NCAR Center Report

Julio Bacmeister

based on contributions from AMP/CGD

NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NESL's Climate & Global Dynamics

U.S. DEPARTMENT OF ENERGY

NSF

WGNE Meeting, Toulouse France, 6 November 2012

Overview

Comparison of simulated climates in ~0.25° CAM and ~1° CAM

November release of CESM1.1/CAM5.2

- Spectral element dynamical core
  - *Specification of surface topography*
- Initial results

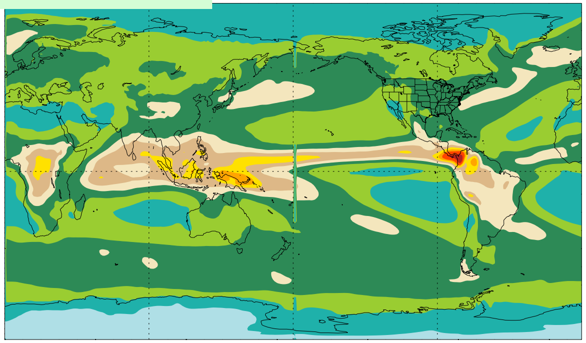
Future plans for atmosphere model

- Physics
- Regional refinement
- Global high resolution w/ spectral element dycore

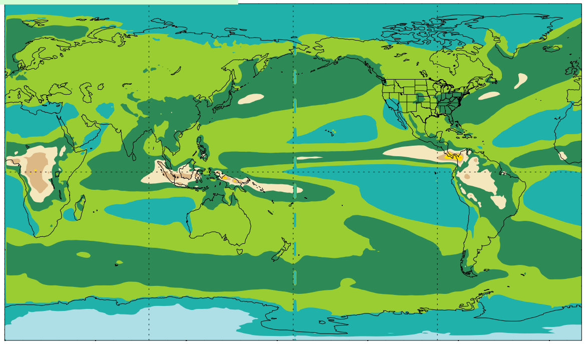
Other Business (APE)

1980-2005 Annual mean LWCF in CAM5 AMIP runs

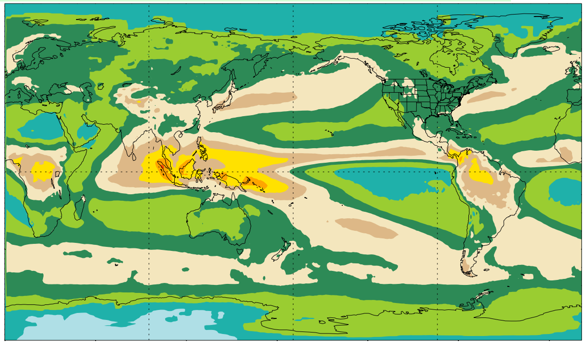
1 degree

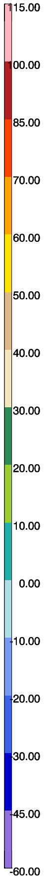


¼ degree



CERES-EBAF



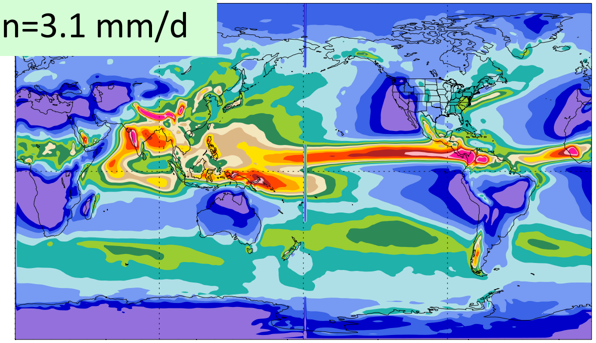


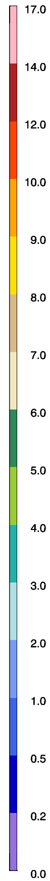
Precipitous drop in tropical cloud radiative forcing as resolution increases to ~25 km (high-clouds reduced)

Even worse resolution sensitivity in CAM4 mid and high latitudes – retuned for ~25km AMIP

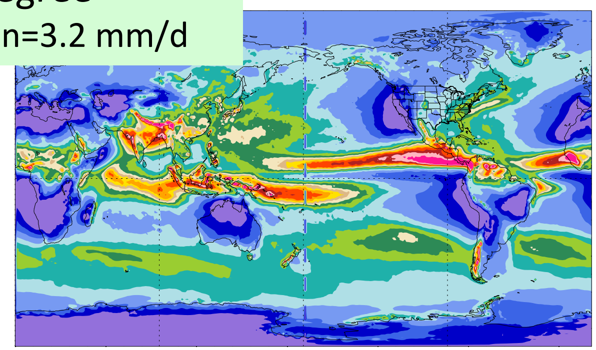
1980-2005 JJA mean precipitation in CAM5 AMIP runs

1 degree
mean=3.1 mm/d

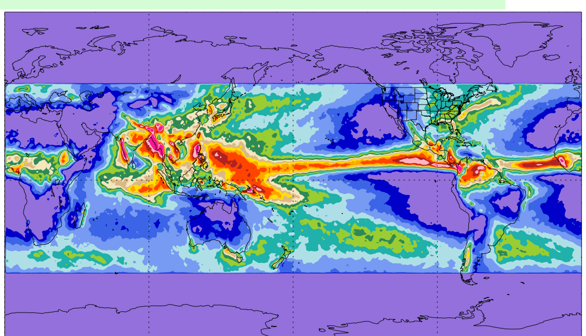




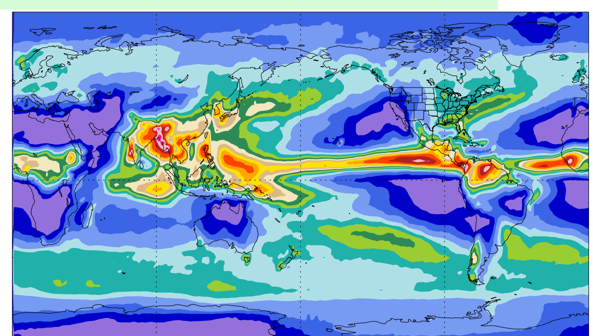
¼ degree
mean=3.2 mm/d



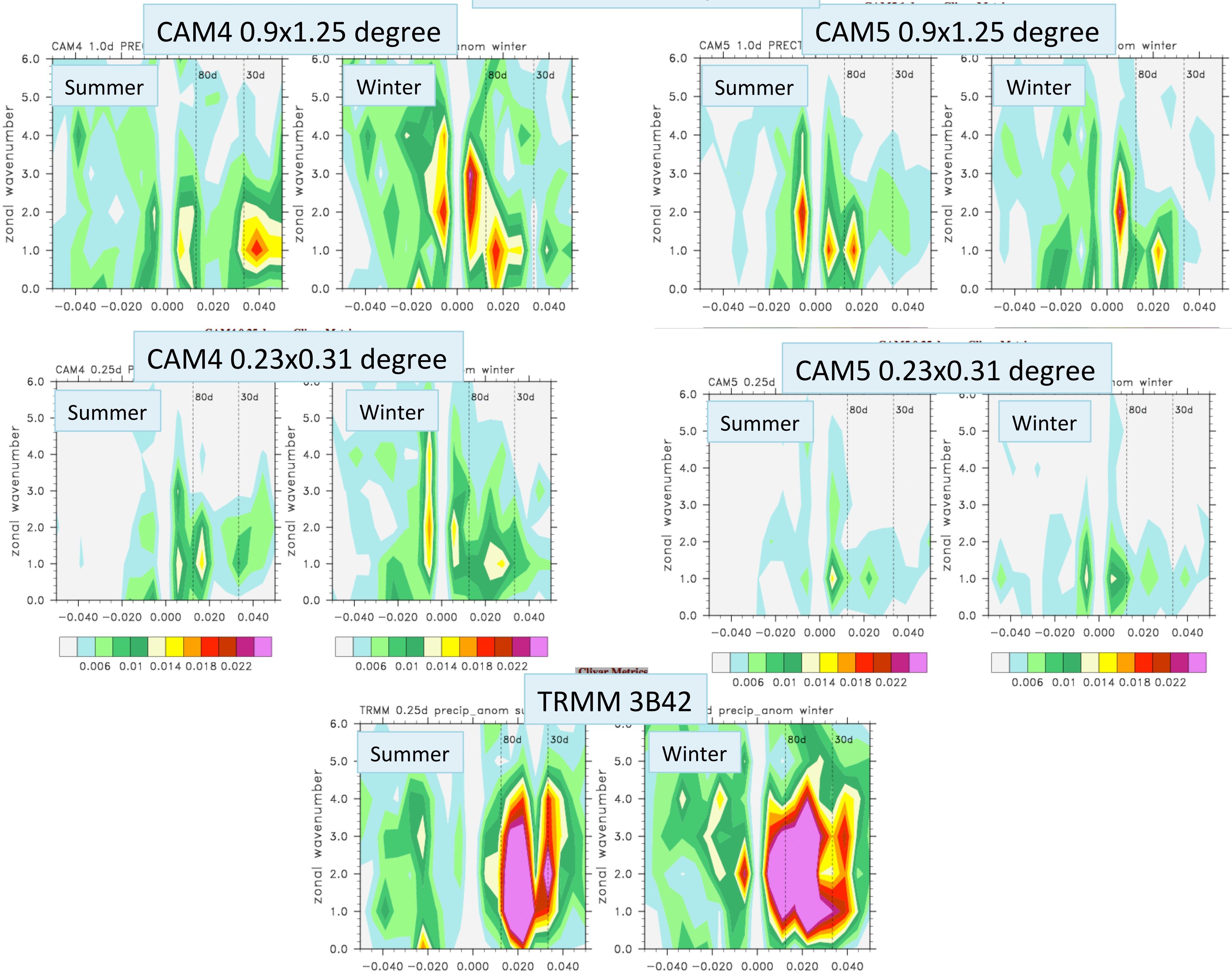
Observed (TRMM 2000-2005)

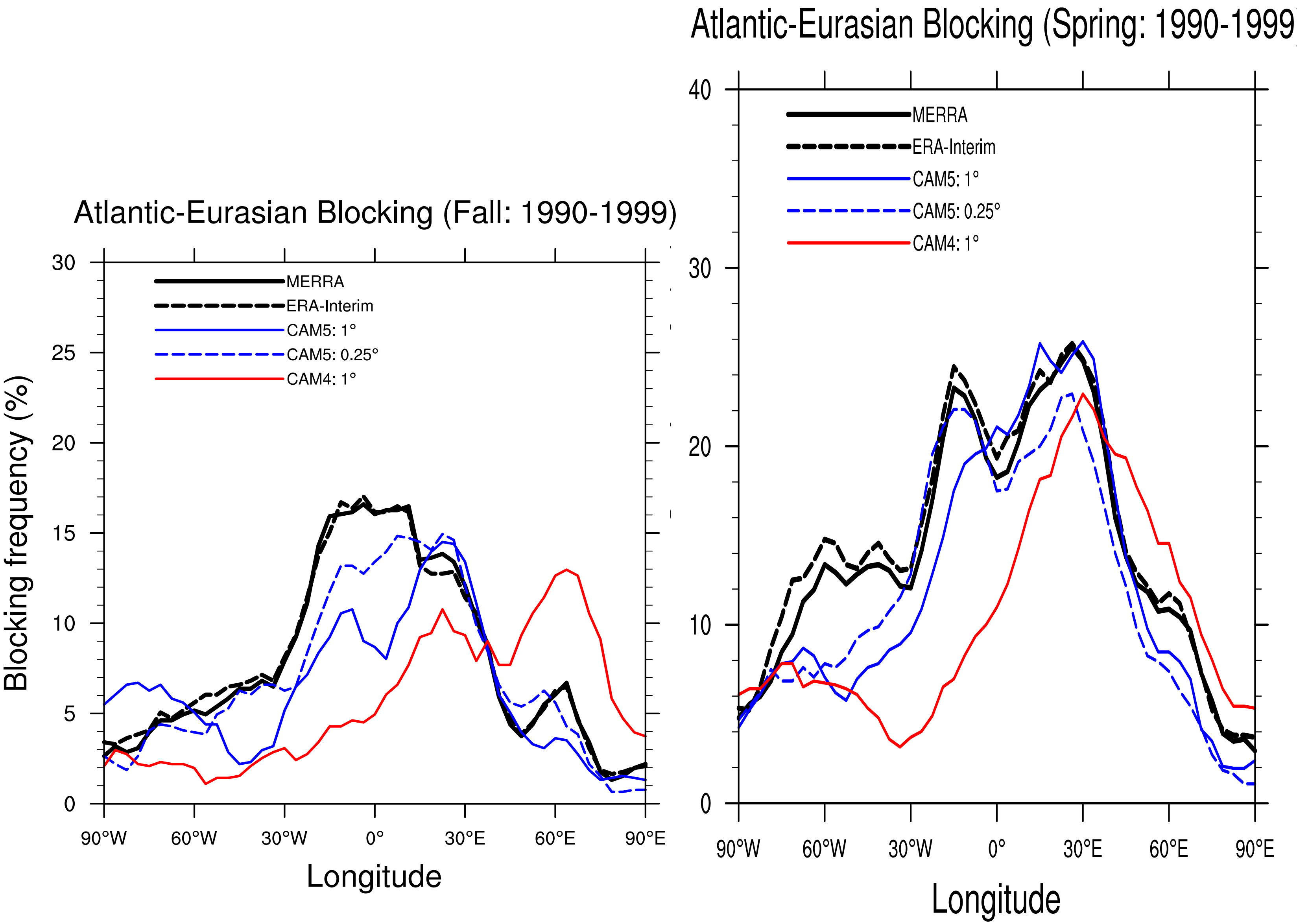


Observed (GPCP 1998-2005)

