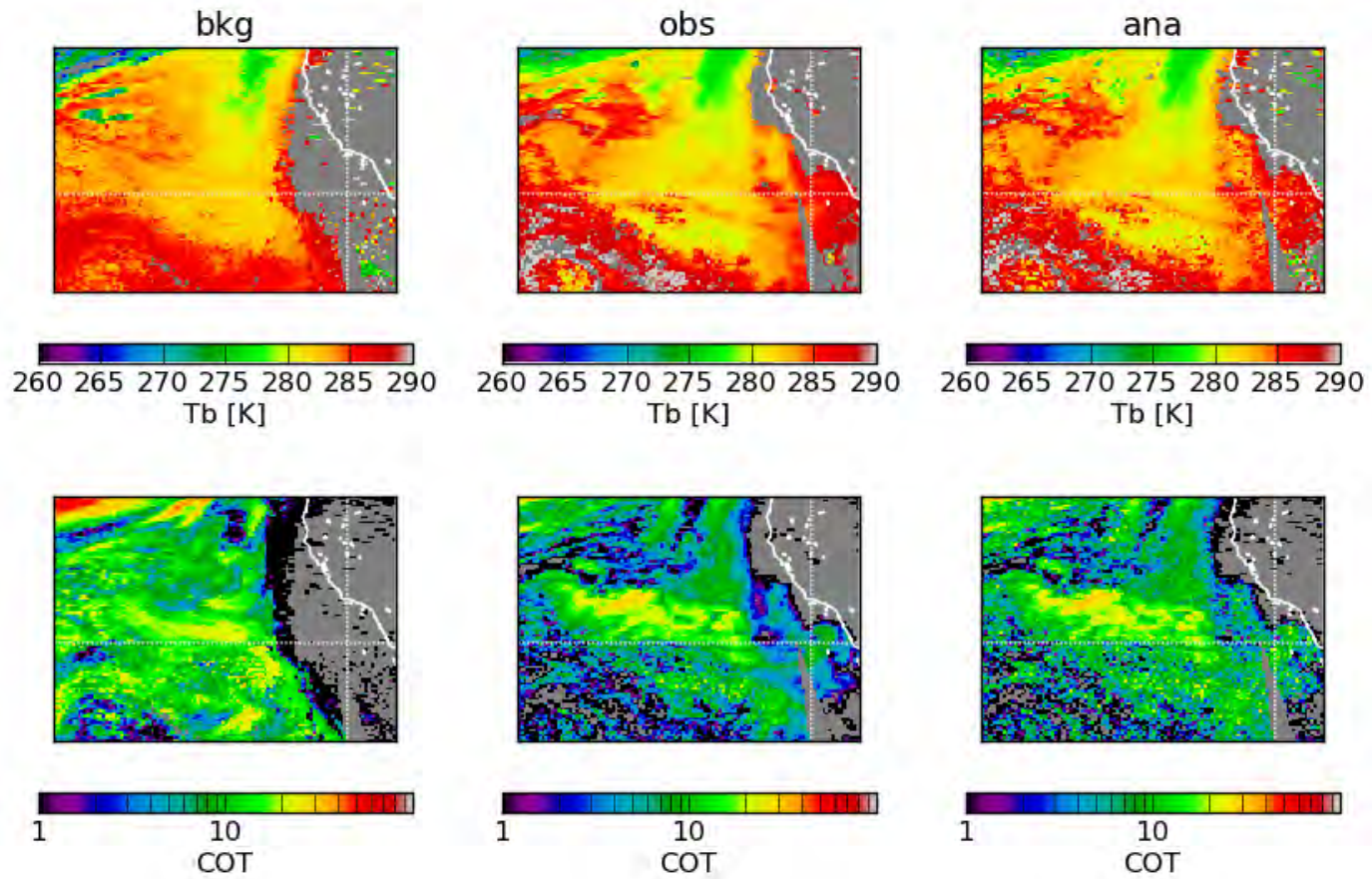
- In short: find PDF parameters that “matches” MODIS hi-res data



