The SciDAC CCSM Consortium Project

Presented by

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Computational Earth Sciences Group
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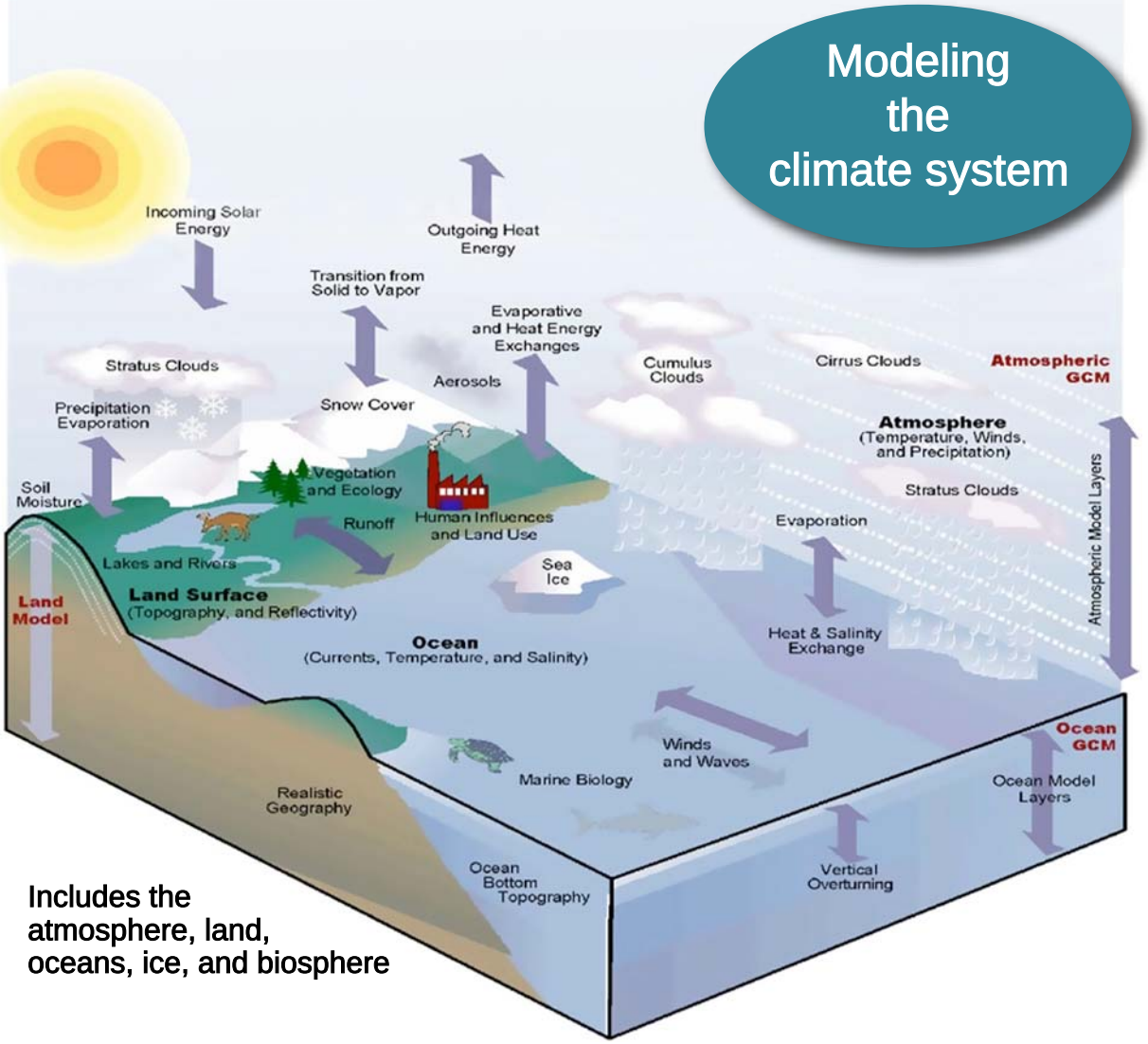
SC07

OAK RIDGE National Laboratory

The Earth climate system

The Grand Challenge problem:

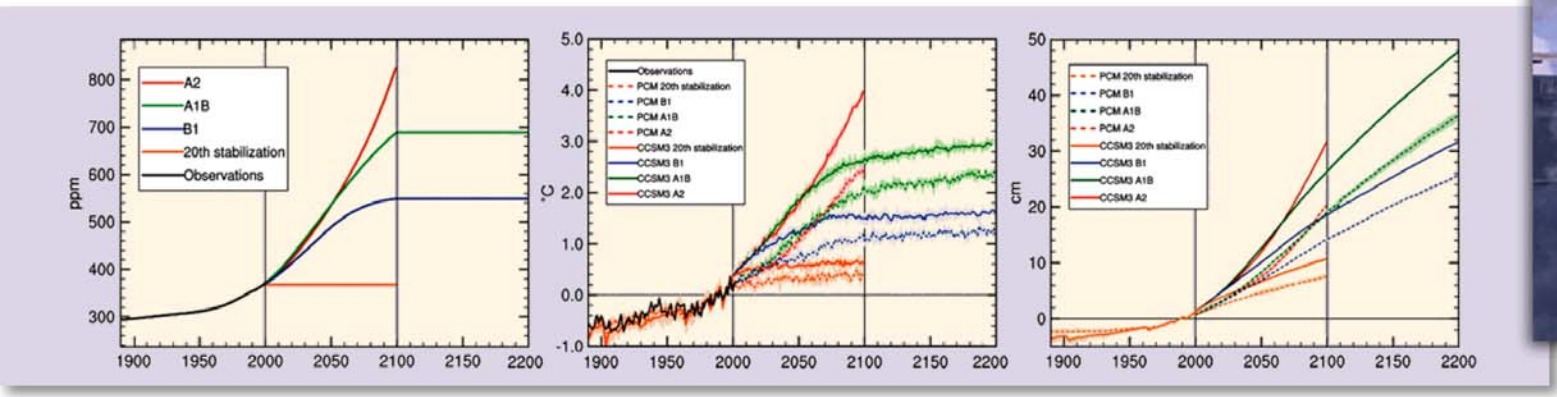
To predict future climates based on scenarios of anthropogenic emissions and changes resulting from options in energy policy



Includes the atmosphere, land, oceans, ice, and biosphere

Why is it important?

