Planning, Execution, Results, Lessons

THEORY

NRC, other Reports

OBSERVATIONS

KNOWLEDGE & UNDERSTANDING

MODEL DEVELOPMENT

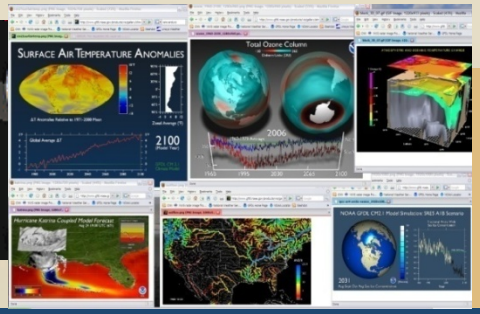
```
if (diagts .and. eots) then
  do 1500 m=1,nt
    do 1490 k=1,km
      fx = cst(j)*dyt(j)*dzt(k)/(c2dtts*dtxcel(k))
      do 1480 i=2,imtm1
        boxfx            = fx*dxt(i)*fm(i,k,jc)
        sddt             = (ta(i,k,m)-t(i,k,jc,nm,m))*boxfx
        svar             = (ta(i,k,m)**2-t(i,k,jc,nm,m)**2)
                           *boxfx
        n                = 0
        termbt(k,1,m,n) = termbt(k,1,m,n) + sddt
        tvar(k,m,n)      = tvar(k,m,n)      + svar
        n      = nhreg*(mskvr(k)-1) + mskhr(i,j)
        if (n .gt. 0 .and. mskhr(i,j) .gt. 0) then
          termbt(k,1,m,n) = termbt(k,1,m,n) + sddt
          tvar(k,m,n)      = tvar(k,m,n)      + svar
```

WELL DESIGNED MODEL EXPERIMENTS

ANALYSIS OF MODEL RESULTS

OBSERVATIONS

Assessments



CHALLENGES

➔ Accounting for the complexity of the system with increasing realism

➔ Increased resolution and rigor to capture the physics, chemistry, dynamics, and biogeochemistry of the system

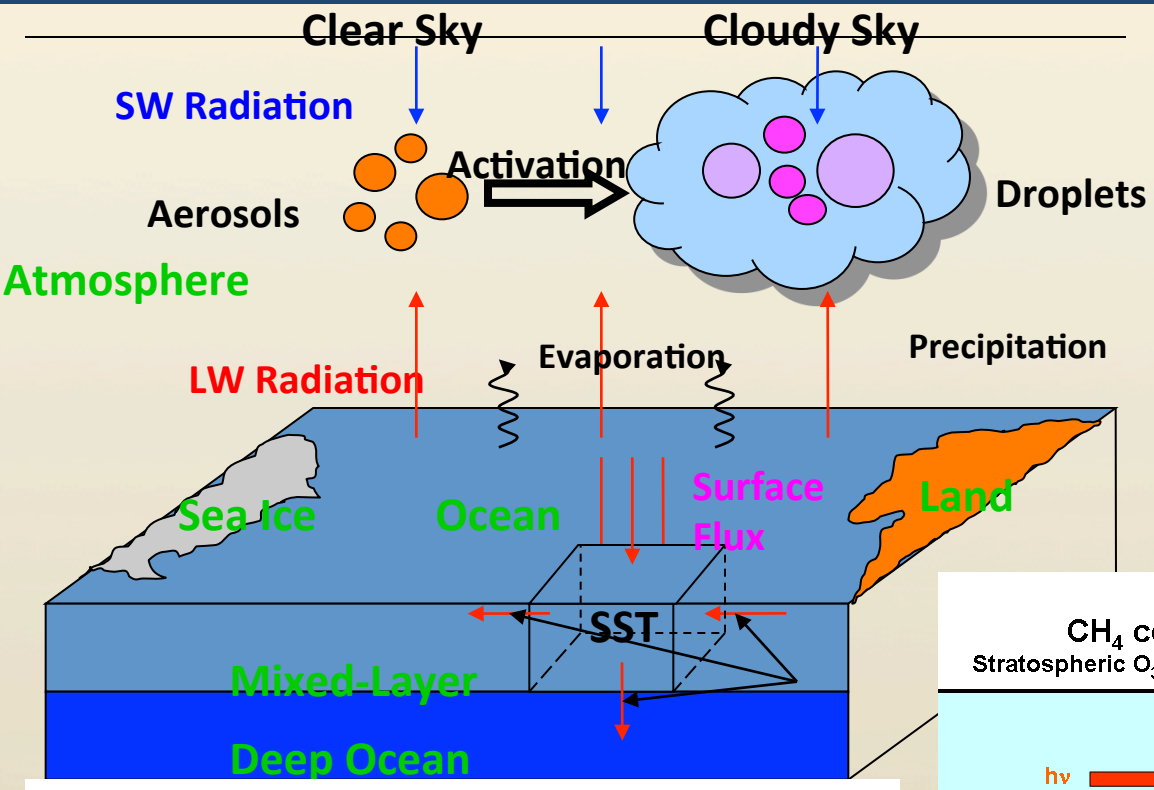
➔ Obtain results at increasingly finer spatial scales with accuracy and credibility

➔ Characterizing, understanding and explaining uncertainties

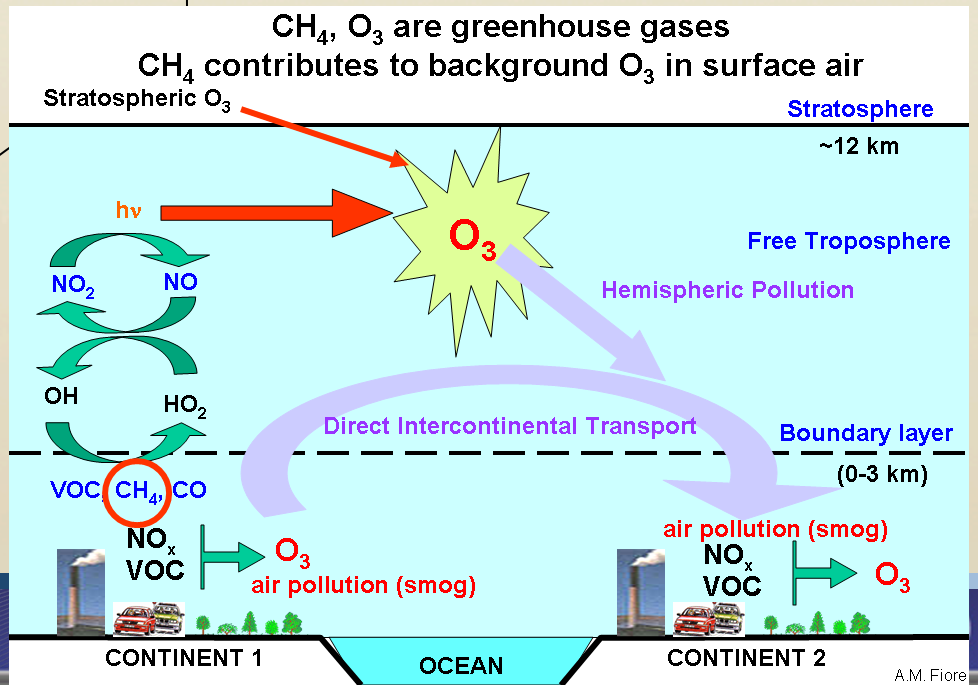
➔ Leadership and managing expectations

➔ Considerations: *Hardware. Software. Brainware.*

Coupled Chemistry-Aerosol-Climate model



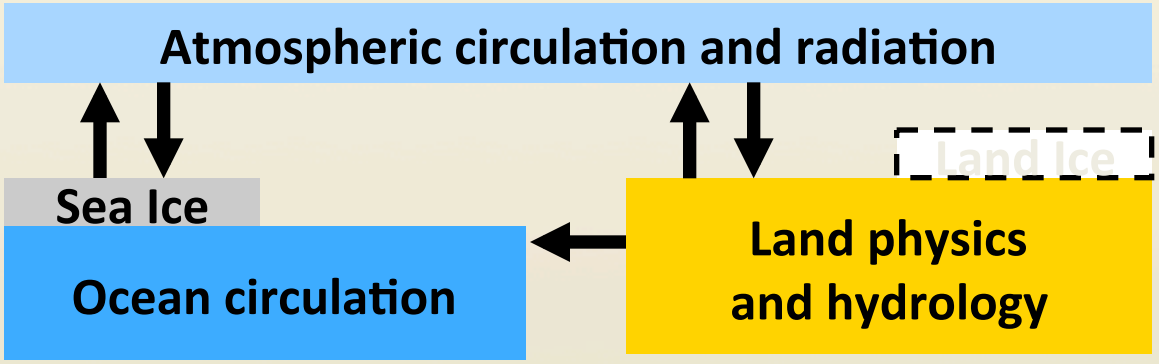
Aerosols and Climate



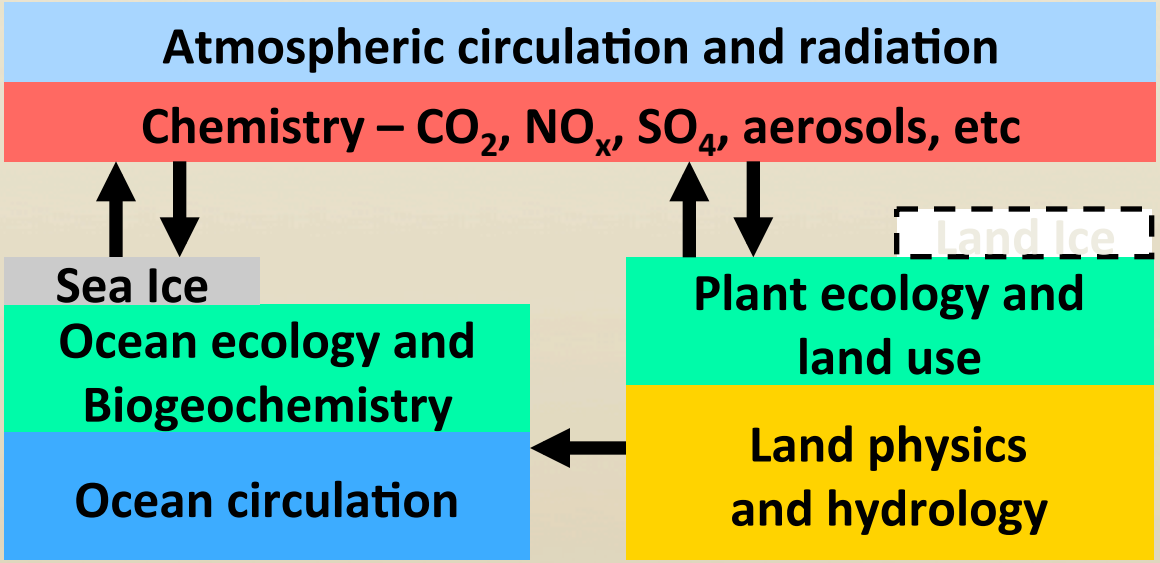
Global Air Quality and Climate

Climate to Earth System Modeling (ESM): *Chemistry- and Carbon-Climate Interactions*

