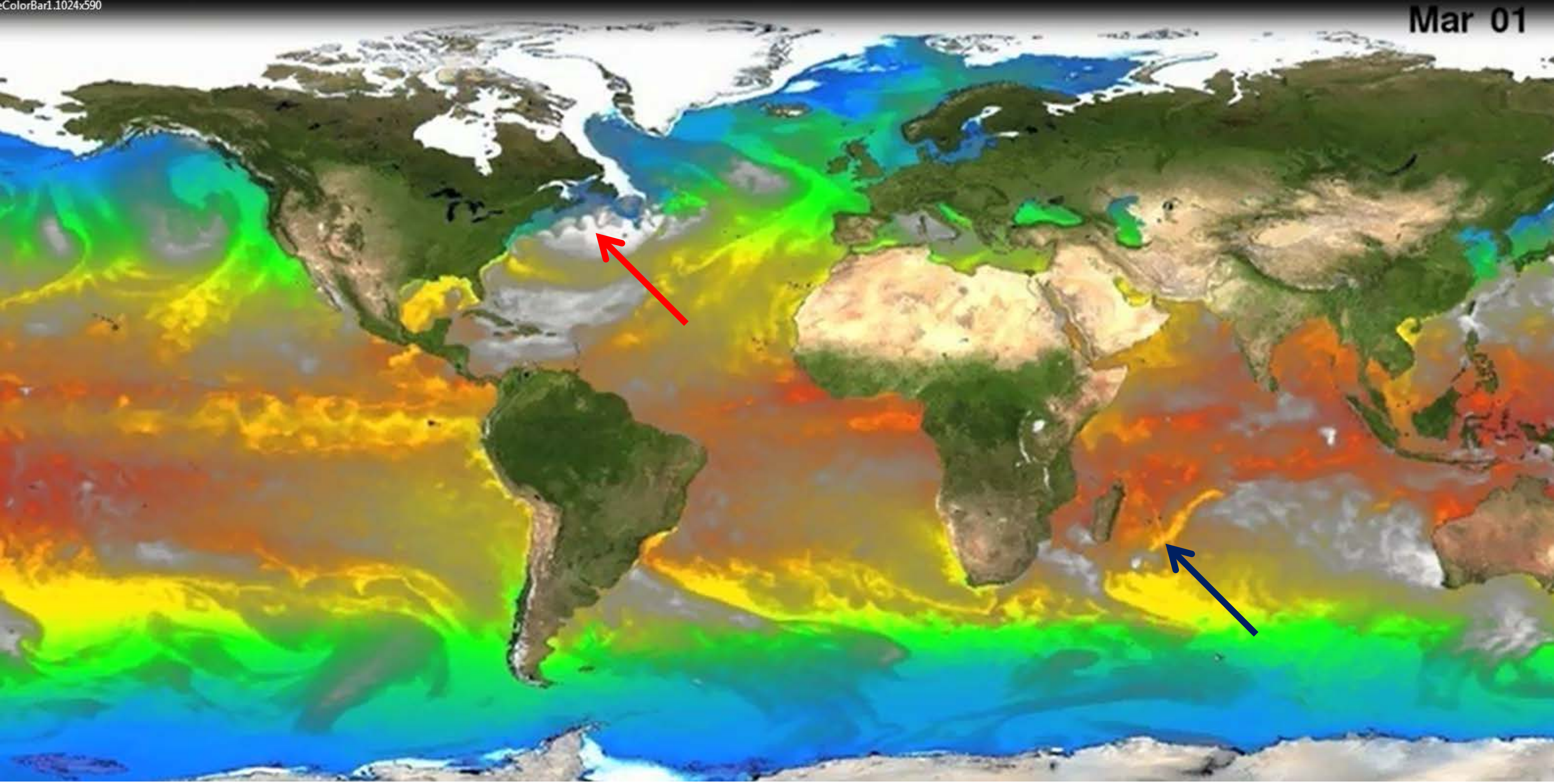

High-resolution CESM simulation run on Yellowstone. This featured CAM-5 spectral element at roughly 0.25deg grid spacing, and POP2 on a nominal 0.1deg grid. Funding from DOE (SCIDAC) and NSF. PIs Small, Bryan, Tribbia, Dennis, Saravanan, Kwon, Schneider.

A snapshot showing latent heat flux (grey scale, largest values shown in bright white are over $500 Wm^{-2}$) overlaid on sea surface temperature (color). Warmest ocean temperatures are red, followed by yellow, green and blue. Note the influence of Gulf Stream meanders on a cold-air outbreak in the North-West Atlantic (red arrow) and a cold temperature wake beneath a Tropical Cyclone in the Indian Ocean (blue arrow), both features are not well simulated by standard resolution climate models.

Office of Science (BER) and NERSC and
DOE/UCAR Co-operative Agreement
US Department of Energy
NCAR-Wyoming Supercomputer Center
National Science Foundation

The use of Yellowstone for very high resolution climate runs.

Justin Small

Julio Bacmeister, Allison Baker, David Bailey, Stu Bishop,
Frank Bryan, Julie Caron, John Dennis,
Jim Edwards, David Lawrence, Andy Mai, Ernesto Muñoz,
Tim Scheitlin, Bob Tomas, Markus Jochum,
Joe Tribbia, Yu-heng Tseng, Mariana Vertenstein
National Center for Atmospheric Research

Special thanks to Allison Baker, Tim Scheitlin and Dave Hart of CISL

Published in JAMES (Small et al. 2014, November)

Outline

- Overview High-resolution climate runs
  - These runs + other groups
- What are the gains from using high resolution?
  - Small-scale features newly-resolved
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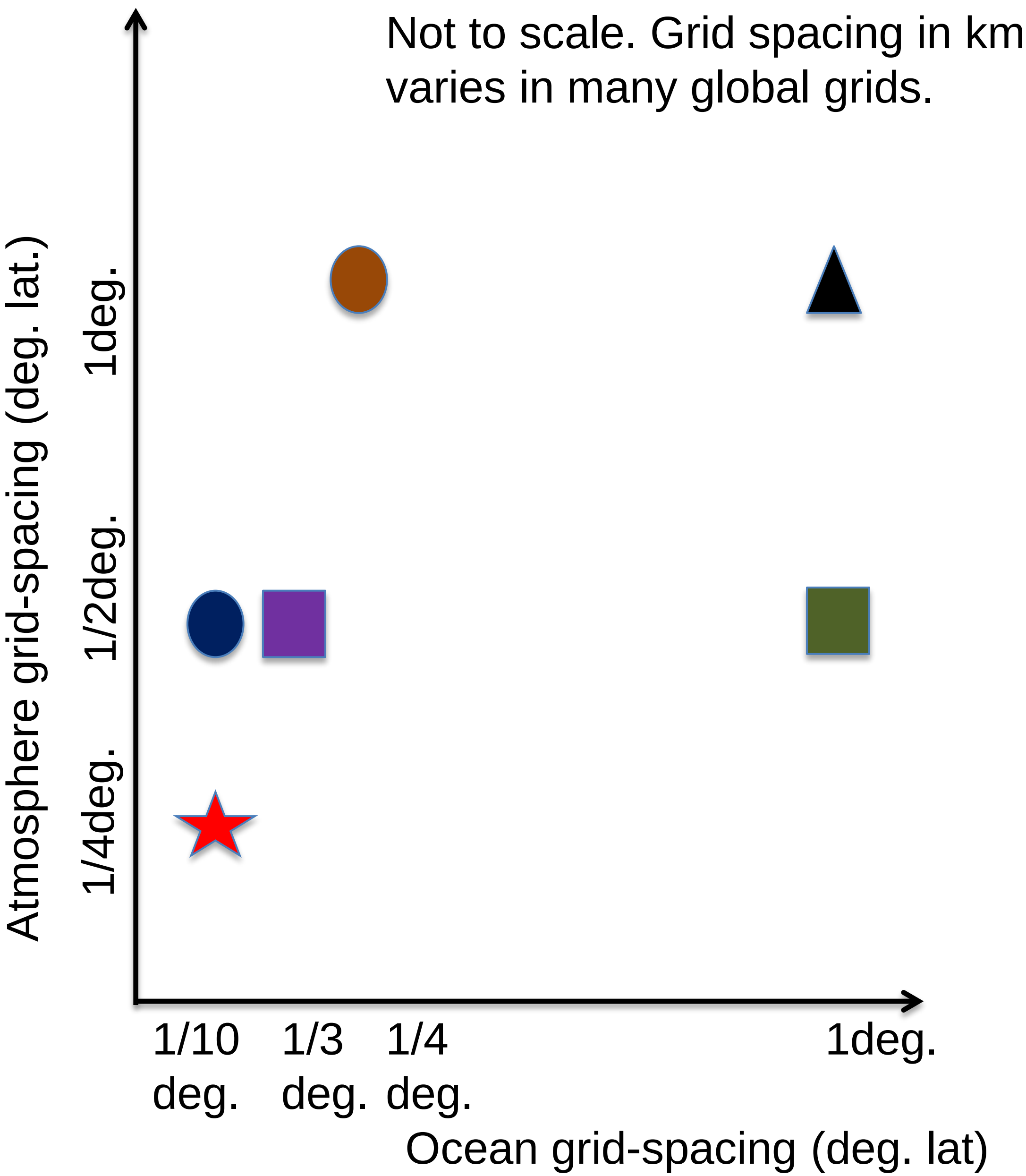
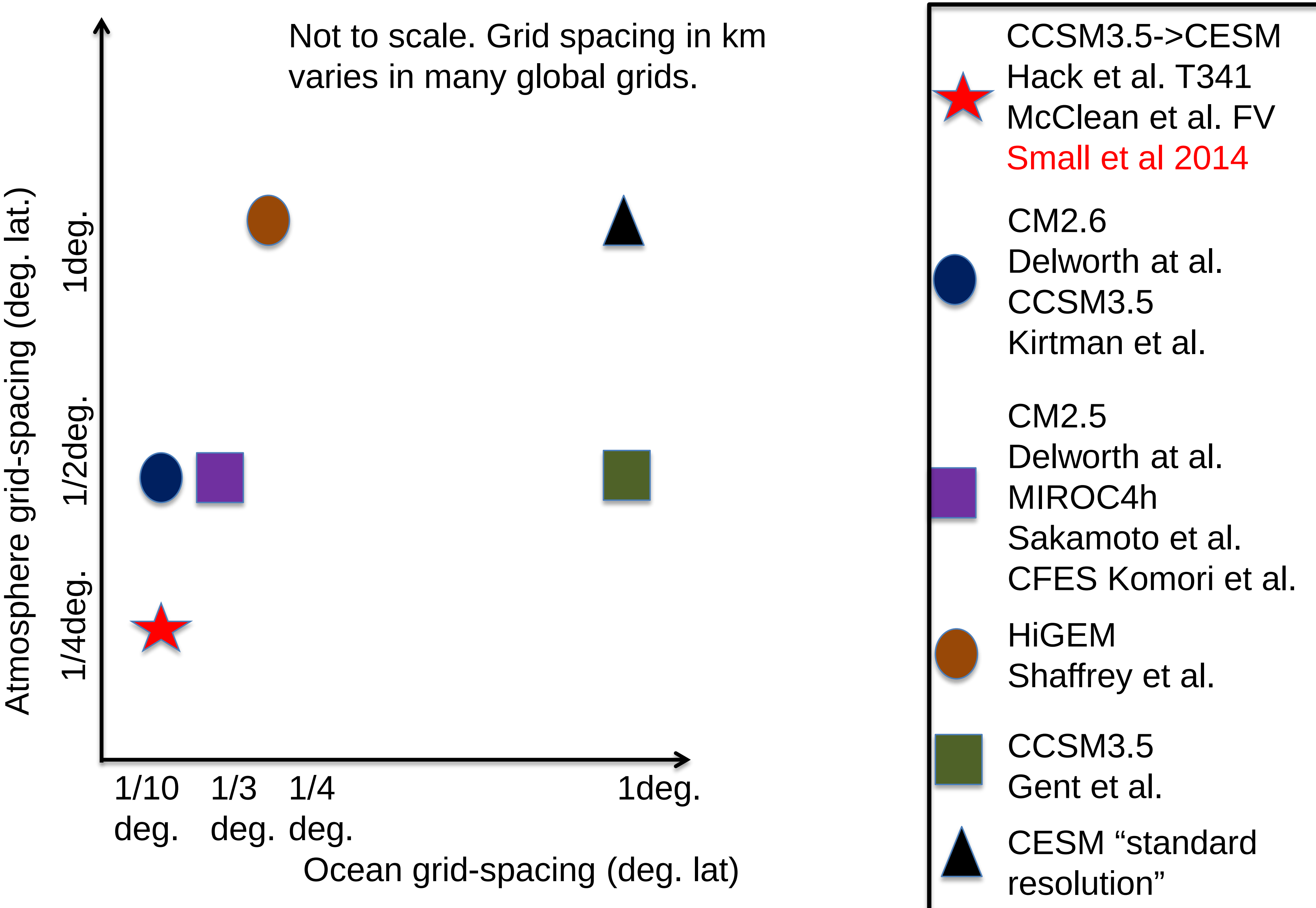
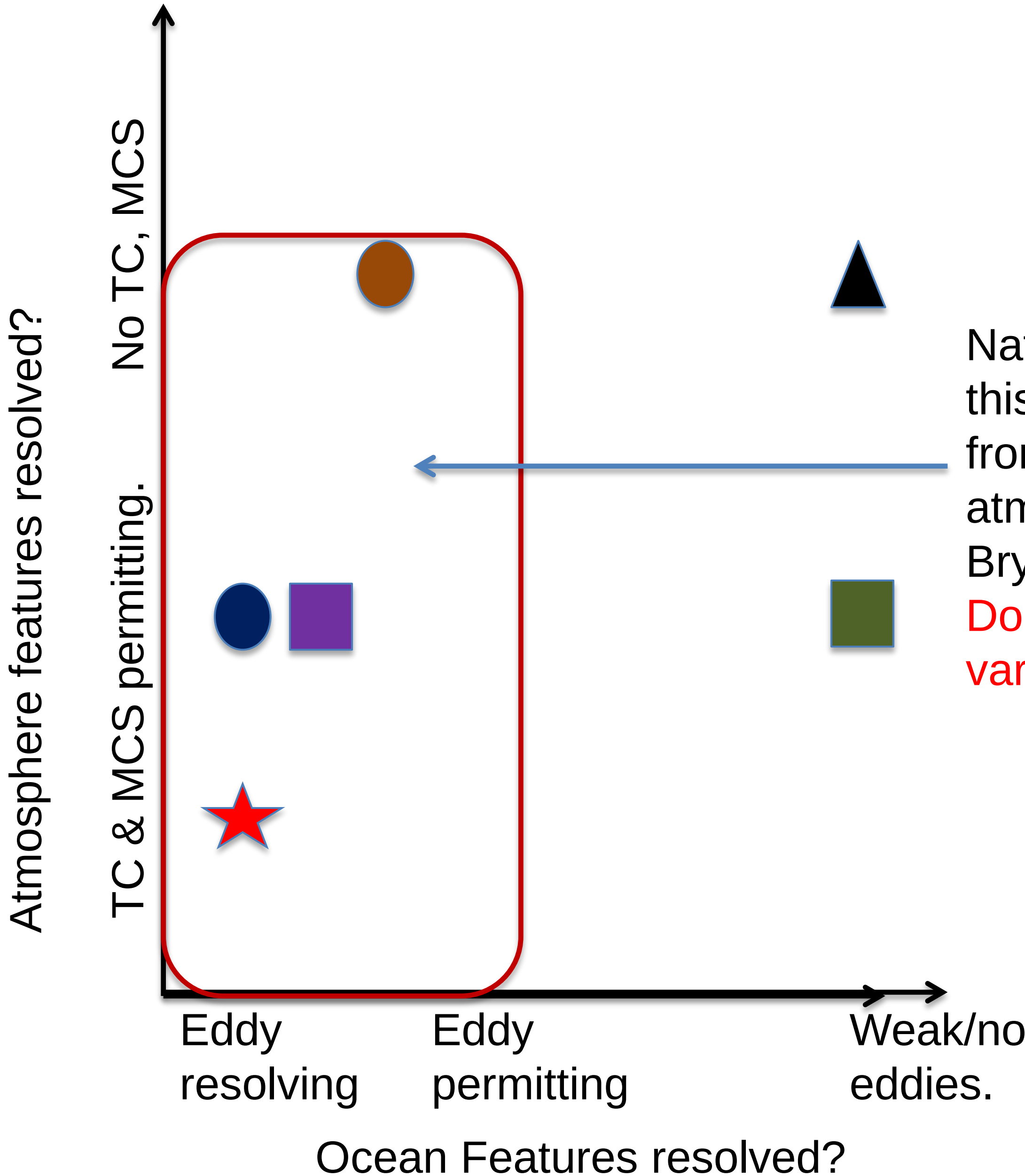
Scales of high-res global simulations



Scales of high-res global simulations



Scales of high-res global simulations

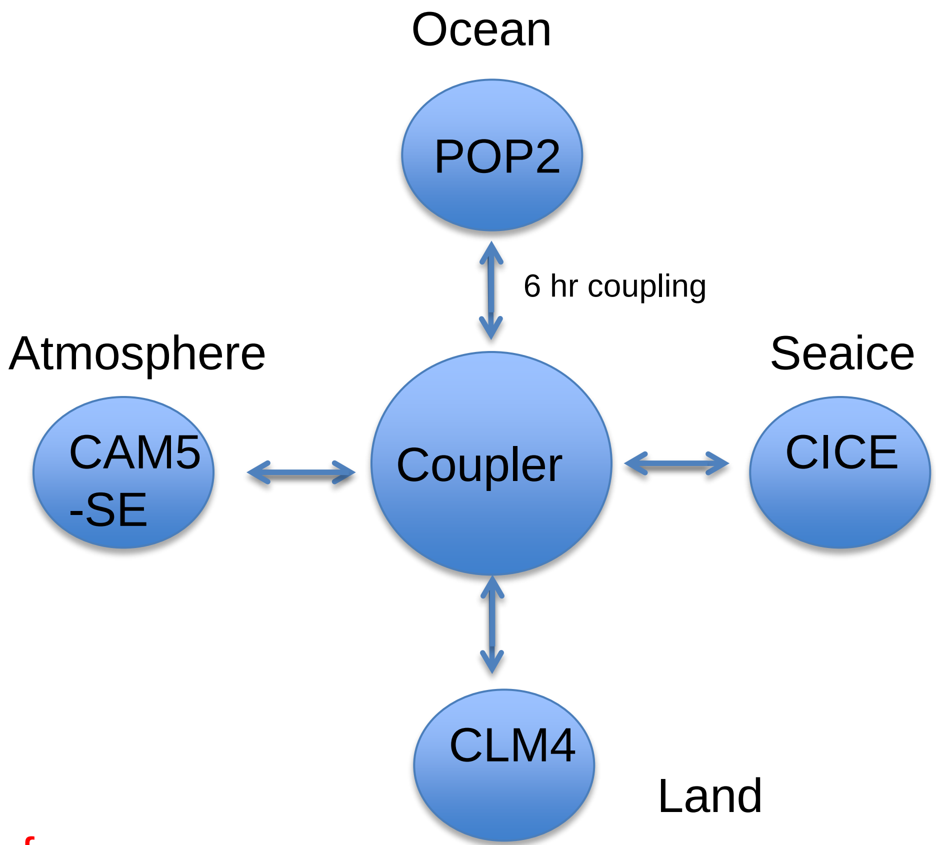


Nature of air-sea interaction changes in this regime, with ocean eddies and fronts forcing a strong response in atmosphere. (Chelton and Xie 2010, Bryan et al. 2010, Kirtman et al. 2012).