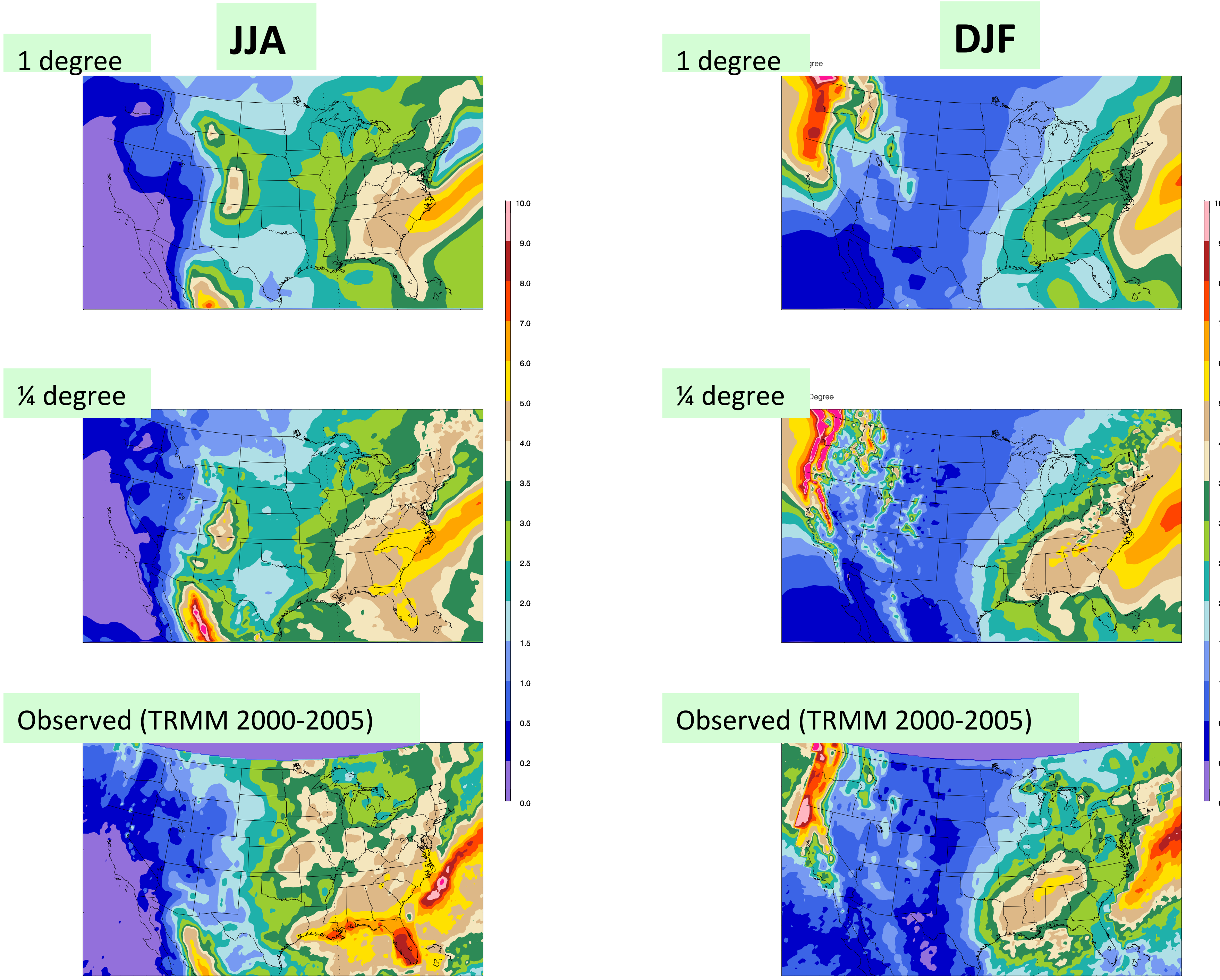


MJO CLIVAR Spectra



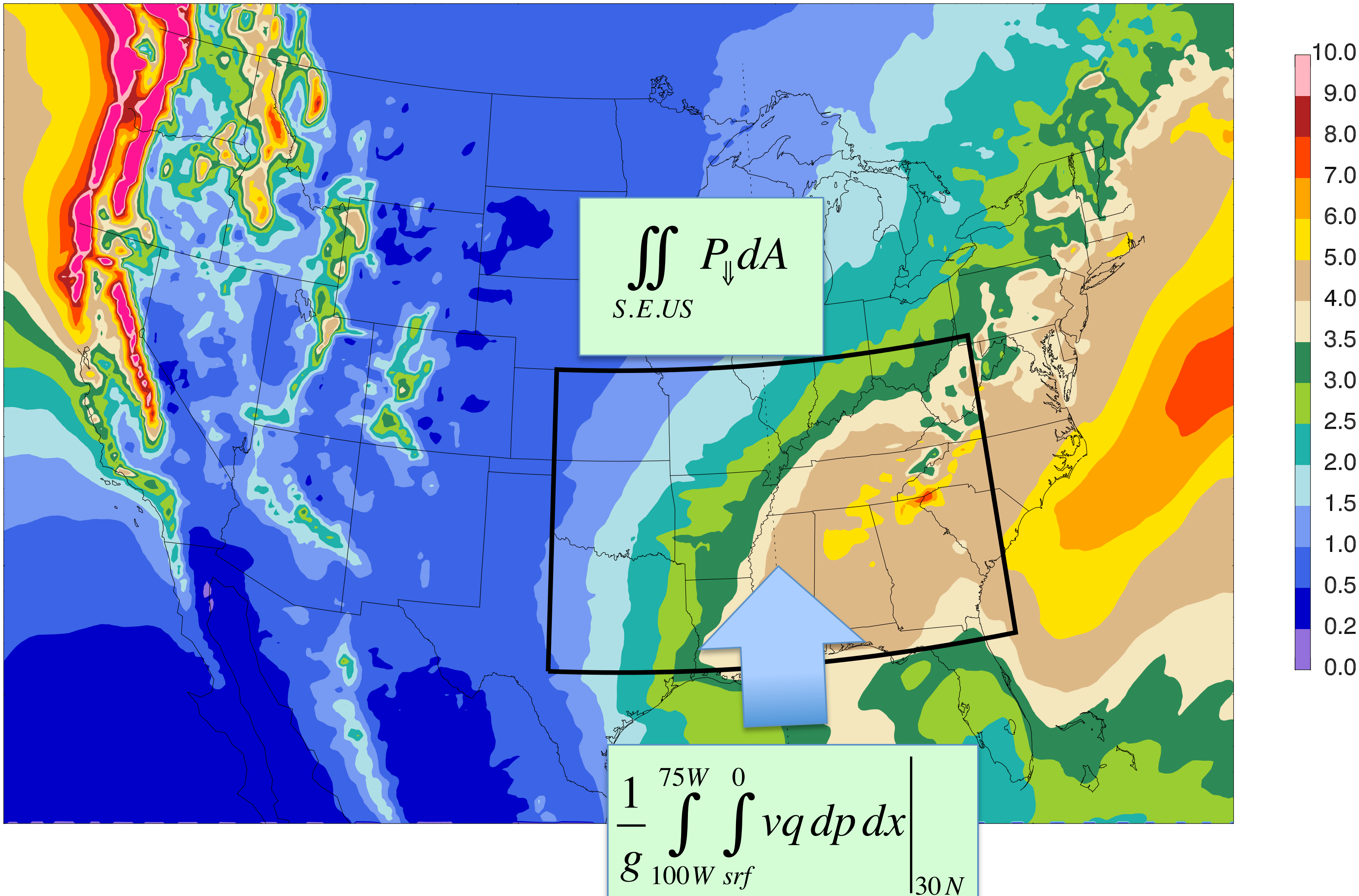


Tibaldi-Molteni index, courtesy *Rich Neale*

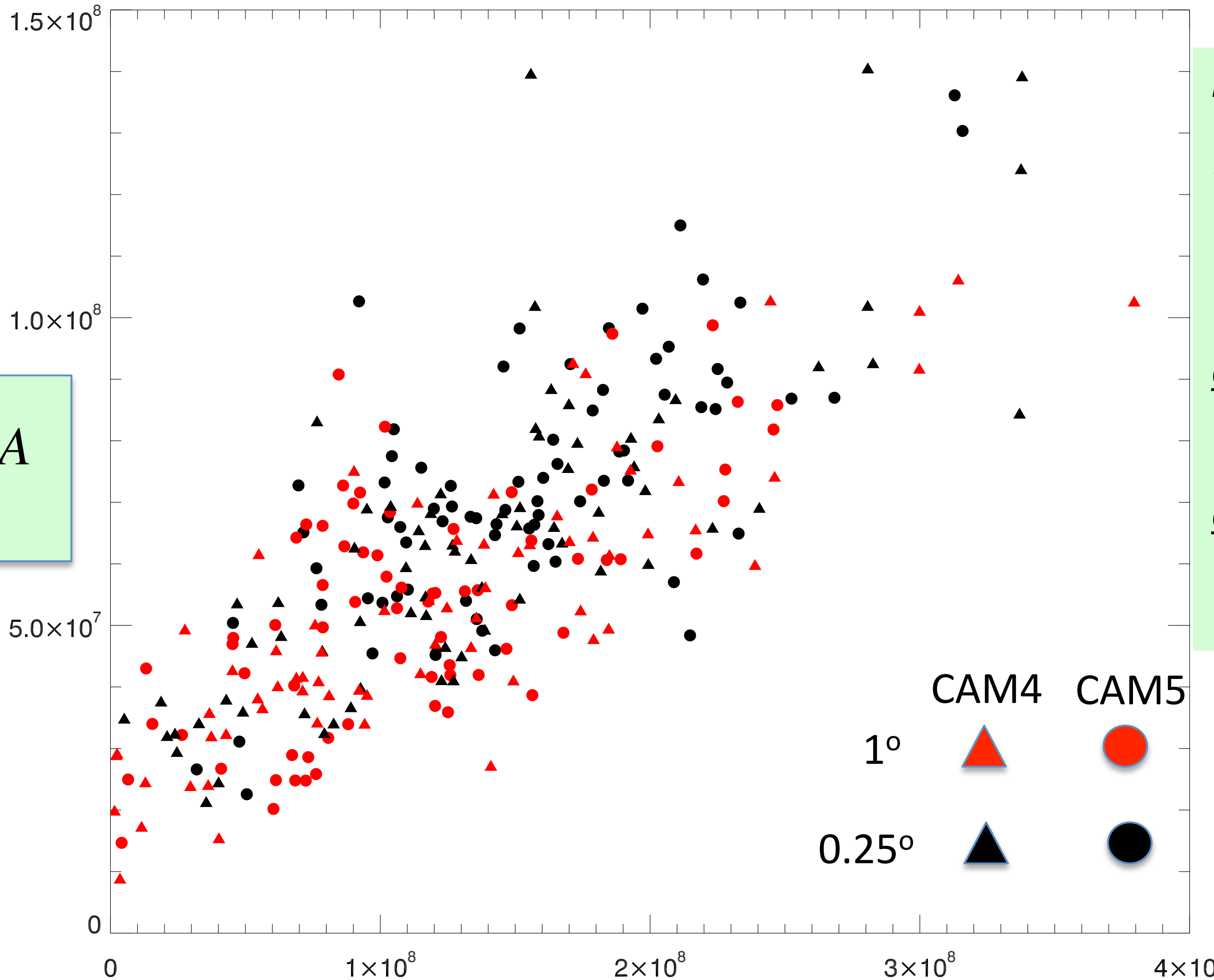


JJA
DJF
1 degree
1 degree
¼ degree
¼ degree
Observed (TRMM 2000-2005)
Observed (TRMM 2000-2005)
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.2
0.0

Winter-early spring precipitation over SE US is a bright spot for high-resolution simulations in CAM.


10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.2
0.0
$\iint_{S.E.US} P_{\Downarrow} dA$
$\frac{1}{g}\int_{100W}^{75W}\int_{srf}^{0} vq\,dp\,dx\Big|_{30N}$

DJF Northward moisture transport into SE US vs. area integrated precipitation



$$\iint_{S.E.US} P_{\Downarrow} dA$$

$$\frac{1}{g}\int_{100W}^{75W}\int_{srf}^{0} vq\,dp\,dx\Big|_{30N}$$

r~0.7 for all cases

"Regional Efficiency" ~0.3-0.4

Precip means

CAM5

7.3e7 kg/s (1/4 deg)

5.2e7 (1 deg)

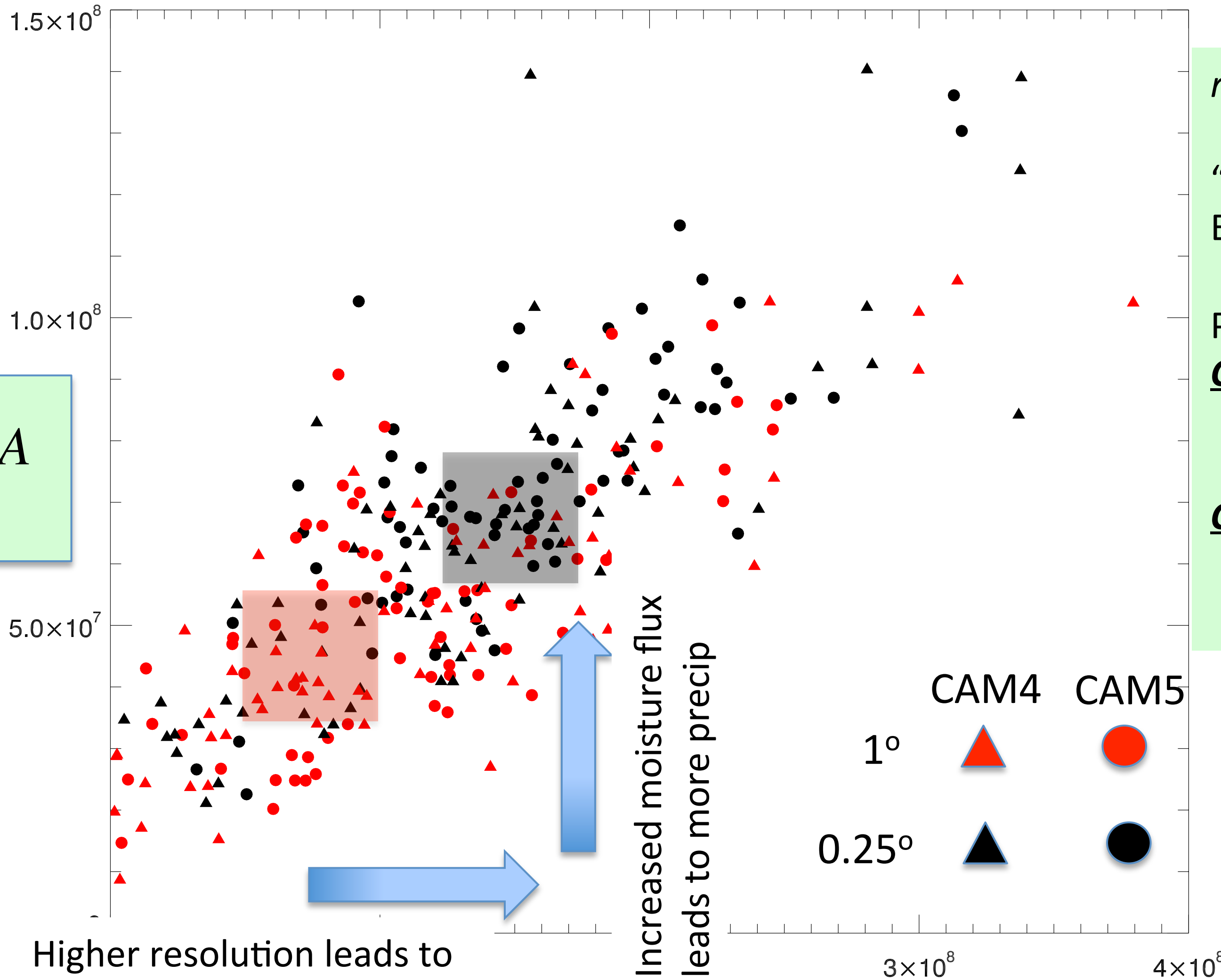
CAM4

6.2e7 (1/4 deg)

4.9e7 (1 deg)

DJF Northward moisture transport into SE US vs. area integrated precipitation

$$\iint_{S.E.US} P_{\Downarrow} dA$$



Higher resolution leads to increased moisture flux

$$\frac{1}{g}\int_{100W}^{75W}\int_{srf}^{0} vq\,dp\,dx\Big|_{30N}$$

r~0.7 for all cases

"Regional Efficiency" ~0.3-0.4

Precip means

<u>CAM5</u>

7.3e7 kg/s (1/4 deg)

5.2e7 (1 deg)

<u>CAM4</u>

6.2e7 (1/4 deg)

