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Status of GEOS-5 Nature Runs for Atmospheric Composition

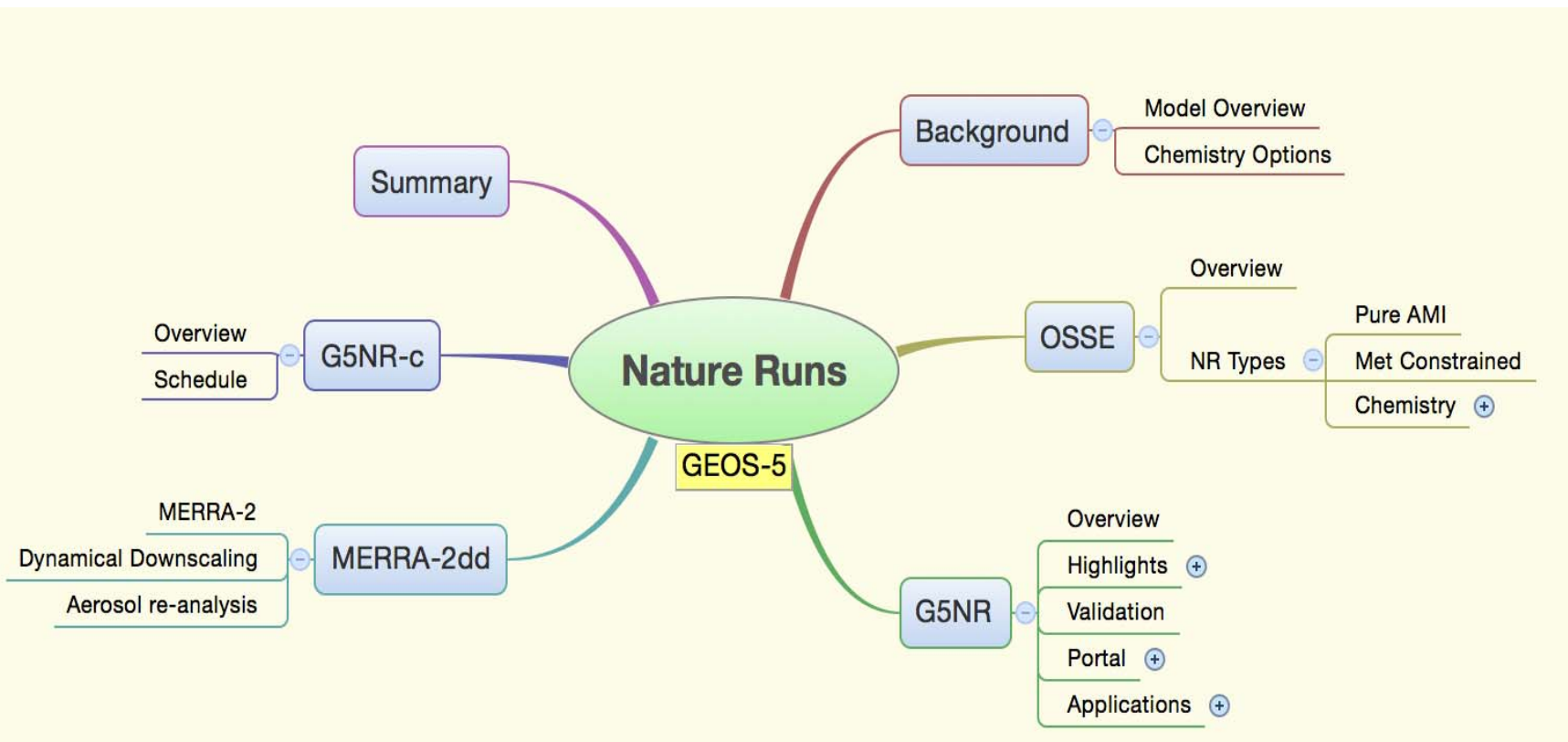
Arlindo da Silva, William Putman and the GEOS-5 Development Team

Arlindo.dasilva@nasa.gov

Global Modeling and Assimilation Office, NASA/GSFC

CEOS Atmospheric Composition Constellation Meeting
ACC-11 at ESA/ESRIN, Frascati, Italy
April 28-30, 2015

Overview



GEOS-5

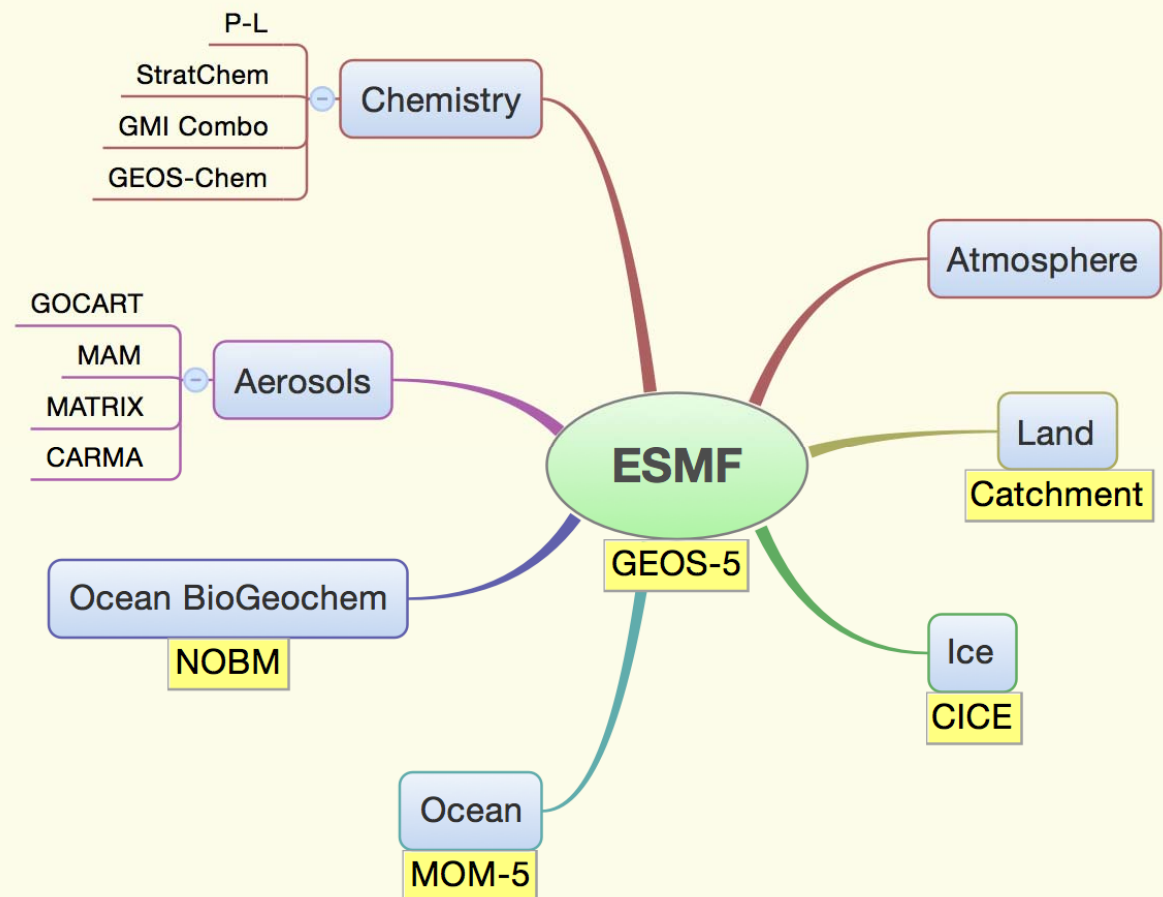
Components coupling via the Earth System Model Framework (ESMF)

Aerosol and chemistry radiatively coupled to GCM

Applications:

- Seasonal forecasts
- Weather and aerosol NRT forecasts
- Reanalysis
- Observing System Simulation Experiments (OSSEs)

Earth System Model



O.S.S.E.



