NW Atlantic warming under climate change: new simulations with high-resolution CESM

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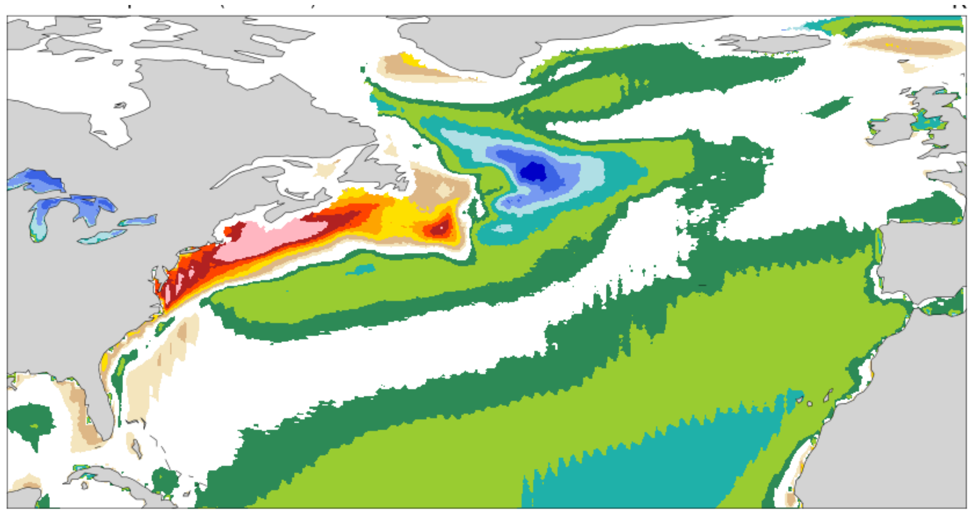
Acknowledging: Mike Alexander, Andrew Thomas, Frank Bryan,
Laurent Terray, Ian Grooms, Adam Phillips

NW Atlantic SST: sensitivity to ocean resolution

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

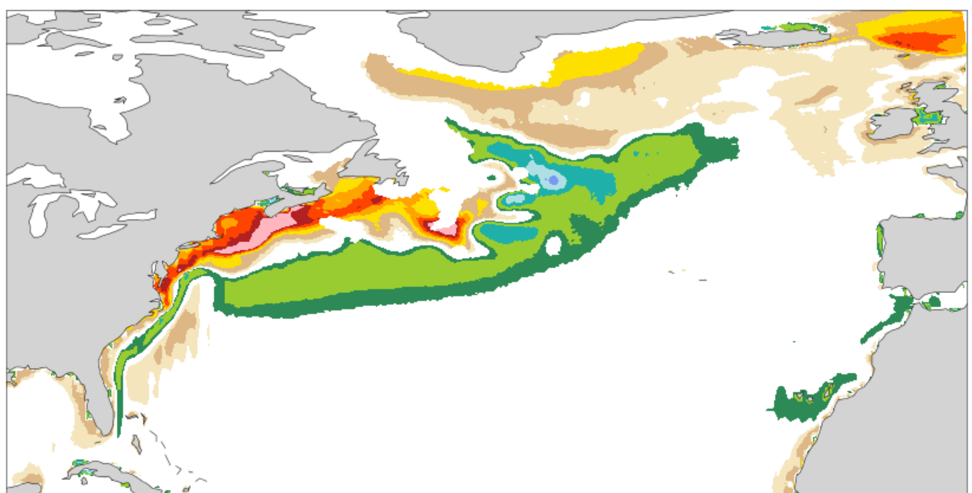
LOW-RES OCEAN SST BIAS



Similar improvement in North-west Pacific/Kuroshio and in Southern Ocean/ACC

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

CHANGE DUE TO HIGH-RES OCEAN



Sign convention – matching colors (top and bottom) implies improvement with resolution.

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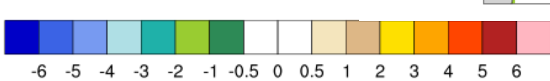
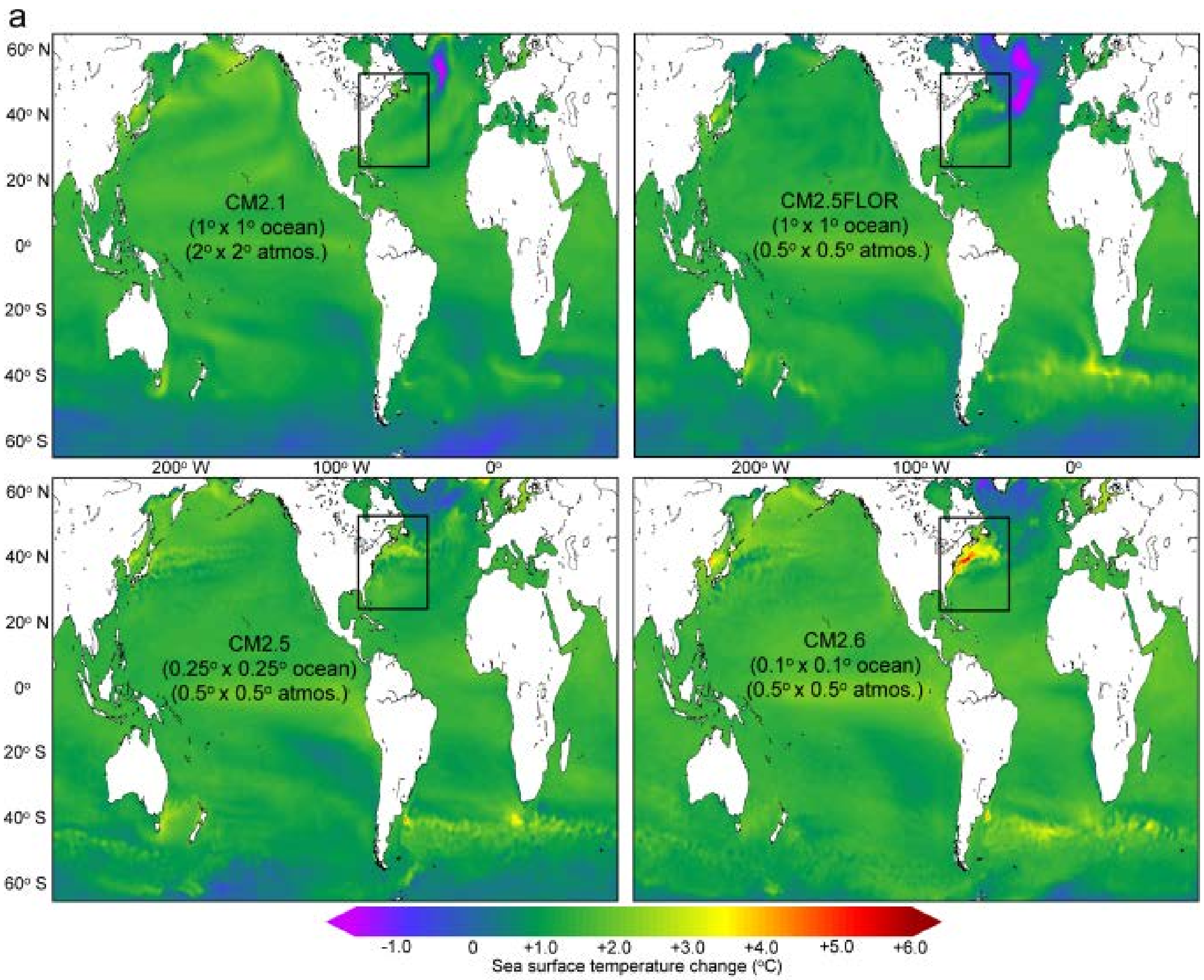


NW Atlantic SST: sensitivity of climate change to ocean resolution

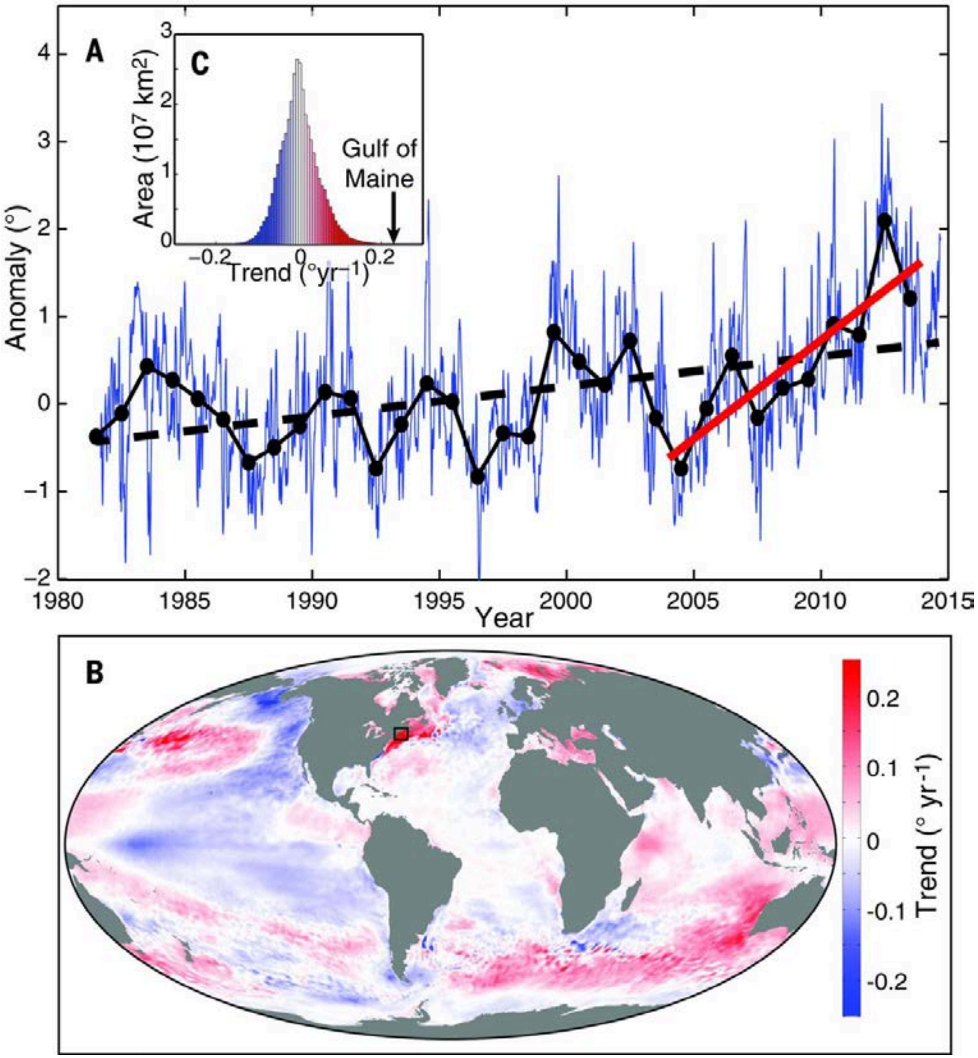


SST difference (averaged over years 60-80) between 1% per year CO_2 increase run and preindustrial control. Bottom right is high-resolution model CM2.6. Model resolutions are labelled. Note enhanced warming in NW Atlantic in CM26.

From **Enhanced warming of the Northwest Atlantic Ocean under climate change**
Vincent S. Saba[1,*], Stephen M. Griffies[2], Whit G. Anderson[2], Michael Winton[2], Michael A. Alexander[3], Thomas L. Delworth[2], Jonathan A. Hare[4], Matthew J. Harrison[2], Anthony Rosati[2], Gabriel A. Vecchi[2] andRong Zhang[2] 2016, JGR

NW Atlantic SST: observations of warming

- Observed warming off US East coast in recent decades
  - Burrows et al 2011, Pershing et al 2015 –link to Gulf Stream and PDO
  - Thomas et al 2017 (submitted), Gulf of Maine lengthening of warm season, partly related to Gulf Stream index (more northern)
- Warming of western boundary currents
  - Wu et al 2012- WBCs warm, shift
- Effect on fisheries
  - E.g. Cod stock reduction (Pershing et al 2015



Pershing et al. 2015, Science. Sea surface temperature trends from the Gulf of Maine and the global ocean.(**A**) Daily (blue, 15-day smoothed) and annual (black dots) SST anomalies from 1982 to 2013, showing the long-term trend (black dashed line) and trend over the decade 2004–2013 (red solid line). (**B**) Global SST trends, 2004–2013. The Gulf of Maine is outlined in black. (**C**) Histogram of global 2004–2013 SST trends, with the trend from the Gulf of Maine indicated at the right extreme of the distribution.