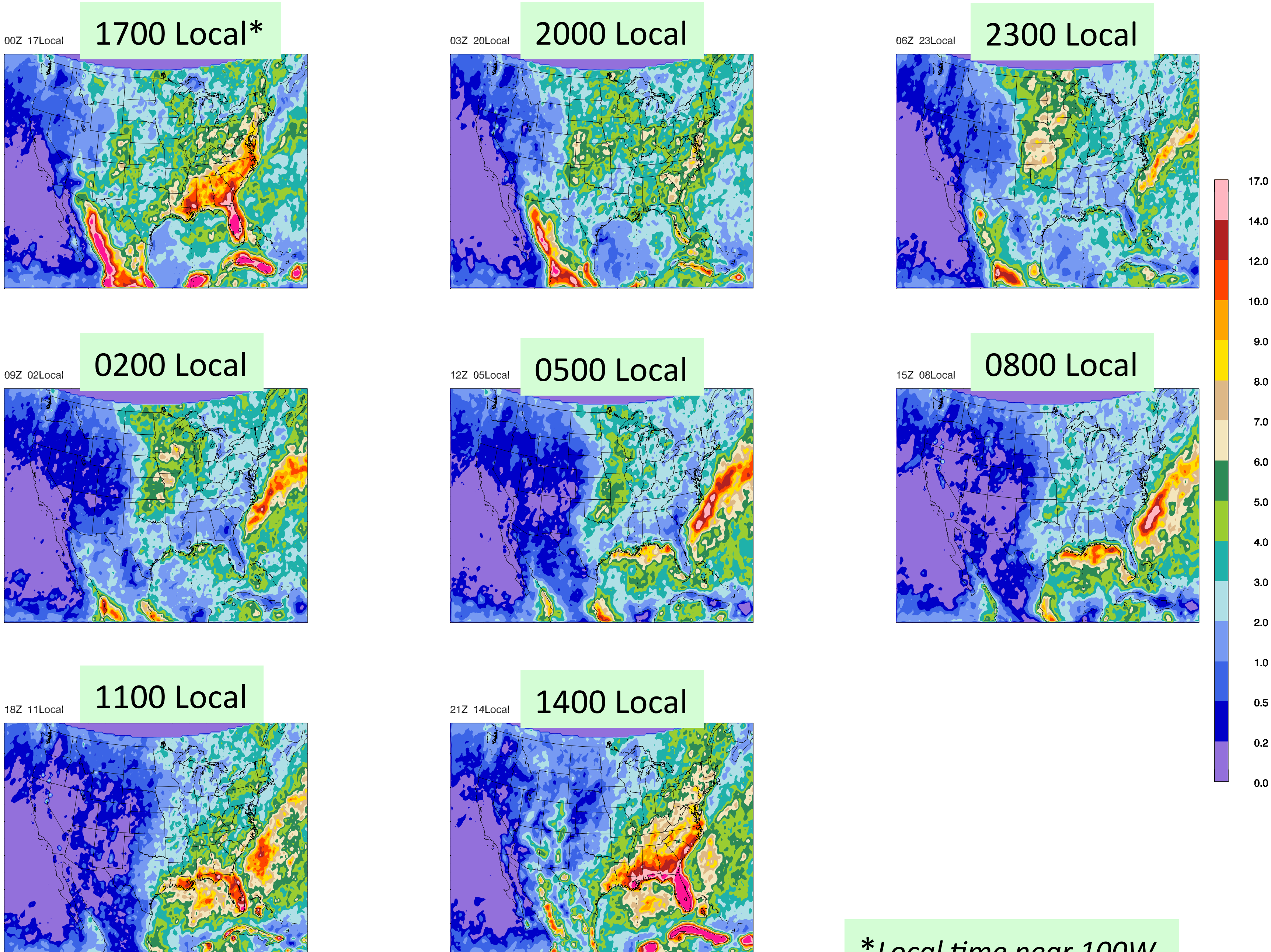
4.9e7 (1 deg)

NOTE:

Increased moisture flux may be related to rougher topography, not resolution itself. High-resolution runs with smoothed topography exhibit weaker precipitation increase in SE US.

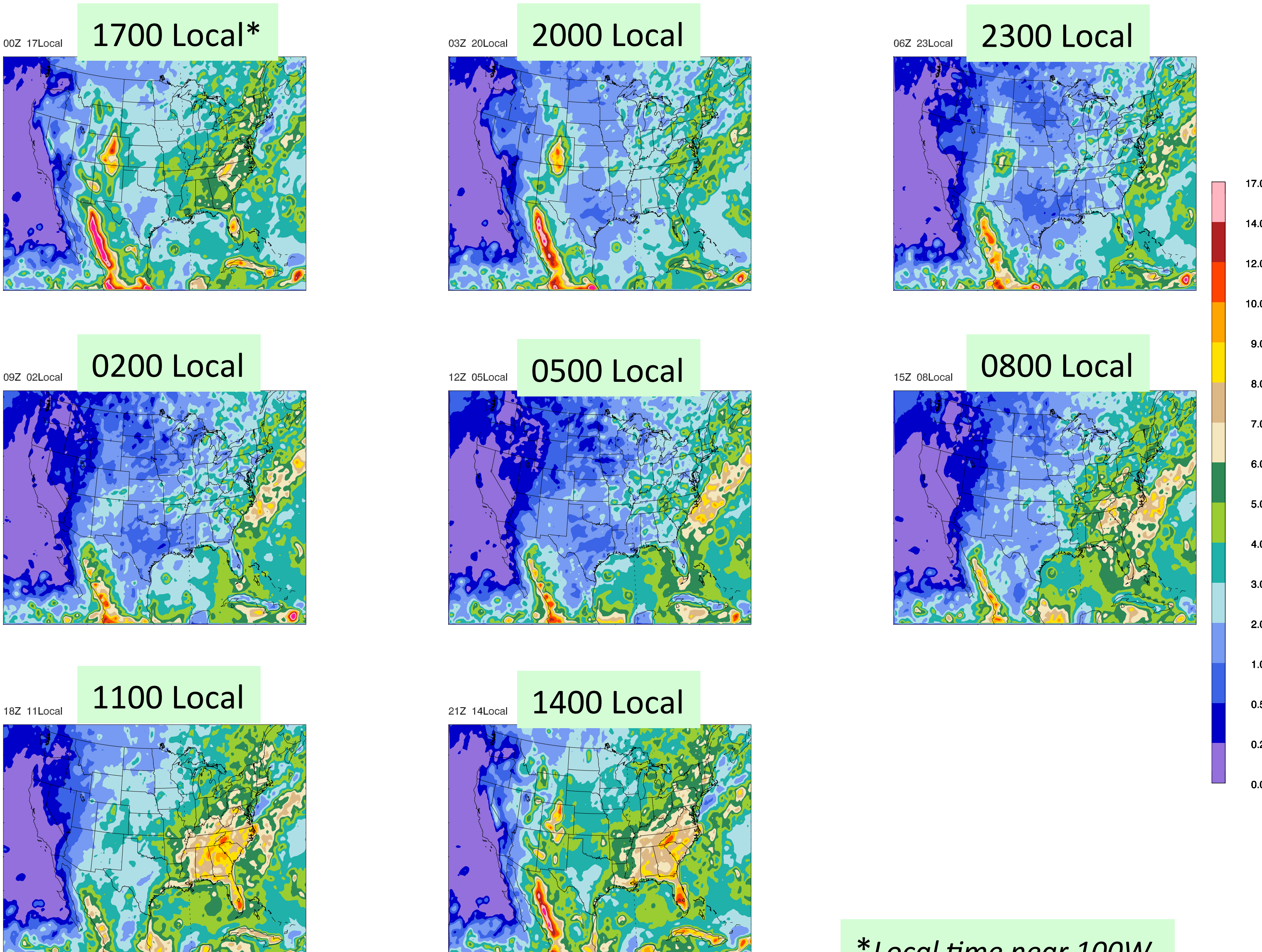
Simulated summer precipitation over US in CAM misses upper-midwest maximum at 1 and ¼ degree.

Mean diurnal cycle of precipitation in JJA 2000-2005 TRMM



**Local time near 100W*

Mean diurnal cycle of precipitation in JJA 2000-2005 CAM5



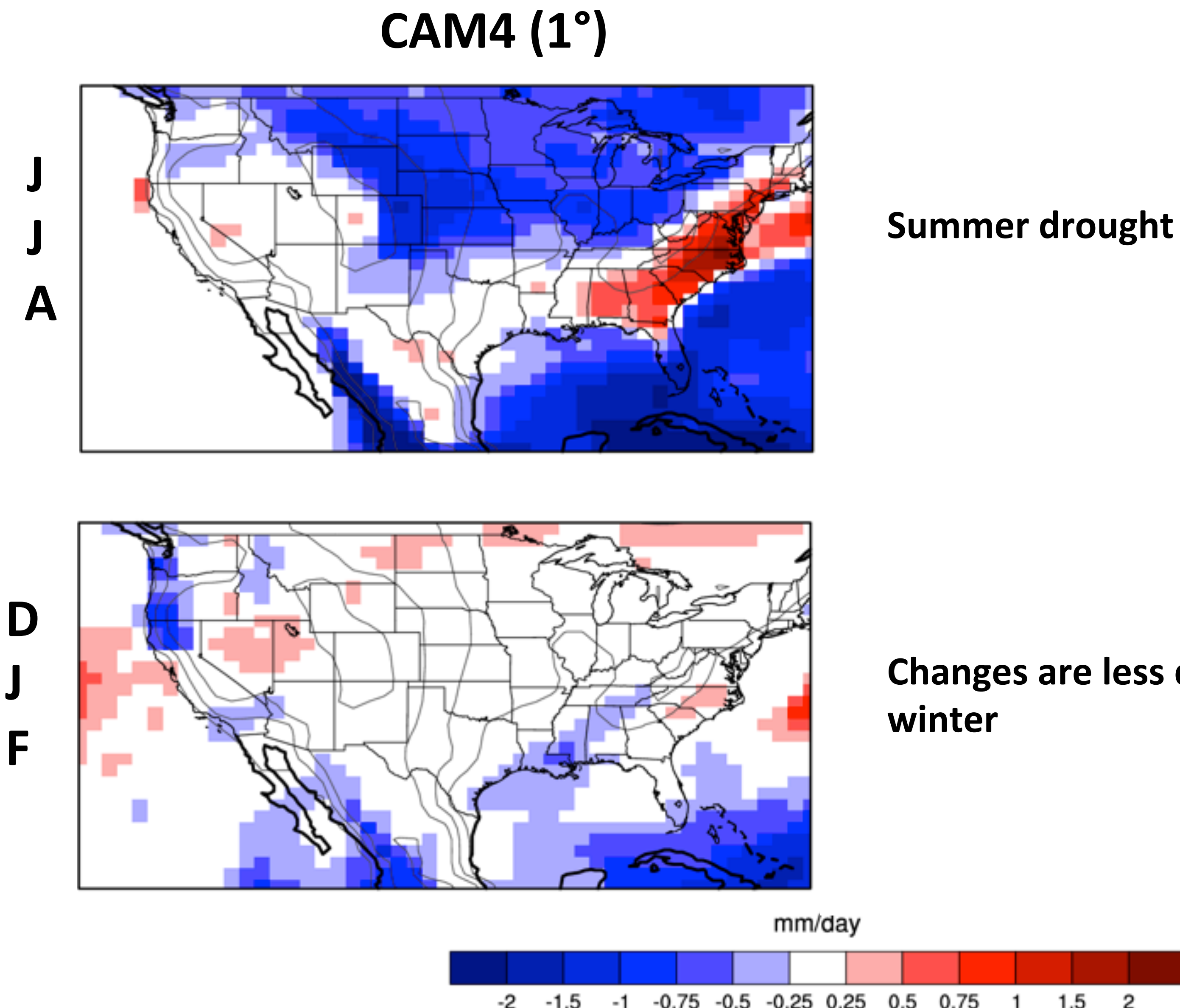
Local time near 100W

What is the impact of resolution for future projections ?

- **Present-day time-slice: Observed SSTs**
- **Future time-slice: SSTs from RCP8.5**
  + use correction for CESM SST bias
  + use correction for sea-ice cover (Hurrell *et al*, 2008)
- **Precipitation change = Prec[2081-2100] – Prec[1981-2000]**