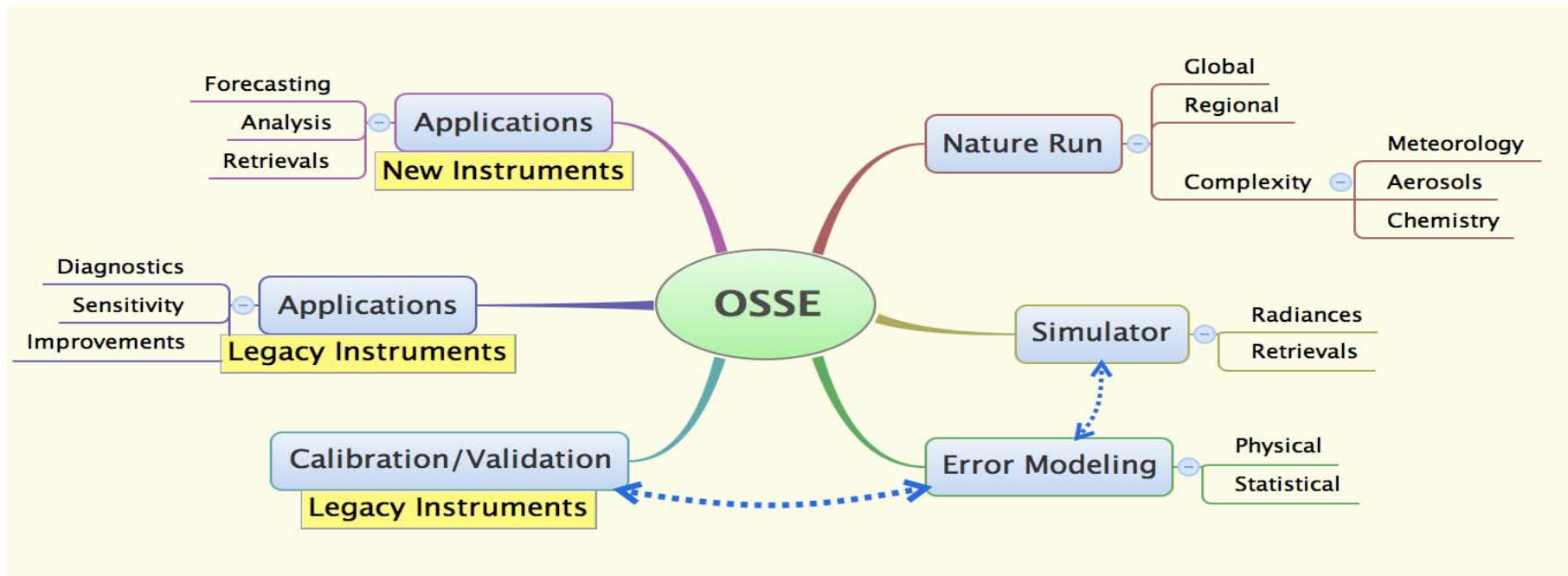
- Observing System
- Simulation
- Experiment

Model-based OSSE

A framework for numerical experimentation in which *observables* are simulated from fields generated by an earth system model, including a *parameterized* description of the *observational error* characteristics.

Simulations are performed in support of an experimental goal.

Elements of an OSSE System



Requirements for a Nature Run



GENERAL REQUIREMENTS

- **Must produce realistic weather and variability**
 - High impact / Extreme events
 - Mid-latitude storms, Tropical cyclones
 - Organized convective clusters
- **Climatology must be representative of Nature**
 - It must resemble the real atmosphere
 - Fall within a statistically acceptable level of variance for the climate of Earth
 - While it will not be exactly the climate of a given year, it must be a statistically possible scenario

TYPES OF NATURE RUNS

- **Free running simulation**
 - No constraints to observed meteorology or atmospheric composition
 - It will not produce specific weather events
 - But it will produce similar events
 - ***Can be used to investigate impact of meteorological errors on transport***
- **Constrained meteorology, free running atmospheric composition**
 - Meteorology constrained by observations
 - Atmospheric composition runs free
 - ***Composition can be validated by field campaigns or satellite data***

Free-running 7 km GEOS-5 Nature Run

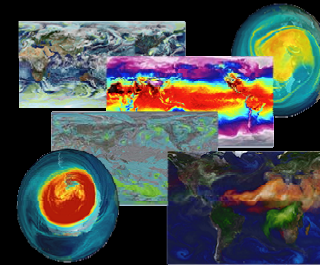


SIMULATION DETAILS

- 2-years : *June 2005 – June 2007*
- 7-km Global Resolution [*72 vertical levels : 0.01mb top*]
- 5-minute physics time step [*5 seconds for dynamics*]
- Non-Hydrostatic Dynamics [*Finite-Volume Cubed-Sphere*]
- Limited deep convection [*RAS with stochastic Tokioka limiter*]
- Resolve mesoscale weather [*storm-scale and cloud clusters*]
- High-resolution constituent transport [*GOCART*]
- Executed on "Discover" at NCCS [*7200 Cores : 11-days/day*]

BOUNDARY CONDITIONS

- SST and Sea-Ice [*1/4-degree Reynolds/OSTIA*]
- CO/CO₂ Fossil fuel emissions [*10-km EDGAR inventory*]
- Land CO₂ fluxes [*CASA-GFED at 10-km with MODIS EVI*]
- Biomass burning [*daily QFED emissions*]
- Volcanic SO₂ [*AEROCOM emissions and injection heights*]
- GOCART [*mixing, chemistry, and deposition*]
 - Key aerosol types [*sulfates, dust, black&organic carbon*]
 - aerosols are *radiatively coupled* with the dynamics