Does this affect mean climate and variability?

Community Earth System Model (CESM)

CAM5 includes aerosols



Simulation set up from present day (~year 2000) conditions.

Land-ice model not used here

Resolution matrix
-length of simulations

Ocean Resolution \ Atmosphere Resolution	0.25deg	1deg
0.1deg	**100 years**	**Not performed**
1deg	90 years	166 years

Simulations were performed in 2012 and 2013 including the early –use period of Yellowstone – “Accelerated Scientific Discovery” thanks to CISL.

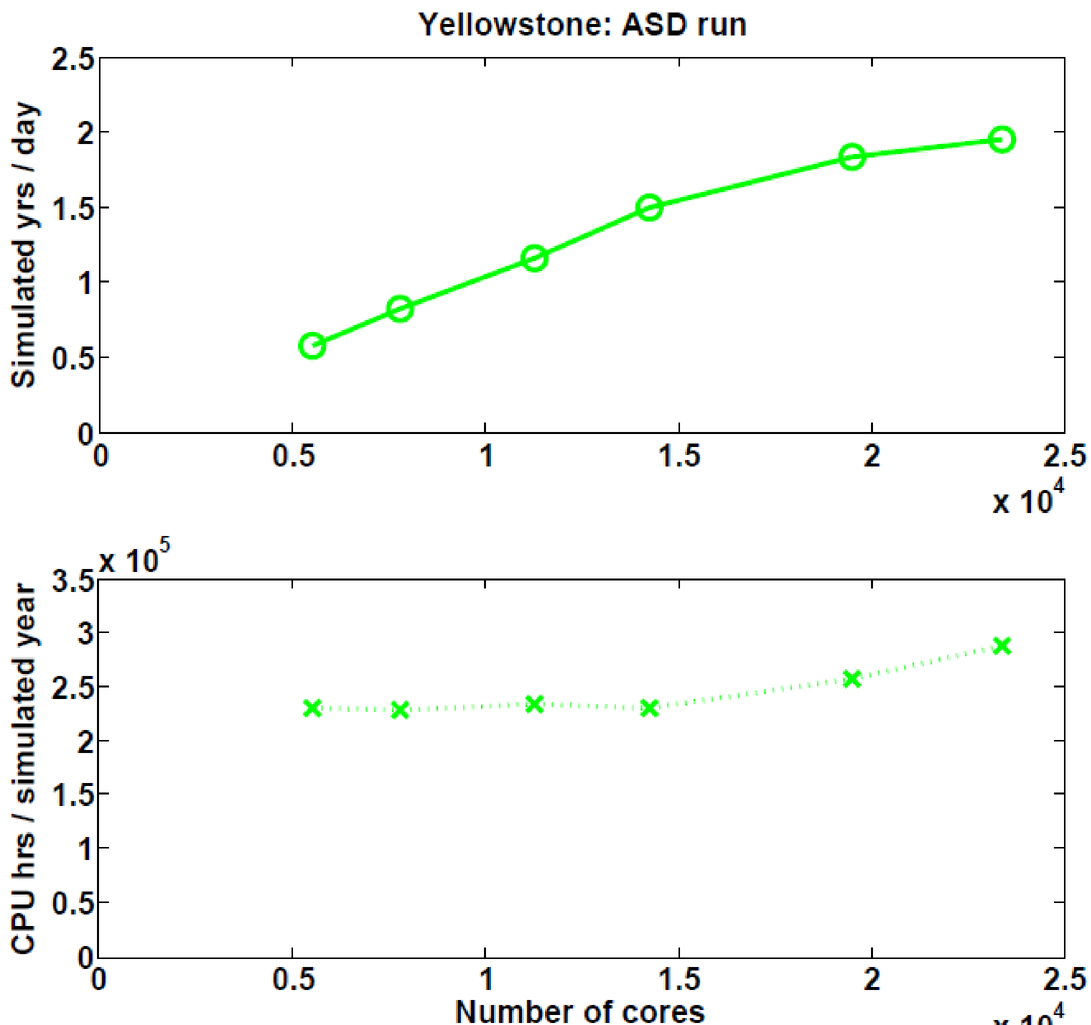
Simulation performed on Yellowstone

- Yellowstone (NCAR-Wyoming Supercomputer Center, at Cheyenne, WY)
- IBM iDataPlex architecture with Intel Sandy Bridge processors.
- 1.5-petaflops high-performance computing system with 72,288 processor cores, 144.6 TB of memory,
- Accelerated Scientific Discovery (ASD) phase used 25M core hours

Yellowstone

Performance characteristics

250,000hours



10,000 cores

25,000 cores

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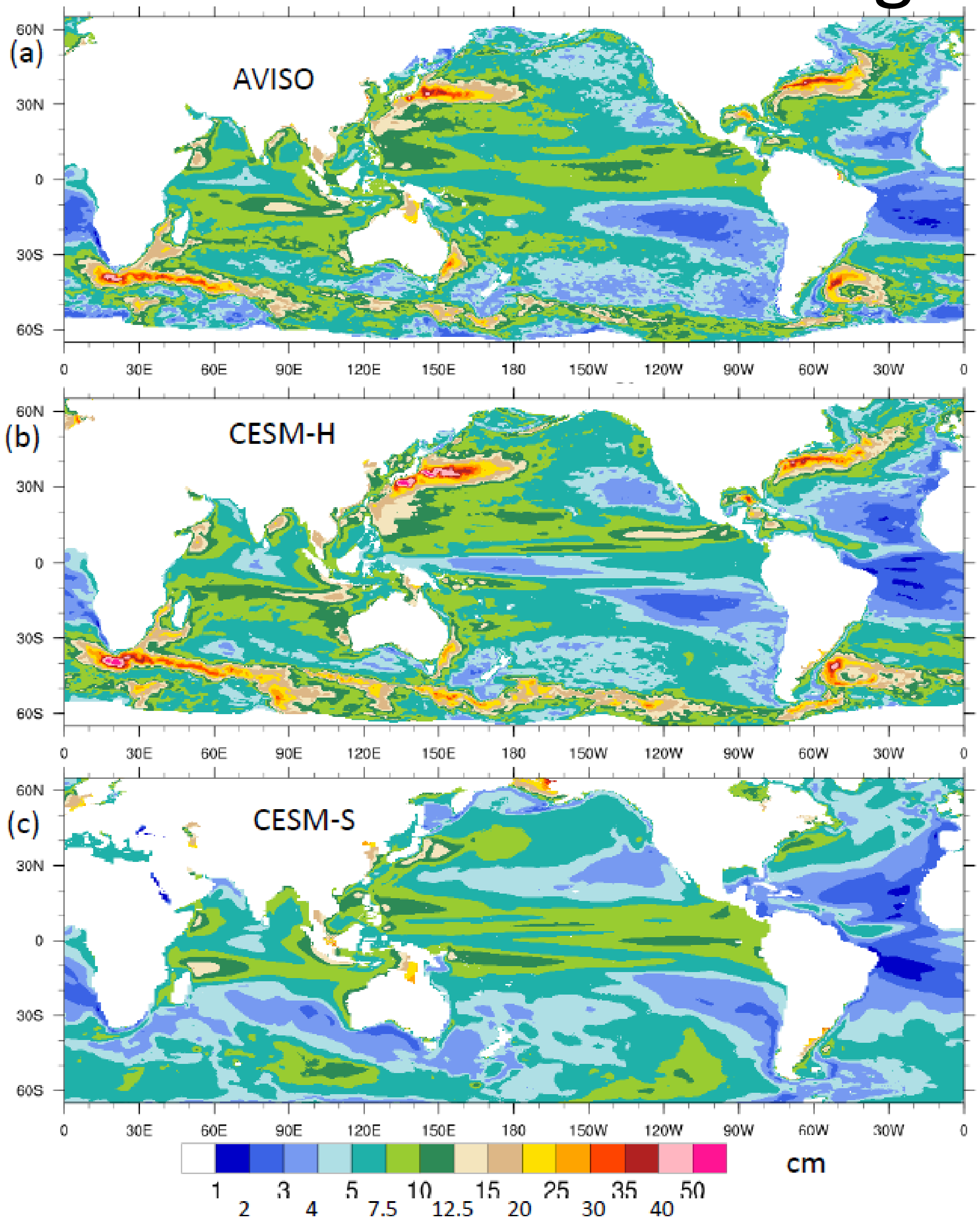
Sea surface temperature (SST) animation

Sea surface height variability

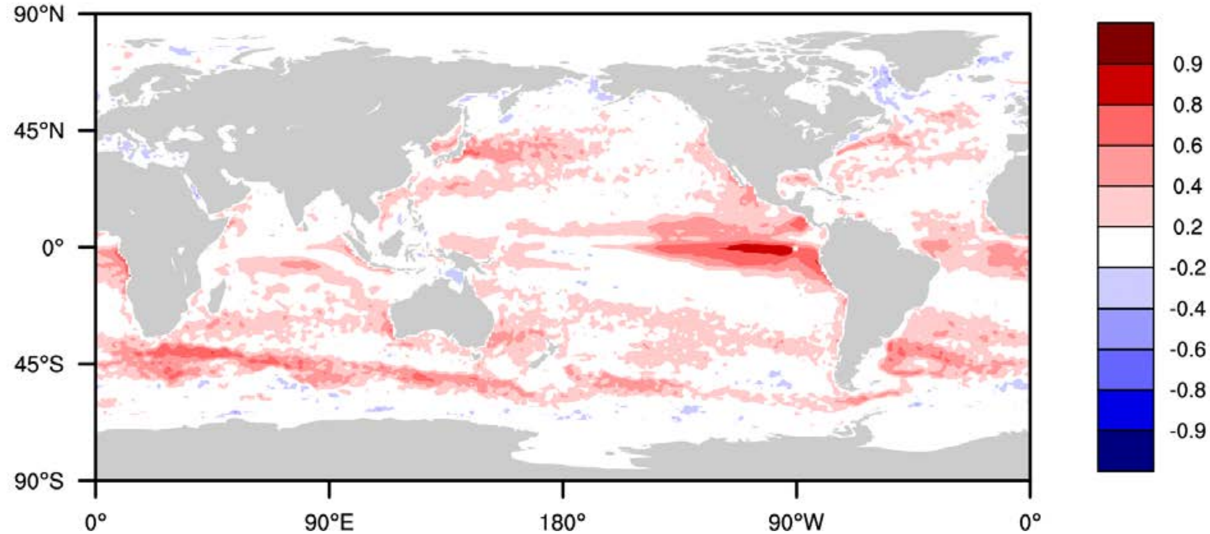


Standard deviation of Sea Surface height. Long-term mean and annual cycle removed.

SST-latent heat flux animation

Correlation of Surface Turbulent Heat Flux and SSH

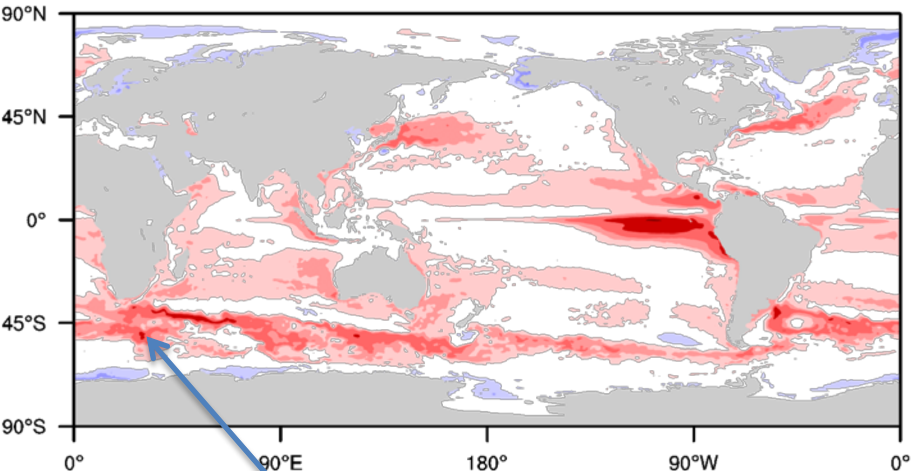
Courtesy Frank Bryan and Bob Tomas, NCAR

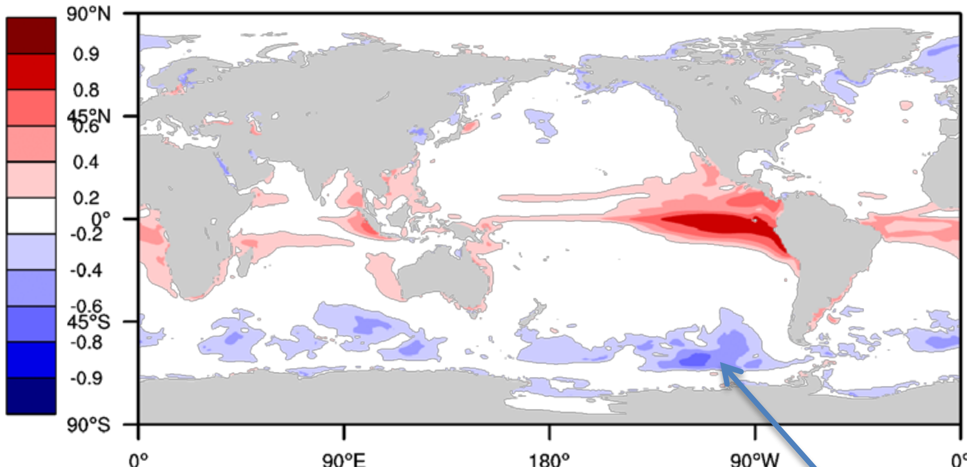


OBS
(JOFURO+AVISO)

