NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

CGD Climate & Global Dynamics

BLUE WATERS ENABLED ADVANCES IN THE FIELDS OF ATMOSPHERIC SCIENCE, CLIMATE, AND WEATHER

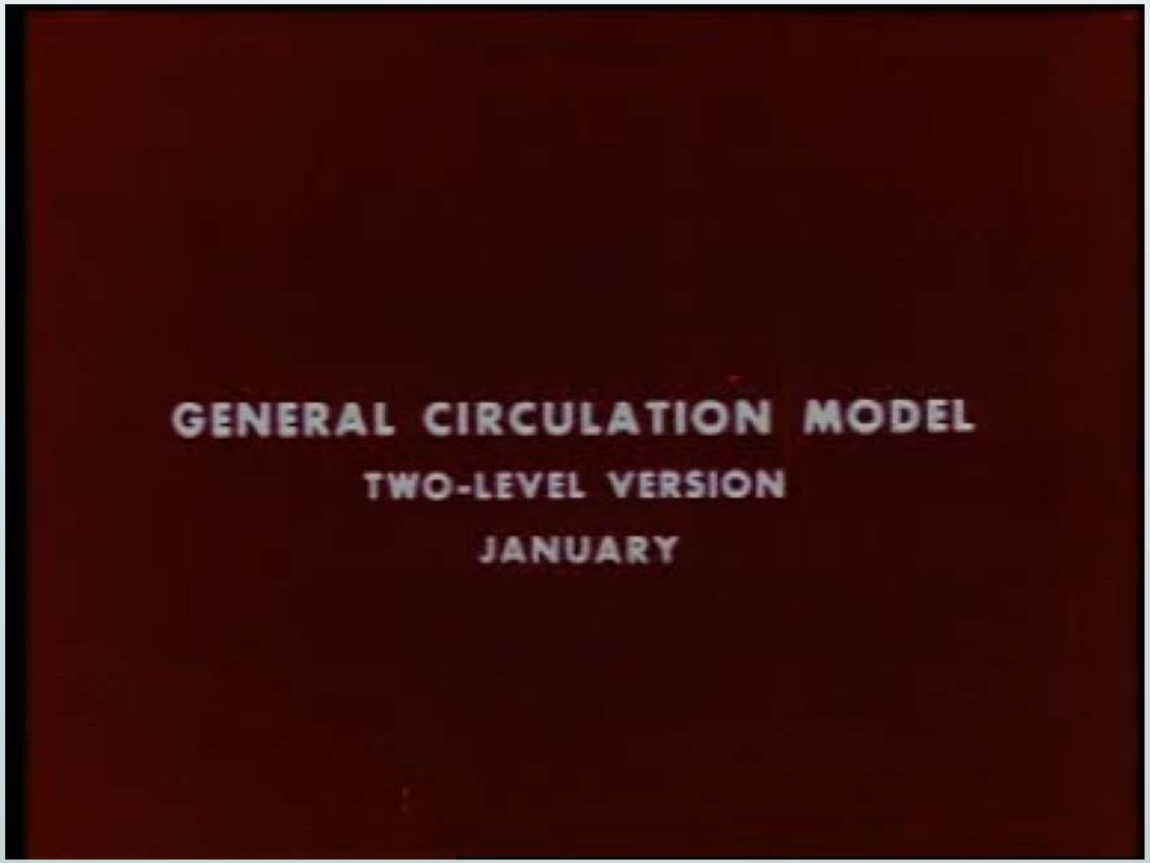
Susan Bates
National Center for Atmospheric Research

Blue Waters Users Symposium
June 6, 2018

BLUE WATERS

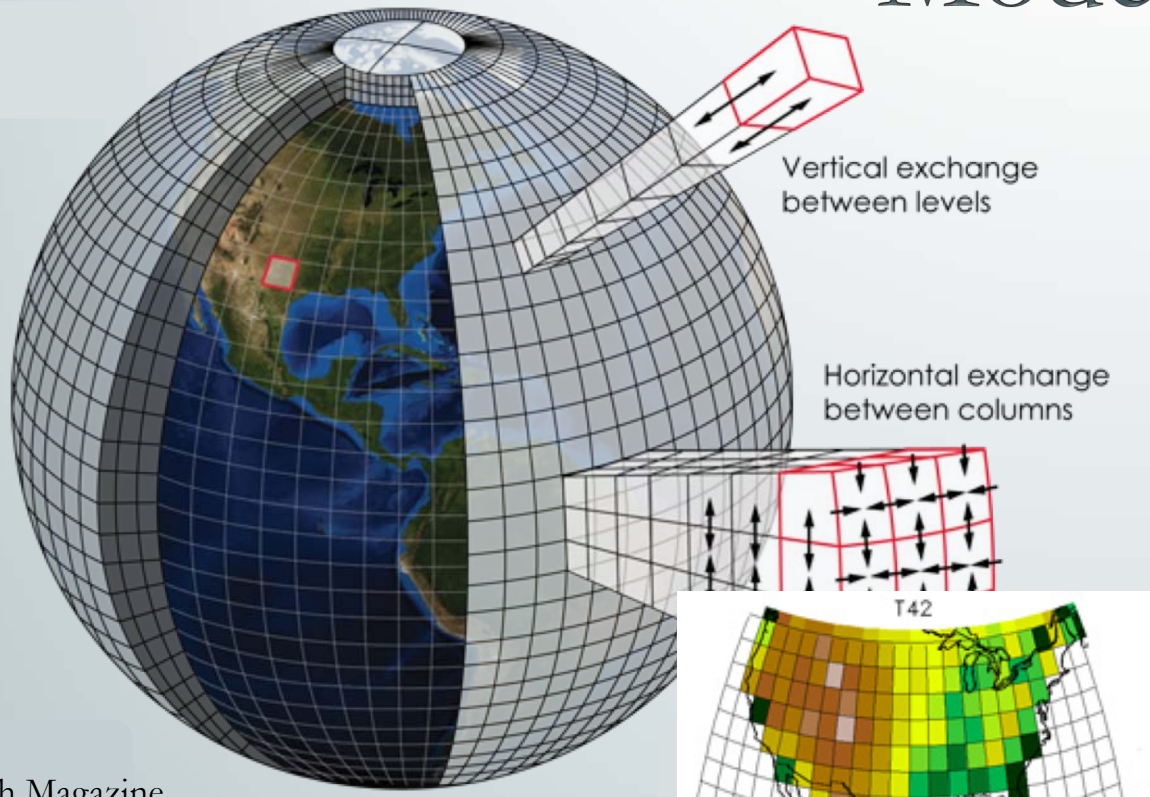
NCAR is sponsored by the National Science Foundation