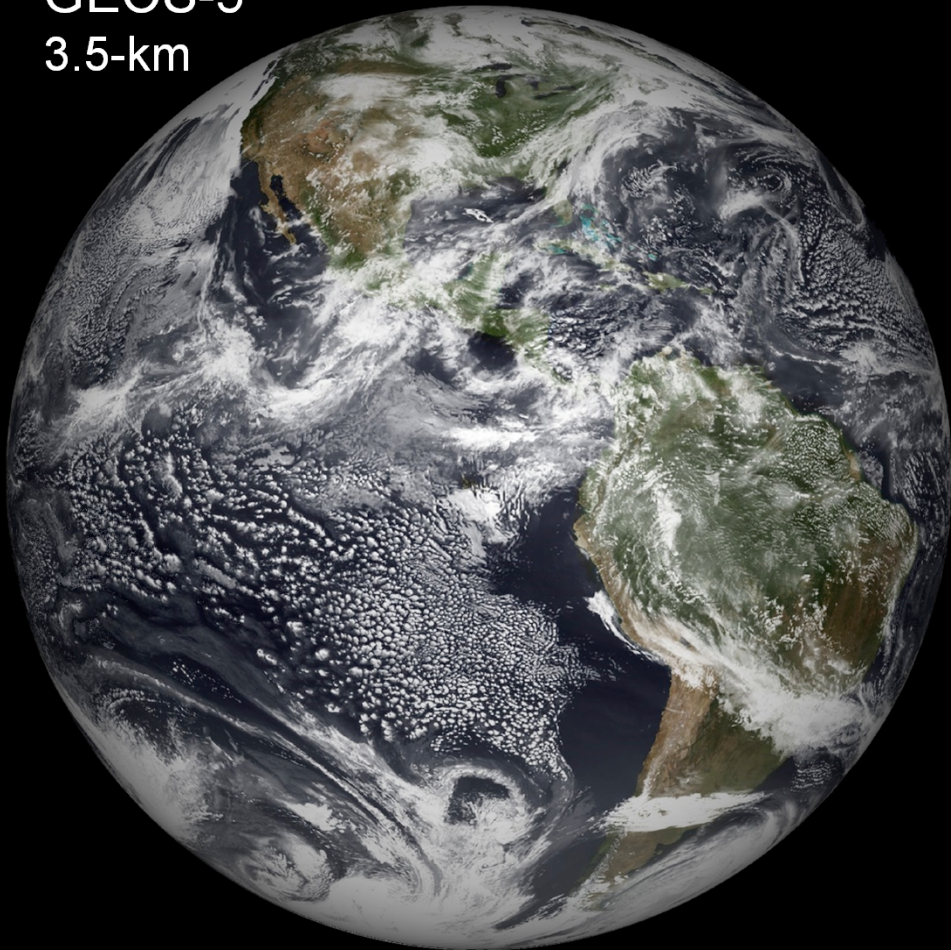


Model resolution \approx Satellite scales

~50-million pixels

GEOS-5

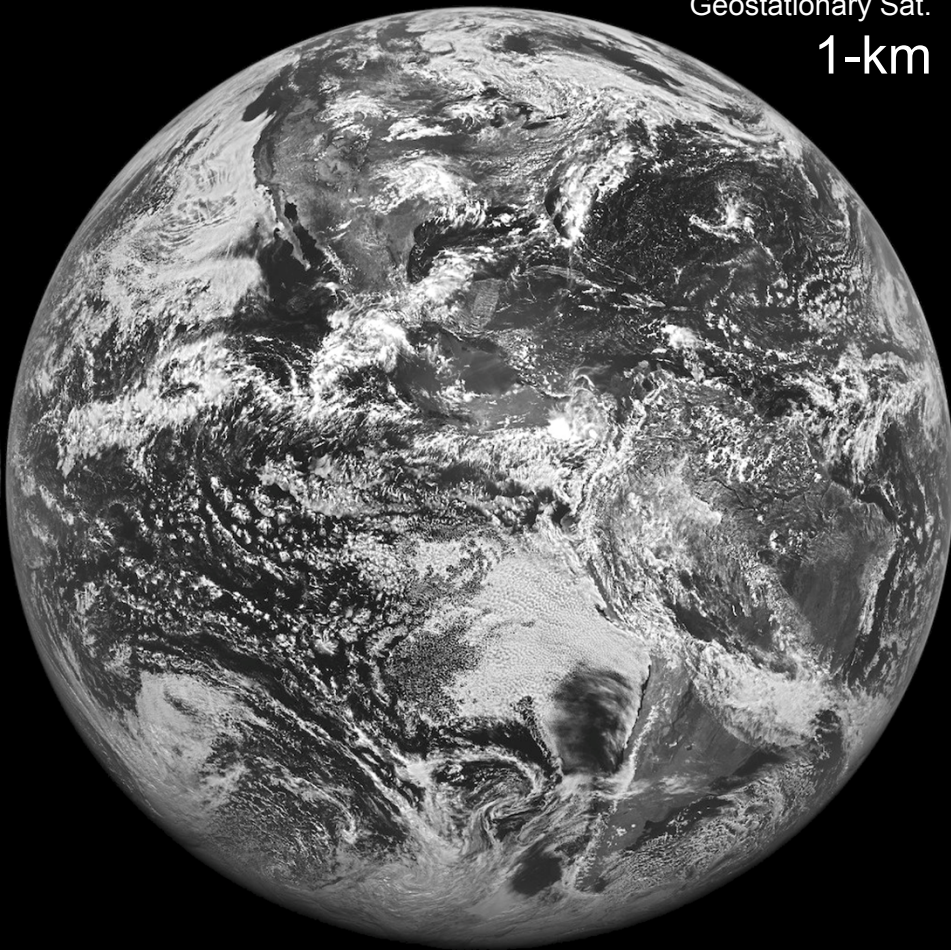
3.5-km



~200-million pixels

Geostationary Sat.

1-km



Clouds

Clouds have a critical role in the Earth's weather/climate system. With horizontal resolution increased to 7-km, GEOS-5 now becomes capable of resolving clusters of clouds rather than simply relying on the statistical effects of clouds over large grid boxes. Cloud systems of the ITCZ, tropical storms, and mid-latitude storms begin to resemble clouds as observed from space.

