Global Modeling and Assimilation Office
Goddard Space Flight Center
National Aeronautics and Space Administration
http://gmao.gsfc.nasa.gov

Next Generation Weather Prediction Research at NASA GMAO

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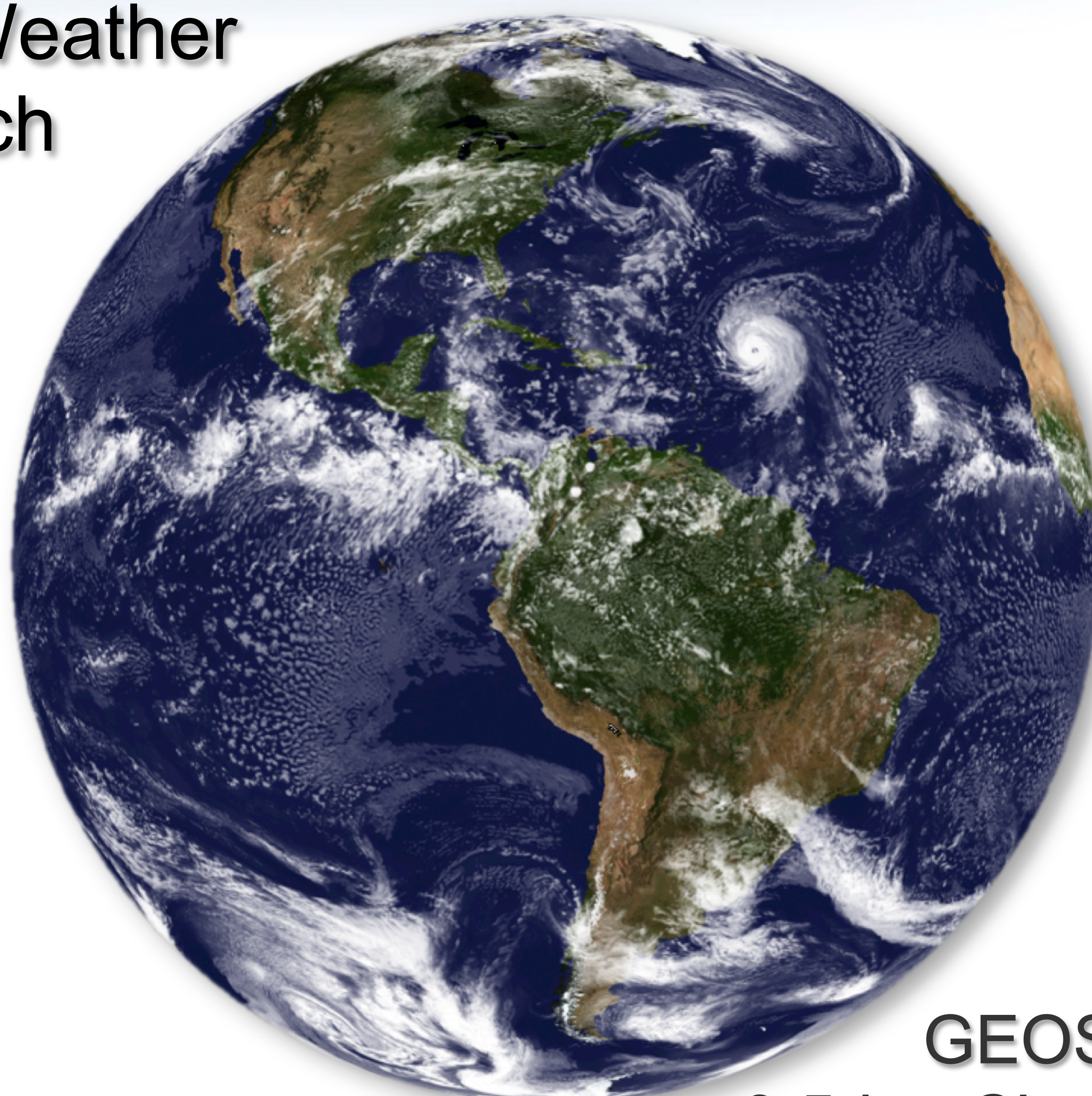


GEOS-5
3.5-km Clouds

Multi-Scale Modeling Approach

Seamless prediction in a unified model development framework

A comprehensive global model for:

simulation – assimilation – weather – climate

Various resolutions

1-deg (climate) ¼-deg (weather) 10- to 3.5-km (mesoscale)

Hydrostatic and non-hydrostatic

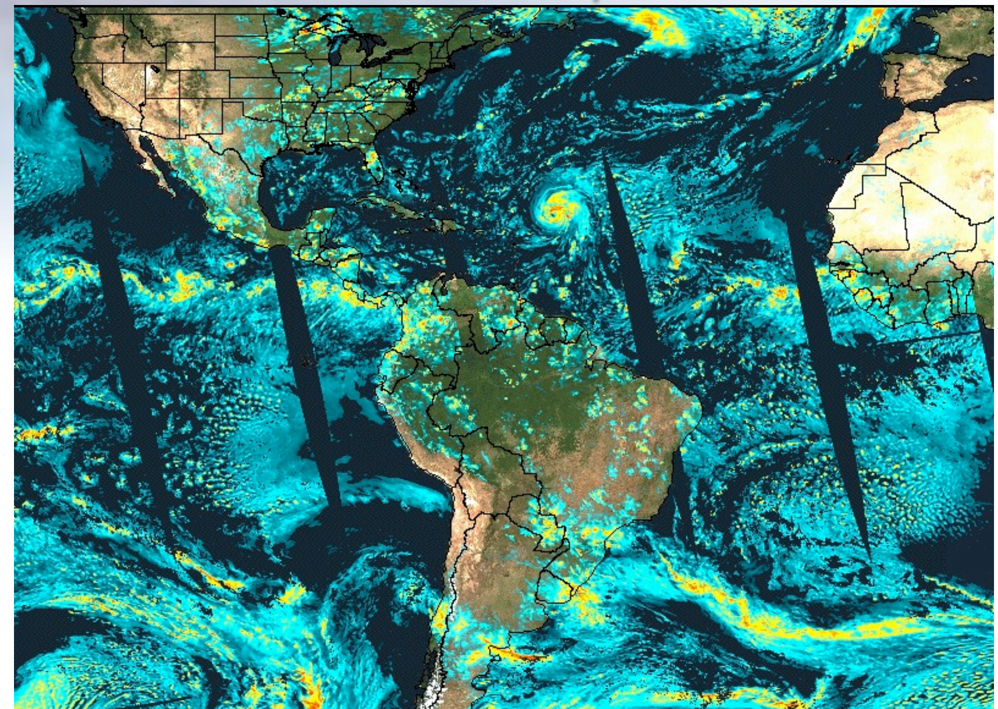
Resolution dependent physics parameterizations

