Introduction to the Community Earth System Model

Marika Holland
CESM Chief Scientist
Climate and Global Dynamics Division
NCAR Earth Systems Laboratory

Outline

- An Overview of the CESM Model
- Science Highlights
  - Using different CESM configurations to investigate climate variability and change
- Some New Developments and Directions

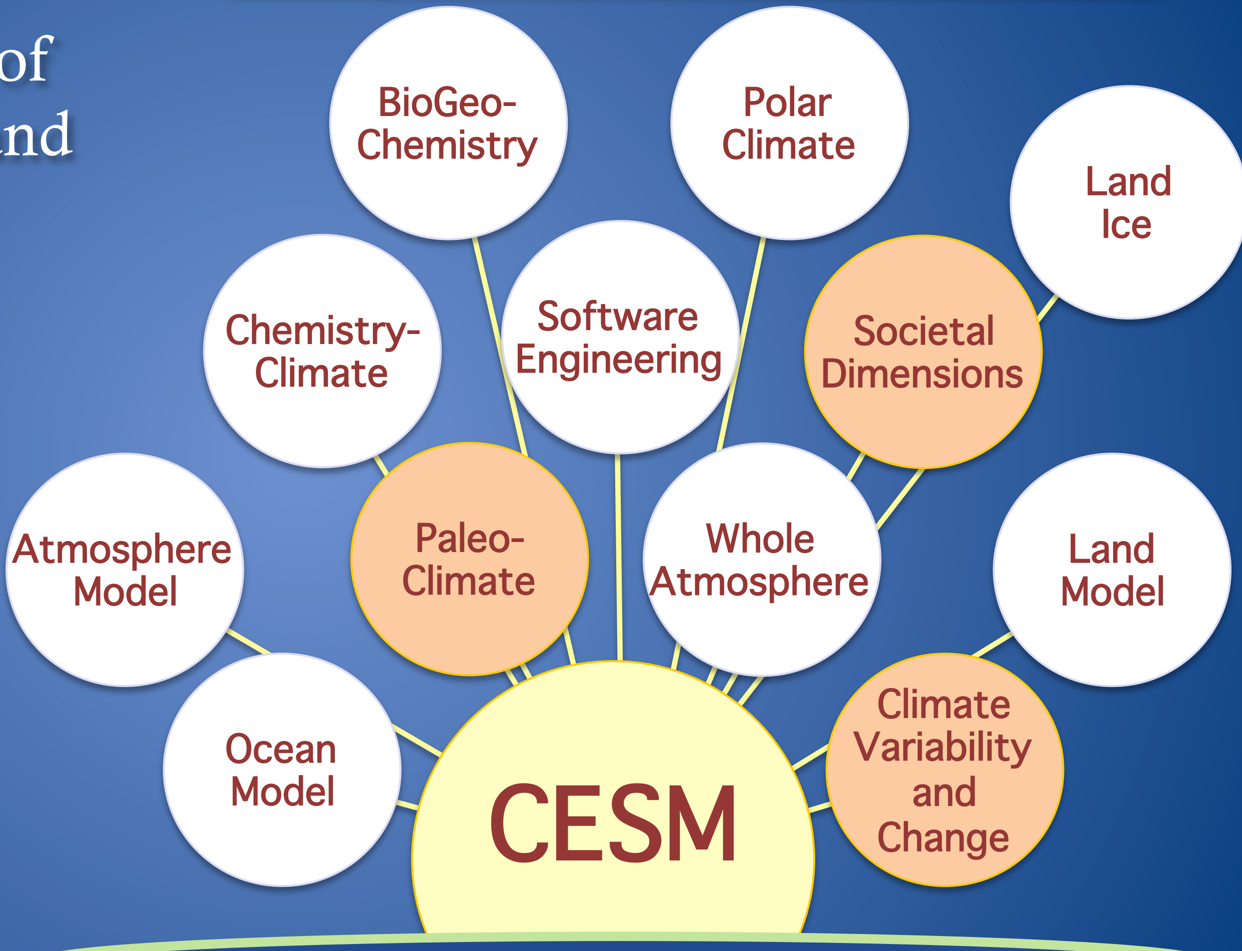
Marika Holland
mholland@ucar.edu

CESM Project

CESM Advisory Board

CESM Scientific Steering Committee

Based on 20+ Years of Model development and application



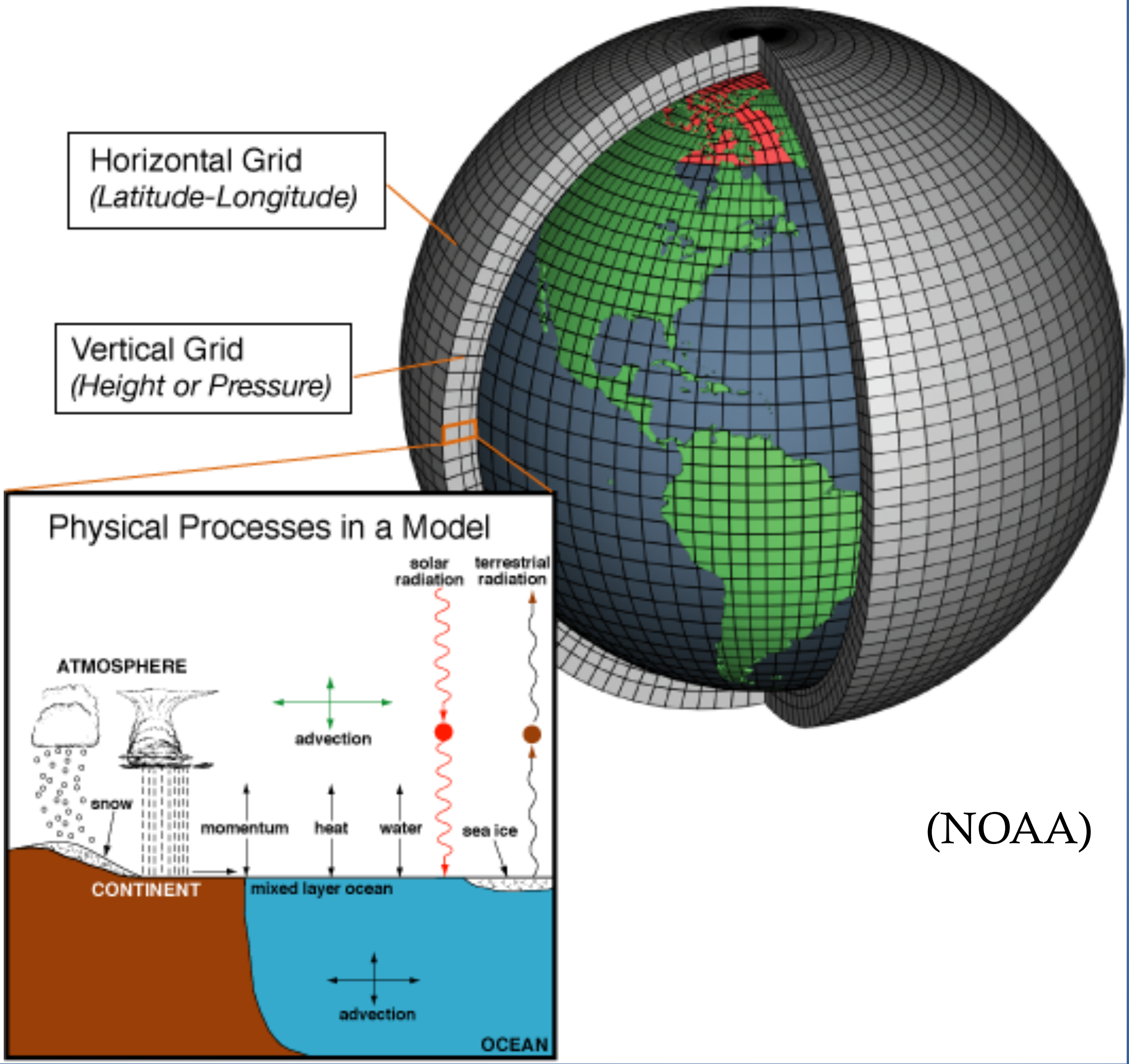
CESM is primarily sponsored by the National Science Foundation and the Department of Energy

Most working groups have winter/spring meetings. Annual meeting in June.

http://www.cesm.ucar.edu/management

Marika Holland
mholland@ucar.edu

Community Earth System Model



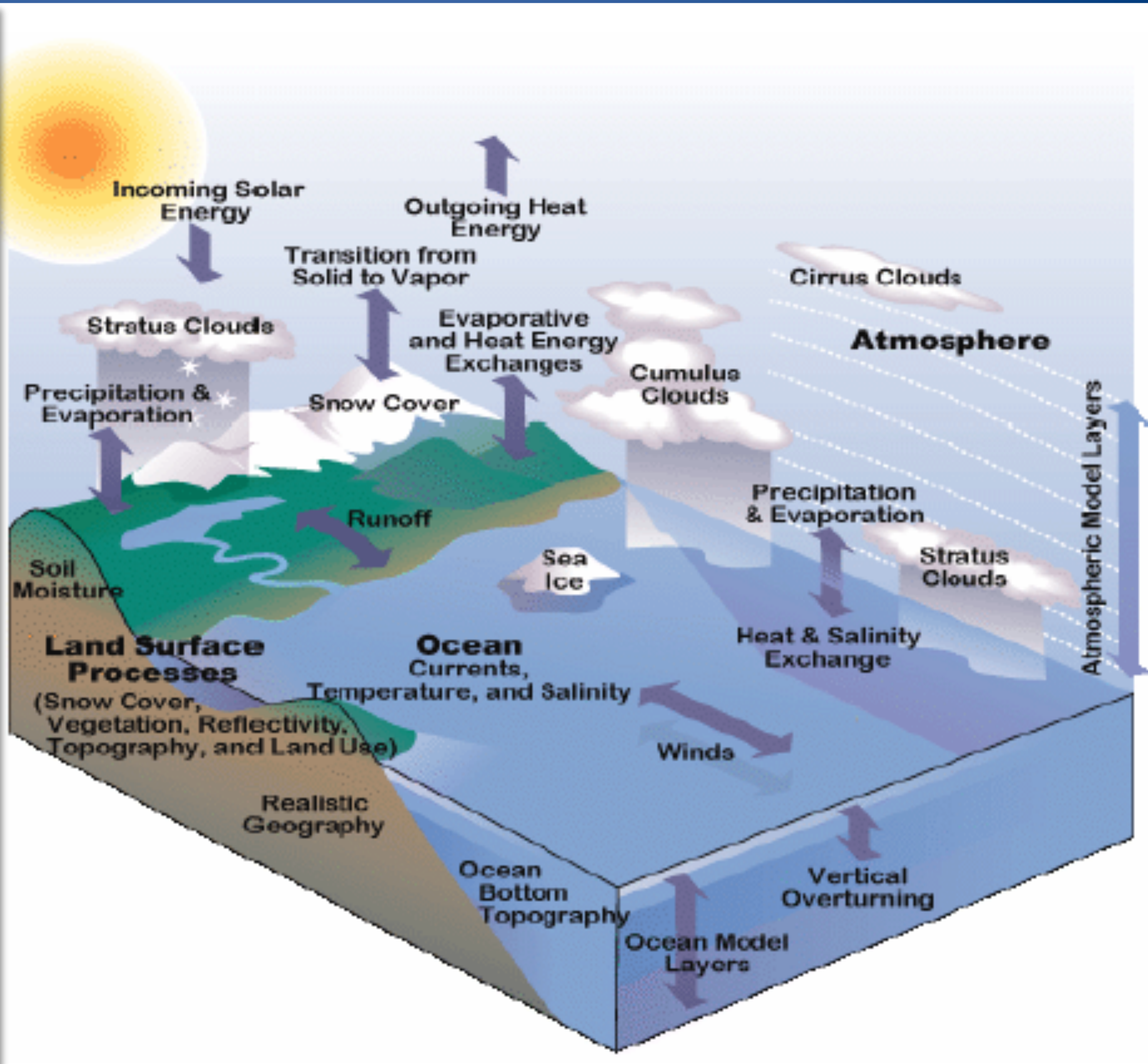
(NOAA)

- Systems of differential equations that describe fluid motion, radiative transfer, etc.
- Planet divided into 3-dimensional grid to solve the equations
- Atmosphere and land traditionally on same horizontal grid
- Similarly for ocean/ice
- Sub-gridscale processes are parameterized

Marika Holland
mholland@ucar.edu

Coupled Climate Models

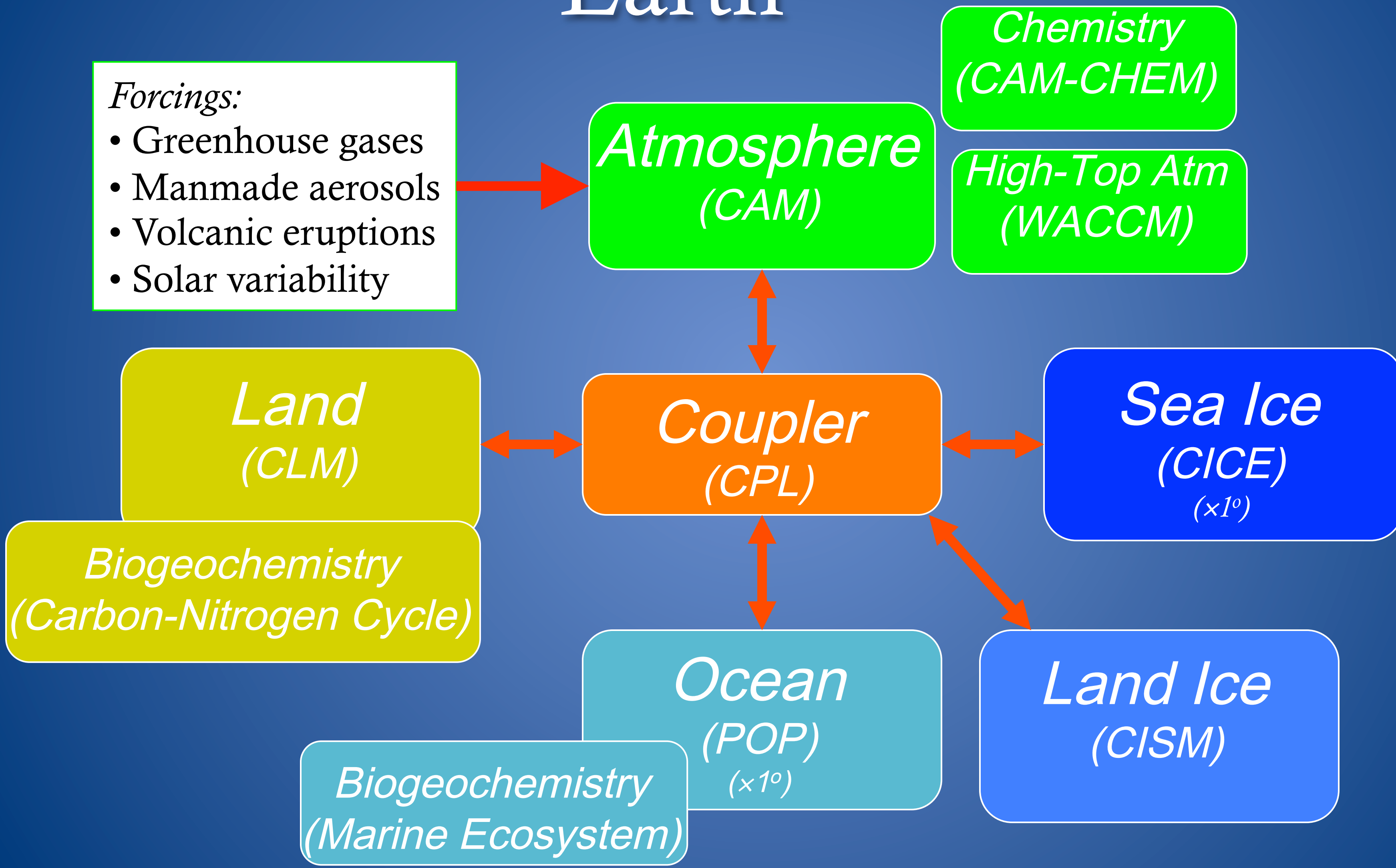
- Include atmosphere, ocean, land, & sea ice components
- Conservative exchange of heat and water across components
- Can apply changes in external forcing – solar input, GHGs, volcanic eruptions
- Provide a virtual laboratory for experimentation