- To the science/engineering community
  - Discoveries of feedbacks between ecosystems and climate
  - Fundamental science of aerosols effect in the atmosphere
  - Advances in modeling and simulation science for climate prediction
- To the public
  - U.S. energy policy
  - Contribution to international assessment of climate change and its causes



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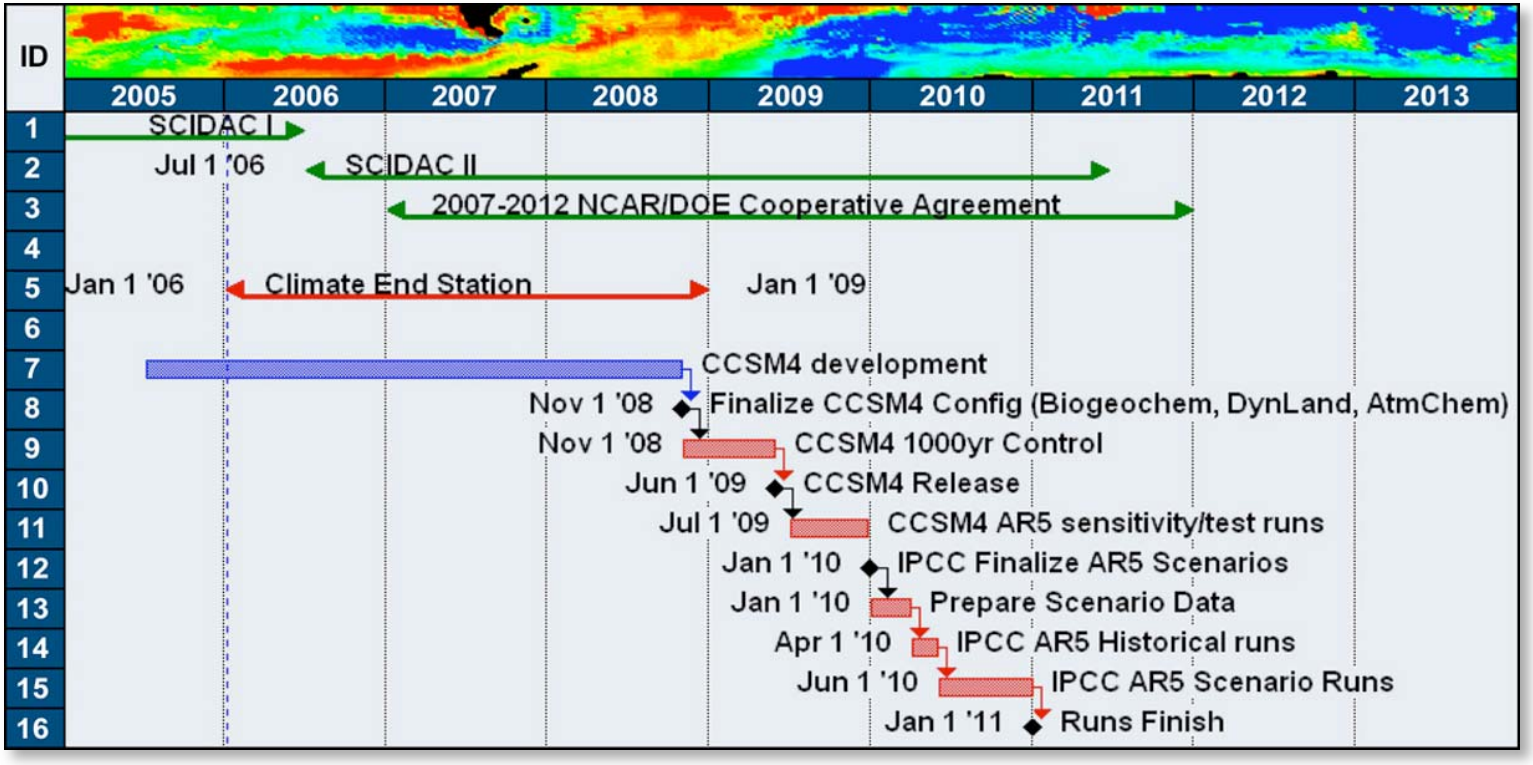
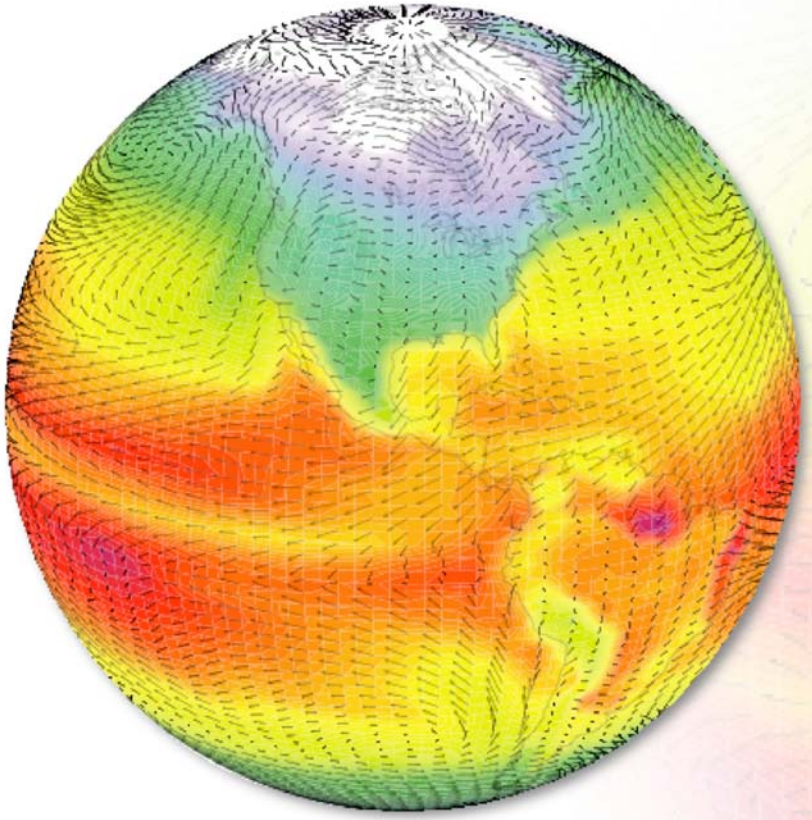
The Big Picture: CCSM development, the Climate End Station (CES), and IPCC AR5