From Cécile Hannay

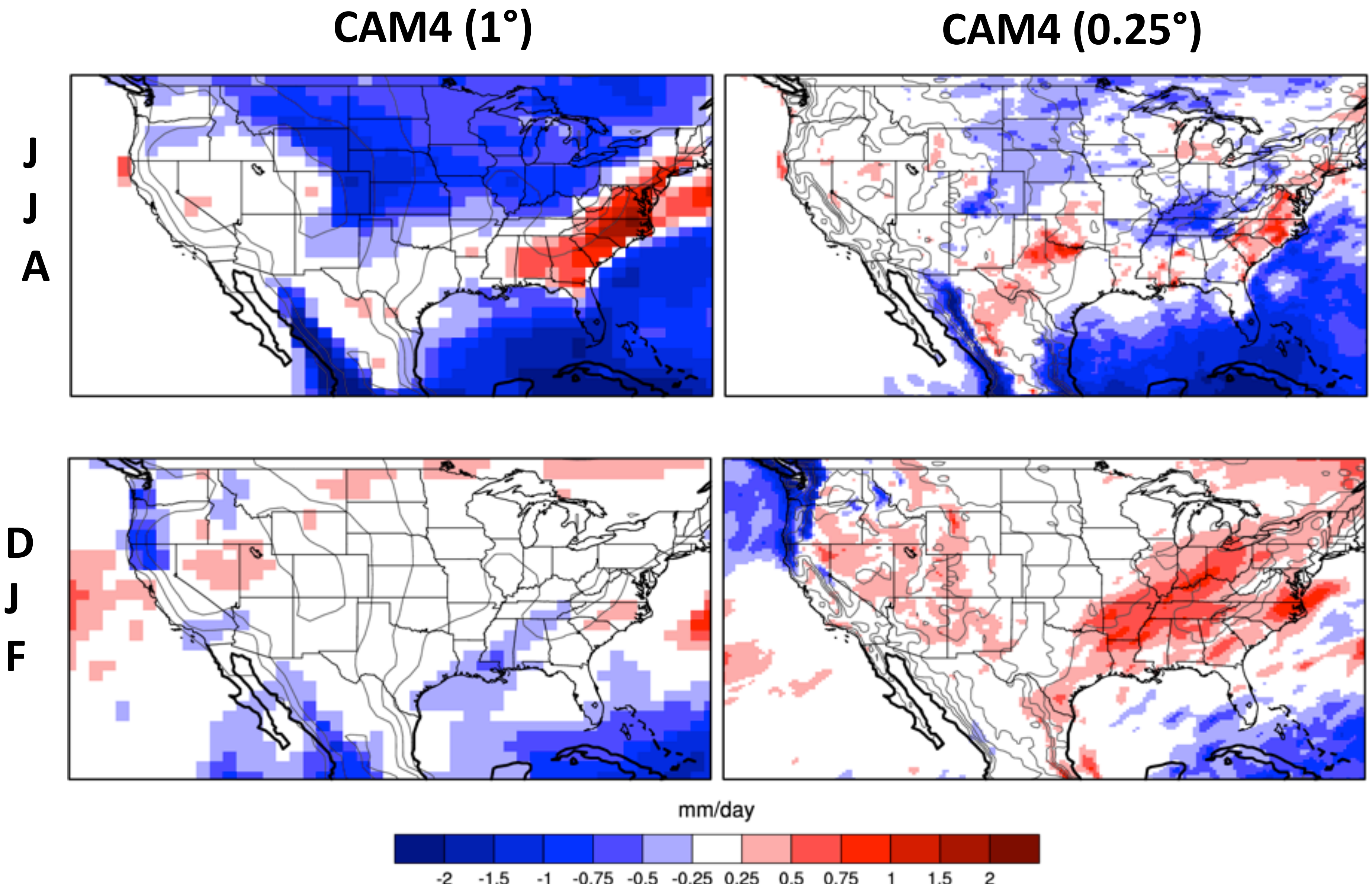
Change in precipitation over the US



Summer drought

Changes are less dramatic in winter

Change in precipitation over the US

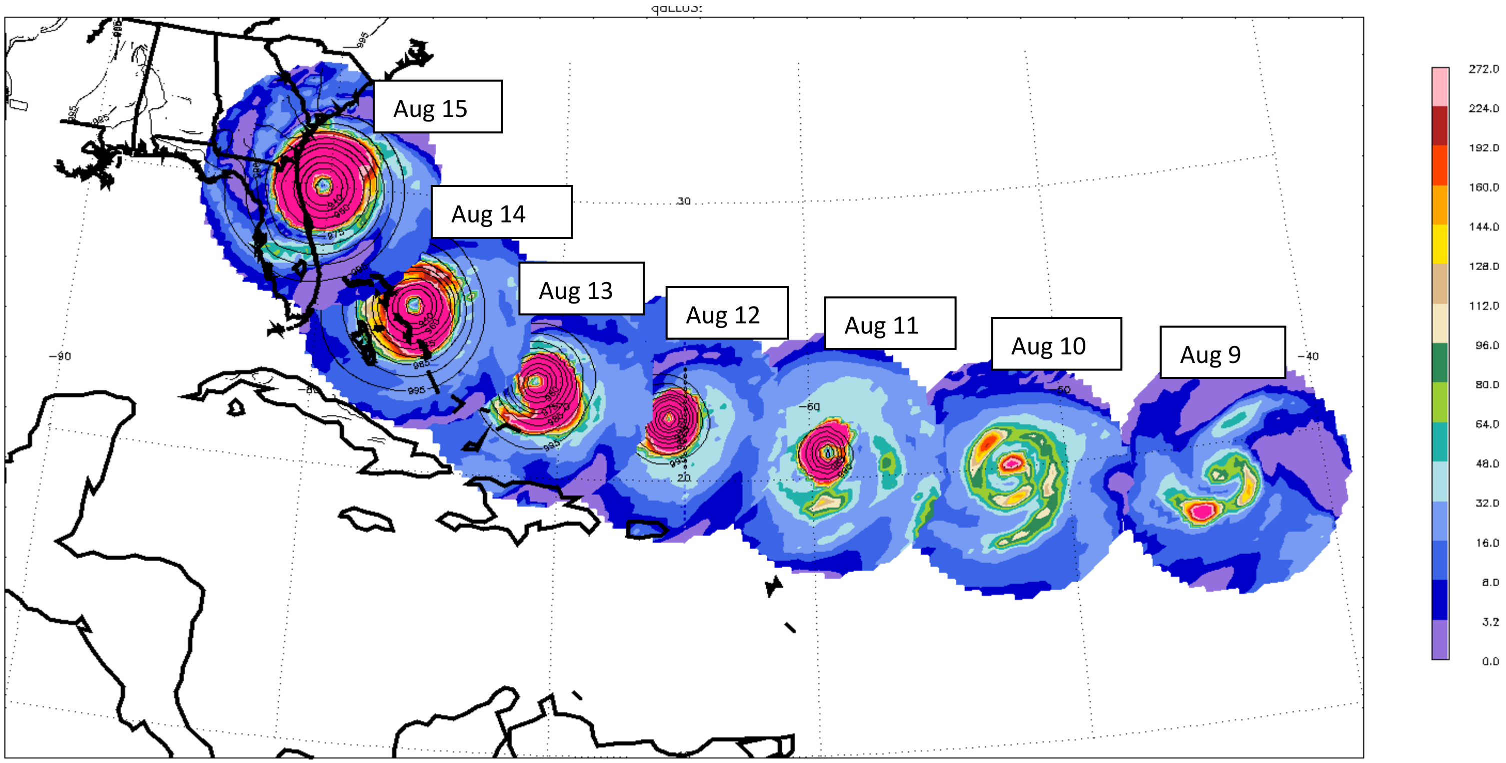


Overview of Tropical Cyclone Statistics

Intense Atlantic hurricanes

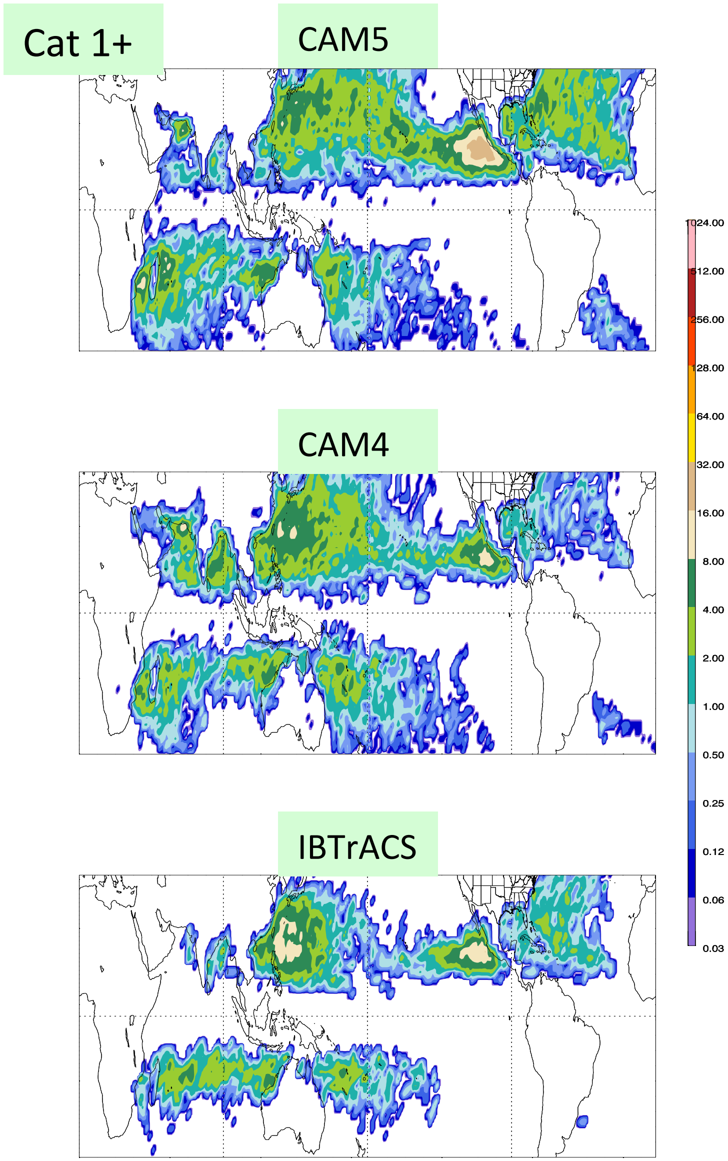
25km (0.25) CAM5

Precipitation within 500 km of storm center

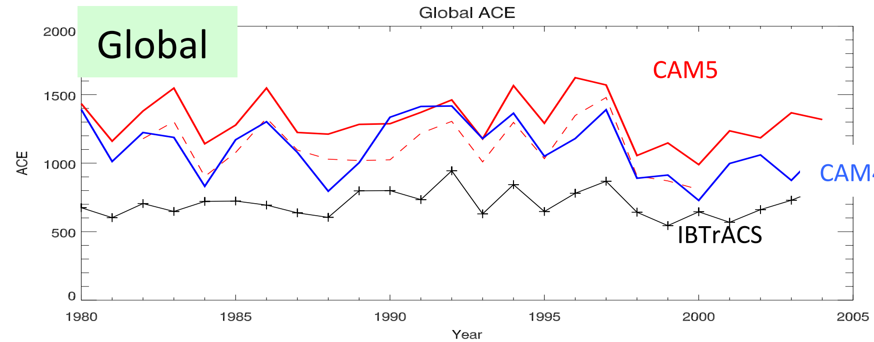


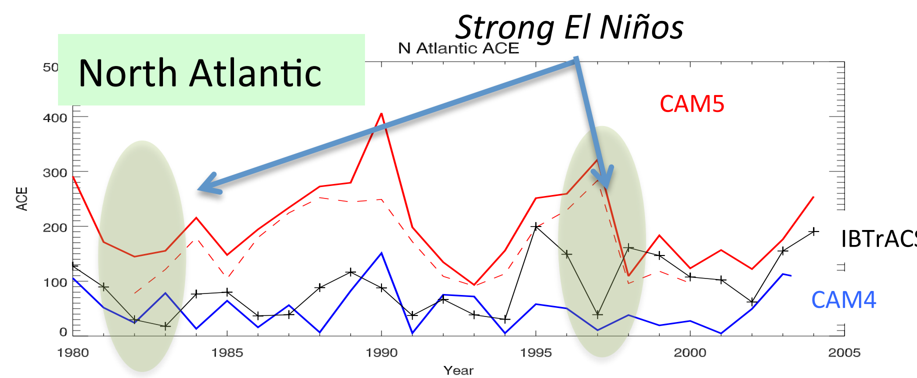
- Forms spontaneously in free-running CAM5 climate model run
- Minimum pressure ~910 hPa and maximum winds ~140 mph
- Realistic "Cape Verde" storm (note dry eye)

Hours per year per 1° gridbox with category 1+

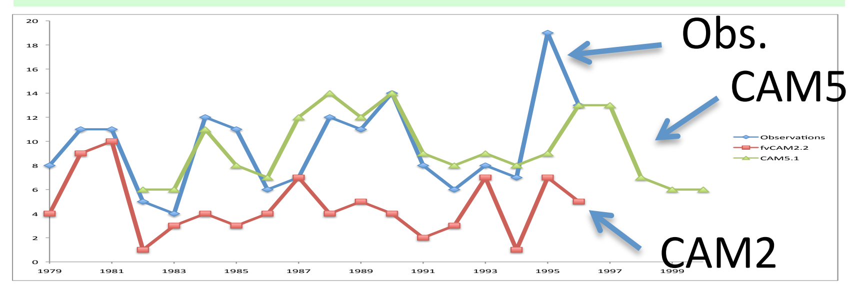


Accumulated Cyclone Energy (ACE, ~ $\sum u_{max}^2$) timeseries





N Atlantic Tropical Cyclone number (storm-Cat 5)



Courtesy Michael Wehner *(DoE/LBNL)*

Overview of Tropical Cyclone Statistics

- Individual storms look realistic.
- Climatological geographic distribution is reasonable
- CAM4 and CAM5 differ strongly in N Atlantic *(Why here and not so much in other basins?)*
- Interannual variability has some positive aspects, but still needs improvement.

Caveats:

- **ONE ensemble member for each model.**
- **Track algorithms influence statistics, especially number of weak storms**

CESM1.1/CAM5.2 November 2012 Release

The CAM family

Model	CAM3 CCSM3	CAM4 CCSM4	CAM5 (CAM5.1) CESM1.0 (CESM1.0.3)	CAM5.2 CESM1.1
Release	**Jun 2004**	**Apr 2010**	**Jun 2010 (June 2011)**	**Nov 2012**
PBL	Holtslag-Boville (1993)	Bretherton et al (2009)	Bretherton et al (2009)	Bretherton et al (2009)
Shallow Convection	Hack (1994)	Hack (1994)	Park et al. (2009)	Park et al. (2009)
Deep Convection	Zhang-McFarlane (1995)	Neale et al. (2008)	Neale et al. (2008)	Neale et al. (2008)
Microphysics	Rasch-Kristjansson (1998)	Rasch-Kristjansson (1998)	Morrison-Gettelman (2008)	Morrison-Gettelman (2008)
Macrophysics	Rasch-Kristjansson (1998)	Rasch-Kristjansson (1998)	Park et al. (2011)	Park et al. (2011)
Radiation	Collins et al. (2001)	Collins et al. (2001)	Iacono et al. (2008)	Iacono et al. (2008)
Aerosols	Bulk Aerosol Model	Bulk Aerosol Model BAM	Modal Aerosol Model Ghan et al. (2011)	Modal Aerosol Model Ghan et al. (2011)
Dynamics	Spectral	Finite Volume	Finite Volume	Spectral element

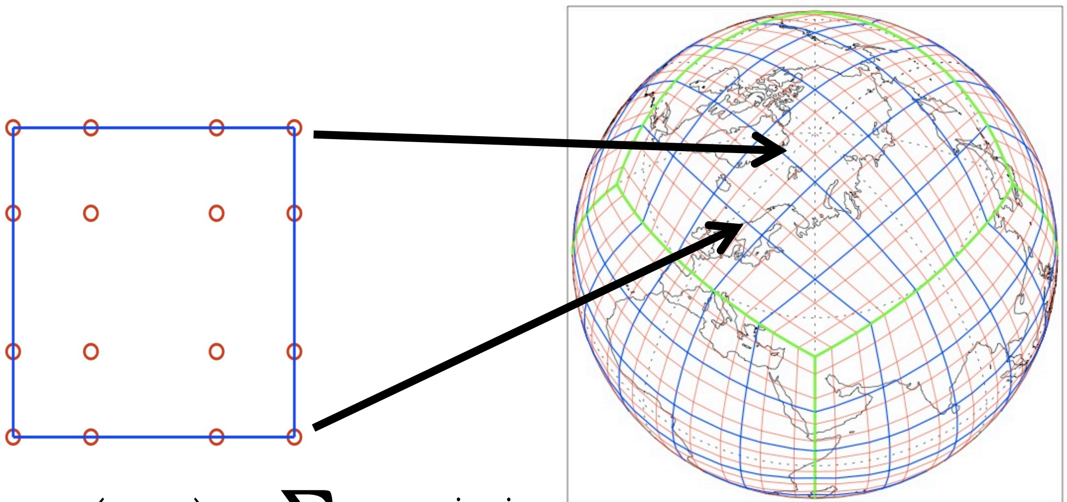
[shaded box] = New parameterization/dynamics

What's new in CAM5.2 ?

- New dynamical core (Spectral Element: SE)
  - Improves scalability of CAM (no polar filter)
- New topography for CAM-SE and stronger divergence damping
  - Generalized procedure for arbitrary grids that consistently accounts for variance lost in smoothing *(Peter Lauritzen)*
  - Divergence damping currently chosen using "eyeball norm"
- Tuning for CAM-SE (dust and stratocumulus)

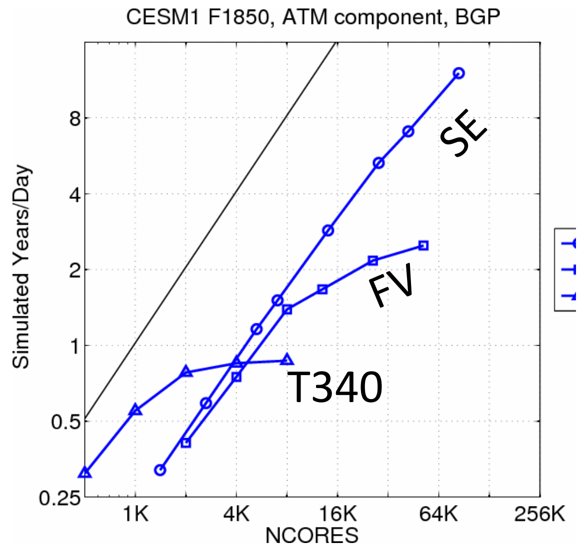
CAM-SE (spectral element) dynamical core

(M. Taylor, DoE Sandia Lab)



$$\Psi_k(x,y) = \sum_{i+j\leq 3} c_{i,j} x^i y^j$$

25 km timings

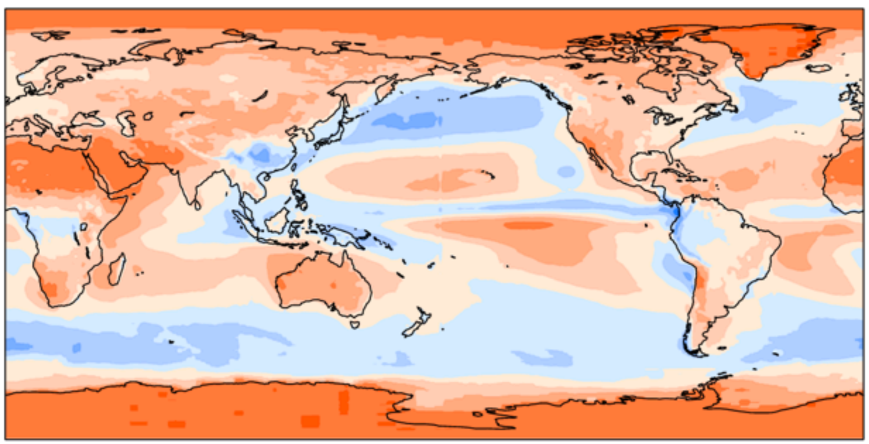


Continuous Galerkin spectral finite elements, explicit RK time-stepping
Energy conservation at element level
Mesh refinement capability exists

SWCF

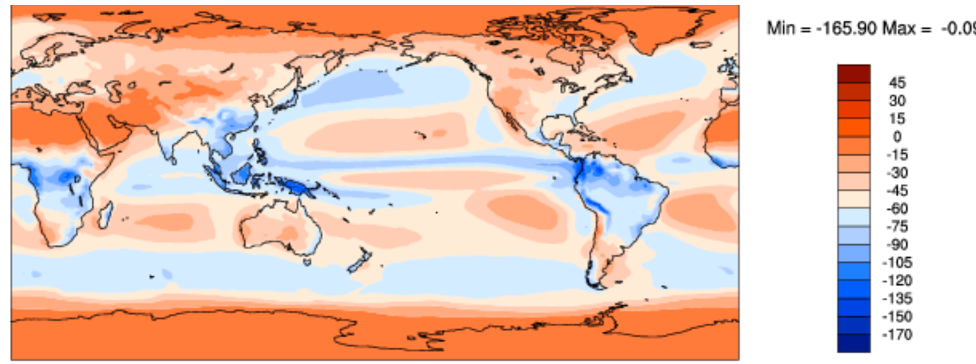
After tuning to fix stratus decks!!