Early Atmospheric Animation



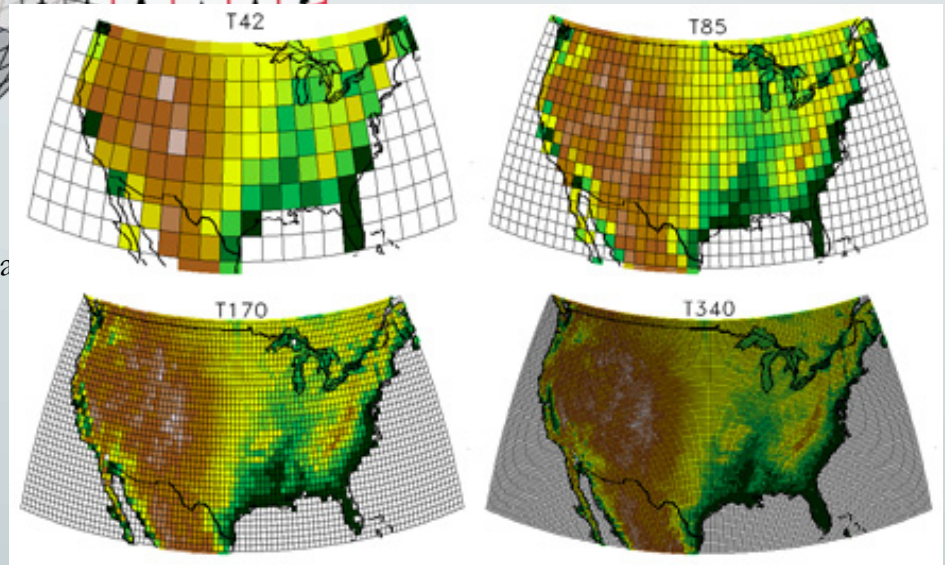
Courtesy Warren Washington

Model Grid



Earth Magazine

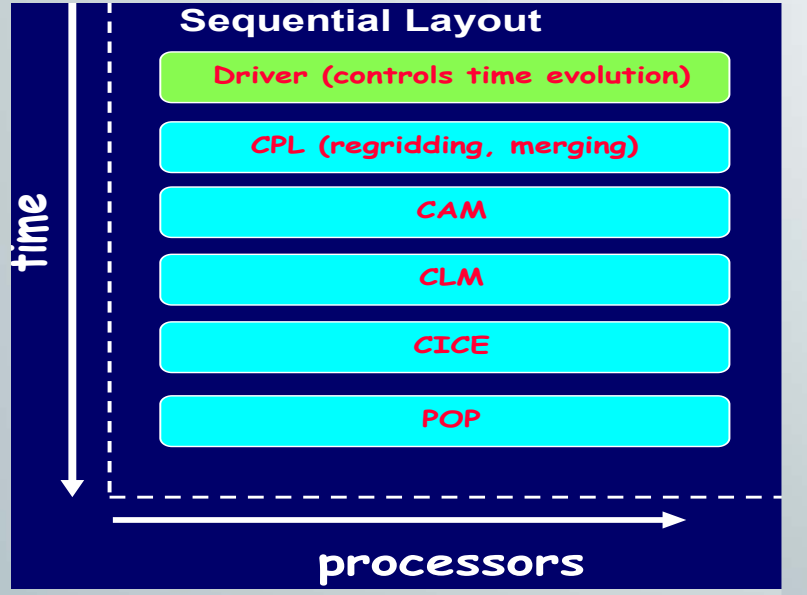
https://www.earthmagazine.org/article/todays-wea

