High Resolution Earth System Modeling using Blue Waters Capabilities

Susan Bates
National Center for Atmospheric Research
Petascale Computing Resources Allocation (PRAC)
PI: Don Wuebbles/Robert Rauber, U. Illinois

Zach Zobel (U. Illinois)
Justin Small, Christine Shields (NCAR)
NCAR collaborators: Nan Rosenbloom, Warren Washington, Julio Bacmeister, Colin Zarzycki, Kevin Reed, Rich Neale, John Truesdale, Cecile Hannay, Gary Strand

NCAR is supported by the National Science Foundation

BLUE WATERS

CGD
Climate & Global Dynamics
a Laboratory of NCAR

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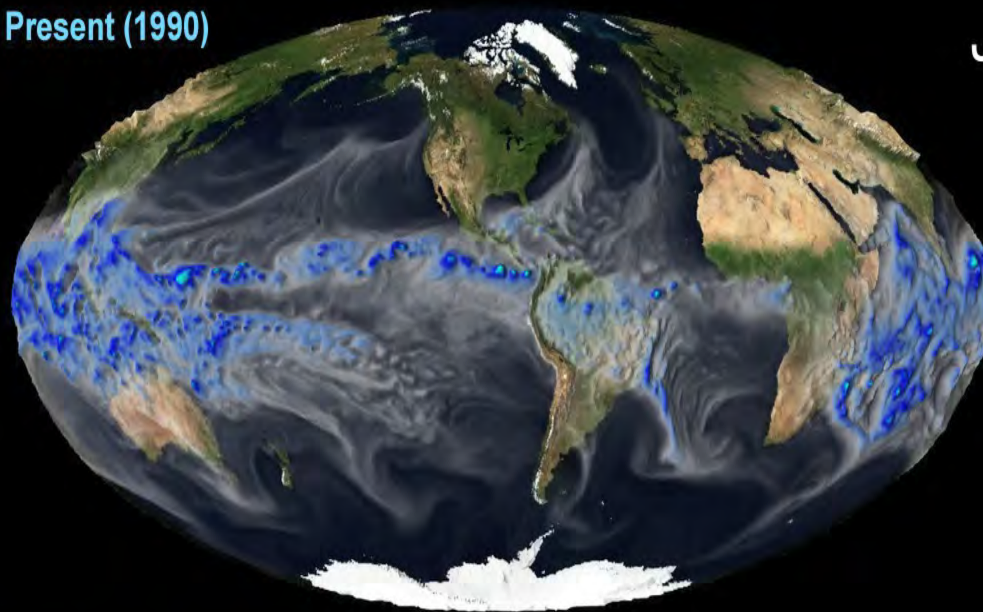
Why Blue Waters?

- 0.25°atmos/land –only (30 years)
  - 12K node-hours per model year = 0.36M node-hours for one simulation
  - 4 present day – 8 future scenarios (**~4.3M**)
- Fully-coupled 0.5° atmos/land - 1° ocean/sea ice
  - 1 PI control, 3 20th Century, 12 future scenarios
- Fully-coupled 0.25° atmos/land - 1° ocean/sea ice
  - 10-12K node-hours per model year = 1-1.8M node-hours for one simulation
  - 1 PI control, 2 climate sensitivity, 3 20th Century, 6 future scenarios (**~12M-21M**)
- Fully-coupled 0.25° atmos/land – 0.1° ocean/sea ice
  - 32.3K node-hours per model year = 3.23M node hours for one simulation
  - 1 PI control, 1 20th Century, 2 future scenarios (**~13M**)

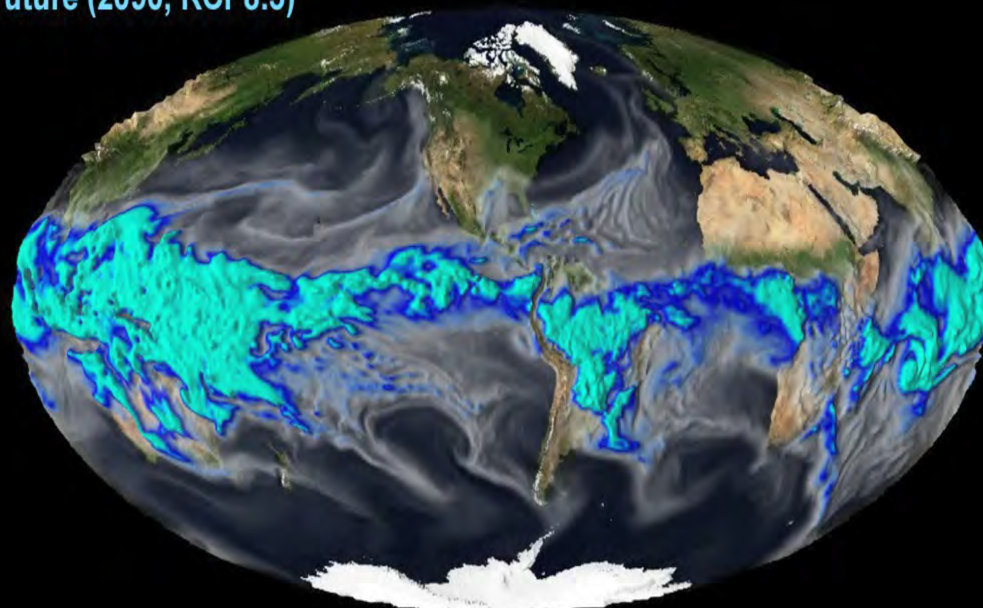
Comparison Between Present and Future Precipitable Water

Jan 01

Present (1990)



Future (2090, RCP8.5)

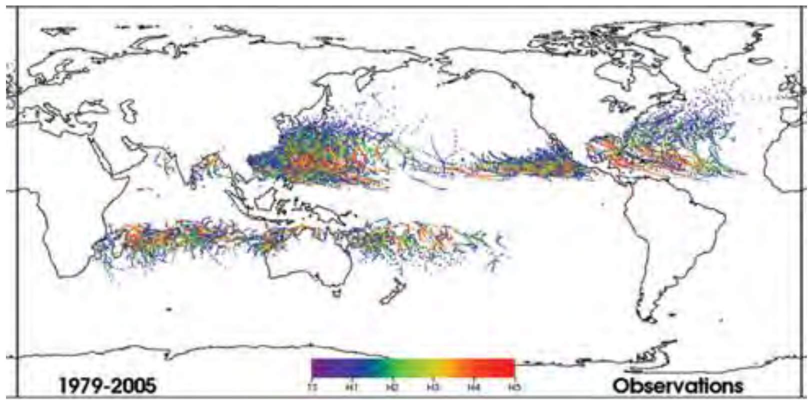


CAM Precipitable Water (TMQ)