Aims

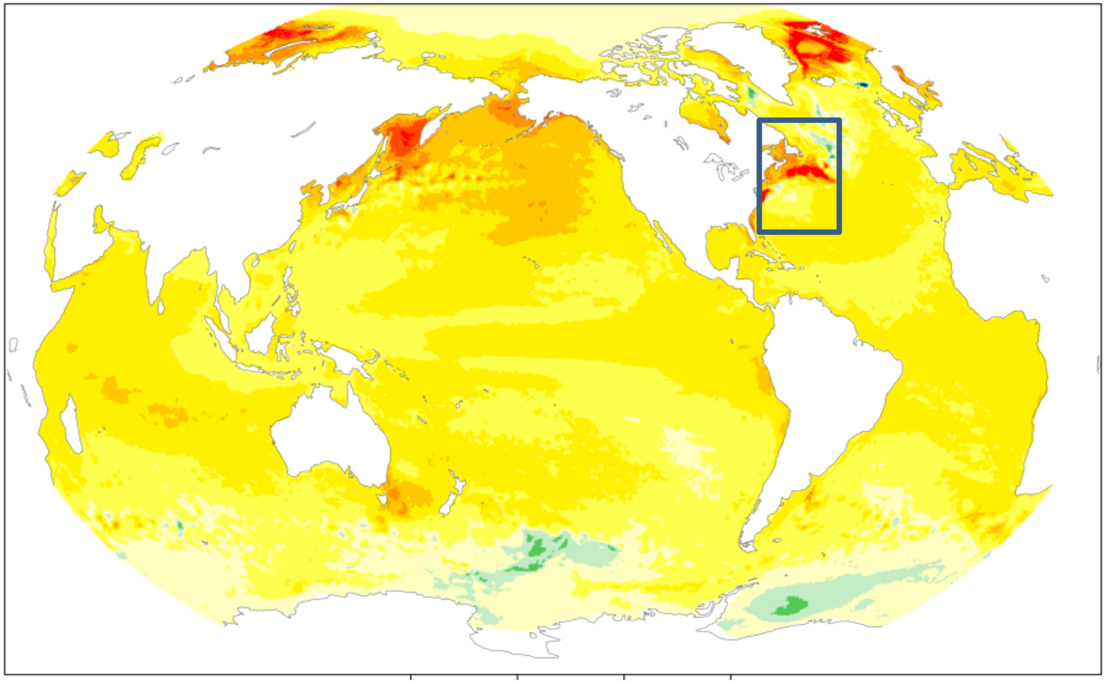
- To determine whether enhanced US East coast warming is seen in high resolution CESM
  - Mini high-res MIP
- Compare with an ensemble of standard resolution models
  - CESM-LE
- Investigate the relationship to AMOC proposed by Saba et al
  - Role of Labrador Current

Climate change scenario with High-resolution CESM

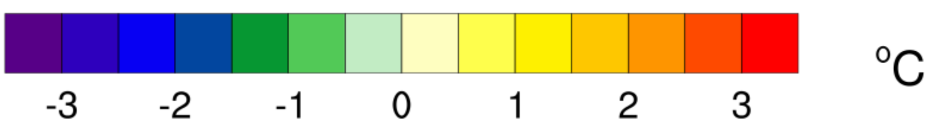
- **NSF allocation: High Resolution Earth System Modeling for International Climate Assessment Using Blue Waters Capabilities**
- PI: Don Wuebbles (University of Illinois)
  - The primary NCAR collaborators and co-PIs: Drs. Warren Washington, Jerry Meehl, Justin Small, and Joseph Tribbia
- High-resolution CESM
  - CAM5.2 SE, 0.25deg
  - POP2, 0.1deg
  - CESM1.0.4, Small et al 2014, JAMES
- Branching off from year 50 of the previous high resolution control run (year 2000 conditions),
  - ran with historical conditions for years 2001-2005,
  - then with the RCP8.5 scenario for 2006-2050.
- Run on Blue Waters supercomputer (University of Illinois)
  - Accompanying simulations include 0.25deg atmosphere, 1deg ocean

SST change, in first half of 21st C

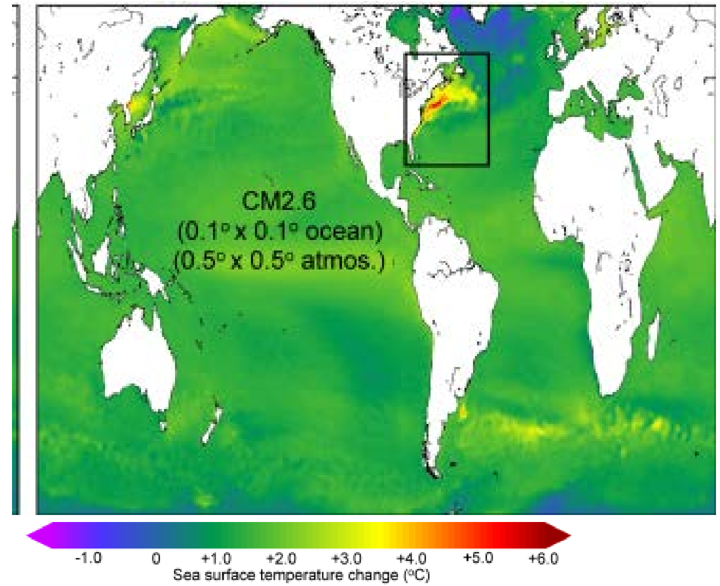
CESM1-high resolution RCP8.5



2006-2015 to 2041-2050



Compare with CM2.6: 1%CO_2

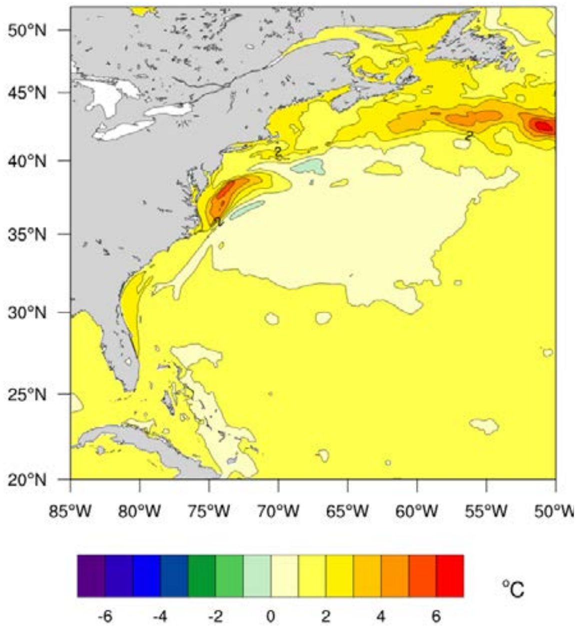


CM2.6 is 0.5deg atmosphere, 0.1deg ocean.

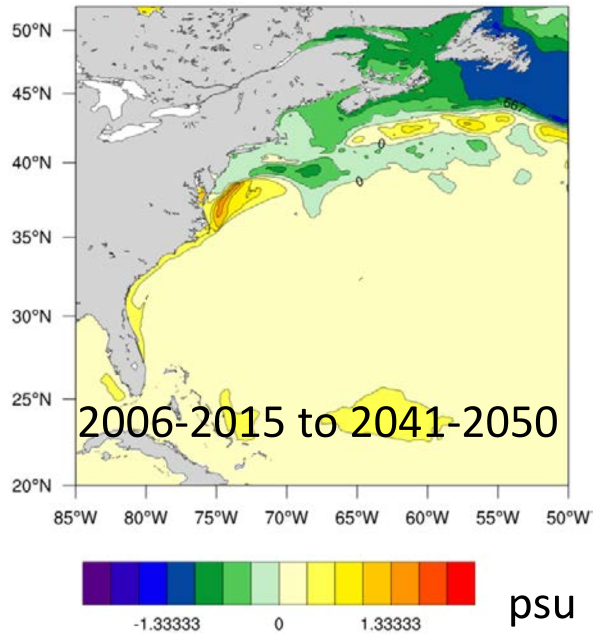
Qualitative agreement comparing the RCP8.5 to the 1%per/yr simulations. North-east USA coast is a hotspot of warming.