High Resolution Model

Low Resolution Model



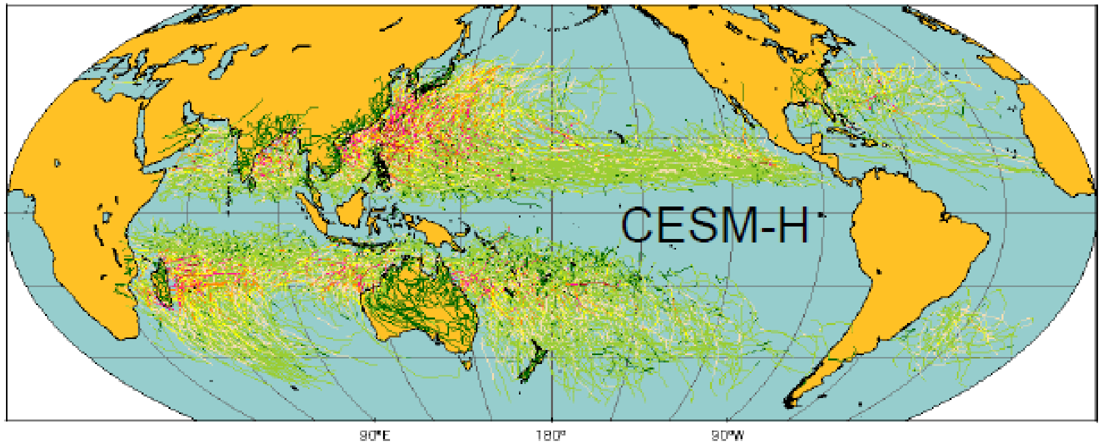


e.g. cool ocean gains heat from atmosphere

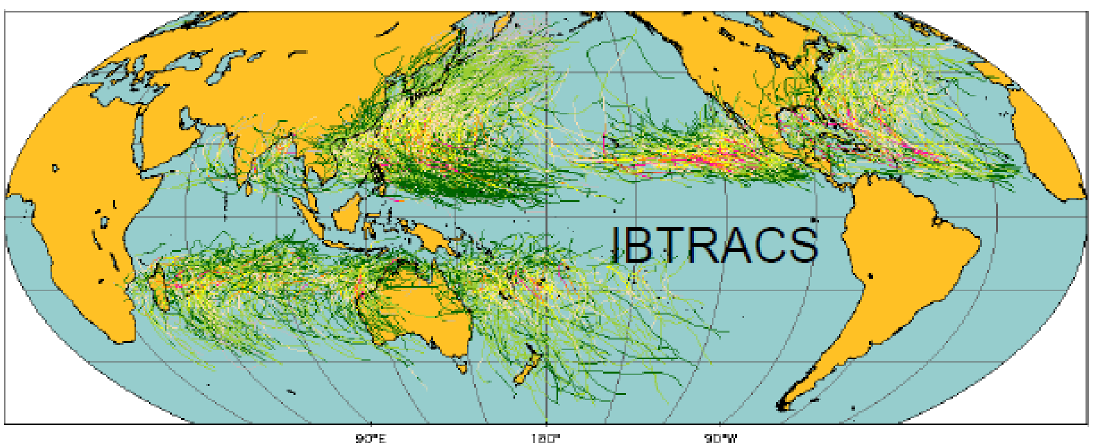
e.g. cool ocean loses heat to atmosphere

Tropical Cyclones

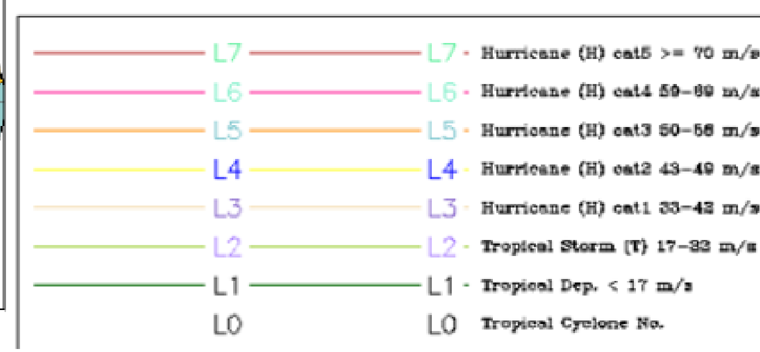
(a)

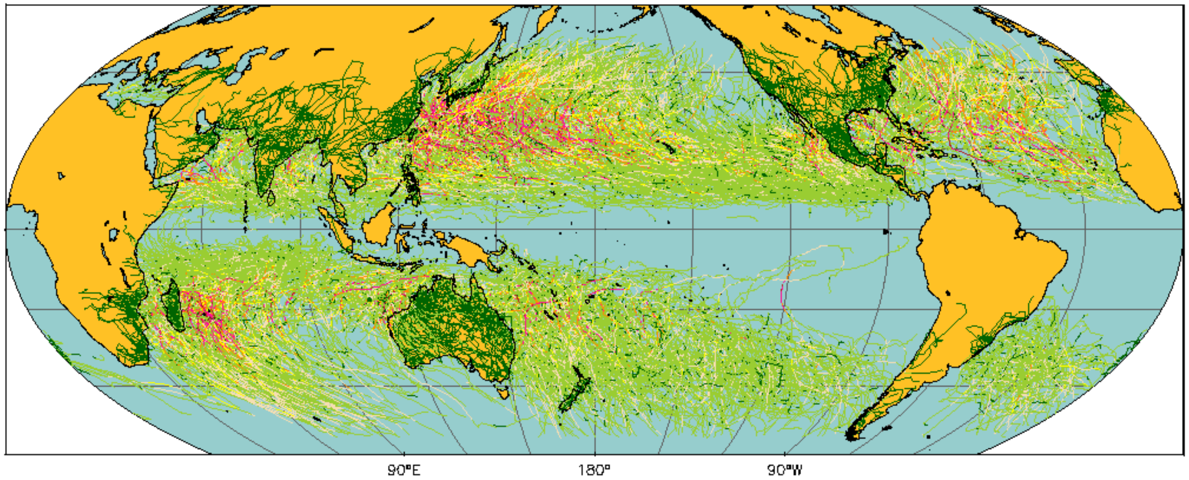


(b)



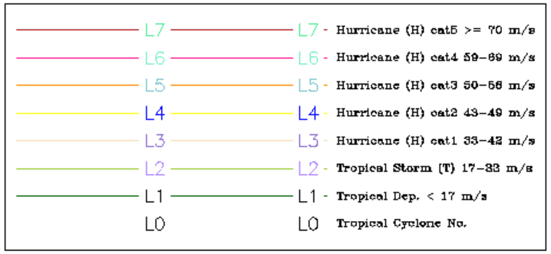
Tropical cyclone and hurricane tracks from a 30 year segment of the ASD run and from 30 years of IBTRACS observations. Note a high density of tracks in the West Pacific and Indian Ocean but low density in the Atlantic and East Pacific hurricane regions.
Storms > 33m/s

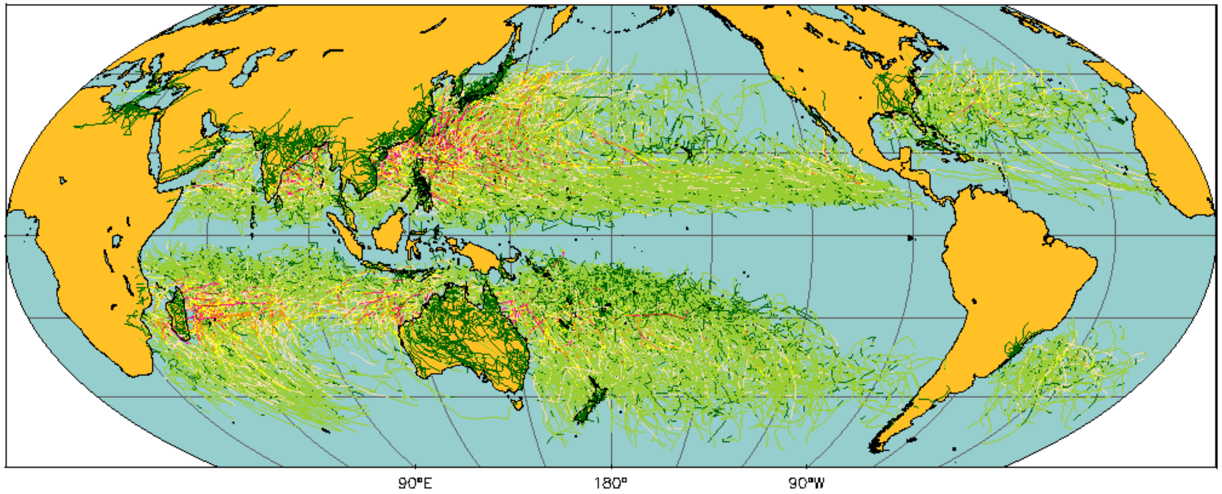




Now including all observed storms in model runs.

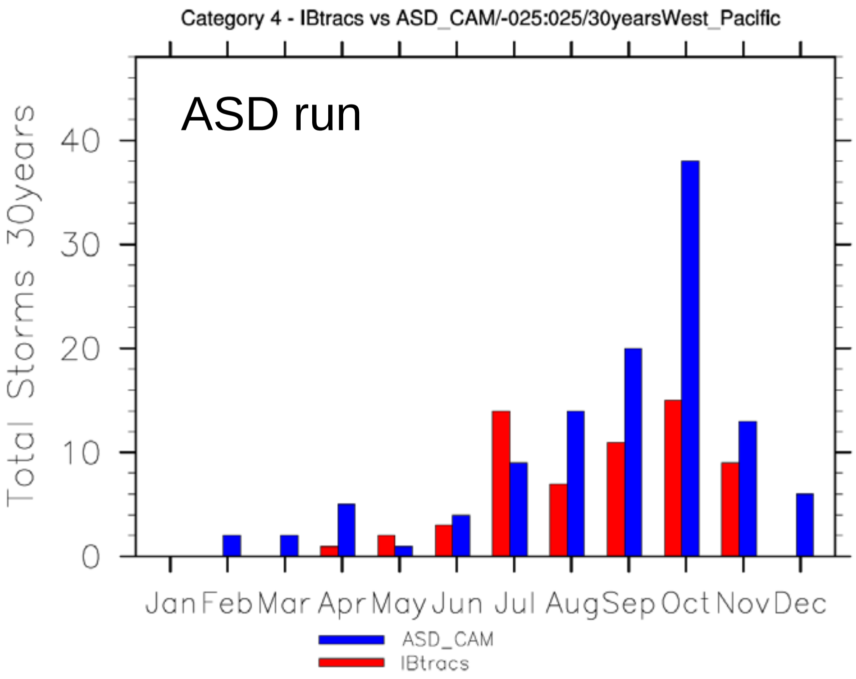
AMIP style run (atmosphere-only, observed SST)

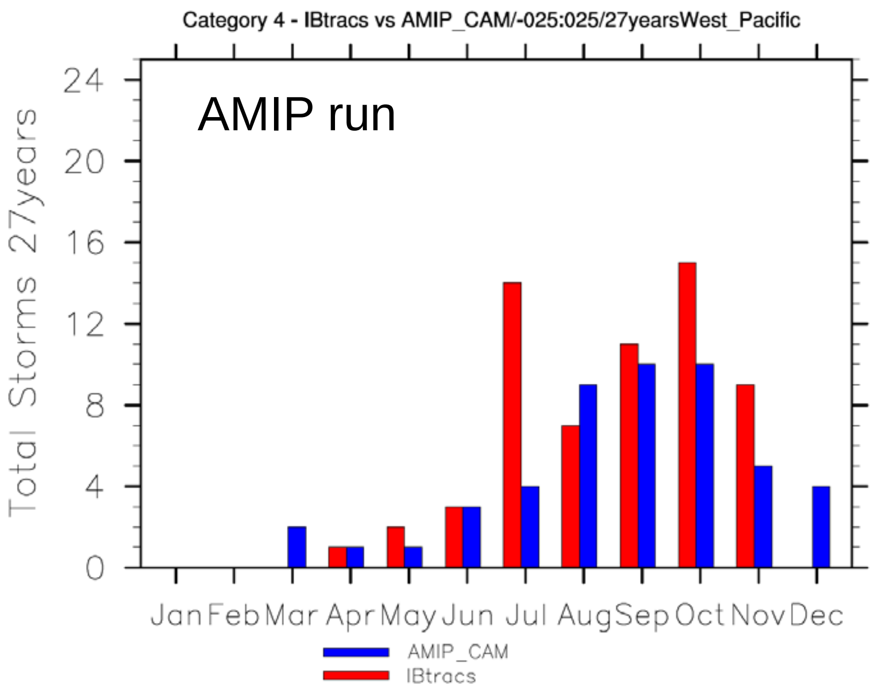




High-res CESM run,

Histogram of Cat 4 storms by month, West Pacific





Biases in tropical storm statistics can be due to

i) Biases in mean state of climate (SST, wind shear etc.)

ii) Deficiencies of physics and resolution in atmosphere model

iii) Deficiencies in air-sea interaction (surface fluxes not well known at high wind speeds)

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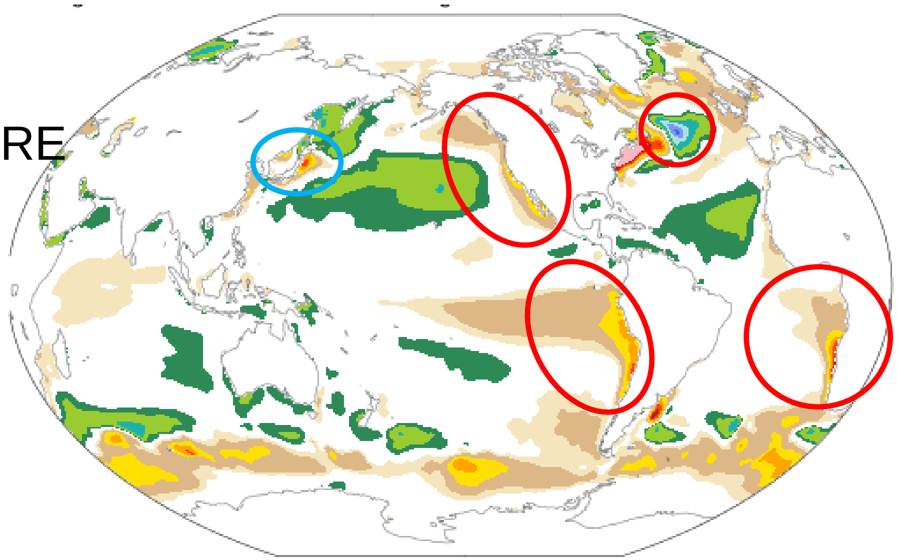
Sea surface temperature bias

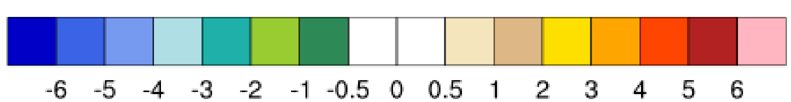
- SST is a fundamental variable for air-sea interaction, governing e.g. where and when rainfall and clouds will occur, on several different scales
- Therefore SST bias reduction is important
- Resolution studies
  - Sensitivity to atmosphere resolution
  - Sensitivity to ocean resolution
  - Overall sensitivity

SENSITIVITY TO ATMOSPHERE RESOLUTION

LOW-RES ATMOSPHERE BIAS

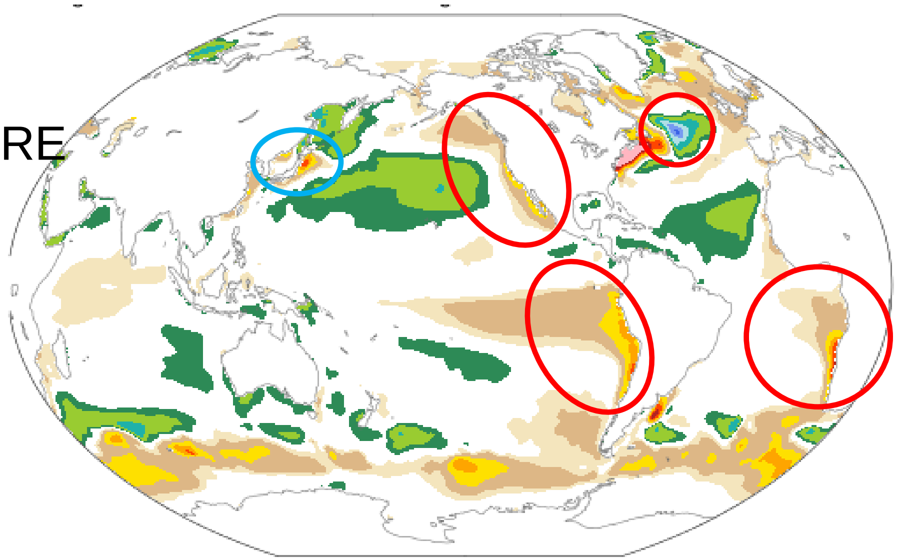


SST bias, CESM with 1deg atmosphere, 1deg ocean. Relative to HADISST. Annual mean



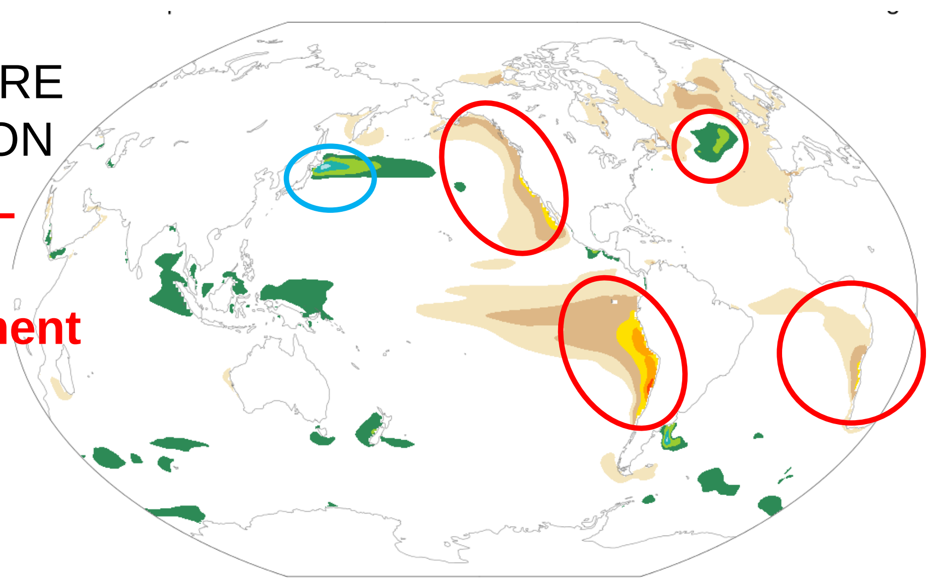
SENSITIVITY TO ATMOSPHERE RESOLUTION

LOW-RES ATMOSPHERE BIAS



SST bias, CESM with 1deg atmosphere, 1deg ocean. Relative to HADISST. Annual mean

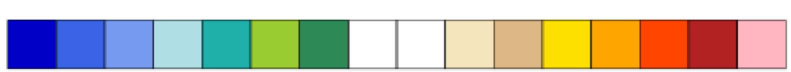
HIGH-RES ATMOSPHERE CORRECTION



SST difference, CESM with 1deg ocean: 1deg. atmosphere minus 0.25deg atmosphere.