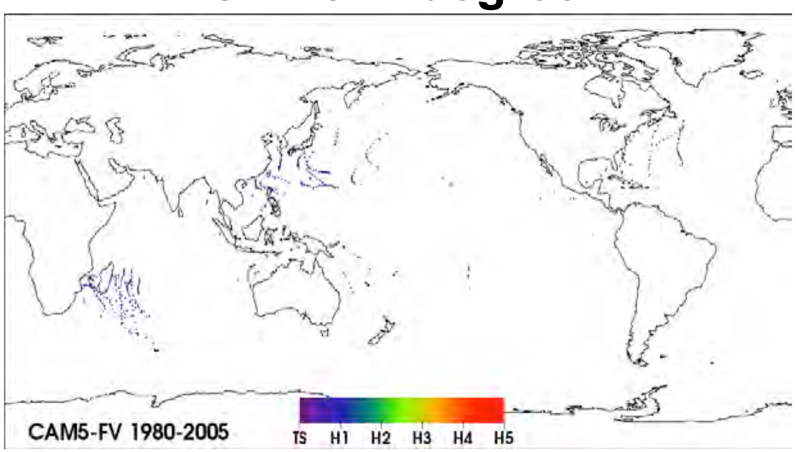
NCAR

Tropical Cyclone (TC) Tracks

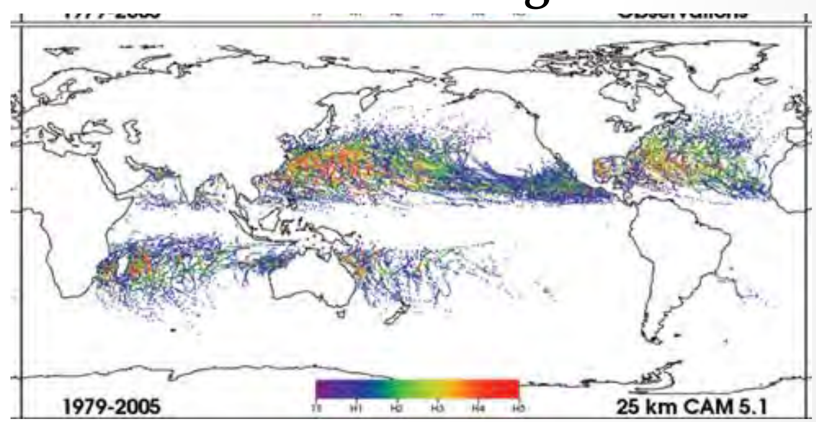
Observations: IBTrACS



CAM5: 1 degree



CAM5: 0.25 degree



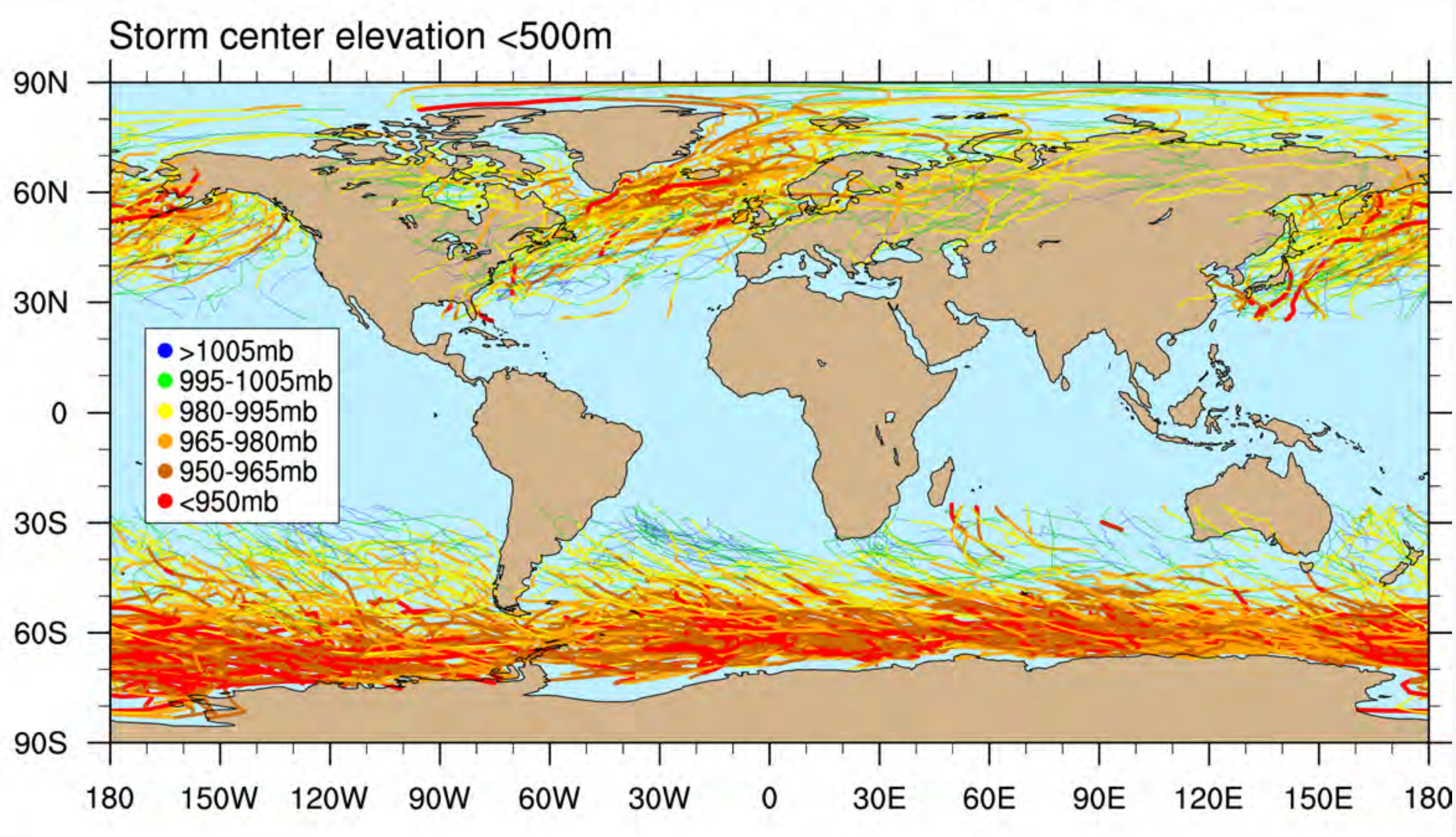
Tropical cyclone algorithm and tracker follows Zhao et al. (2009) using 3-hourly model output.

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

Extra-tropical Storm (ETC) Tracks

(for one model year)

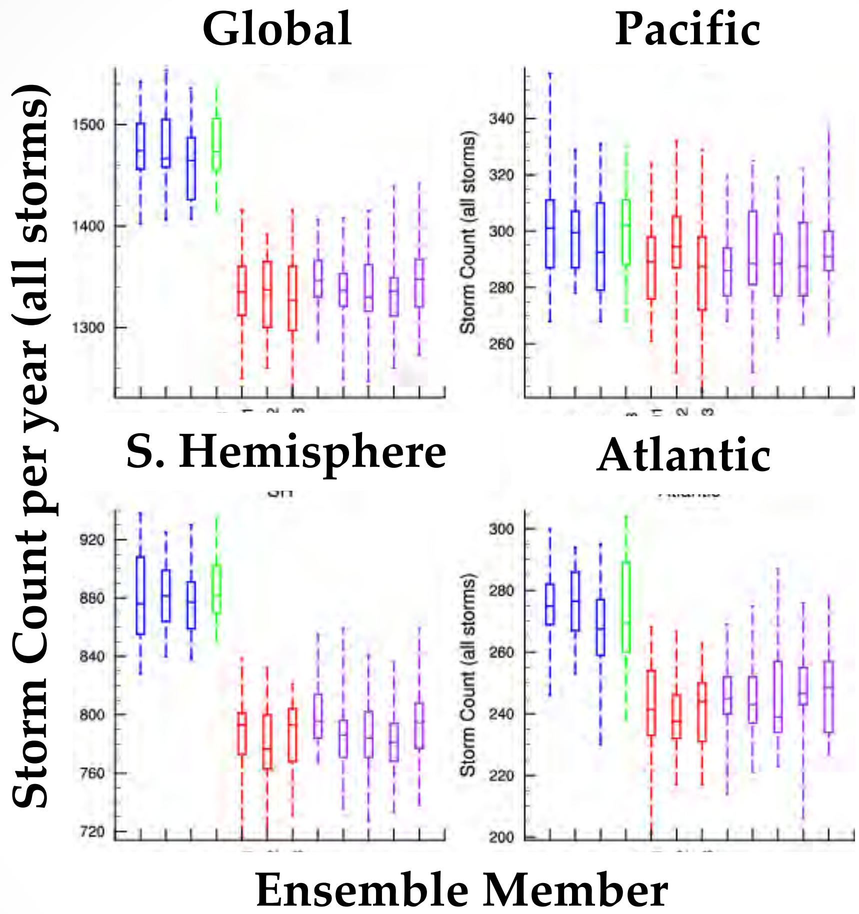
0.25° atmos-only



Extratropical cyclone tracks and storm properties are found using TempestExtremes (Ullrich and Zarycki, 2016).