CERES-EBAF
mean = -47.1



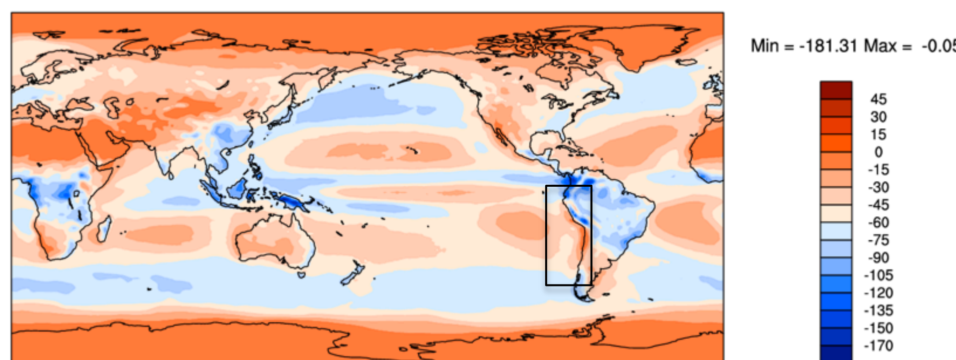
FV 1deg
mean = -47.5

ANN



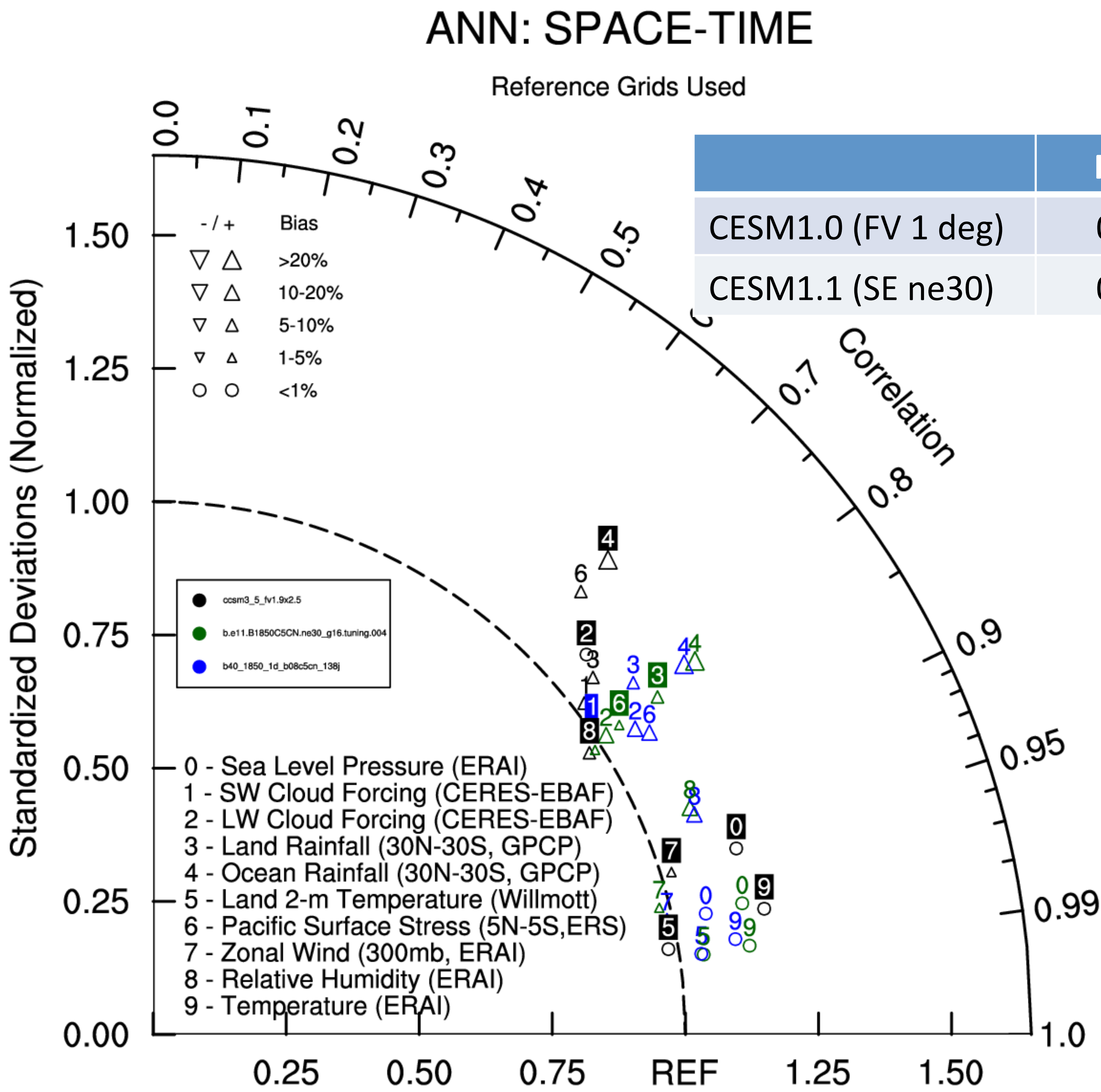
SE ne30
mean = -46.3

ANN



Future development:

Change in vertical advection of T

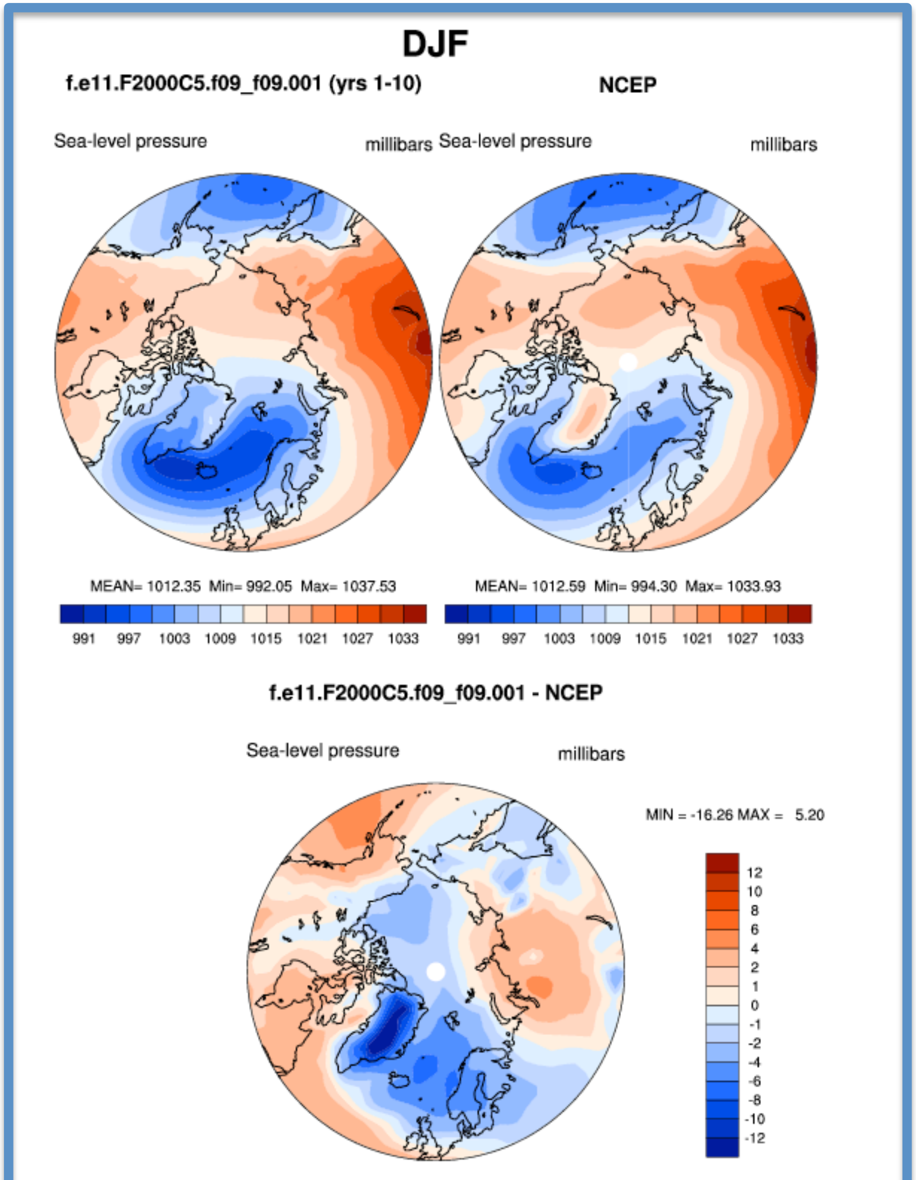


	RMSE	Bias
CESM1.0 (FV 1 deg)	0.788	1.483
CESM1.1 (SE ne30)	0.794	1.319

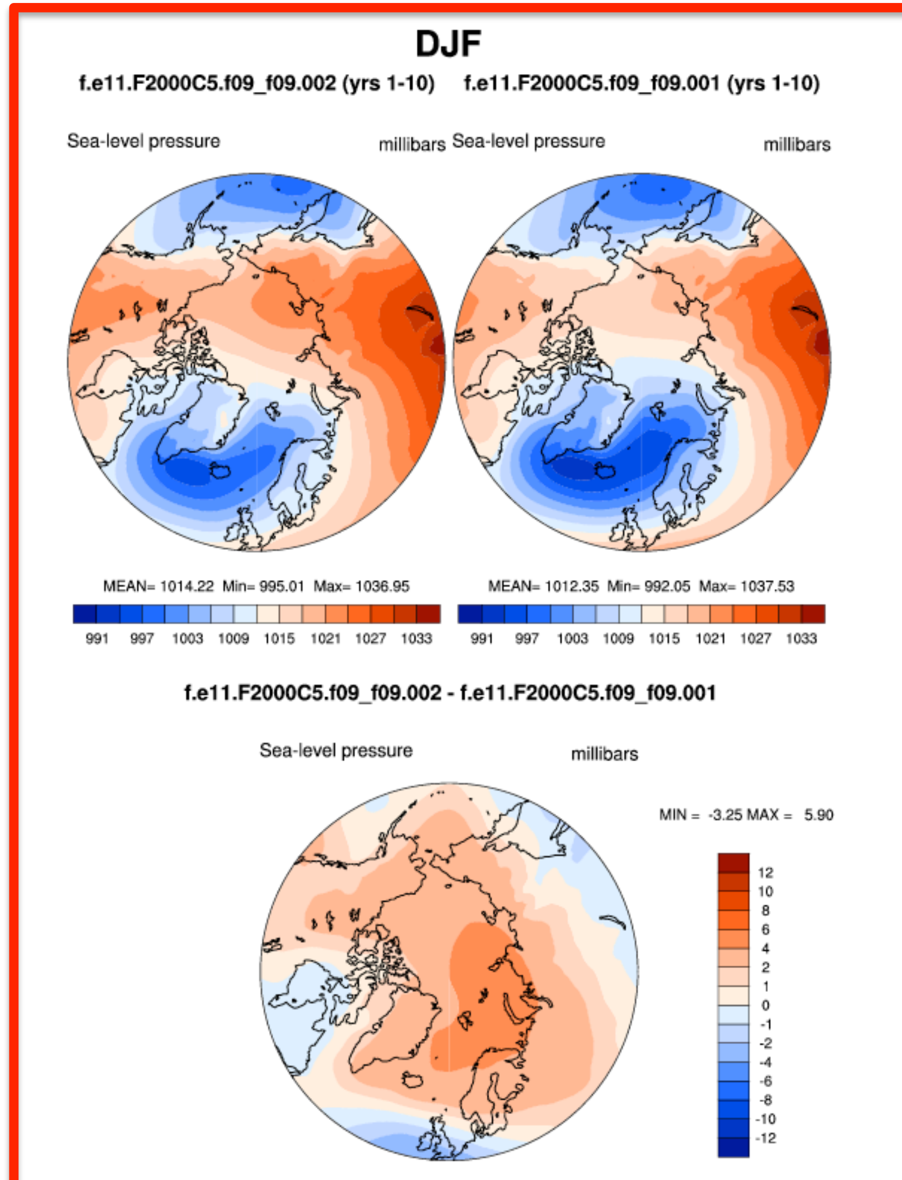
Topography specification changes answers in FV also

Sea level pressure (PSL): CAM5-FV 1 degree

Control and OBS



Consistent (SGH & SGH30) and Control



Near-term physics development

- ***Tuning!***
- Unified Convection (UNICON) *(In-house- Sungsu Park)*
  - unifies treatment deep + shallow
- Cloud Layers Unified By Binormals (CLUBB) *(University-led "Climate Process Team" [CPT])*
  - third-order turbulence closure centered around an assumed double Gaussian PDF
  - treatment for shallow+PBL+macrophysics
- PDF-based macrophysics *(CPT w/ DOE-LLNL)*
- SP-CAM (super-parameterization) *(University-led collaboration)*
- Next generation MG microphysics *(internal collaboration – NCAR/MMM)*
  - prognostic precipitation, mixed phase ice nucleation and convective microphysics
- Aerosol scheme *(Collaboration w/ DOE PNNL)*
  - Prescribed Aerosol (BAM /MAM)
  - MAM4 ("aging" black carbon)
- Sub-column infrastructure *(In-house effort, external funding)*
  - all schemes see the same sub-columns: consistency among processes