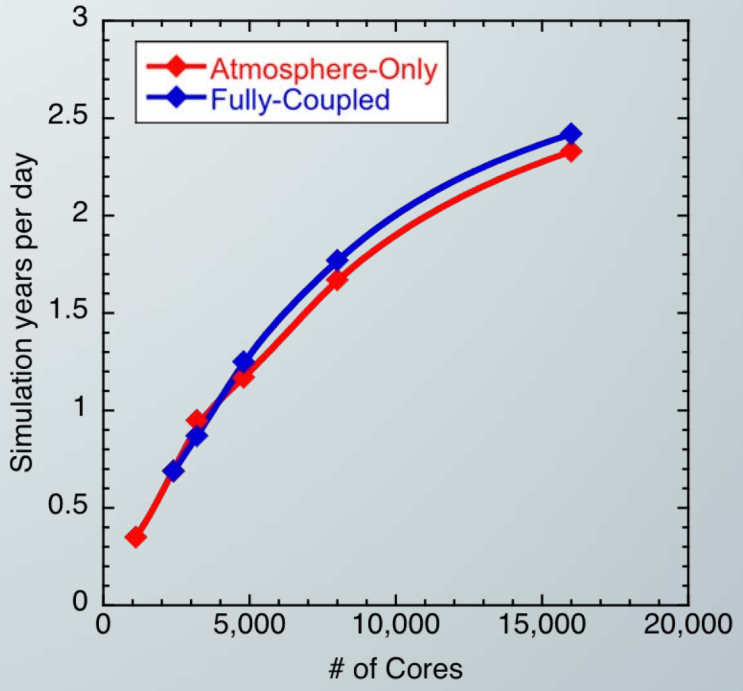


UCAR/NCAR Multimedia Gallery
https://www2.ucar.edu/news/understanding-climate-change-multimedia-gallery

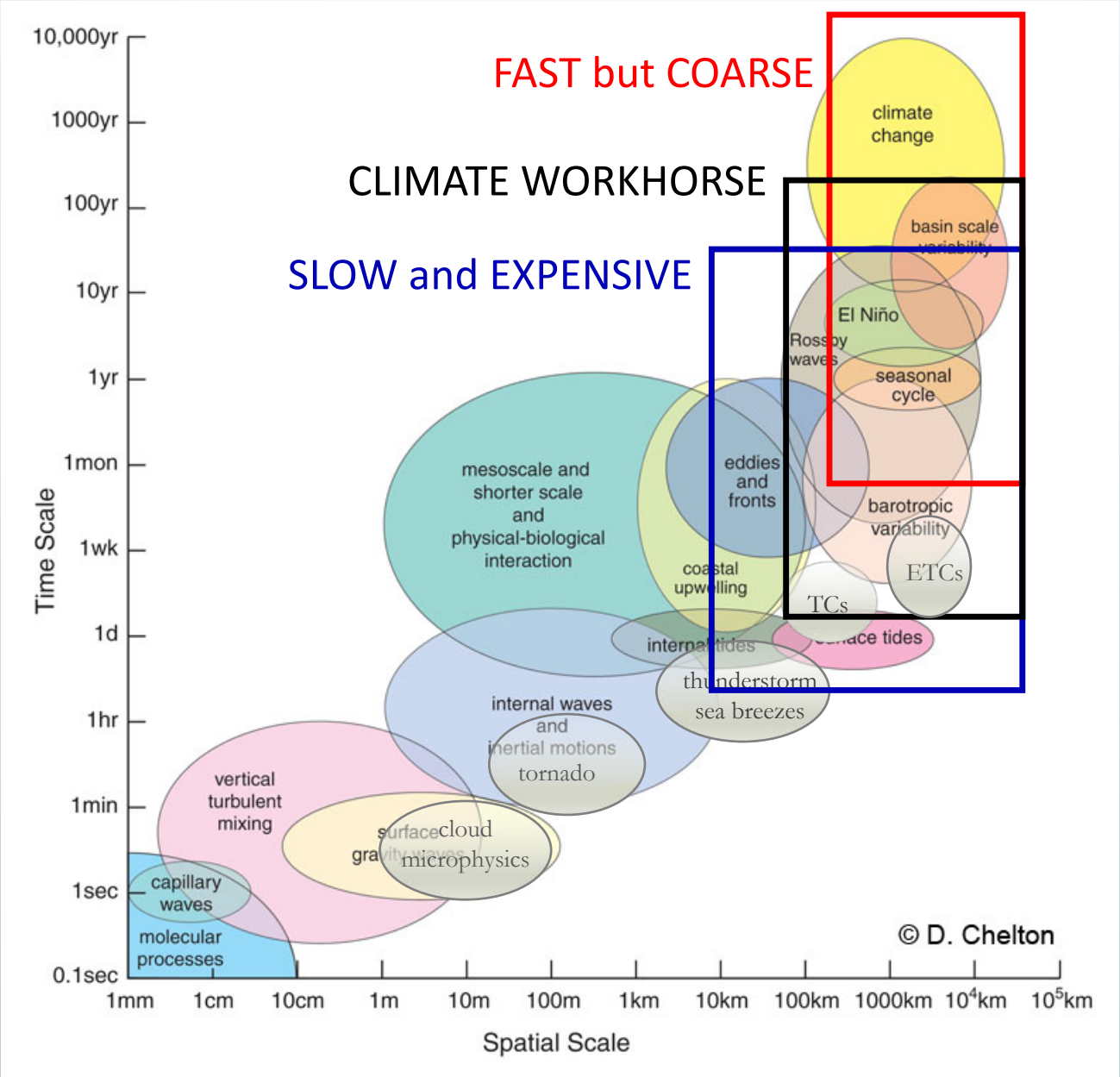
- Systems of differential equations that describe fluid motion, radiative transfer, etc.
- Planet divided into 3-dimensional grid to solve the equations
- More grid boxes = higher resolution