Climate Model



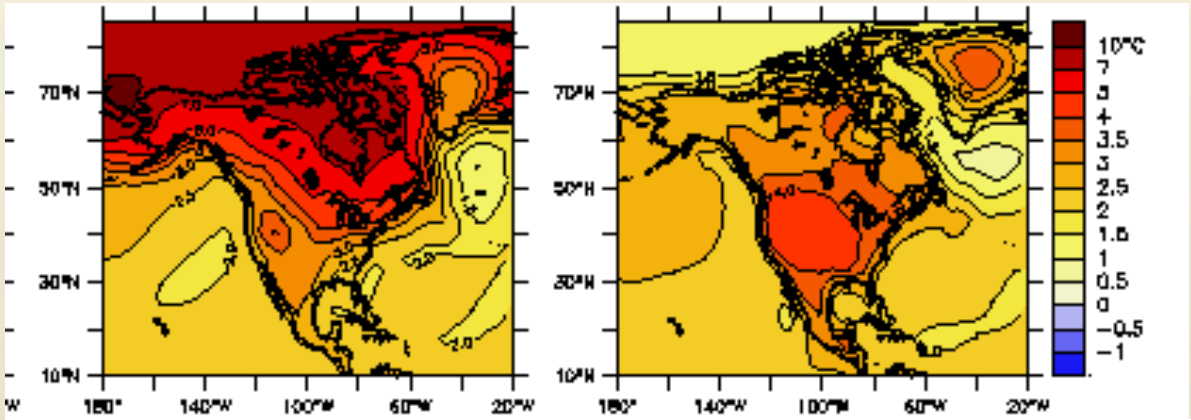
Earth System Model



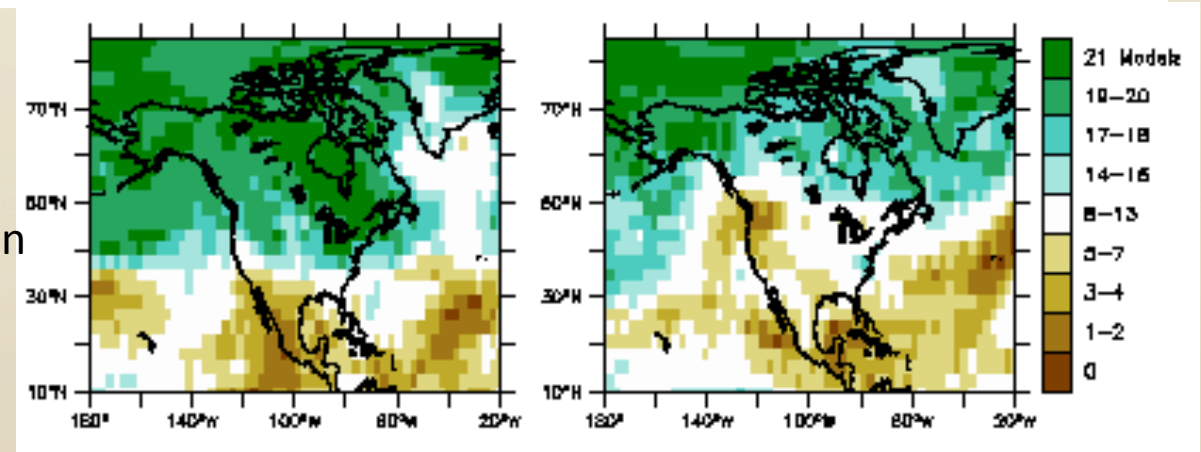
AR4 ➔ Projected changes in temperature and precipitation in 21st century A1B emission scenario; averaged over ~20 models with spatial resolutions of ~ 200km

Winter Summer

Warming everywhere



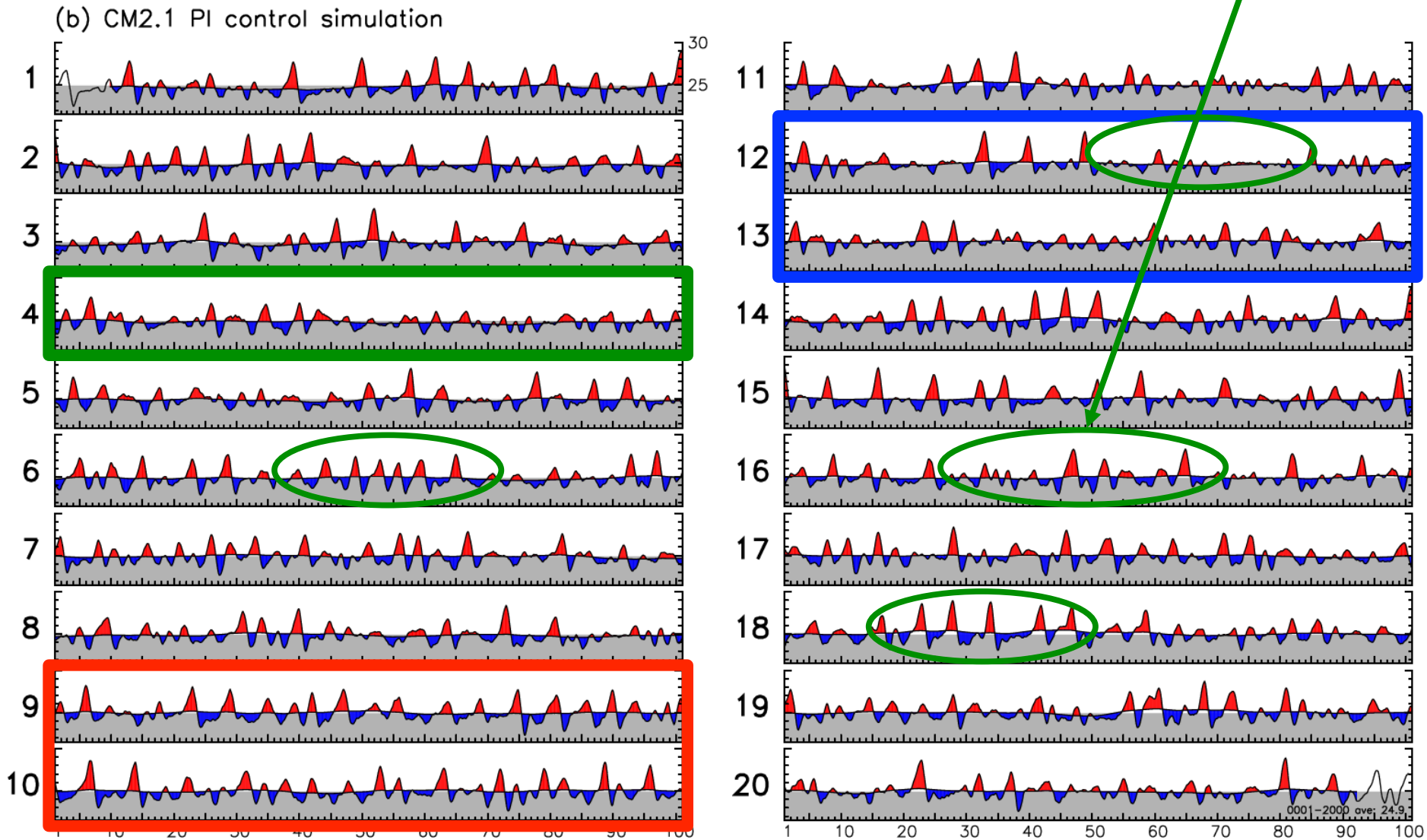
Green => wetter
Brown=> drier
White => uncertain



Winter: wetter in Northeast – drier in Southwest –
Summer: Drying extends northward, with larger uncertainty

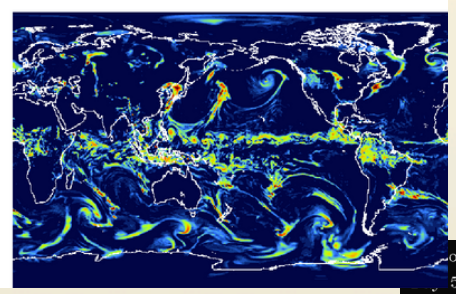
20 centuries of NINO3 SSTs

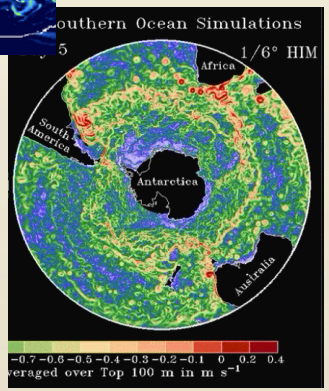
annual means & 20yr low-pass



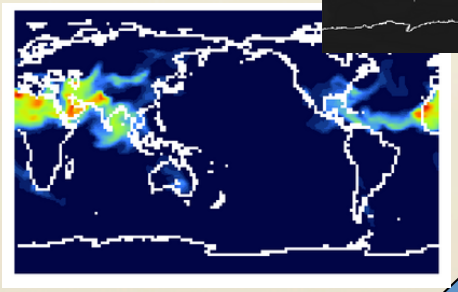
NOAA/ GFDL Modeling

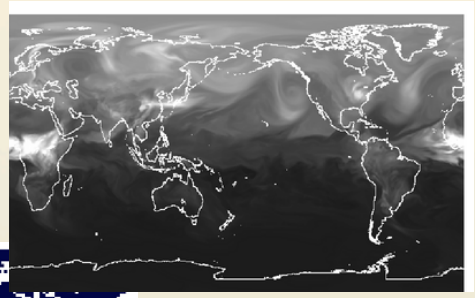
{Conceptualization about five years ago……}