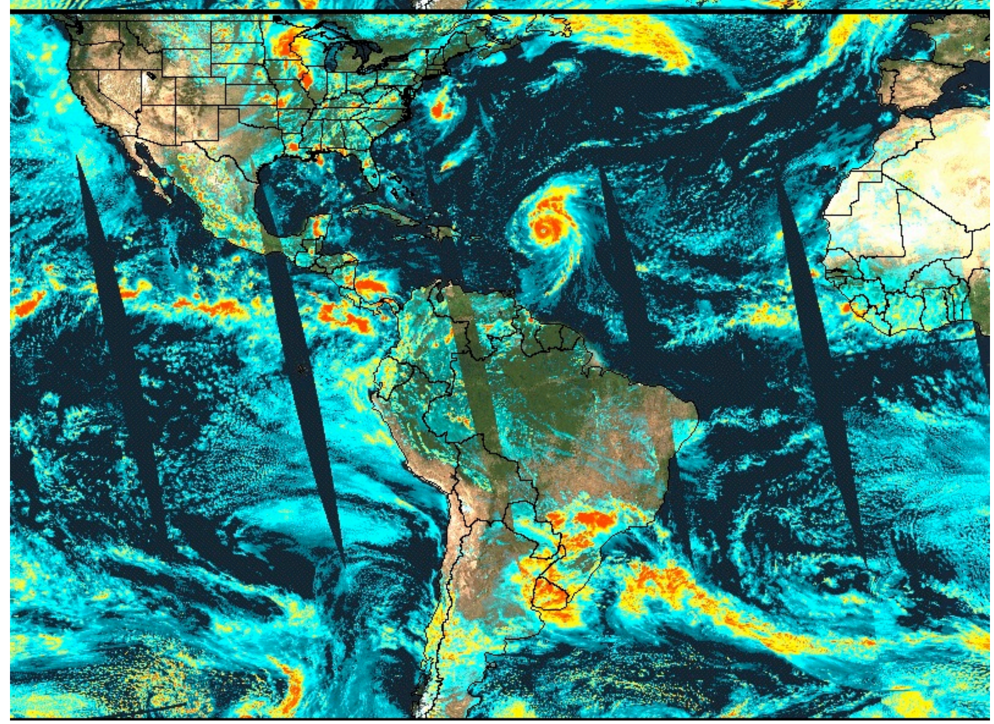
- Moist processes and aerosol cloud interactions
- Multi-moment cloud micro-physics
- Cloud and deep convective parameterization
- Non-precipitating shallow convection
- Gravity wave drag

Multiple HPC platforms [Including accelerators GPUs/MICs]

Within a single codebase and a single build

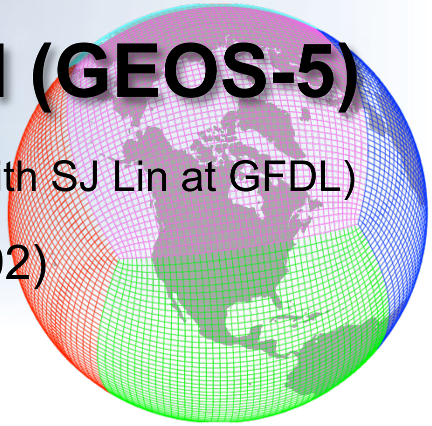
7-km GEOS-5 Cloud Optical Thickness





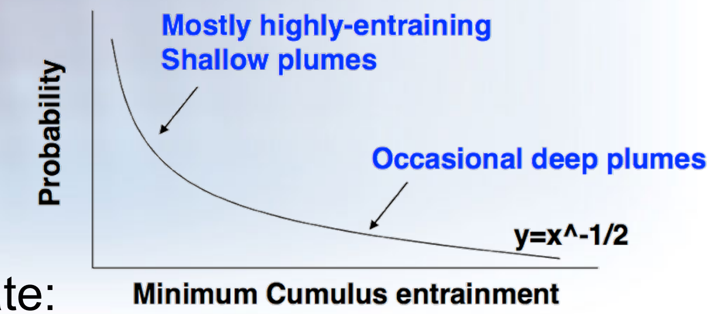
MODIS Cloud Optical Thickness

The Goddard Earth Observing System model (GEOS-5)



- Non-Hydrostatic Cubed-Sphere Finite-Volume dynamics (in collaboration with SJ Lin at GFDL)
- Relaxed Arakawa-Schubert convection scheme (Moorthi and Suarez, 1992)
  - Includes a stochastic trigger for deep convection (Tokioka, 1988)
- Prognostic cloud cover and cloud water/ice schemes
  - includes large scale condensation, evaporation, autoconversion and accretion of cloud water and ice, sedimentation of cloud ice and re-evaporation of falling precipitation (Bacmeister et al., 2006)
  - Two-moment cloud microphysics for stratus (Morrison and Gettelman, 2008) and convective (Barahona et al. 2013) clouds.
  - Explicit ice nucleation (Barahona and Nenes, 2009) and CCN activation (Fountoukis and Nenes, 2005) coupled to the aerosol.
- Longwave radiative processes (Chou and Suarez, 1994) [options to use RRTMG]
- Shortwave radiative processes (Chou, 1990 and 1992) [options to use RRTMG]
- Turbulence parameterization is based on the Lock (2000) scheme, acting together with the Richardson-number based scheme of Louis and Geleyn (1982)
- Monin-Obukhov surface layer parameterization (Helfand and Schubert, 1995)
- Gravity wave parameterization computes the momentum/heat deposition into the grid-scale flow due to orographic (McFarlane, 1987) and nonorographic (after Garcia and Boville, 1994) gravity wave breaking
- Catchment based Land Surface Model (Koster et al, 2000)