Processor Layout
Community Earth System Model





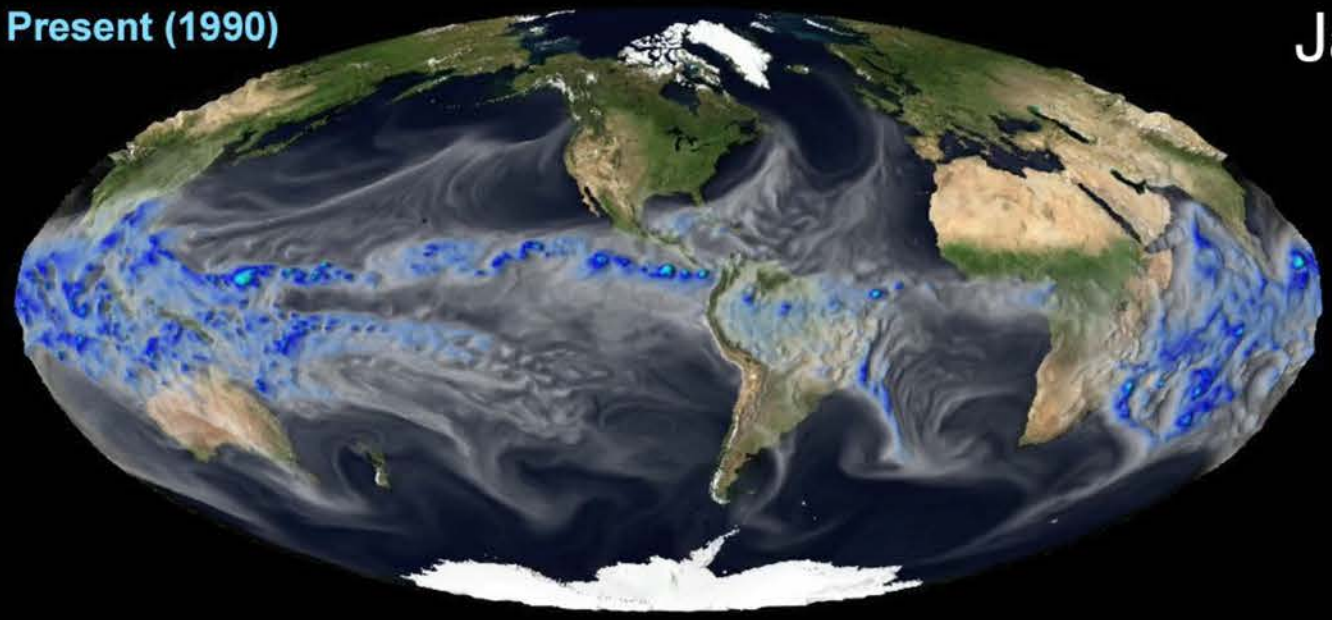
Computational Modeling Challenges



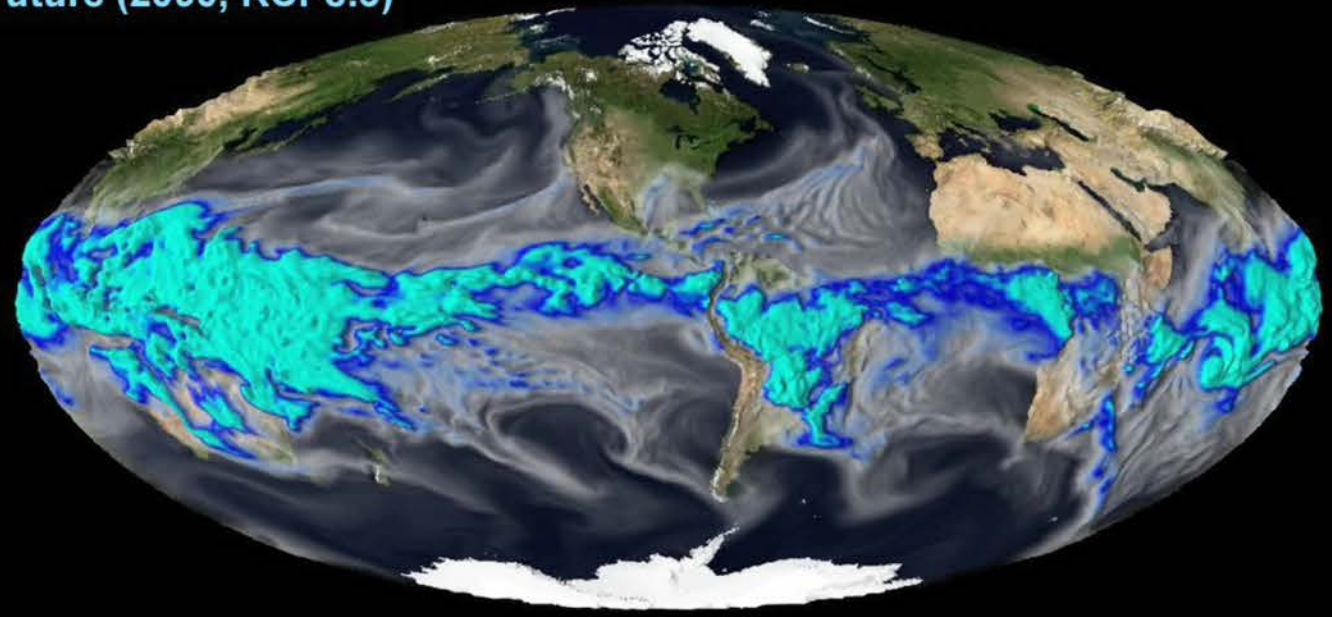
Comparison Between Present and Future Precipitable Water