Focus on US East coast: surface

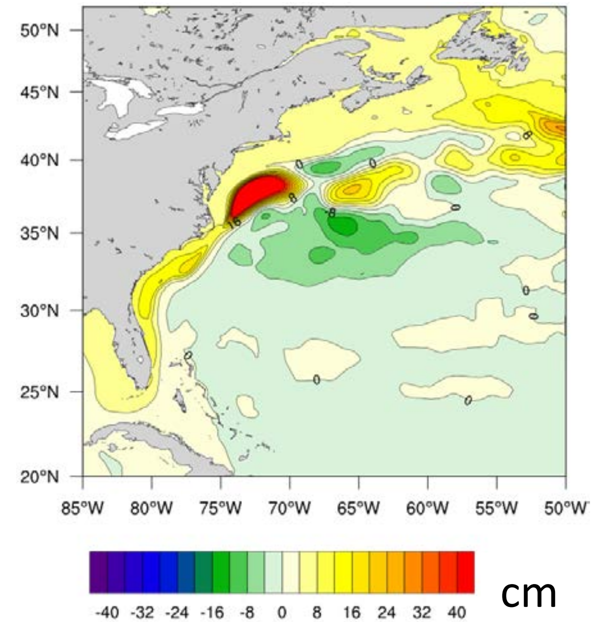
CESM1: SST change

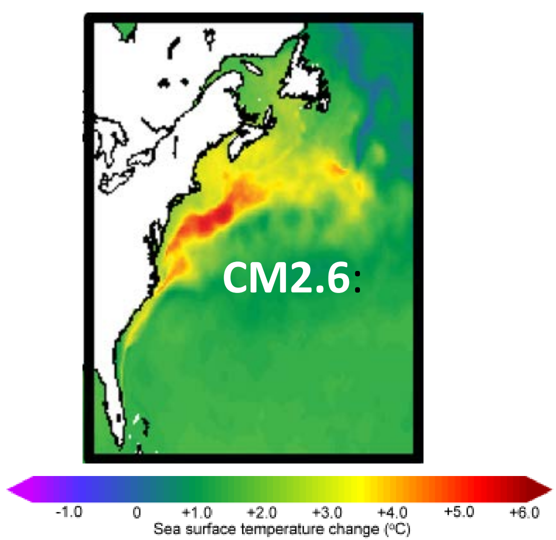


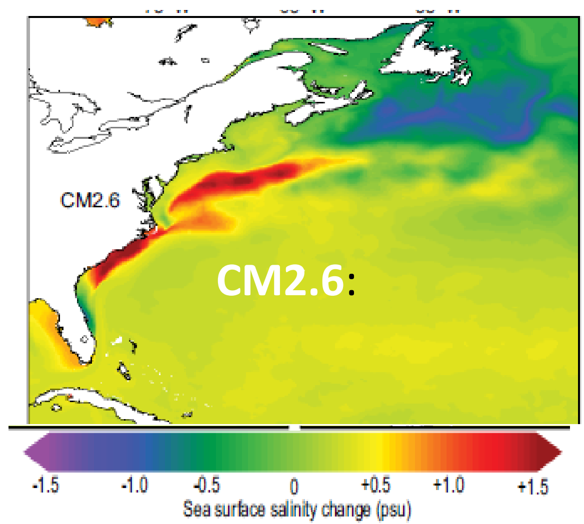
CESM1: Surface salinity change



CESM1: SSH change

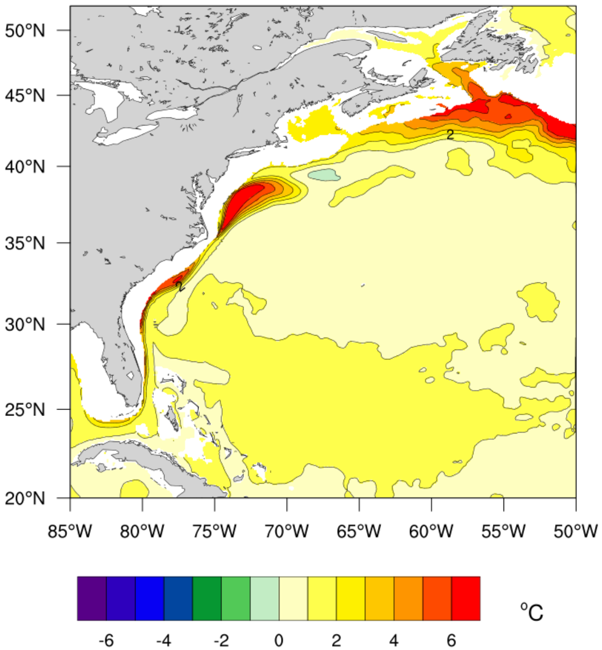




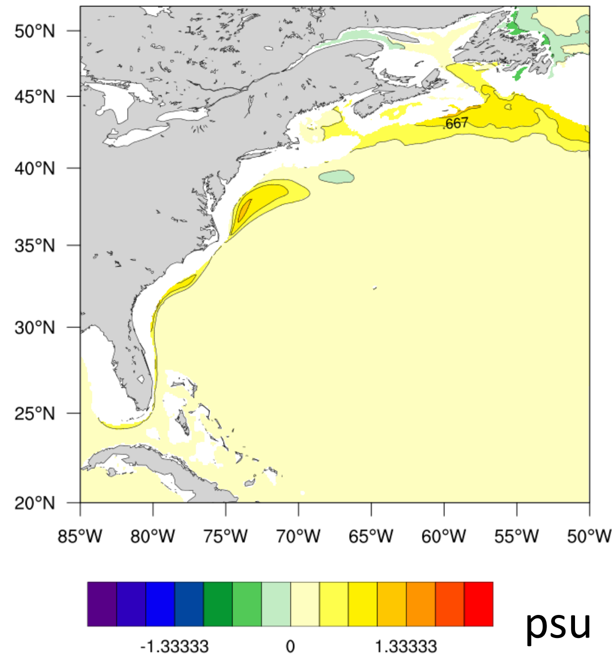


Focus on US East coast: at depth

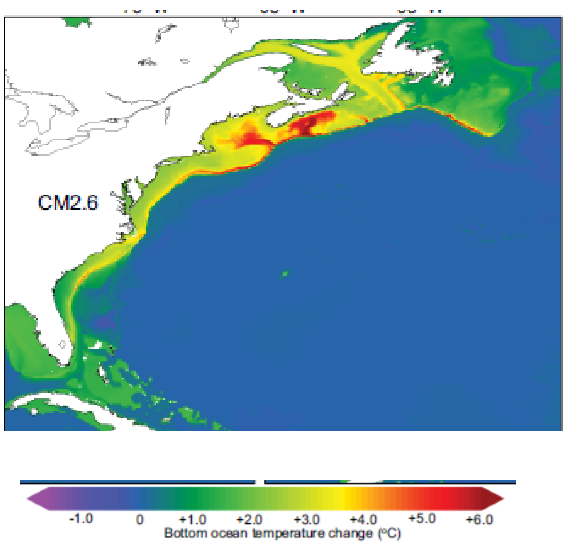
CESM1: Temperature @155m

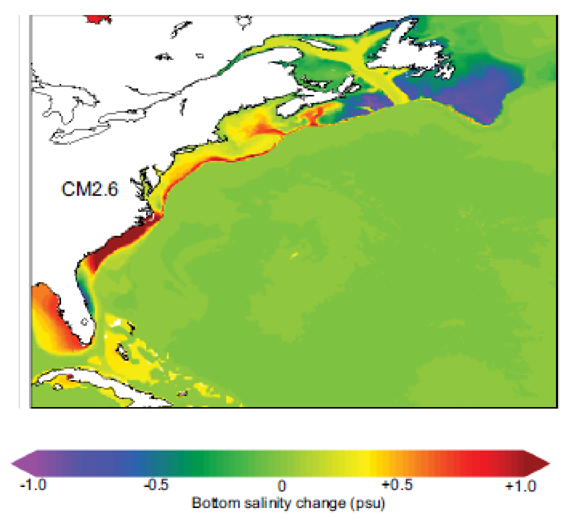


CESM1: Salinity @155m



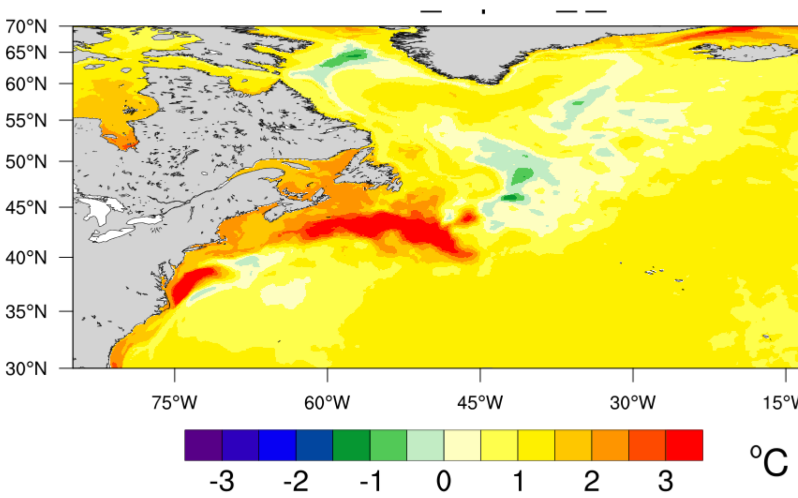
Note: CESM show values at 155m, CM shows values at ocean bottom.



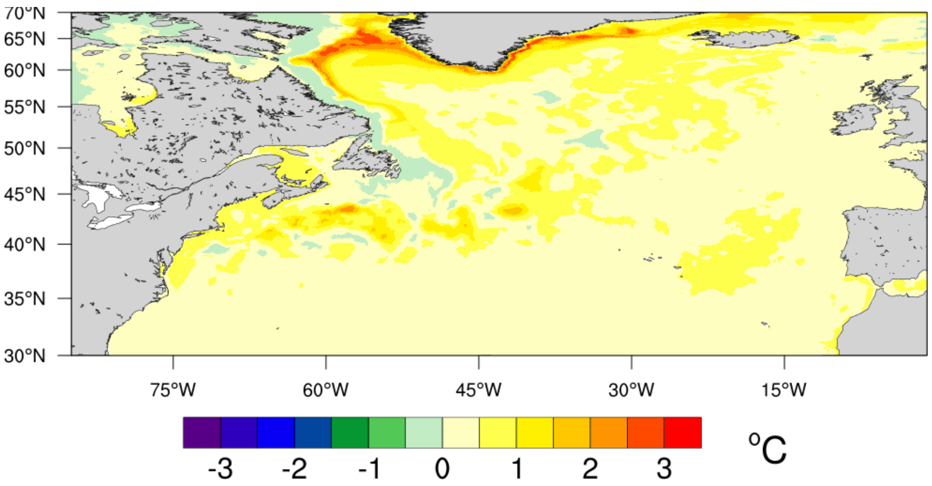


What about climate model drift?

CESM1 RCP8.5: SST change



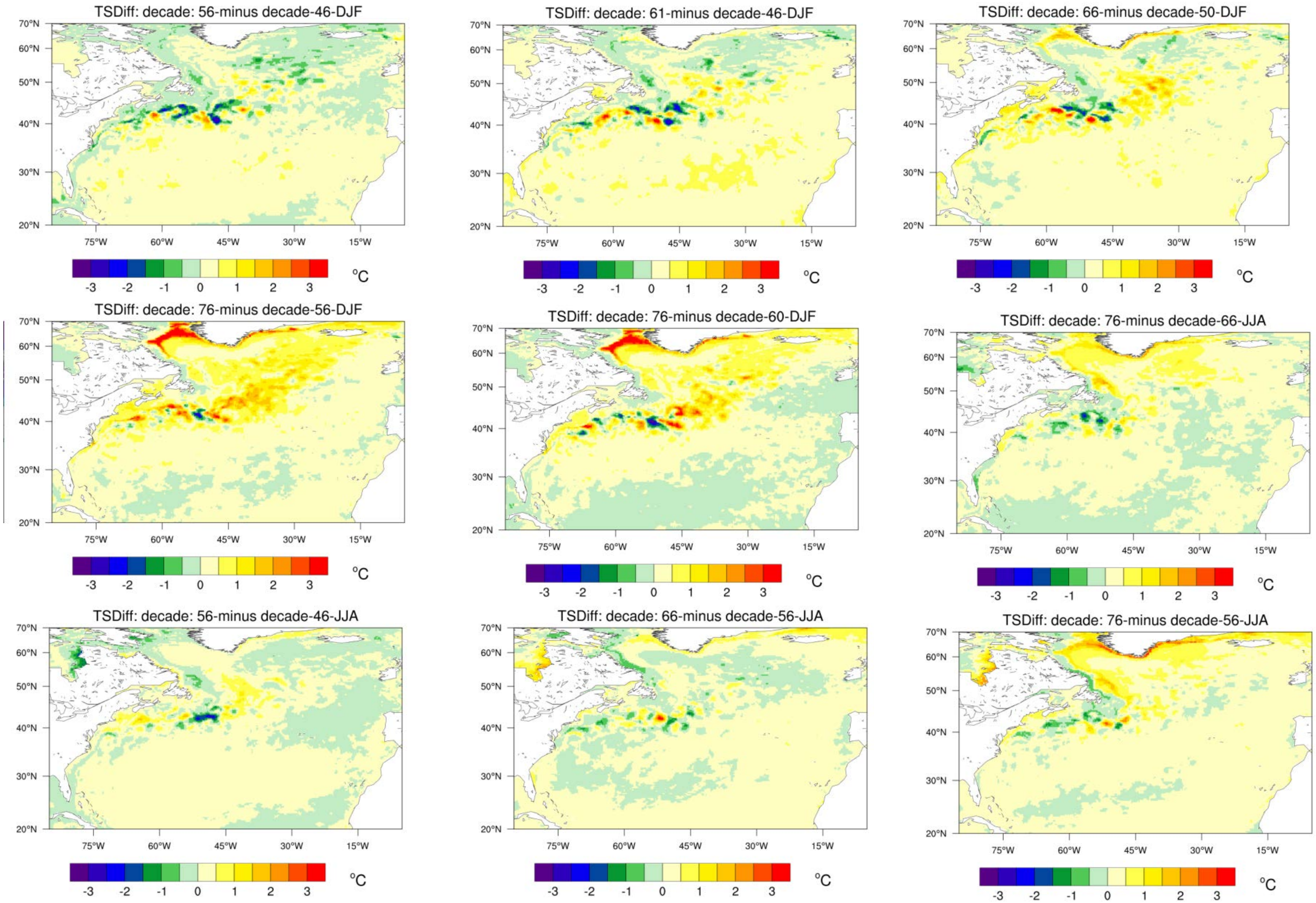
CESM1 Control: SST change



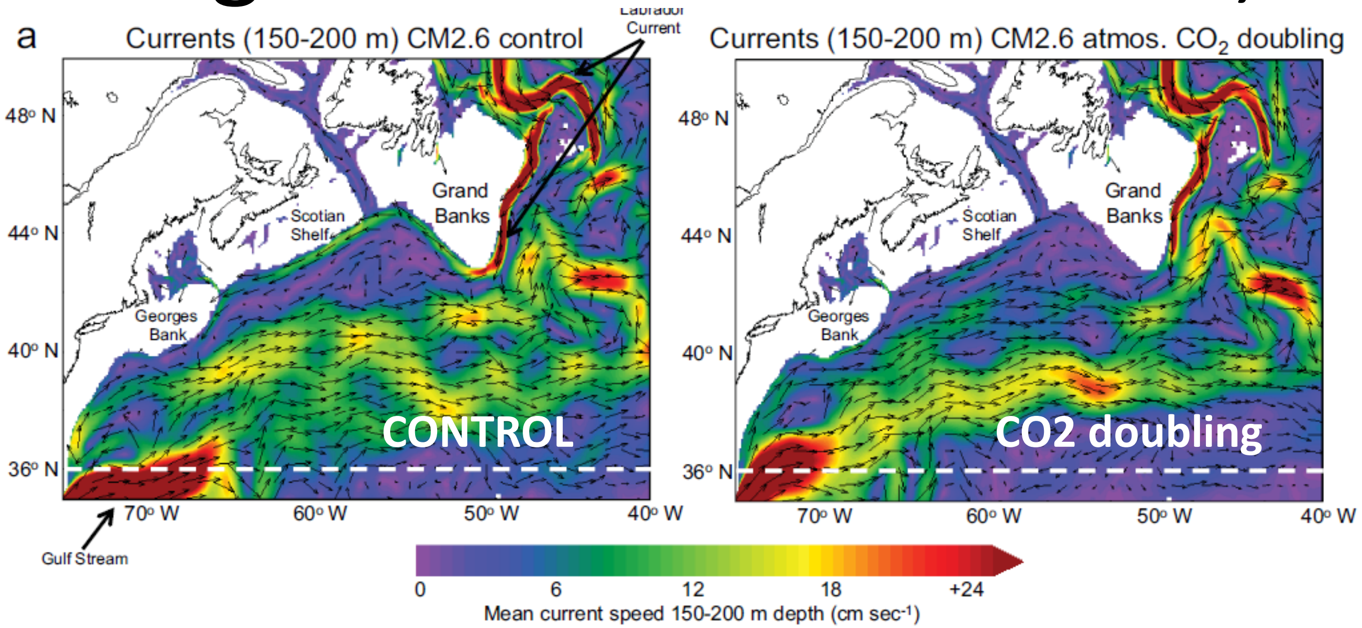
Control run does have slightly enhanced warming off US East coast but much weaker

