Results from the CFSv2 CMIP5 Decadal Forecasts

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Basic Experiment: CMIP5 Decadal Forecasts

• Compare forecasts made with different ocean initial conditions (full initialization).
  – CFSR 1980- (“NCEP simulations”) assimilation in its native ocean model.
  – NEMOVAR 1960- (“COLA simulations”) interpolated to foreign ocean model grid.
Evaluation of the CFSv2 CMIP5 Decadal Predictions

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## CMIP5 Model Description

<table>
<thead>
<tr>
<th>CMIP5 Near-Term Players</th>
<th>CMIP5 official model_id</th>
<th>AGCM</th>
<th>OGCM</th>
<th>Initialization</th>
<th>Perturbation</th>
<th>Aerosol</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Atmosphere/Land</td>
<td>Ocean</td>
<td>sea ice</td>
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<tr>
<td>Beijing Climate Center, China Meteorological Administration (BCC) China</td>
<td>BCC-CSM 1.1</td>
<td>2.6°L26</td>
<td>1°L40</td>
<td>no SST, T&amp;S (SODA)</td>
<td>No</td>
<td>no</td>
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<tr>
<td>Canadian Centre for Climate Modelling and Analysis (CCCMA) Canada</td>
<td>CanCM4</td>
<td>2.8°L35</td>
<td>1.4°x0.9° L40</td>
<td>ERA40/Interim</td>
<td>SST (ERSST&amp;OISST), T&amp;S (SODA &amp; GODAS)</td>
<td>HadISST1.1</td>
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<td>Centro Euro-Mediterraneo per Cambiamenti Climatici (CMCC-CM) Italy</td>
<td>CMCC-CM</td>
<td>0.75°L31</td>
<td>0.5-2° L31</td>
<td>no</td>
<td>SST, T&amp;S (INGV ocean analysis)</td>
<td>CMCC-CM climatology</td>
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<td>Centre National de Recherches Météorologiques, andCentre Européen de Recherche et Formation Avancées en Calcul Scientifique (CNRM-CERFACS) France</td>
<td>CNRM-CM5</td>
<td>1.4°L31</td>
<td>1°L42</td>
<td>no</td>
<td>T&amp;S (NEOMOVAR-COMBINE)</td>
<td>No</td>
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<tr>
<td>National Centers for Environmental Prediction and Center for Ocean-Land-Atmosphere Studies (NCEP and COLA) USA</td>
<td>CFSv2-2011</td>
<td>0.9°L64</td>
<td>0.25-0.5° L40</td>
<td>NCEP CFSR reanalysis</td>
<td>NCEP CFSR ocean analysis (NCEP runs)</td>
<td>NCEP CFSR reanalysis</td>
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<td>EC-EARTH consortium (EC-EARTH) Europe</td>
<td>EC-EARTH</td>
<td>1.1°L62</td>
<td>1°L42</td>
<td>ERA40/Interim</td>
<td>Ocean assimilation (ORAS4/NEOMOVAR S4)</td>
<td>NEMO3.2-LIM2 simulation forced with DFS4.3 atmospheric fields through the CORE bulk formulae</td>
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<td>Institut Pierre-Simon Laplace (IPSL) France</td>
<td>IPSL-CM5A-LR</td>
<td>3.8°L39</td>
<td>2°L31</td>
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<td>SST anomalies (Reynolds observations)</td>
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<td>Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology</td>
<td>MIROC4h</td>
<td>0.6°L56</td>
<td>0.3°L48</td>
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<td>SST, T&amp;S (Ishii and Kimoto 2009)</td>
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<td>MIROC5</td>
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<td>1.4°L50</td>
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</tbody>
</table>
CFS v2 (Saha et al. 2013)

1. An atmosphere of T126L64 (GFS)

2. An interactive ocean (MOM4) with 40 levels in the vertical, to a depth of 4737 m, and horizontal resolution of 0.25 degree at the tropics, tapering to a global resolution of 0.5 degree northwards and southwards of 10N and 10S respectively