Sign convention – matching colors implies improvement with resolution.

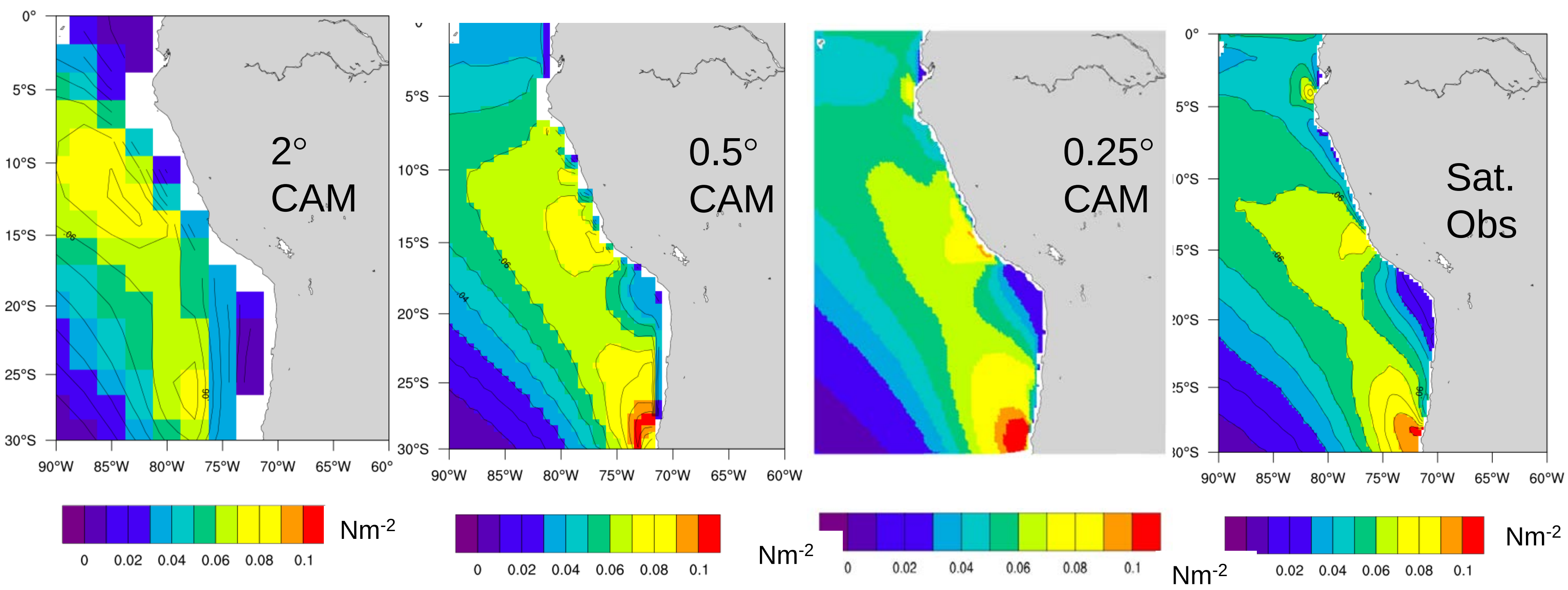
Red circles: bias improved with hi-res atmos.
Blue circles: bias gets worse with hi-res atmos.



Gent et al 2010

Eastern boundaries

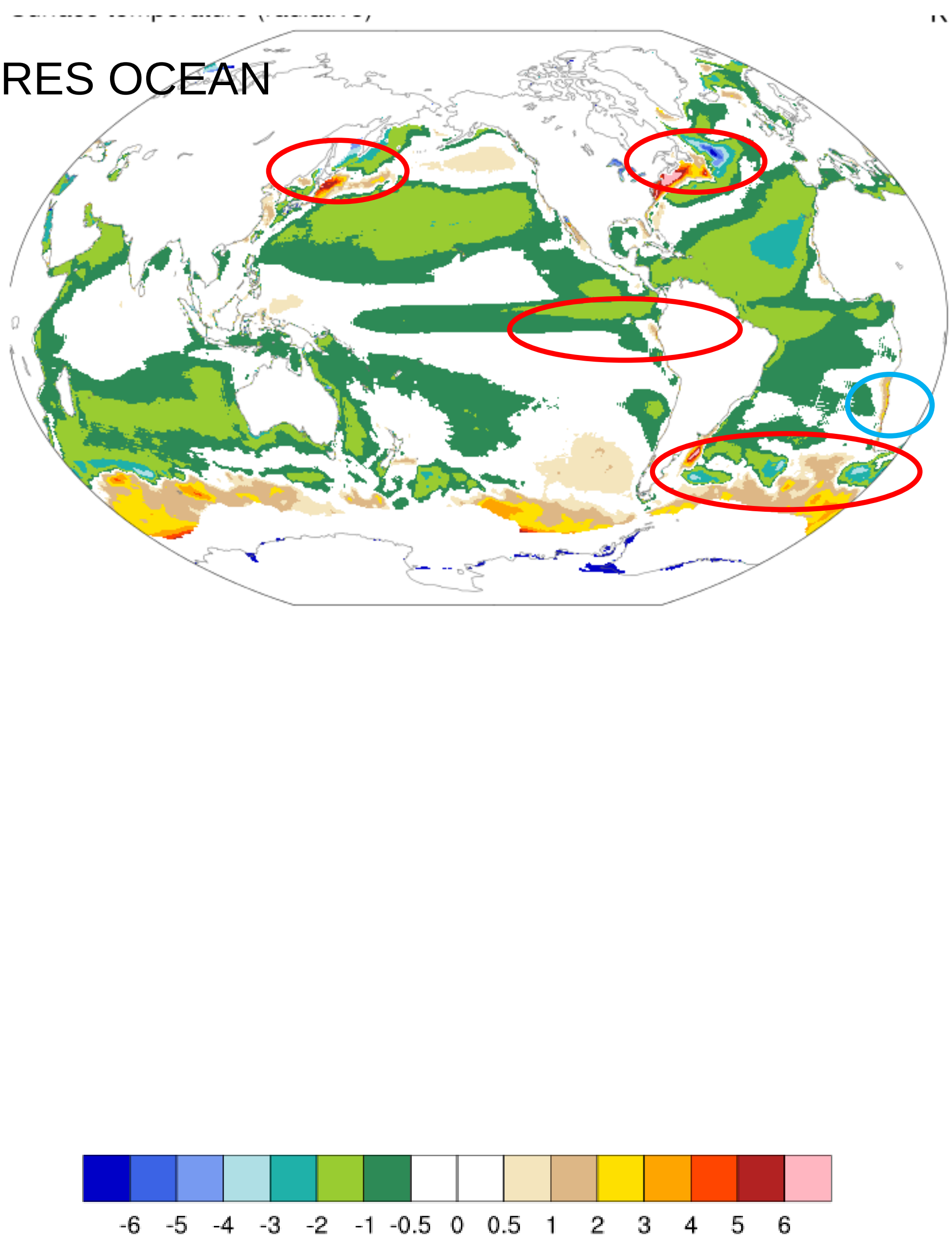
- Northward wind stress off Peru/Chile upwelling
- Coastal wind (Gent et al 2010) and wind stress curl (Small et al 2015) problems



SENSITIVITY TO OCEAN RESOLUTION

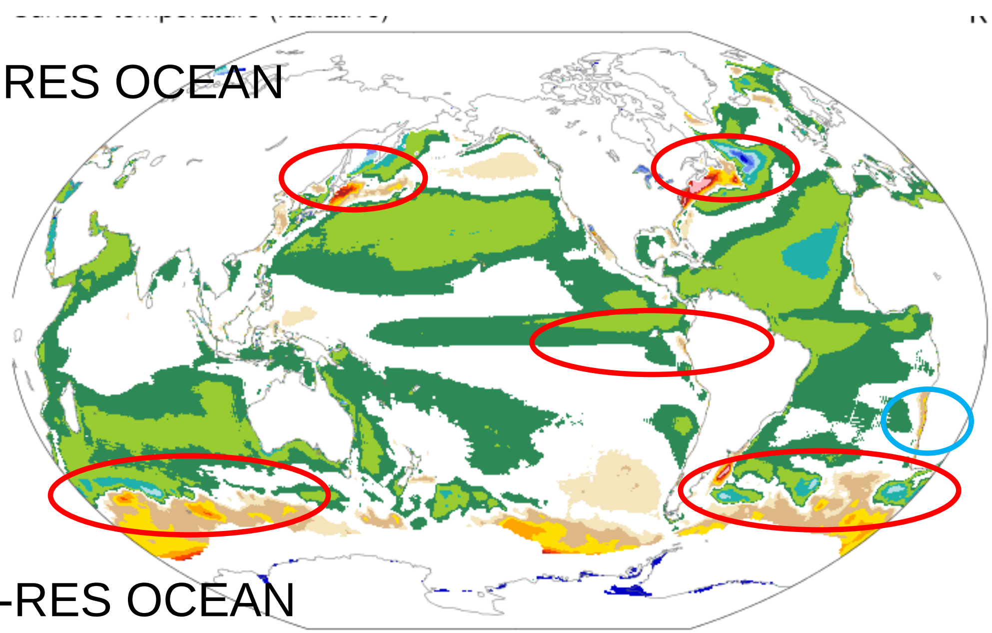
LOW-RES OCEAN BIAS

SST bias, CESM with 0.25deg atmosphere, 1deg ocean. Relative to Reynolds (2007). Annual mean



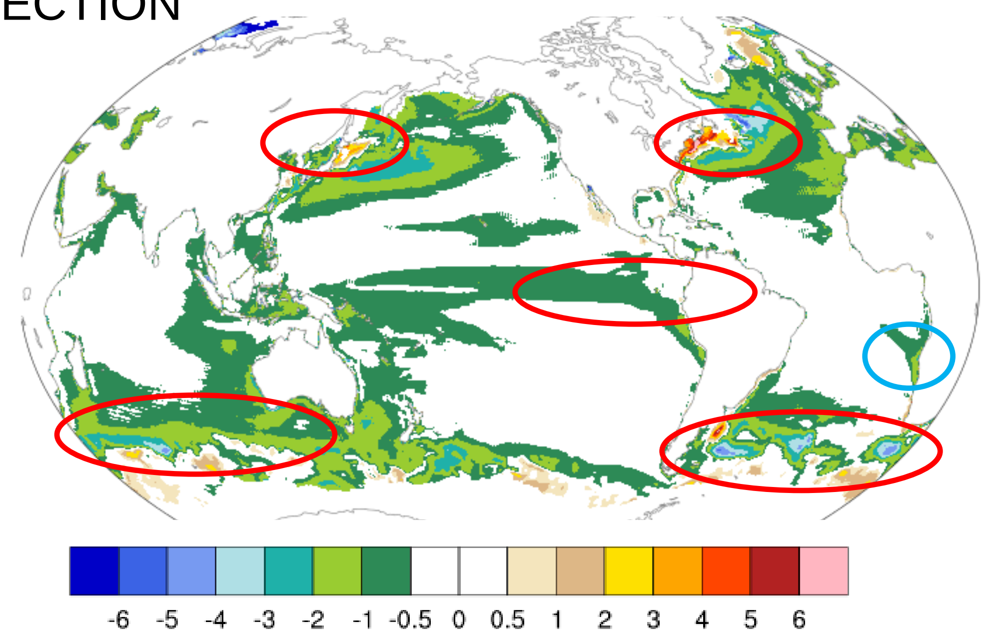
SENSITIVITY TO OCEAN RESOLUTION

LOW-RES OCEAN BIAS



SST bias, CESM with 0.25deg atmosphere, 1deg ocean. Relative to Reynolds (2007). Annual mean

HIGH-RES OCEAN CORRECTION



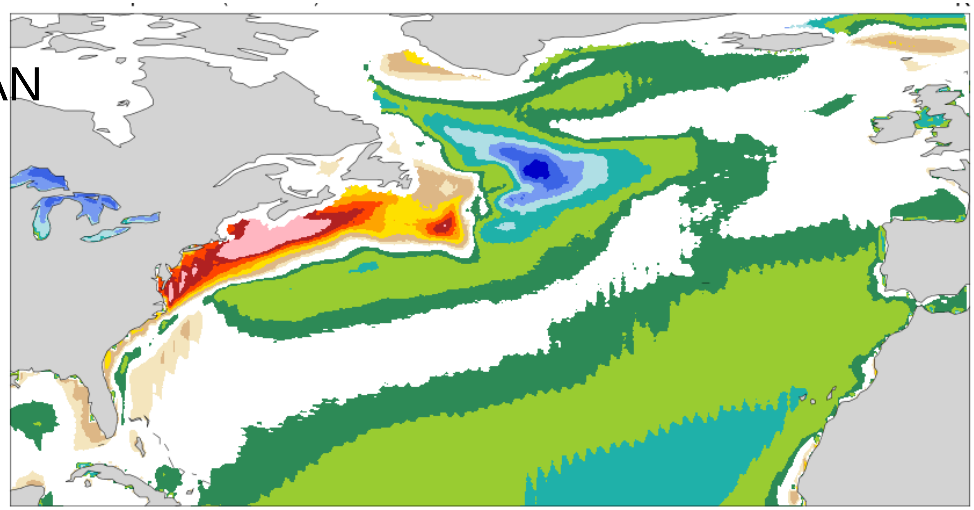
SST difference, CESM with 0.25deg atmosphere: 1deg. Ocean minus 0.1deg ocean.

Red circles: bias improved with hi-res ocean.

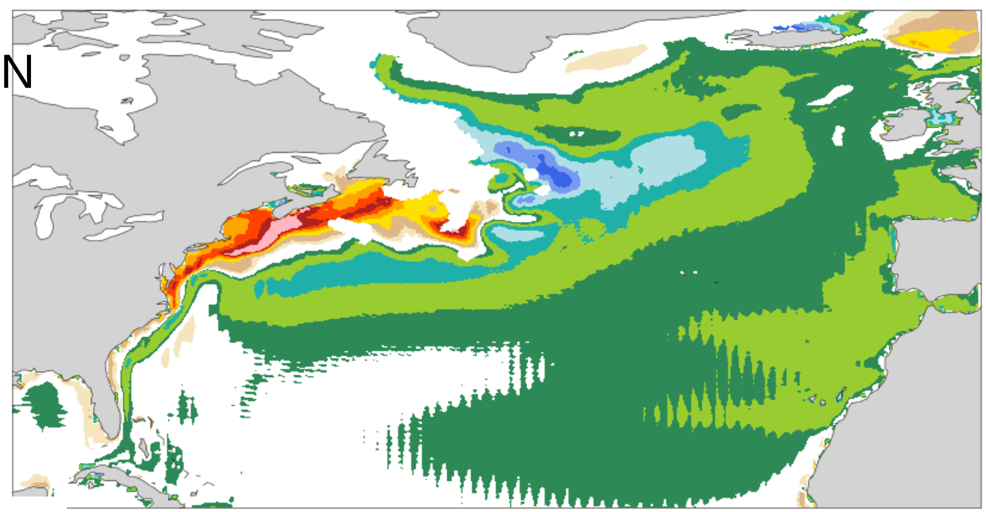
Blue circles: bias gets worse with hi-res ocean.