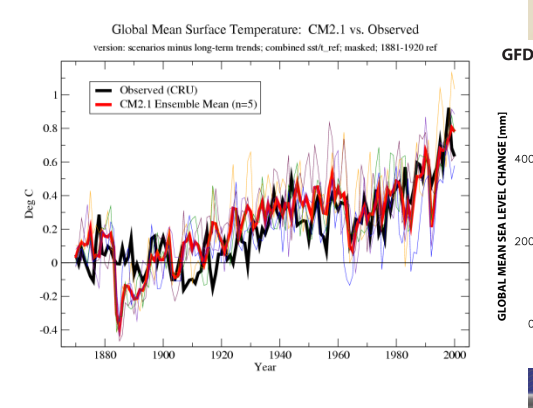


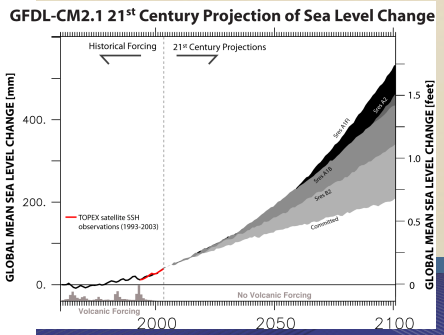
Resolution pipeline





Earth system pipeline





Climate projections

FOUR GFDL Model Streams for CMIP5, AR5: *Differences relative to CM2.1 indicated below* [CM2.1 components → AM2, LM2, MOM4, SIS]

1. CM3

New atmosphere model (AM3). Interactive tropospheric and stratospheric chemistry, aerosols & aerosol-cloud interactions.
New land model and hydrology (LM3).

2. ESM2

Carbon biogeochemistry (land and ocean),
2 ocean configurations: MOM4.1 (ESM2M) and GOLD (ESM2G, isopycnal model).

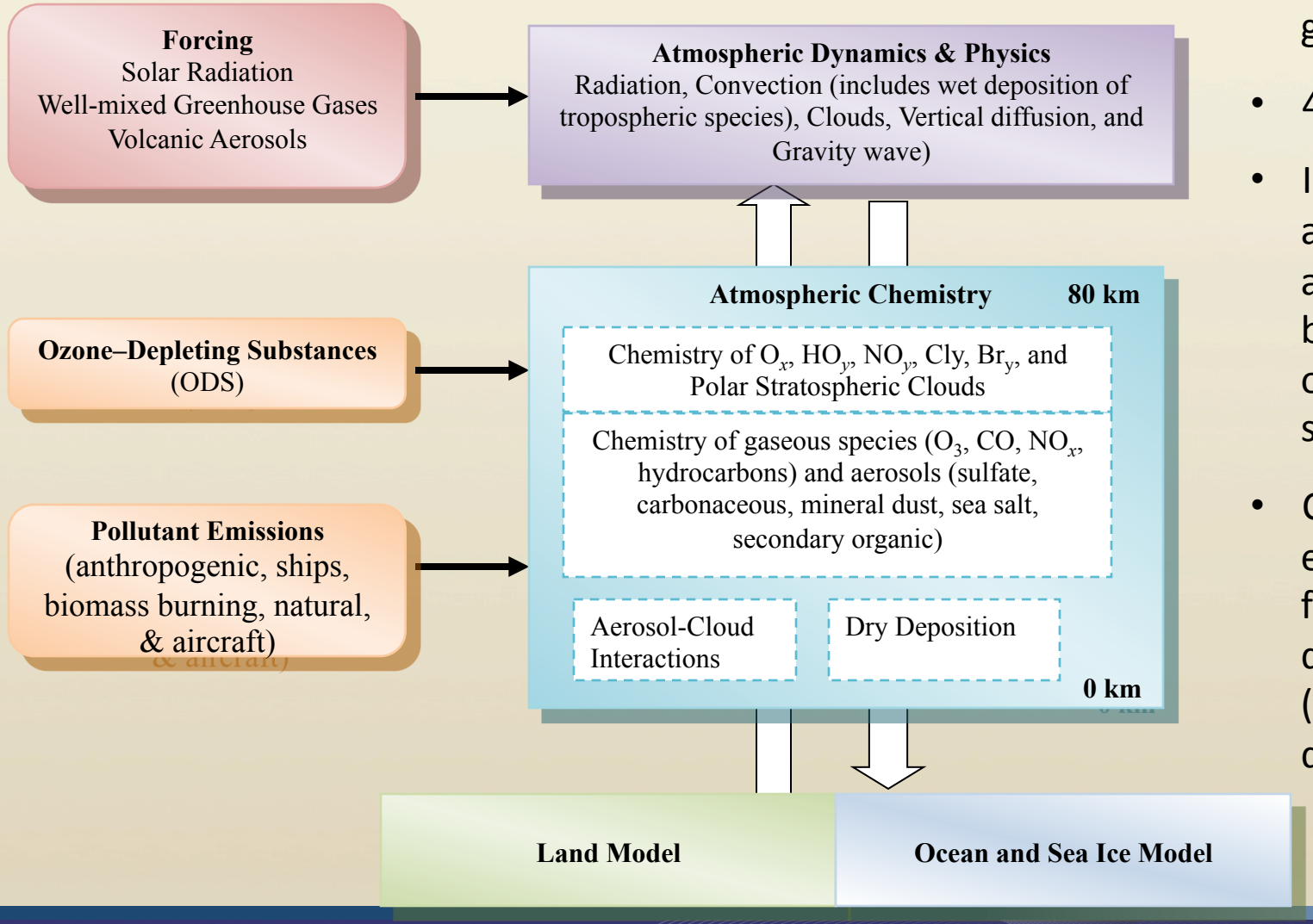
3. CM2.x

Decadal predictability research using GFDL's ensemble Kalman-filter analysis.
Begin with CM2.1, possibly advancing to higher resolution/ complexity.

4. HiRAM

High resolution (25 km) time slice integrations with AM2 (incl. alternative physics), forced by SSTs and sea-ice.

CM3 Coupled Climate Model



- Cubed – sphere grid (~200km)
- 48 vertical levels
- IPCC – AR5 anthropogenic and biomass burning emissions of short-lived species
- Constant natural emissions except for lightning NO_x, dust and sea-salt (meteorology dependent)

Donner et al., *J. Climate*, 2011

Interactive microphysics, chemistry and dynamics in the GFDL AM3/CM3 (used for AR5)

- **Aerosol-Liquid Cloud Interactions**

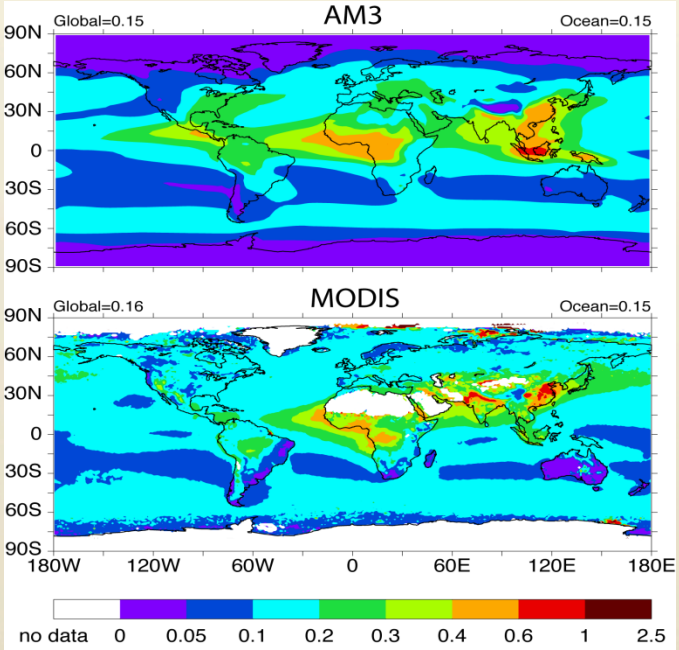
A prognostic scheme of cloud droplet number concentration (Ming et al., 2007) with an explicit treatment of aerosol activation at cloud base (Ming et al., 2006).