3. An interactive 3 layer sea-ice model

4. An interactive land model with 4 soil levels
CFSv2 Biases

• TOA radiative imbalance
  +7.4 W m$^{-2}$ downward, 3.6 W m$^{-2}$ into ocean

• AMOC disappears
  Time scale of years

• Sea ice disappears
  Time scale of years
How Serious a Problem is CFSv2 AMOC bias? Consider AMOC in CFSv1

Mean Atlantic Meridional Overturning Streamfunction (Sv)

(a) GODAS, 1979–2004

(b) CFS, 335–YR

Huang, Hu, Schneider, Wu, Xue, and Klinger 2012
CFSv2 AMOC in 30-year runs

**CFSR Ocean Initial Conditions**

AMOC (Sv), CFS_v2, IC: CFSR, 30-yr

(a) Mean State

(b) 26.5N, 1000m

**NEMOVAR Ocean Initial Conditions**

AMOC (Sv), CFS_v2, NEMO, 30-yr

(a) Mean State

(b) 26.5N, 1000m

Huang and Zhu
Question: What is the role of AMOC for Decadal Prediction?
CFSv2 Known Errors

• A serious code bug was identified by COLA scientists in the atmosphere-ocean coupling in the North Atlantic.
  – Large errors in surface fluxes as seen by the ocean. Location of errors depends on number of processors.
    • NE North Atlantic in COLA runs
    • NW North Atlantic in NCEP runs
  – Only small improvement in AMOC strength when error is corrected.
## Experiments

<table>
<thead>
<tr>
<th>Run</th>
<th>Initial Condition Years</th>
<th>Length (years)</th>
<th>Ensemble Members</th>
<th>Atmosphere ICs</th>
<th>Ocean ICs</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCEP Volc</td>
<td>1980-2005 every 5 years + selected years</td>
<td>10</td>
<td>4</td>
<td>CFSR</td>
<td>CFSR</td>
</tr>
<tr>
<td>COLA Volc</td>
<td>1960-1990 every 5 years</td>
<td>10</td>
<td>3</td>
<td></td>
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<tr>
<td>COLA NoVolc</td>
<td>1960-2005 every 5 years</td>
<td>10</td>
<td>4</td>
<td>CFSR</td>
<td>NEMOVAR</td>
</tr>
<tr>
<td></td>
<td>1960-2005 yearly</td>
<td>3</td>
<td>2</td>
<td></td>
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<tr>
<td></td>
<td>1960-2005 yearly</td>
<td>10</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1960, 1980, 2005</td>
<td>30</td>
<td>4</td>
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</tr>
</tbody>
</table>

**NO HISTORICAL/UNINITIALIZED/FREE RUNS**
Model Performance Interannual Time Scales (COLA NoVolc)

NINO3.4
SSTA ACC
Results Decadal Time Scales
Outline of Analysis

• Compare common cases for NCEP Volc, COLA Volc, and COLA NoVolc
  – Ensemble means

• Verification data
  – NCEP reanalysis for atmosphere
  – NEMOVAR reanalysis for ocean
2m Air Temperature Predictions
Year 2-5, 6-9 Averages
T2m Anomaly Correlation

YEARS 2-5

Corr NCEP-rean T2m 1980–2000 yrs 2–5

Corr NEMO-rean T2m 1980–2000, yrs 2–5

Corr NEMO-rean T2m 1980–2000, 2–5 yrs

Corr NCEP-rean T2m 1980–2000 yrs 6–9

Corr NEMO-rean T2m 1980–2000, yrs 6–9

Corr NEMO-rean T2m 1980–2000,6–9yrs

NCEP Volc

COLA Volc

COLA NoVolc

YEARS 6-9
T2m Biases

YEARS 2-5

Bias NCEP T2m 1980–2000, yrs 2–5
Bias NEMOV T2m 1980–2000, yrs 2–5
Bias NEMO T2m 1980–2000, yrs 2–5

Bias NCEP T2m 1980–2000, yrs 6–9
Bias NEMOV T2m 1980–2000, yrs 6–9
Bias NEMO T2m 1980–2000, yrs 6–9

NCEP Volc
COLA Volc
COLA NoVolc

YEARS 6-9
T2m Bias Differences

COLA Volc minus NCEP Volc

Bias NEMOV–NCEP T2m 1980–2000, yrs 2–5

Years 2-5

COLA Volc minus COLA NoVolc

Bias NEMOV–NEMO T2m 1980–2000, yrs 2–5

Years 6-9
Atlantic Multidecadal Variability SST Index 1980-2010

COLA NoVolc

NCEP Volc
What are the Mechanisms for the Decadal Predictability of T2m in these Experiments?