Relaxed Arakawa-Schubert (RAS) Convection

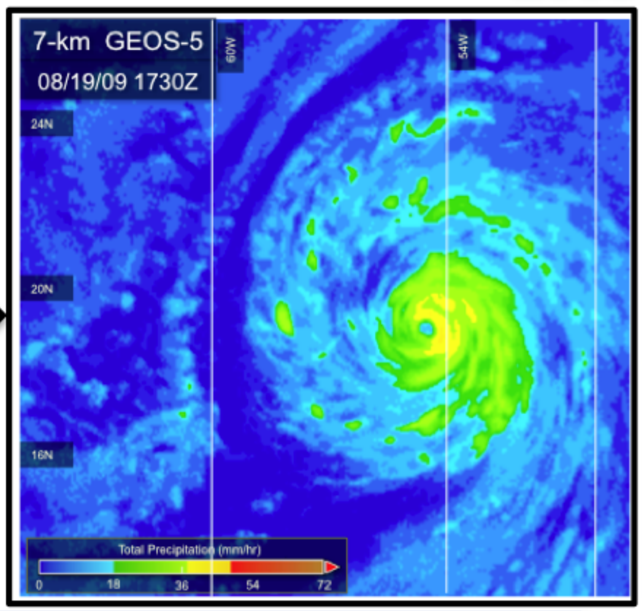


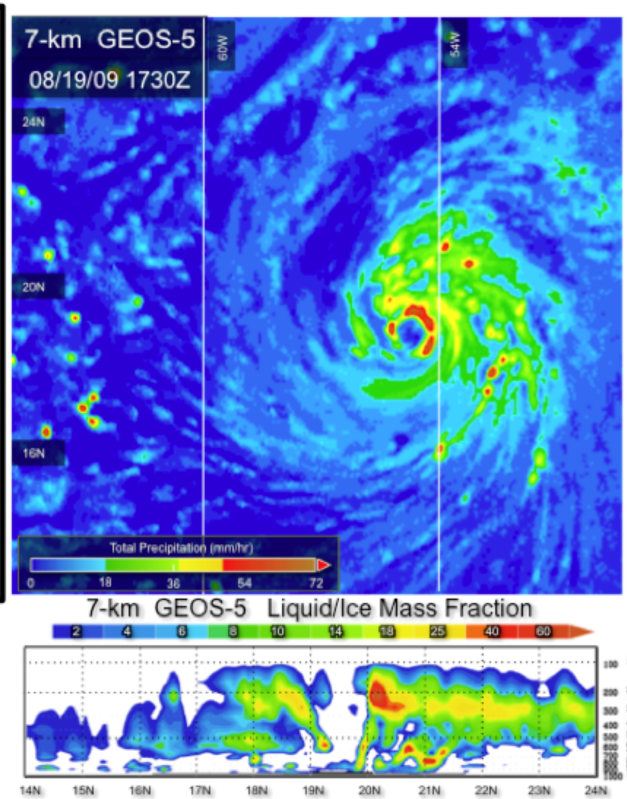
- Stochastic Determination of Cumulus Entrainment in RAS
  - Based on Tokioka et al. (1988) Minimum entrainment rate:

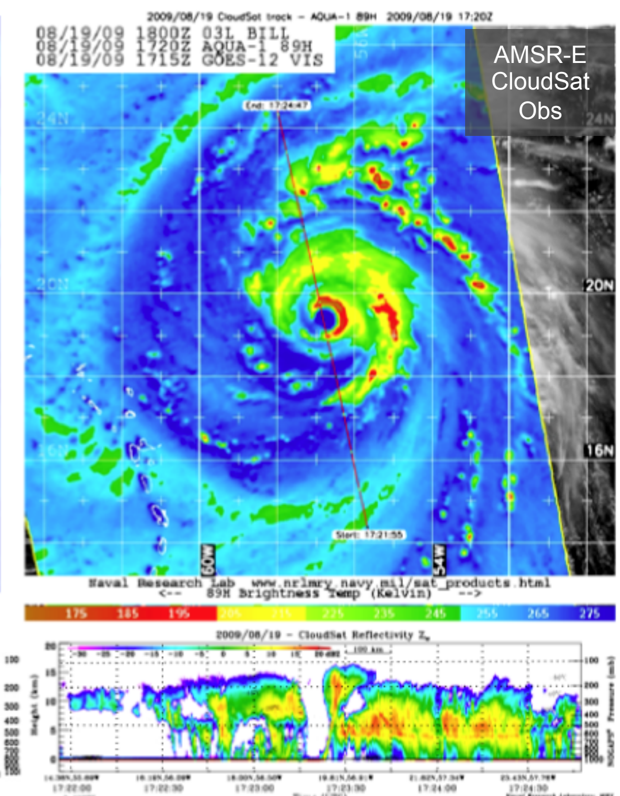
    μ_min= 0.2/MAXD

    where MAXD is a resolution dependent parameter specifying the diameter for the largest convective plume
  - Stochastic determination of the Tokioka limit determined at random
  - Selective suppression of RAS convection scheme as we move to higher resolution