□ *Markov Chain Monte Carlo Method*



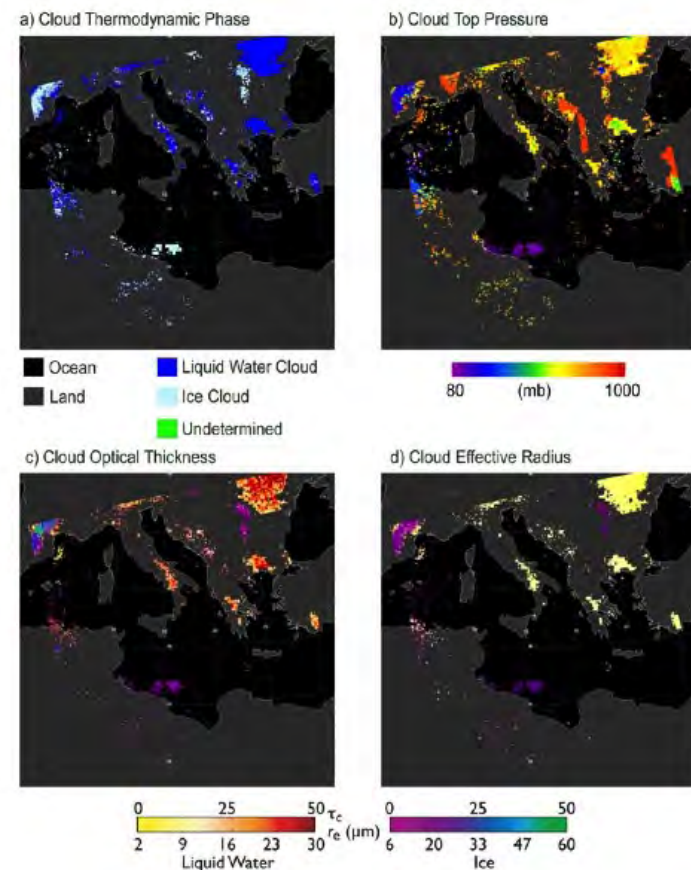
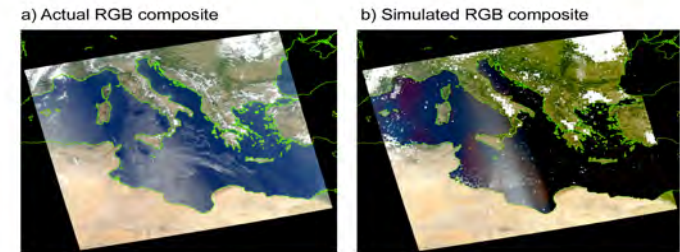
# Stratocumulus



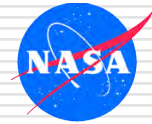


# Cloudy OSSEs

- MODIS Cloud Retrieval Simulator
  - PDF based **sub-grid sampling** of GEOS-5 fields (ICA)
  - Spatial “clumping”
  - Radiances for 27 MODIS channels
  - Operational **MOD06** cloud retrieval algorithm
- Extension for aerosols
  - Add aerosol optical properties
  - Produce **MOD04**