7 km GEOS-5 Nature Run Global Mesoscale Simulation

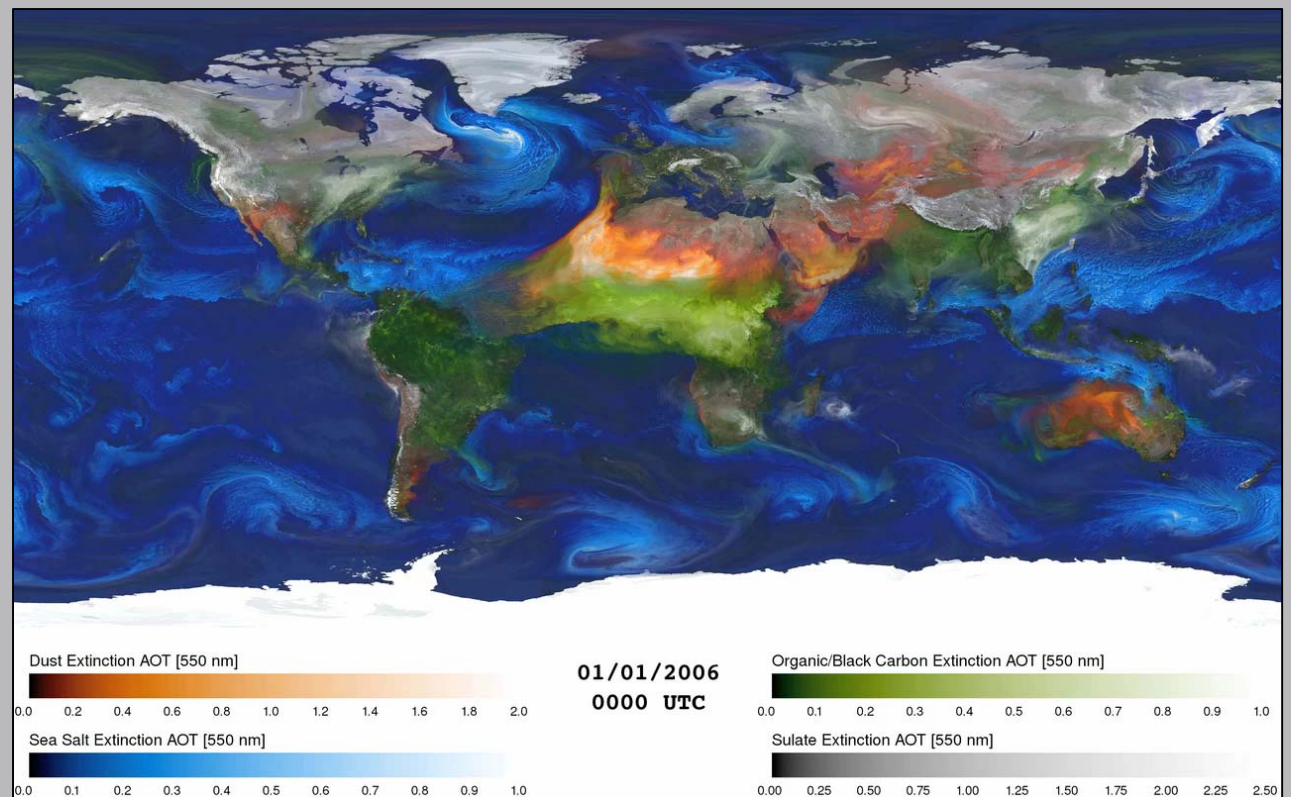


Global Aerosols

Aerosols play an important role in both weather and climate. They are transported around the globe far from their source regions, interacting with weather systems, scattering and absorbing solar and terrestrial radiation, and modifying cloud micro- and macro-physical properties. They are recognized as one of the most important forcing agents in the climate system.

7 km GEOS-5 Nature Run Global Mesoscale Simulation

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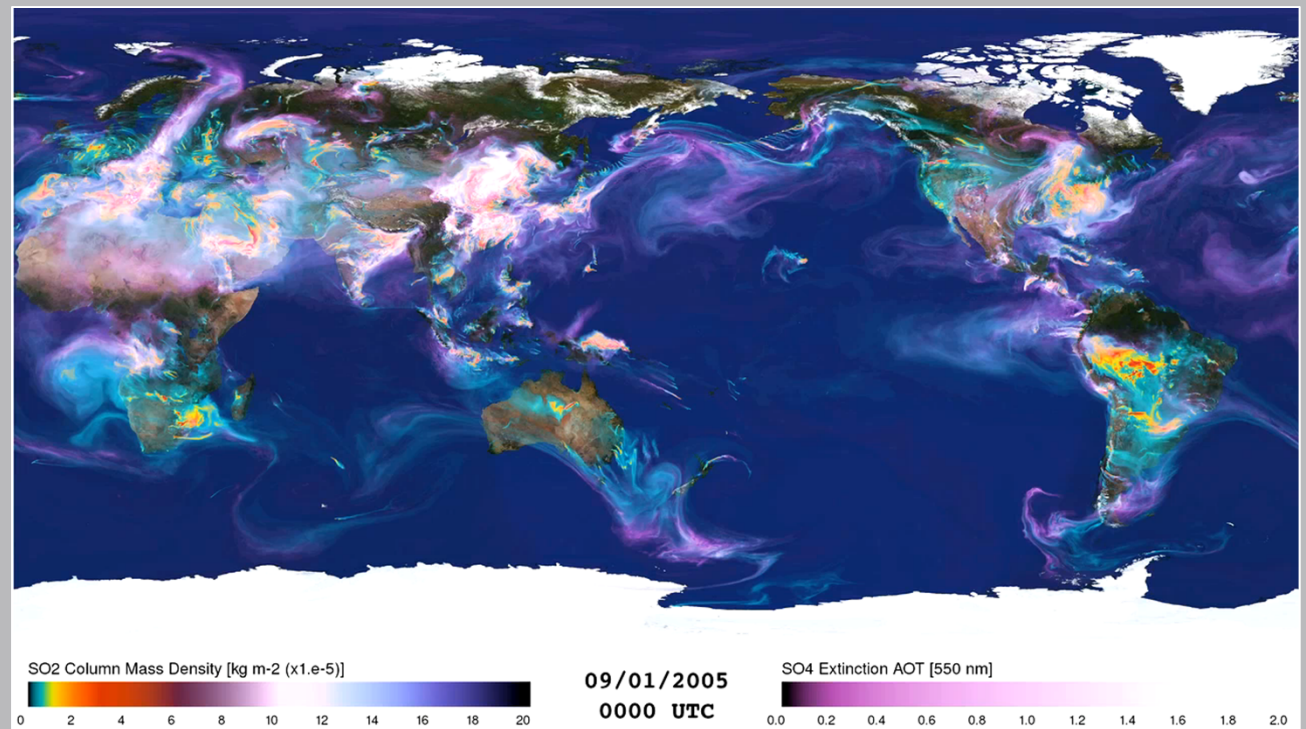


Sulfur Dioxide Sulfate Aerosols

Sulfur dioxide (SO_2), produced during the burning of fossil fuels and from volcanic eruptions, is a short lived gas which can act as pollutant near the surface with detrimental health and acidifying effects. With a mean life time of just a couple of days in the troposphere, emitted SO_2 is quickly converted to sulfate aerosol (SO_4) through oxidation by OH or by reaction with H_2O_2 within clouds. The resulting SO_4 exerts a direct radiative effect on the atmosphere and it can also have an indirect radiative effect by inducing changes in cloud and precipitation microphysics.

7 km GEOS-5 Nature Run Global Mesoscale Simulation

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Carbon Species: CO & CO₂

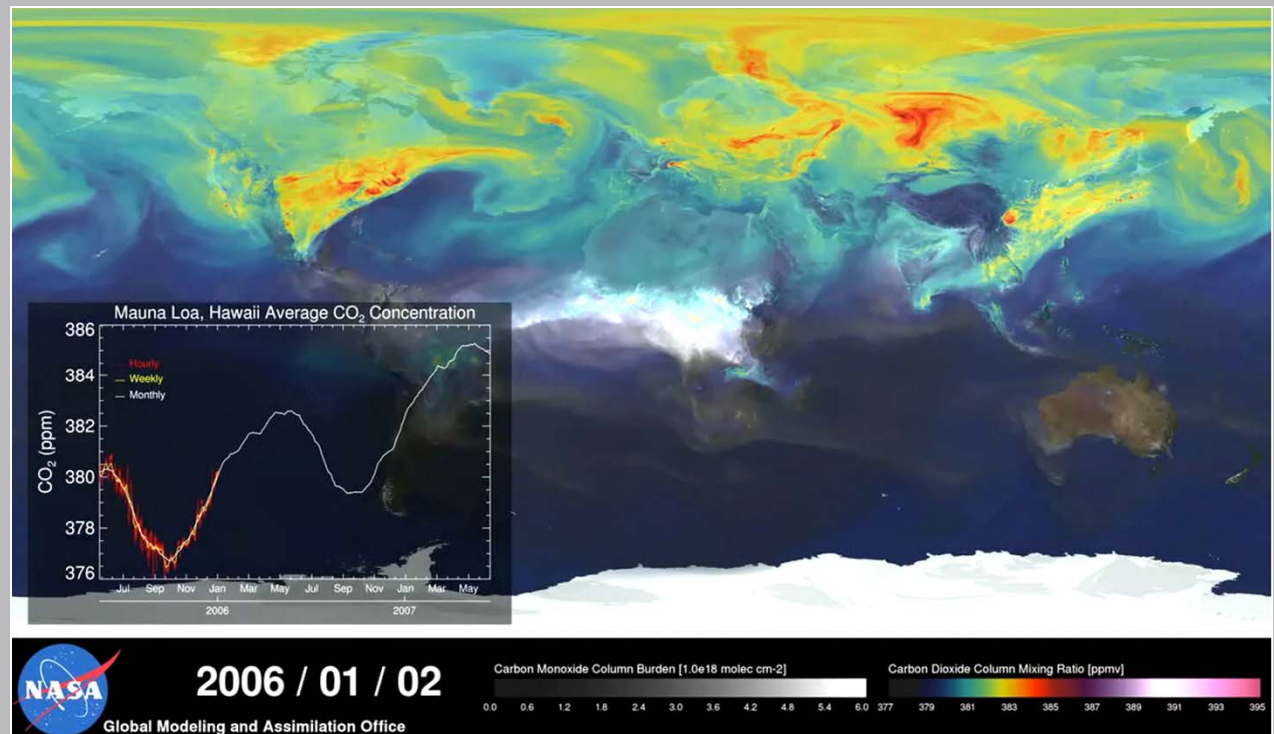
This visualization shows column concentrations of atmospheric CO₂ (colored shades) and CO (white shades underneath) from January 1, 2006 to December 31, 2006. CO₂ variations are largely controlled by fossil fuel emissions and seasonal fluxes of carbon between the atmosphere and land biosphere.