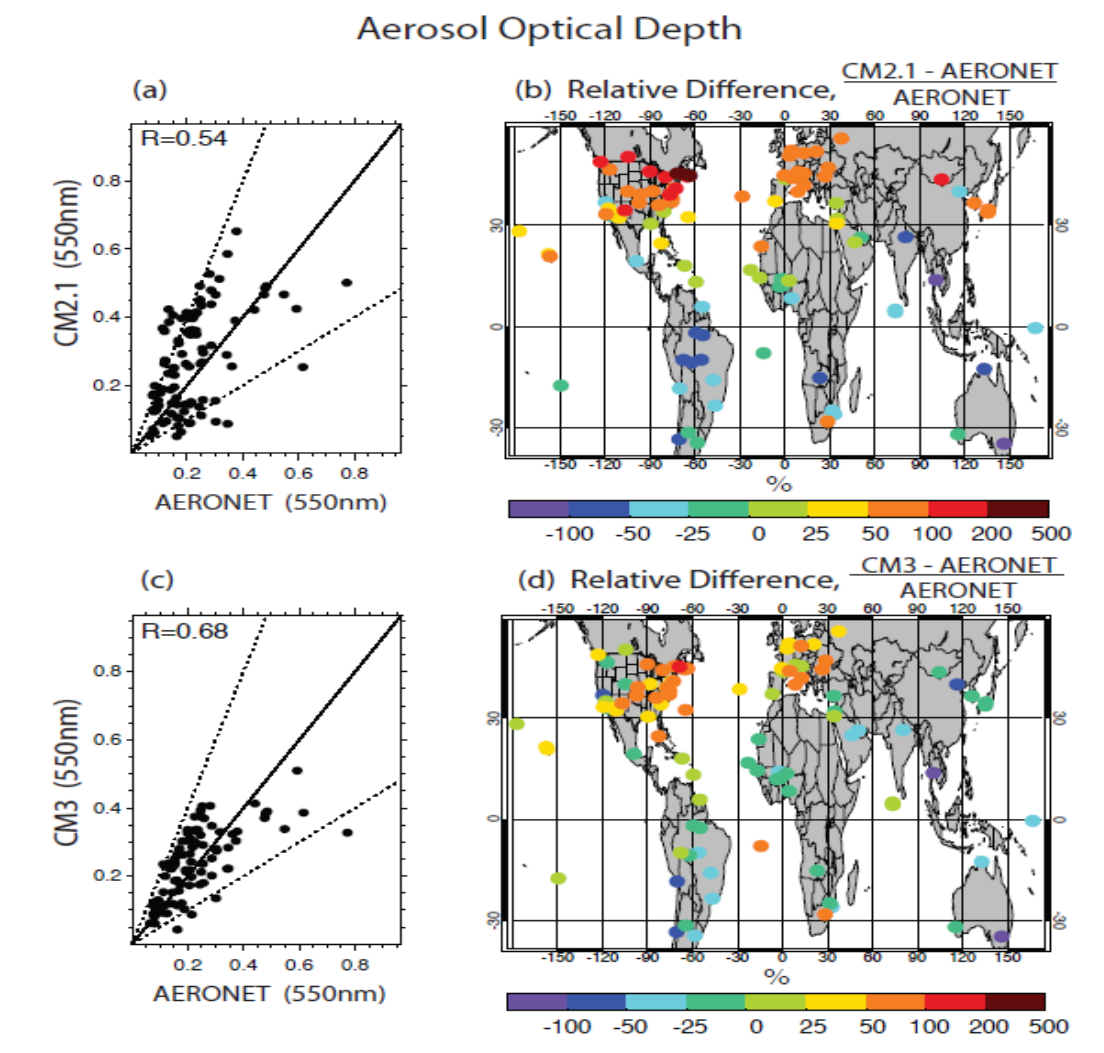
- **Convection Parameterization**

Move from the relaxed Arakawa-Schubert (RAS) in AM2 to the Donner deep convection scheme (Donner, 1993) and the University of Washington (UW) shallow convection scheme (Bretherton et al., 2003). By providing in-plume updraft velocity, the latter two are ideal for implementing aerosol/ cloud microphysics.

- **Online aerosol transport and tropospheric and stratospheric chemistry**

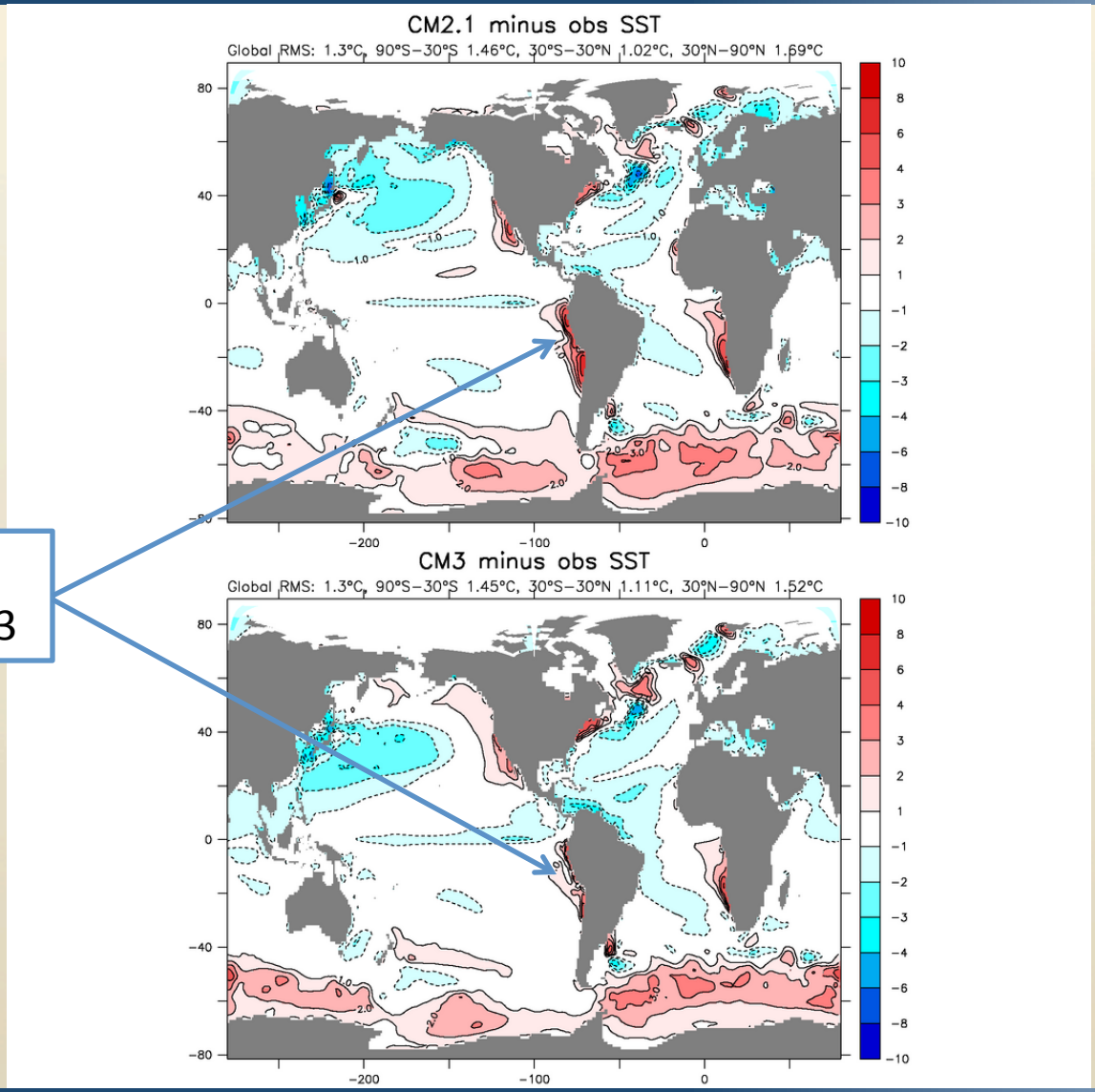
Evaluate aerosol properties simulated with CM3 for IPCC-AR5 using in-situ and remote sensing data





Donner et al., submitted to J. Climate

CM3 results: Ocean model improvements

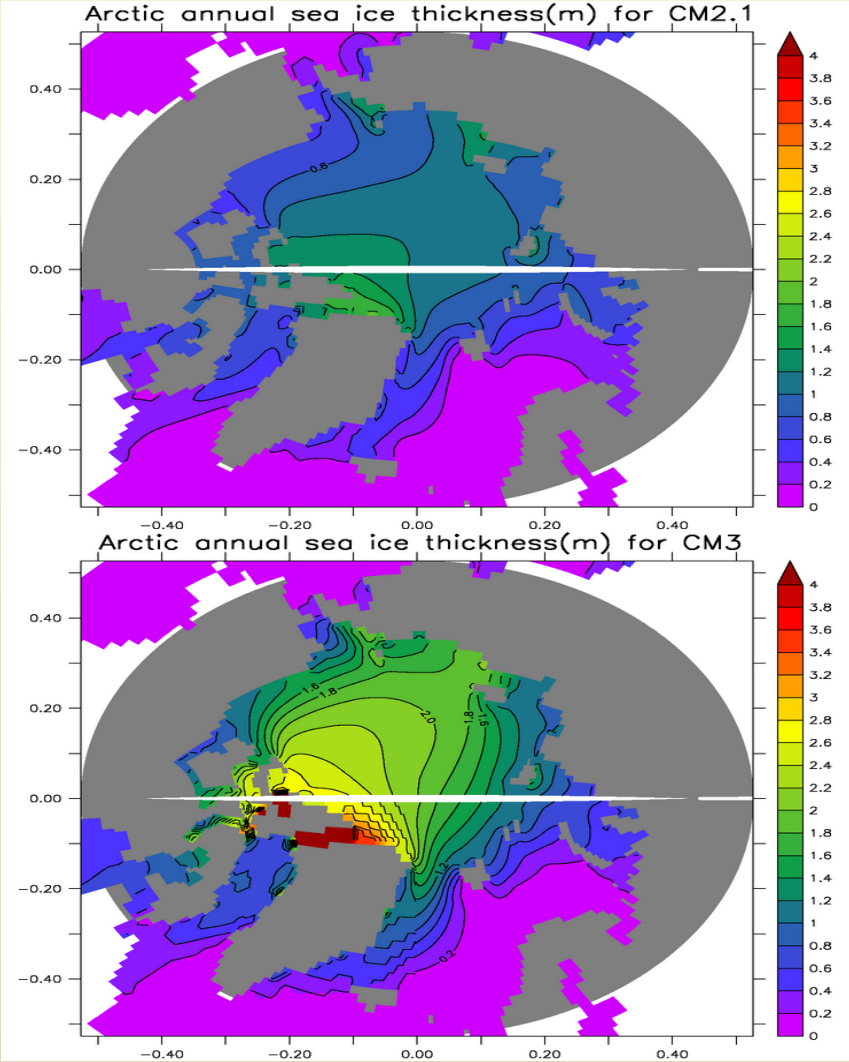


reduced coastal warm bias in CM3

Griffies *et al.* (2011, *J. Climate*, in press)

CM3 results: Sea ice improvements

CM2.1 had thin sea ice relative to other AR4 models and observations. CM3 agrees better with observations



Griffies *et al.* (2011, *J. Climate*, in press)