- CES FY 2007 allocation
  - 1.5 million CPU hours on Phoenix Cray X1E
  - 5 million CPU hours on Jaguar Cray XT3
- Earth System Grid distributing model results



Integration and evaluation of new components in a coupled earth system model



- Confidence in modeling the physical climate system does not extend to modeling the biogeochemical coupling.
- Observational data are used to validate and constrain the process models for terrestrial carbon cycle (CLAMP).
- Atmospheric aerosol direct and indirect effects.
- Dimethyl sulfide from ocean ecosystem and chemical coupling for biogeochemistry.
- Extension of cryosphere to include ice sheets.
- New dynamical formulations and algorithms.
- Scalability toward petascale.

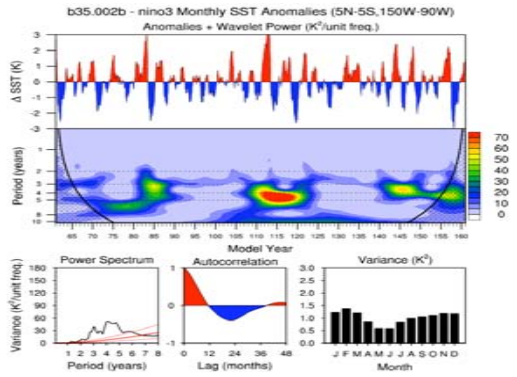
CCSM3.5—An interim version for carbon-nitrogen work

CCSM3.5 shows a much improved ENSO – Mariana Vertenstein and Bill Collins (NCAR)

Conclusions from control simulations

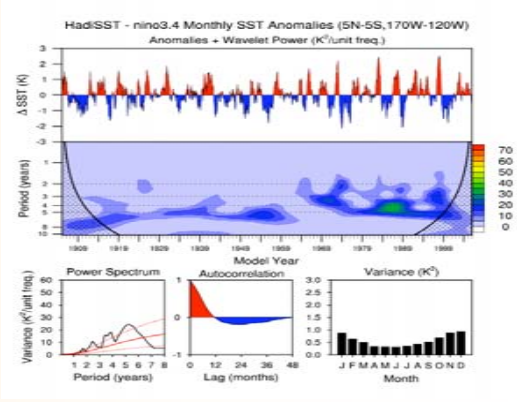
- Significantly reduced some major biases:
  - ENSO frequency,
  - mean tropical Pacific wind stress and precipitation,
  - high latitude (Arctic) temperature and low cloud biases.
- Much improved surface hydrology in CLM3.5.
- Improved ocean and sea ice components.

CCSM3.5 modifications to the deep convection scheme by Neale and Richter



Current and near-term simulations

- We have assembled an interim version, CCSM3.5, so that a carbon-nitrogen cycle can be run in an up-to-date version of CCSM.
- Present day and 1870 control integrations (at 1.9x2.5_gx1v5 resolution) are presently being run on the Cray XT4 (Jaguar) at ORNL.
  - Performance of 32 model years/day for 1870 control.
  - Performance of 40 model years/day for present day integration.
- In the near future, control integrations with the full carbon-nitrogen cycle included will also be run, along with 20th and 21st century integrations.
- Spin up procedure for CCSM3.5/BGC involves greater complexity than previous non-BGC simulations.



HadiSST Observations

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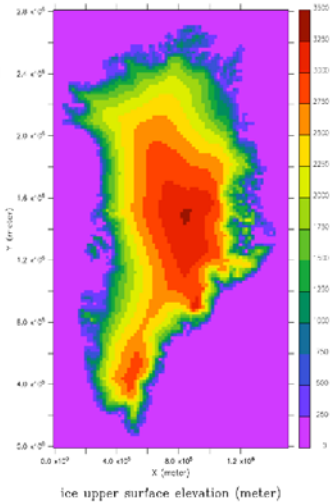
Ice sheet mode

William Lipscomb

- GLIMMER has been added to CCSM, with wrapper code for exchanging fields between GLC and the coupler.
- The Community Land Model (CLM) has been modified to compute the ice sheet surface mass balance in glaciated columns and pass the mass balance to GLC via the coupler.
- CLM allows multiple vertical columns for each land unit in each grid cell. Work is under way to compute the mass balance for ~10 elevation classes (i.e., columns) in each glacier land unit.