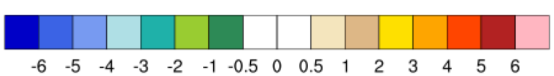
Western Boundaries and Antarctic Circumpolar Current

LOW-RES OCEAN BIAS



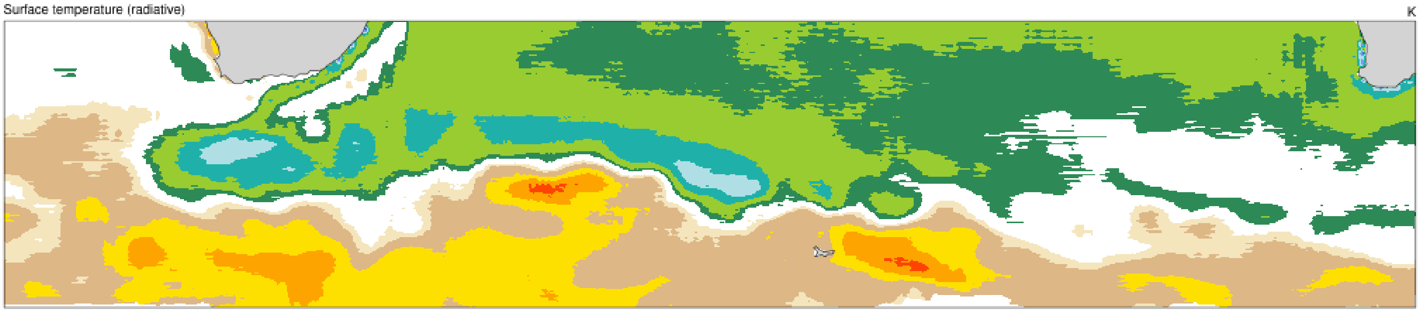
HIGH-RES OCEAN CORRECTION



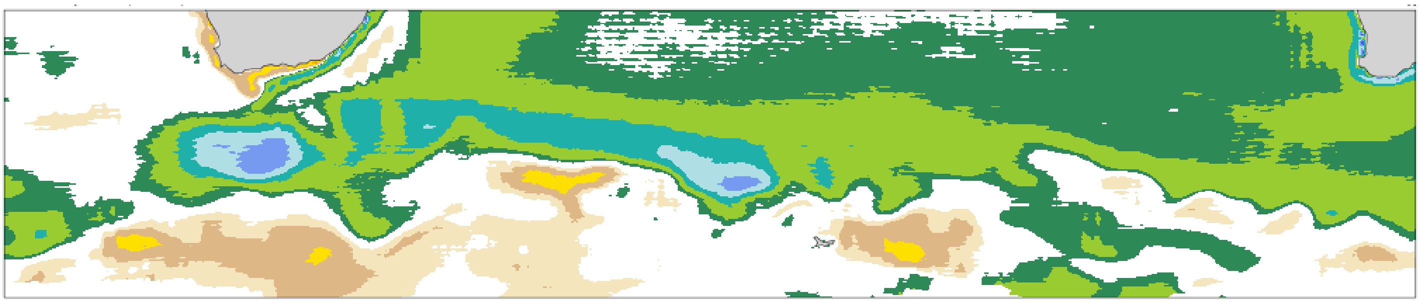


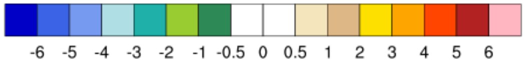
Western Boundaries and Antarctic Circumpolar Current

LOW-RES OCEAN BIAS



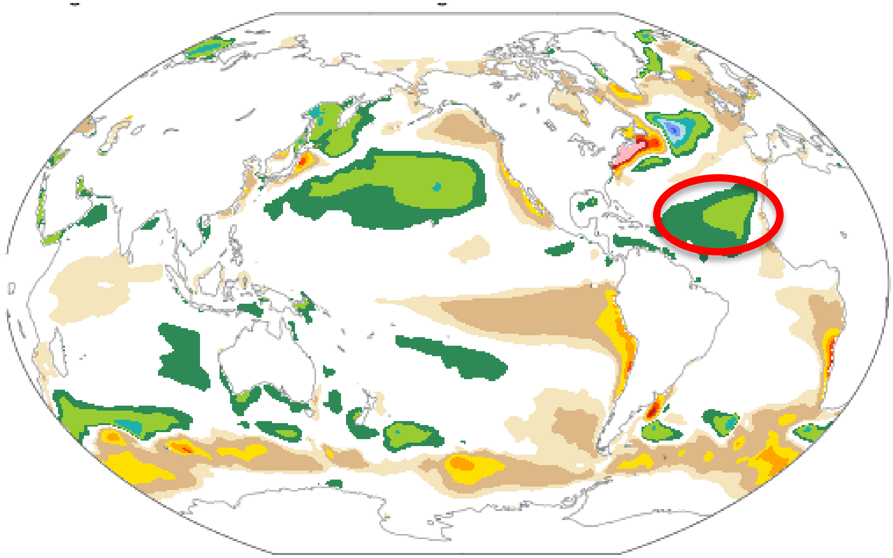
HIGH-RES OCEAN CORRECTION





SENSITIVITY TO **OVERALL** RESOLUTION

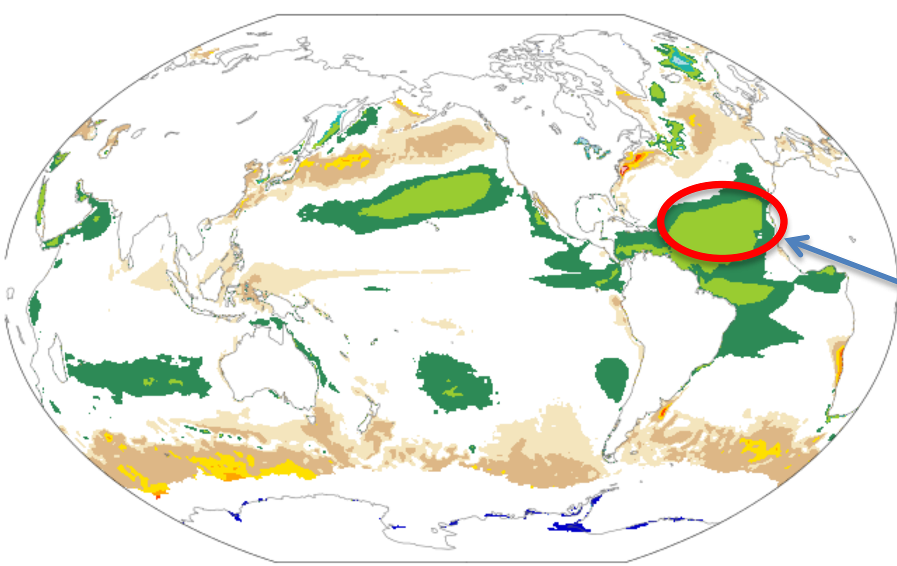
LOW-RES CESM



SST bias, CESM with 1deg atmosphere, 1deg ocean. Annual mean

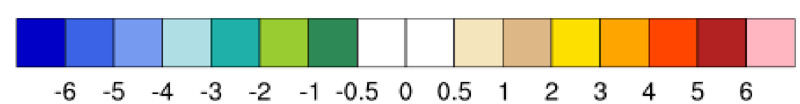
Compare to CCSM4 standard res – change of physics

HIGH-RES CESM



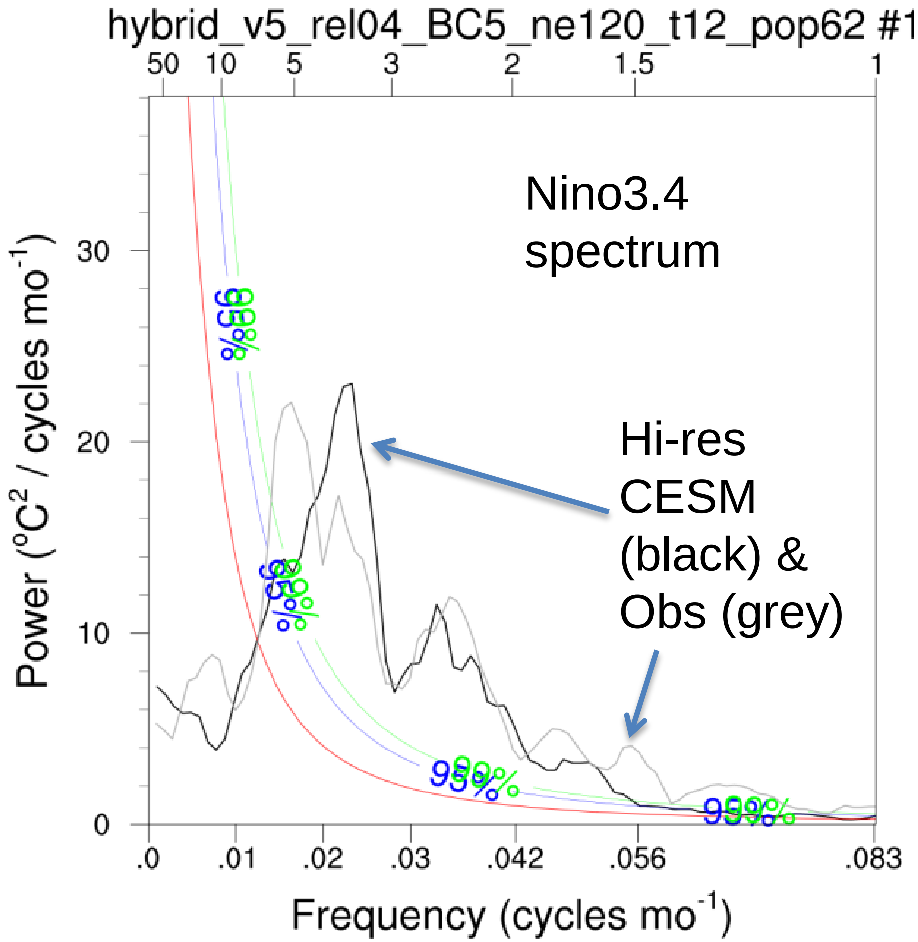
SST bias, CESM with 0.25deg atmosphere, 0.1deg ocean. Annual mean

TC generation region – too cool



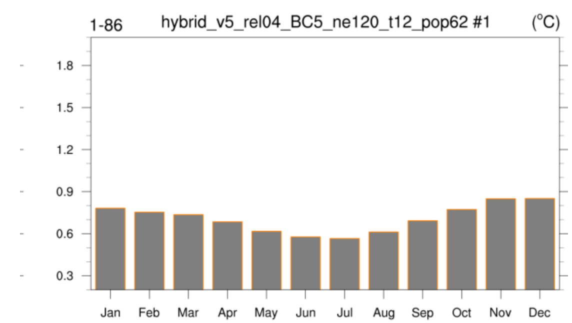
ENSO

Niño3.4 index

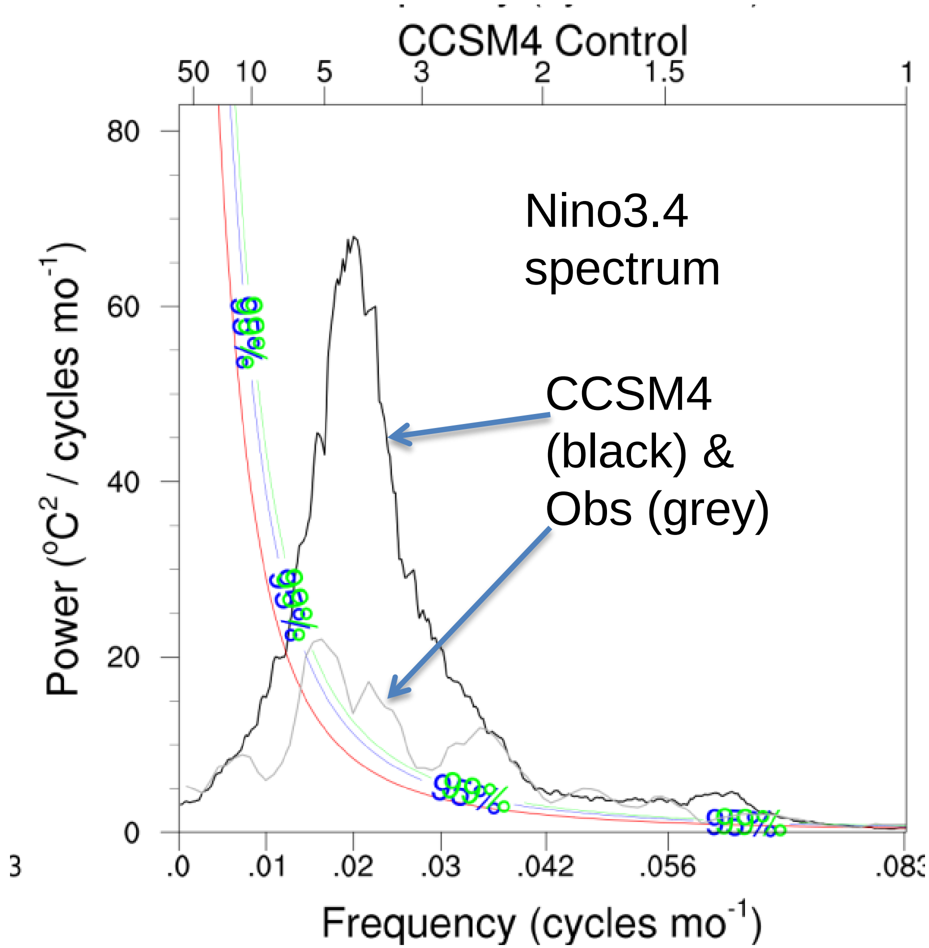


Above: Power spectrum of Nino3.4 index from full record of observations (thin line), the high-resolution coupled model (thick solid line) and from the standard resolution CCSM4 long baseline run. 95% significance levels are overlaid.

SST averaged over Equatorial Eastern Pacific



Above: Seasonal cycle of Nino3.4 variability.



Niño3.4 index

Now from CCSM4. Note change in ordinate.

Caveat: Lots of multi-decadal, centennial variations in ENSO amplitudes revealed by long integrations (Wittenberg 2009, Deser et al. 2012)

ENSO amplitude

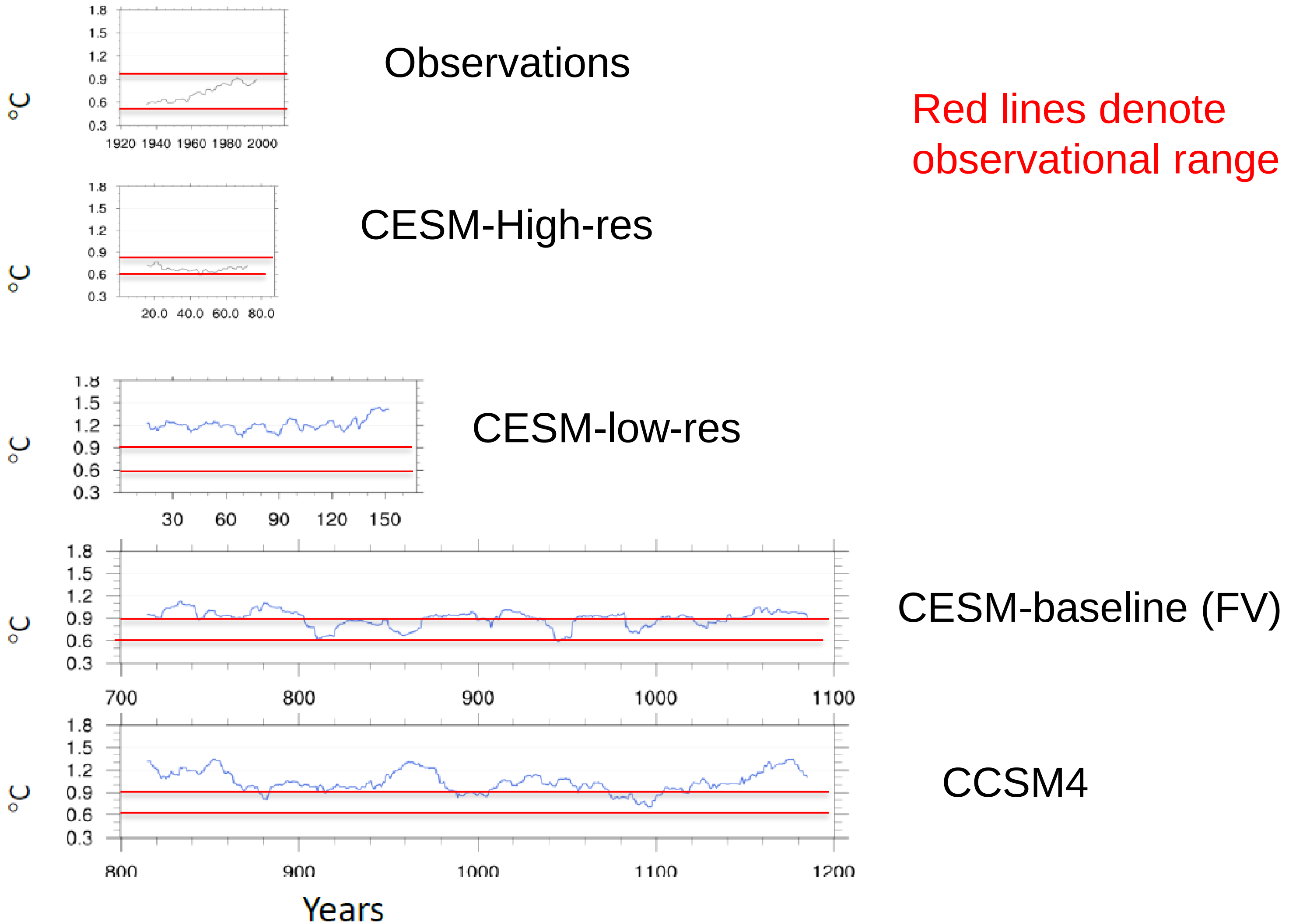
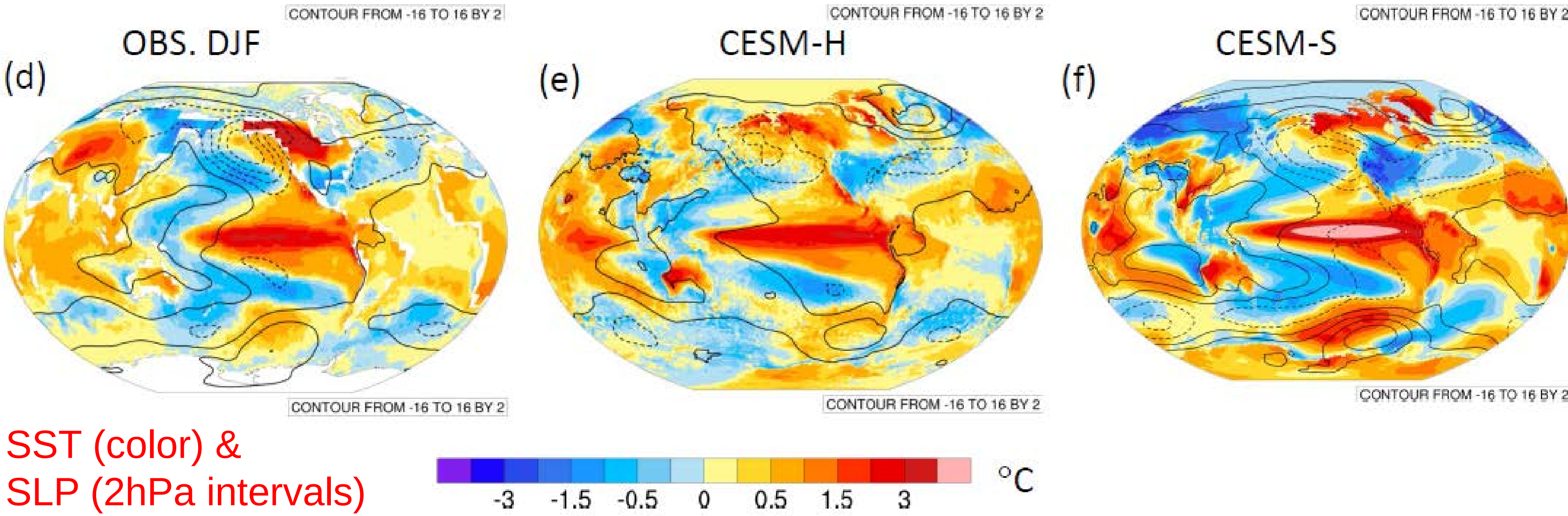


Fig S3: The Nino3.4 index, shown as running 30-year standard deviations [Deser et al. 2012]. Top to bottom: HadISST, CESM-H, CESM-S, CESM long control run, CCSM4 long control run. The absissa range for years is at same scale for each plot.