…and natural variability

Some randomly selected differences of decades in control run



Changes to Labrador Current, Gulf Stream

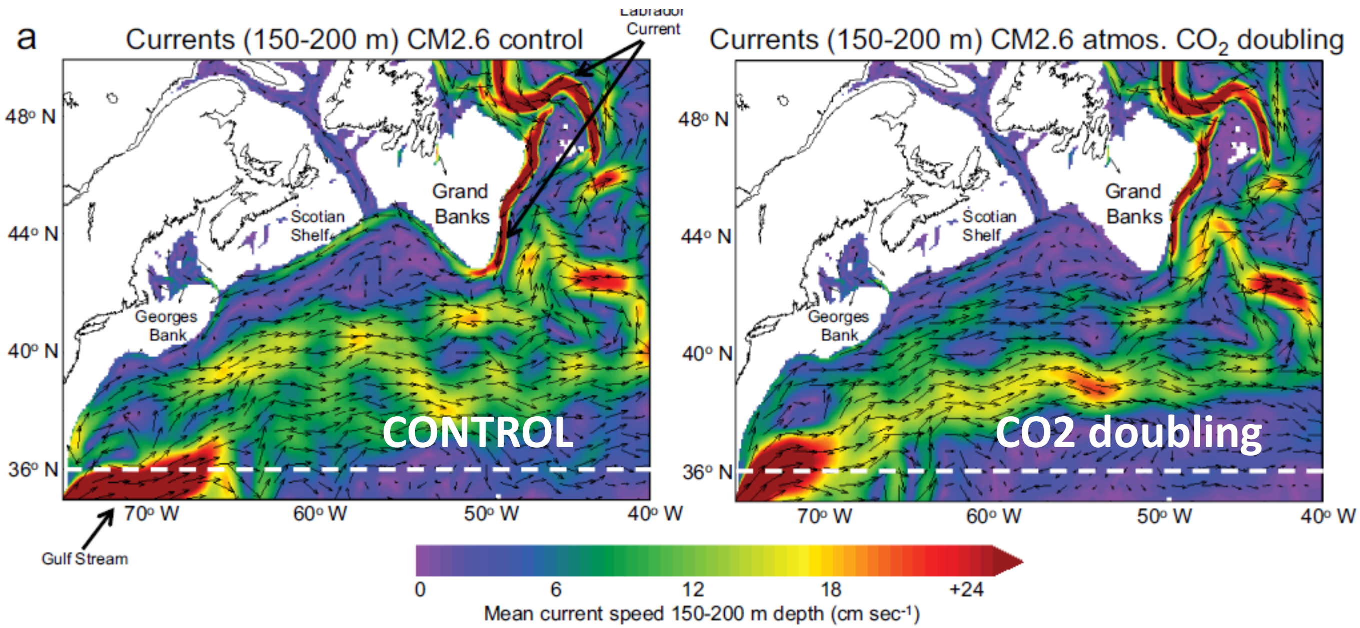


From Saba et al

Labrador current has less intrusion into East coast waters

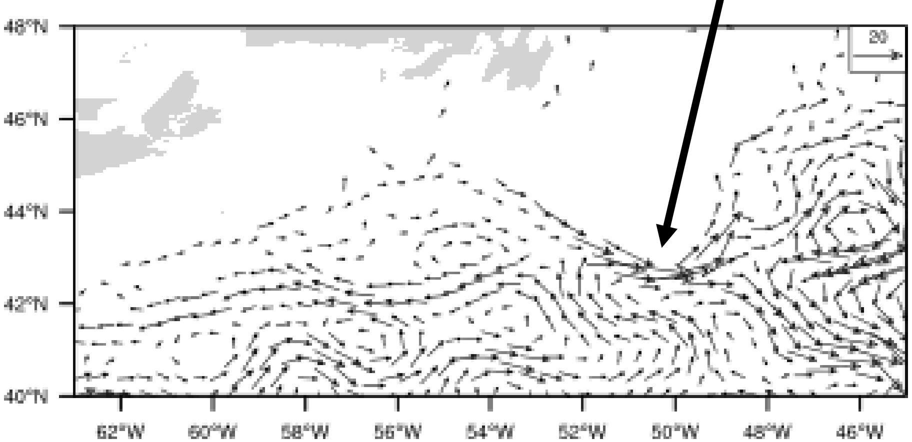
Saba et al. hypothesise that weakening of AMOC (later slides) leads to retreat of Labrador current, northward shift of Gulf Stream, replacement of cold Labrador slope water by warm Atlantic slope waters (Saba et al. 2016)

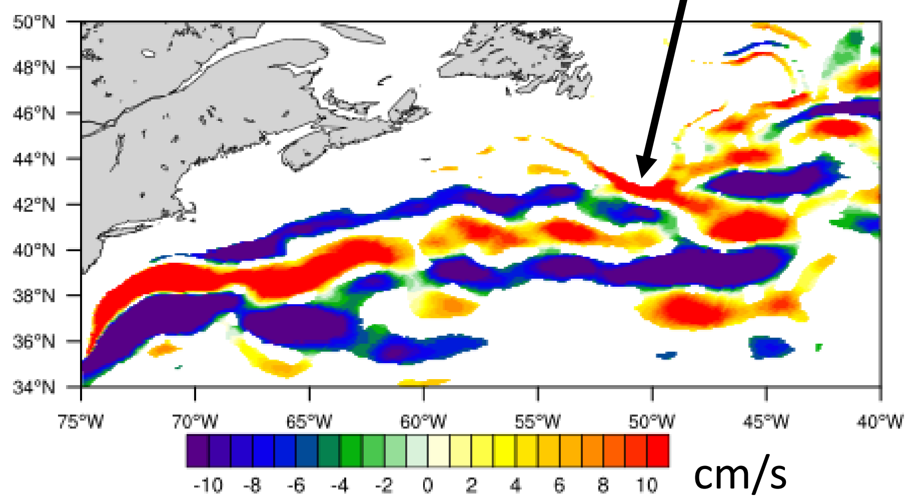
Changes to Labrador Current, Gulf Stream



From Saba et al

Labrador current has less intrusion into East coast waters

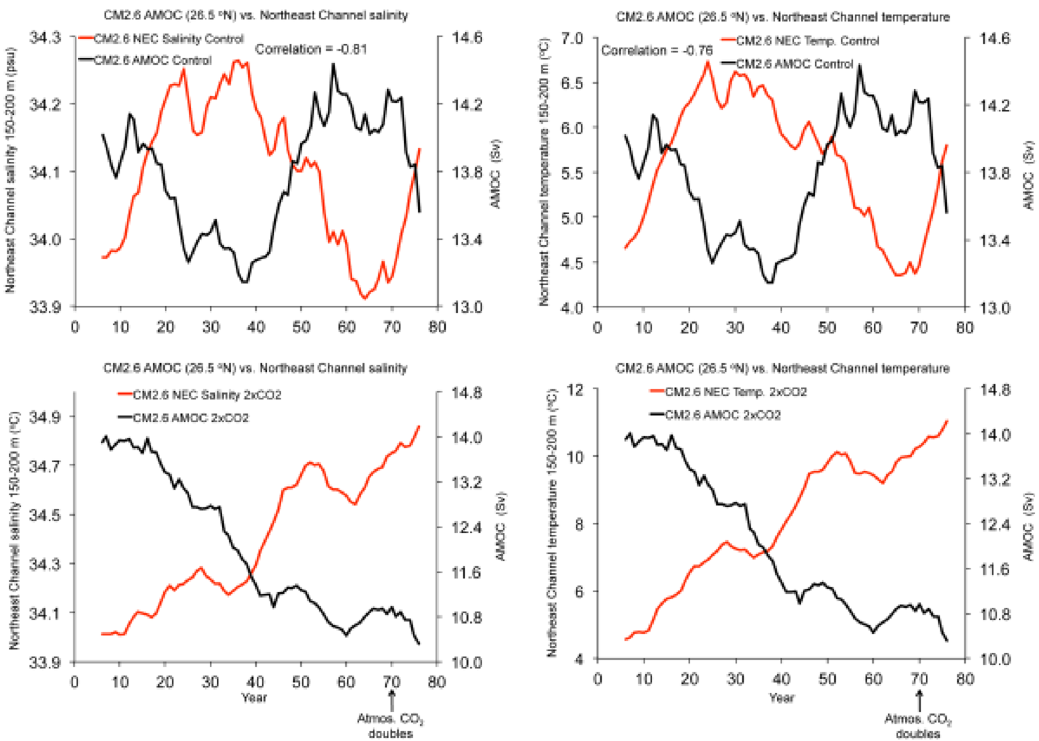




CESM1: DIFFERENCE 2041-2050 minus 2006-2015 in 155m currents

CESM1: As left but DIFFERENCE 2041-2050 minus 2006-2015 in 155m ZONAL VELOCITY

Relationship to AMOC



Relationship of NW Atlantic coastal salinity (left) and temperature (right) (red curves) with AMOC (black curves). Top panels are from pre-industrial control, bottom are from double CO2 run.

All Results from **Enhanced warming of the Northwest Atlantic Ocean under climate change**
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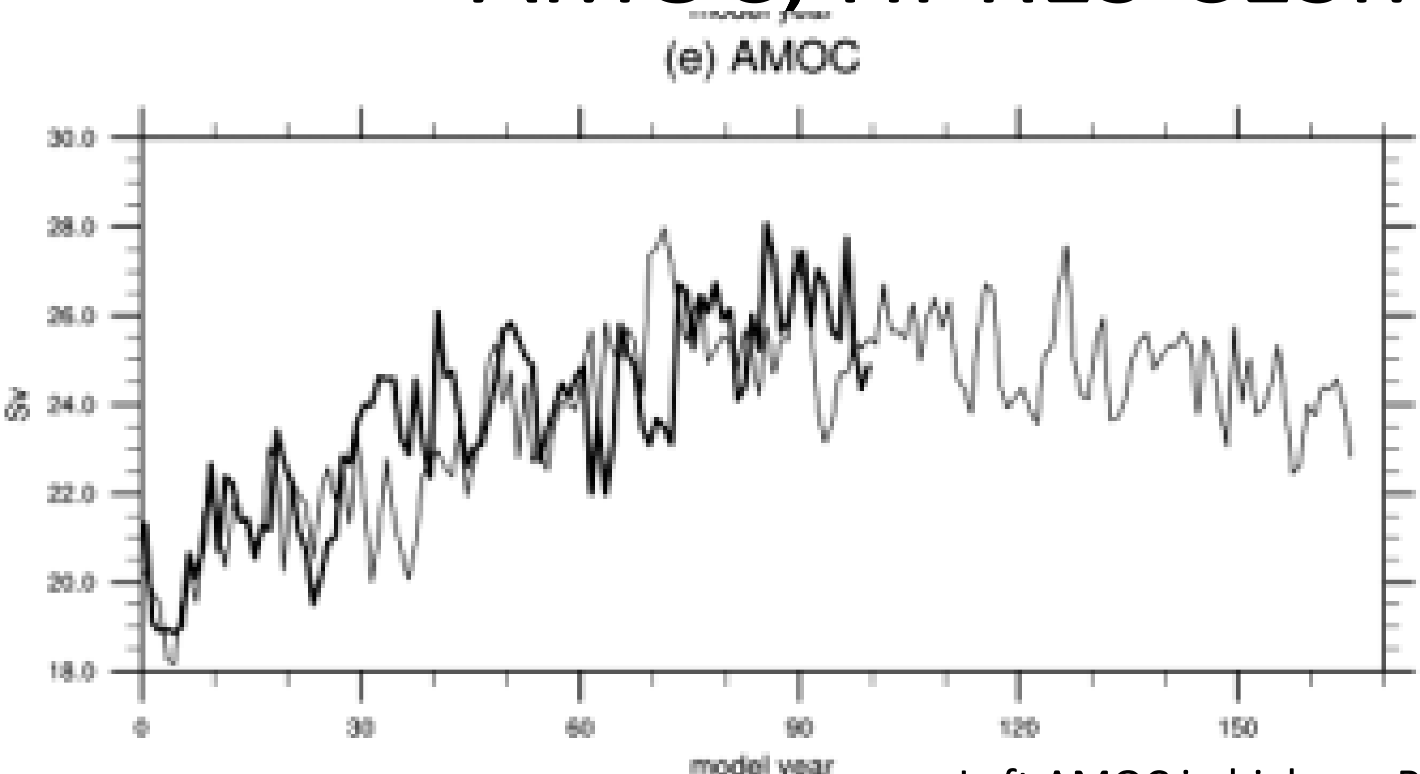
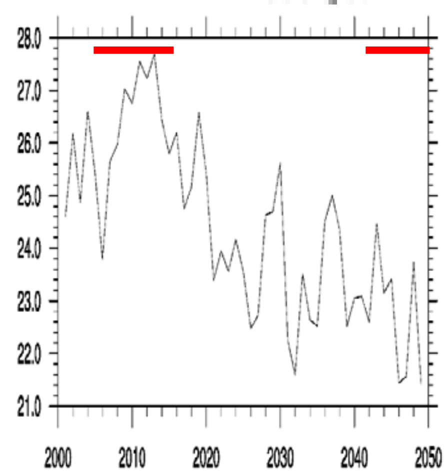
AMOC, HI-RES CESM



Right: From Small et al 2014 AMOC in high-res CESM control (solid) and standard CESM (thin), year 2000 conditions.