Present Day and Future ETC Storm Count

0.25° atmos-only

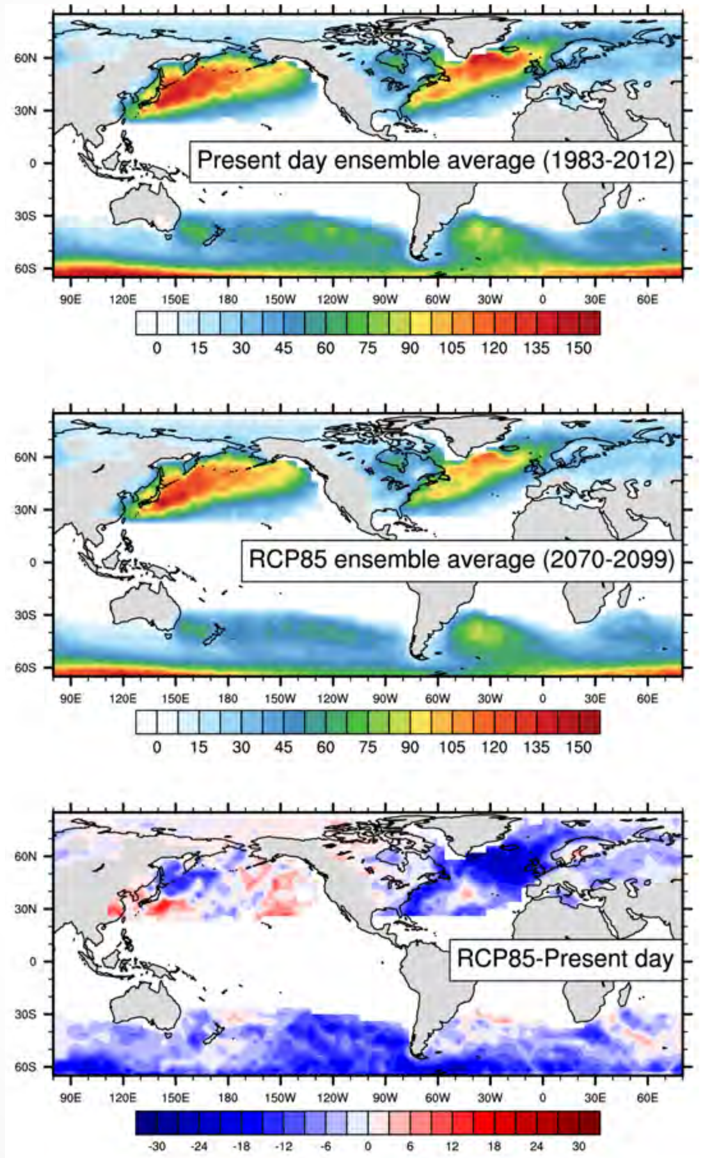


Present Day 1985-2005
Present Day 1985-2005 (modified dust)
Future RCP8.5 2070-2090
Future RCP8.5 2070-2090 (modified SST)

Present Day and Future ETC Track Density

0.25° atmos-only

All storms

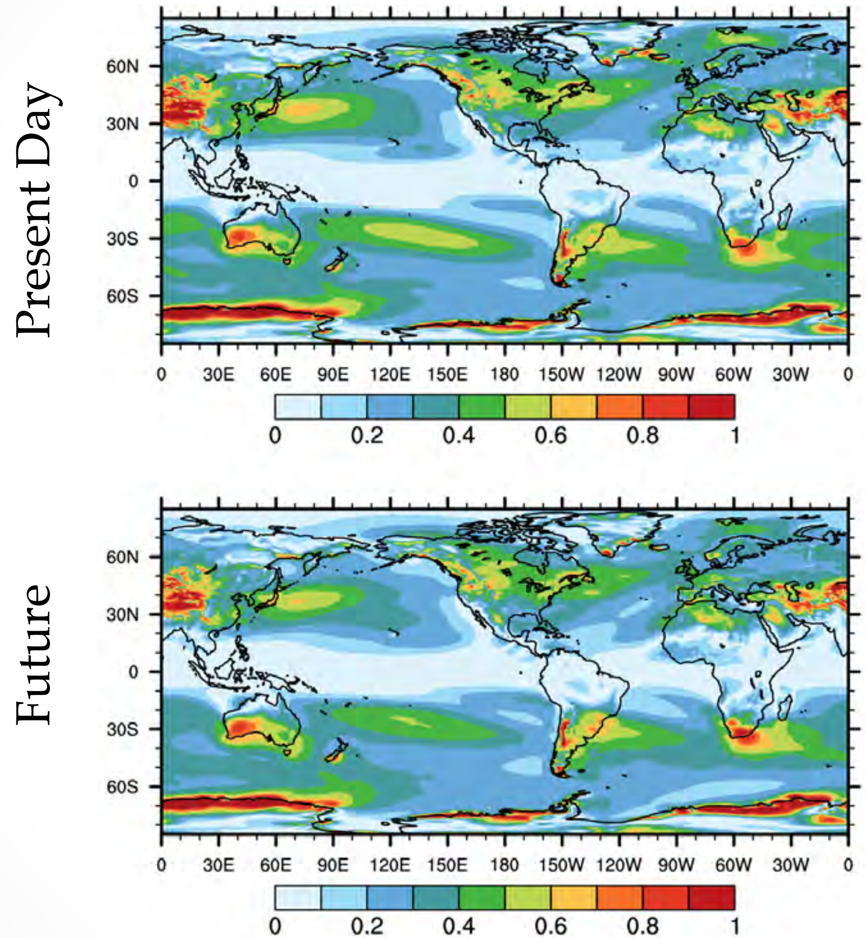


Units are average hours per year in which a storm is found within a $4^o \times 4^o$ gridbox

Eady Growth Rate (850mb)