Greenland topography in GLIMMER



We will soon begin coupled climate experiments with a dynamic Greenland ice sheet. The model will be tuned as needed to produce a realistic control ice sheet, then applied to standard IPCC forcing scenarios. The model also will be used for paleoclimate studies of the Eemian interglacial (~125 ka), when the GIS was smaller and sea level was several meters higher. We will do climate change experiments with the Antarctic and Laurentide ice sheets when a more realistic ice sheet model is available.

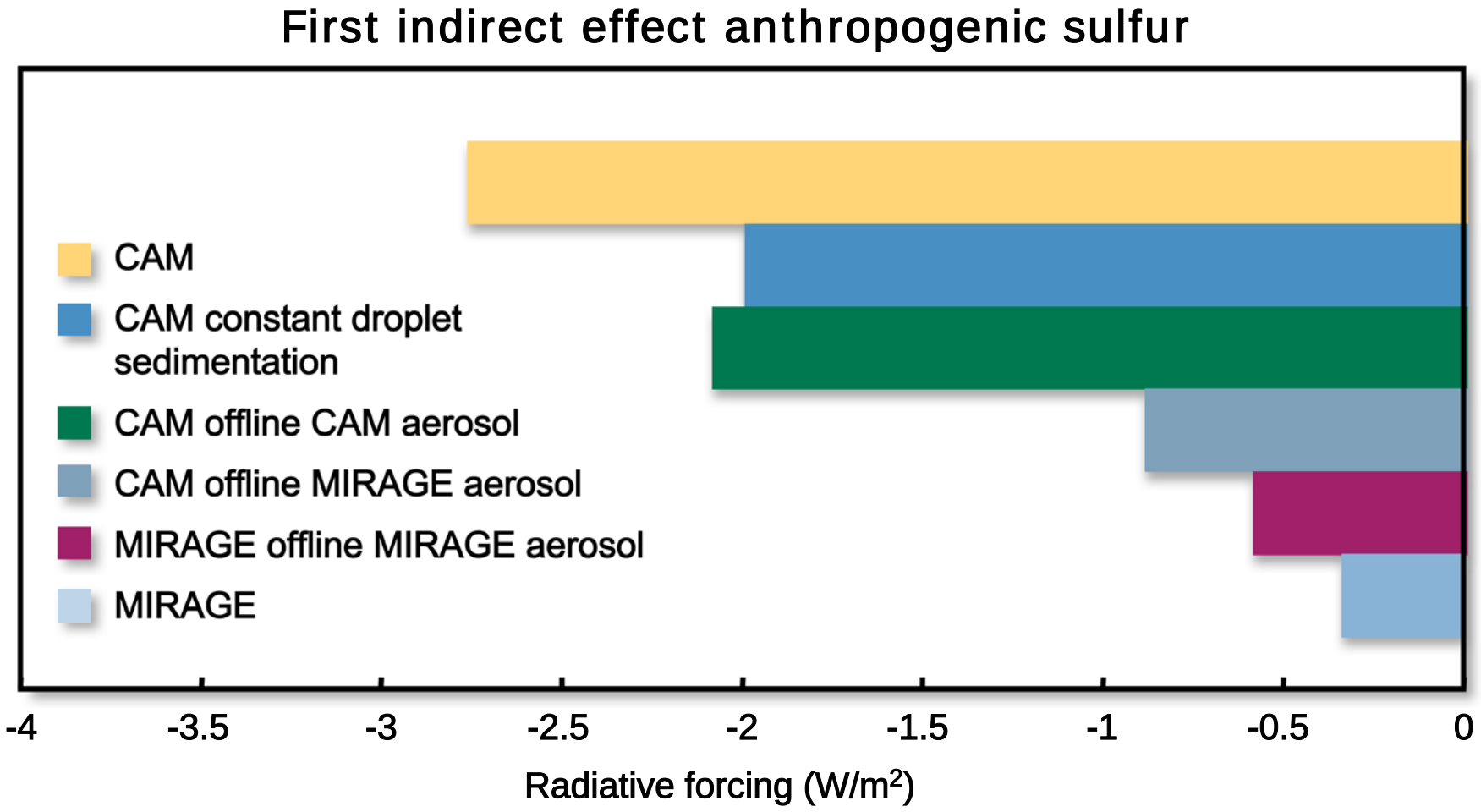
- The rate of 21st century ice sheet melting and sea level rise is extremely uncertain and is now recognized as a high priority for climate models.
- We have coupled the GLIMMER model to CCSM and will soon begin climate experiments with a dynamic Greenland ice sheet.
- We will devote substantial resources (2–3 FTEs) to improving the ice sheet model during the next several years.
- We aim to make a useful contribution to IPCC AR5 (~2013), but time is limited. Models must be frozen by 2009 or 2010.

Reconstructed GIS from the last interglacial (Cuffey and Marshall, 2000), when sea level was about 6 m higher than today.

Effect of a 6 m sea level rise on the southeast United States (Weiss and Overpeck, University of Arizona).