• The memory of the system is in the ocean’s thermal and mechanical inertia, which determines the time scales of the response to external forcing and of the internal variability.

• This suggests a heat budget analysis would be a good place to start.
Heat Content Predictions

• Heat content $H$ is vertical integral of internal energy:

$$H(x, y) = \int_{z=-D(x,y)}^{z=0} \rho cT \, dz \approx \rho cD(x,y)\overline{T}(x,y)$$

where $\overline{T}$ is the vertically averaged temperature, and $D(x,y)$ is taken to be the full depth of the ocean.
Year 2-5, 6-9 Averages

• Verification against NEMOVAR Ocean Analysis.
Heat Content Anomaly Correlation

YEARS 2-5


Corr NCEP HC 1980–2000, yrs 6–9

Corr NEMOV HC 1980–2000, yrs 6–9

Corr NEMO HC 1980–2000, yrs 6–9

NCEP Volc

COLA Volc

COLA NoVolc

YEARS 6-9
Heat Content Biases

Plots are of $H/(4500\rho c)$, units °K

YEARS 2-5

NCEP Volc

COLA Volc

COLA NoVolc

YEARS 4-9
Heat Content Bias Differences

COLA Volc minus NCEP Volc


Years 2-5

COLA Volc minus COLA NoVolc


Years 6-9
Heat content biases show substantial ocean memory, because differences between the CFSR and NEMOVAR ocean reanalyses are so large,

Anomalies do not demonstrate much memory.
Heat Content Budget

• $H$ Satisfies the 2-dimensional energy budget:

$$\frac{dH}{dt} = NHF + O \quad (1)$$

*NHF* is net surface heat flux

*O* is the tendency due to ocean dynamics and physics
Global Mean Ocean Heat Content Diagnosis

• Compare $\frac{dH}{dt}$ and NHF
  
  $[\ ] = \text{global mean}$

  $$\left[ \frac{dH}{dt} \right] = \left[ NHF \right] \quad (2)$$

• **Verified:** CFSv2 results satisfy (2).

• Examine $[H]$, $[dH/dt]$ for CFSR and NEMOVAR reanalyses, NCEP and COLA forecasts.
Global Mean $H$ From Ocean Reanalyses

**NEMOVAR**

NEMOVAR [H] 1yr rm 1960–2010

- 1960: 5.64
- 1980: 5.66
- 2005: 5.92

**CFSR**

CFSR [H] 1yr rm 1980–2009

- 1980: 5.9
- 2005: 5.92
[H] Predictions

COLA NoVolc

COLA Volc

NCEP Volc
$[dH/dt]$
Local Heat Content Partial Diagnosis

- Compare $dH/dt$ and NHF
  - Local case: consider the correlation of $dH/dt$ and NHF
    - If $O=0$, the correlation is 1.
    - The difference of the correlation from 1 is a measure of the importance of ocean dynamics in the heat content budget.
    - Can calculate $O$ as a residual to explicitly examine the role of ocean dynamics.
Example: Correlation of H and NHF Annual Cycles
Correlation NHF and $dH/dt$, 2 year running means

**COLA NoVolc**

**COLA Volc**
Summary/Conclusions

1. Versions of CFSv2 used for COLA and NCEP predictions seem to be similar.
2. NCEP and COLA VOLC have similar skill for 2m air temperature decadal, despite large biases and strong differences in ocean heat content initialization.
3. Volcanic forcing is a strong contributor to “skill” for the CMIP5 experimental design.
4. Heat budget diagnosis shows promise for understanding mechanisms.