Marika Holland
mholland@ucar.edu

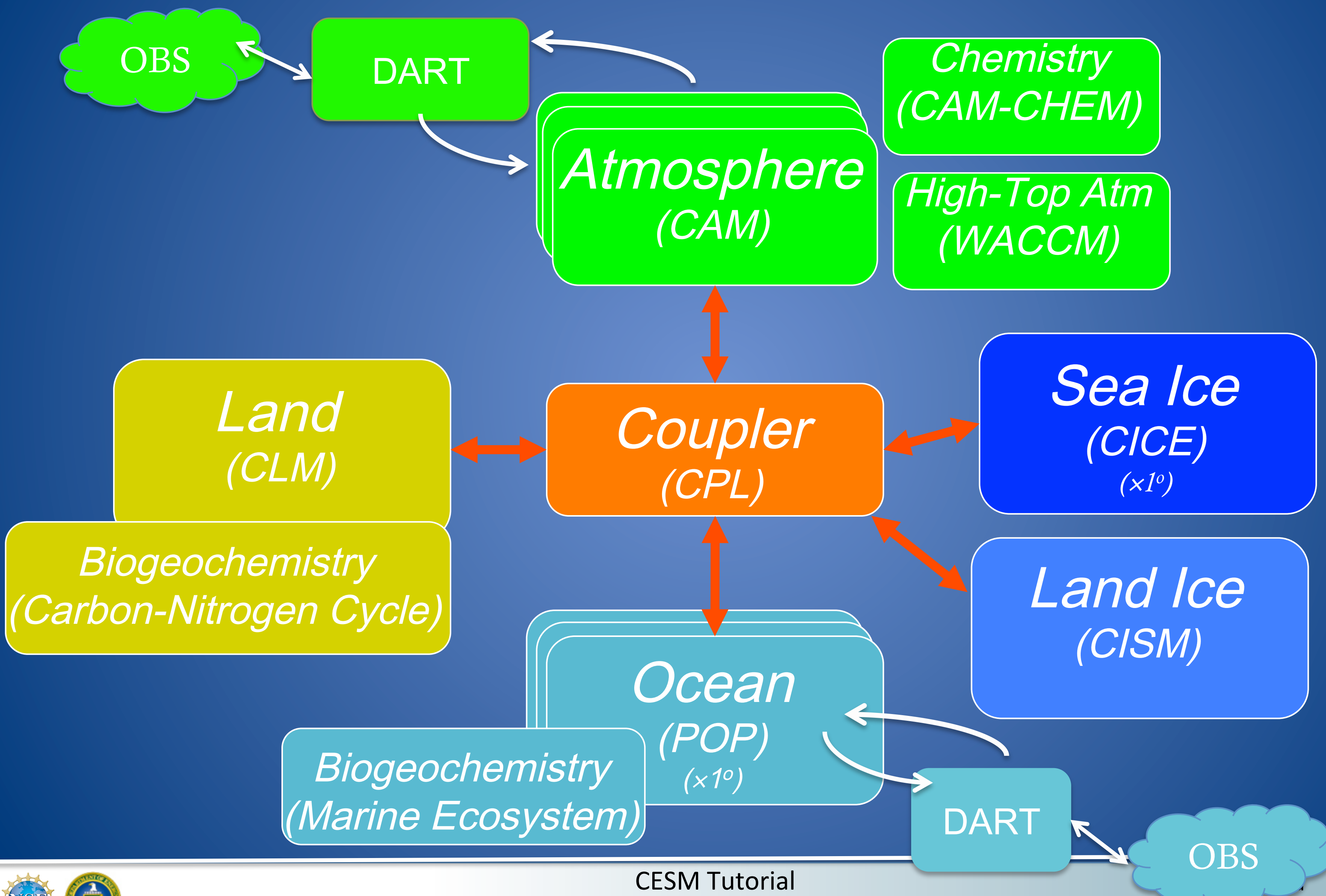
Community ~~Climate~~ System Model

Earth



Marika Holland
mholland@ucar.edu

Community Earth System Model



mholland@ucar.edu

Climate & Global Dynamics

Notes on CESM Configurations

- All component models can be active
- All component models can be replaced with "data models"
  - These read in relevant fields for model forcing (for example the datm used in an ocean-only run may read in NCEP for forcing)
  - The ocean model can also be replaced with a slab model
- Numerous options are available within components
  - Can be chosen with namelist options
  - For example different sea ice albedo formulations, etc.
- Increasing number of supported component sets available (including ability to run 20th & 21st century runs)

Marika Holland
mholland@ucar.edu

CESM CMIP5 Simulations

- CCSM4=CAM4, CLM4, CICE4, POP2 (1^o resolution for atm/ocn)
  - PI run, 6-20^{th} Century Runs, 6-runs for RCP2.6, RCP4.5, RCP6.0 and RCP8.5
- CESM1-CAM5=CAM5, CLM4, CICE4, POP2 (1^o resolution)
  - PI run, 3-20^{th} Century Runs, 3 runs for each RCP
- CESM1-FASTCHEM=CAM-CHEM, CLM4, CICE4, POP2 (1^o)
  - PI run, 3-20^{th} century runs
- CESM1-BGC=CAM4, CLM4, CICE4, POP2, carbon cycle (1^o)
  - PI run, 1-20^{th} Century run, 1-RCP4.5, 1-RCP8.5
- CESM1-WACCM=WACCM4, CLM4, CICE4, POP2 (2^o atm/1^o ocn)
  - PI run, 3-20^{th} century, 3-RCP4.5
- CCSM4_DP (Decadal Prediction) Simulations

Marika Holland
mholland@ucar.edu

CESM Model Releases

- Targeting annual (May/June) releases
- Configurations in multiple categories
  - Scientifically vetted (with runs/"assessment")
  - Functionally vetted (routine testing)
  - Development only (no testing; use at own risk)
- Webpage with "scientifically supported" compsets: http://www2.cesm.ucar.edu/models/scientifically-supported
- New bulletin board (DiscussCESM Forum) for updates on releases and other model support – encourage subscription

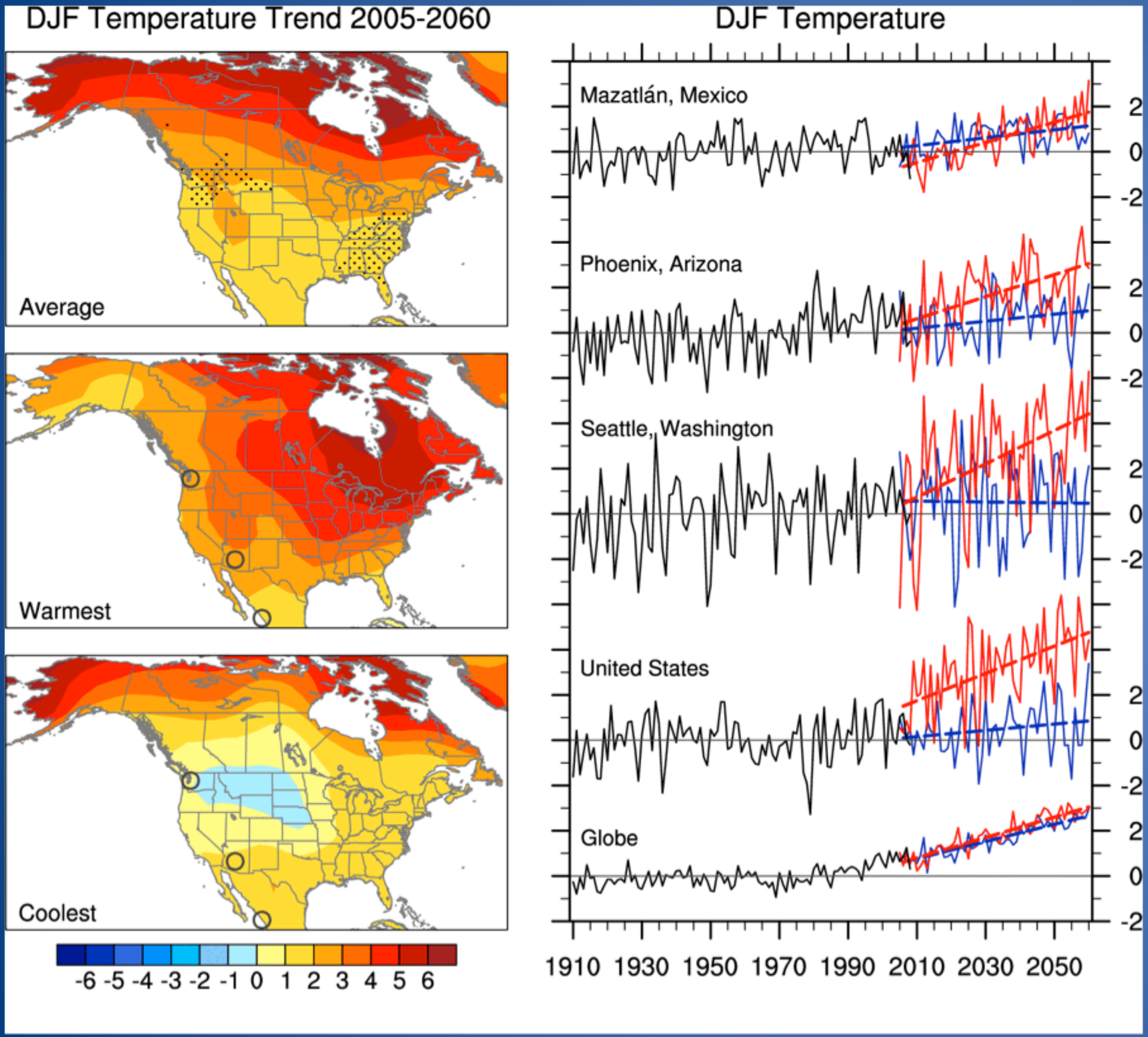
Marika Holland
mholland@ucar.edu

CESM Community Integrations

- CESM integrations with broad cross-working group science applications
- To be made available in timely fashion to scientific community via ESG

Marika Holland
mholland@ucar.edu

Community Integrations - Large Ensemble
Science Motivation



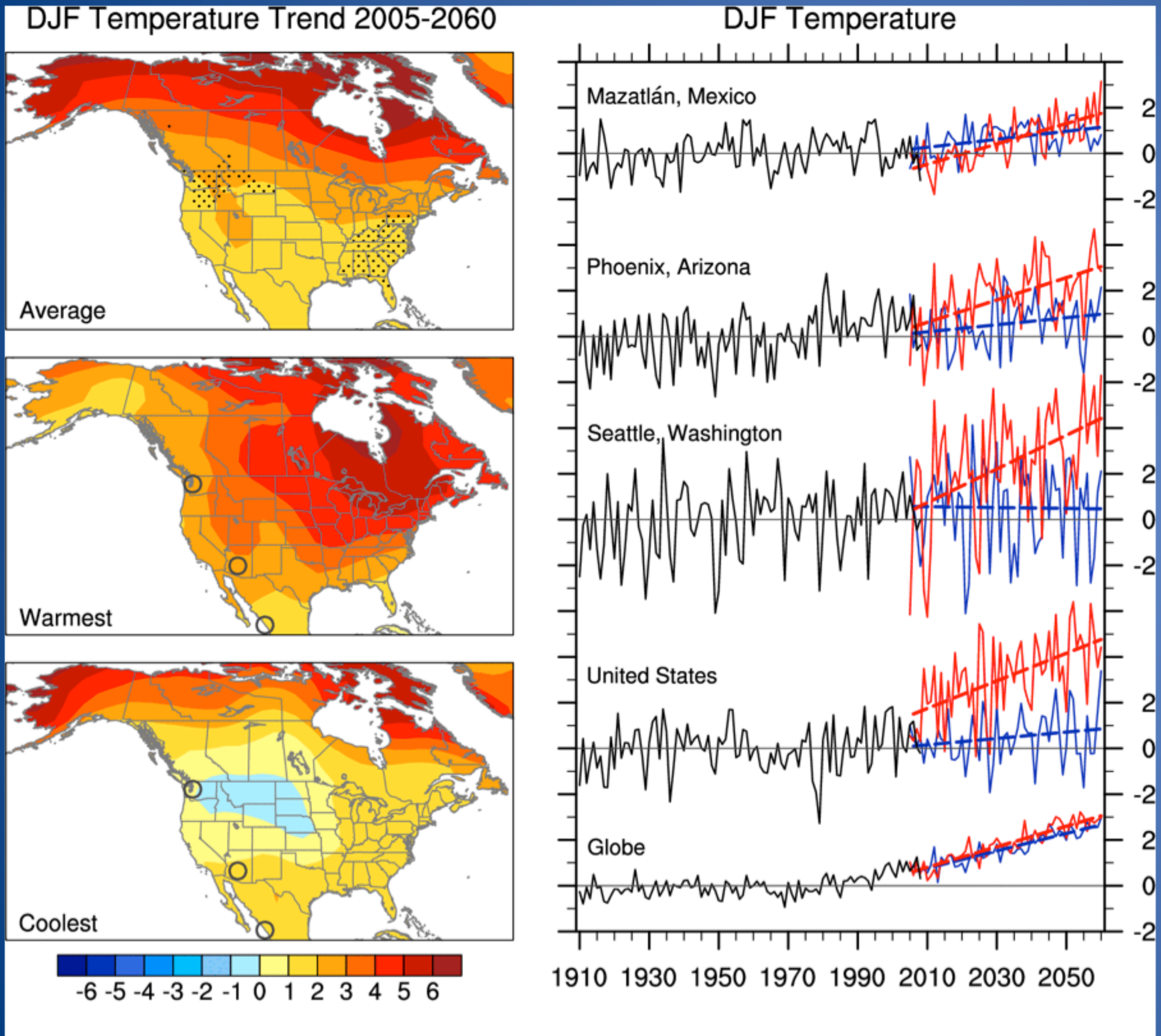
From Deser et al., 2012, Nature Climate Change