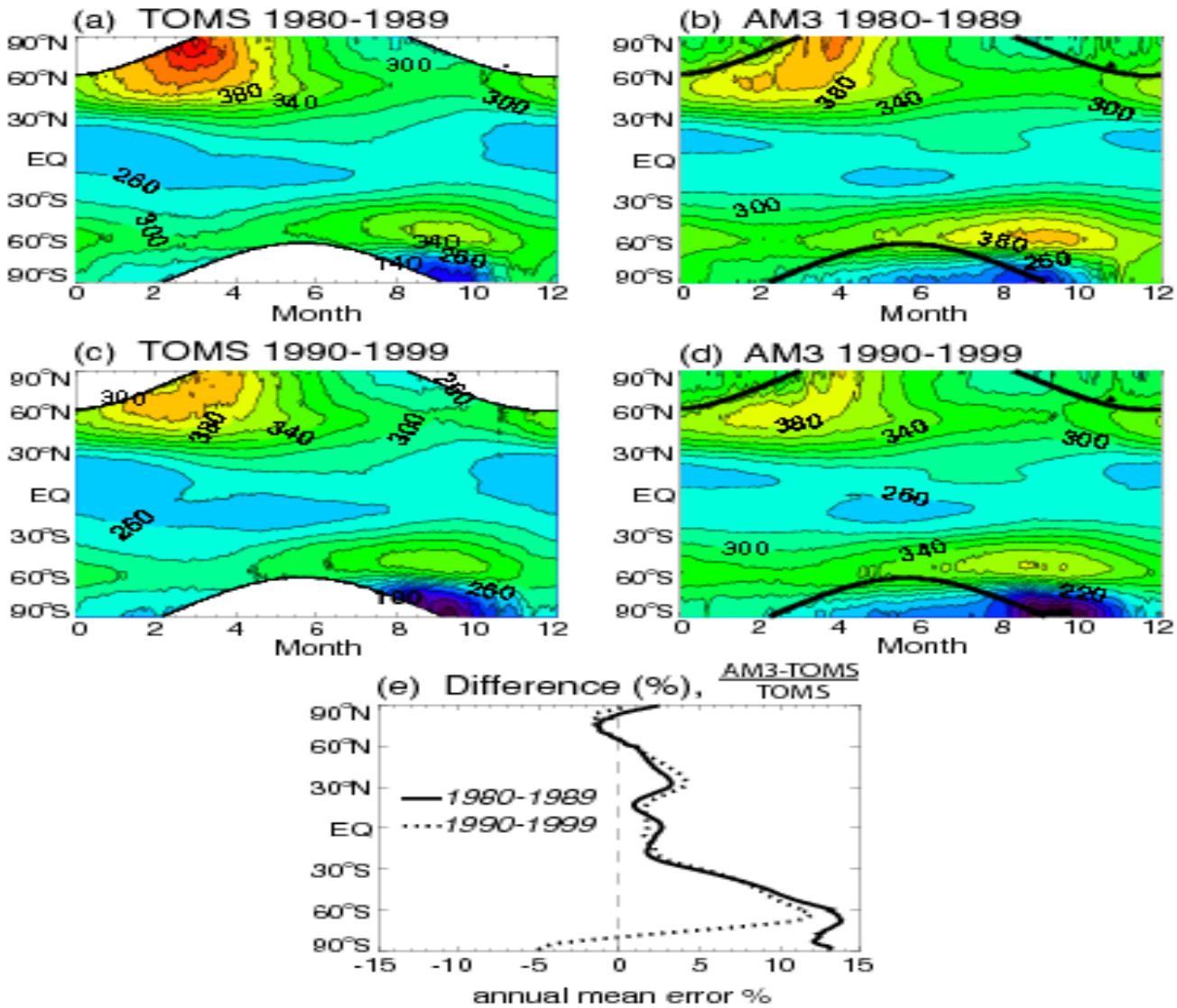
CM3: First NOAA/ GFDL Climate Model with Aerosol-Cloud Interactions

Globally Averaged Temperature Change
(1980-2000) minus (1881-1920)
(5-member ensembles for models)
(from Donner *et al.,* 2011, *J. Climate,* in press)

CM2.1 (no indirect effect)	0.66°C
CM3 (includes indirect effect)	0.32°C
GISS Observations	0.52°C
CRU Observations	0.56°C

CM3 cloud-aerosol interactions from physically based aerosol activation driven by sub-grid PDFs of vertical velocity in shallow cumulus and stratiform clouds (Ming *et al.,* 2006, *JAS;* Golaz *et al.,* 2011, *J. Climate,* in press).

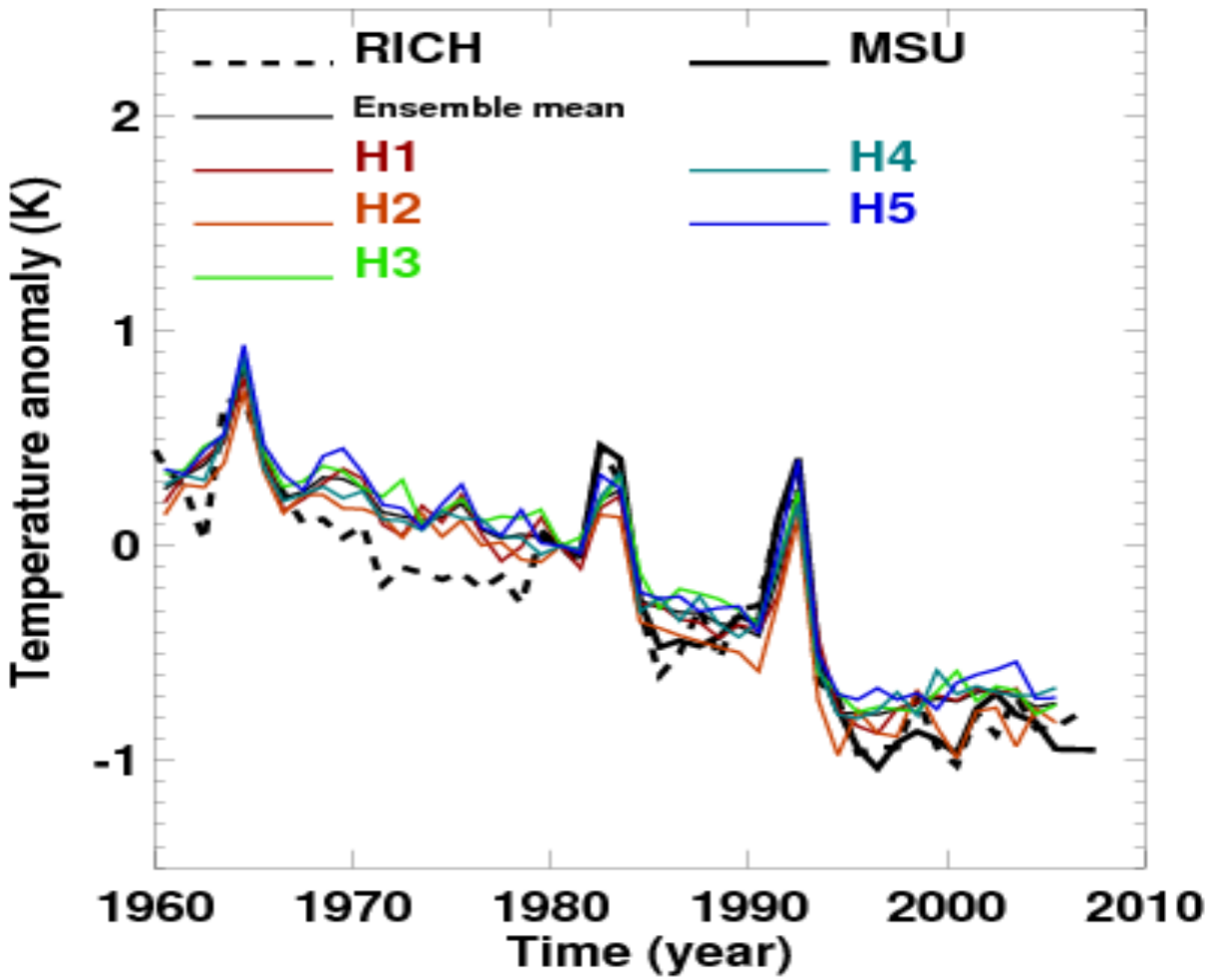
CM3 results: Total Column Ozone (Dobson Units); comparison with TOMS



Donner *et al.* (2011, *J. Climate*, in press)

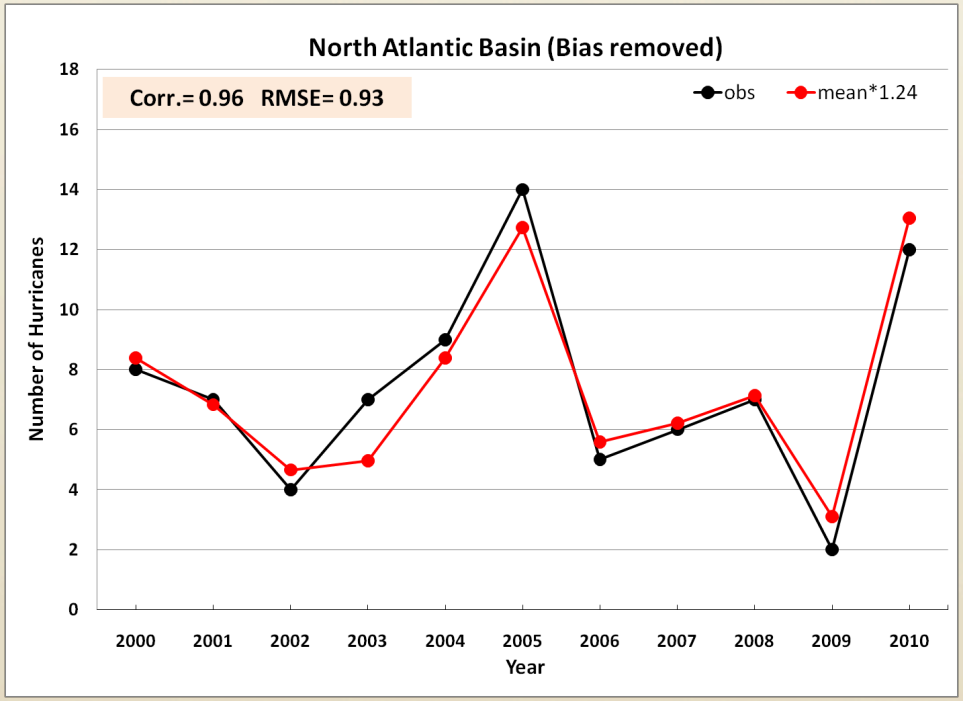
Stratospheric Temperature Anomaly

(global mean, MSU channel 4, ~80 hPa)