0.25° atmos-only

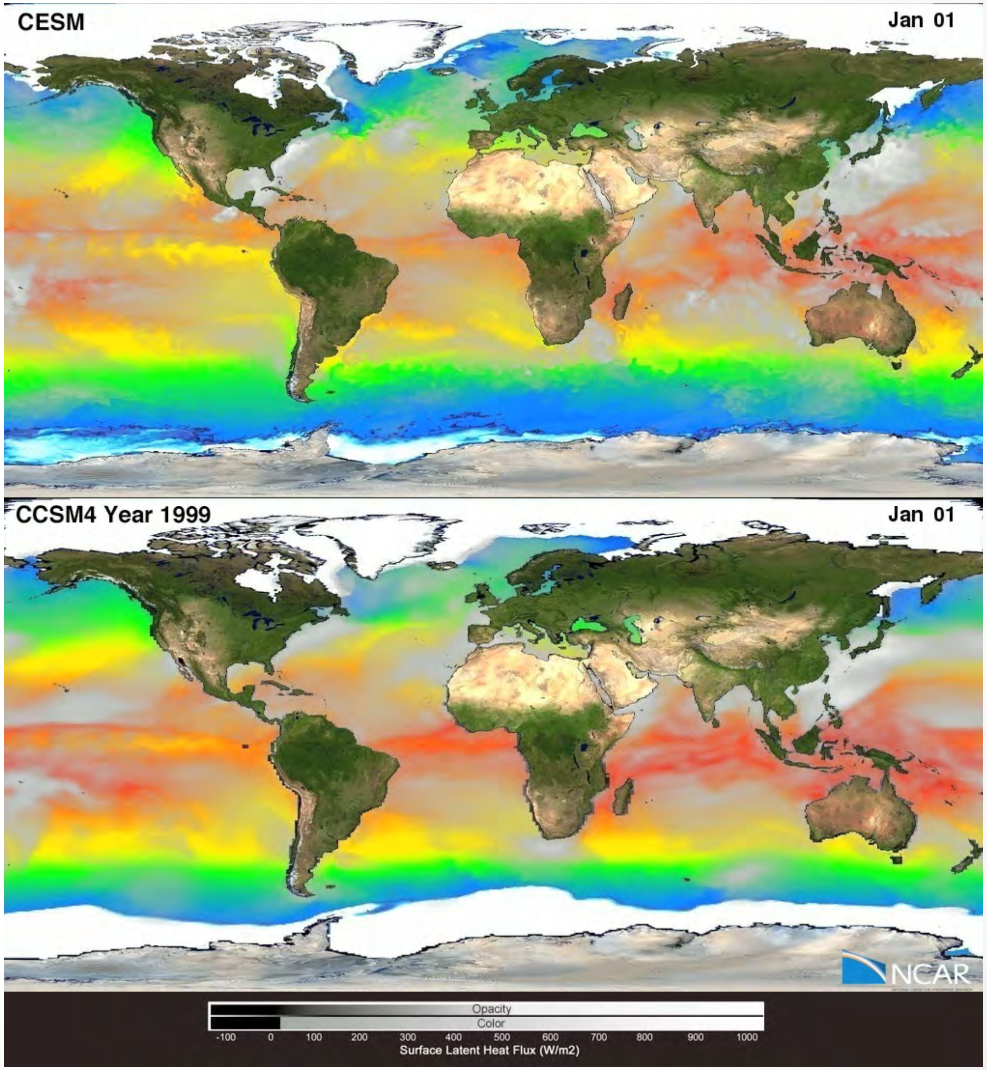
Units = day^{-1}



High Resolution Ocean

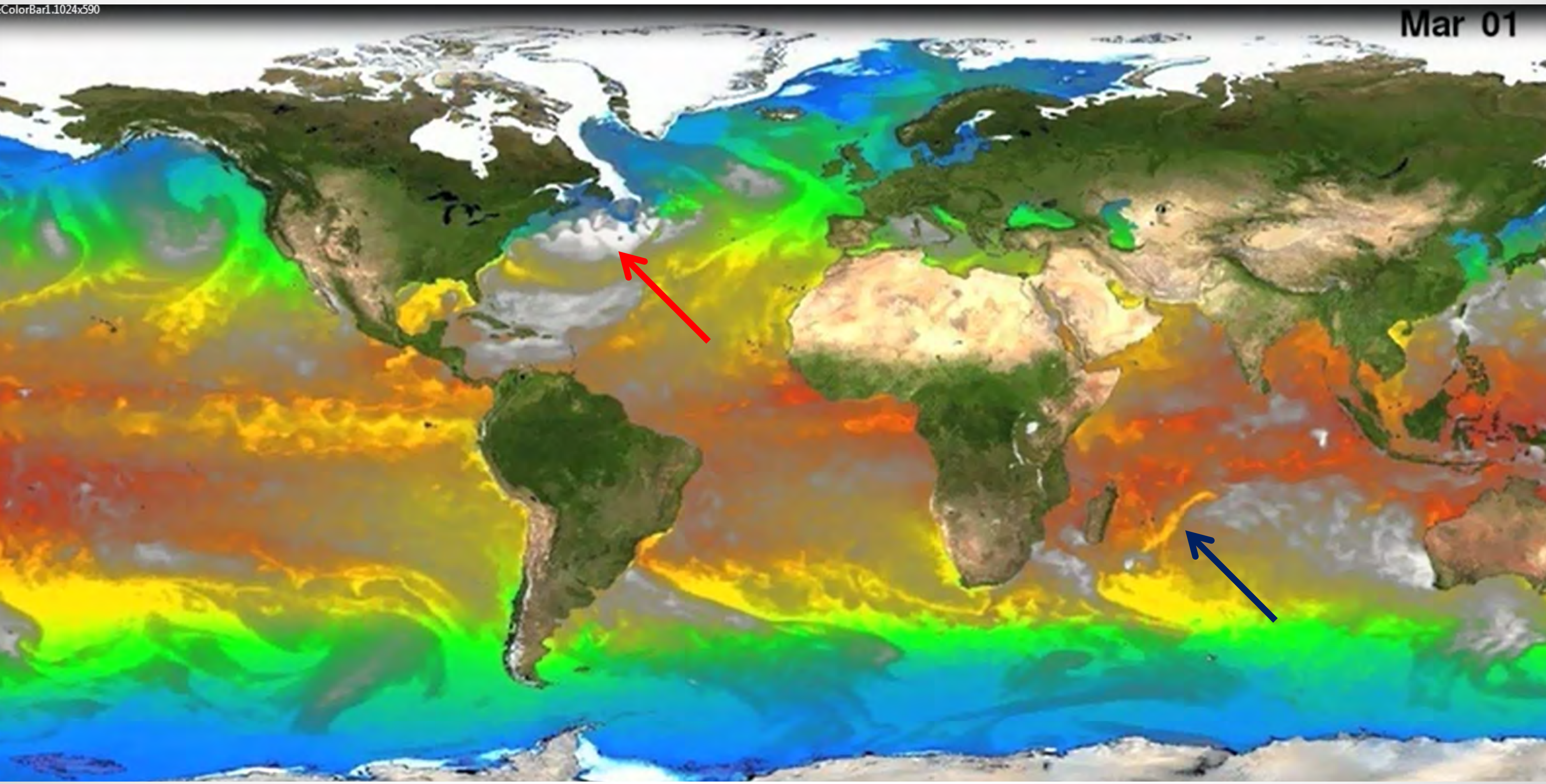
0.25° atmos - 0.10° ocean

1° atmos – 1° ocean



High Resolution Ocean

0.25° atmos - 0.10° ocean

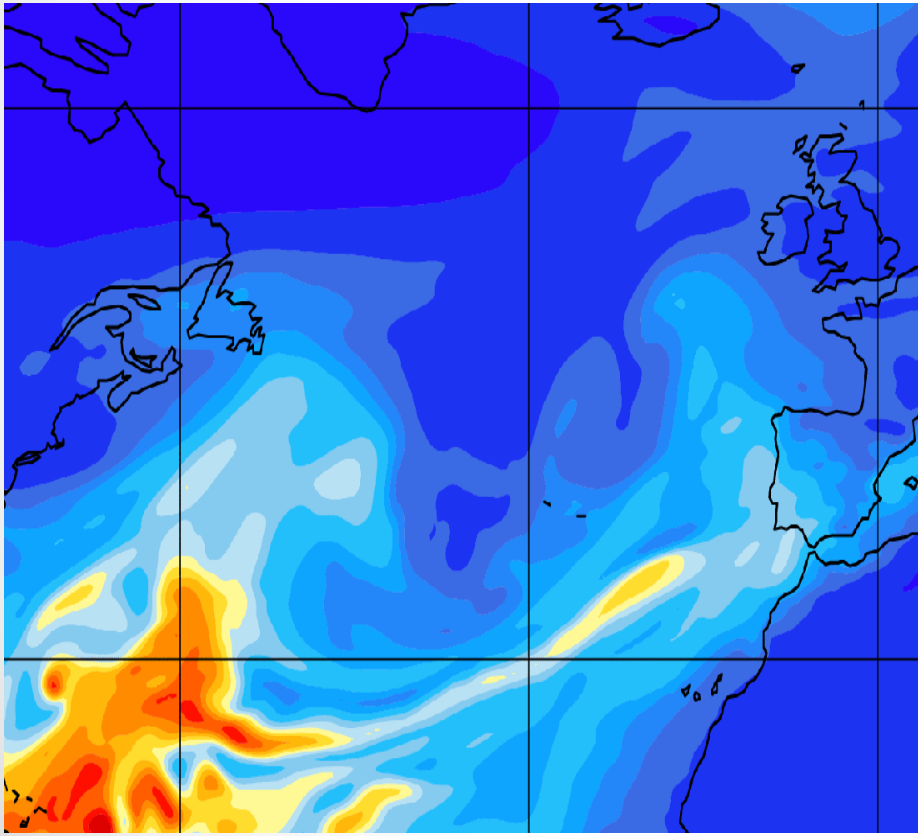


Ocean Resolution

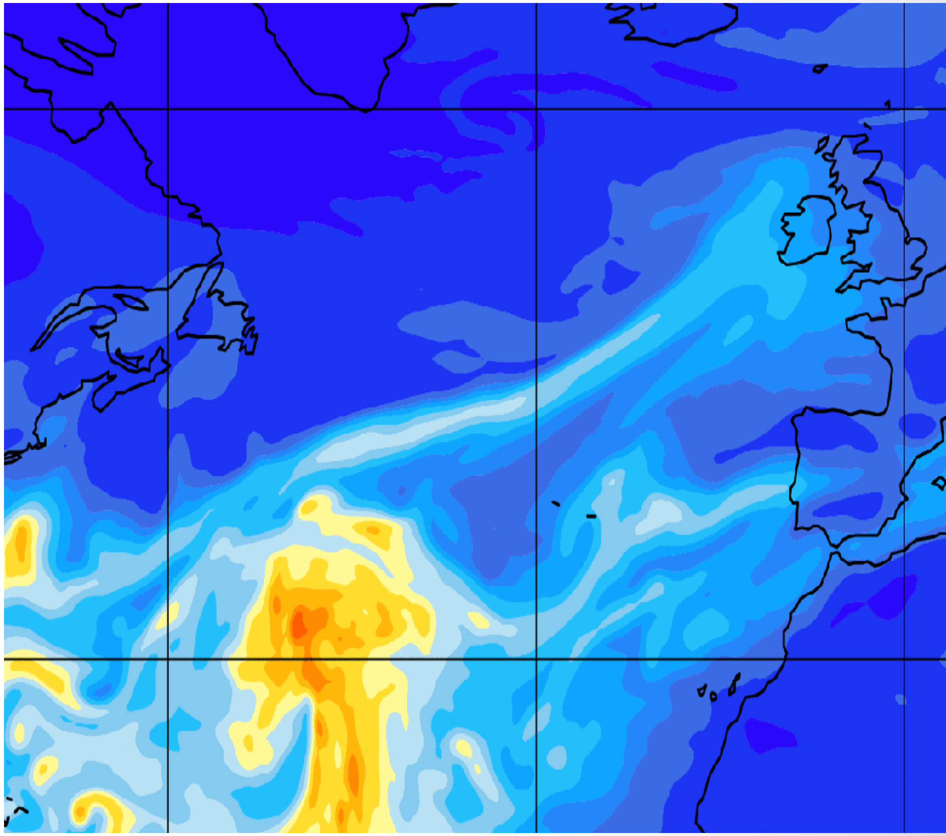