2009 Atlantic Hurricane Bill





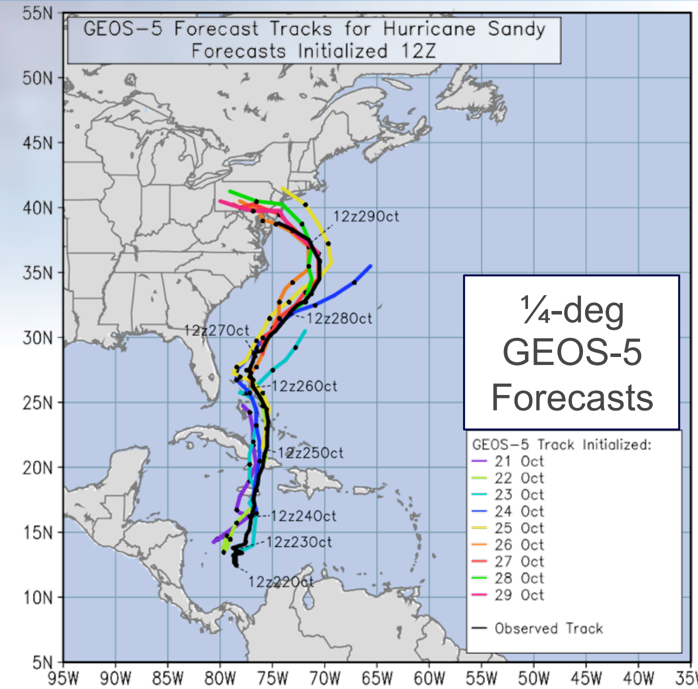


Before relaxation of the deep convection:
- a lack of intense convective precipitation
- an excess of shallow precipitation
- a very small eye, filled with drizzle

Numerical Weather Prediction

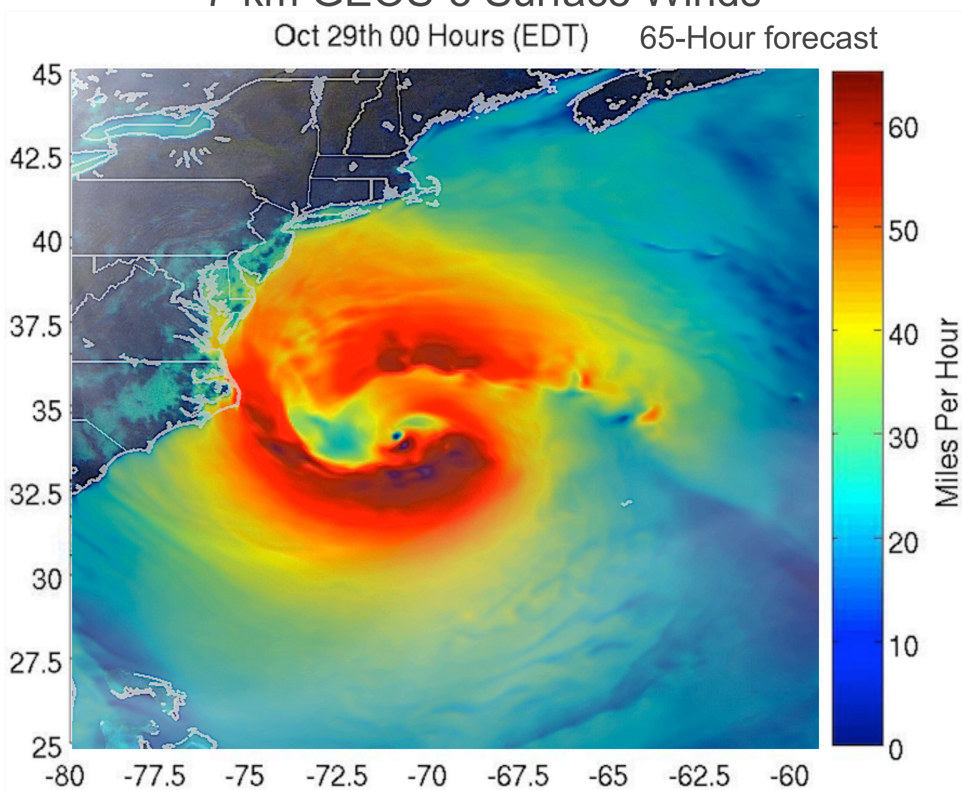
Hurricane Sandy

- Accurate 5-day Track Forecasts from GEOS-5
  - ¼-deg particularly from Oct 26 through landfall
- High-resolution improves intensity and structure
  - Fine-scale details of surface winds and eye-wall
  - Fidelity of warm front in the northeast quadrant