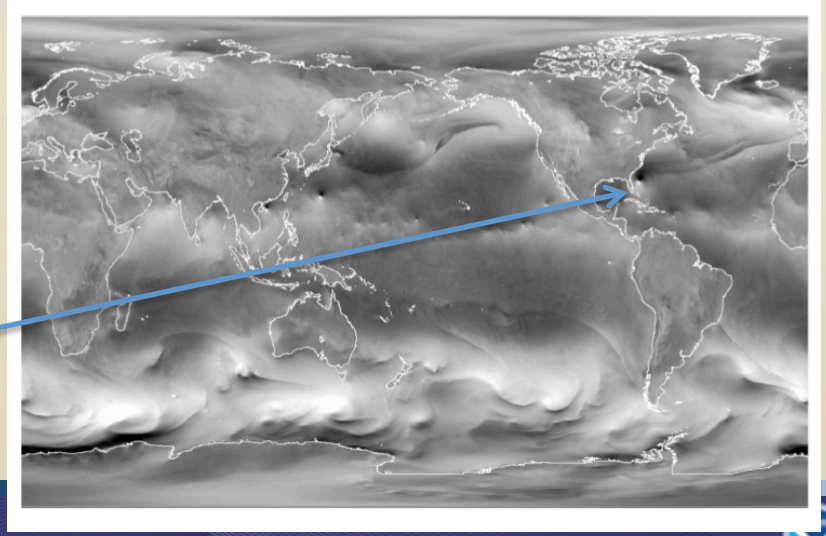
An example of seasonal (JASO) predictions of Atlantic hurricanes (2000-2010)

(*Chen and Lin 2011, manuscript*)



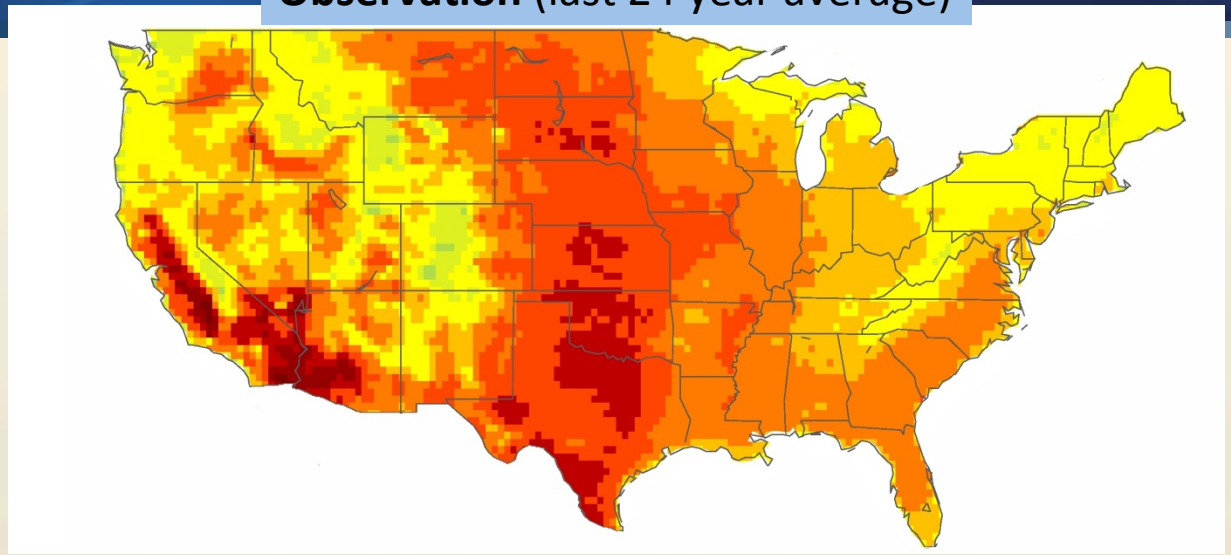
- 25-km GFDL HiRam
- Initialized forecasts
- Correlation = 0.96
- RMSE=0.93 (hurricanes)

An Atlantic hurricane in
25 km model
(snapshot of zonal surface wind)

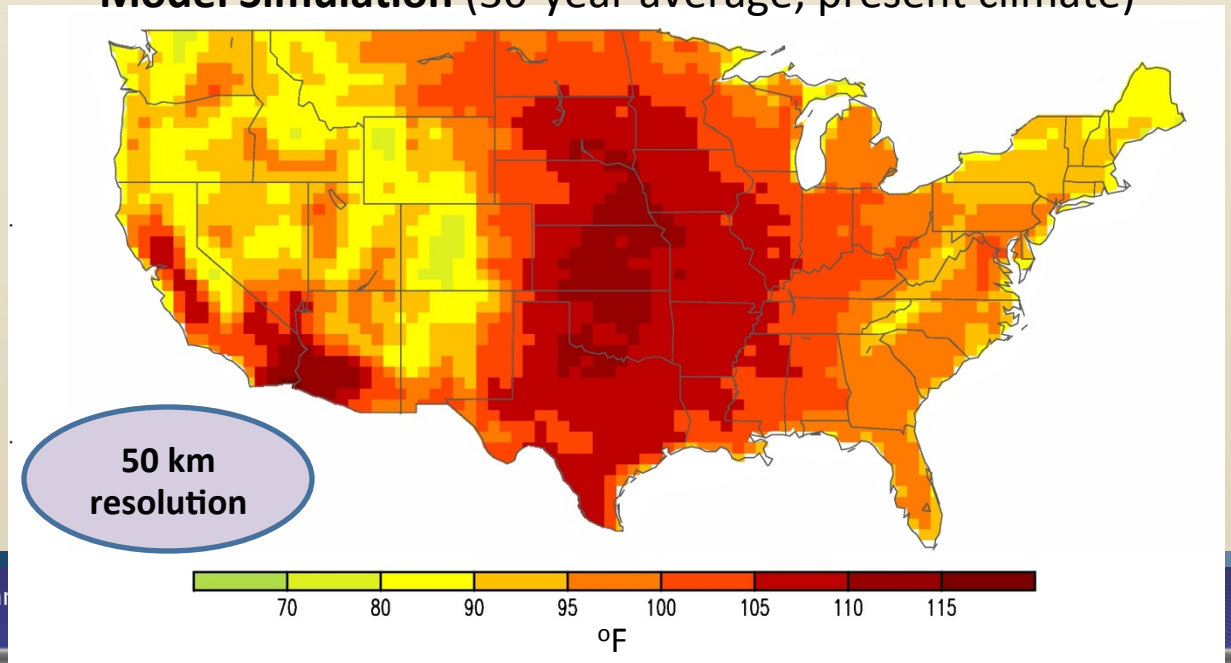


Severity of Summer Heat Waves

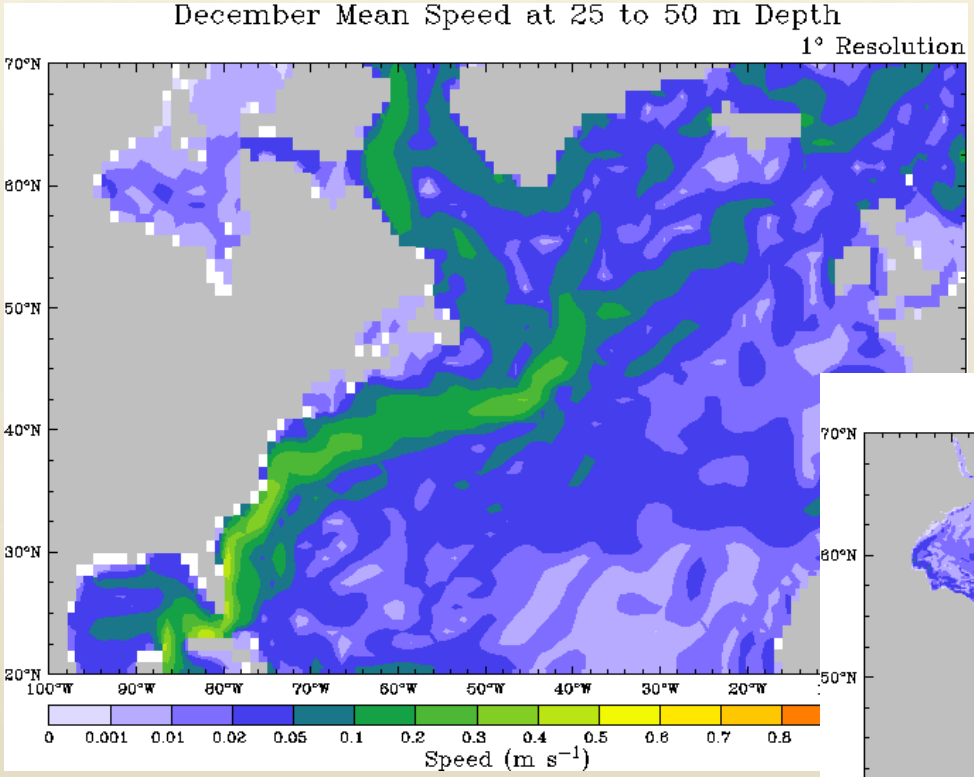
Observation (last 24 year average)