AMOC defined as maximum overturning streamfunction in Northern Hemisphere below 500 m depth



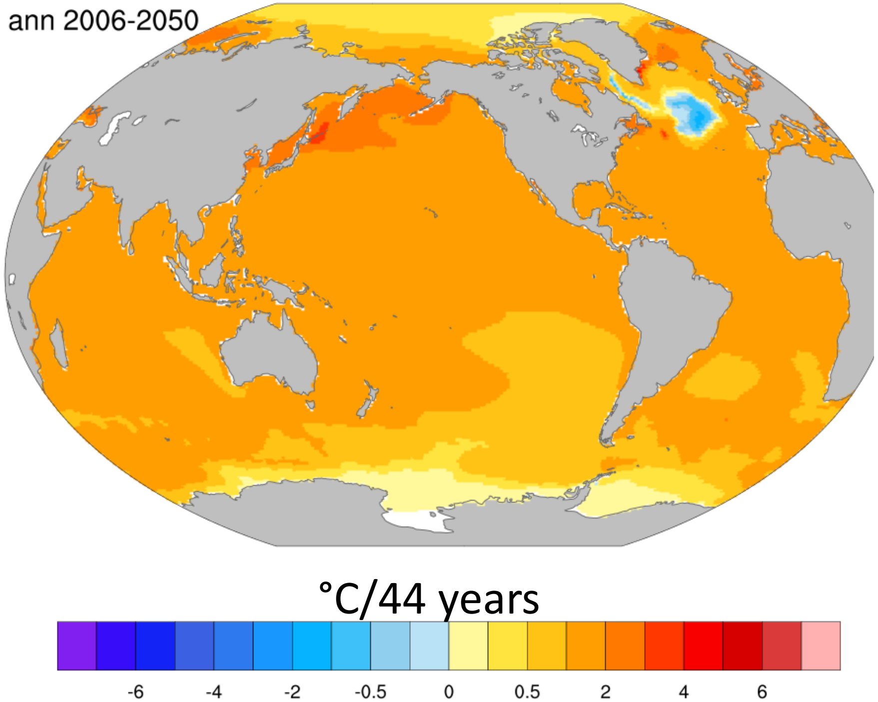
Left AMOC in high-res RCP8.5 in CESM. The run is initialized from year 50 of the high-res control (solid line above) and the two figures are lined up by equivalent year. In the RCP8.5, an initial increase in AMOC to year ~ 2012 is followed by a decrease. In contrast, in the control the AMOC keeps rising. The temperature differences in previous slides (2041-2050 minus years 2006-2015) show low AMOC minus high AMOC periods, as in Saba et al. 2016.

Comparison with CESM-LE

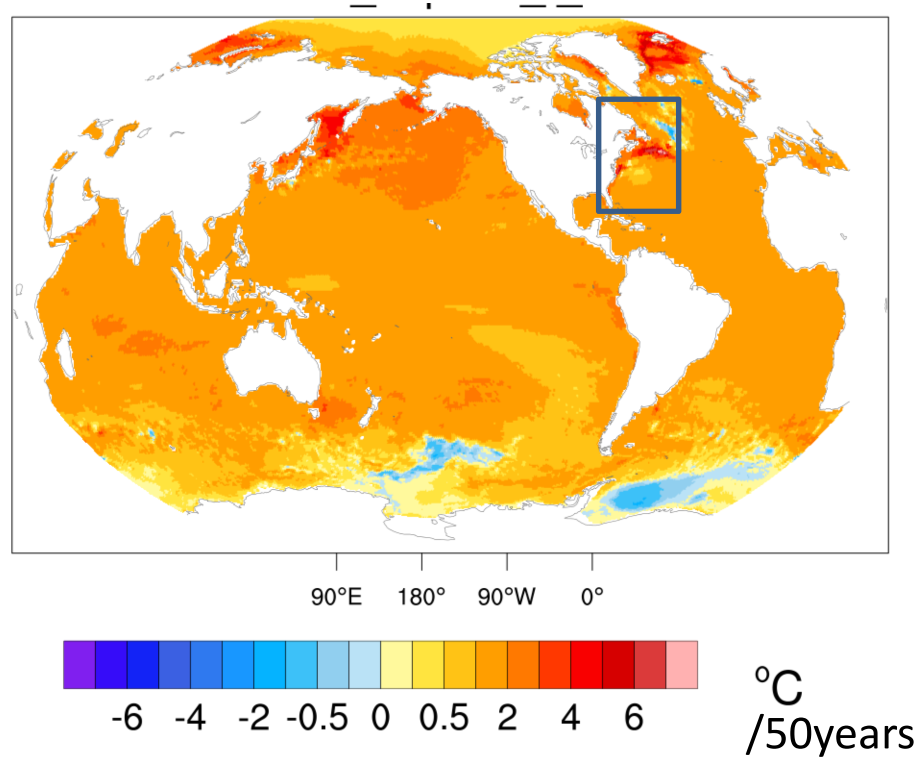
- Linear trend 2006-2050
- Regression SST on AMOC (see later)

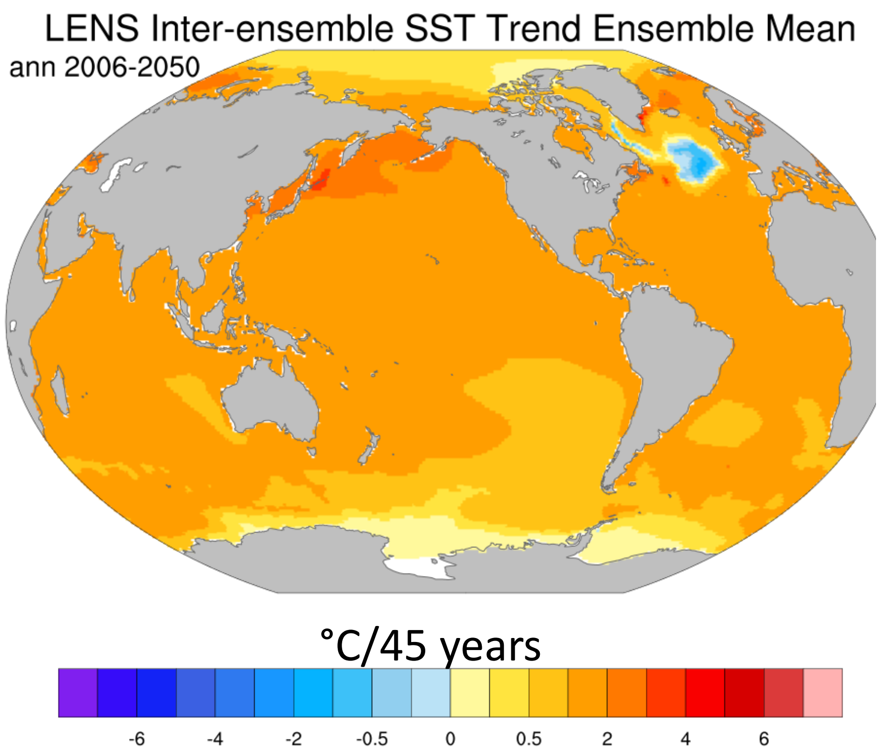
CESM-Large Ensemble (LE) – Kay et al., Deser et al.

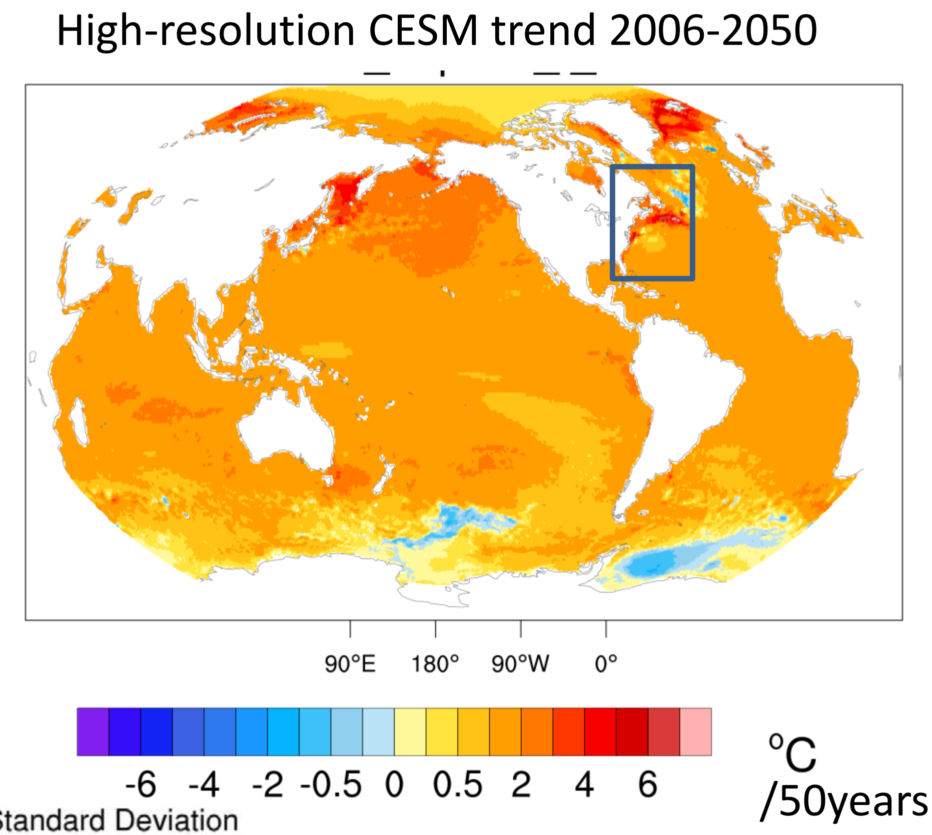
LENS Inter-ensemble SST Trend Ensemble Mean