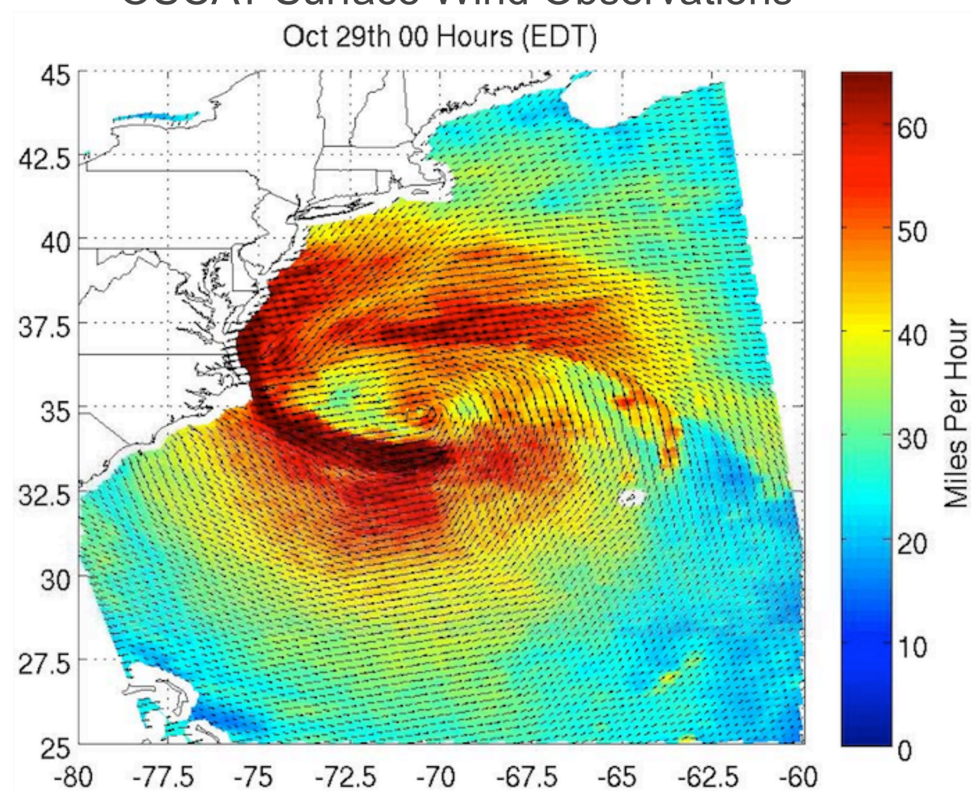


http://gmao.gsfc.nasa.gov/research/atmosphericassim/tracking_hurricanes/

7-km GEOS-5 Surface Winds



OSCAT Surface Wind Observations



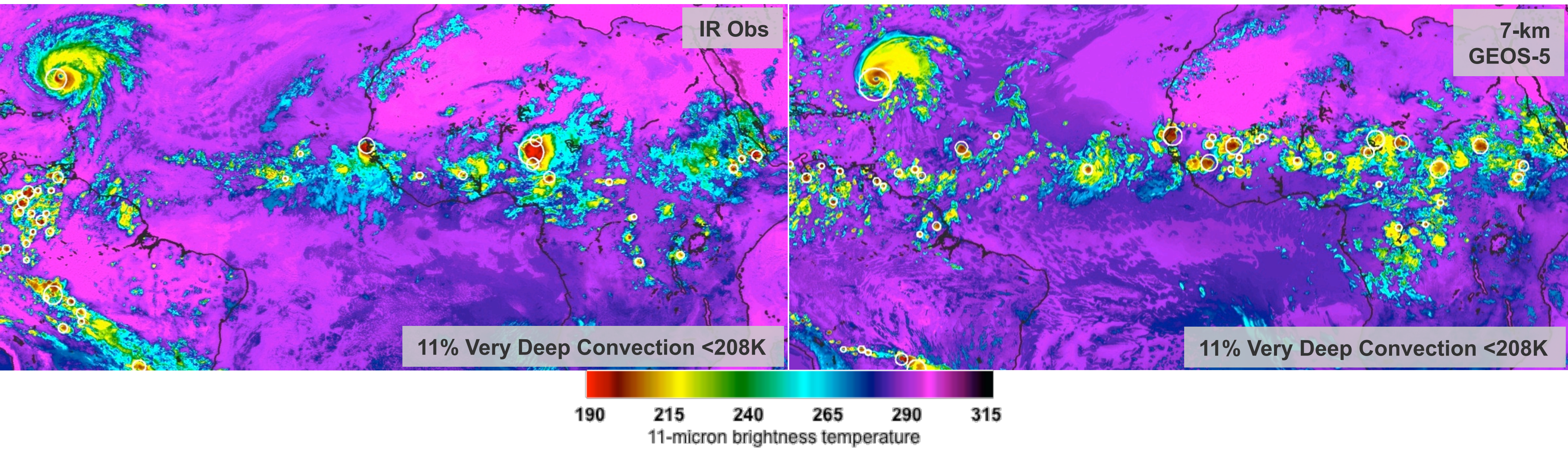
Statistical Distribution of Detected Cloud Clusters

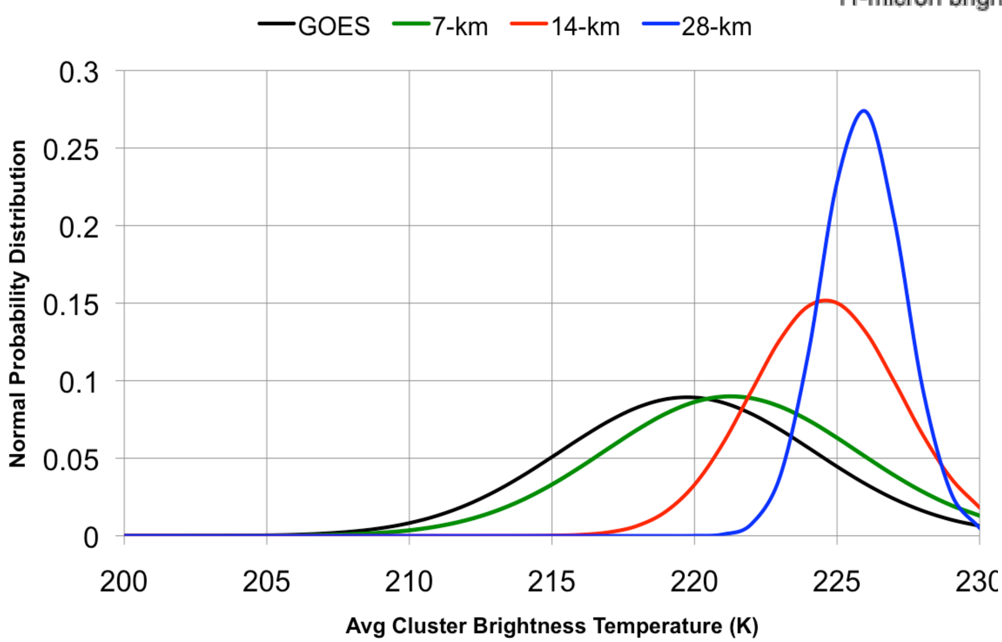
Deep convective clusters detected from GEOS-5 and IR observations in the tropics [15-19 September 2010]