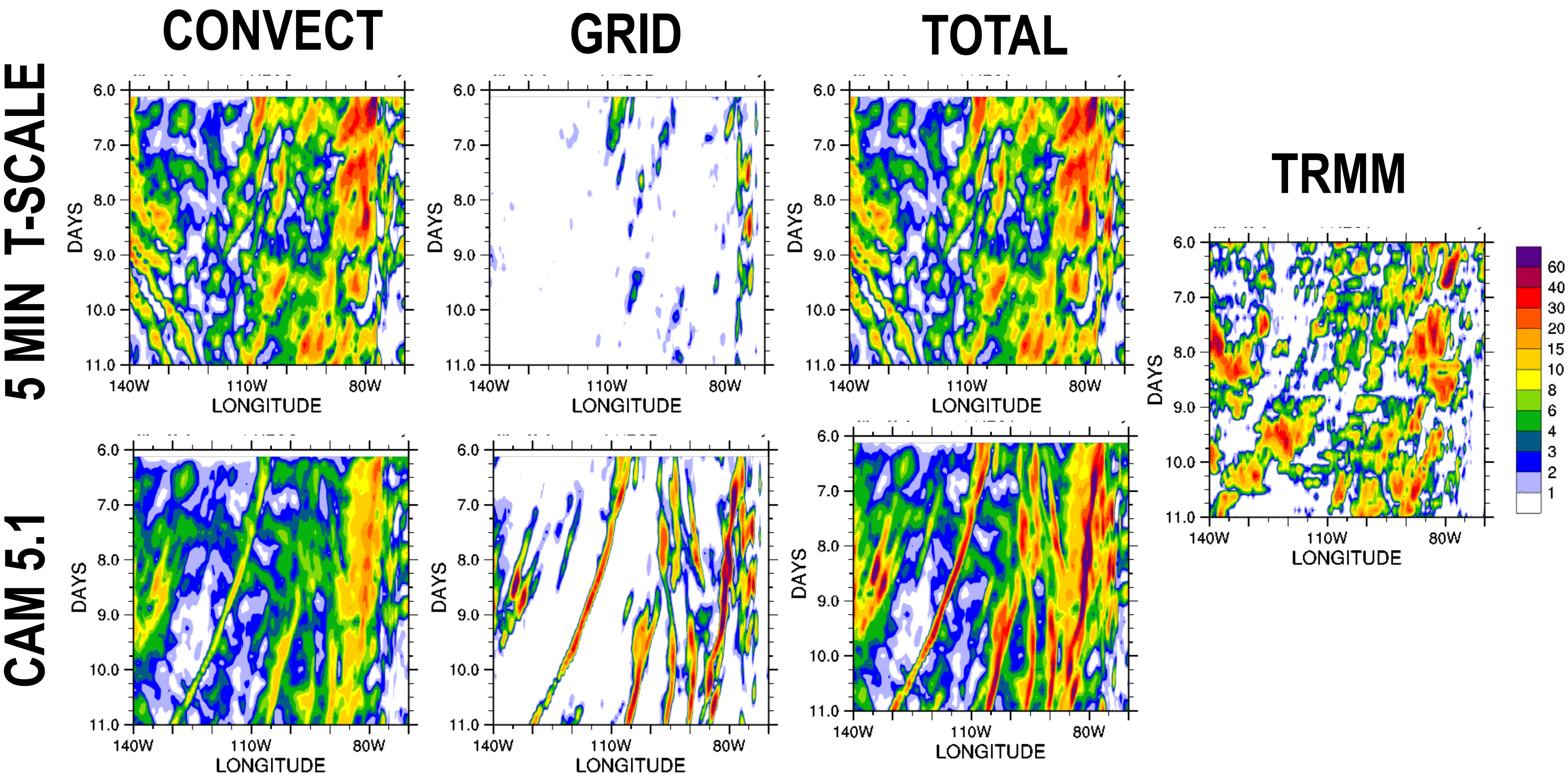
Nothing formal on improving mountain wave/orographic blocking but thinking about …

General near-term plans

- Dynamics
  - Lagrangian vertical transport (all variables)
  - Conservative Semi-LAgrangian Multi-tracer (CSLAM) advection
  - Regional mesh refinement in CAM-SE, begin testing MPAS dycore
- Resolution
  - High resolution runs (0.25 and finer). Horizontal resolution dependence (climate change response).
  - Vertical resolution dependence (L30 -> L31, L60)

- Address systematic precipitation biases
  - double ITCZ, Asian monsoon, summertime US rainfall
  - CAPT framework, high-resolution, UNICON, …

INDIVIDUAL FORECAST IC = 6 JAN



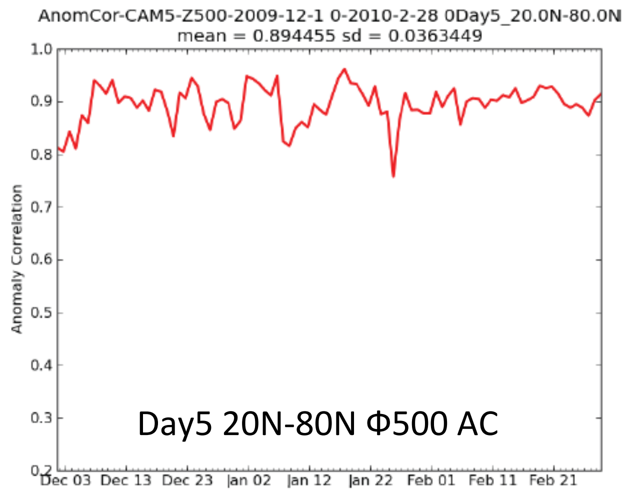
from Dave Williamson

Model Skill for Hindcast Experiments

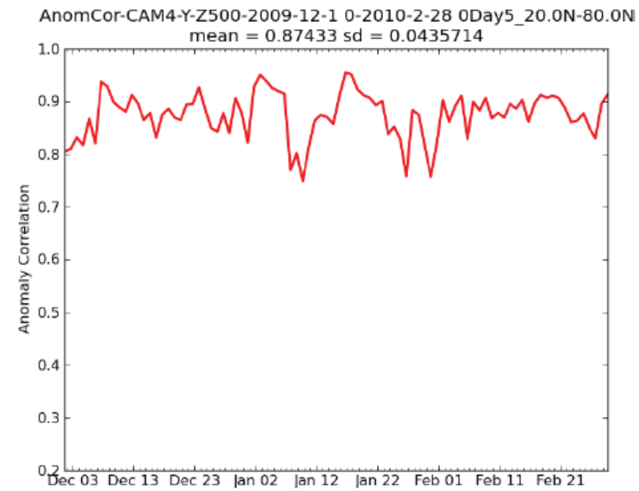
The values are comparable to those achieved by the major forecast centers.

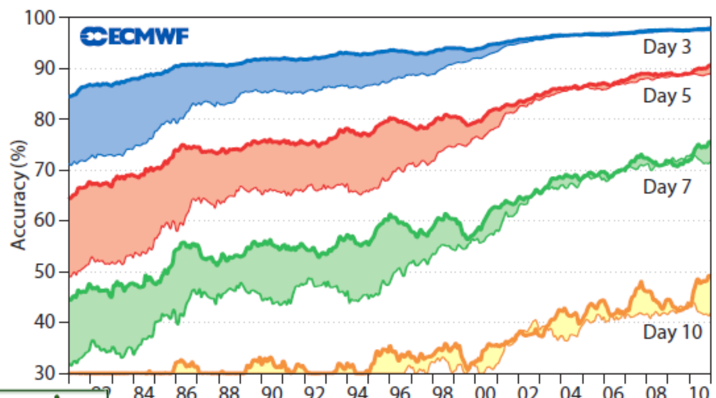
Anomaly Correlation

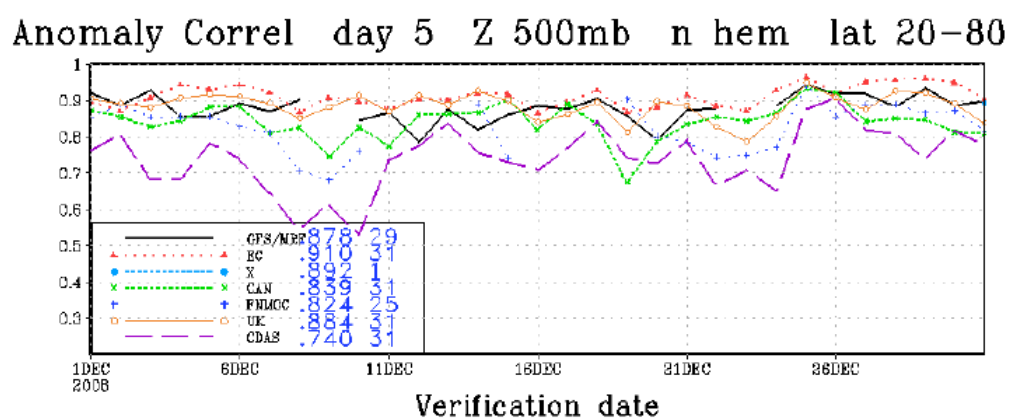
(a) CAM5 DJF NH



(b) CAM4 DJF NH







CAPT
Cloud-Associated Parameterizations Testbed

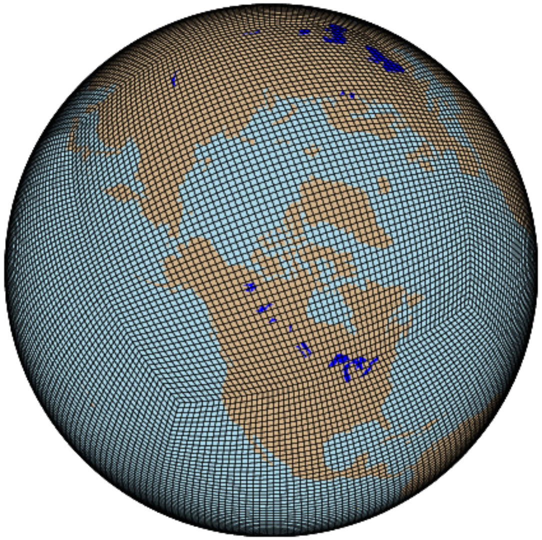
Thanks: Steve Klein and Jim Boyle, LLNL

CAM5 Regionally Refined

1° global resolution, refined to 1/8°

Sandia National Laboratories

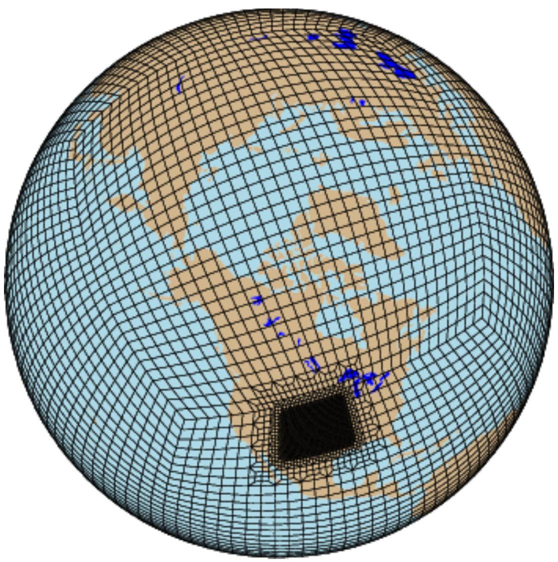
Argonne National Laboratory — Leadership Computing Facility



Global 1/8°

CAM5-SE has a very efficient, scalable and *expensive* global 1/8° configuration.

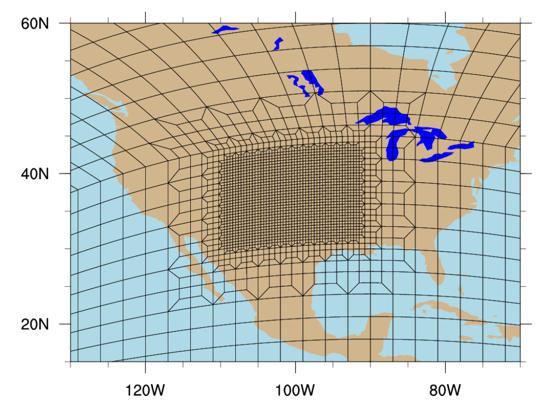
- 6M core hours per year (ANL Intrepid)
- Yellowstone: 1-2M core hours?
- 3.1M physics columns



SGP 8x Regionally Refined

1° global resolution, refined to 1/8° continental sized region centered over SGP ARM site.

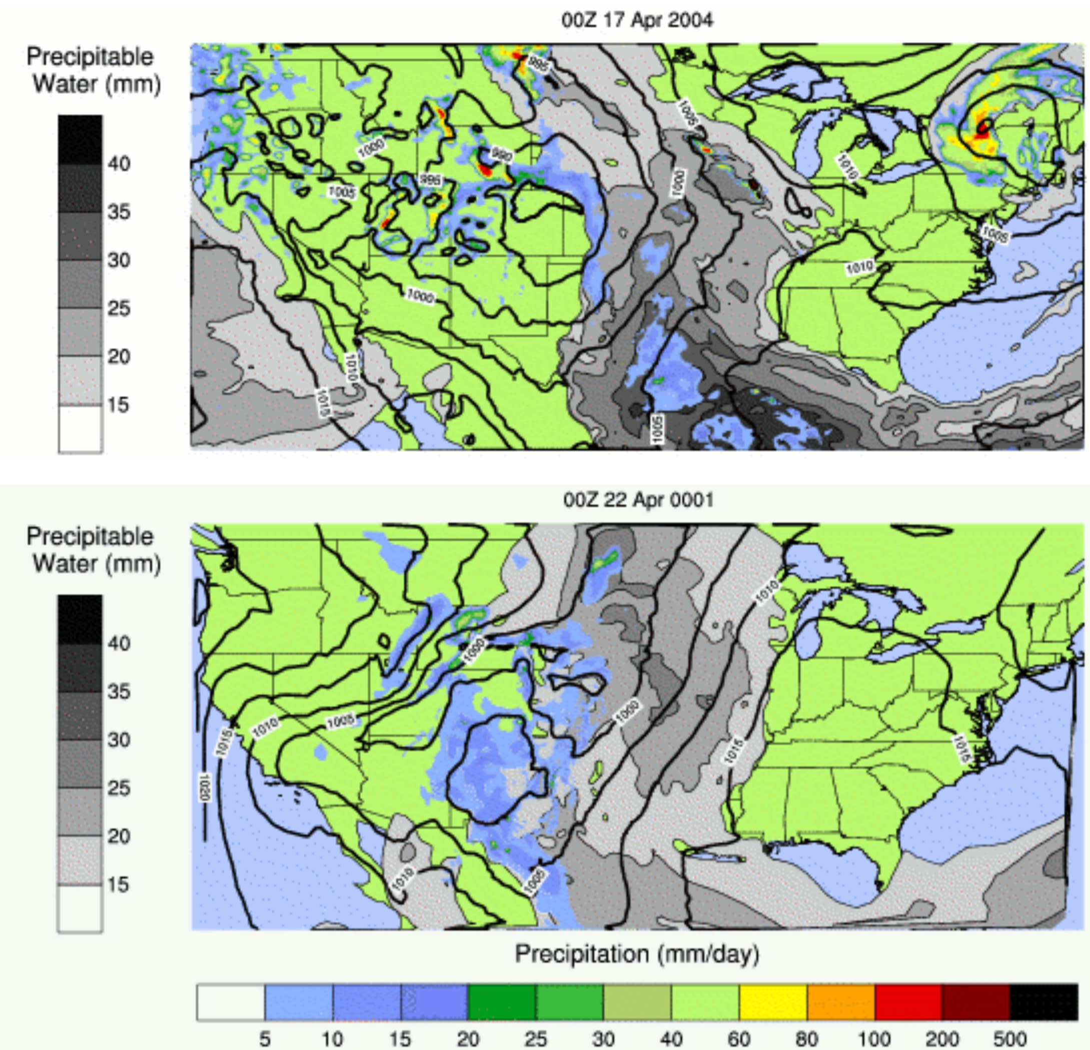
- 0.12 M core hours per year (Sandia Linux cluster).
- 67K columns.



Courtesy: Mark Taylor, Sandi

Precipitable water (gray), precip rate (color), sea level pressure (contours)

Sandia National Laboratories



Global 1/8° Simulation

Snapshots show propagating convective system not seen at lower resolutions. Detailed frontal structure and tapping of moisture

Regionally Refined Simulation

Similar convective systems form in the 1/8° region, strongly dissipated as it propagates into the 1° region

Courtesy: Mark Taylor, Sandia

WGNE’ S APE

Aqua-Planet Experiment

Comparison of Atmospheric GCM Simulations on a Water-Covered Earth

Mike Blackburn (University of Reading, UK)
David Williamson (NCAR, USA)
Brian Hoskins (University of Reading, UK)
Yoshi-Yuki Hayashi (Kobe University, Japan)
Kensuke Nakajima (Kyushu University, Japan)
&
14 APE Modelling Groups

IS FINALLY FINISHED!