0.25° atmosphere
1° vs 0.10° ocean

Sample UK Events,
TMQ

Movies of 1 year's worth of AR events strung together

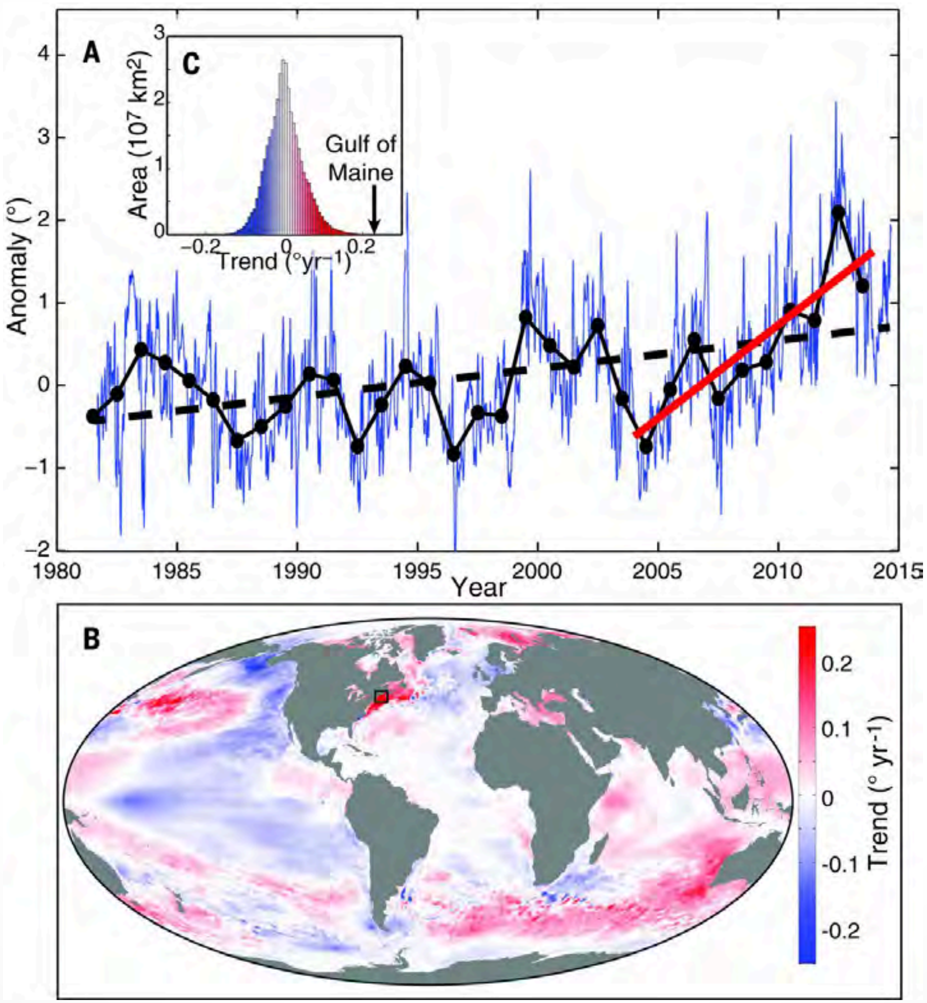


1 degree



0.1 degree

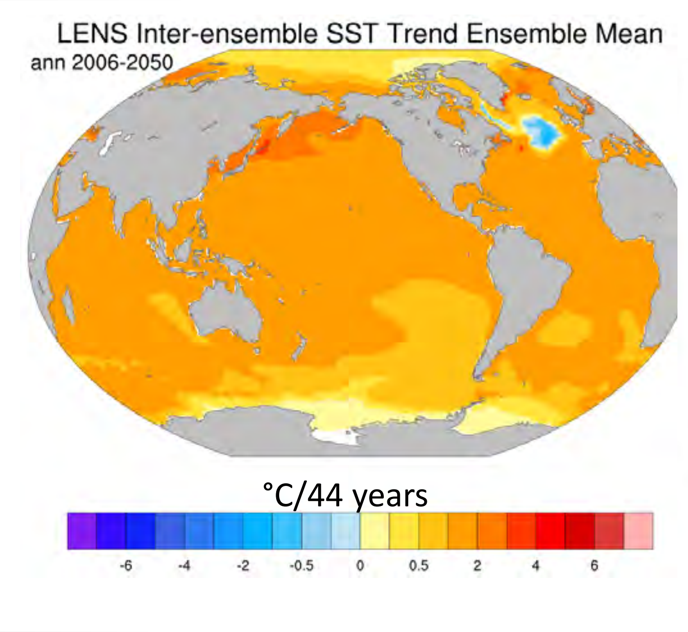
Ocean Warming Trends



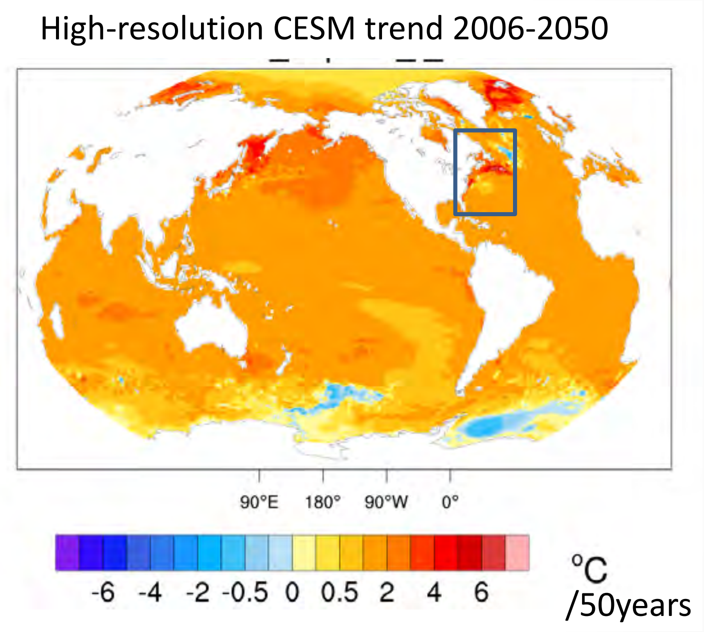
Pershing et al. (2015)