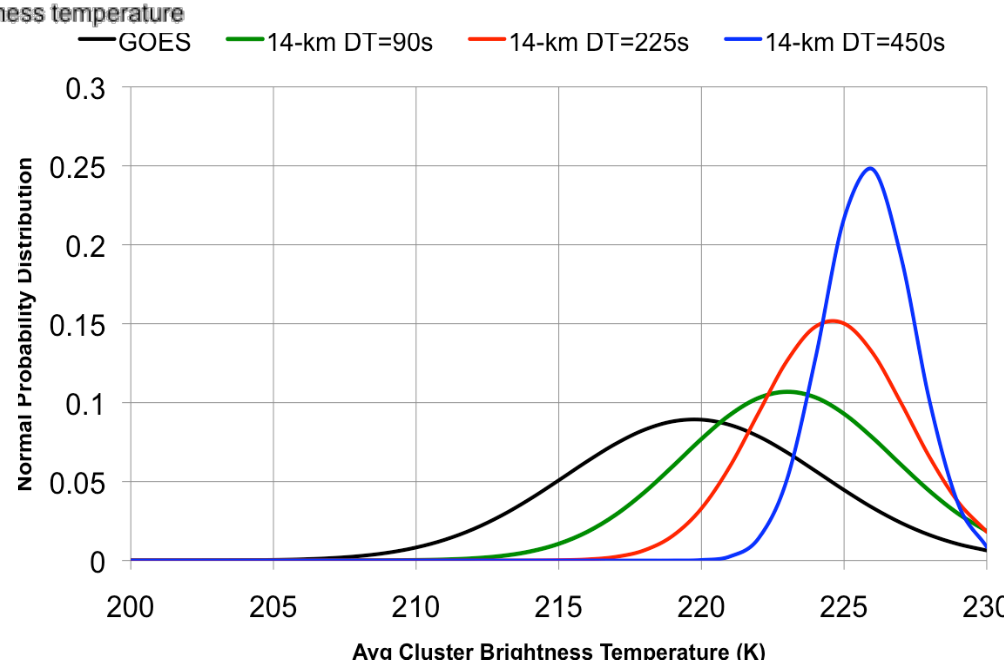
Detected clusters (top) and probability distributions (bottom) of detected cloud clusters

IR observations compared to GEOS-5 with increasing resolution [28-km 14-km 7-km] (bottom-left)

IR observations compared to GEOS-5 varying dynamics/physics coupling time-step at 14-km (bottom-right)



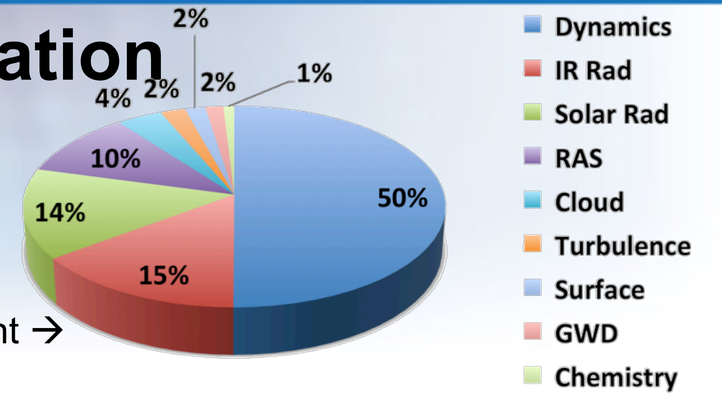


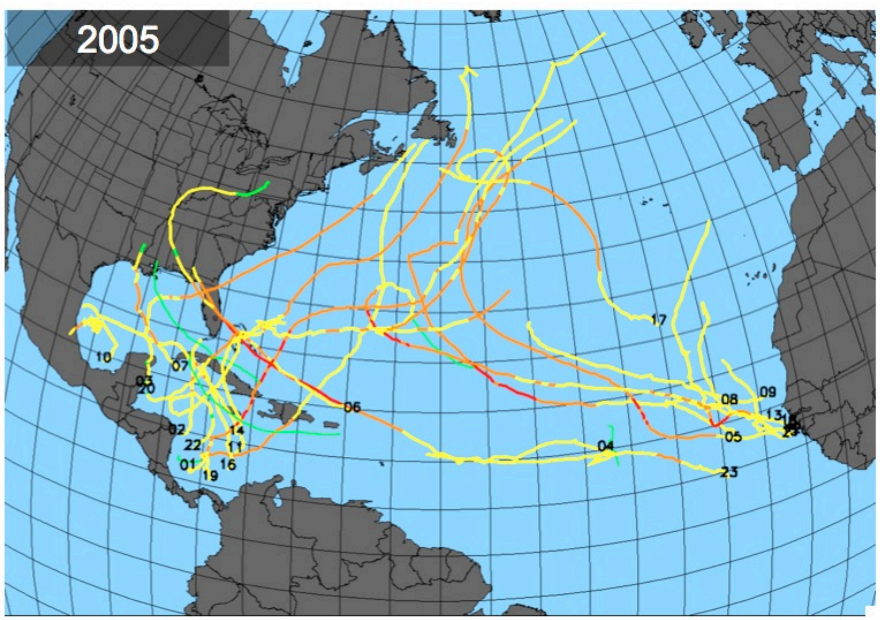


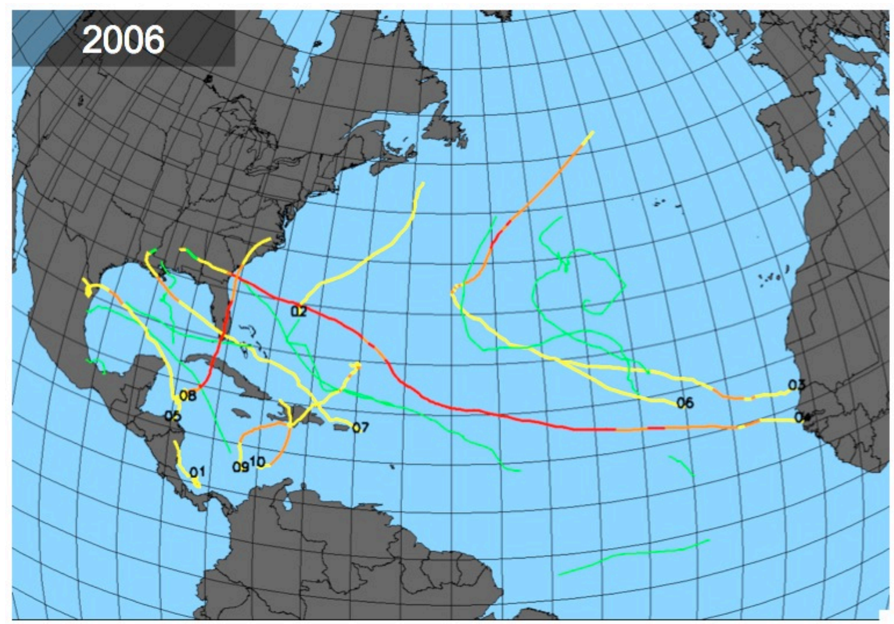
10-km GEOS-5 Global Mesoscale Simulation