Jan 01

Present (1990)



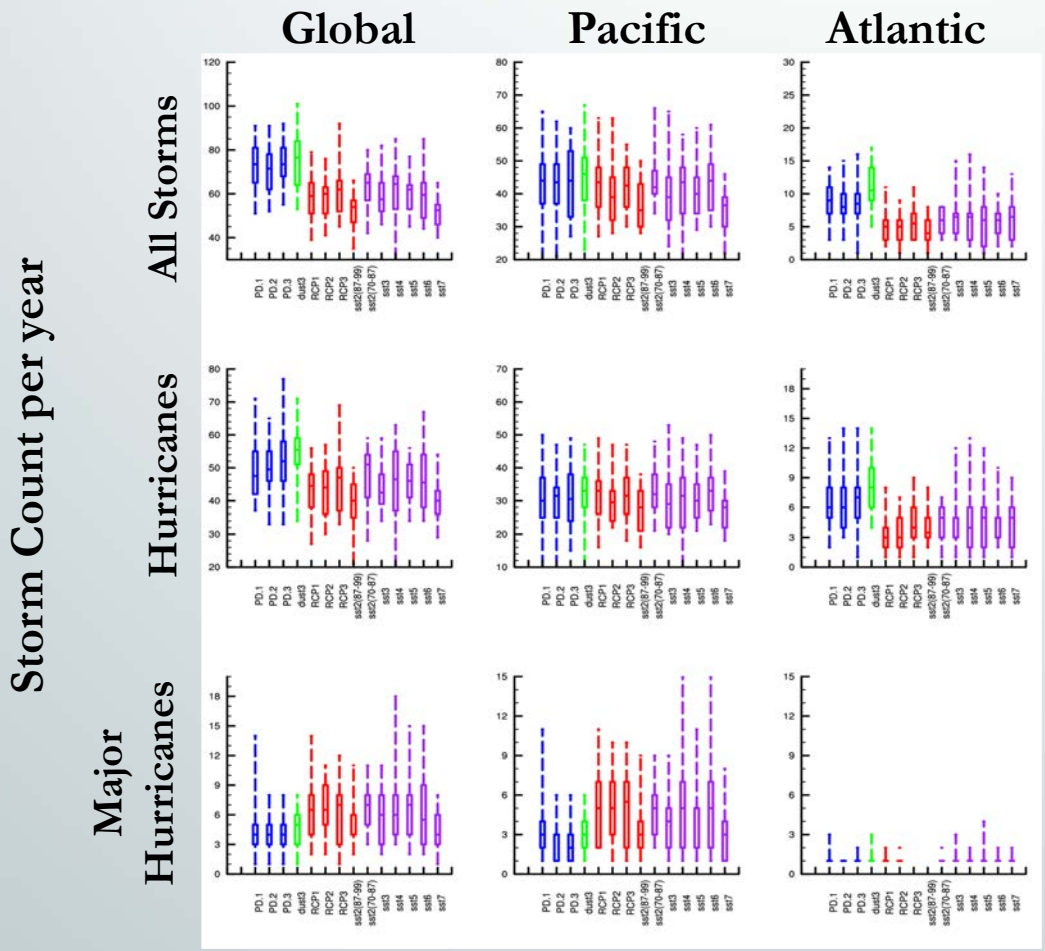
Future (2090, RCP8.5)



CAM Precipitable Water (TMQ)

NCAR

How will Tropical Cyclones Change in the Future?



Present Day 1985-2005
Present Day 1985-2005 (modified dust)
Future RCP8.5 2070-2090
Future RCP8.5 2070-2090 (modified SST)

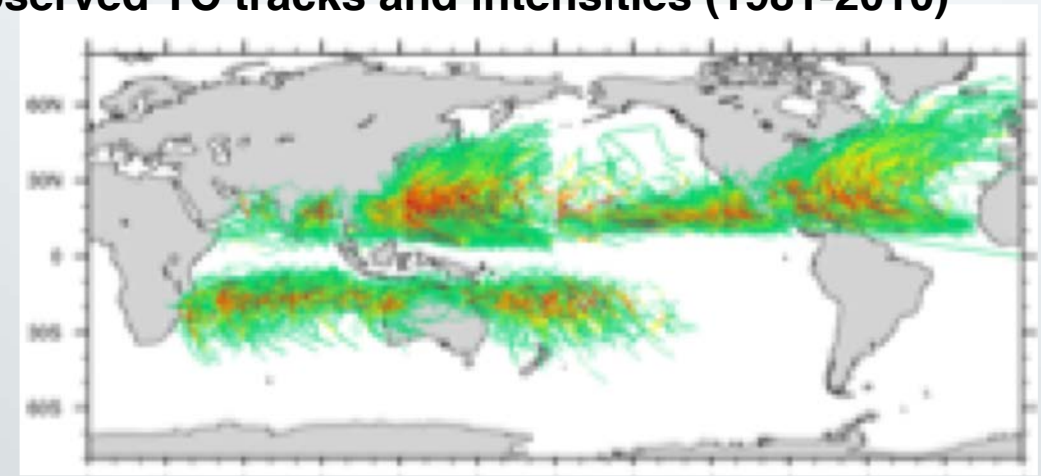
- Community Earth System Model (CESM)
- 0.25° atmosphere/land
- Forced with interannually-varying sea surface temperature and sea ice
- 908 nodes
- 1.4 model years per calendar day