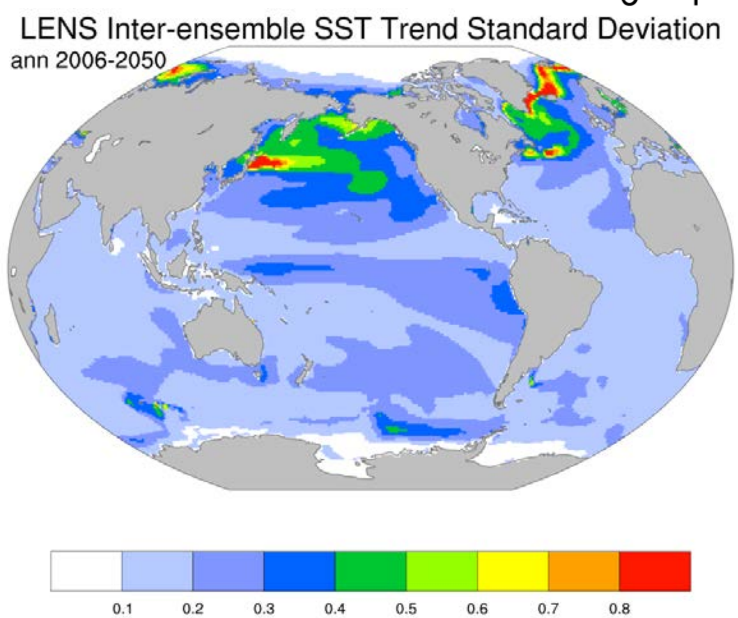


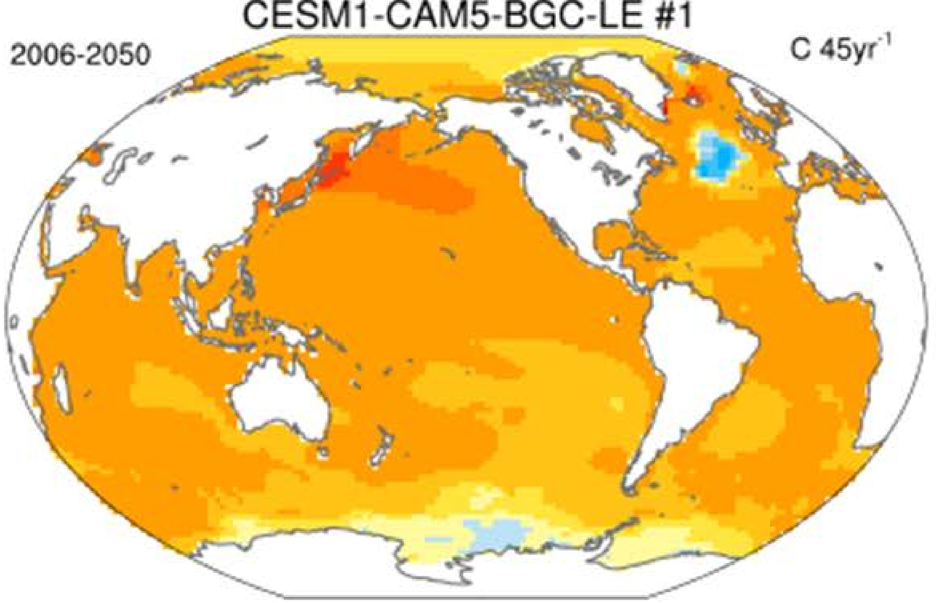
High-resolution CESM trend 2006-2050

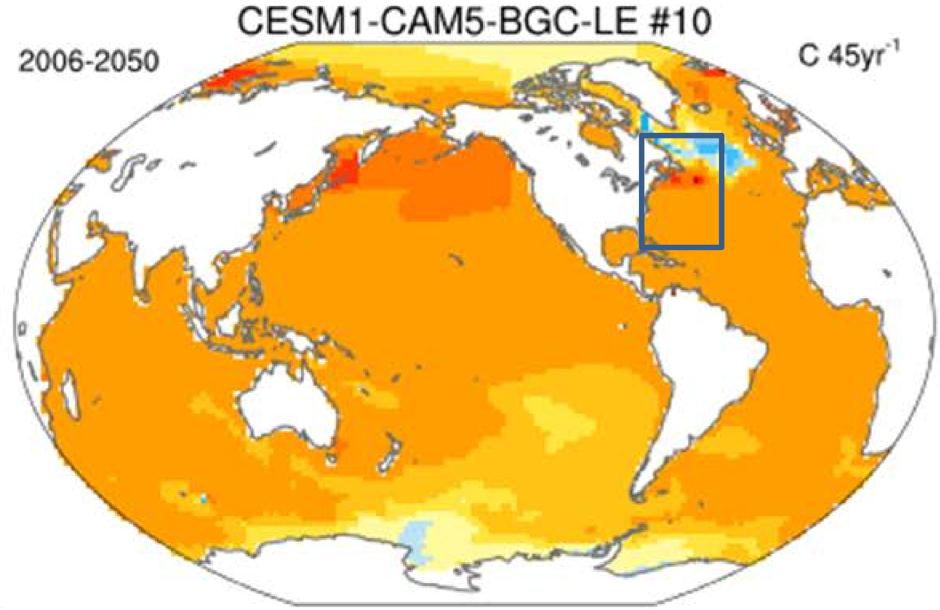


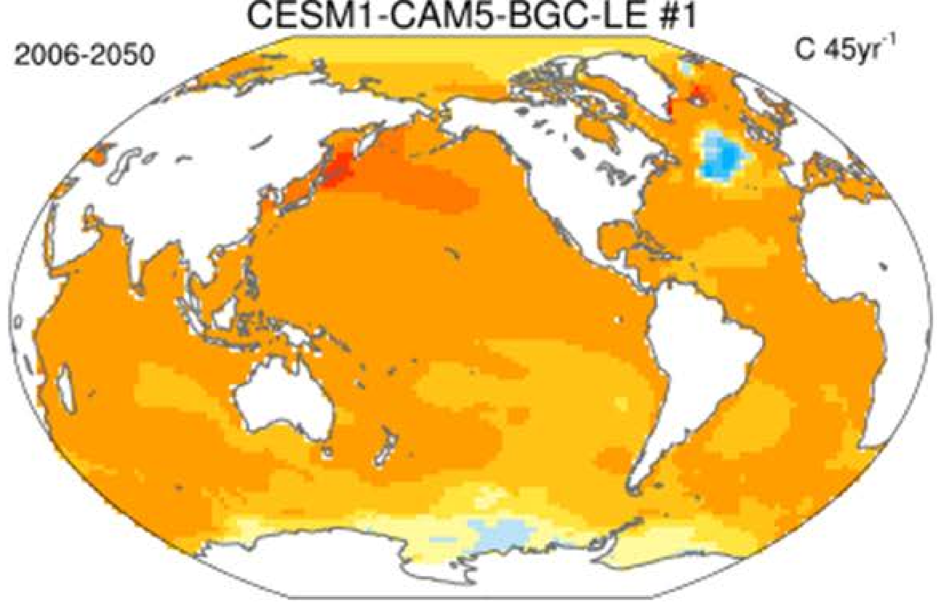

LENS Inter-ensemble SST Trend Ensemble Mean
ann 2006-2050
°C/45 years
-6
-4
-2
-0.5
0
0.5
2
4
6

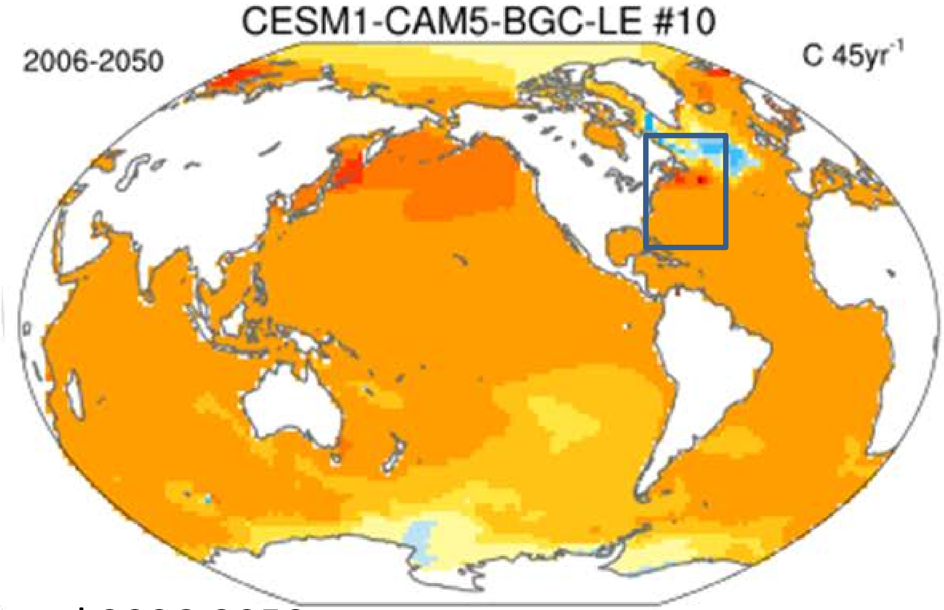

High-resolution CESM trend 2006-2050
90°E
180°
90°W
0°
-6
-4
-2
-0.5
0
0.5
2
4
6
°C
/50years


LENS Inter-ensemble SST Trend Standard Deviation
ann 2006-2050
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