Indirect effect

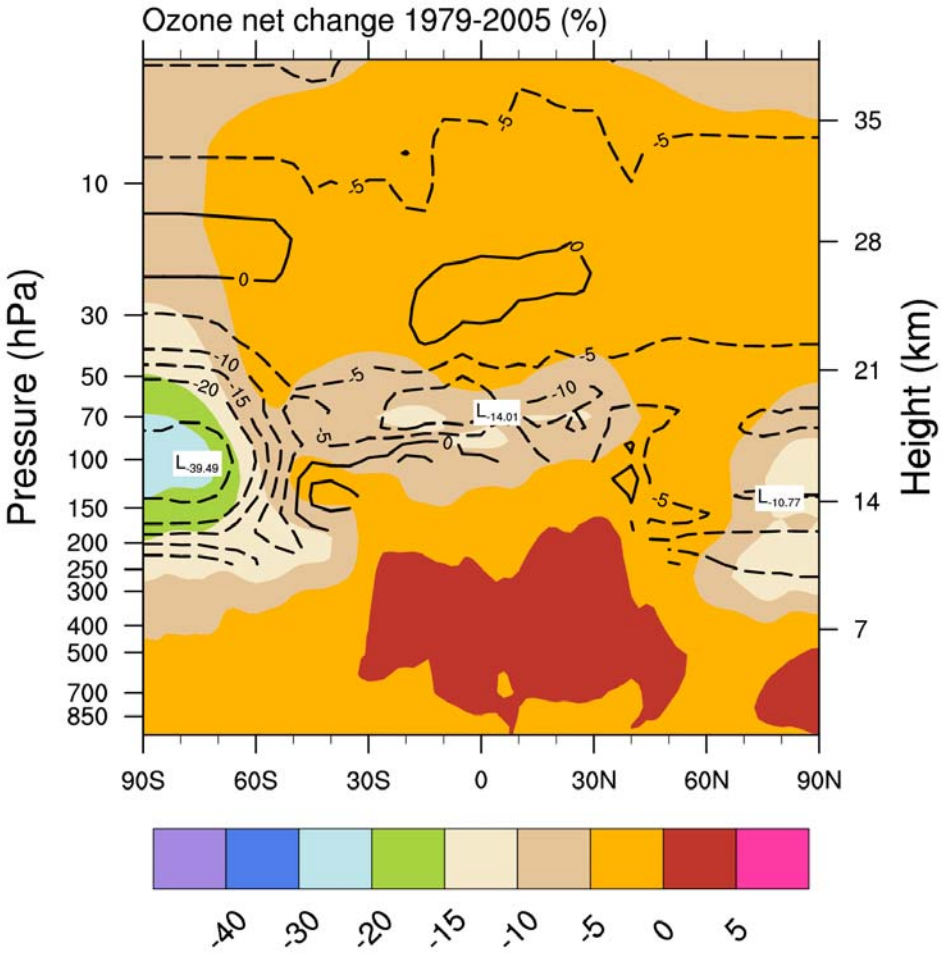
Steve Ghan (PNNL)



CAM3: Tropospheric and stratospheric chemistry

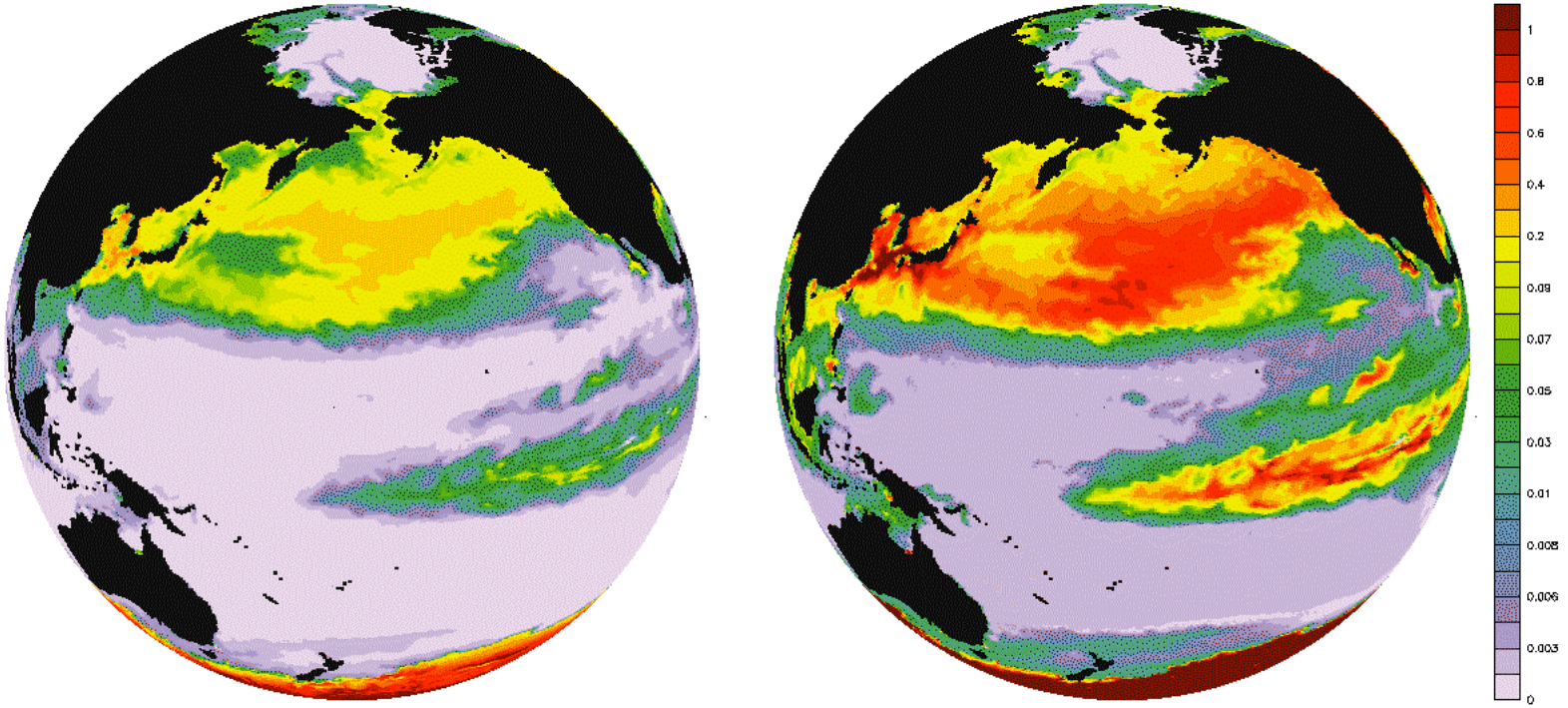
J. F. Lamarque (NCAR)