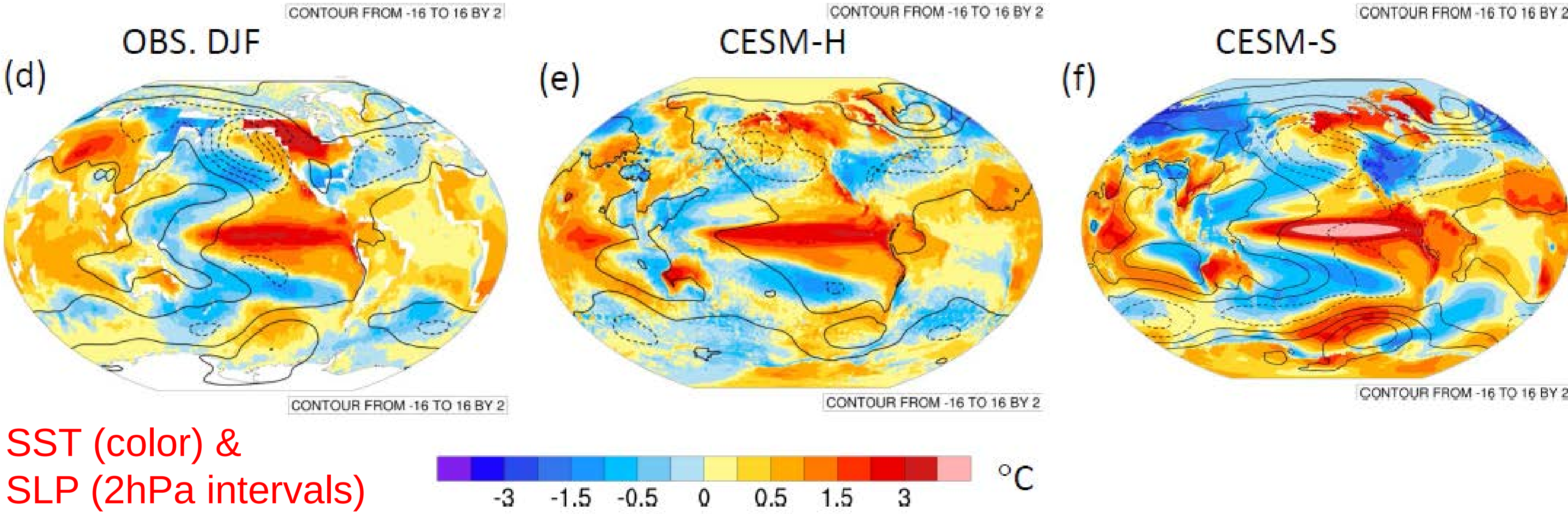
ENSO composites



SST (color) &
SLP (2hPa intervals)

Fig. 13. ENSO composites based on warm minus cold events of greater than +/- 1 standard deviation of Nino3.4 timeseries.

ENSO composites



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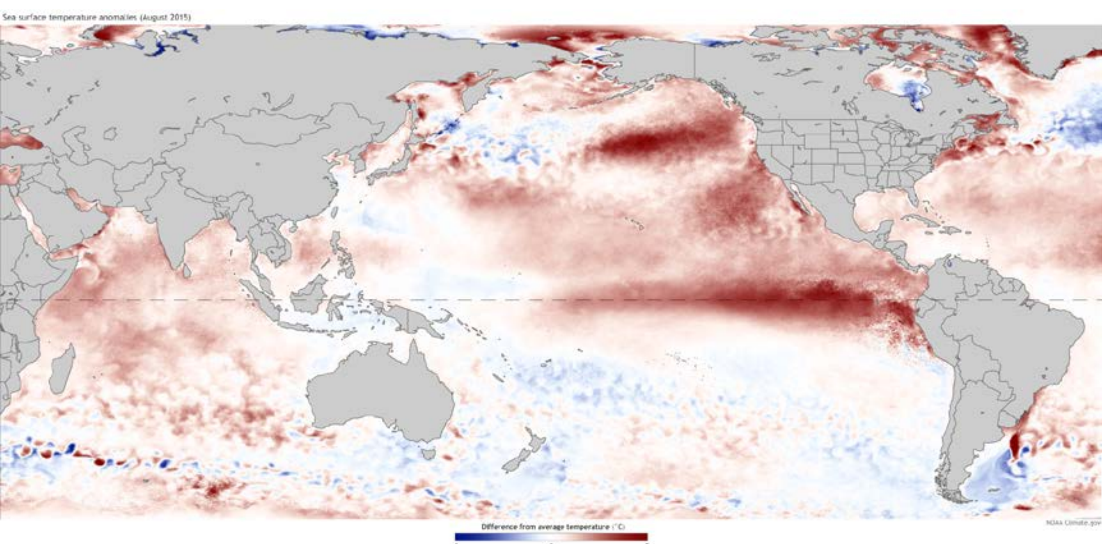
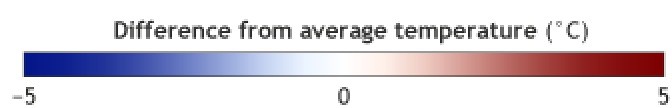


Sea surface temperatures during August 2015 compared to the 1981-2010 average. Climate.gov figure, based on data from NOAA View.



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Small-scale large-scale interactions

- Some potential studies
- ENSO and hurricanes,
- Atmospheric rivers, ENSO, PDO

Animation of precipitation

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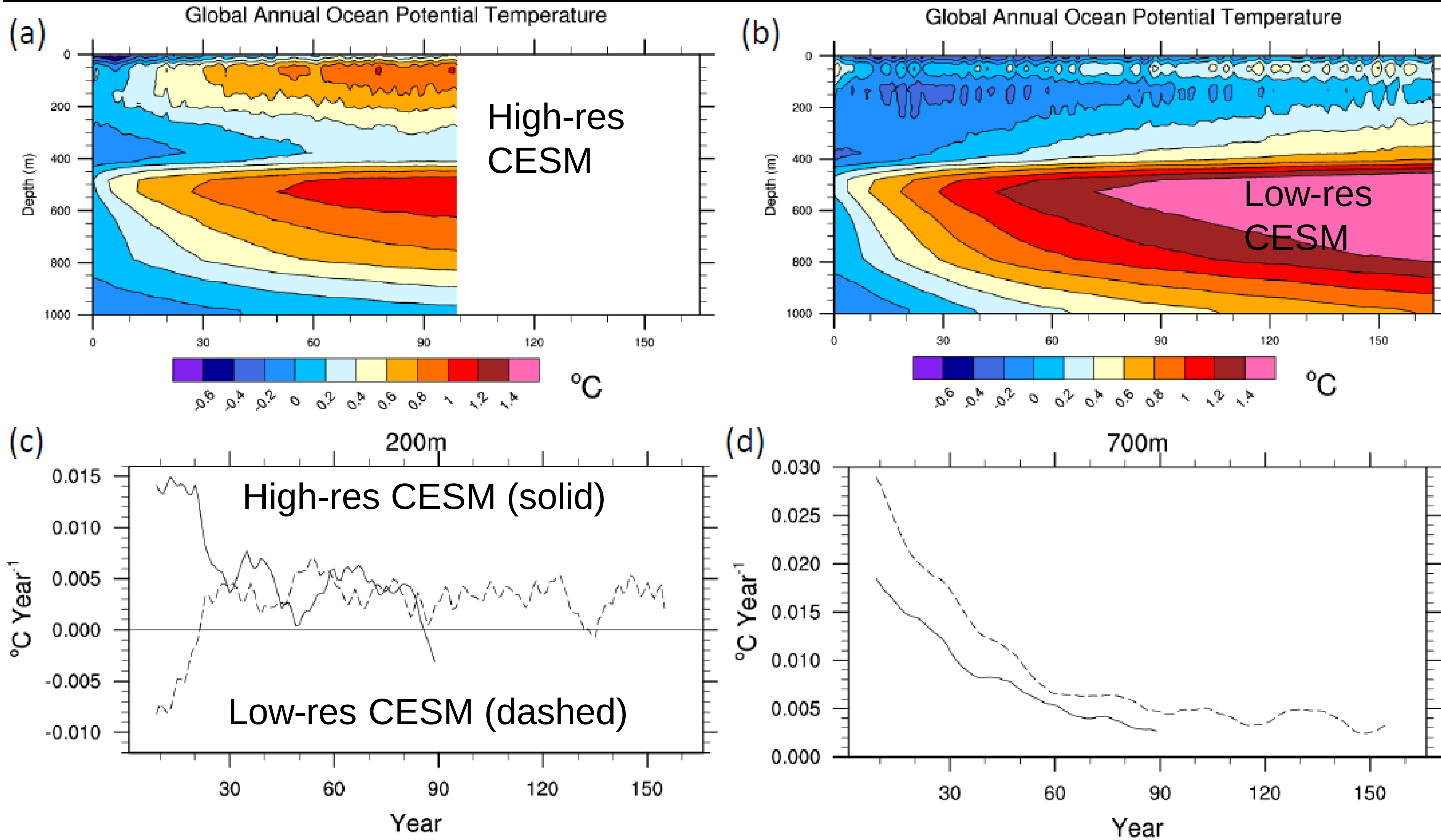
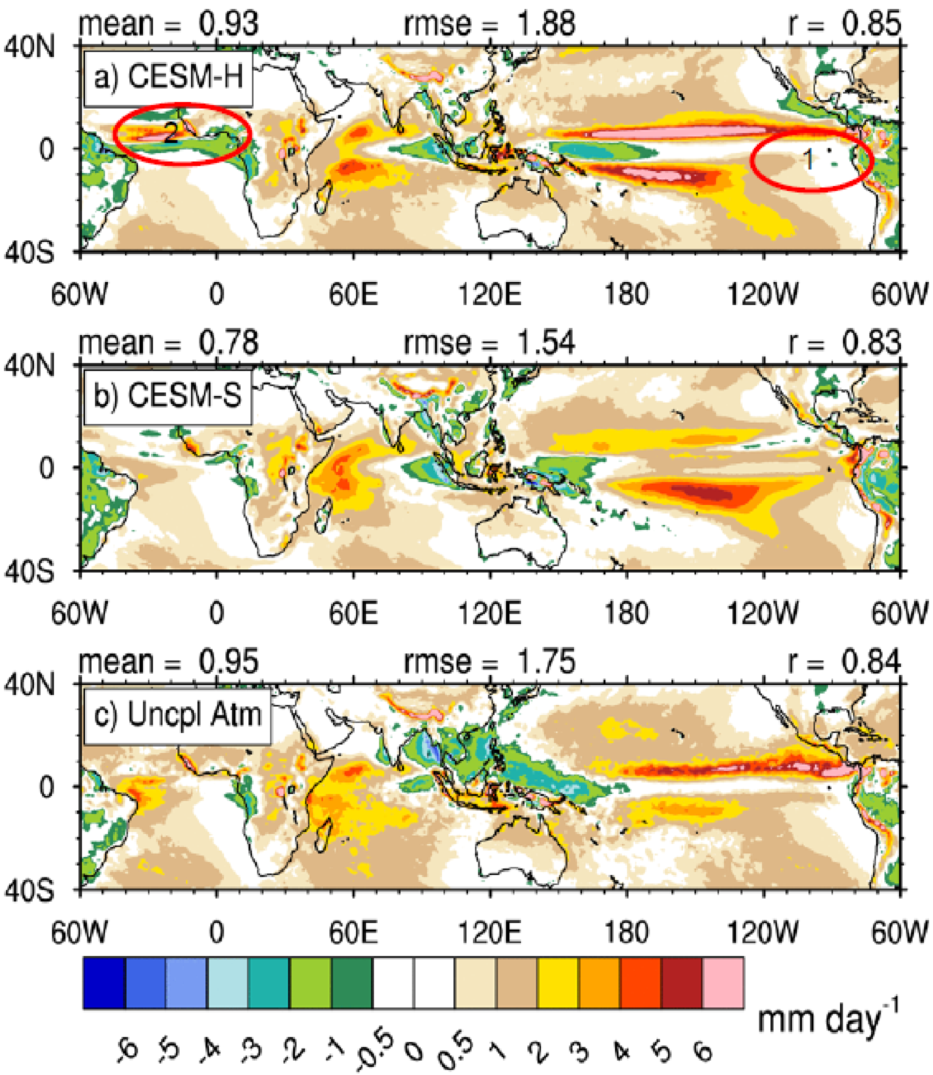


Fig. 2. a, b) globally averaged ocean potential temperature difference from initial condition, vs depth to 1000m, for a) CESM-H, and b) CESM-S. c, d) Time rate of change of temperature for CESM-H (solid) and CESM-S (dashed), at a depth of c) 200m and d) 700m. Data in c, d) has been smoothed twice with a 10-year running mean to remove effect of transients.