Purpose:

- To robustly determine simulated natural variability
- To assess climate extremes and their changing likelihood
- To investigate detection/attribution of climate changes in the 20th-21st centuries

Marika Holland
mholland@ucar.edu

Community Integrations - Large Ensemble
Experimental Design



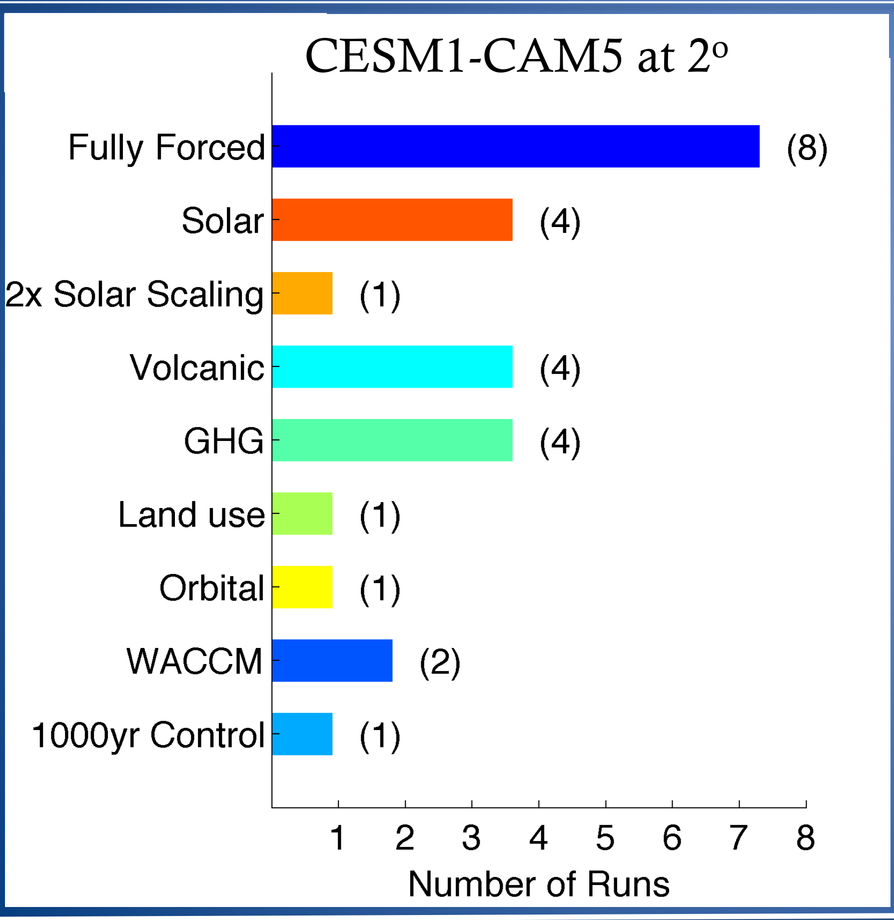
From Deser et al., 2012, Nature Climate Change

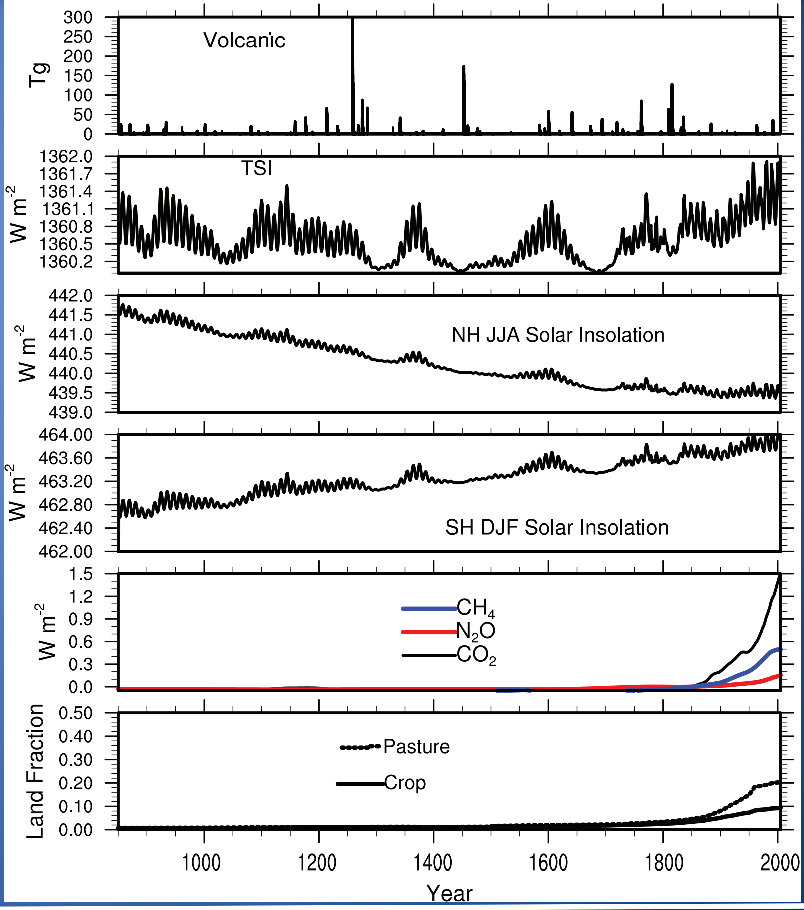
- ~30 Members, 1920-2080, RCP8.5
- CESM-CAM5-BGC (1-degree) with prescribed CO2.
- Pre-industrial control will also be available
- Initial state varied by a round-off **level** change
- High-frequency output

Marika Holland
mholland@ucar.edu

Community Integrations: Last Millennium Ensemble

- Motivation: To assess and attribute climate variations over the last millennium
- Simulations from 850-2005; ensembles of fully-forced + single forcing CESM-CAM5 experiments (23) and fully-forced WACCM runs (2)
- CESM1-CAM5 2-degree pre-industrial control integration will also be available

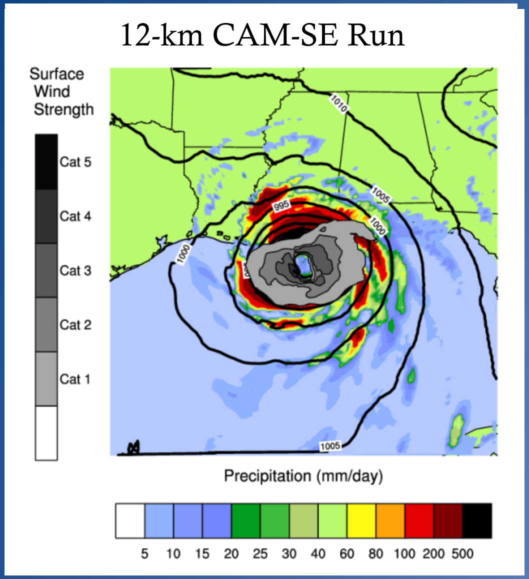




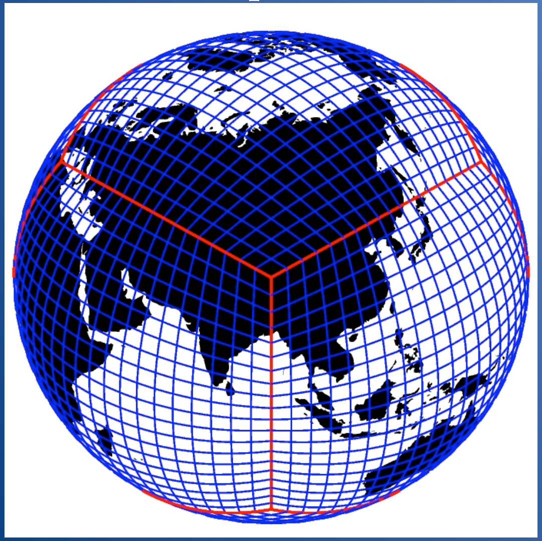
Marika Holland
mholland@ucar.edu

Community Integrations – High Resolution Control

Tropical Cyclones



Cubed Sphere



- Fully couple configuration
  - 25km CAM5-SE
  - 1-degree ocean
- Multi-century integration
- Likely to start early 2014
- Will solicit community input on experiment design, desired output, etc.

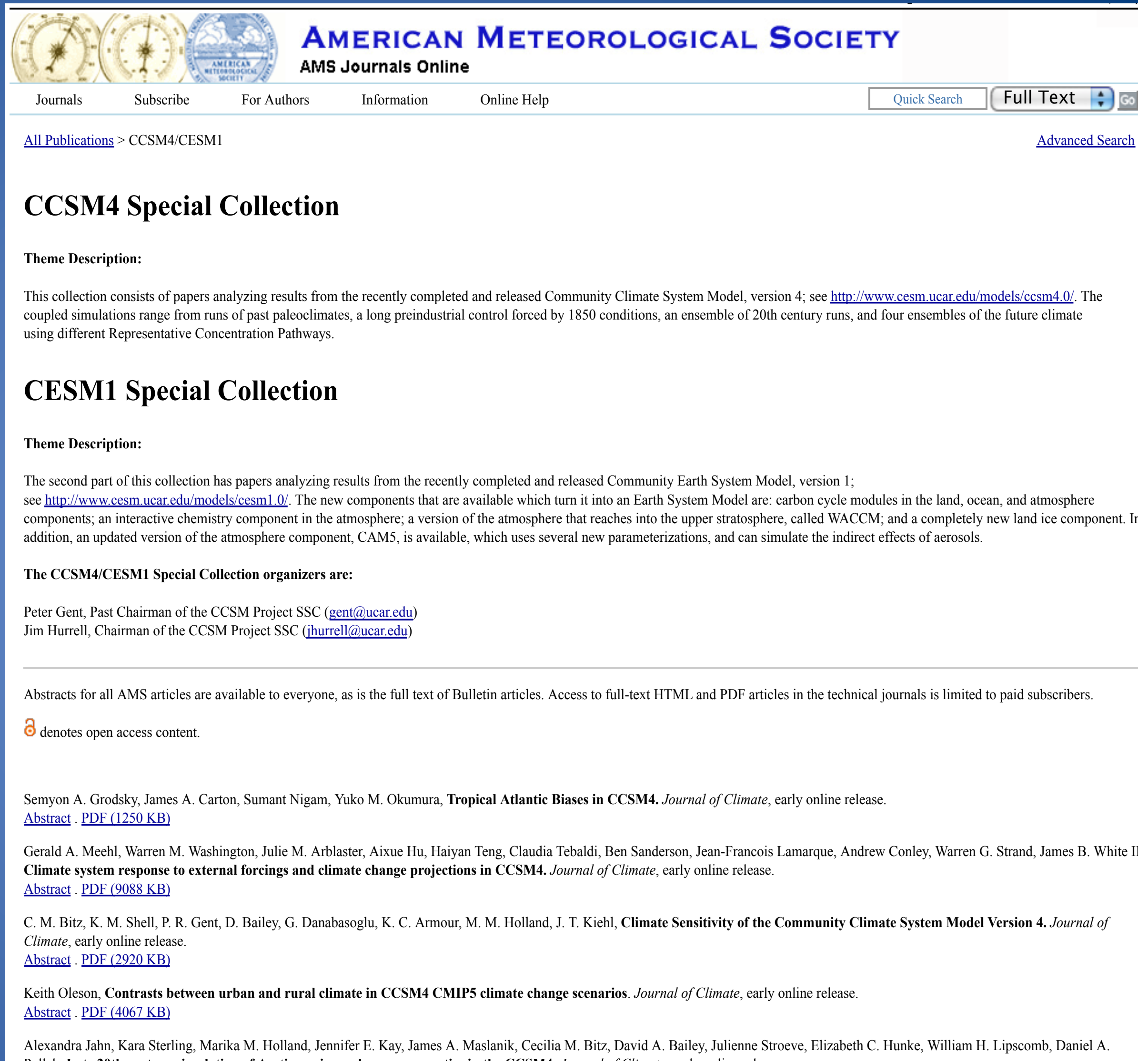
Marika Holland
mholland@ucar.edu

Science Highlights

Marika Holland
mholland@ucar.edu

CCSM4/CESM1 J. Climate Special Collections

- >50 Papers available via AMS early-online release
- Document major model components and numerous aspects of simulated variability and change from all CESM configurations


AMERICAN METEOROLOGICAL SOCIETY

AMS Journals Online

Journals Subscribe For Authors Information Online Help Quick Search Full Text

All Publications > CCSM4/CESM1 Advanced Search

CCSM4 Special Collection

Theme Description:

This collection consists of papers analyzing results from the recently completed and released Community Climate System Model, version 4; see http://www.cesm.ucar.edu/models/ccsm4.0/. The coupled simulations range from runs of past paleoclimates, a long preindustrial control forced by 1850 conditions, an ensemble of 20th century runs, and four ensembles of the future climate using different Representative Concentration Pathways.

CESM1 Special Collection

Theme Description:

The second part of this collection has papers analyzing results from the recently completed and released Community Earth System Model, version 1; see http://www.cesm.ucar.edu/models/cesm1.0/. The new components that are available which turn it into an Earth System Model are: carbon cycle modules in the land, ocean, and atmosphere components; an interactive chemistry component in the atmosphere; a version of the atmosphere that reaches into the upper stratosphere, called WACCM; and a completely new land ice component. In addition, an updated version of the atmosphere component, CAM5, is available, which uses several new parameterizations, and can simulate the indirect effects of aerosols.

The CCSM4/CESM1 Special Collection organizers are:

Peter Gent, Past Chairman of the CCSM Project SSC (gent@ucar.edu)
Jim Hurrell, Chairman of the CCSM Project SSC (jhurrell@ucar.edu)

Abstracts for all AMS articles are available to everyone, as is the full text of Bulletin articles. Access to full-text HTML and PDF articles in the technical journals is limited to paid subscribers.

denotes open access content.