Vertical distribution of the zonal–mean ozone change (1979–2005). Color contours are for the model results (average of 2 simulations) and line contours are from TOMS/SBUV.



Toward an Earth System Model: Ocean biogeochemistry feeding atmospheric chemistry

P. Cameron-Smith, C. Chuang, D. Bergmann (LLNL), S. Elliott (LANL)



The figure shows ammonia (NH_3) in the marine boundary layer (picomoles) on the right, and its dissolved form, ammonium (NH_{4+}), in the ocean mixed-layer in micromoles on the left.

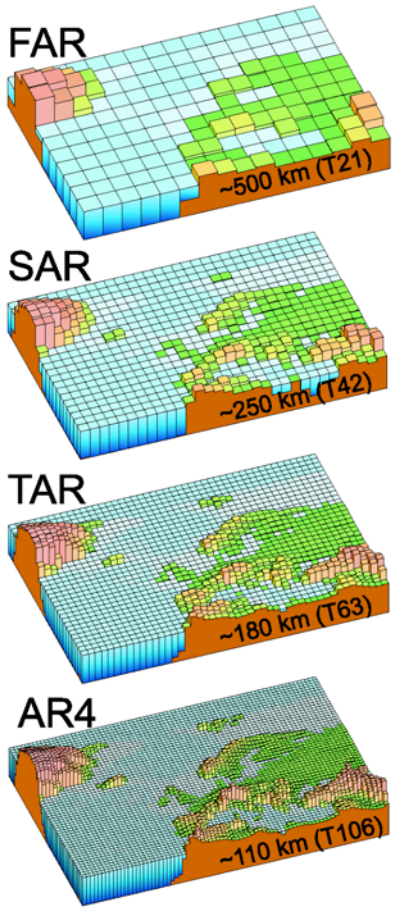
Correcting transport errors during numerical transport of correlated moment sequences

R. McGraw, BNL/SUNY-SB Science Application Partnership:
"Statistical approaches to aerosol dynamics for climate simulation"

PROBLEM: Nonlinear transport algorithms, designed to reduce numerical diffusion over coarse model grids, can destroy consistency within a sequence of aerosol size/composition moments transported as independent "chemical" tracers.

Until now this has been the most serious impediment to the widespread use of moment methods for aerosol simulation in climate models.

SOLUTION: We present a new approach based on non-negative least squares (NNLS) that finally eliminates this consistency problem—with the added bonus of providing a much more accurate scheme for source apportionment and transport of aerosol mixtures. It should work with any transport scheme.