Precipitation bias

Relative to TRMM



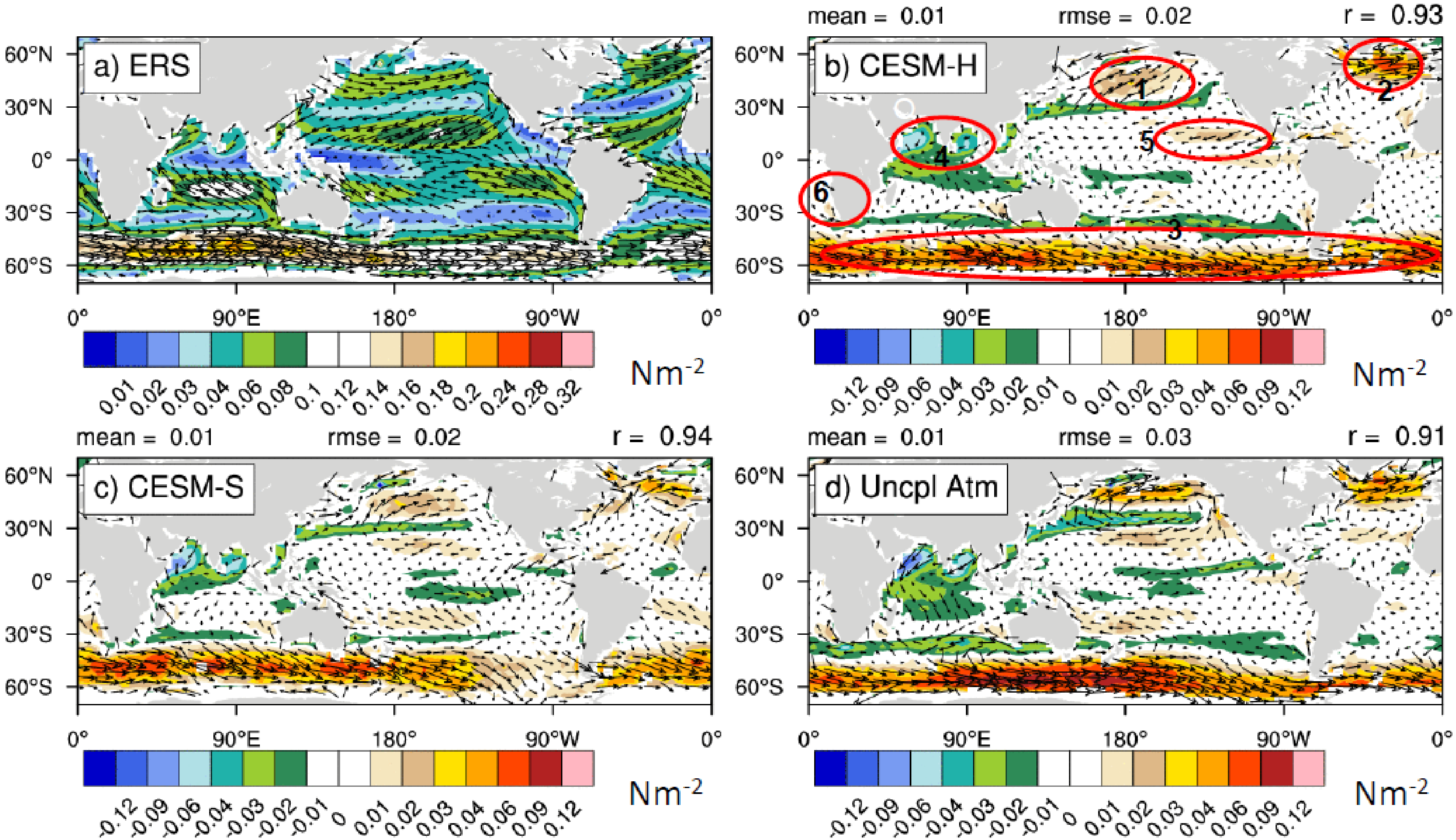
High-res CESM

Low-res CESM

High-res Atmosphere only

High-res CESM has overly-strong ITCZ. Coupling makes it worse (same for 1deg ocean or 0.1deg ocean)

Wind stress bias



Wind stress too strong in CESM in mid-latitudes at all resolutions.

Summary

- 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.

Recommendations (my own view)

- Physics studies need to be continued at standard resolution to improve biases
- Targeted high-resolution studies
  - High-res MIP (Haarsma, Roberts, Bacmeister et al)
- Mesh-refinement
  - CAM-SE, MPAS(A), MPAS(O)
  - Scale-aware parameterization challenge

Data Access

- Data available
  - On hpss and spinning disk (/glade/p/ncgd0001)
  - on Earth System Grid (ESG)
  - http://www.earthsystemgrid.org/
- Data:
  - 14 year coupled spin up
  - 86 year main run
  - 40 years of 6-hour or daily data for a number of ocean, atmosphere, ice, land fields
  - Lower-resolution runs

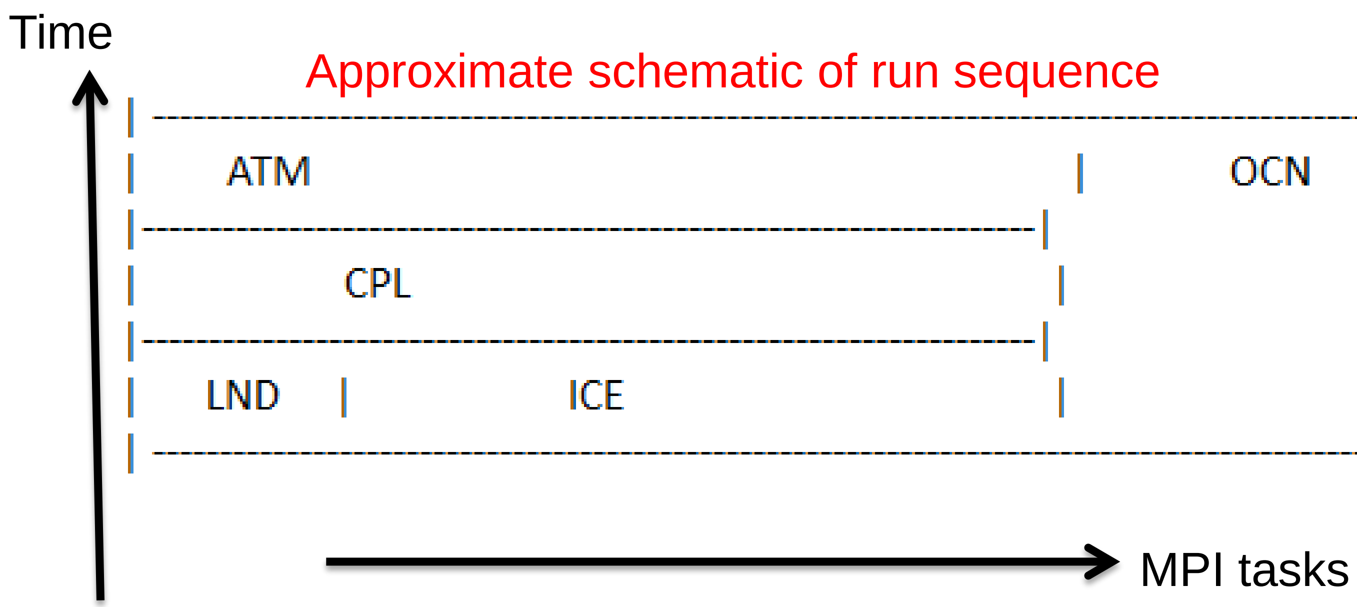
Can be combined for 100 year run

Animation

- Courtesy Tim Scheitlin (CISL, NCAR)
- Color shows SST
- Overlay shows latent heat flux
- Hourly data

Performance on Yellowstone

- Statistics:
  - 2.0 simulated years per day
  - 1 TB of data generated per day
  - 23,404 cores of Yellowstone
  - 300K pe-hours per sim. Year
  - Ocean 2 minute timestep
  - Atmos 10 or 15 minute
- Component configuration
  - Ocean model (6,124 cores)
  - Sea-ice model (16,295 cores)
  - Atmosphere (17,280 cores)
  - Land (900 cores)
  - Coupler (10,800 cores)



Mesoscale Convective Systems over the Rockies and Plains

SHOW ANIMATION

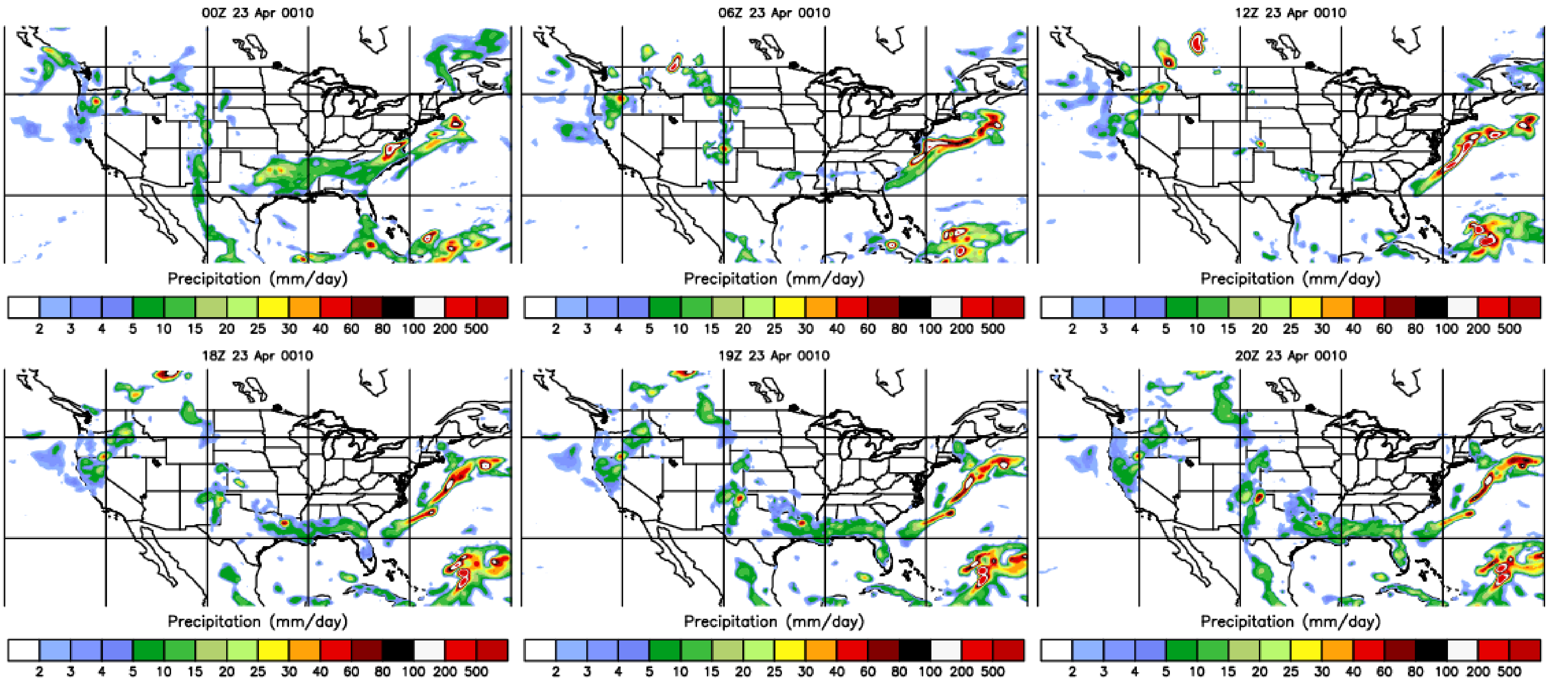
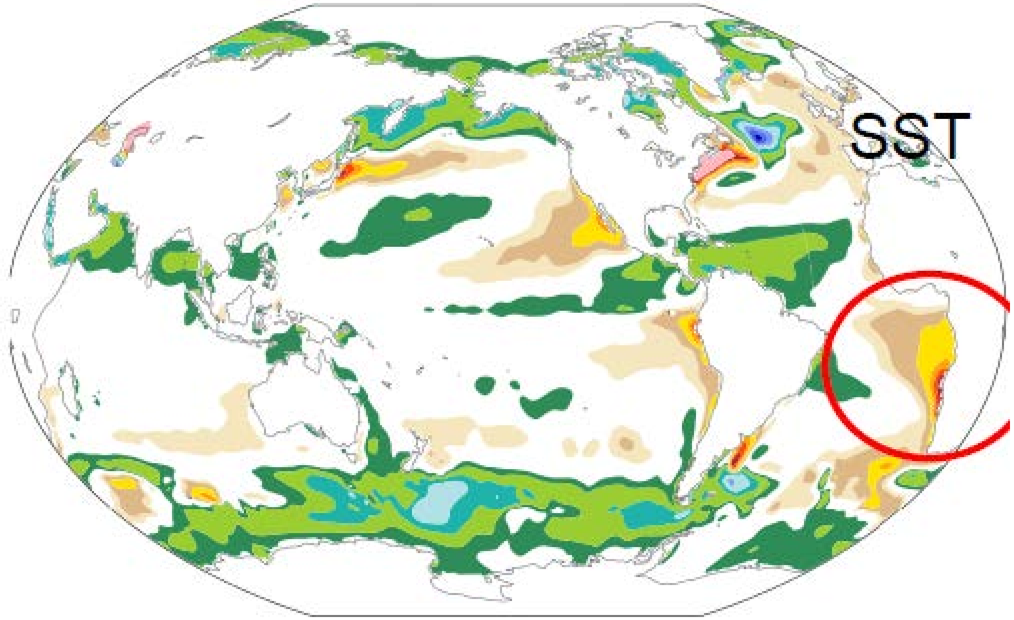


Fig 14B: A sequence for one eastward propagating precipitation event originating over the Rocky Mountains and moving into the Central Plains. The panels show precipitation at 00Z,06Z,12Z,18Z,19Z,and 20Z to illustrate the formation, progression and dissipation of this particular event.

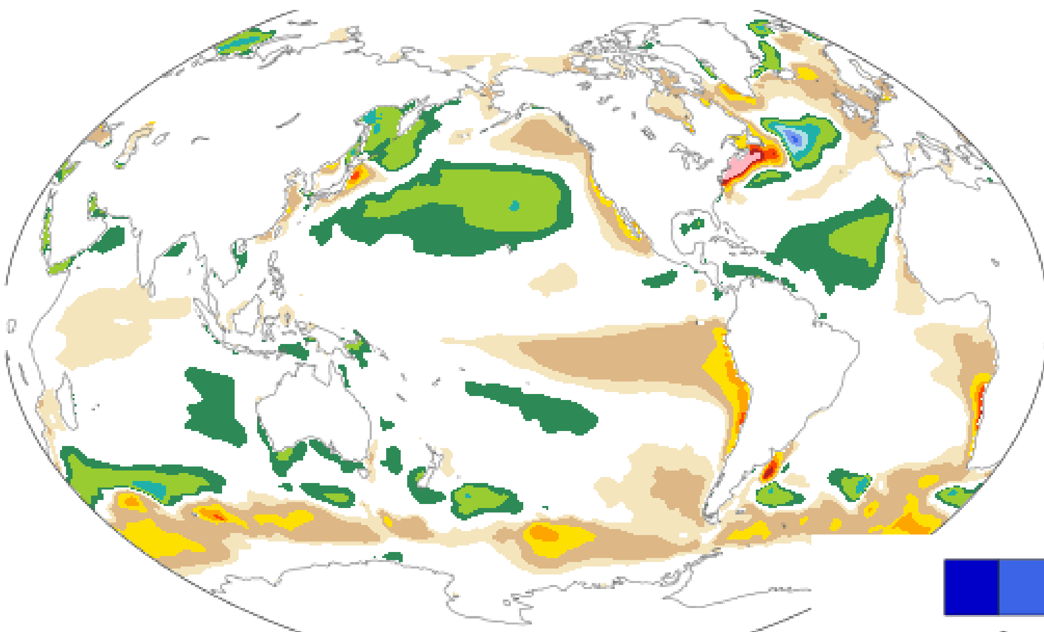
Way forward

- RCP8.5 Scenario run
- Experiments on mesoscale air-sea coupling
- Mesh-refinement of CAM at eastern boundaries – for Benguela?
- Link to BGC BIASES IN EASTERN BOUNDARIES

CCSM4 vs CESM

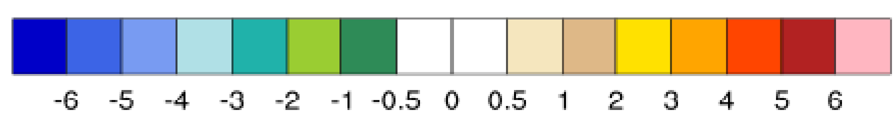


CCSM4 1° model (from Gent e
2011). Long term, annual mea
difference from Hurrell et al. 2
observations.