Semyon A. Grodsky, James A. Carton, Sumant Nigam, Yuko M. Okumura, **Tropical Atlantic Biases in CCSM4.** *Journal of Climate*, early online release.
Abstract . PDF (1250 KB)

Gerald A. Meehl, Warren M. Washington, Julie M. Arblaster, Aixue Hu, Haiyan Teng, Claudia Tebaldi, Ben Sanderson, Jean-Francois Lamarque, Andrew Conley, Warren G. Strand, James B. White III. **Climate system response to external forcings and climate change projections in CCSM4.** *Journal of Climate*, early online release.
Abstract . PDF (9088 KB)

C. M. Bitz, K. M. Shell, P. R. Gent, D. Bailey, G. Danabasoglu, K. C. Armour, M. M. Holland, J. T. Kiehl, **Climate Sensitivity of the Community Climate System Model Version 4.** *Journal of Climate*, early online release.
Abstract . PDF (2920 KB)

Keith Oleson, **Contrasts between urban and rural climate in CCSM4 CMIP5 climate change scenarios**. *Journal of Climate*, early online release.
Abstract . PDF (4067 KB)

Alexandra Jahn, Kara Sterling, Marika M. Holland, Jennifer E. Kay, James A. Maslanik, Cecilia M. Bitz, David A. Bailey, Julienne Stroeve, Elizabeth C. Hunke, William H. Lipscomb, Daniel A.

http://journals.ametsoc.org/page/CCSM4/CESM1

Marika Holland
mholland@ucar.edu

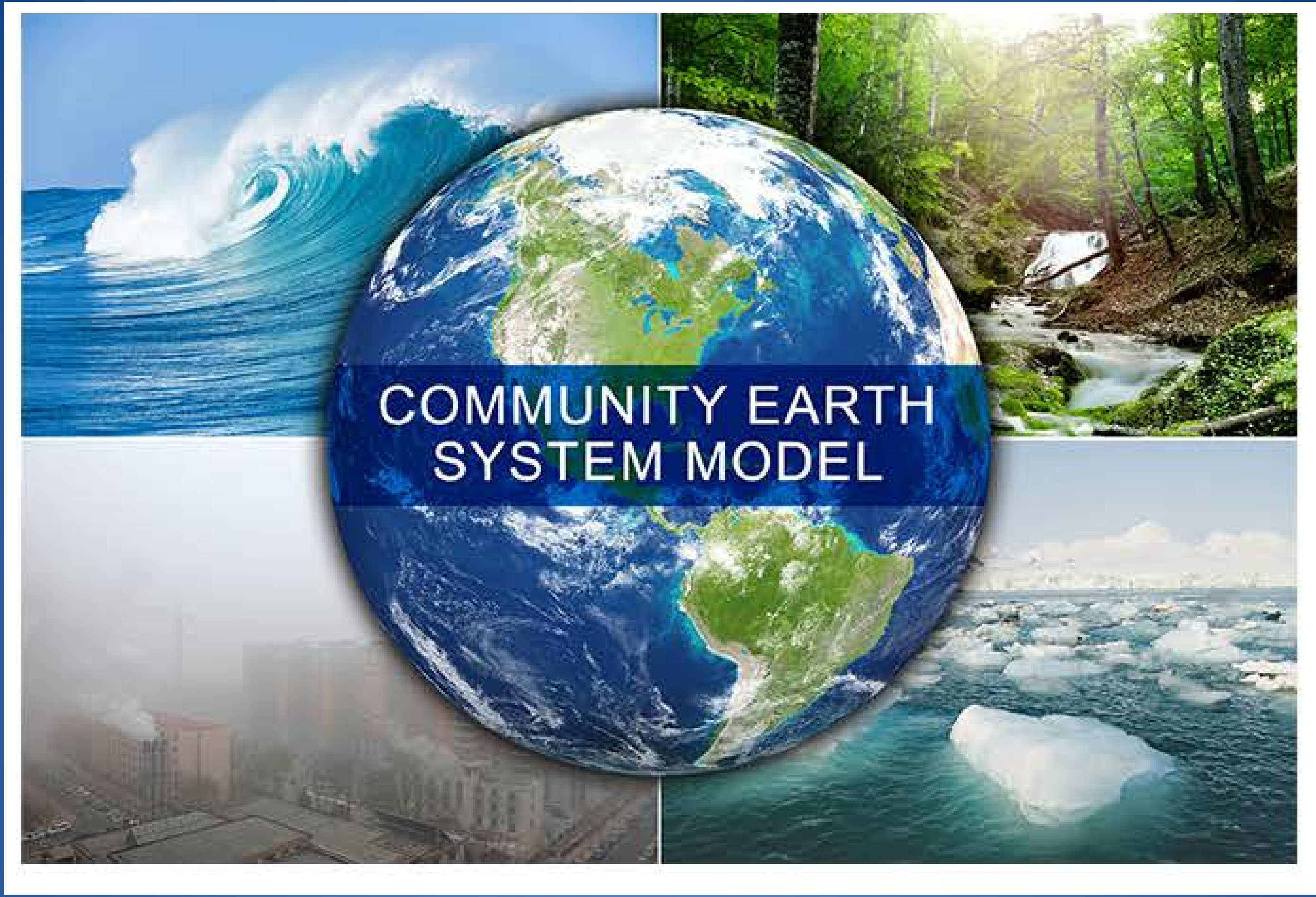


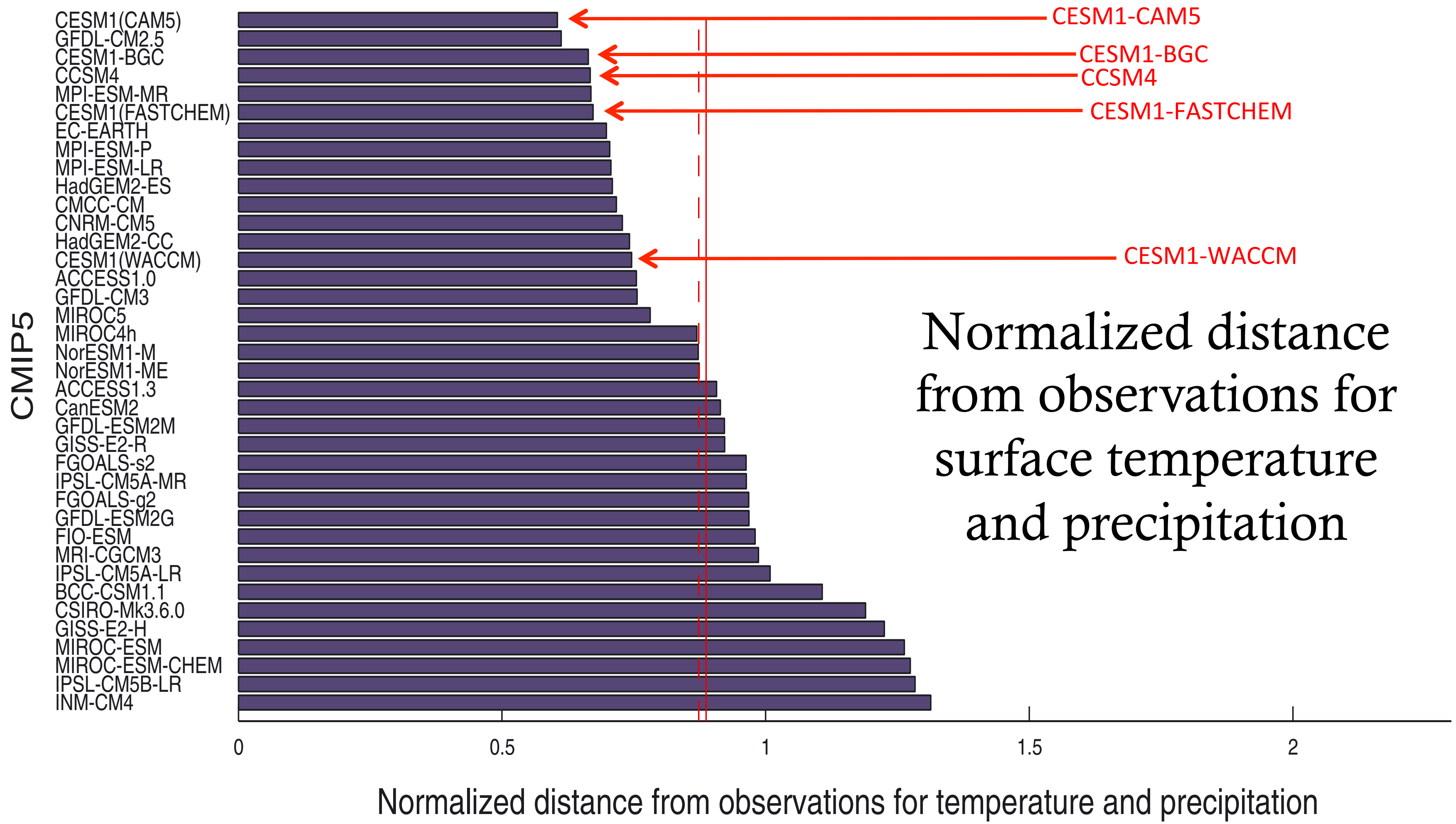
Figure courtesy of Steve Ghan and DOE Graphics team

BAMS Article:

The Community Earth System Model: A Framework for Collaborative Research
J.W. Hurrell, M.M. Holland, P.R. Gent, S. Ghan, J.E. Kay, P.J. Kushner, J.-F. Lamarque, W.G. Large, D. Lawrence, K. Lindsay, W.H. Lipscomb, M.C. Long, N. Mahowald, D.R. Marsh, R.B. Neale, P. Rash, S. Vavrus, M. Vertenstein, D. Bader, W.D. Collins, J.J. Hack, J. Kiehl, S. Marshall, available online

Marika Holland
mholland@ucar.edu

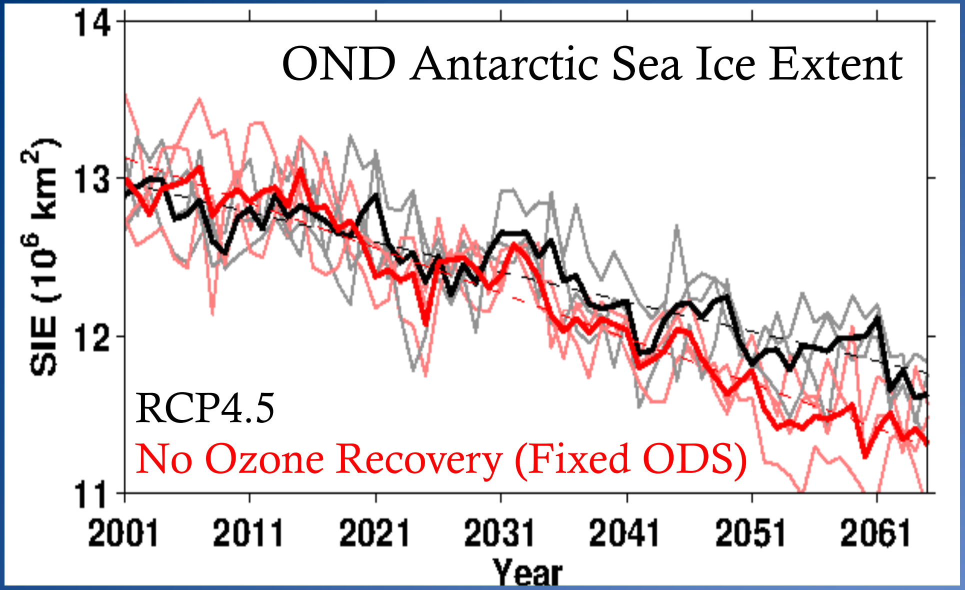
CMIP5 Model Intercomparison



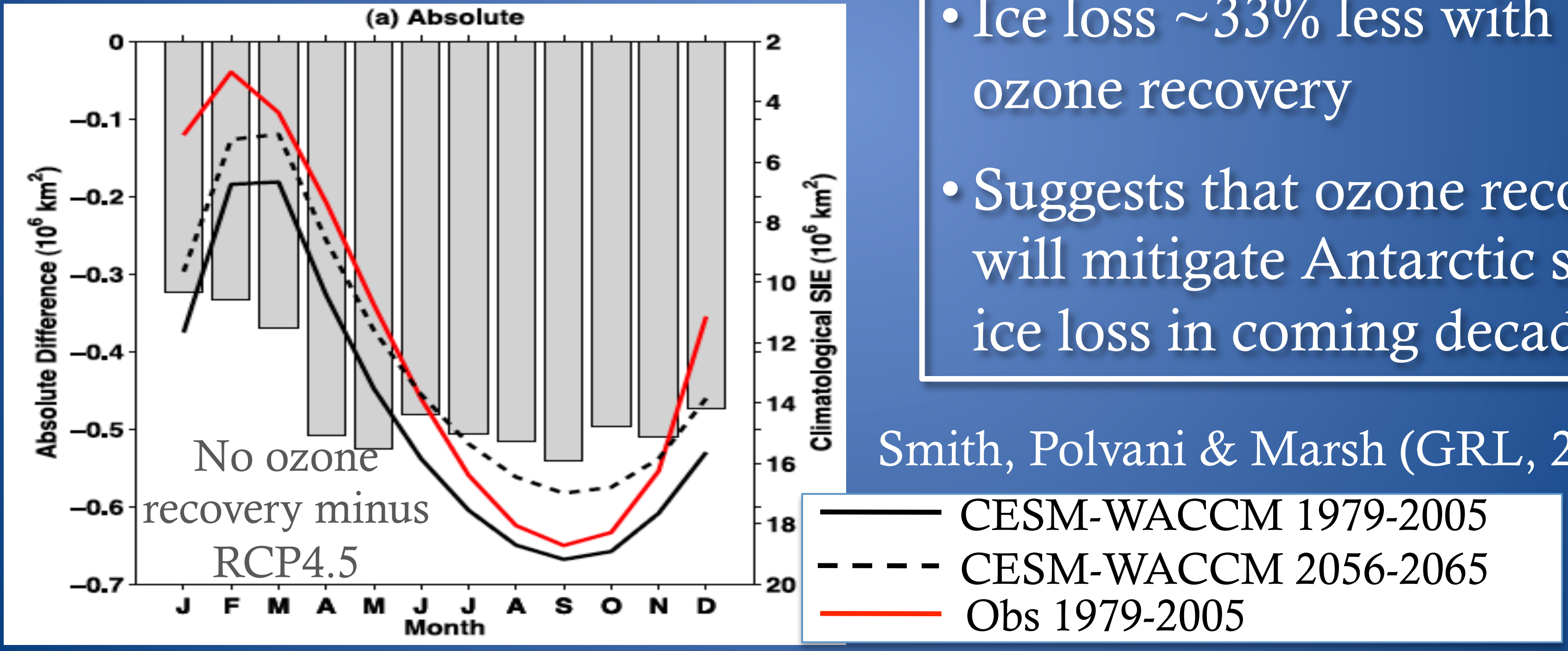
(Knutti, Masson, Gettelman, GRL, 2013)