S. Bates and N. Rosenbloom, NCAR

Tropical Cyclones – Atmospheric Resolution and Coupling

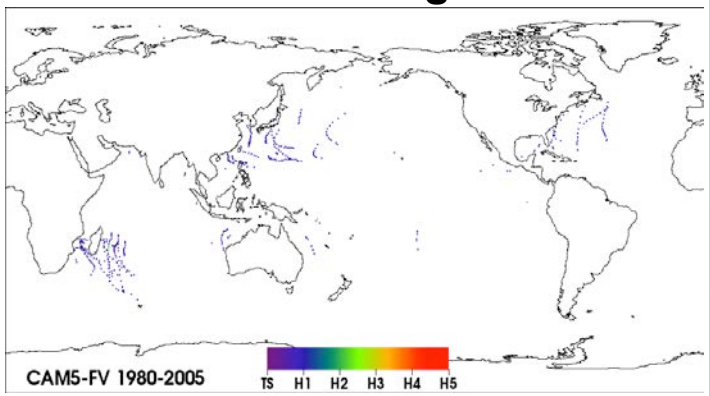
- Community Earth System Model (CESM)

Observed TC tracks and intensities (1981-2010)



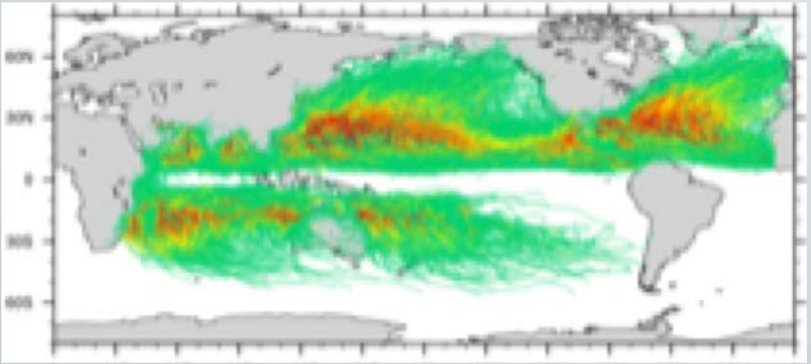
IBTrACS
https://www.ncdc.noaa.gov/ibtracs/

CAM5: 1 degree

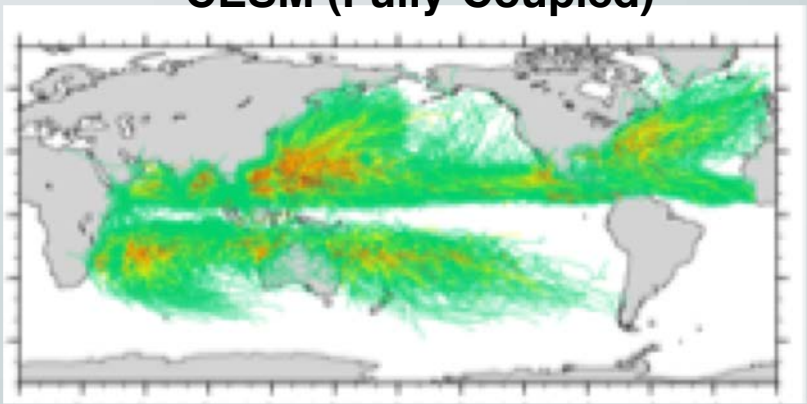


Courtesy Kevin Reed
(See also Wehner et al. 2014, *JAMES*)

CESM (Atm-Only)



CESM (Fully-Coupled)

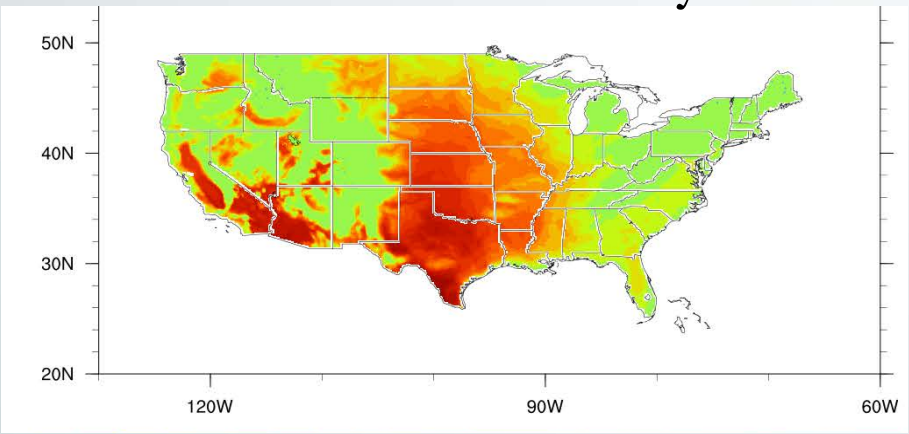


Both coupled and uncoupled versions of CESM simulate realistic spatial reasonably captures key features of observed TC activity