bias, CESM
1deg
sphere, 1deg
n. Relative to
ISST. Annual
n

Caution – CESM is still evolving – work in progress



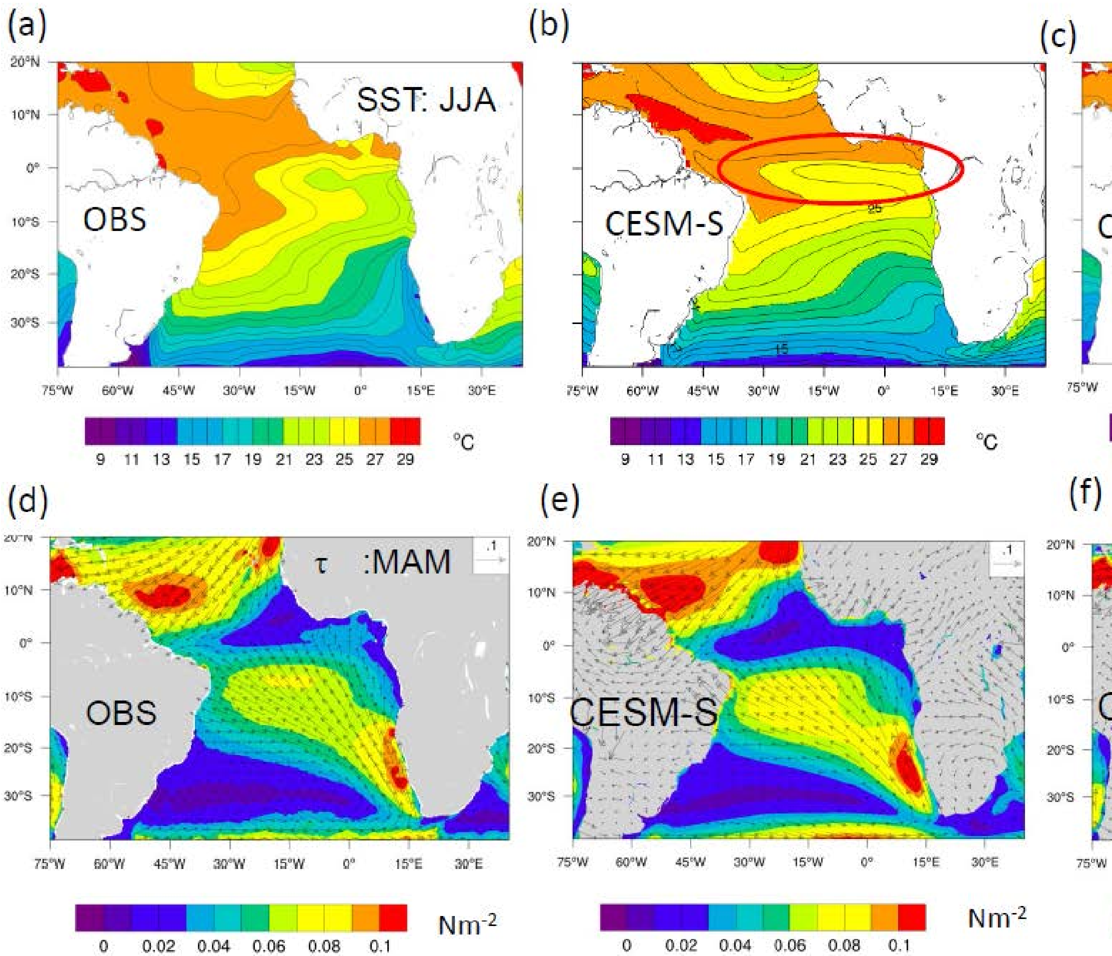
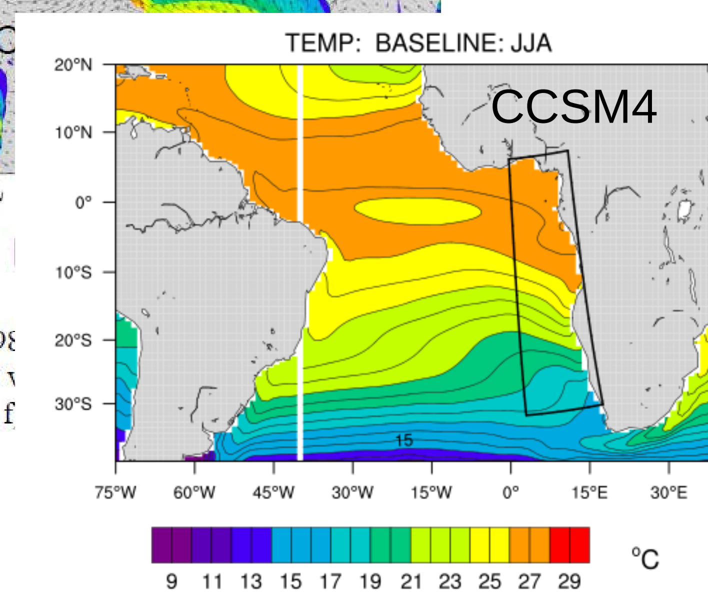
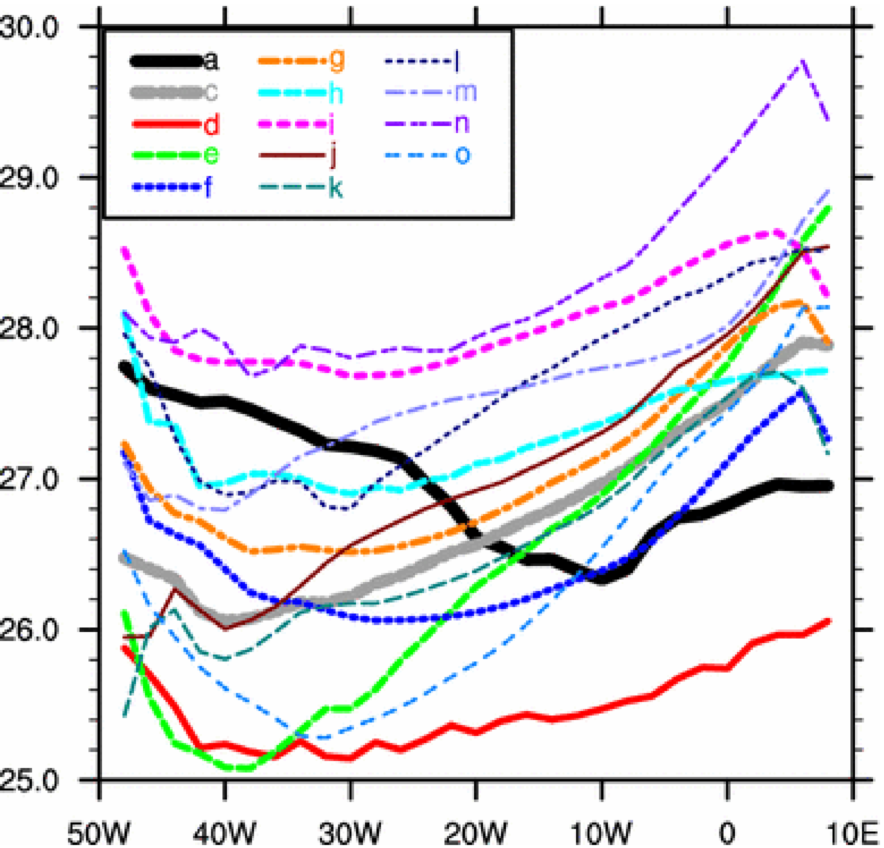


Fig. 11. a-c) Climatological Mean SST for June-July-August (JJA). a) from Levitus/WOA98
Corresponding climatological mean wind stress vectors (Nm^{-2}) and magnitude of the mean v
May (MAM) from d) QuikSCAT observations (Risien and Chelton 2008), e) CESM-S and f



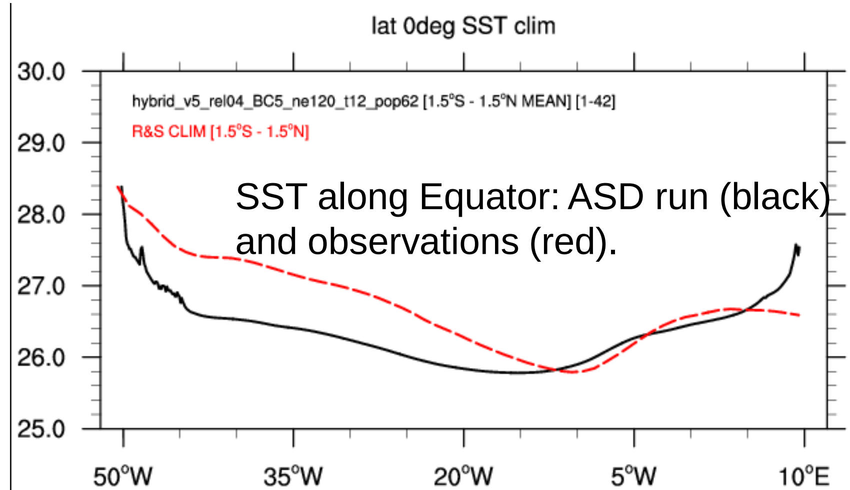
Atlantic Equatorial SST

(a)

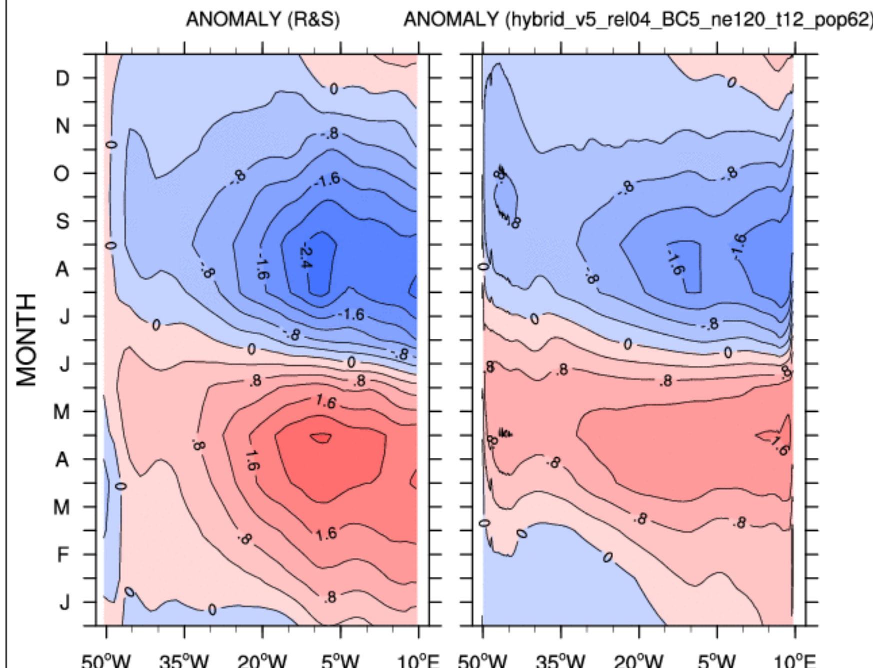


SST along Equator: CMIP 3 models and observations (black). From Richter and Xie 2008.

(b)



(c)



Seasonal cycle of SST along Equator.

Seasonal SST evolution

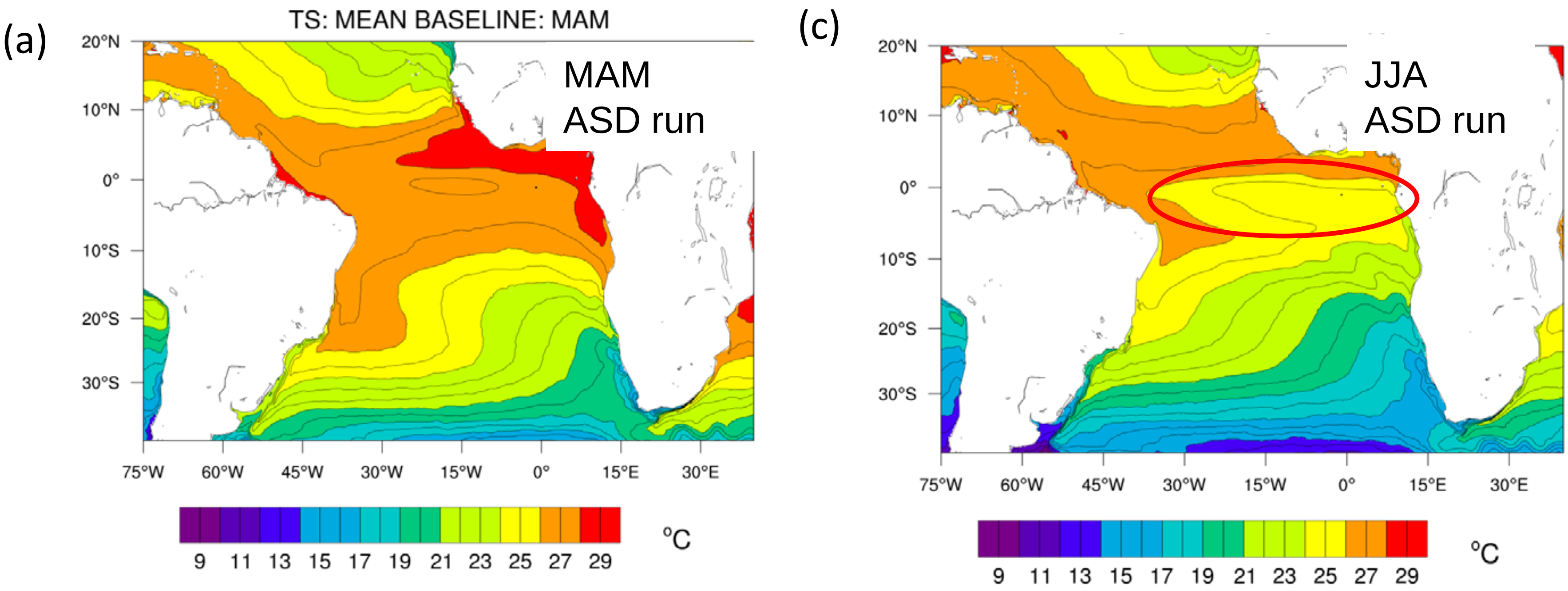
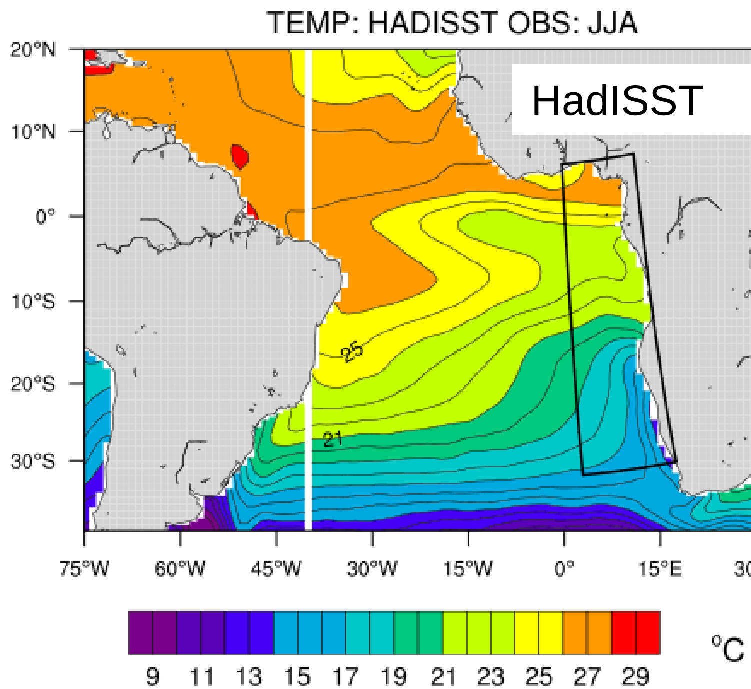
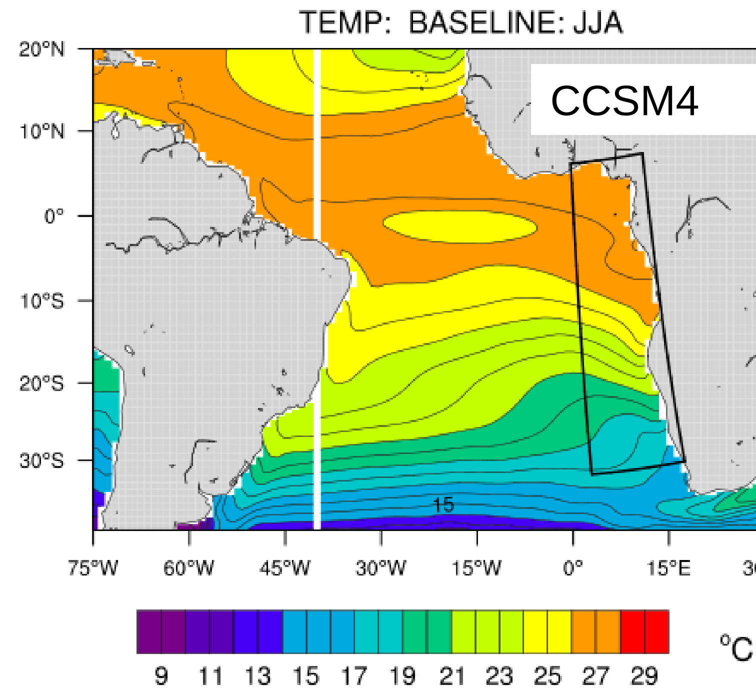
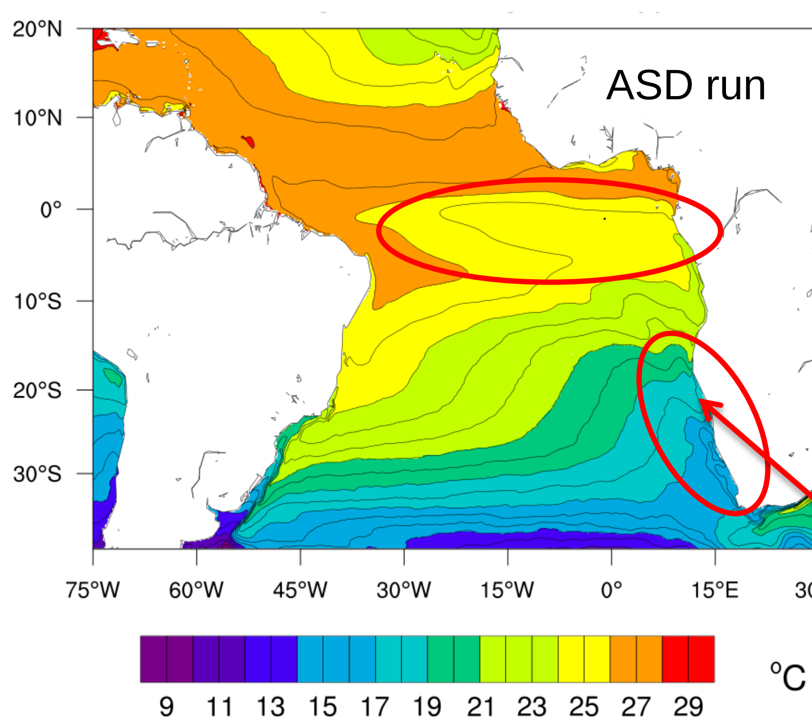


Fig. 10. Climatological Mean SST from ASD run (yr 1-42 of hybrid) in a) March-April-May (MAM) and c) JJA.







Mean SST field for JJA
Note presence of cold tongue in ASD run, (although it is warmer than observed), very different to CCSM4

Discussed last week, OMWG meet