Compared to 1° CESM

1° atmos – 1° ocean



1° atmos - 0.10° ocean

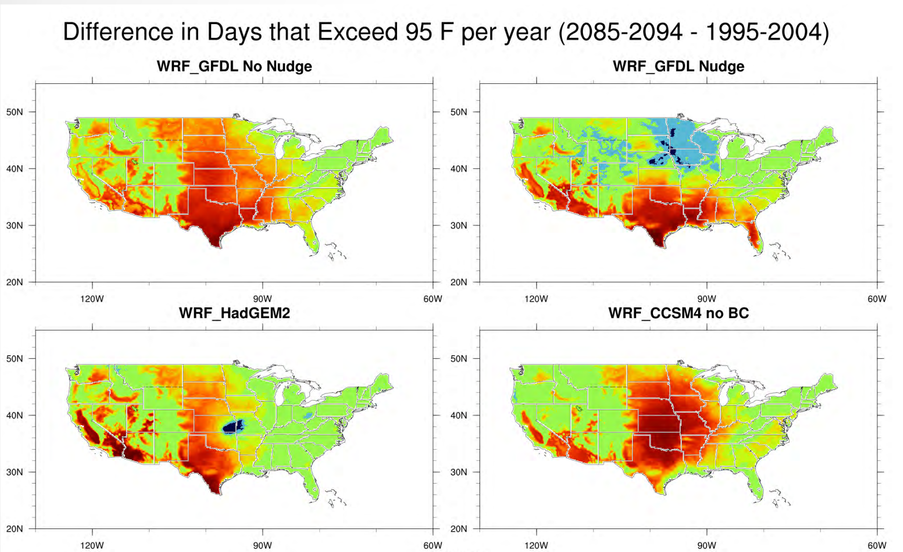


Courtesy Justin Small

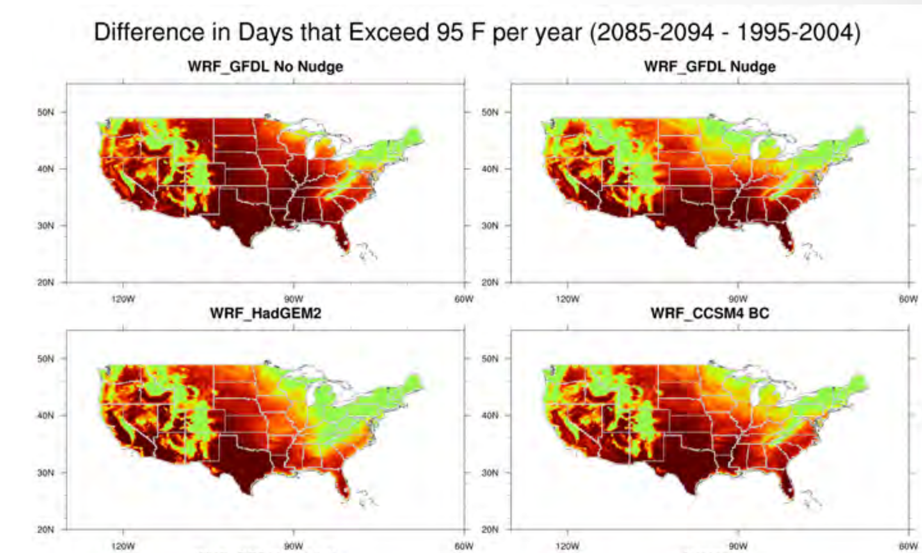
Future Changes in Days that exceed 95°F

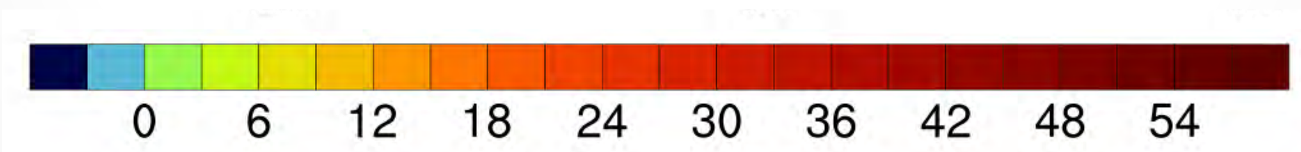
12km atmos

RCP4.5 – Present Day



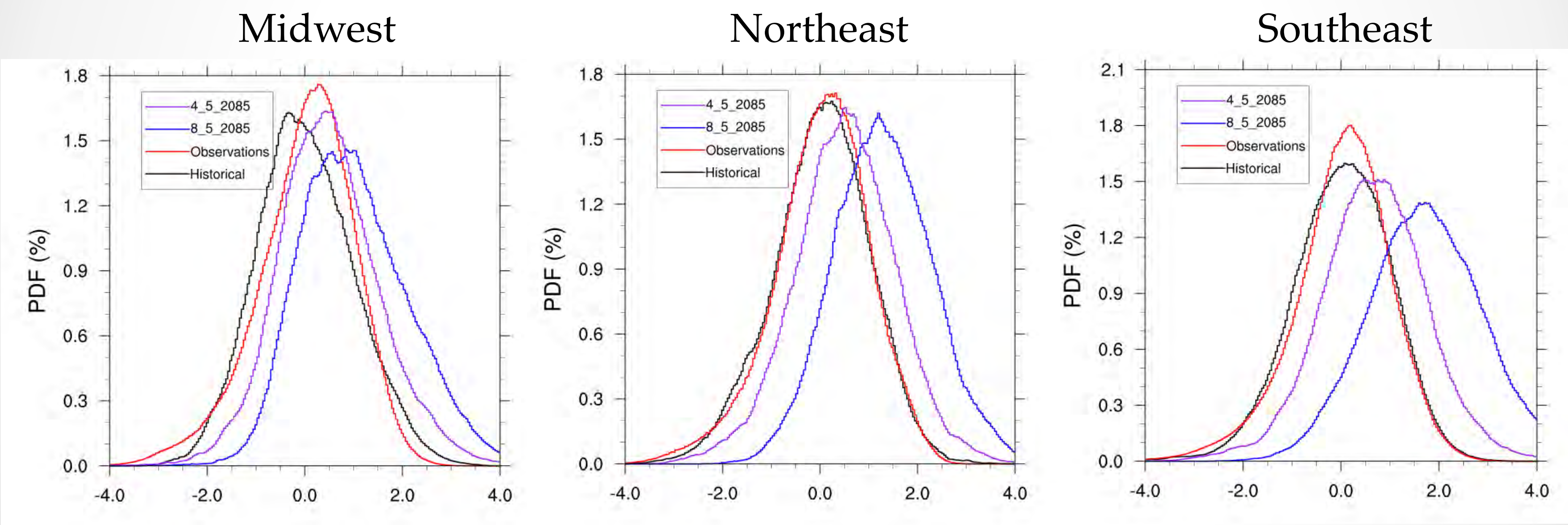
RCP8.5 – Present Day





Regional Maximum Temperature

12km atmos



Publications

- Bacmeister, J. T., K. A. Reed, C. Hannay, P. Lawrence, S. Bates, J. Truesdale, N. Rosenbloom, , and M. Levy, 2016: Projected changes in tropical cyclone activity under future warming scenarios using a high-resolution climate model, *Climatic Change*, doi: 10.1007/s10584-016-1750-x.

- Gettelman, A., D.N. Bresch, C.C. Chen, J.E. Truesdale, and J.T. Bacmeister, 2017: Projections of future tropical cyclone damage with a high-resolution global climate model, *Climatic Change*, doi:10.1007/s10584-017-1902-7.