CO₂ concentrations are enhanced by carbon sources, mainly from human activities. During Northern Hemisphere spring and summer months, plants absorb a substantial amount of CO₂ through photosynthesis, thus removing CO₂ from the atmosphere.

Atmospheric CO, a pollutant harmful to human health, is produced mainly from fossil fuel combustion and biomass burning. Here, high concentrations of CO (white) are mainly from fire activity in Africa, South America, and Australia.

7 km GEOS-5 Nature Run Global Mesoscale Simulation

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G5NR Data Portal

<http://gmao.gsfc.nasa.gov/projects/G5NR/>



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G5NR Documentation

File Specification
Data Access Guide
GEOS-5 Configuration
Validation

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GEOS-5 Nature Run, Ganymed Release

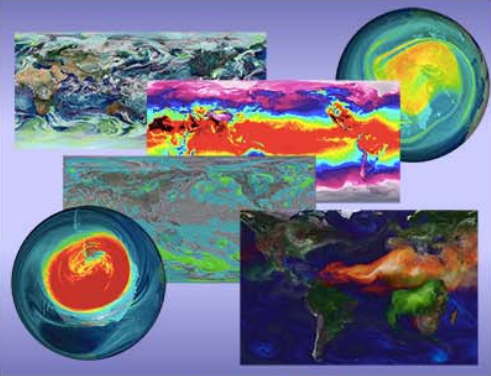
Non-hydrostatic 7 km Global Mesoscale Simulation

The GEOS-5 Nature Run (Ganymed Release) is a 2-year global, non-hydrostatic mesoscale simulation for the period June 2005 through May 2007 with a 7 km horizontal resolution. In addition to standard meteorological parameters (wind, temperature, moisture, surface pressure), this simulation includes 15 aerosol tracers (dust, seasalt, sulfate, black and organic carbon), O₃, CO and CO₂. This model simulation is driven by prescribed sea-surface temperature and sea-ice, daily volcanic and biomass burning emissions, as well as high-resolution inventories of anthropogenic sources.

Simulation Images, Animations, and Data

Highlights **Images** Get Data Documentation

IMAGES



G5NR Image Server at NCCS

G5NR Data Portal

<http://g5nr.nccs.nasa.gov/images/cloudsvis/2005/06/01/>



Cloudsvis

2005-06-01

0000z

Full resolution image



G5NR Data Portal

Documentation



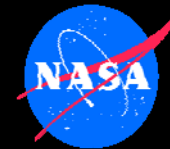
Simulation Images, Animations, and Data

Highlights Images Get Data **Documentation**

DOCUMENTATION

- **File Specification.** This document has a comprehensive list of datasets available, as well as description of the horizontal and vertical grids.
- **Data Access Guide.** This wiki page has specific information on the location of our files and instructions on how to access from a variety of applications such as GrADS, Matlab, IDL or even from a C/Fortran program. Sample code is also provided.
- **GEOS-5 Configuration.** This document documents the particular configuration of the GEOS-5 earth system model used for the G5NR simulation. It includes an overview of the main parameterizations, boundary conditions and emissions files.
- **G5NR Validation.** This Technical Memorandum documentation on the scientific performance of the G5NR datasets. This is a required reading for understanding the strengths and limitations of the G5NR simulation and its applicability to a given application.

G5NR Validation Document



NASA/TM-2014-104606/Vol. 36

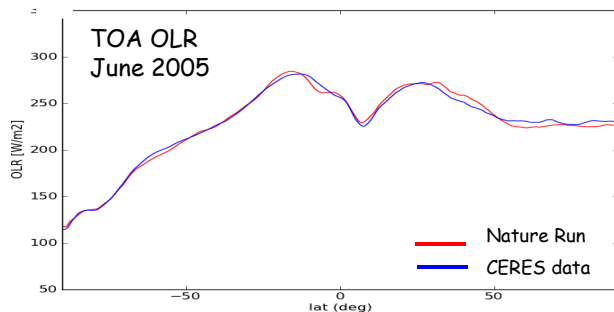


Technical Report Series on Global Modeling and Data Assimilation,
Volume 36

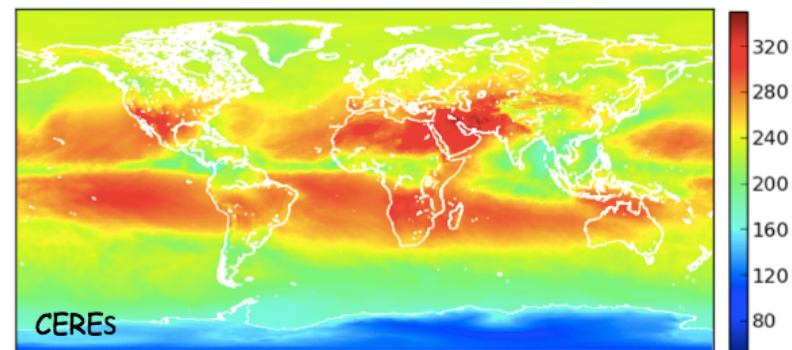
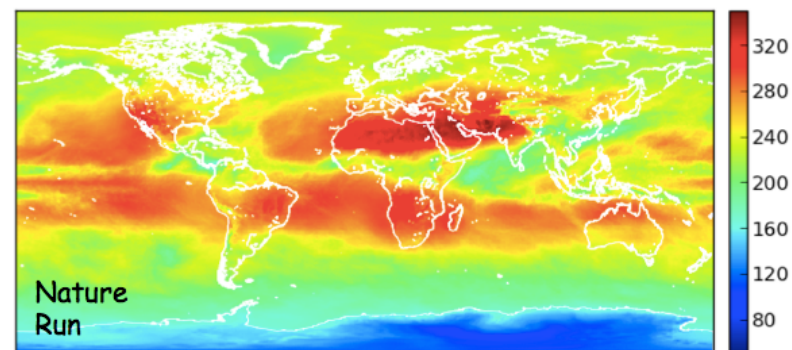
Randal D. Koster, Editor