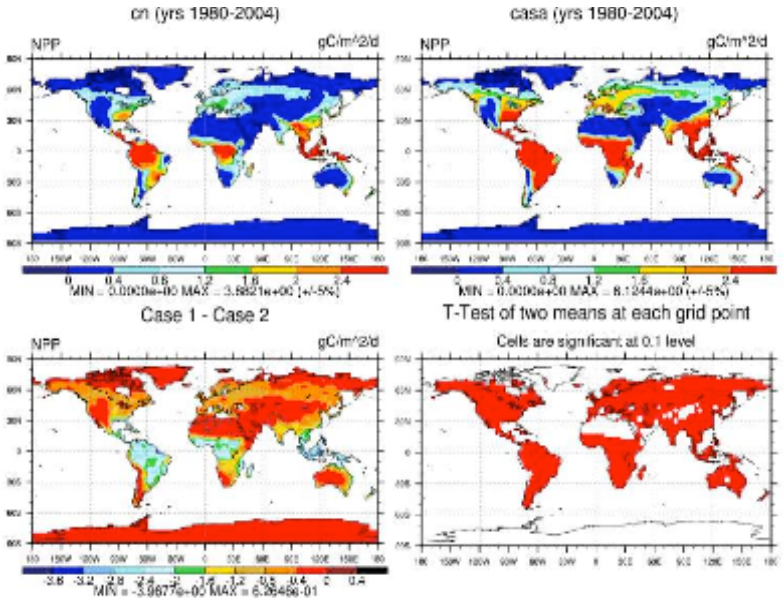


IPCC model resolutions
1990–2007

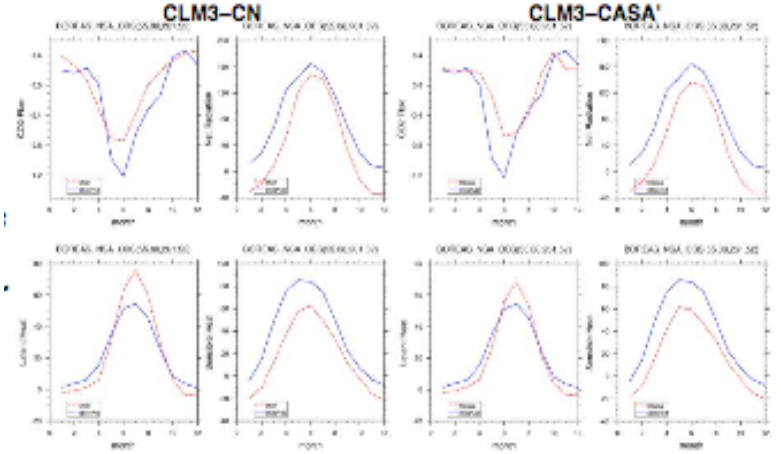
Carbon–Land Model Intercomparison Project (C–Lamp)

Object: Compare terrestrial biogeochemistry models in CCSM3

- Offline and partially coupled experiments compared against best-available observations
- Community-developed performance metrics and evaluation methodology
- Runs being performed on the Climate Science End-Station
- Model output available via the Earth System Grid
- Experimental protocol and metadata standards being extended to international community
- Preliminary results from offline experiments on poster



Comparison of spatial pattern of modeled NPP



Comparison of CO_2 and energy fluxes against Fluxnet tower observations

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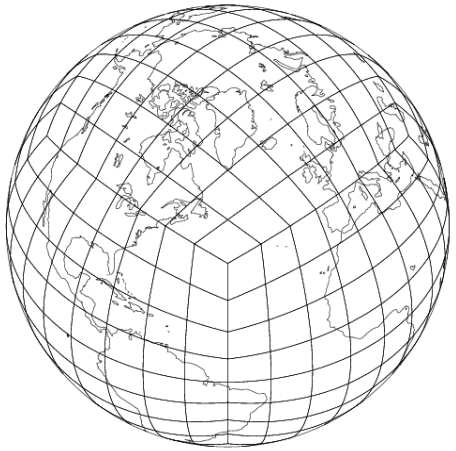
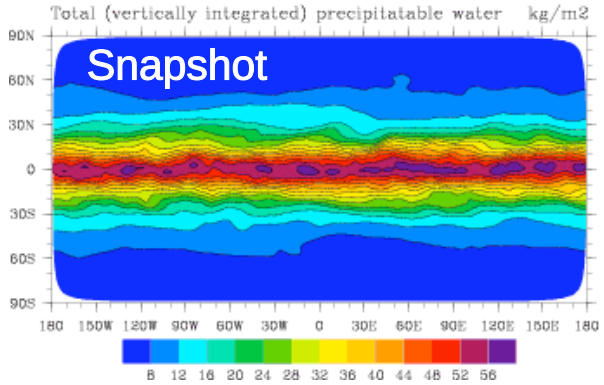
CAM scalable dycore integration and evaluation

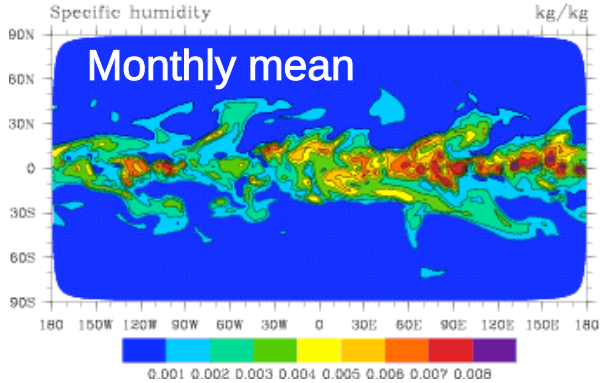
M. Taylor (Sandia)



- Cubed-sphere dycores in CAM (with J. Edwards IBM/NCAR):
  - Motivation: more scalable dycores.
  - Using NCAR's HOMME.
  - Process split model with full dynamics subcycling.
  - Next steps: evaluation of aqua planet results, interpolation to/from other CCSM component grids. Possible other dycores: GFDL cubed-sphere, CSU Icosahedral.

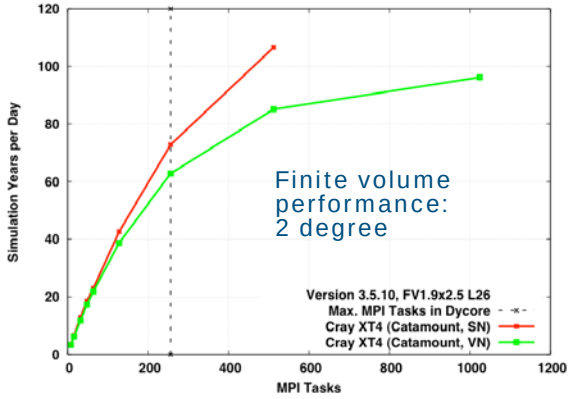


- Cubed-sphere dycore improvements:
  - Developed conservative formulation of spectral elements based on compatibility. First dycore in CAM to locally conserve both mass and energy.
  - Developed efficient hyper-viscosity to replace element based filtering. The filter was causing bad grid imprinting in moisture and other fields.