- May-2005 through April-2007
- 72-levels Surface to 0.01 hPa
- Hydrostatic DT=450s ; RAD=1800s
- Over 400 TB of output
- “Nature Run” for OSSEs

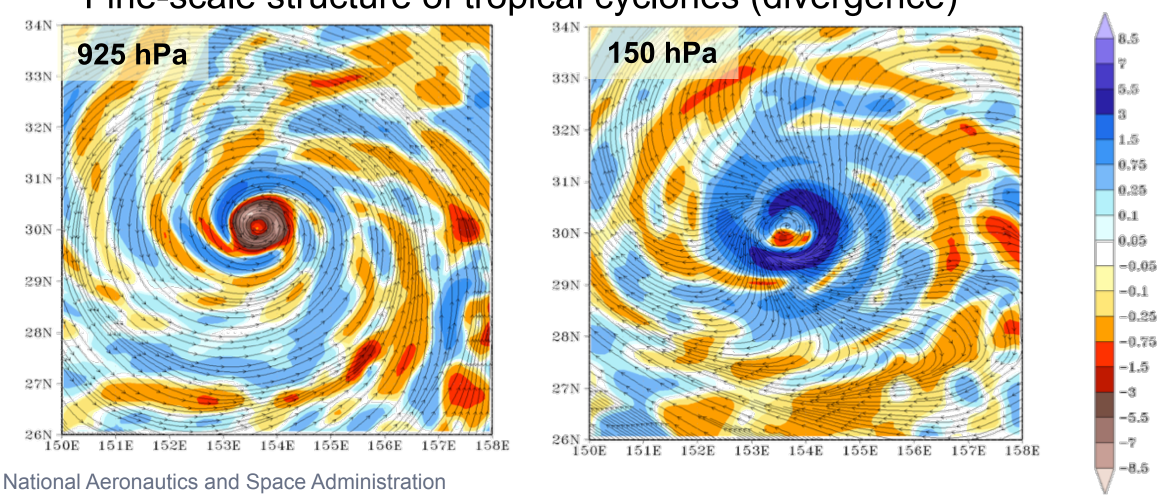
- 25 simulated days / wallclock day
- 3-million processor hours
- Using 3750 Intel Westmere Cores
- Computational breakdown by component →







Fine-scale structure of tropical cyclones (divergence)

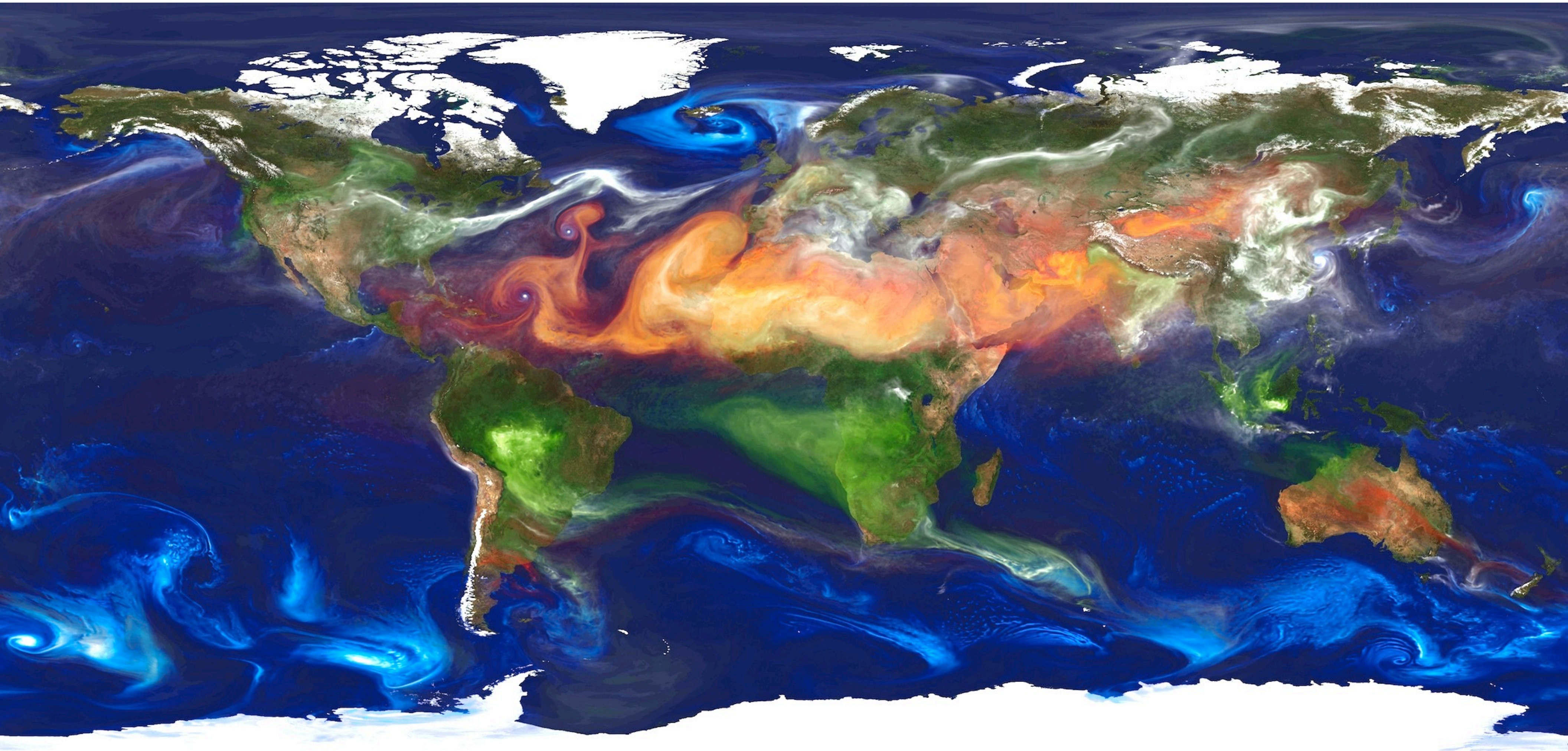


2005 (Jun-Dec)			2006 (Jan-Dec)		
North Atlantic			North Atlantic		
	10-km GEOS-5	Obs		10-km GEOS-5	Obs
Storms	23	28	Storms	10	10
TS	7	13	TS	3	5
Hurr	16	15	Hurr	7	5
Major	6	7	Major	3	2