Special issue of *J. Meteor. Soc. Japan* (Vol. 91A, 2013, 9 papers)

https://www.jstage.jst.go.jp/jstage/edit/jmsj/html/Annoucement.html

APE ATLAS – comprehensive intercomparison plots (online 2012)

http://library.ucar.edu/collections/technotes/

Data archive is available on APE web page

http://climate.ncas.ac.uk/ape/

Papers in special issue of J. Meteor. Soc. Japan

Blackburn, M., and B. J. Hoskins, 2013: Context and aims of the Aqua Planet Experiment. J. Meteor. Soc. Japan, 91A, doi:10.2151/jmsj.2013-A01.

Blackburn, M., D. L. Williamson, K. Nakajima, W. Ohfuchi, Y. O. Takahashi, Y.-Y. Hayashi, H. Nakamura, M. Ishiwatari, J. McGregor, H. Borth, V. Wirth, H. Frank, P. Bechtold, N. P. Wedi, H. Tomita, M. Satoh, M. Zhao, I. M. Held, M. J. Suarez, M.-I. Lee, M. Watanabe, M. Kimoto, Y. Liu, Z. Wang, A. Molod, K. Rajendran, A. Kitoh, and R. Stratton, 2013: The Aqua Planet Experiment(APE): Control SST simulation. J. Meteor. Soc. Japan, 91A, doi: 10.2151/jmsj.2013-A02.

Williamson, D. L., M. Blackburn, K. Nakajima, W. Ohfuchi, Y. O. Takahashi, Y.-Y. Hayashi, H. Nakamura, M. Ishiwatari, J. McGregor, H. Borth, V. Wirth, H. Frank, P. Bechtold, N. P. Wedi, H. Tomita, M. Satoh, M. Zhao, I. M. Held, M. J. Suarez, M.-I. Lee, M. Watanabe, M. Kimoto, Y. Liu, Z. Wang, A. Molod, K. Rajendran, A. Kitoh, and R. Stratton, 2013: The Aqua Planet Experiment(APE): Response to changed SST fields. J. Meteor. Soc. Japan, 91A, doi:10.2151/jmsj.2013-A03.

Nakajima, K., Y. Yamada, Y. O. Takahashi, M. Ishiwatari, W. Ohfuchi, and Y.-Y. Hayashi, 2013: The variety of spontaneously generated tropical precipitation patterns found in APE results. J. Meteor. Soc. Japan, 91A, doi:10.2151/jmsj.2013-A04.

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APE ATLAS

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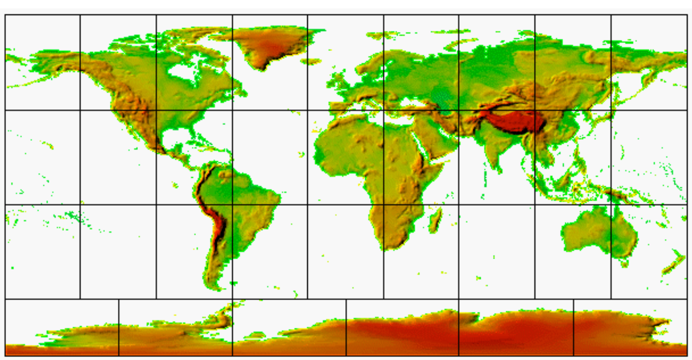
Thank You

New software (3 Fortran programs)

1. gen_netCDF_from_USGS: Reads USGS 30 arc seconds terrain dataset in 33 tiles and converts it a single NetCDF file (7.5GB; elevation stored as integer)

(only changes to raw data is for the Caspian sea)

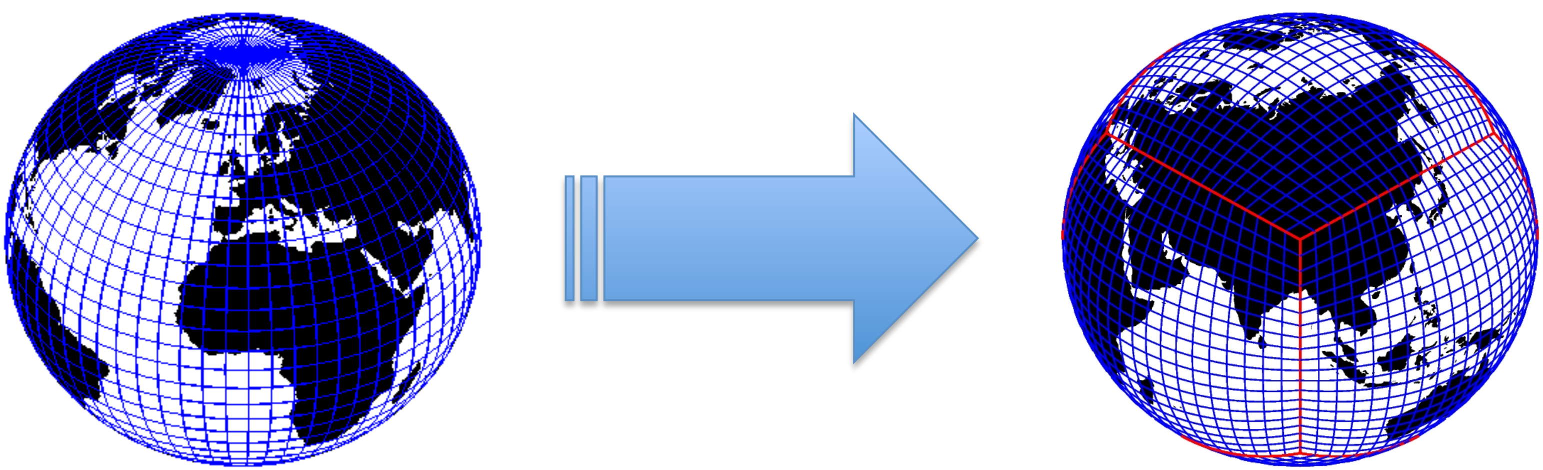


http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info

New software (3 Fortran programs)

2. bin_to_cube: bin USGS 30 arc seconds data to ~3km quasi-isotropic cubed-sphere grid and compute SGH30

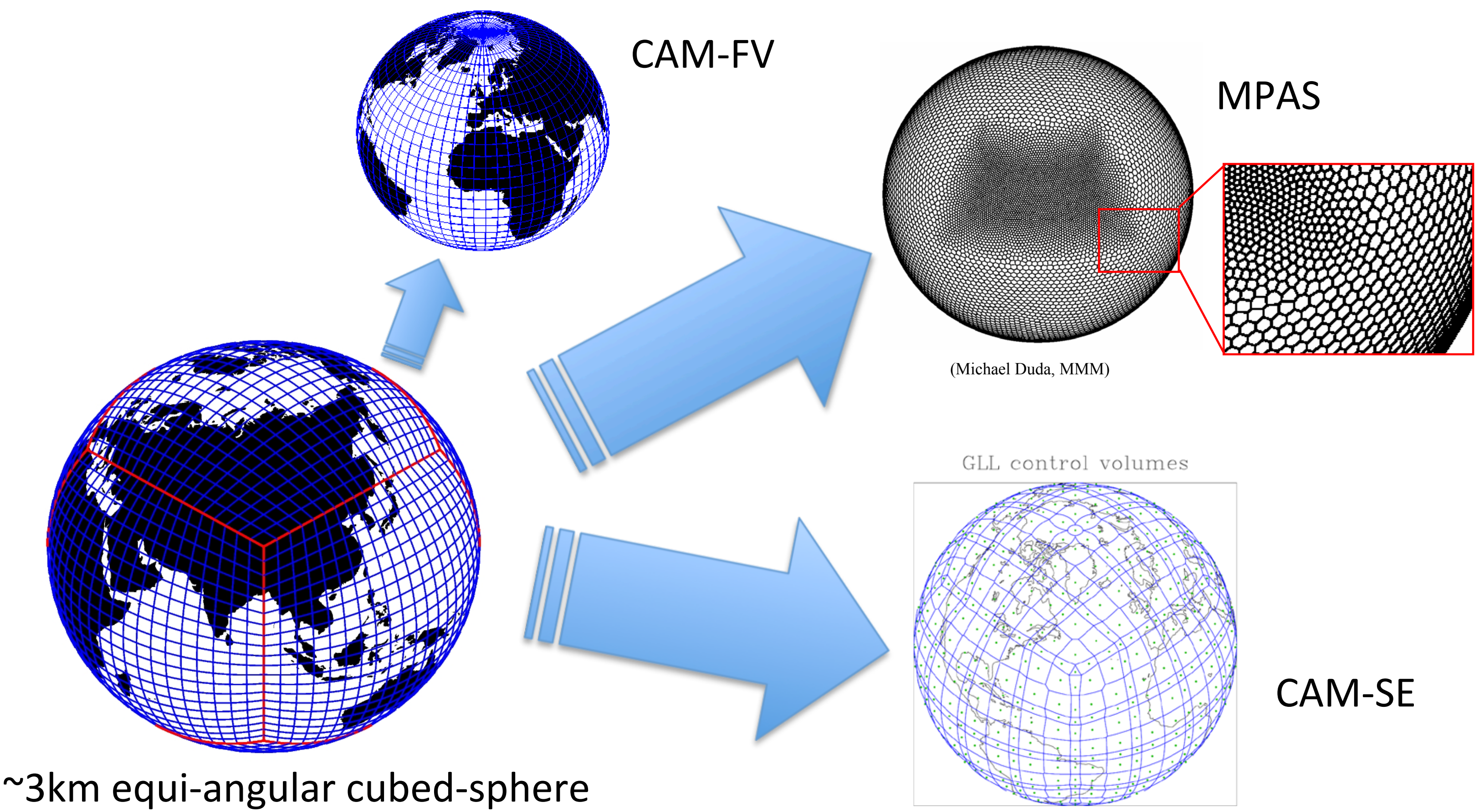
Adjustments to land fraction: Extend land fraction for Ross Ice shelf by setting all landfractions south of 79S to 1



-> quasi-isotropic separation of scales (for SGH30 and SGH).

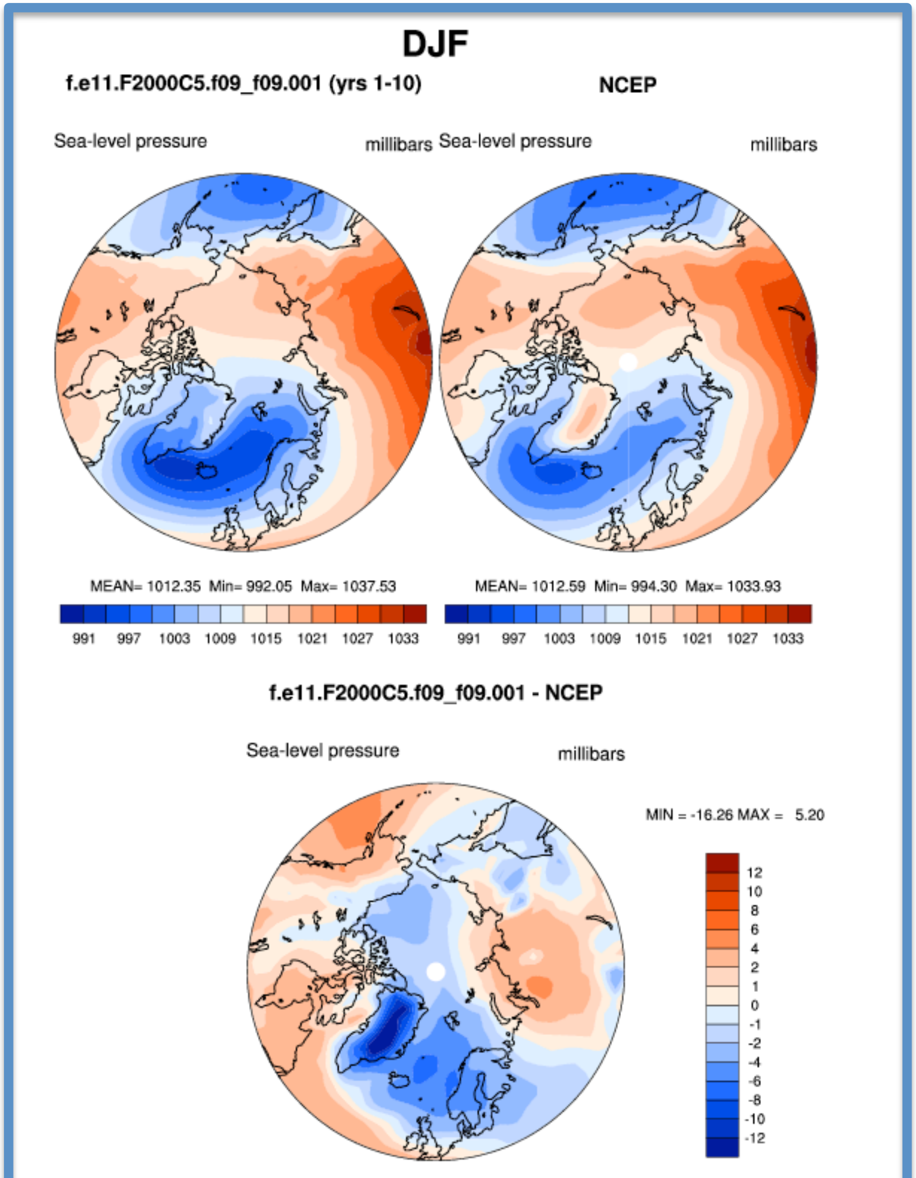
3. Cube_to_target: Rigorously remap (volume conserving) variables from ~3km cubed-sphere to any structured or unstructured target grid (compute SGH)

If PHIS is smoothed (externally or internally) SGH is re-computed to account for smoothing in sub-grid-scale variance