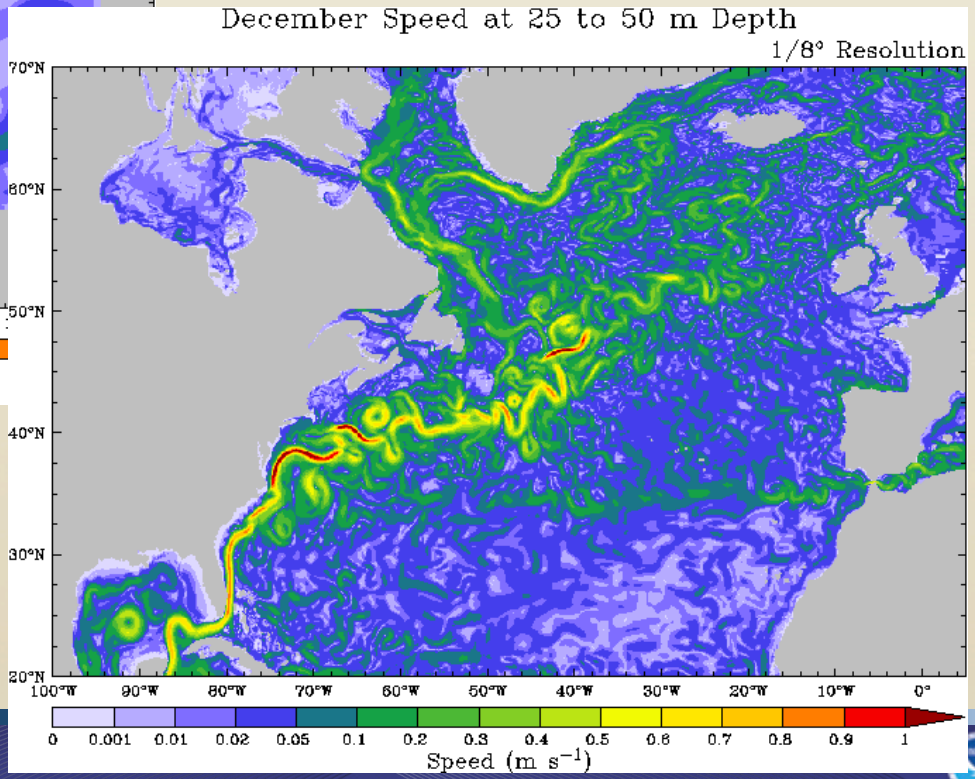
Model Simulation (30-year average; present climate)



Challenge: Resolution of Coastal-scale Processes



1/8 degree ocean simulation



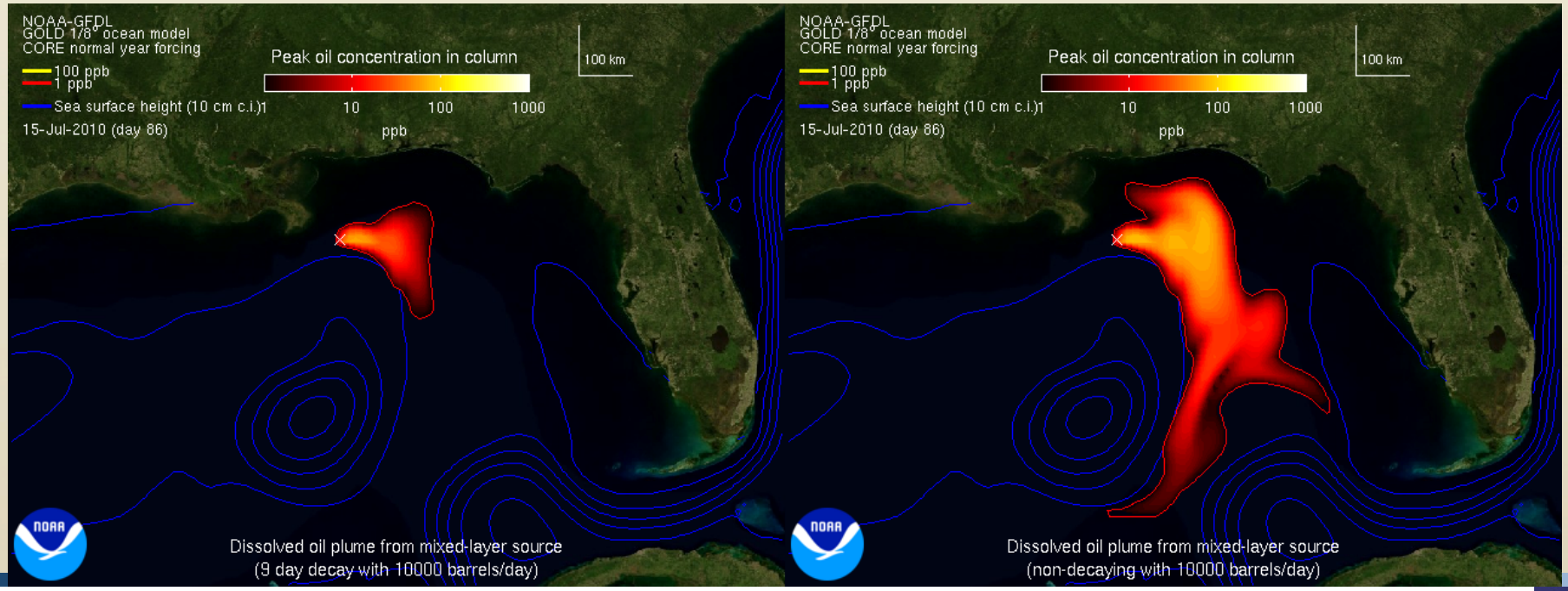
1 deg. Resolution (most AR4 and AR5 climate change simulations)

Recent Research Highlight: High-resolution Ocean Modeling of DWH

- Many of the oceanic consequences of climate change can best be explored with realistic high-resolution global ocean climate models, like those now being developed at GFDL.
- Example below: The roles of ocean transport and microbial decay in determining the impacts of the Deepwater Horizon oil spill, explored with a 1/8° global ocean climate model in a collaboration between NOAA/GFDL & NOAA/OR&R.

Simulated Dissolved Oil Concentrations in the Mixed Layer on July 15, 2010

with Microbial Decay (6 day Half-life) | Omitting Microbial Decay

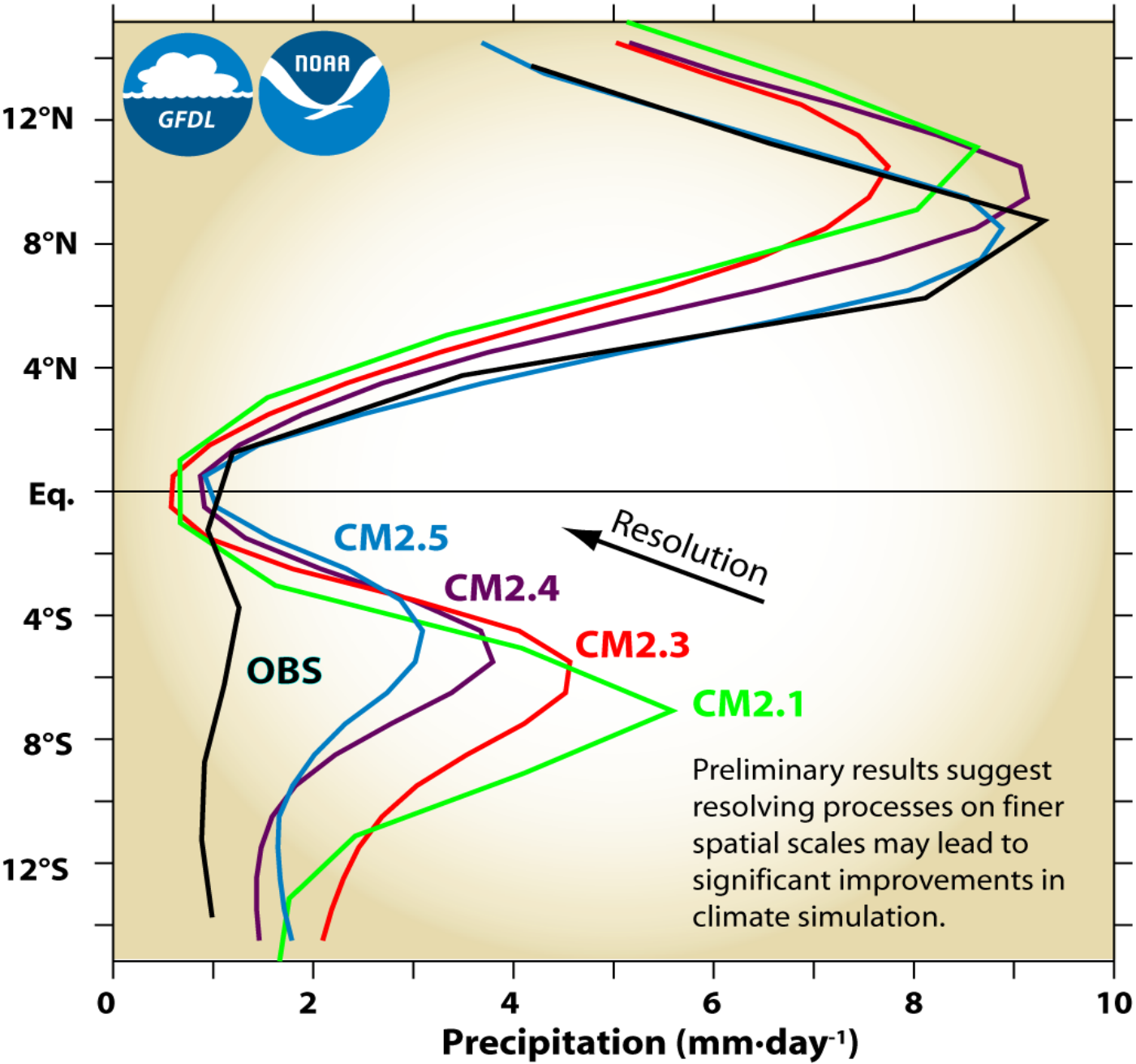


Reference: A. Adcroft, R. Hallberg, J.P. Dunne, B.L. Samuels, J.A. Galt, C.H. Barker and D.Payton (2010):
Simulations of underwater plumes of dissolved oil in the Gulf of Mexico, Geophys. Res. Lett., doi:10.1029/2010GL044689, in press.