Marika Holland
mholland@ucar.edu

Influence of Ozone Recovery on Antarctic Sea Ice Loss



- CESM-WACCM4 integrations with fixed ozone depleting substances (ODS)
- Ice loss ~33% less with ozone recovery
- Suggests that ozone recovery will mitigate Antarctic sea ice loss in coming decades



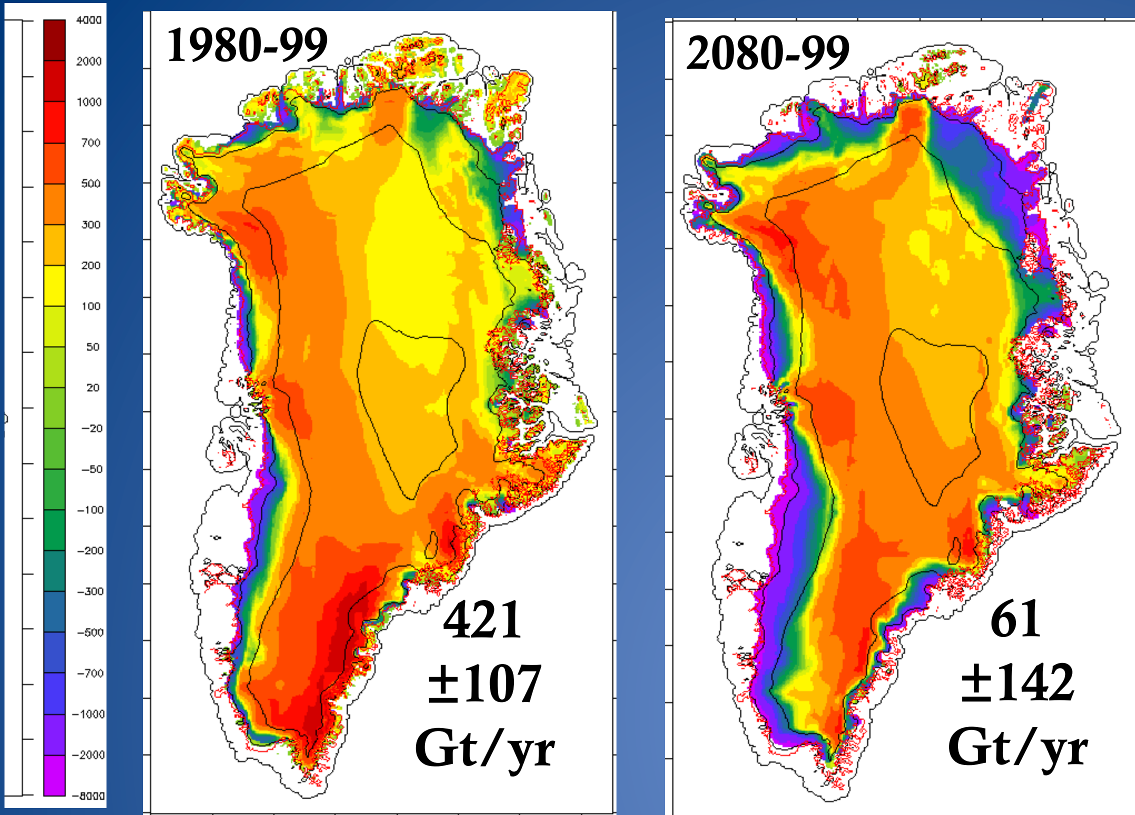
Smith, Polvani & Marsh (GRL, 2012)

Marika Holland
mholland@ucar.edu

CESM1-CISM

Changing Ice Sheet Conditions

Community Ice Sheet Model (CISM)



Simulated Greenland surface mass balance (red = net growth purple = net melting)

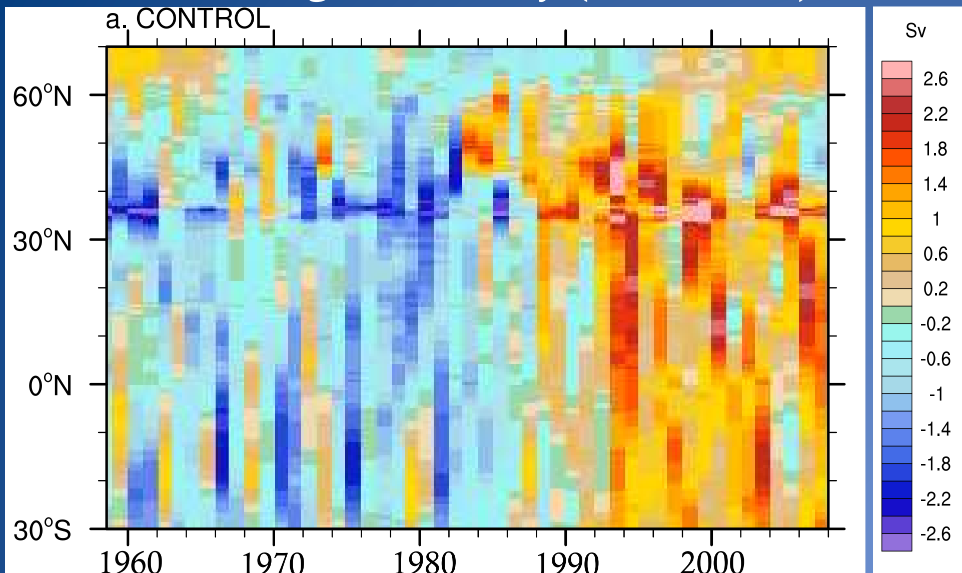
- Fully coupled CMIP5 simulations (preindustrial, 20th century, RCP8.5) with Greenland ice sheet model have been performed
  - 20th century surface mass balance (SMB) agrees well with regional models
  - SMB approaches zero by late 21st century, implying long-term instability

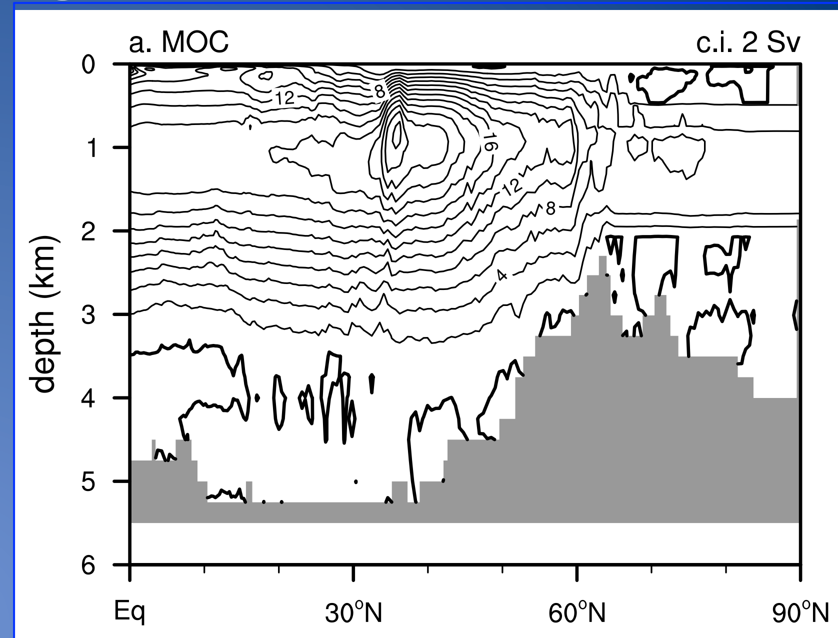
Slide courtesy of Bill Lipscomb

Marika Holland
mholland@ucar.edu

Atlantic Meridional Overturning Circulation Variations

AMOC strength anomaly (1958-2008)

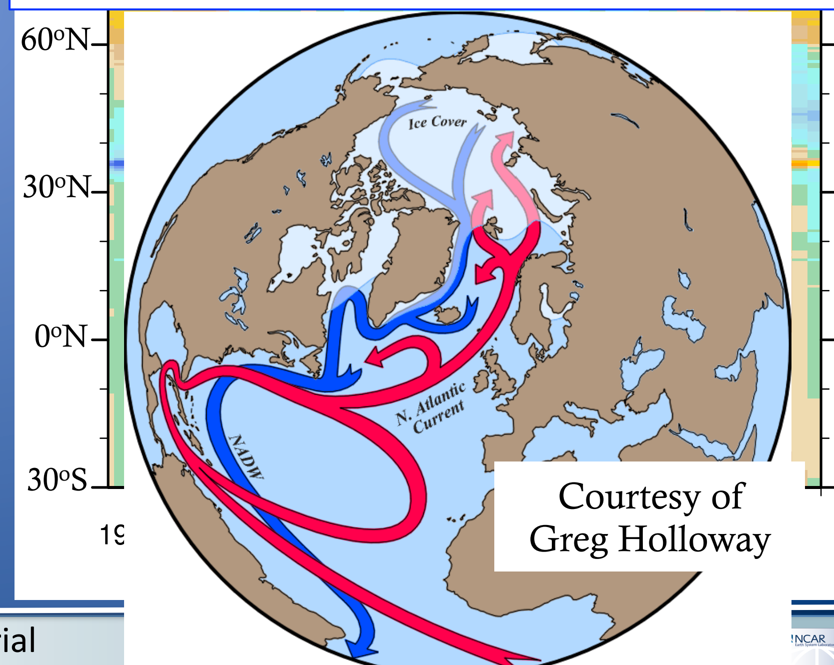




CESM Ocean-Ice (CORE-II) experiments

- AMOC variations well approximated by a linear superposition of momentum and buoyancy forced anomalies
- Buoyancy forcing explains decadal variations, with Labrador Sea turbulent forcing mostly responsible

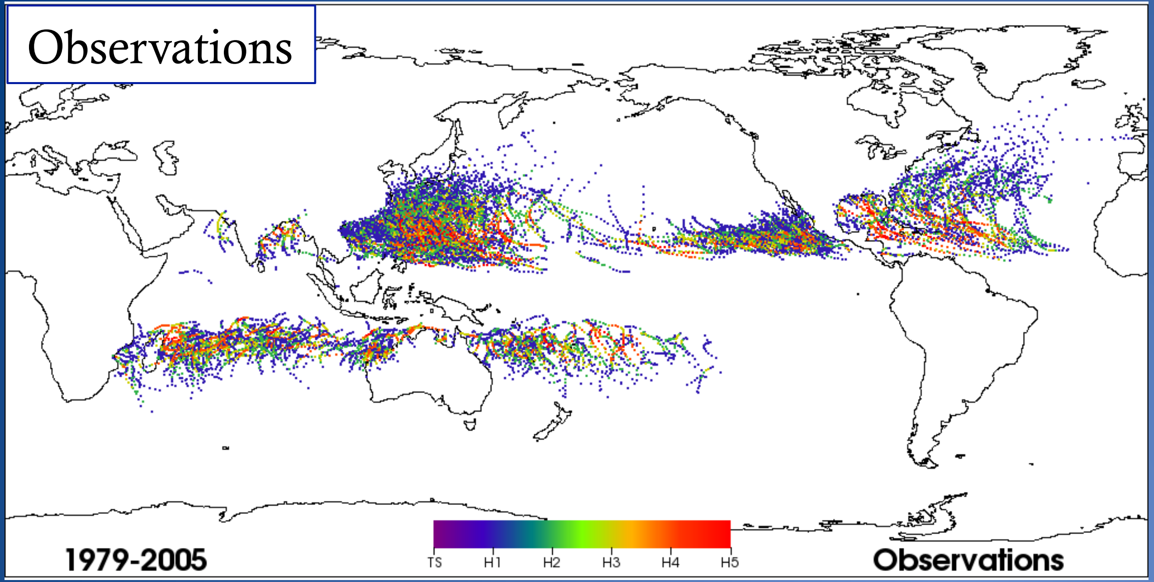
Yeager and Danabasoglu (2013)