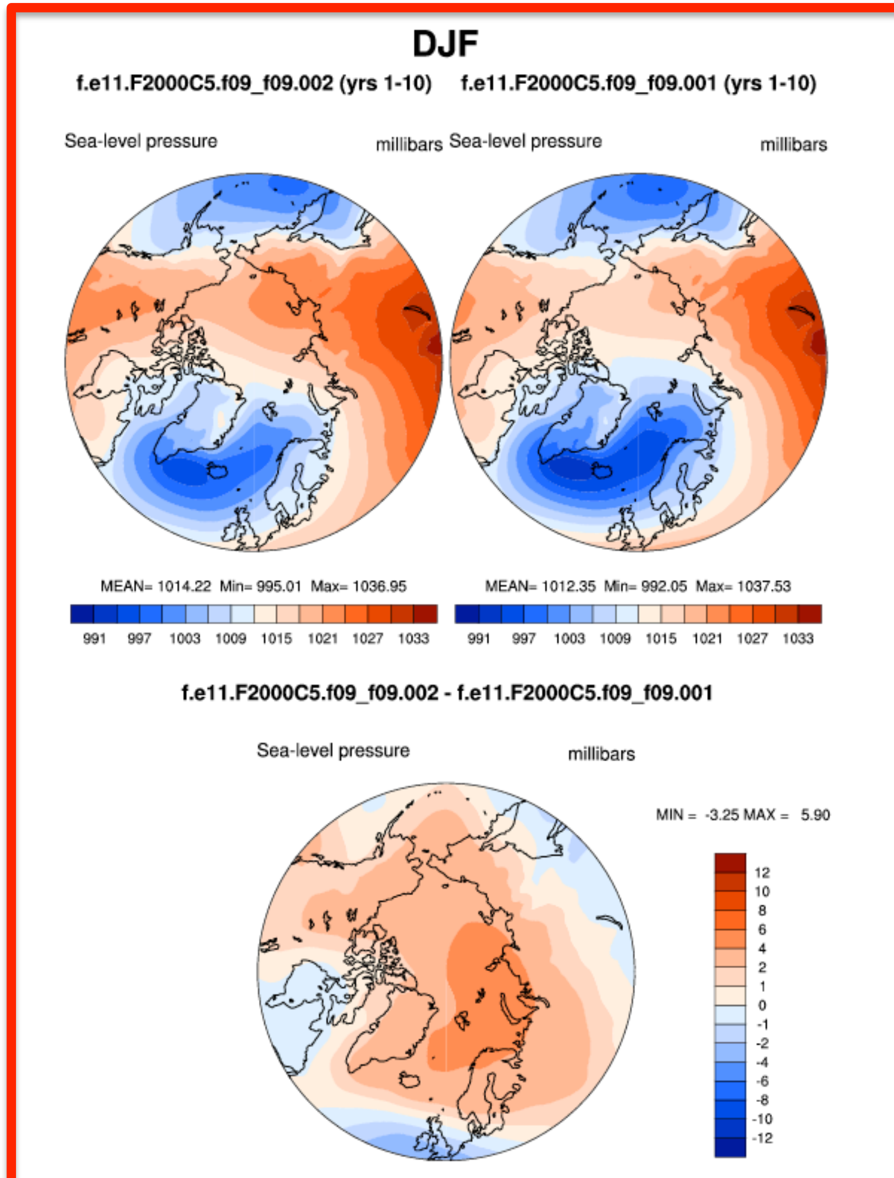


Sea level pressure (PSL): CAM-FV 1 degree

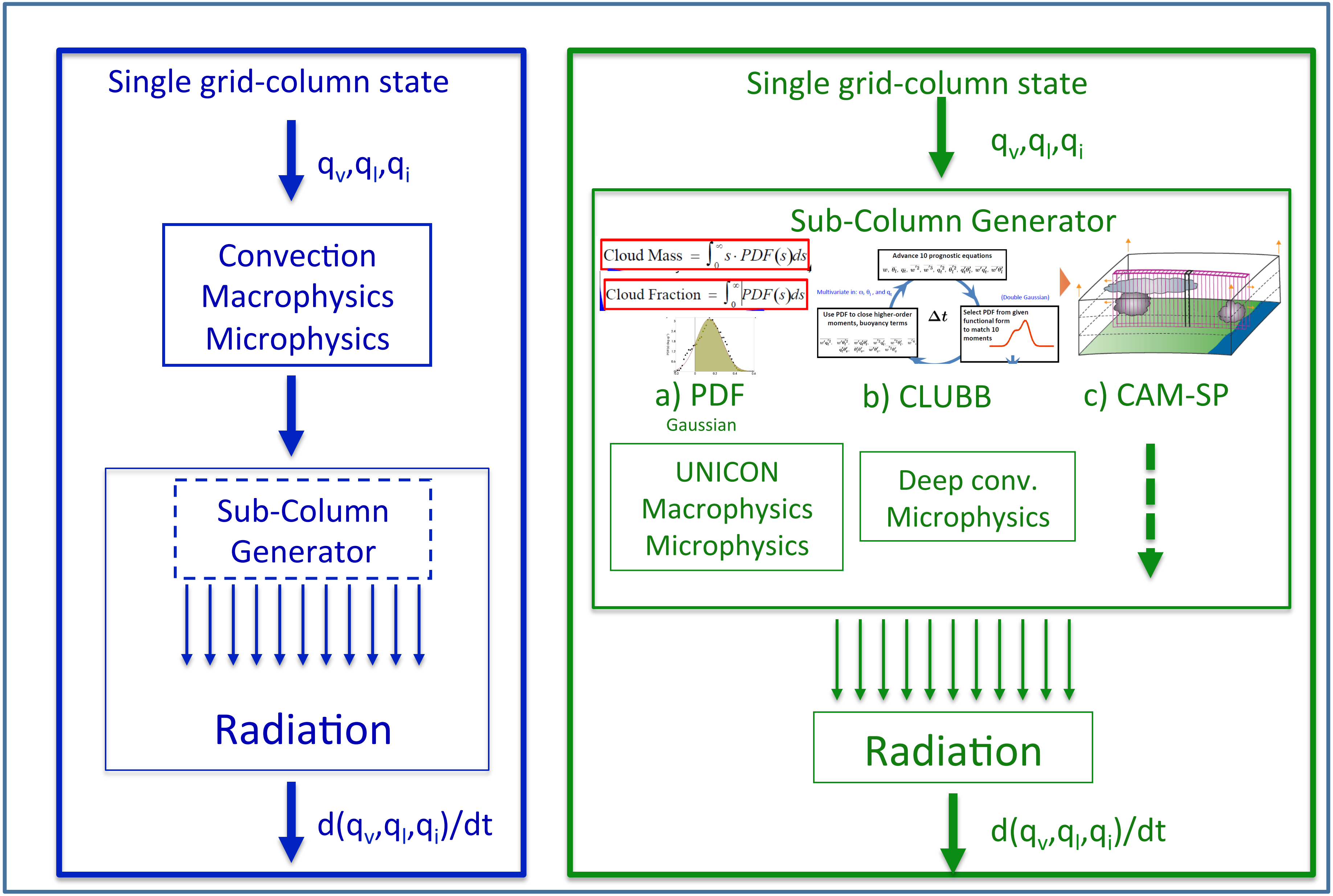
Control and OBS



Consistent (SGH & SGH30) and Control

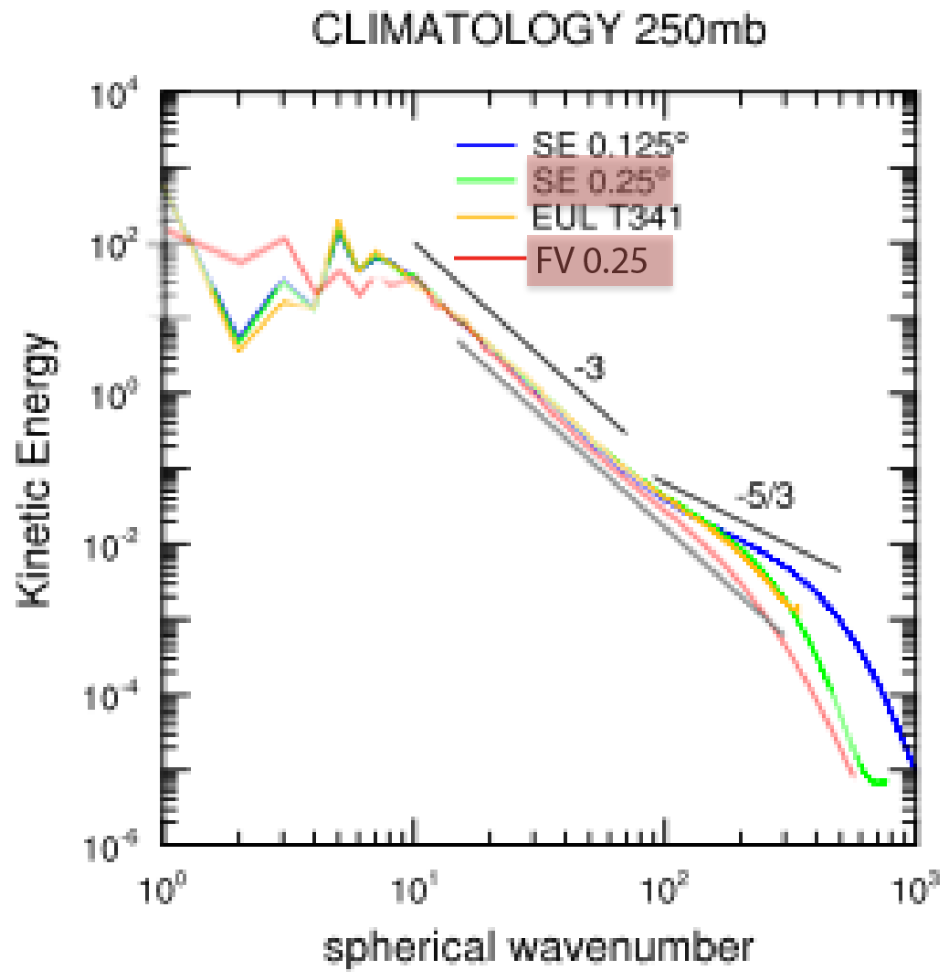


Physics framework in CAM5+



Slide courtesy: Rich Neale

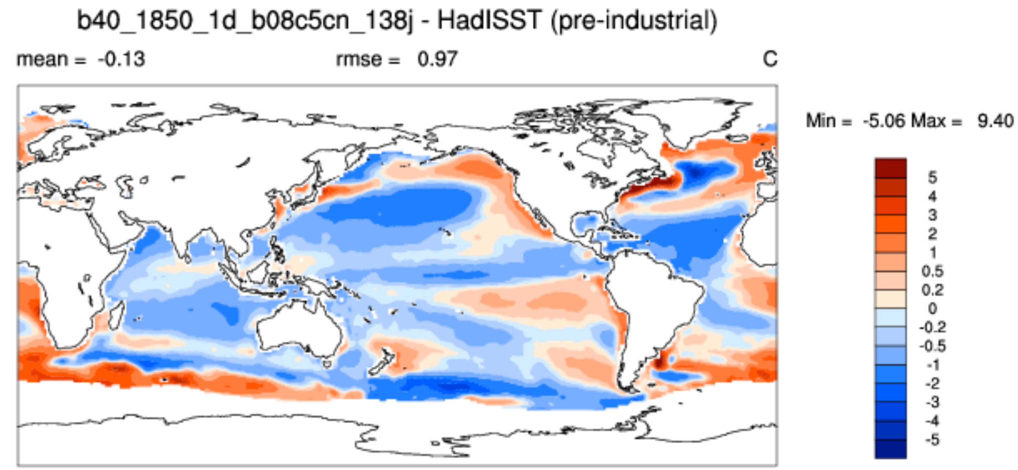
Horizontal Kinetic Energy spectra



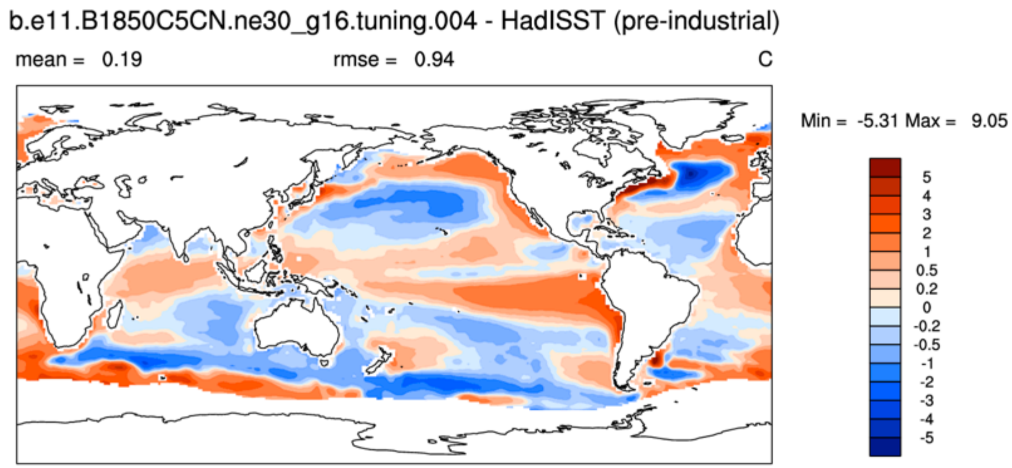
CAM-SE has higher effective resolution for given nominal resolution – not quite a whole octave

Temperature biases

CESM1.0 FV 1deg
mean = -0.13
RMSE = 0.97

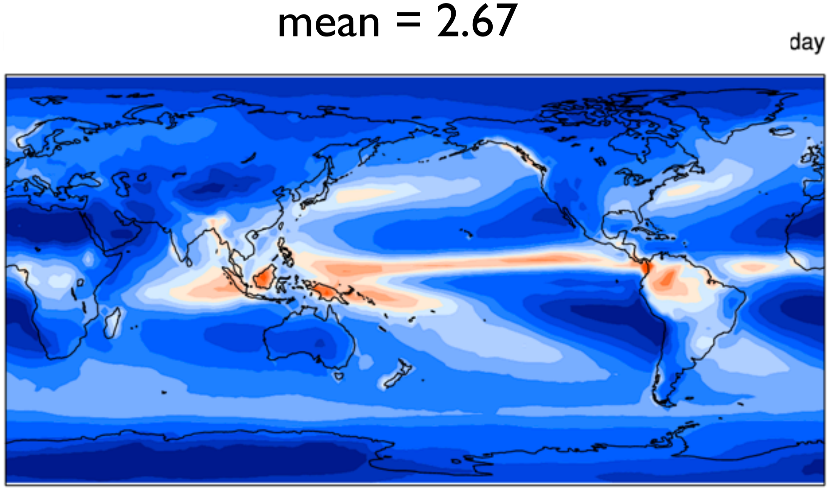


CESM1.1 SE ne30
mean = 0.19
RMSE = 0.94

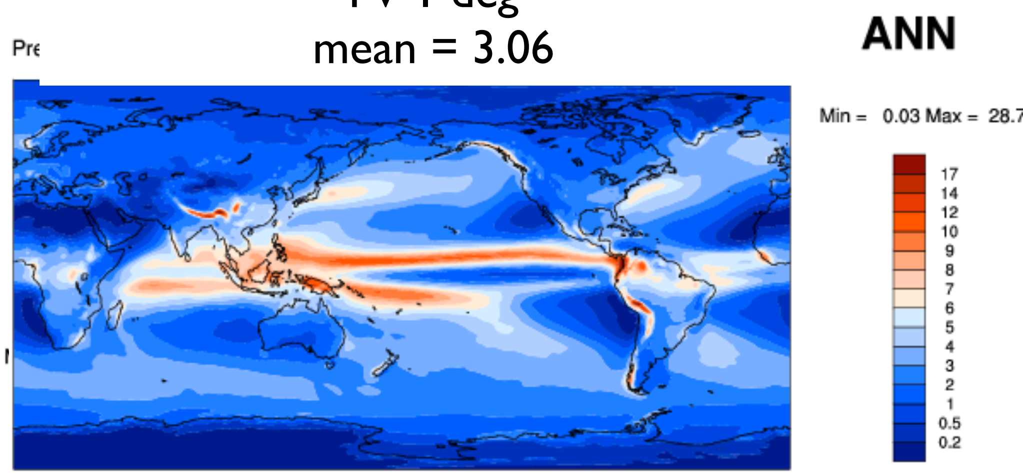


Precipitation

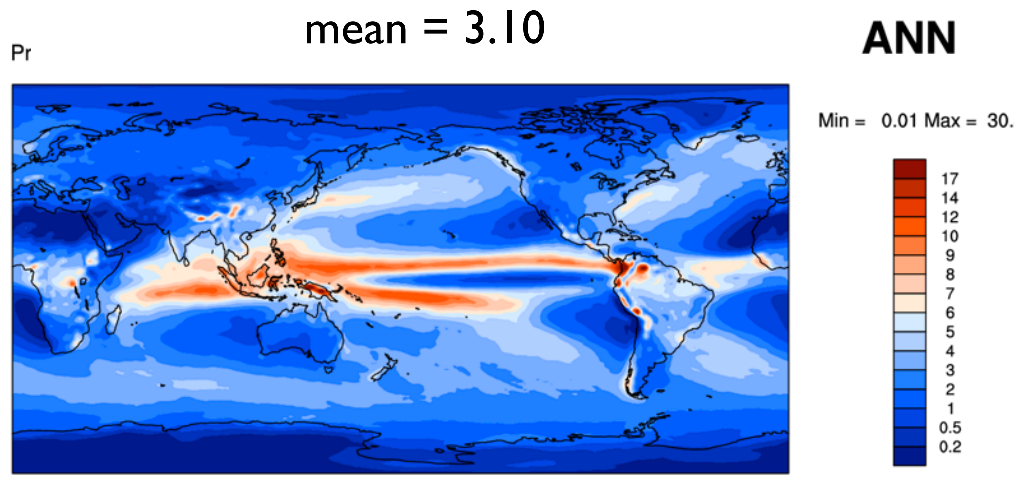
GPCP
mean = 2.67



FV 1 deg
mean = 3.06



SE ne30
mean = 3.10



Hours per year per 1° gridbox with category 1+ and 3+