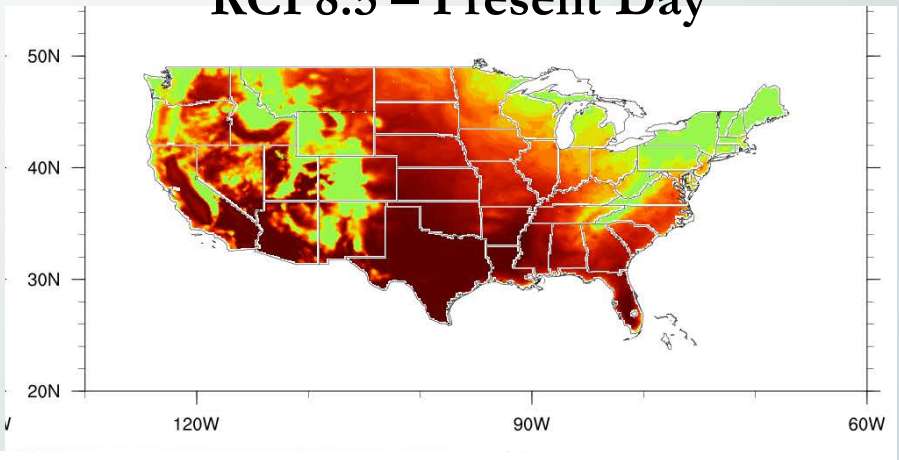
R. Sriver and H. Li
University of Illinois

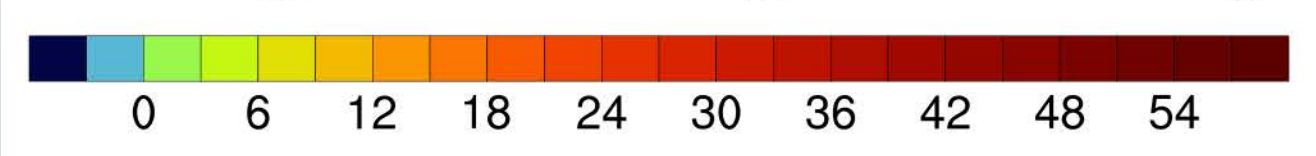
Future Changes in Extreme Temperature

RCP4.5 – Present Day



RCP8.5 – Present Day





- Weather, Research, and Forecasting Model (WRF)
- 12km atmos
- 90 nodes
- 4 months every 1 calendar day
- 150 years
- higher resolution to capture some of the mesoscale processes that take place on small scales that are important for extreme temperature and precipitation (e.g. Midwest soil moisture for summer TMAX; convective processes for extreme precipitation)

D. Wuebbles and Z. Zobel
University of Illinois
Blue Waters Professor

Quantifying Entrainment in Clouds and Storms

- **Entrainment** is the introduction of dry air from outside the cloud inward, by its own turbulent motions (eddies).
  - Predicting entrainment (and the resulting cloud dilution– drying and cooling) is important for: forecasting cloud/storm development & precipitation in weather forecasting models and climate models

The turbulent eddies that entrain dry air also give a cumulus cloud its "cauliflower" appearance.

- Cloud simulations have historically underestimated entrainment.
- It has commonly been stated that this is a result of inadequate model resolution for properly representing the smaller eddies contributing to the entrainment. But no one knew for sure…

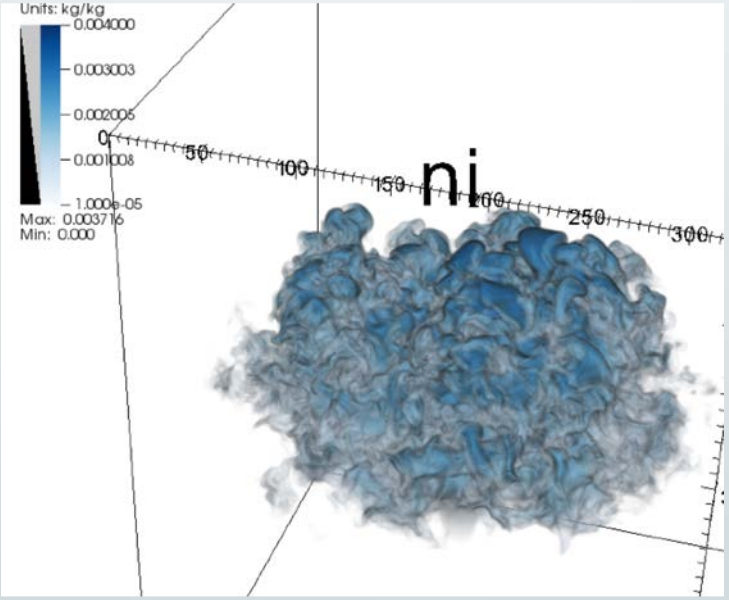
Sonia Lasher-Trapp, U. Illinois
Blue Waters Professor

ILLINOIS

Entrainment: Model and Tools

- CM1 model– George Bryan, NCAR
- Coarse-grained, pure MPI, 3-D cloud model designed to scale to tens of thousands of processors
- Requires model output at high temporal resolution (3 to 6 seconds)

<u>10 meter grid spacing</u>:
1152 x 1152 x 700 grid points (~930 M), Δt = 0.15 s, for 1800 s
→ 4096 processors for ~80 hrs
→ Output files ~7 GB x 300 files ~2 TB



Resolving ~ 40-50 m eddies

- Limit at which further grid refinement is unproductive at diluting the cloud = ~15m
- Before this study, the impact of increasing resolution on entrainment was only speculation.
- Impact: guide parameterizations in larger-scale weather and climate models.