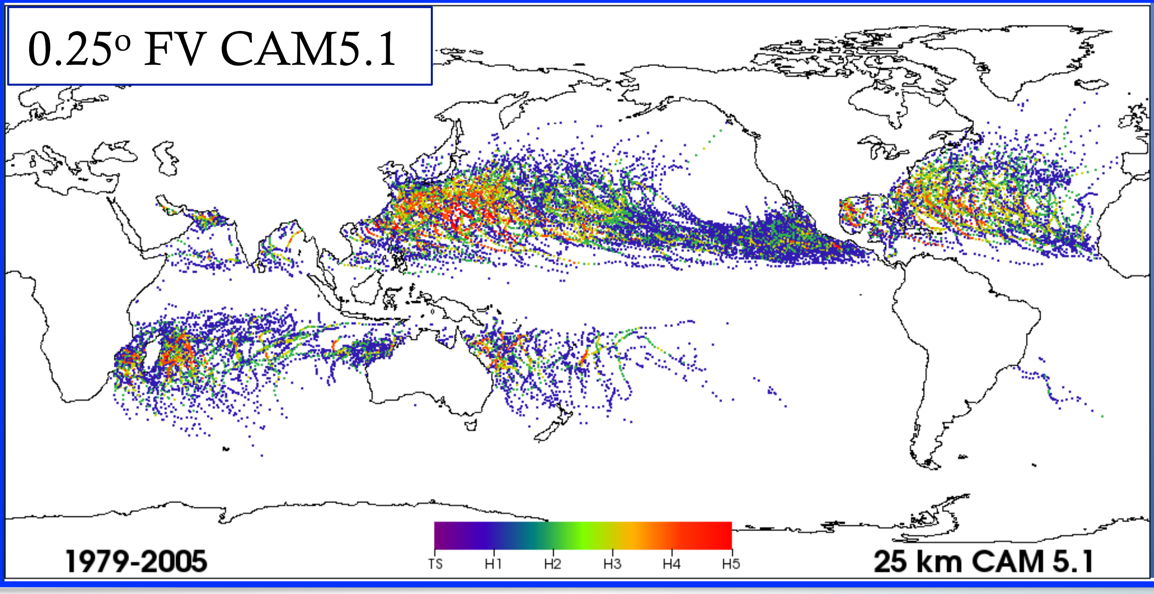


Courtesy of Greg Holloway

mholland@ucar.edu

Changing Extremes: Projected Changes in Tropical Cyclones



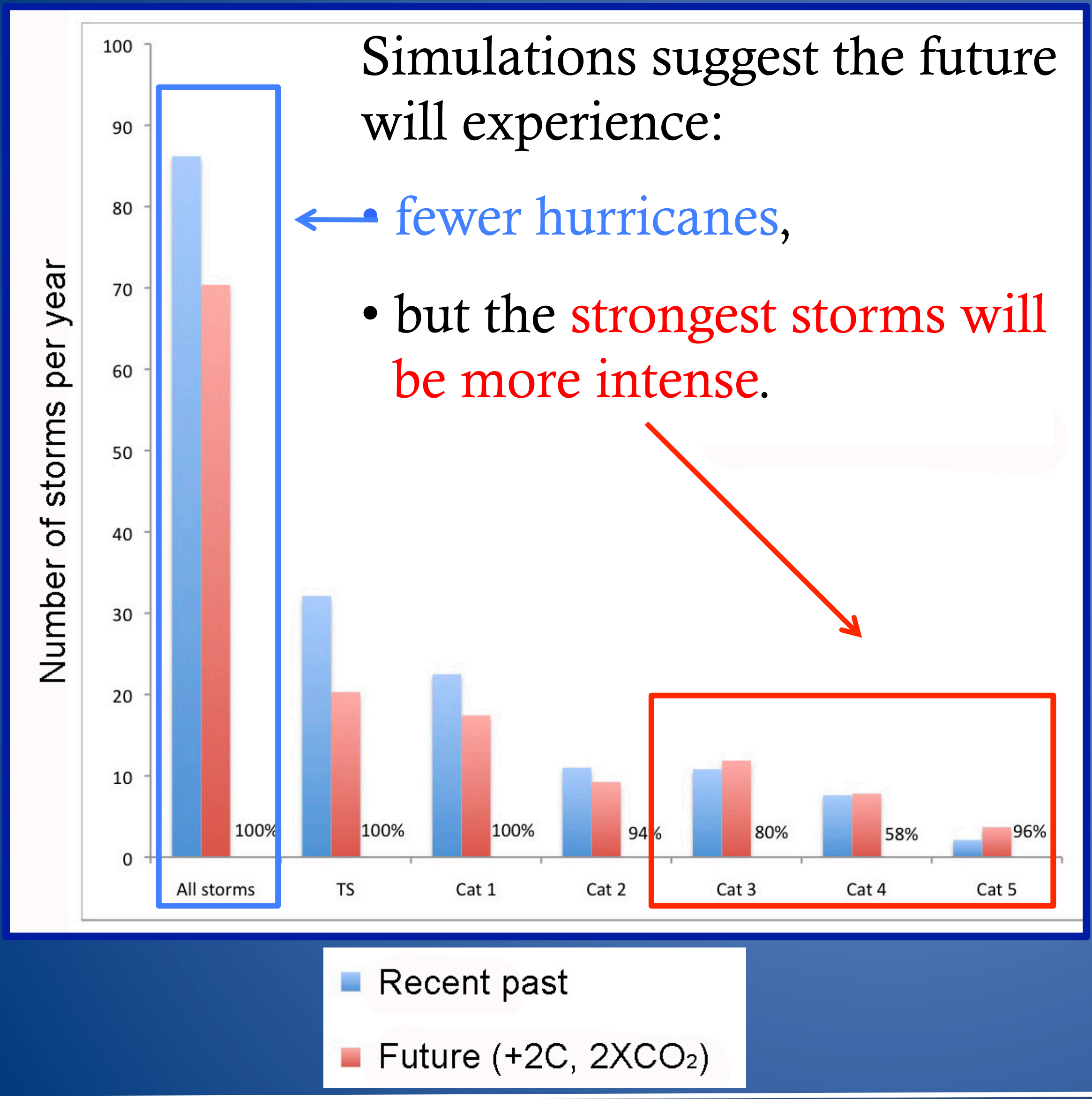


High resolution (0.25°) atmosphere simulations produce an excellent global hurricane climatology

Courtesy of
Michael Wehner, LBNL

Marika Holland
mholland@ucar.edu

Changing Extremes: Projected Changes in Tropical Cyclones



High resolution (0.25°) atmosphere simulations produce an excellent global hurricane climatology

Courtesy of
Michael Wehner, LBNL

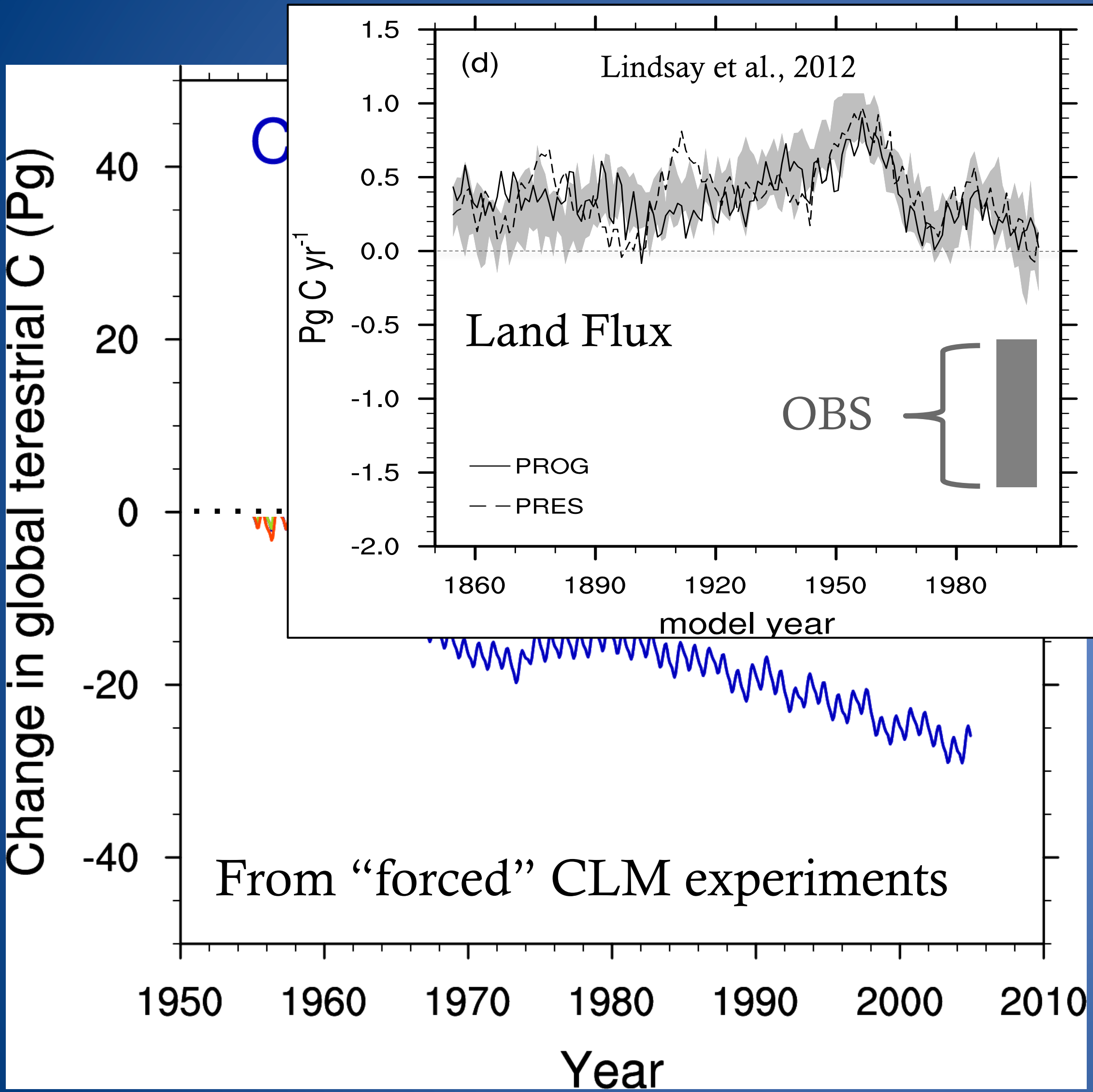
Marika Holland
mholland@ucar.edu

Future Directions and Remaining Challenges

A need for continued model improvements
Investigation of small-scale phenomena
Incorporation of New Capabilities

Marika Holland
mholland@ucar.edu

Changes in the Global Terrestrial Carbon Budget



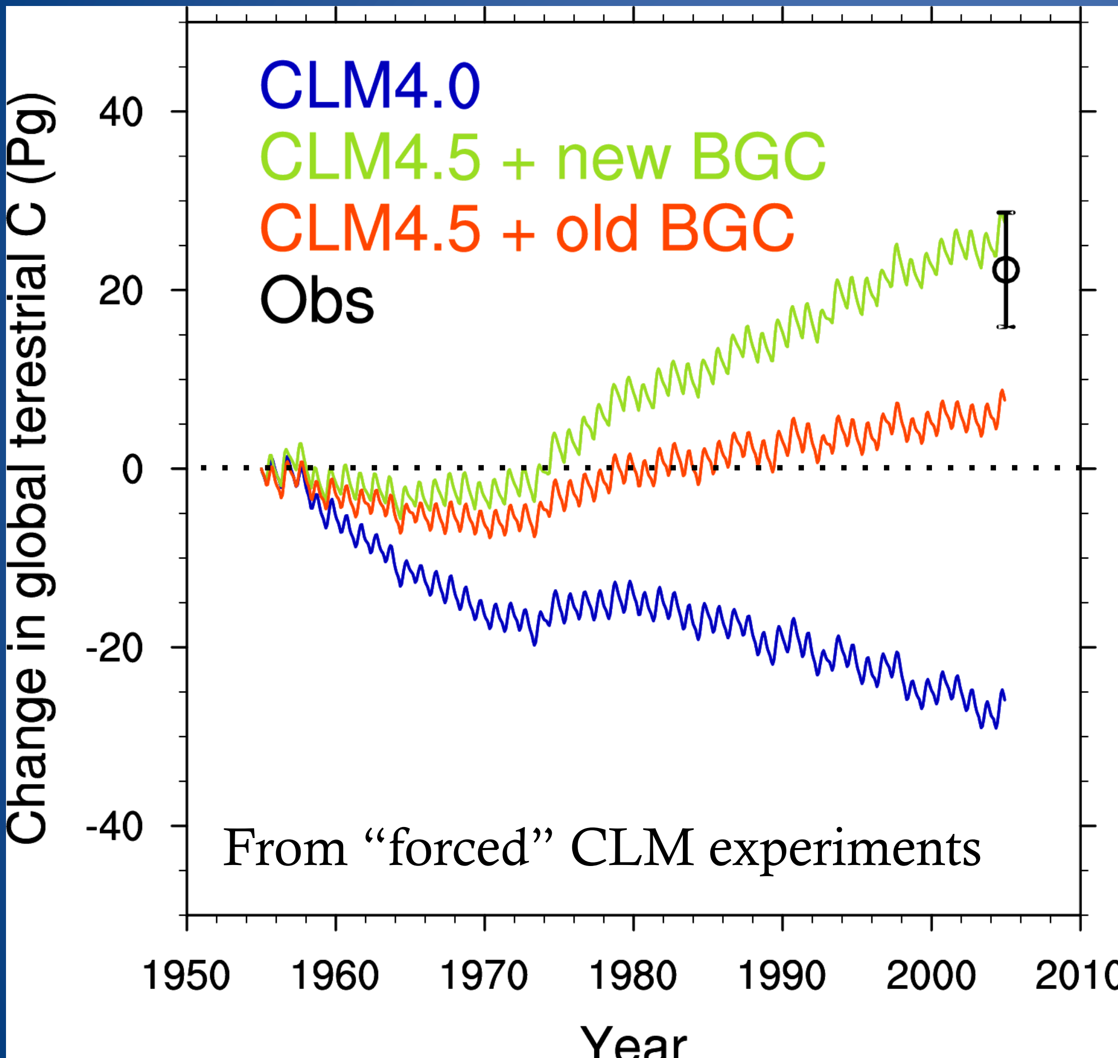
Accumulated carbon from

- losses due to land cover change,
- gains due to CO_2 fertilization
- regional losses or gains due to climate-carbon feedbacks.

From Land Model only experiments forced with atmospheric conditions

Marika Holland
mholland@ucar.edu

Changes in the Global Terrestrial Carbon Budget



Accumulated carbon from

- losses due to land cover change,
- gains due to CO_2 fertilization
- regional losses or gains due to climate-carbon feedbacks.

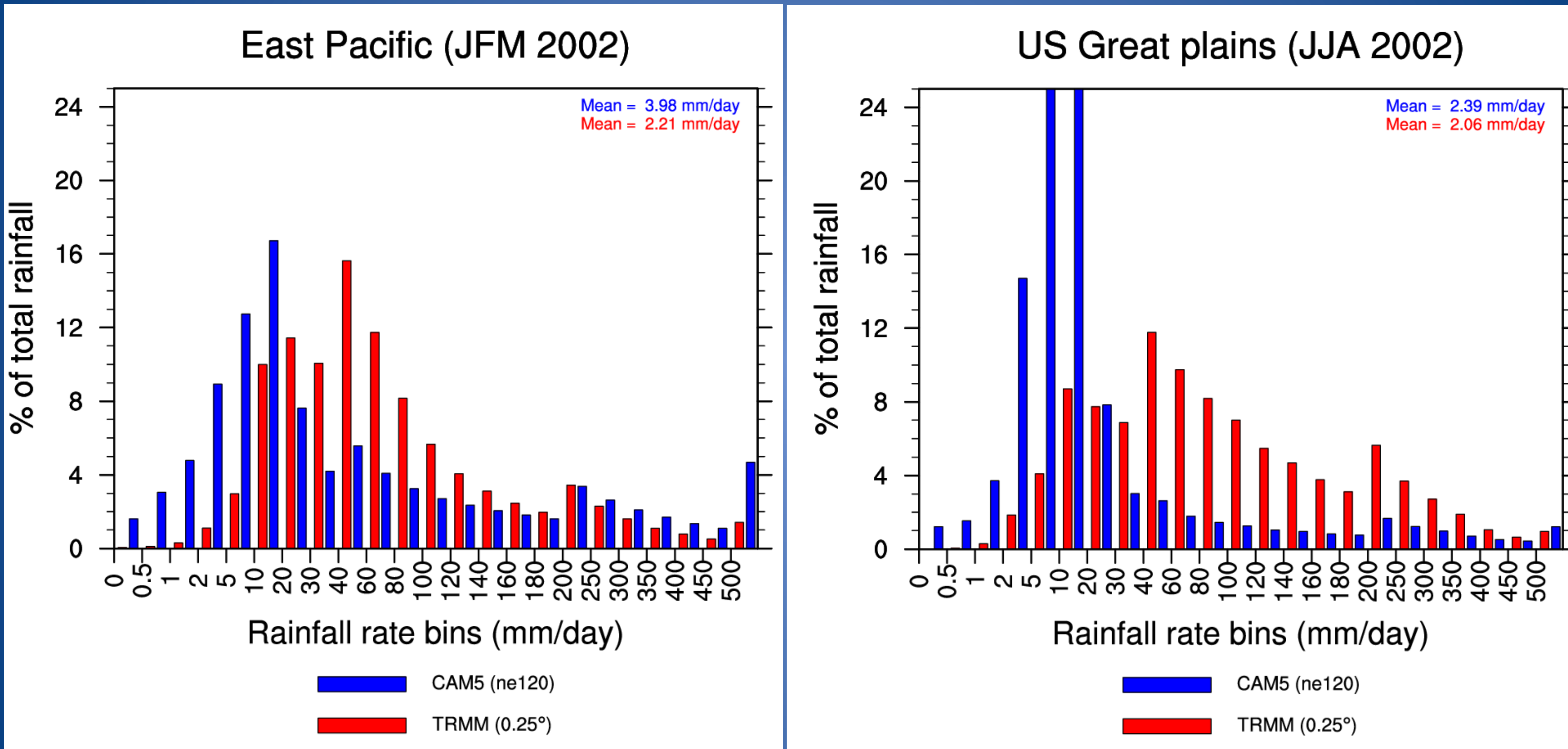
More realistic land carbon uptake results from reduced N-limitation on CO_2 fertilization.