10-km GEOS-5 Global Mesoscale Simulation

- In addition to providing a realistic representation of the meteorology
- Using GOCART the simulation also provides aerosol direct effects including:
  global aerosol distribution – aerosol vertical profiles – aerosol optical thickness

Dust (red-orange) – Organic and black carbon (green) – Sea salt (blue) – Sulfates (white)

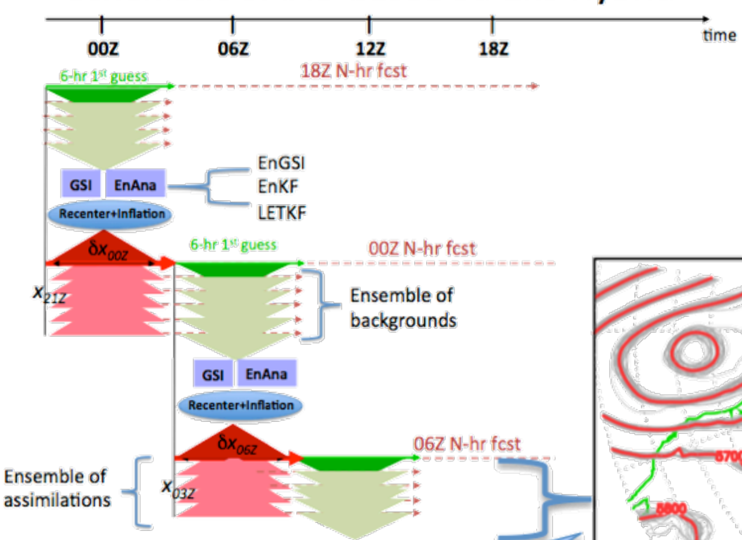


http://gmao.gsfc.nasa.gov/research/aerosol/modeling/nr1_movie/

4d-Atmospheric Data Assimilation

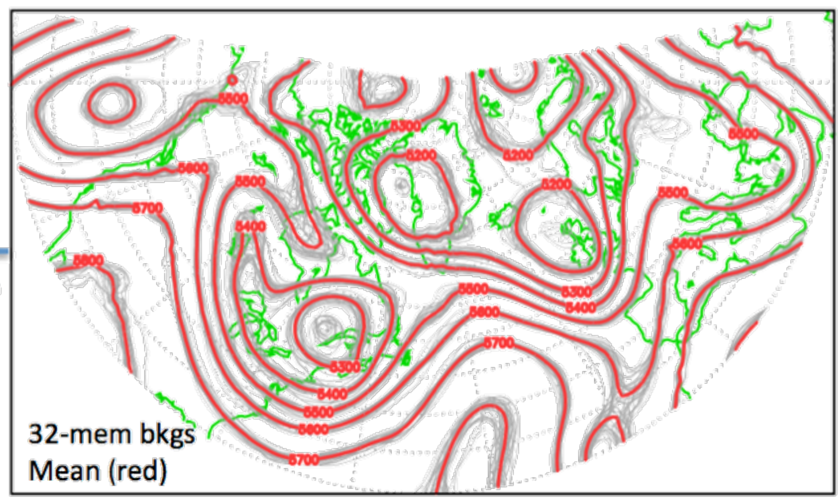
- Future 4d-strategy will be ensemble-based in one of following flavors:
    - o Hybrid-4d-Var – flow-depended initial error covariance
    - o 4d-Ens-Var – ensemble replaces TL and AD models
- Analysis core: Gridpoint Statistical Interpolation (GSI)
- GEOS-5 GCM using cubed-sphere dynamics
- Assimilation still based on incremental analysis update (IAU)
- Implementation will be an upgrade on current 3d-hybrid development

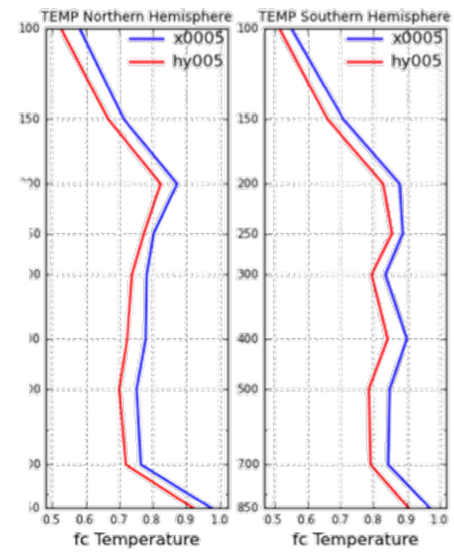
Schematic of IAU-based 3d-Ens-Hybrid



Spaghetti plot shows typical spread in GMAO ensemble of backgrounds

H 500 mb 00 UTC 20120410





Above: results from Hybrid system (red) show reduced 24-hr RMS errors in temperature

Computational Costs

10-day AMIP-Style simulation at 72 levels

Resolution	CPUs	WallClock Time (Hours)
b72 (2-deg)	48	0.25
c72 (1-deg)	96	0.5
d72 (0.5-deg)	384	1
e72 (0.25-deg)	768	4.75
c720 x 72L (14-km)	1350	8
c1440 x 72L (7-km)	4000	22

Scaling for Lat-Lon Version at d72 (1/2 deg)

Layout NX	Layout NY	Total PEs	Total Time (hrs)
6	36	216	1.72
8	48	384	1.21
12	72	864	0.72

Scaling for Cubed-Sphere Version at c180 (1/2 deg)

Layout NX	Layout NY	Total Pes	Total Time (hrs)	Speedup from Lat-Lon
6	36	216	1.49	1.15x
8	48	384	0.61	1.98x
12	72	864	0.35	2.06x