Evaluation of the 7-km GEOS-5 Nature Run

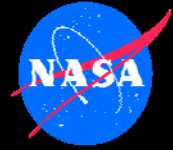
Ronald Gelaro, William M. Putman, Steven Pawson, Clara Draper, Andrea Molod, Peter M. Norris, Lesley Ott, Nikki Privé, Oreste Reale, Deepthi Achuthavarier, Michael Bosilovich, Virginie Buchard, Winston Chao, Lawrence Coy, Richard Cullather, Arlindo da Silva, Anton Darmenov, Ronald M. Errico, Marangelly Fuentes, Min-Jeong Kim, Randal Koster, Will McCarty, Jyothi Nattala, Gary Partyka, Siegfried Schubert, Guillaume Vernieres, Yuri Vikhliav, and Krzysztof Wargan



OLR (W/m²) June 2005



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 C ₅	now
FP for Inst. Teams	50 km	1997-	MODIS C ₅	In progress
NCA	25 km	2010-11	MODIS C ₅ , MISR	Now
MERRA-2	50 km	1979-present	AVHRR, MODIS C ₅ , MISR, AERONET	Summer 2015
MERRA-2 Dynamical Downscaling	12.5 km	2000-2014	AVHRR, MODIS C ₅ , MISR, AERONET	Q4 2015

GEOS-5 Global 12.5 km Nature Run w/ Chemistry



■ Components

- Atmospheric GCM on cubed-sphere, **non-hydrostatic**
- Same framework as MERRA-2dd, but constituents run free
- Prescribed SST, sea-ice, **Meteorology**
- Constituents
 - Radiatively coupled aerosols
 - Carbon species
 - GEOS-Chem Chemistry

■ Emissions

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

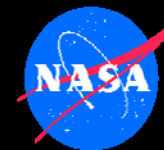
■ GEOS-5 NR-Chem

- Global, 12.5 km
- 72 layers
- Pilot Year: 2013
- Validation: SEAC4RS

■ Availability:

- Q3 2015

Proof of Concept: Global, 12.5 km GEOS-5 + GMI Combo Simulation



GEOS-5

Dynamical core: Cubed sphere

Discretization: 12.5 km x 12.5 km (c720), 72 layers
224 million cells

Heartbeat: 3.75 minutes
Regular replay wall clock: 1h 51m per day

Processors: 4032
Partition: sp3
Intel mpt

Chemistry

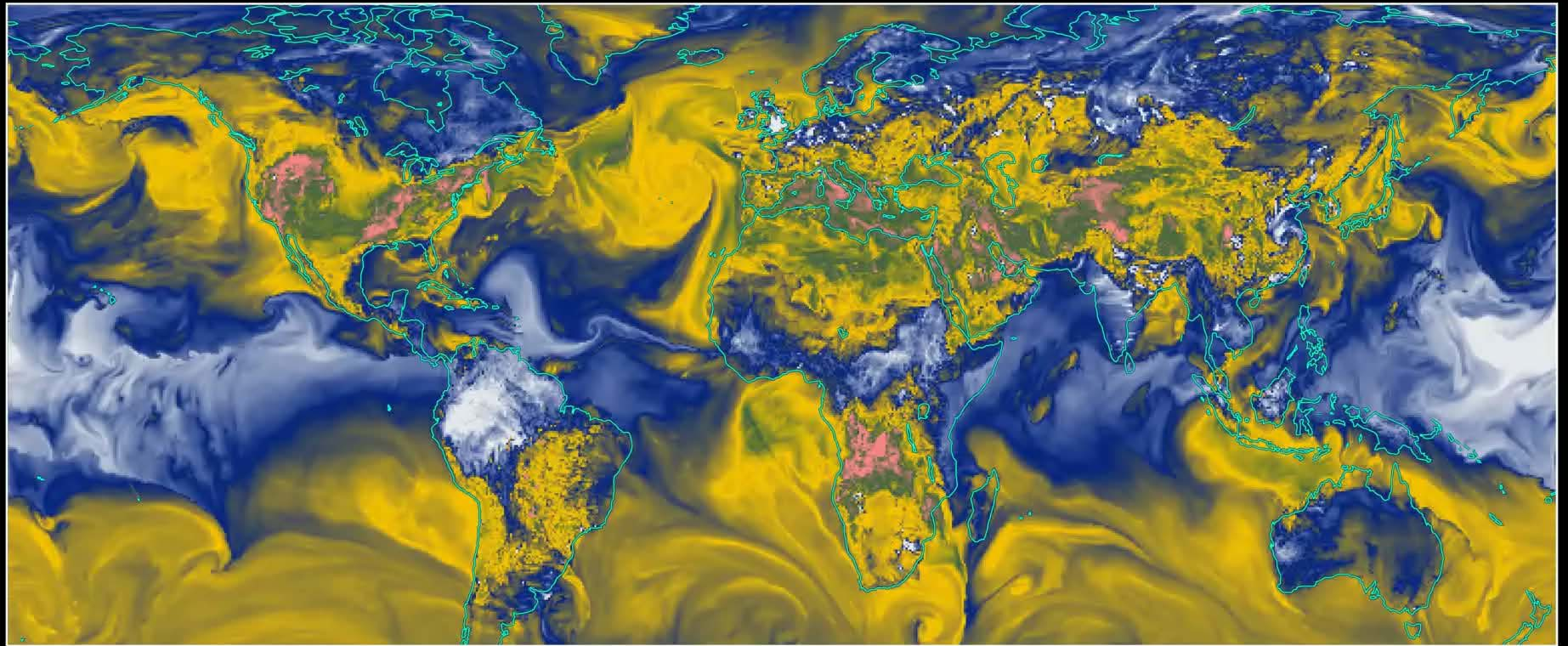
Global Modeling Initiative stratosphere/troposphere
mechanism
GMIchem_GridComp

72 transported and 51 short-lived (not transported) species
gmichem_internal_rst: 110.2 GB

321 thermal reactions, 81 photolytic reactions
Update interval: 15 minutes

Solver: Sparse Matrix Vectorized Gear-type method (SMVGEAR)
Jacobson, M. Z. (1995) Computation Of Global Photochemistry with SMVGEAR II. Atmos.
Environ., 29A, 2541 – 2546.