Koven et al., 2013

Marika Holland
mholland@ucar.edu

Bias Example: Rainfall frequency

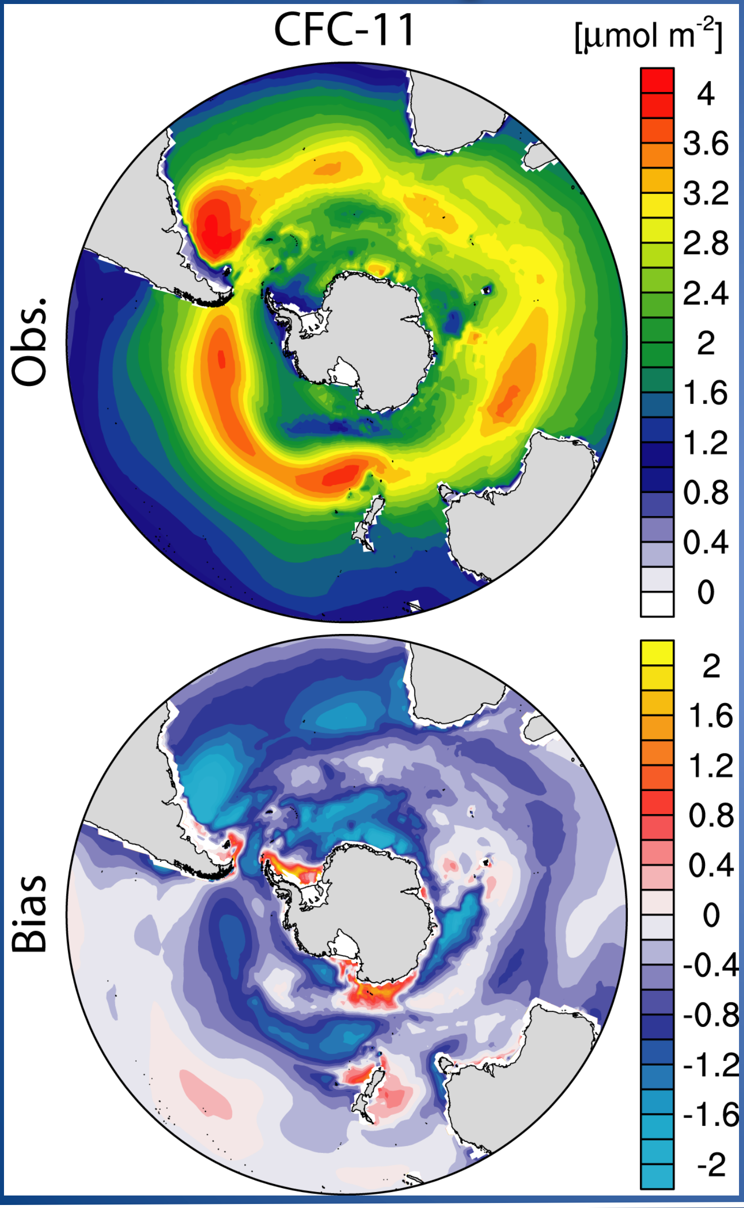
Common bias for many regions: Too much light rainfall, not enough heavy



Courtesy of Rich Neale

Marika Holland
mholland@ucar.edu

Bias Example: Southern Ocean Ventilation



CESM1-CAM5 20th Century Simulation

Comparisons of simulated and observed ocean CFCs

Indicate too little Southern Ocean uptake

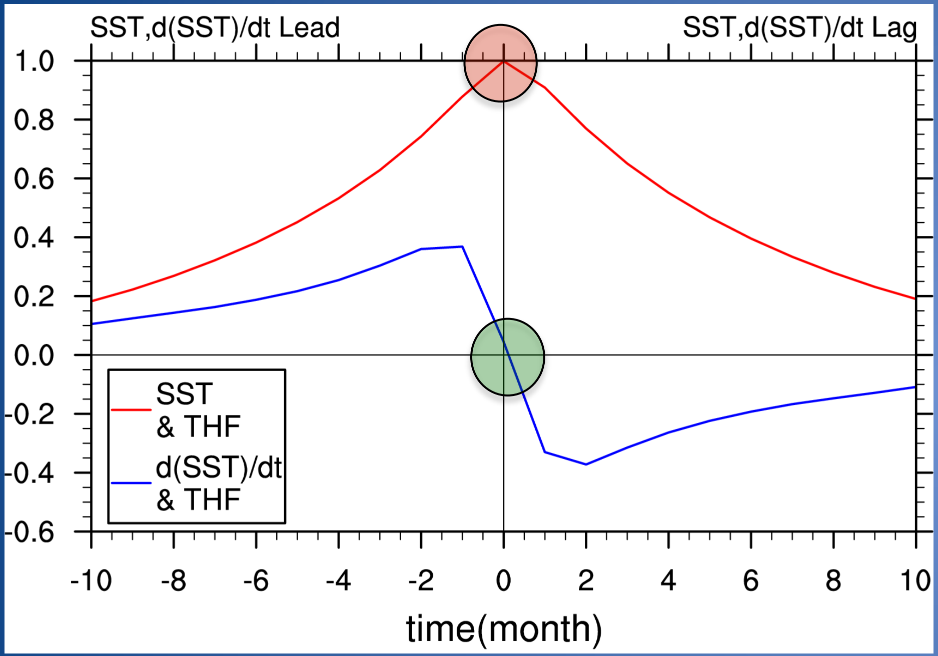
Has implications for simulated ocean heat and carbon uptake

Courtesy of Matt Long

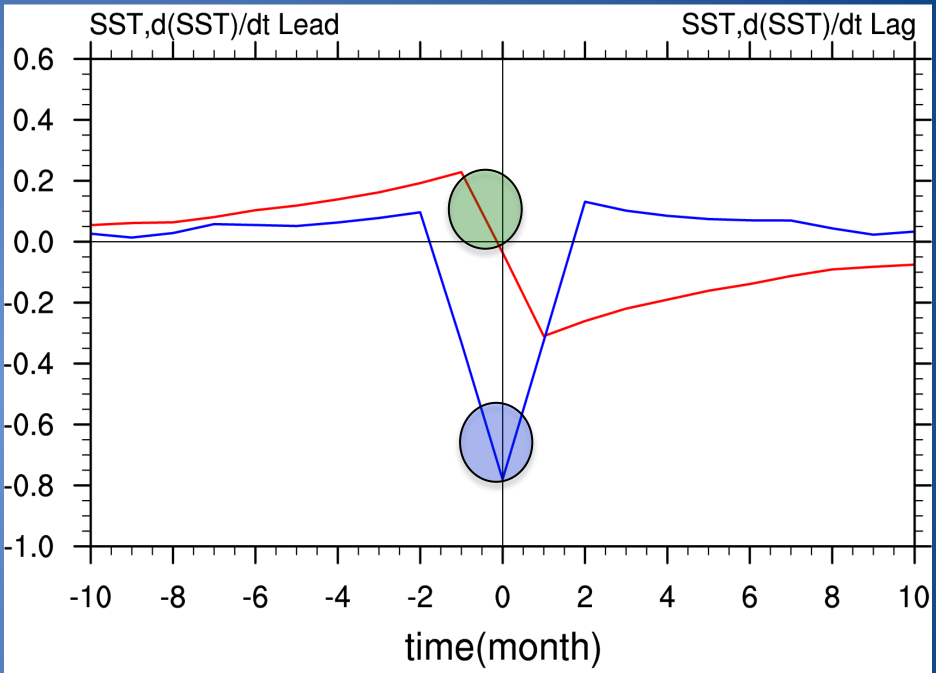
Marika Holland
mholland@ucar.edu

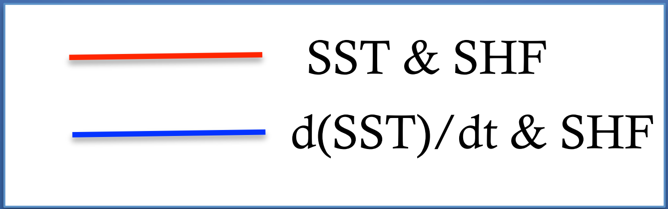
Higher Resolution Simulations Enabling Studies on Ocean-Atmosphere Scale Interactions

