Mesoscale-resolving simulations of global marine climate change in the RCP8.5 scenario

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Whitt, Bailey, Bates, Bryan, Long, Small (NCAR) Brett, Feloy, Richards (UH), L. Thompson (UW) (2019), to be submitted to JAMES; with special thanks to NCAR CCR and University of Illinois/Wuebles group, Bluewaters!
Comparative overview

Methodology
Evaluation/benchmarking
Century-scale changes
Temperature, salinity, and large-scale circulation
Global patterns
Regional examples (Justin’s talk!)
Simulations

High-res timeslices
2x 10-year 0.1° ocean/sea-ice “timeslice”
2000s: CORE repeating atmospheric normal year
2100s: ICs and BCs perturbed by LENS/RCP8.5 anomalies
After ~20 year CORE normal-year spin-up

High-res fully-coupled (HR):
2006-2097, RCP8.5-extension, fully-coupled
0.25°/0.1° atmosphere/ocean
After ~50 year present-day/historical spin-up (Small et al. 2014)

LENS:
40-member ensemble of fully-coupled CESM
Typical 1.0°/1.0° resolution (Kay et al. 2015)
RCP8.5 scenario follows pre-industrial spin-up and historical runs

This is not a resolution sensitivity study!
Ideas

Each modeling approach has pros and cons.

Quantify similarities and differences via three-way intercomparison.

Identify areas where high-resolution anomalies are above or below LENS envelope, thus differences are unlikely to be random.

Climate change anomaly projection
SST

Stippling indicates where high-resolution fields are outside the LENS envelope.

(A) HR-RCP8.5, 2010-2017

(B) Time Slice, 2000s

Qualitatively indistinguishable

2090-2097 minus 2010-2017

(F) 2100s minus 2000s

Some different anomalies:
Arctic
Subpolar North Atlantic
Southern Ocean
Eastern Tropical Pacific
Early-century
Differences are small, but qualitatively similar. Why?

Also similar to results with CCSM, but smaller differences in N. Atl. (Kirtman et al. 2012).

Late century anomalies:
All three models are within the LENS envelope at low-to-mid latitudes

Inconsistencies with LENS are greatest at high-latitudes:
More Arctic warming in both models
Less Southern Ocean warming in fully-coupled high-res
8-yr SST trends highlight differences between methods
Second 4 yr mean minus first 4 yr mean

(A) LE-RCP8.5, 2010-2017 trend
(B) HR-RCP8.5, 2010-2017 trend
(C) Timeslice, 2000s trend

(D) 2050-2057 trend
(E) 2050-2057 trend
(F) 2050s trend

(G) 2090-2097 trend
(H) 2090-2097 trend
(I) 2100s trend

Forced trends
Coupled internal variability
Internal ocean variability/drift
Zonal mean temperature

Indistinguishable without close analysis.

Quantitatively different from LENS almost everywhere, and in nearly identical ways.

Also similar to CCSM results (Kirtman et al. 2012)

Anomalies are qualitatively similar and mostly quantitatively similar above 1 km

**Notable differences in fully-coupled run:**
- Greater Arctic warming & Greater reduction in max sea-ice
- Less SO warming,
  Smaller reduction in max sea-ice
Notably different anomalies: NE. Tropical Pacific Indian

(A) HR-RCP8.5, 2010-2017

(B) Time Slice, 2000s

Qualitatively similar early-century and future anomalies

Widespread quantitative differences

(E) 2090-2097 minus 2010-2017

(F) 2100s minus 2000s

Notably different anomalies: NE. Tropical Pacific Indian
SSS, high-res minus LENS mean

Most differences are consistent
Broadly saltier; this is more like Argo observations of ML salt

Notable inconsistencies:
Mid-latitude N. Atlantic
Low-latitude N. Pacific

Notable consistent differences
Less salty subtropical N. Atl.
Less fresh in the subpolar N. Atl.
Fresher SO in the Indian Sector
Saltier Antarctic margins
SSH

Qualitatively and quantitatively consistent with LENS over most of the ocean.

Increase in SSH drop across the ACC

Higher SSH in subtropical N. and S. Pacific

Higher SSH in tropical Indian

Very different changes in the N. Atlantic

(A) HR-RCP8.5, 2010-2017

(B) Time Slice, 2000s

(E) 2090-2097 minus 2010-2017

(F) 2100s minus 2000s

Qualitatively similar, but widespread quantitative differences relative to LE

Qualitatively and quantitatively consistent with LENS over most of the ocean.
Increase in SSH drop across the ACC
Higher SSH in subtropical N. and S. Pacific
Higher SSH in tropical Indian

Very different changes in the N. Atlantic
SSH, high-res minus LENS

Many consistent differences relative to LENS
- Weaker SSH drop across ACC
- Higher SSH in the Arctic
- Higher-SSH equatorward of WBC extensions like ARC, GS, KE

Consistent differences
- Lower SSH in the western subpolar N. Atlantic
- Higher SSH in the western Indian

Some inconsistent differences:
- E. Tropical Pacific
- Antarctic Margin
- Subtropical N. Atlantic
Surface geostrophic velocity

More realistic early-century surface circulation at high-resolution

(A) LE-RCP8.5, 2010-2017  (B) HR-RCP8.5, 2010-2017  (C) Time Slice, 2000s

2090-2097 minus 2010-2017  (H) 2090-2097 minus 2010-2017  (I) 2100s minus 2000s

Stronger ACC, and southward shift in Atlantic/Indian sector
Weaker Gulf Stream (Is there a shift??)
Stronger Kuroshio
Large differences in the initial states, less difference in anomalies
AMOC at 24 N

Maximum AMOC declines are within the LENS envelope, even though initial states are well outside the envelope.

Anomalies in N. heat transport associated with different spatial structure of AMOC response.
Pointwise T and SSH anomalies are mostly within the LENS envelope in the upper ocean.

Notable exceptions are at high latitudes:
Enhanced Arctic warming; reduced SO warming

Many differences (high-res minus LENS) are qualitatively similar in HR and timeslice, despite different atmospheres and spin-ups

SSS anomalies exhibit widespread departures from LENS, but still qualitatively similar

Timeslices are useful for studying mesoscale dynamics under climate change. However, greatest care is needed in regions of greatest interest, such as WBCs, equatorial Pacific, subpolar N. Atl., etc.
SH winter MLD

(A) HR-RCP8.5, 2010-2017

(B) Time Slice, 2000s

2090-2097 minus 2010-2017

(F) 2100s minus 2000s
NH winter MLD

(A) HR-RCP8.5, 2010-2017

(B) Time Slice, 2000s

(E) 2090-2097 minus 2010-2017

(F) 2100s minus 2000s
Temperature @ 579 m high-res minus LE mean

Fairly large early-century differences in the main thermocline
Sea ice extent

Note different y-axis

Early century

Late century
Root-mean-square surface current speed (from monthly mean velocity vectors)

(A) HR-RCP8.5, 2010-2017

(B) Time Slice, 2000s

(E) 2090-2097 minus 2010-2017

(F) 2100s minus 2000s

Very different equatorial anomalies