Sequence of coupled models with increasing resolution

MODEL	ATMOSPHERE	OCEAN	LAND	Comments
CM2.1	2° lon x 2.5°lat 24 levels	1° lon x 1/3-1° lat	LM2	IPCC AR4 model
CM2.1.1	2° lon x 2.5°lat 24 levels	1° lon x 1/3-1° lat	LM2	Higher order advection in ocean, and low viscosity
CM2.3	1° lon x 1.25°lat 24 levels	1° lon x 1/3-1° lat	LM2	Same ocean as CM2.1, higher resolution atmosphere
CM2.4	1° lon x 1.25°lat 24 levels	25Km in Tropics to 9 Km in polar regions Square grid.	LM2-LM3	Same atmosphere as CM2.3, higher resolution ocean
CM2.5	50 Km atmosphere, 32 levels, cubed sphere grid	Similar to CM2.4, uses z* as vertical coord.	LM3	Uses icebergs in ocean Similar ocean to CM2.4, higher resolution atmosphere
CM2.6	50 Km atmosphere, 32 levels	10 Km in Tropics to 3 Km in polar regions	LM3	Same atmosphere as CM2.5, higher resolution ocean

GFDL Coupled Model East Pacific Precipitation (150°W-90°W)



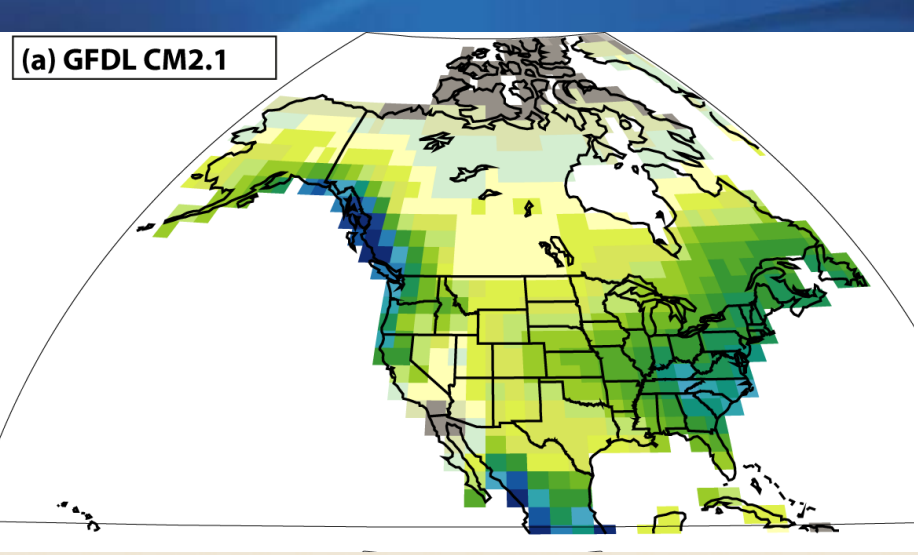
Observed rainfall

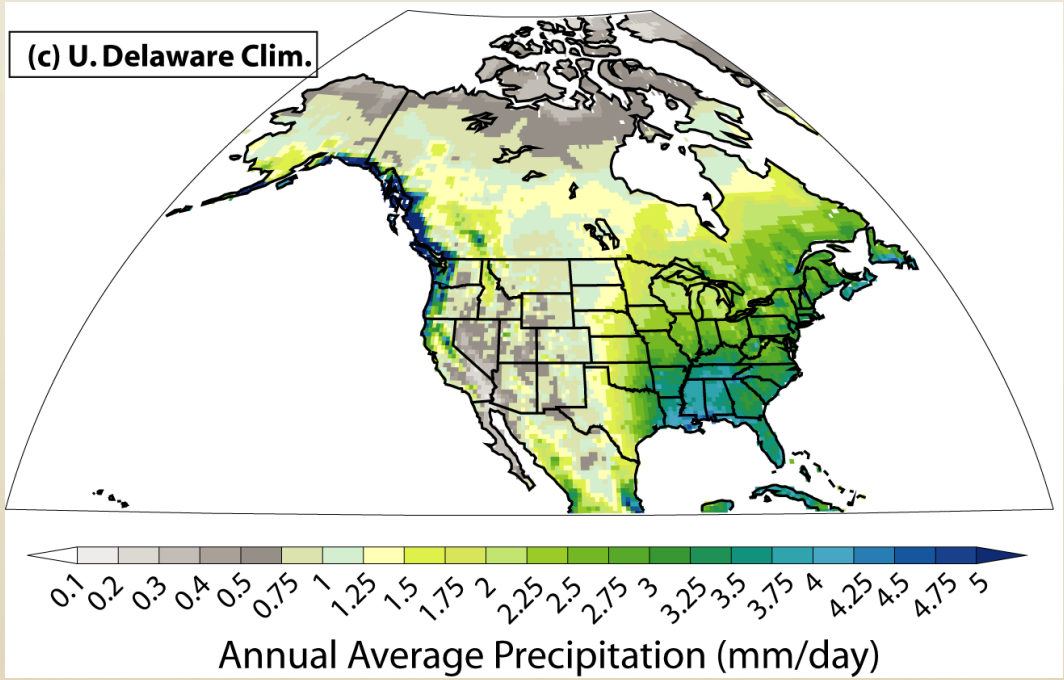
GFDL CM2.1
2° Atmosphere
1° Ocean

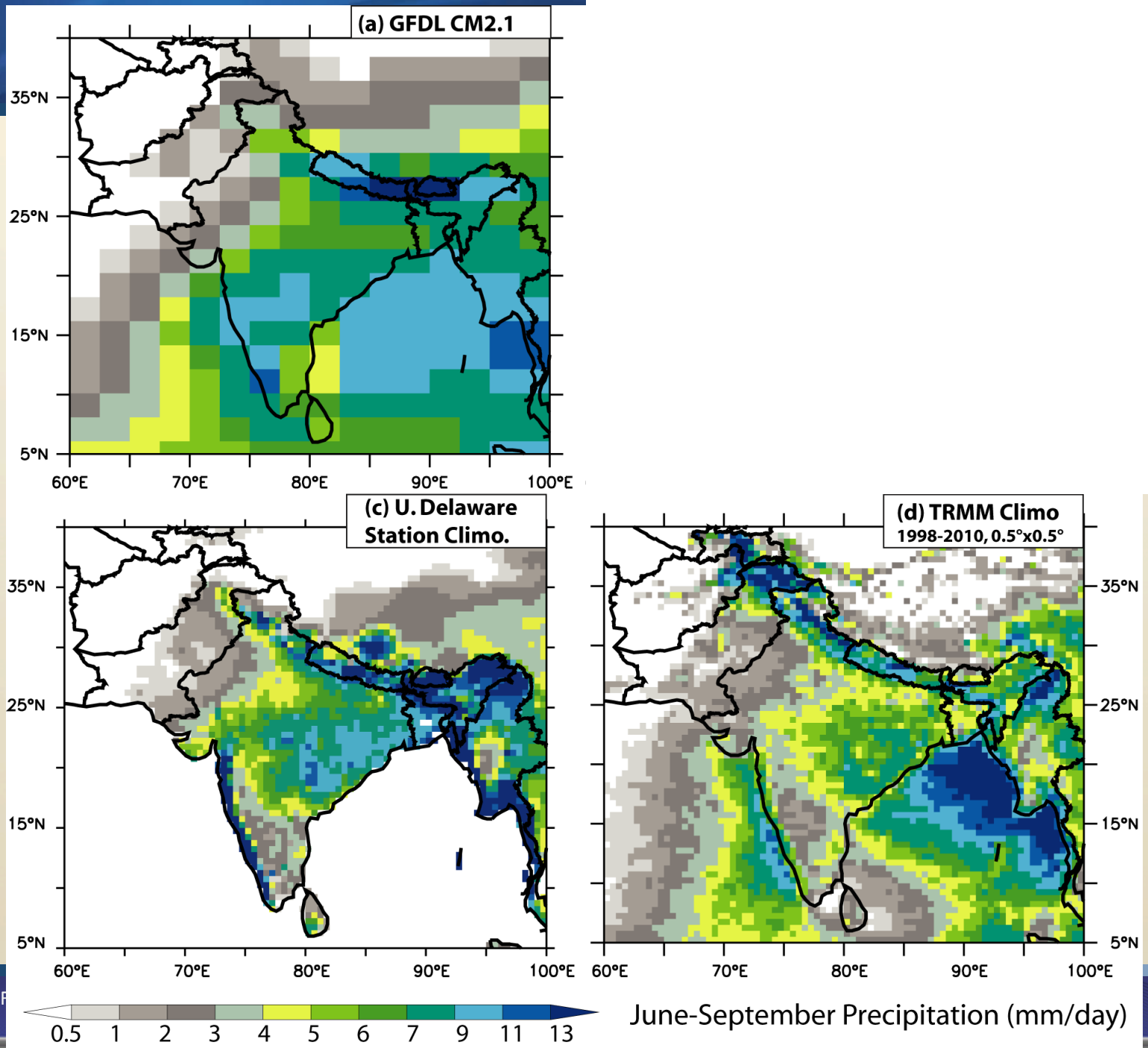
GFDL CM2.3
1° Atmosphere
1° Ocean

GFDL CM2.4
1° Atmosphere
1/4° Ocean

GFDL CM2.5
1/2° Atmosphere
1/4° Ocean


(a) GFDL CM2.1


(c) U. Delaware Clim.
0.1
0.2
0.3
0.4
0.5
0.75
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3
3.25
3.5
3.75
4
4.25
4.5
4.75
5
Annual Average Precipitation (mm/day)


(a) GFDL CM2.1
(c) U. Delaware Station Climo.
(d) TRMM Climo
1998-2010, 0.5°x0.5°
35°N
25°N
15°N
5°N
60°E
70°E
80°E
90°E
100°E
0.5
1
2
3
4
5
6
7
9
11
13
June-September Precipitation (mm/day)

The END

Thank you