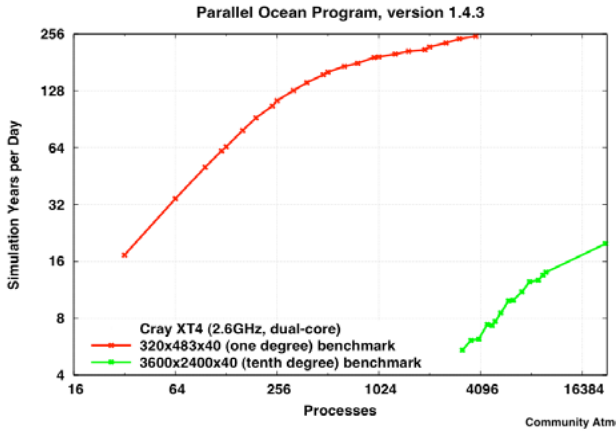


Extending scalability of the Community Atmosphere Model

Pat Worley, Art Mirin, Ray Loy

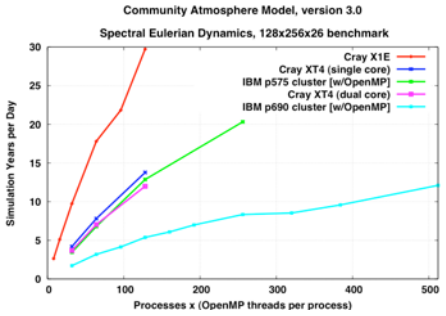


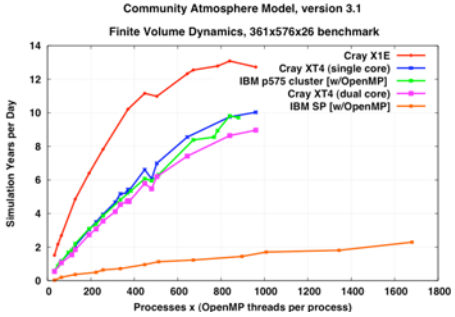
POP performance: 1 degree, 0.1 degree



Work plan: FV dynamics

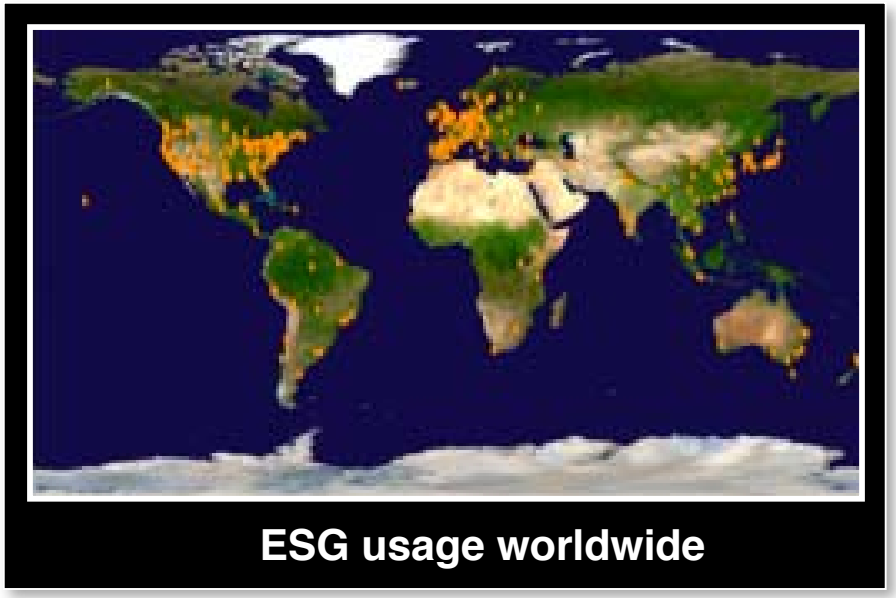
1. Allow the latitude/vertical decomposition to have fewer subdomains than the latitude/longitude decomposition: *complete*
2. Allow the number of active MPI processes to be smaller in the dynamics than in the physics: *complete*
3. Allow auxiliary processes: *initial design and implementation complete*
4. Introduce runtime argument specifying separation between active processes in logical ordering (stride), allowing the user to specify which processors are active and which are idle in the dynamics
5. Decompose tracer advection with respect to tracer index (implementing latitude/vertical/tracer decomposition)
6. Consider finer vertical decomposition for tracer advection (vs main dynamics)
7. Consider overlap of tracer advection (n tracer subcycle) with main dynamics (corresponding to (n+1) tracer subcycle)





Earth System Grid—International distribution of simulation results

- International central site: Earth System Grid
  - Sponsored by DOE SciDAC project. Integrates major centers for supercomputing and analysis coordinated internationally through PCMDI
  - IPCC AR4: 12 experiments, 24 models, 17 climate centers, 13 nations
  - C-LAMP experiments
- Archive status and activity:
  - 6000 registered users
  - Downloaded: 250 terabytes in 2007
  - Current contents: 100,000 simulated years of data
  - Data sets: 1M files, 180 terabytes
  - New portals: ORNL, NCAR
- Access point: https://www.earthsystemgrid.org/



ESG usage worldwide

INCITE award: NLCF Climate-Science Computational End Station allocation

PI: Warren Washington (NCAR), partners: CCSM, COSIM, PCMDI, SciDAC,NASA-GSFC, PNNL, CCRI (universities)

- Extensible *community models* available for computational science
- Coordination of effort among agencies and institutions
- *Scalability* from 500 to 5,000 to 50K processors
- FY 07 award: 5M node-hours Cray XT3
- FY 08 request: 25M node-hours Cray XT4

Summary

- SciDAC2 CCSM Consortium will collaborate with NSF and NASA projects to build the next-generation Earth System Model.
- The LCF Climate End Station provides a significant portion of the development and climate change simulation resources.
- Scalability and extensibility are required for petascale science applications.

Contact

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