- Reed, K. A., J. T. Bacmeister, N. A. Rosenbloom, M. F. Wehner, S. C. Bates, P. H. Lauritzen, J. E. Truesdale, and C. Hannay, 2015: Impact of the dynamical core on the direct simulation of tropical cyclones in a high-resolution global model. Geophys. Res. Lett., 42, 3603–3608.

- Zarzycki, C. M., Reed, K. A., Bacmeister, J., Craig, A. P., Bates, S. C., and Rosenbloom, N. A., 2016: Impact of ocean coupling strategy on extremes in high-resolution atmospheric simulations, *Geosciences Model Development*, 9, 779-788, doi:10.5194/gmd-9-779-2016.

- Zobel, Zachary, et al. "Evaluations of high-resolution dynamically downscaled ensembles over the contiguous United States." *Climate Dynamics* (2017): 1-22.

Definitions

Tracking Algorithm

$$ZN == |Q_{threshold}| >= |Q_{mean}| + 0.3(|Q_{max} - Q_{mean}|)$$

Mean = zonal mean and Max = zonal maximum *ZN = Zhu and Newell (1998)*

- Pineapple Express

  850 mb Wind Speed >= 10 m/s
  270º > Wind Direction > 180º
  DY/DX >= 2 (minimum DY = 200km)

- UK Storms

  850 mb Wind Speed >= 25 m/s
  360º > Wind Direction > 180º
  DY/DX >= 2 (minimum DY = 200km)

- France/Iberian Peninsula

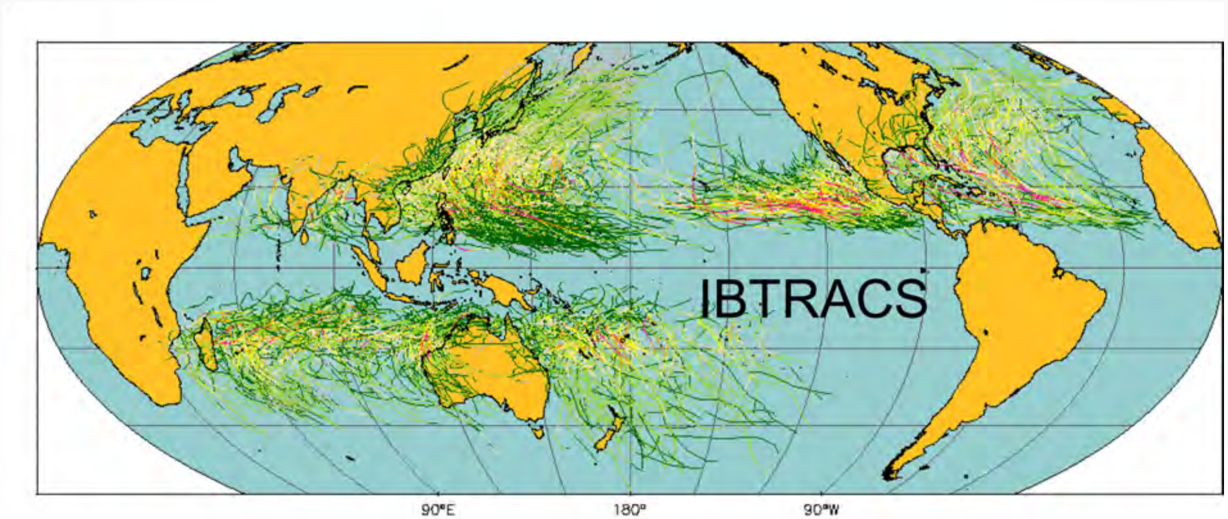
  850 mb Wind Speed >= 15 m/s
  360º > Wind Direction > 180º
  DY/DX >= 2 (minimum DY= 200km)

Summary of High Res Ocean

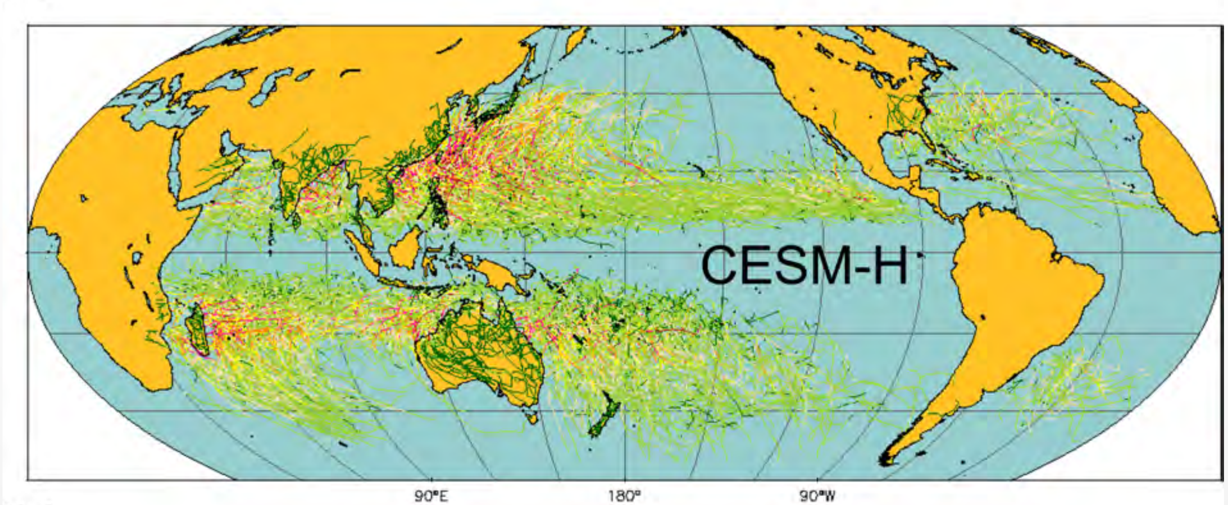
- Improvements with resolution
  - Atmosphere - TCs, Extreme precip, eastern boundary SST
  - Ocean – eddies, western boundary SST, small scale air-sea interaction
  - ENSO
- Stays same with resolution
  - Southern ocean wind bias
  - Subsurface warming
- Gets worse with high resolution
  - ITCZ too strong
- Caveat: results apply to CESM.

Tropical Cyclone (TC) Tracks

Observations



0.25° atm/lnd – 0.1° ocn/sea ice

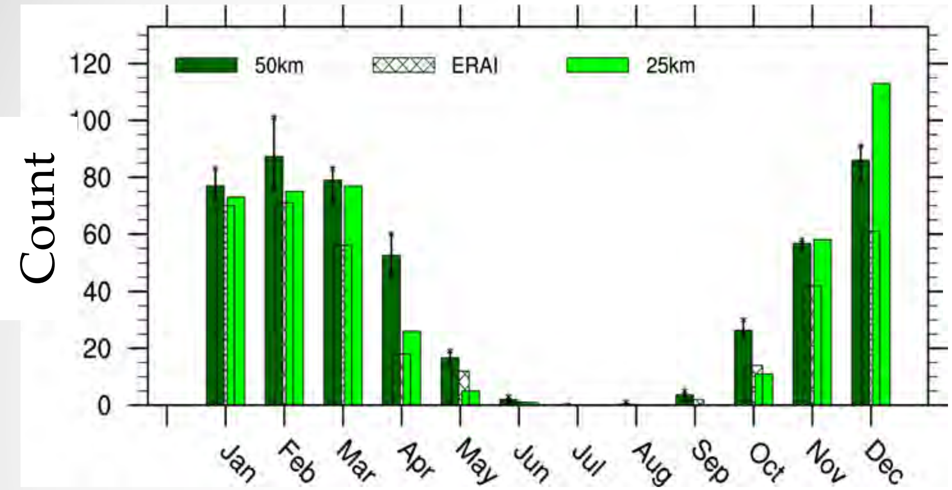


Small et al., 2014 (*JAMES*)