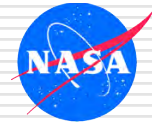


# Concluding Remarks

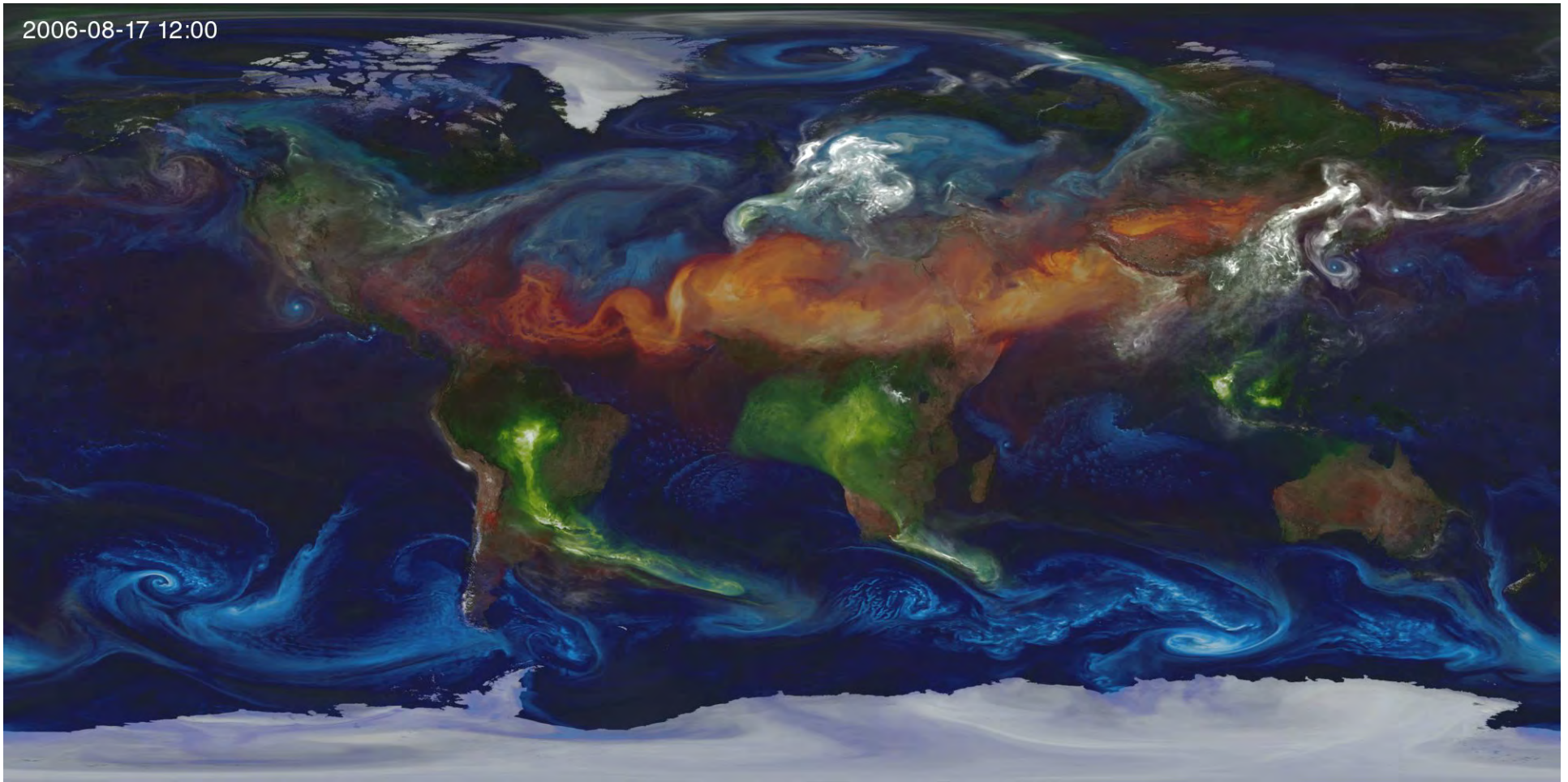
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- MODIS data have provided the foundation for GEOS-5 aerosol and cloud modeling and data assimilation.
- Going further...
  - Modeling of cloud-aerosol microphysical processes in GEOS-5 will present new challenges and opportunities
  - GEOS-5 data assimilation evolving into an hybrid Ensemble-variational system
  - As we move to more direct measurements (radiances) close collaboration with instrument team is crucial.

# GEOS-5 Aerosols



2006-08-17 12:00



GEOS-5 10km Global Mesoscale Simulation: SST, aerosol emissions<sup>30</sup>