Ocean Weather



Atmosphere Weather





Courtesy of Frank Bryan

Marika Holland
mholland@ucar.edu

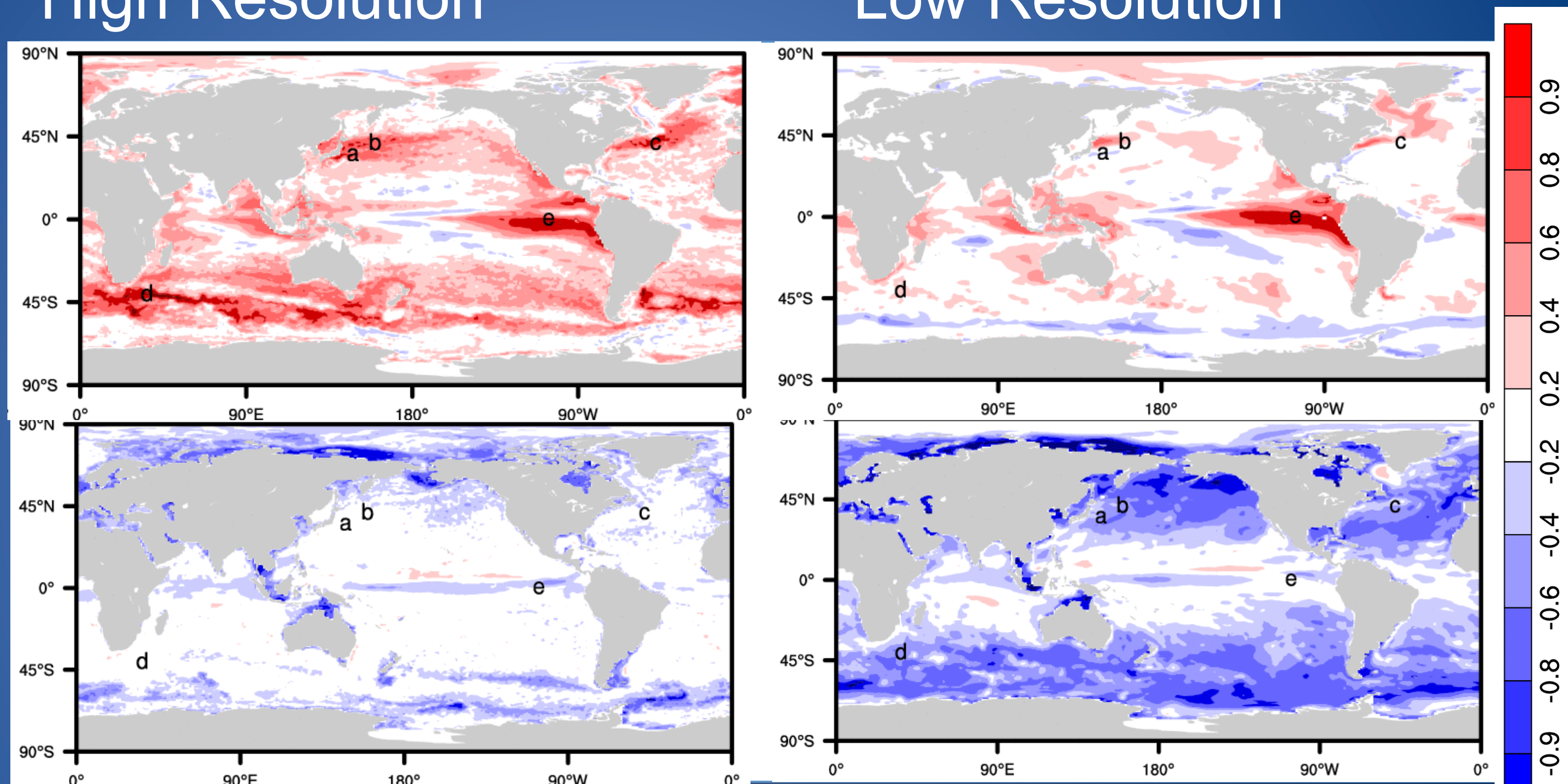
Ocean-Atmosphere Scale Interactions

Correlation

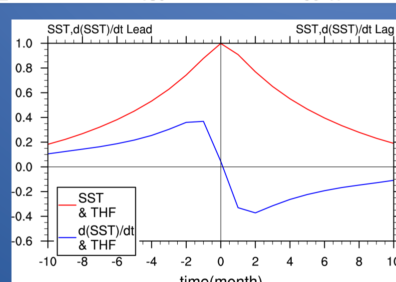
High Resolution | Low Resolution

SST & SHF

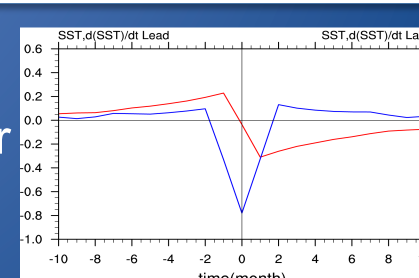
d(SST)/dt & SHF



Ocean Weather



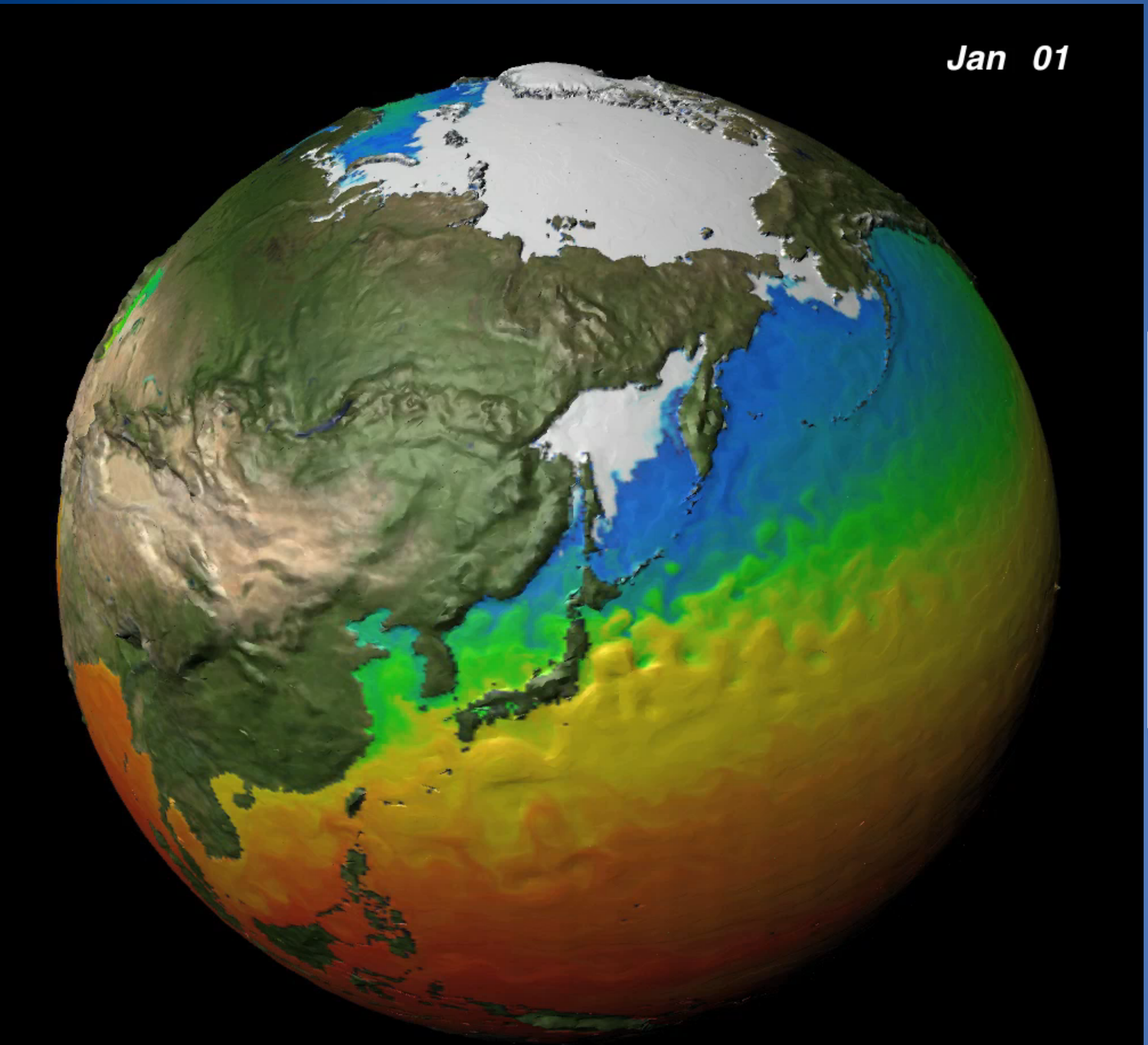
Atm Weather



Courtesy of Frank Bryan

Marika Holland
mholland@ucar.edu

Future Directions: Study of High Resolution Phenomena



SST, Sea ice cover and Sea Surface Height

- Fully coupled CESM1-CAM5-SE simulations with a 25km atmosphere and 0.1° ocean
- 60 years in length

- Yellowstone-NWSC Accelerated Science Discovery Run
- Project support from DOE-BER and NSF

Courtesy of Justin Small, Tim Scheitlin

Marika Holland
mholland@ucar.edu

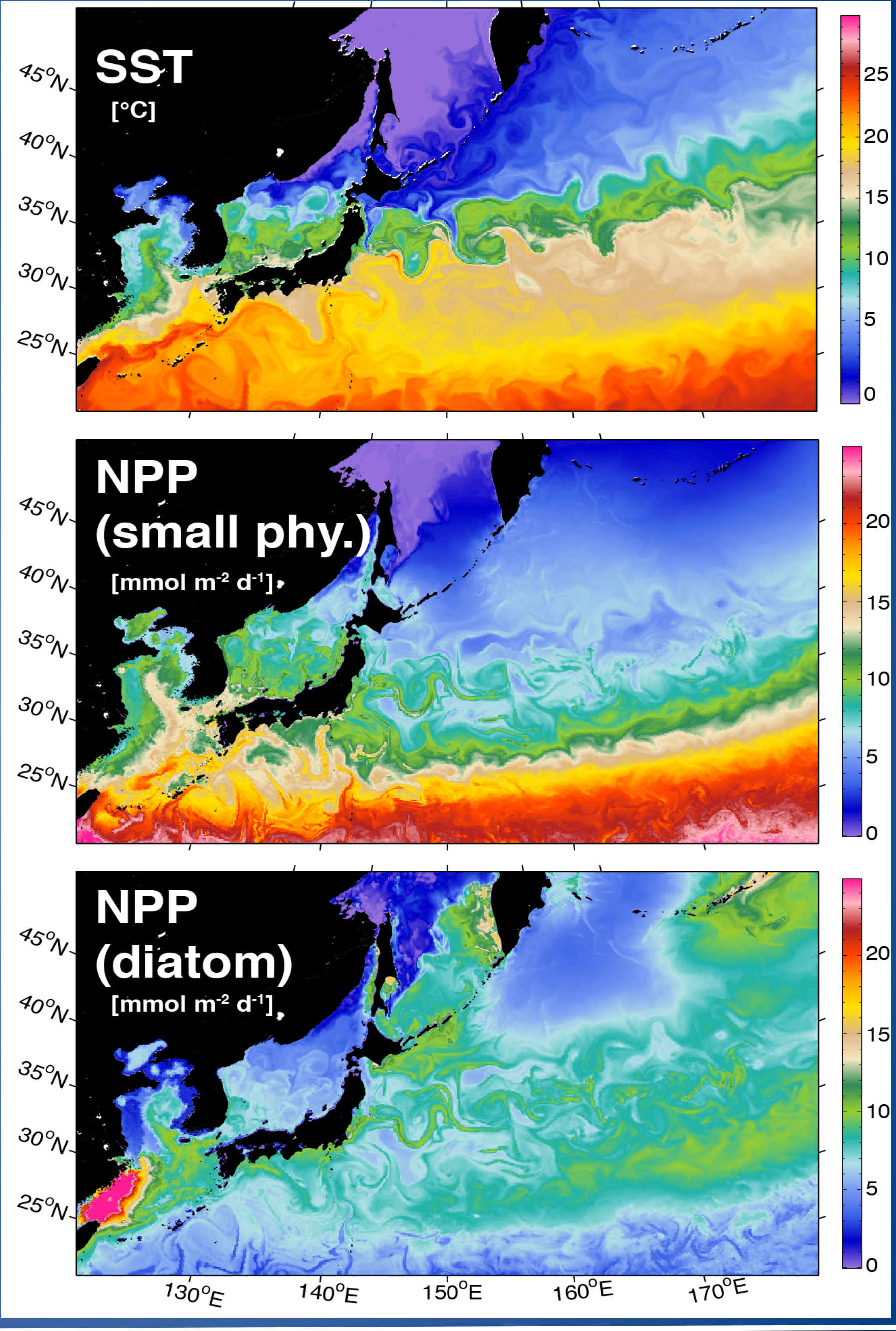
Global eddy-resolving ecosystem calculations

Guiding research questions

- What is the impact of eddies on ecosystem dynamics and biogeochemical function?
- How does mesoscale variability in biological fields aggregate as a function of space and time?

Kurioshio Current region

Snapshot of SST and upper ocean (z > –100m) net primary productivity (NPP) from two phytoplankton functional types.

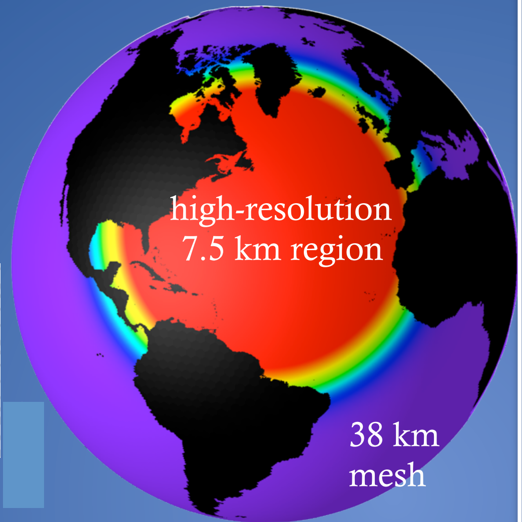


Courtesy of Matt Long

Marika Holland
mholland@ucar.edu

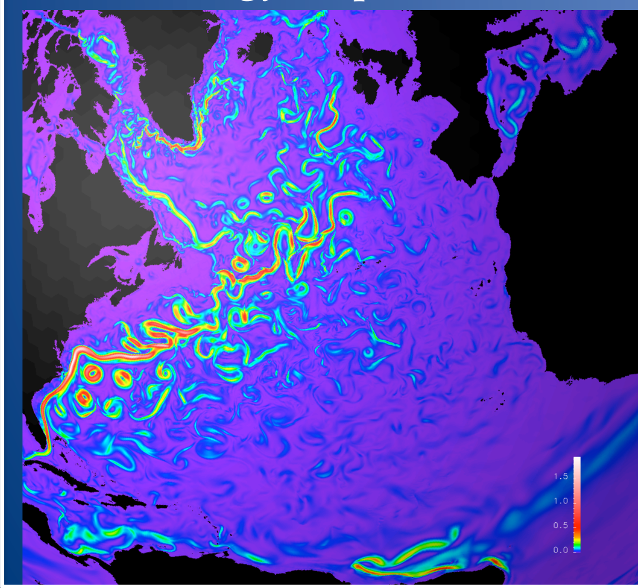
Need for scale-aware parameterizations

Building a Global, Multi-scale Ocean Model



MPAS
Model for Prediction Across Scales

Kinetic energy snapshot



Ringler et al. *Ocean Modelling,* 2013

With interests in using CESM across a wide range of resolutions and new developments that will enable regional refinement, there is a need for scale-aware parameterizations

Marika Holland
mholland@ucar.edu

Future Directions: New Capabilities
Example - Development of an Isotope-Enabled CESM

Simulating Stable Water Isotopes in the Climate System

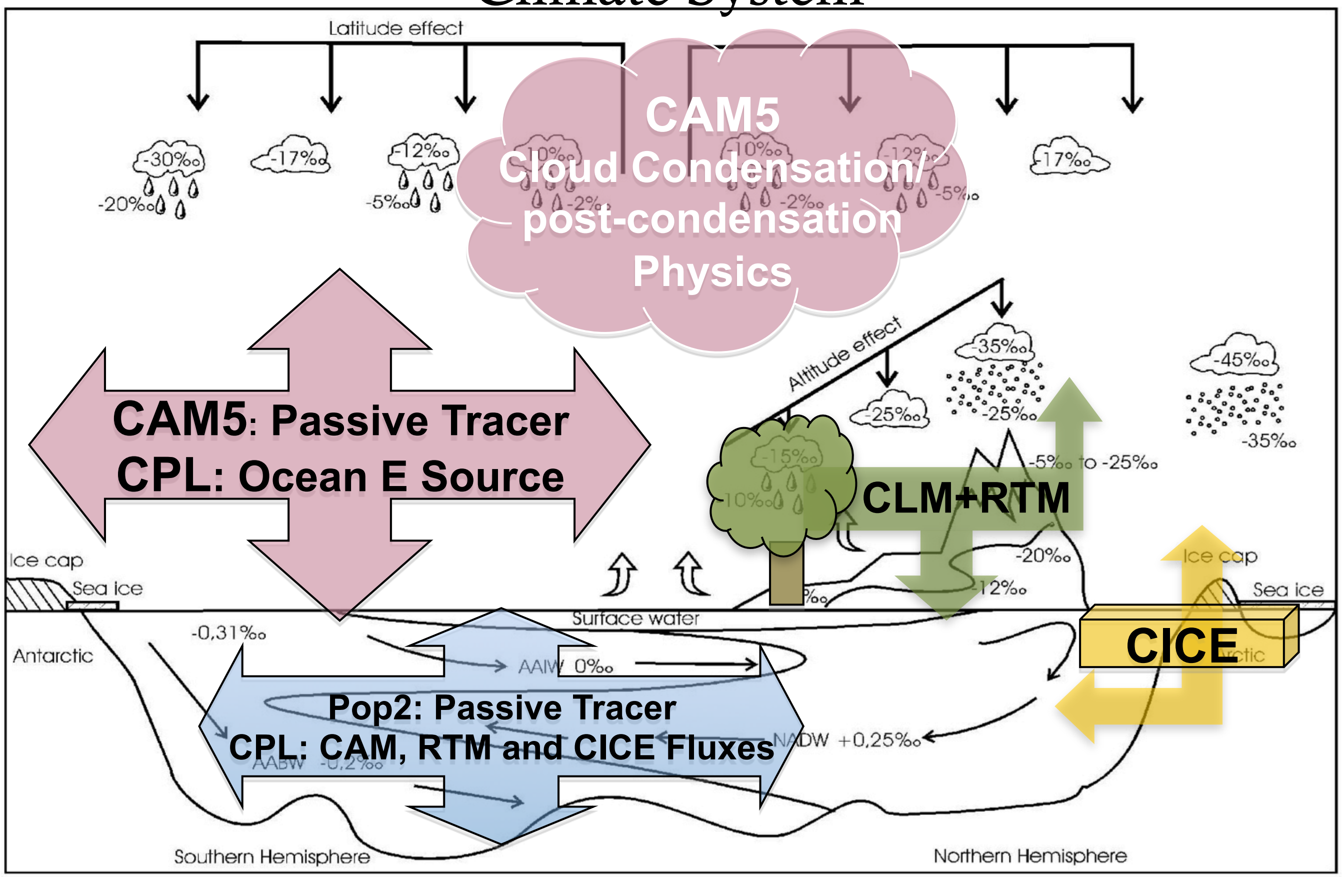


Figure adapted from Paul, A. et al. 1999: Simulation of Water Isotopes in a Global Ocean Model, in *Use of Proxies in Paleoclimatology: Examples from the So. Atlantic,* Fischer G. and W. Wefer, eds., Springer-Verlag, 655-686.

Community effort partnering NCAR, U. Wisc, U. CO, U. Bern, DOE LBL

Slide courtesy of B. Otto-Bliesner

Marika Holland
mholland@ucar.edu

And More…

All component models incorporating improved parameterizations and processes

Marika Holland
mholland@ucar.edu

In summary:

- CESM is a flexible, extensible and well supported community tool
- CESM applications continue to increase
- Numerous CESM simulations are currently available through CMIP5 for analysis; additional community runs becoming available
- Model developments and improvements are ongoing

NCAR is sponsored by the National Science Foundation

Marika Holland
mholland@ucar.edu

Questions?

Marika Holland
mholland@ucar.edu