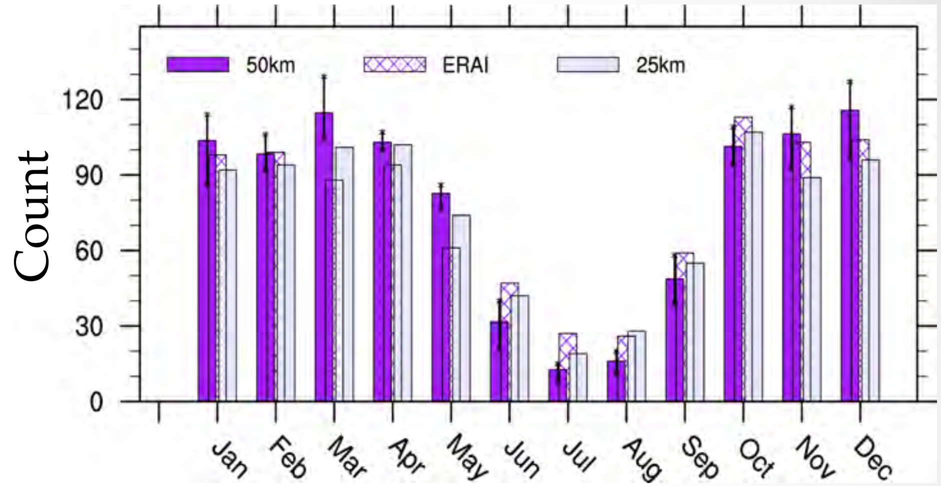
AR Climatology Resolution

50 km Ensemble Suite
25 km (1deg ocn) Single Run

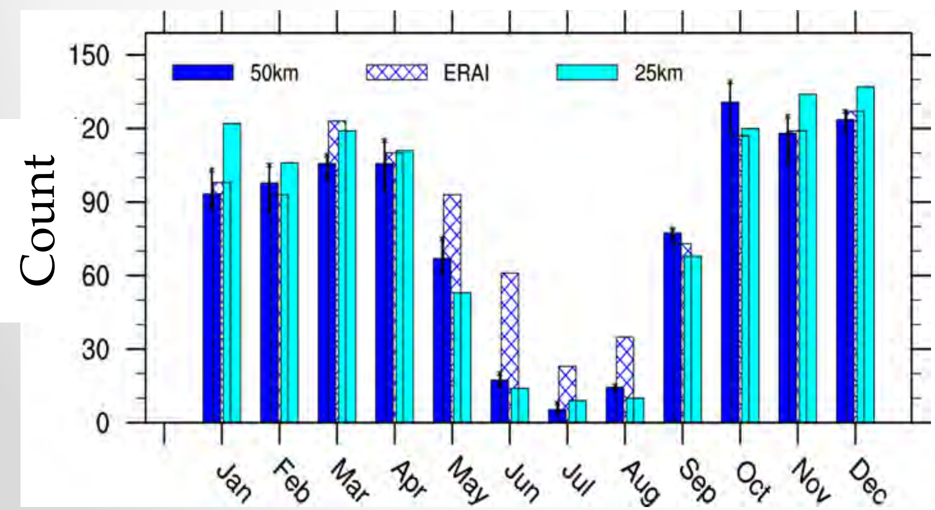
California



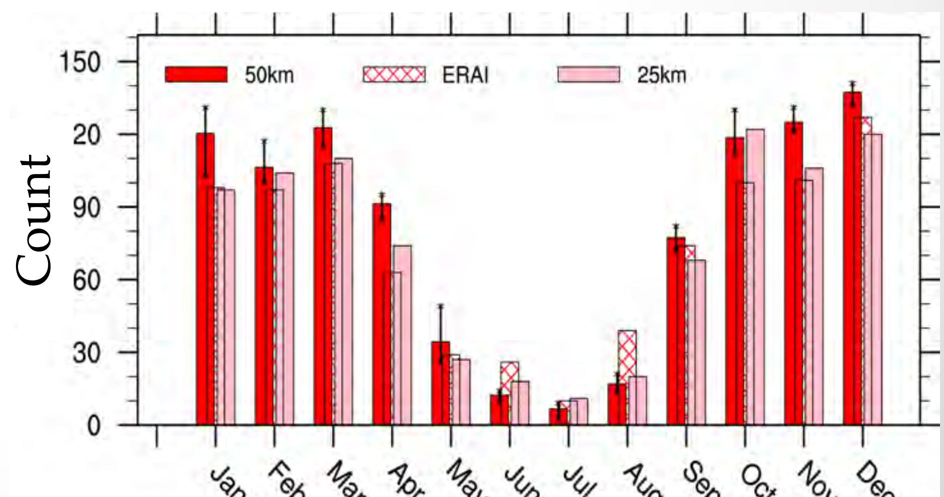
France/Iberian



Pacific Northwest



UK



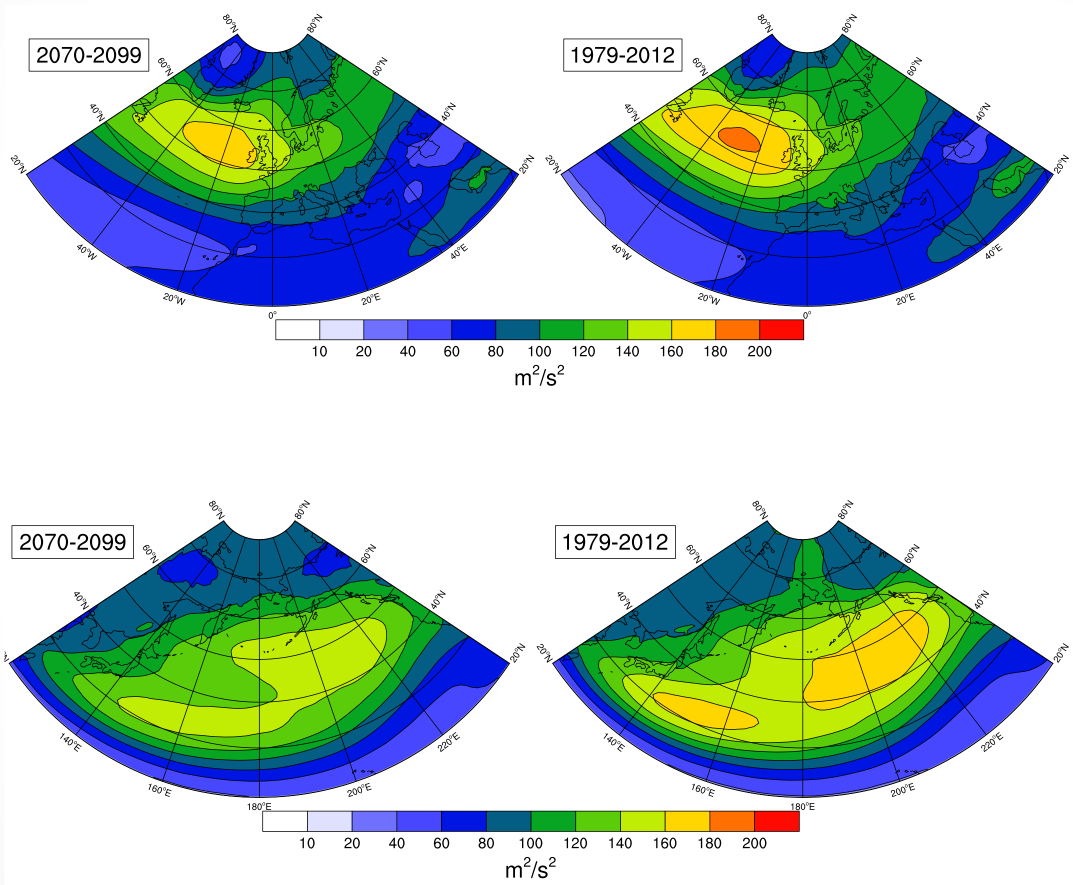
Eddy Kinetic Energy

(500mb)

0.25° atmos-only

Units = m^2/s^2

Future | Present Day



Courtesy Rich Neale