Surface Ozone

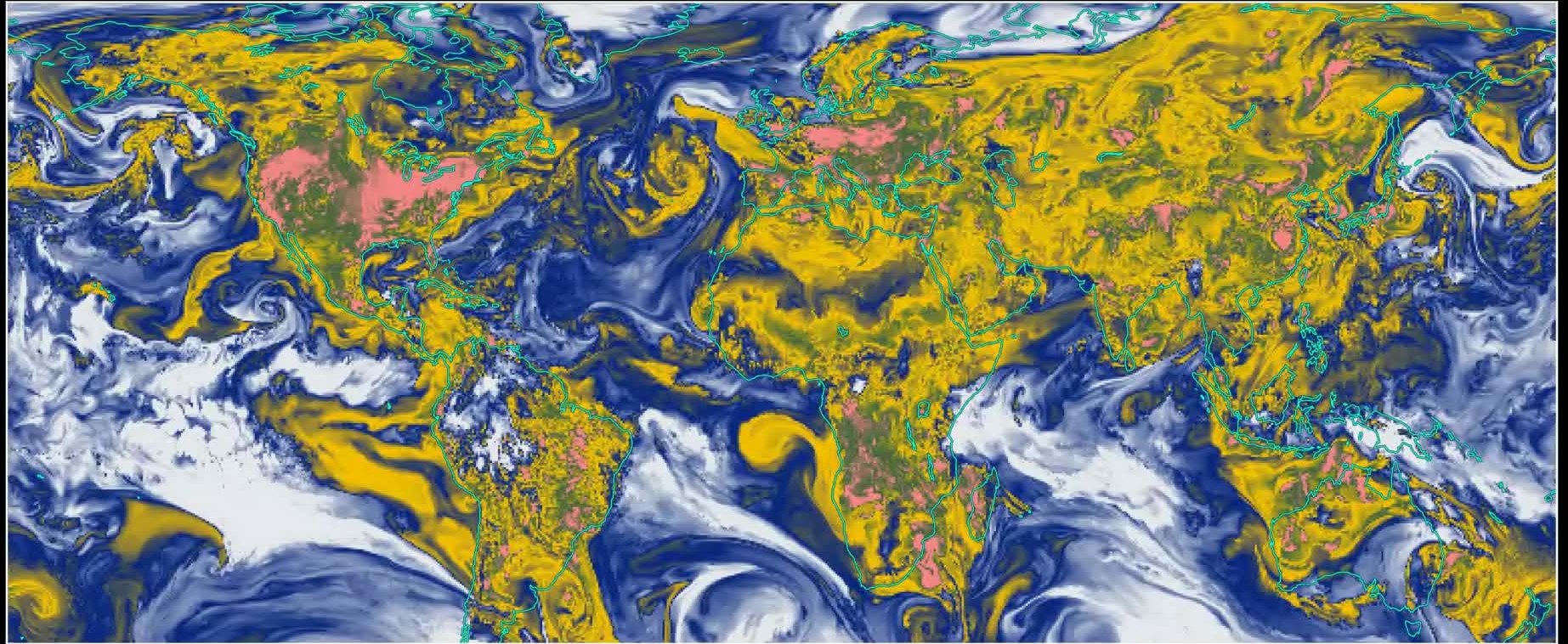


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GEOS-5 CCM
12.5 km x 12.5 km

NO + NO₂ 1.8 km Above Ground



Fri 10 Aug 2012 Sat 11 Aug Sun 12 Aug Mon 13 Aug Tue 14 Aug



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GEOS-5 CCM
12.5 km x 12.5 km

Concluding Remarks



SUMMARY

- A GEOS-5 based global, non-hydrostatic 7 km (Free Running) Nature Run including aerosols, CO, CO₂ and SO₂ is available
- A full gas chemistry NR based on GEOS-Chem mechanisms is in the works
 - Observed Meteorology

SAMPLE APPLICATIONS

- GEO-CAPE Working Group
 - CO constellation OSSEs (NCAR)
 - Radiance simulation at aerosol channels:
TEMPO/GOES-R synergisms
- MODIS Cloud & Aerosol Retrieval Simulator
- PACE Simulator

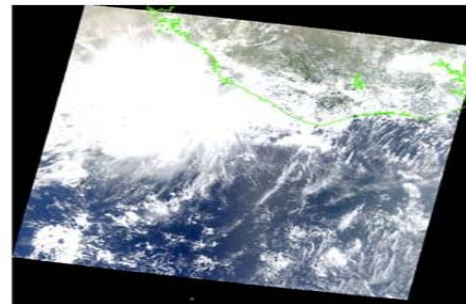
Extra Slides

MODIS Cloud & Aerosol Retrieval Simulator

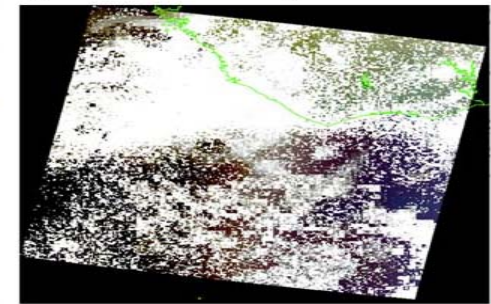


- PDF based **sub-grid sampling** of GEOS-5 fields (ICA)
- Spatial “clumping”
- Radiances for 27 MODIS channels
- Cloud and aerosol extinction, ssa, phase function
- Operational Retrievals
 - Clouds: **MOD06**
 - Aerosols: **MOD04**