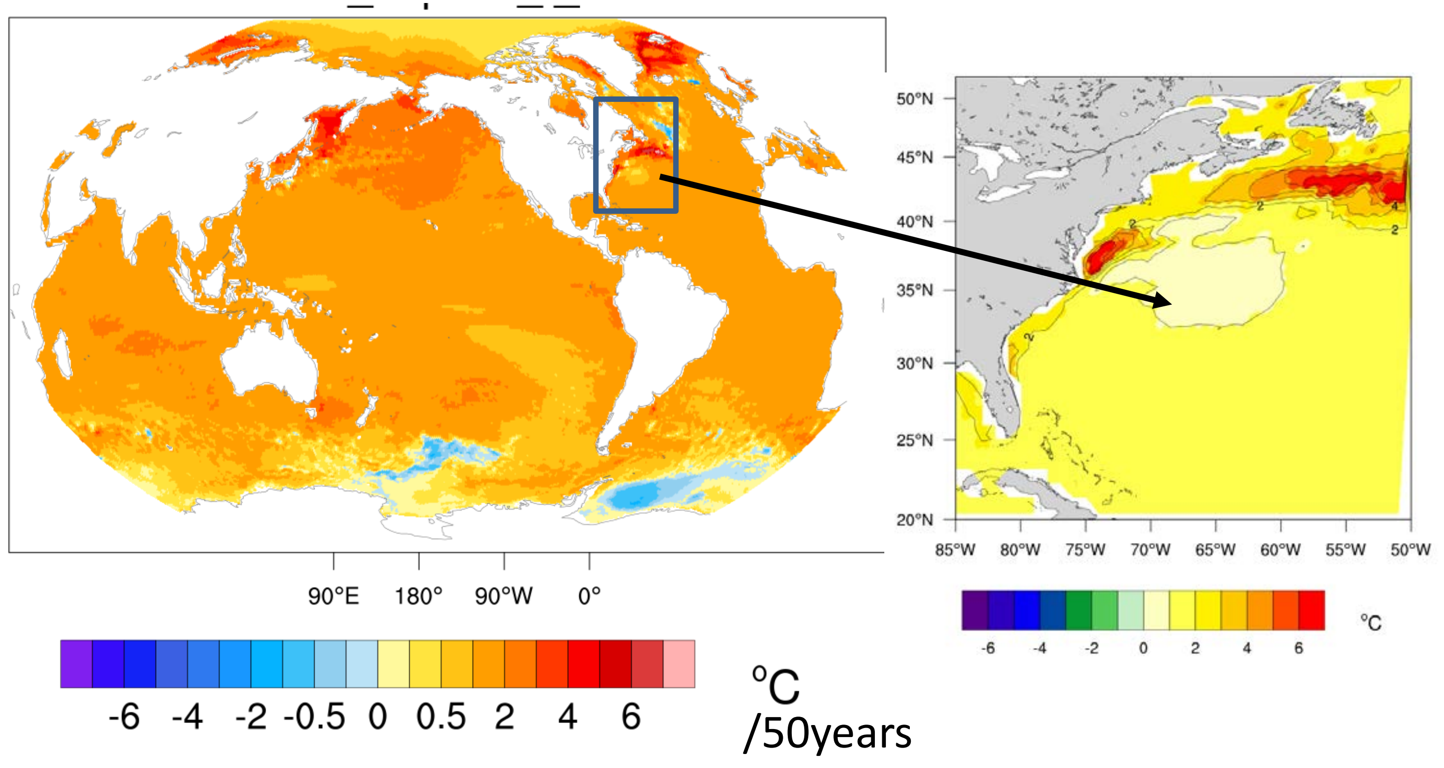

CESM1-CAM5-BGC-LE #1
2006-2050
C 45yr-1


CESM1-CAM5-BGC-LE #10
2006-2050
C 45yr-1





High-resolution CESM trend 2006-2050



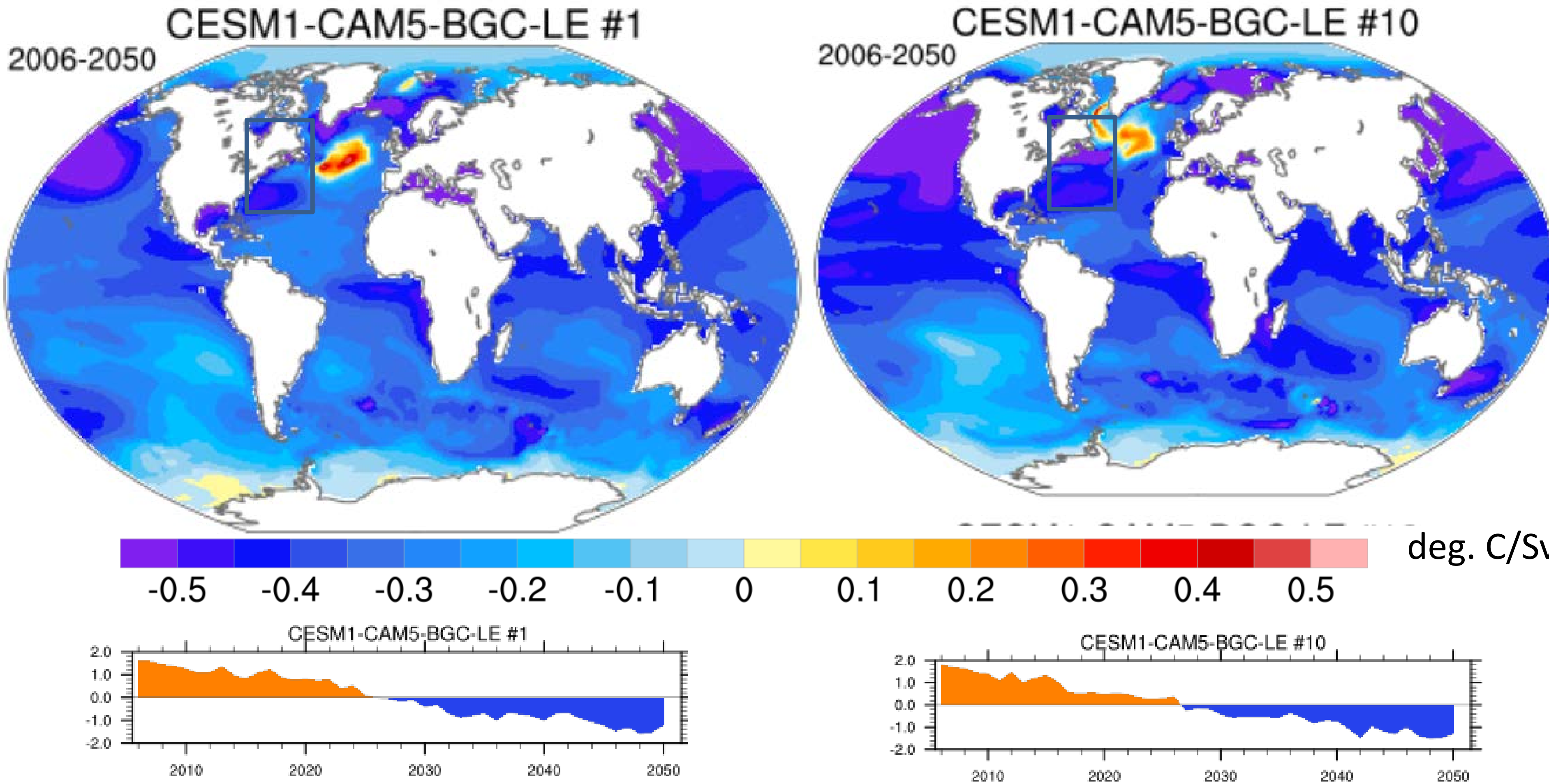
Aims Conclusions

- To determine whether enhanced US East coast warming is seen in high resolution CESM
  - **Yes**
- Compare with an ensemble of standard resolution models
  - Ensemble mean of CESM-LE does not show enhanced warming
  - But a hint that some members have enhancement
- Investigate the relationship to AMOC proposed by Saba et al
  - Labrador Current, Gulf Stream changes consistent with Saba et al.
  - AMOC –US East coast SST regressions consistent with Saba et al.

Discussion points

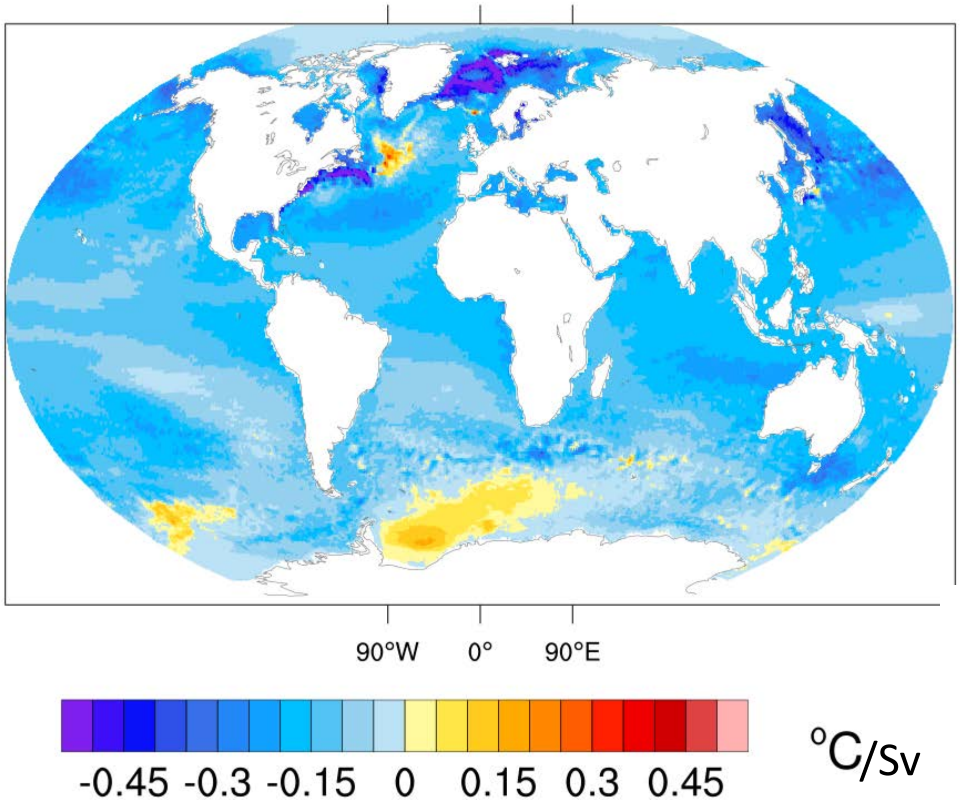
- Does high-res CESM have warmer temps due to strong AMOC decline (as opposed to resolution per-se)?
  - Are the mean values of AMOC, and AMOC decline, in high-res CESM realistic?
- How do changes in SST affect extremes of wind, precipitation ?
- What drives the enhanced warming – atmosphere factors vs oceanic advection
- Can we use natural variability of high-res control to estimate variability of 50 year trends (Thompson et al. 2015)?

AMOC-SST-regressions

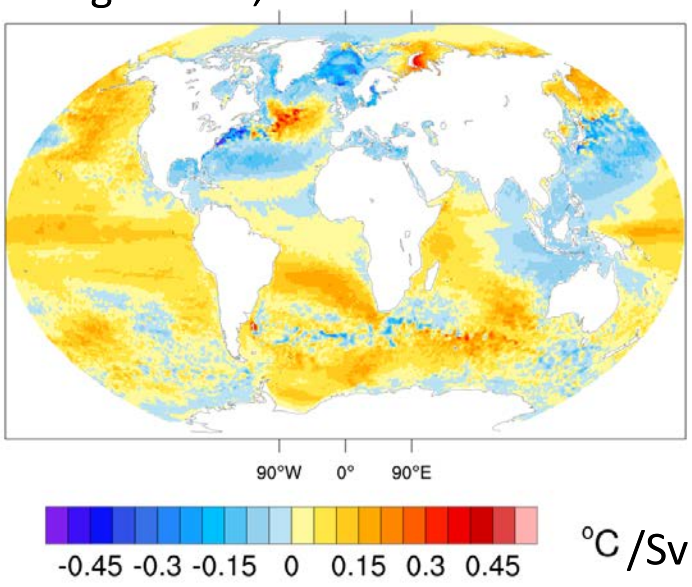


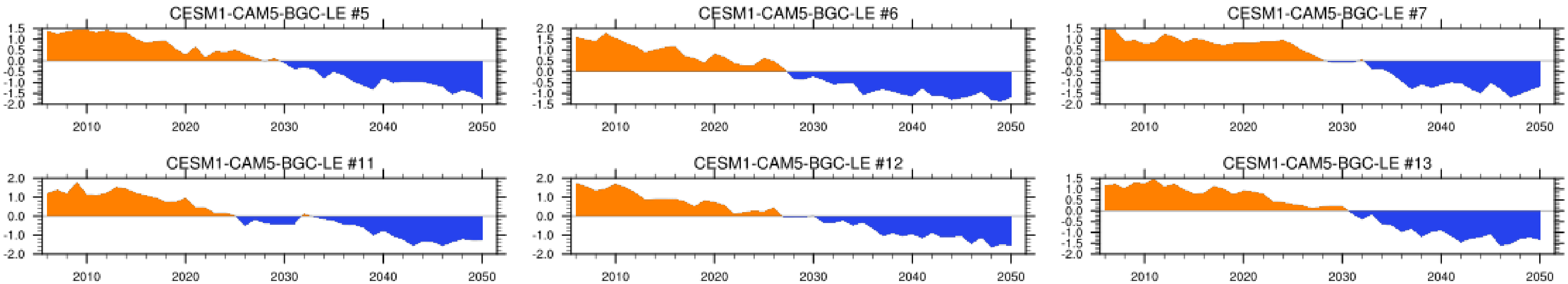
SST regressed on AMOC, no trends removed. Two example CESM-LE members.
AMOC decline is similar (bottom plots) but SST trends off US East coast differ

High-resolution CESM SST-AMOC regression

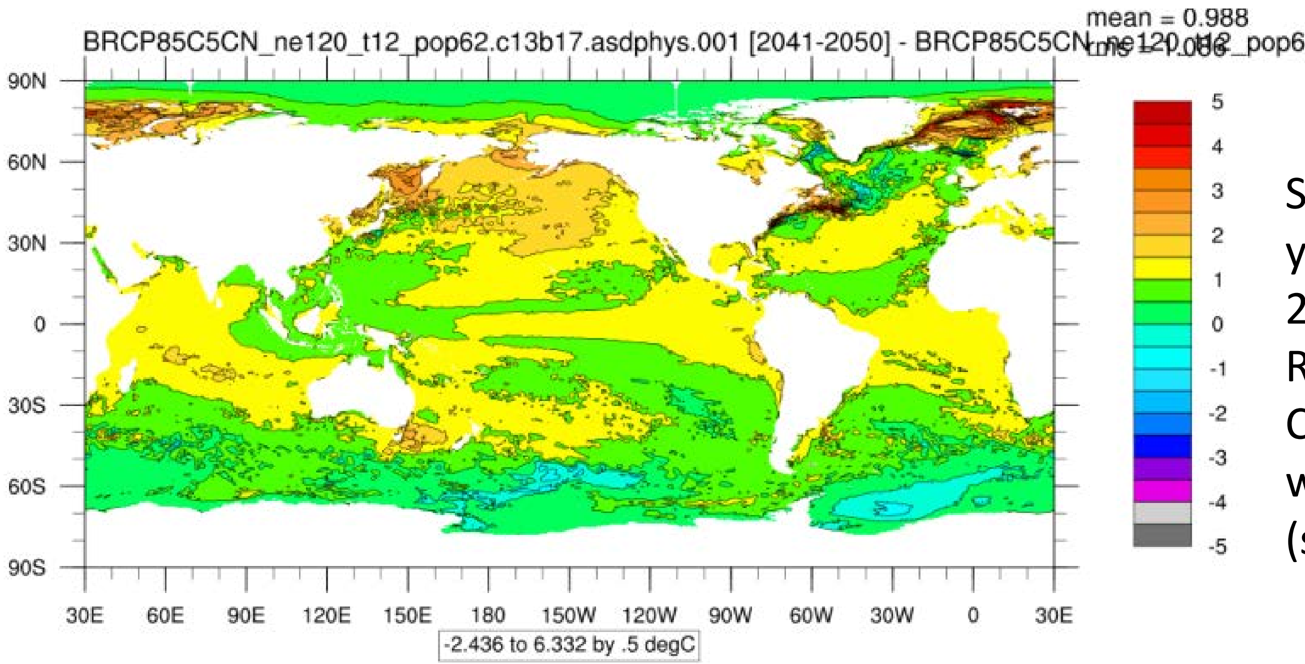


High-resolution CESM SST-AMOC regression, trends removed

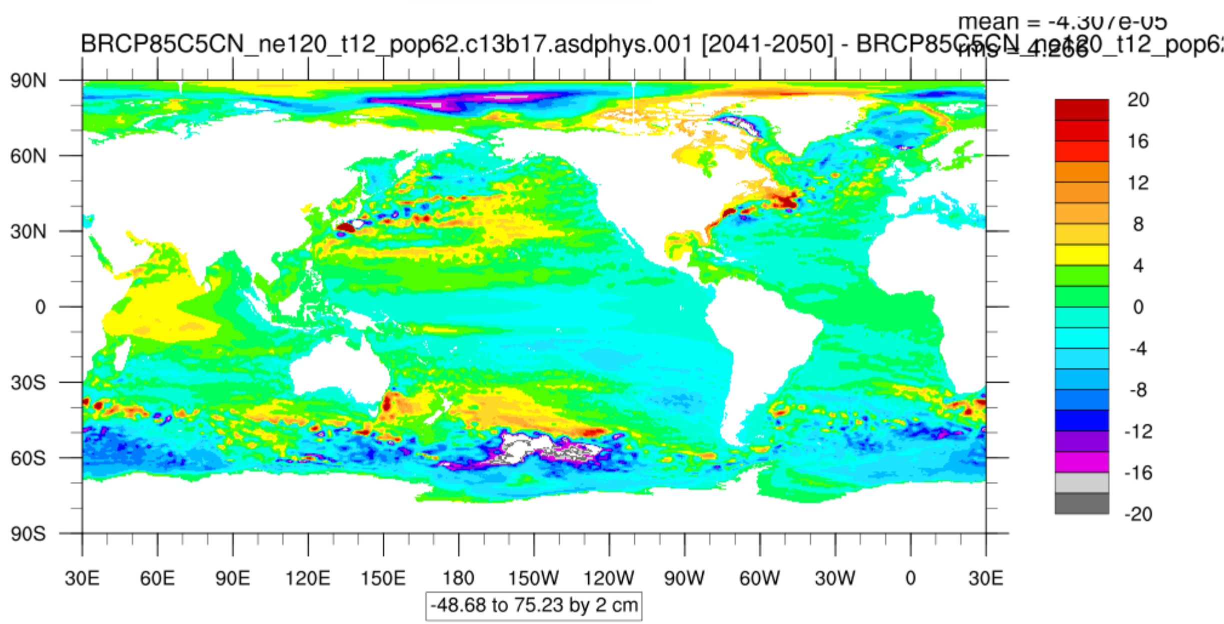



CESM1-CAM5-BGC-LE #5
CESM1-CAM5-BGC-LE #6
CESM1-CAM5-BGC-LE #7
CESM1-CAM5-BGC-LE #11
CESM1-CAM5-BGC-LE #12
CESM1-CAM5-BGC-LE #13
2010
2020
2030
2040
2050