Sonia Lasher-Trapp, U. Illinois
Blue Waters Professor

ILLINOIS

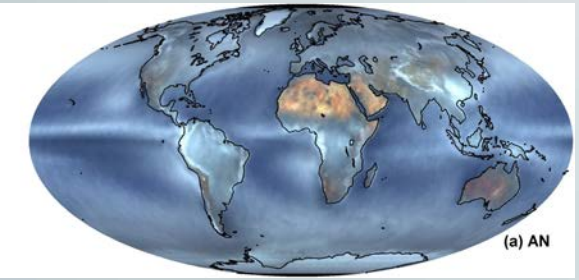
PRAC: Understanding the development and evolution of violent tornadoes in supercell thunderstorms

Leigh Orf
University of Wisconsin - Madison

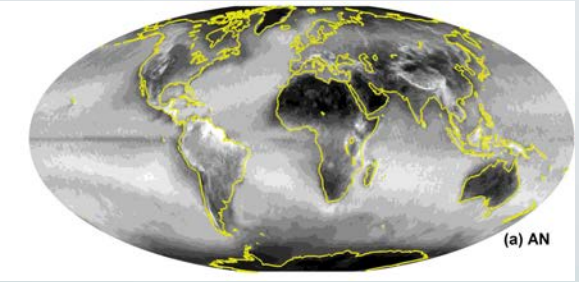
The Terra Data Fusion Project

Terra/MISR spectral radiance data from 2000 to 2015 (240 TB) was processed on Blue Waters to examine how the Earth's color and texture changed over this period.

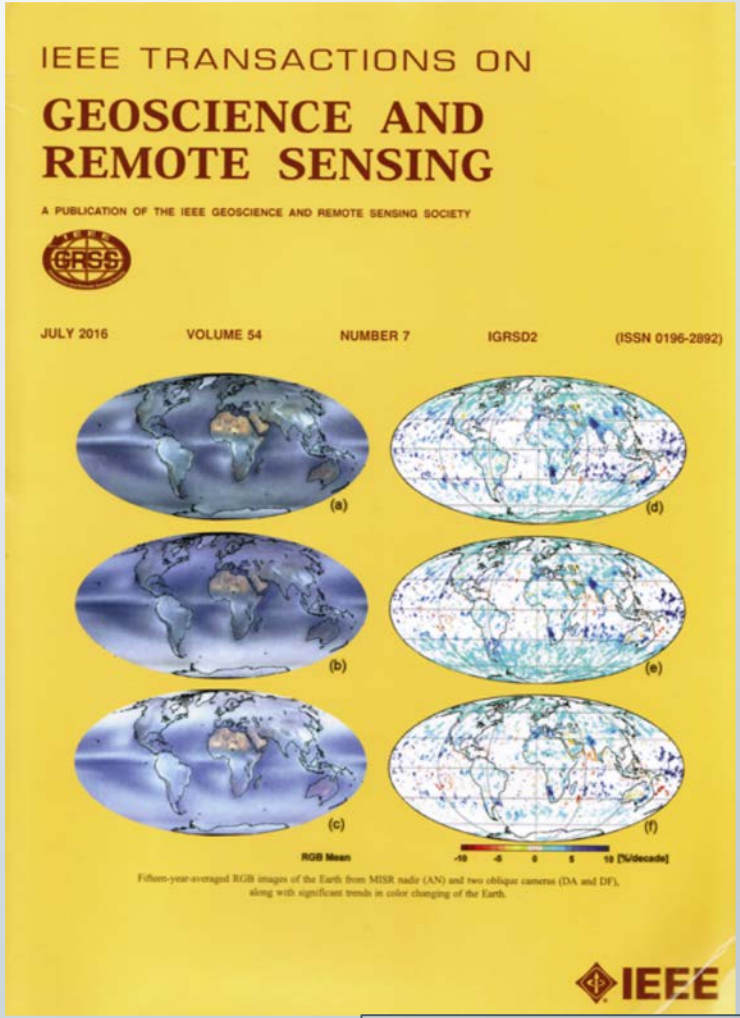
Annual Mean Color



Annual Mean Texture



The first color composite and texture images of the Earth's climate



Zhao, G., L. Di Girolamo, D.J. Diner, C.J. Bruegge, K. Mueller, and D.L. Wu, 2016: Regional changes in Earth's color and texture as observed from space over a 15-year period. *IEEE Trans. Geosci. Remote Sens., 54(7),* 4240-4249, doi:10.1109/TGRS.2016.2538723

Larry Di Girolamo, U. Illinois
Blue Waters Professor

Cutting Edge Research Enabled by Blue Waters

- Resolution
- Number of simulations (ensembles), scenarios
- Amount of data saved
- Frequency of sampling
- Mechanisms investigated or novel way in which they were investigated

WHY BLUE WATERS?

- Blue Waters provided a massively parallel system, one of the largest storage and bandwidth computing facilities and excellent sharing services.
- Blue Waters, with its huge number of nodes, its high speed, and its large storage capability for high-resolution model output and analysis allows us to push the spatial scale limit much farther than in the past.
- The hardware needed to run these kinds of simulations quickly exceeds the limits of most computers.
- Blue Waters staff have helped us to learn new and practical ways to visualize the output for easier analysis.
- The Blue Waters staff understand the needs of our project and facilitate getting jobs through the queue. It's not just the machine that enables our science but the staff as well.
- If we didn't have Blue Waters, we would have accomplished about 1/10 of what we did.
- These are the calculations that I had been waiting to perform during my career, and Blue Waters presented that opportunity!
- Machines like Blue Waters can create incredible simulations and amazing amounts of data that will long exceed the machine's life span.