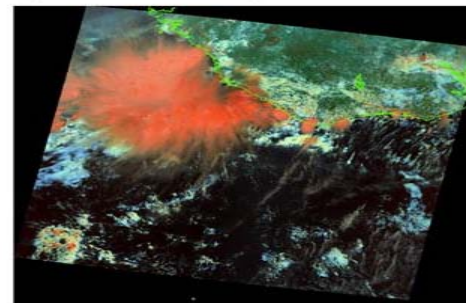
a) Actual RGB composite



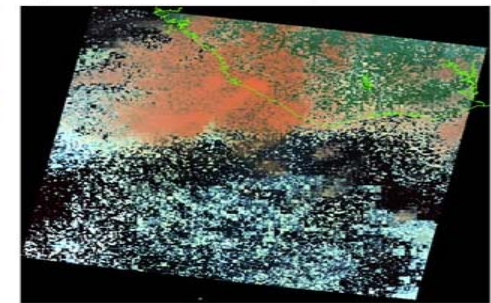
b) Simulated RGB composite



c) Actual SWIR composite



d) Simulated SWIR composite



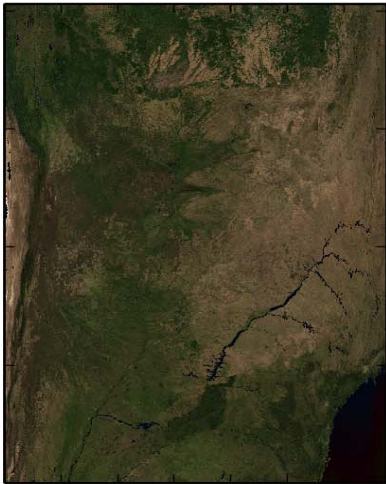
Wind et al., 2013, GMD

Brazilian Smoke Case

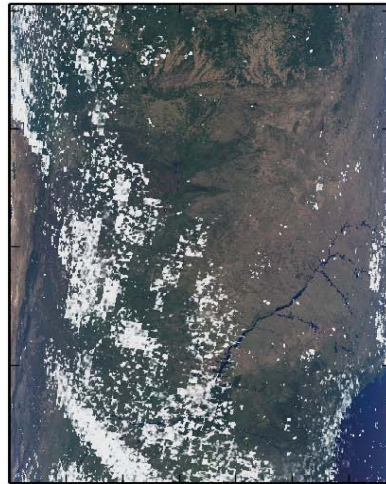
Simulated RGB Images



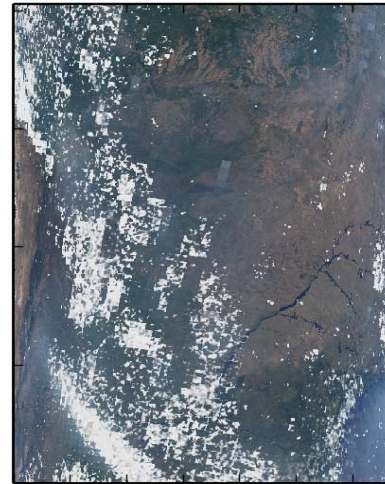
Albedo Only



Clouds and Atmosphere Only



Everything



Aerosol and Atmosphere Only



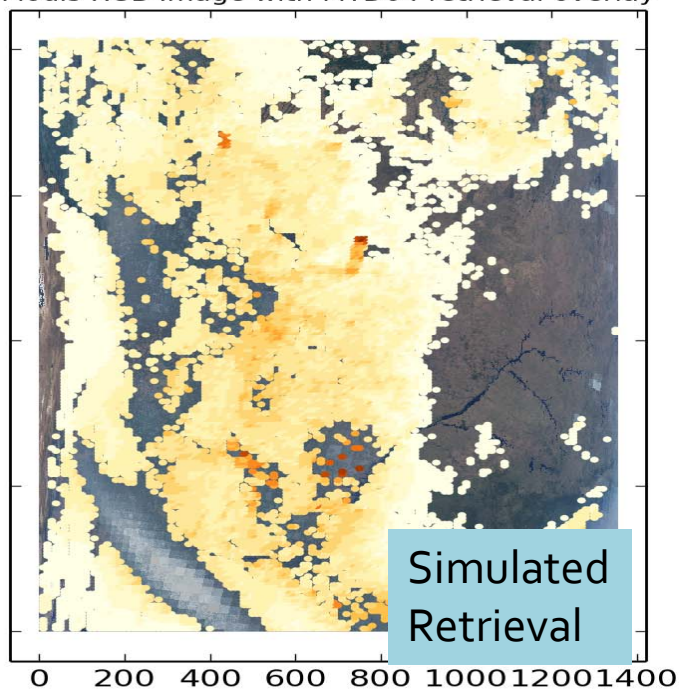
Aqua Granule: 8 September 2012 17:30 UTC

Brazilian Smoke Case

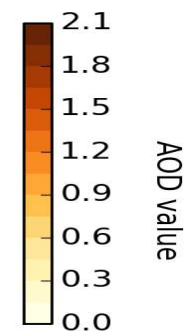
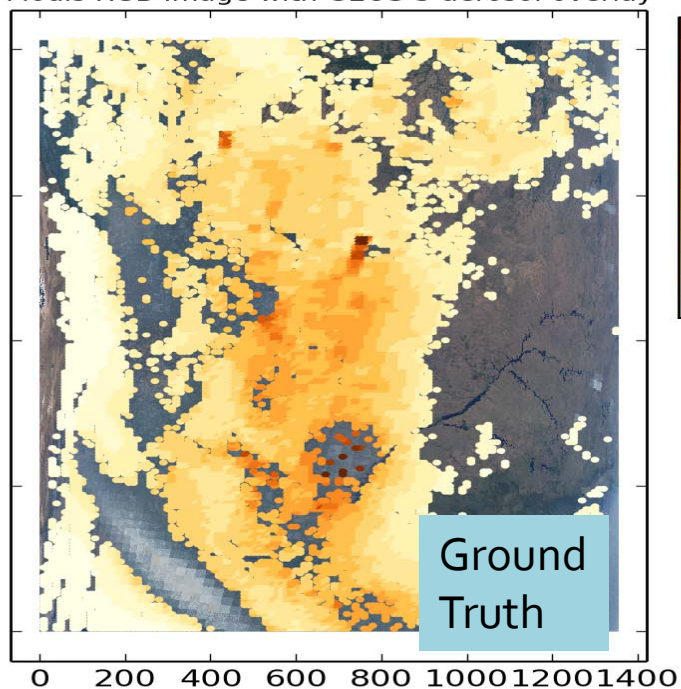
Simulated MODIS Aerosol Retrievals



Modis RGB Image with MYD04 retrieval overlay



Modis RGB Image with GEOS-5 aerosol overlay



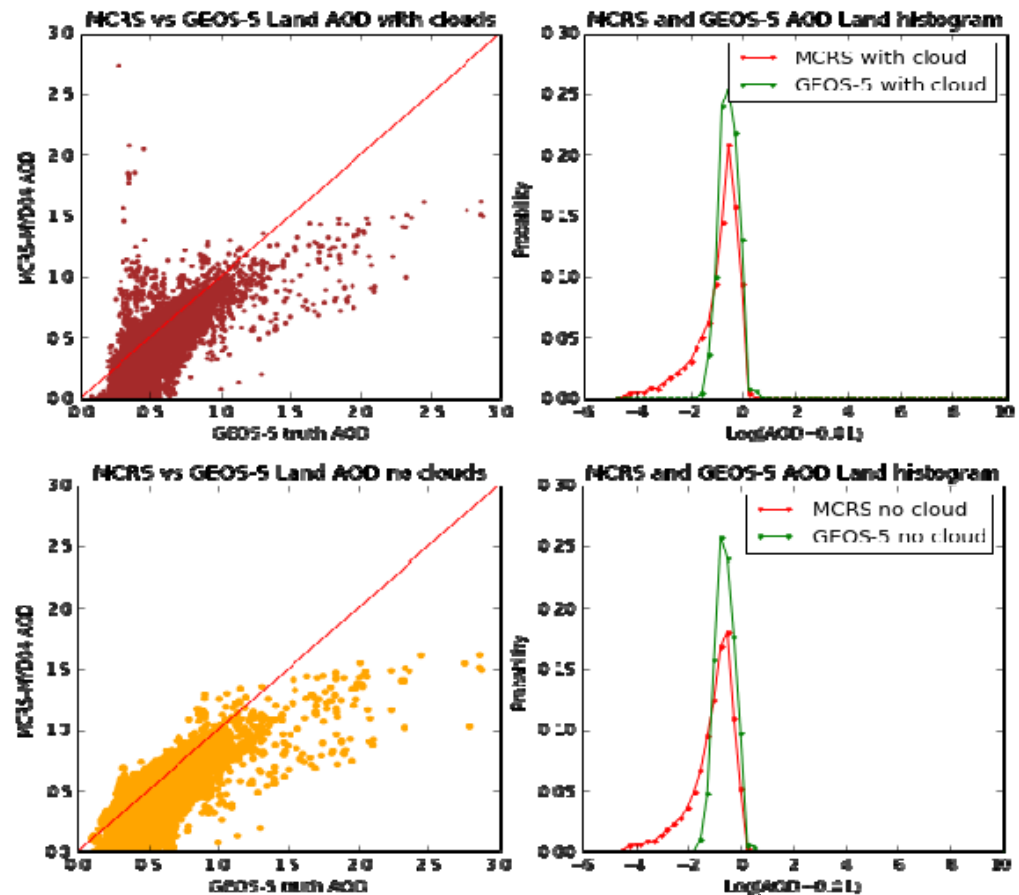
8 Sept
2012
17:30 UTC

Brazilian Smoke Case

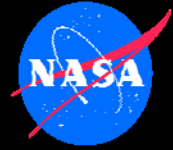
Simulated MODIS Aerosol Retrievals



- Retrievals tend to underestimate AOD
- Cloud contamination while present is not a major factor
- In the no-cloud simulation, surface inhomogeneity leads to data rejection
- Bias can be traced back to SSA albedo variability due to RH
 - MODIS aerosol models assume a constant SSA



PACE Simulator



- GEOS-5 non-hydrostatic 7 km atmosphere with GOCART aerosols
- Coupled to GEOS-5 10 km ocean component with biogeochemistry
- Simulation of
 - Water leaving radiances
 - (t.o.a. reflectances)