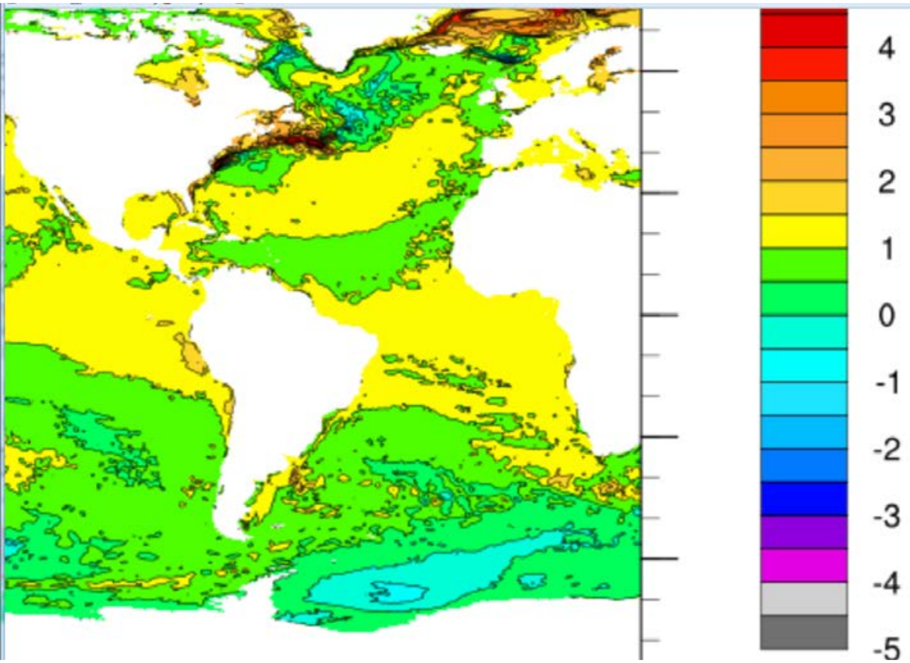
Results from High-res CESM RCP8.5



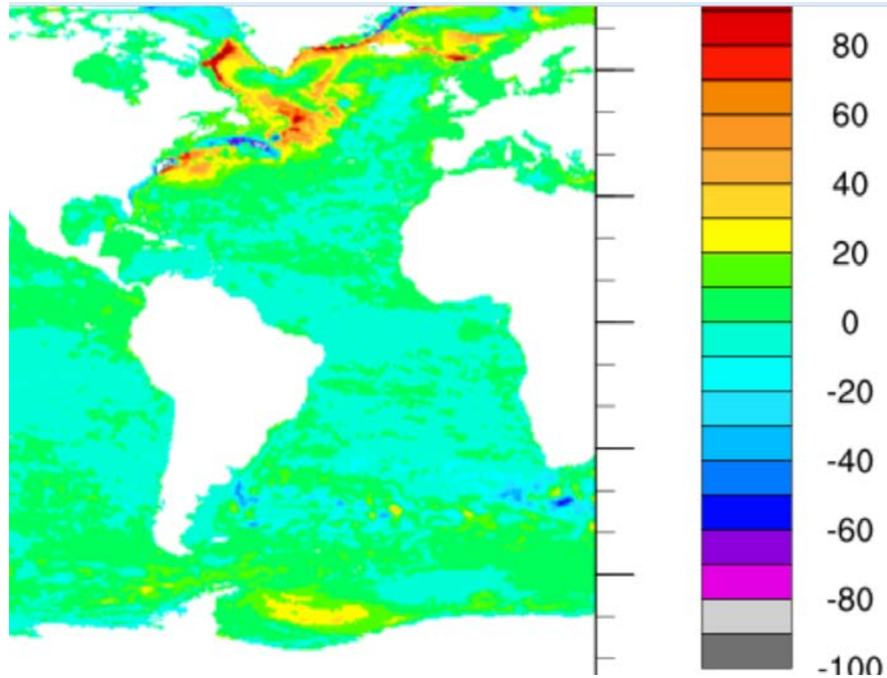
SST difference between years 2041-2050 and years 2006-2015 of new high-res RCP8.5 scenario with CESM. Note enhanced warming in NW Atlantic (see also next slide)



Sea surface height difference between years 2041-2050 and years 2006-2015 of new high-res RCP8.5 scenario with CESM. Note enhanced SSH rise in NW Atlantic.

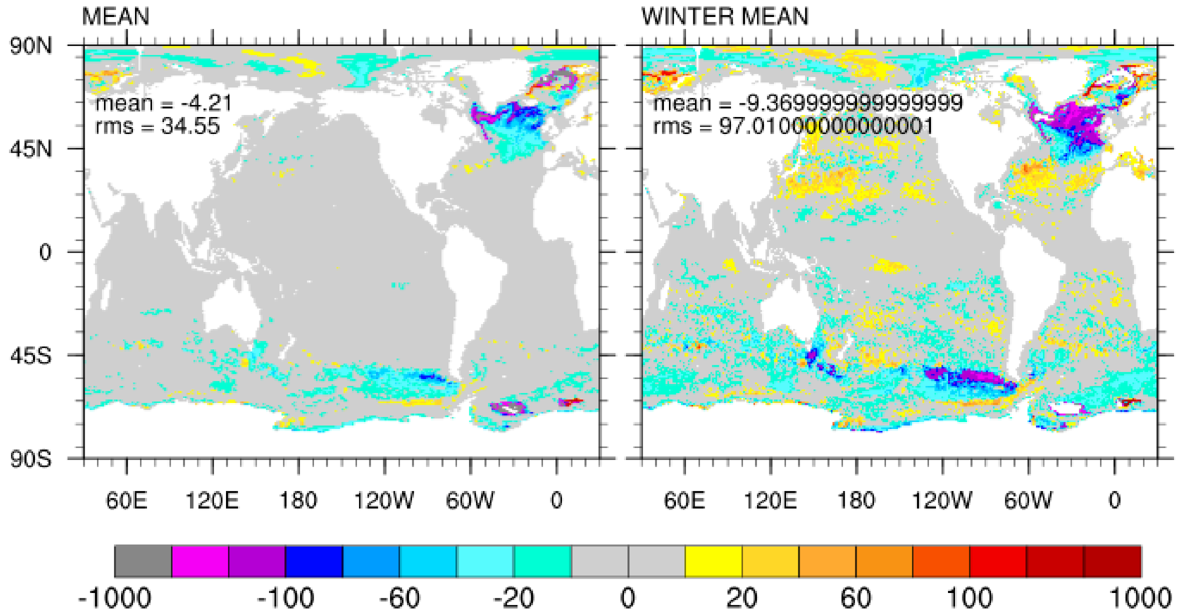


Surface temperature change

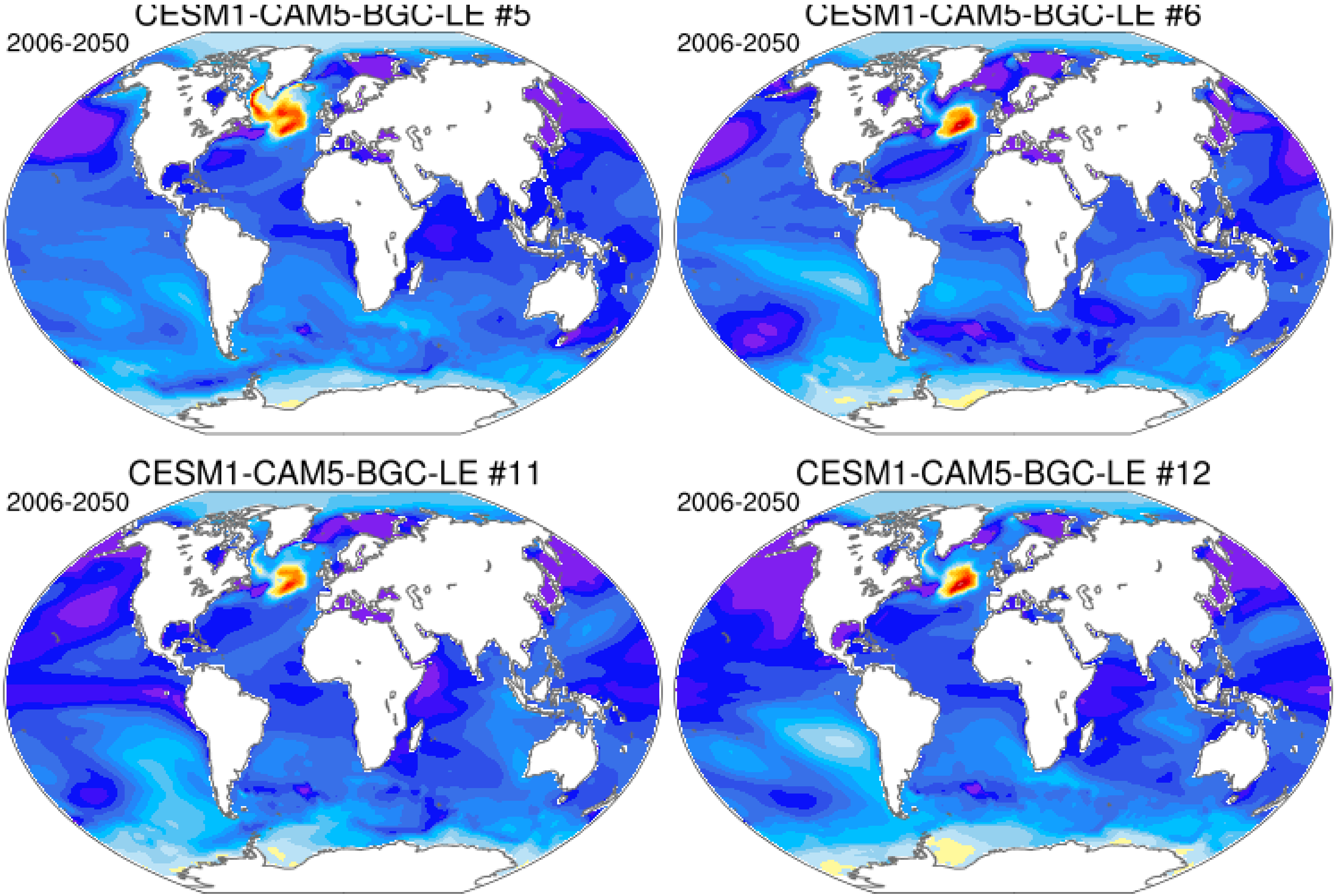


Net surface heat flux change. Positive values warm ocean

Changes to mixed layer depth



MLD defined on 0.03kg/m3 criterion.
Difference 2041-2050 minus 2006-2015.



How is AMOC defined

Future work

- Look at seasonal differences
- Look at duration of summer (Andy Thomas – ask for lecture slides)
- Close up on SST, and current change in N. Atlantic
- Extremes in sea level and SST, winds