Approaches to reduce model biases to improve in climate prediction

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GCMs produce in vicinity to the eastern boundaries (Figure 1(b); see Table 1 for a list of the models used to generate the ensemble mean). This is usually accompanied by an underrepresentation of the stratuscumulus decks that leads to excessive shortwave radiation reaching the ocean surface (Figure 2(a) and (b)).

The poor GCM performance in reproducing SST and cloud cover is troubling because it undermines the credibility of climate change projections for the region. The response of stratocumulus clouds in these projections varies widely among models, with some models projecting increasing cloud cover (negative feedback) and others predicting decreasing cloud cover (positive feedback).

This disagreement adds substantially to the uncertainty of global temperature projections under greenhouse gas forcing. Moreover, eastern boundary regions are also subject to pronounced year-to-year variability in upwelling strength and SST. This variability can have severe impacts on fisheries and also affect weather over the adjacent continents.

GCMs form the basis of many seasonal prediction systems and thus eastern ocean biases may hamper skillful predictions of climate anomalies around coastal upwelling regions. Given the importance of tropical eastern boundaries to the climate system, it is crucial to alleviate the persistent GCM biases in the region. The present article aims to contribute to this goal by summarizing...
Two alternative approaches

1. Anomaly coupling \(\rightarrow\) Improved seasonal prediction in the Tropical Atlantic
   
   (Counillon et al. to be submitted)

2. Supermodelling \(\rightarrow\) Reduces the Pacific double Inter-tropical Convergence Zone bias
   
   (Shen et al. 2016, 2017)
The Atlantic Niño

First EOF of June-August precipitation
Linearly related SST and surface wind vectors

Chang et al. 2006
The Atlantic Niño
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The Bjerknes Positive feedback and delayed negative feedbacks underlie the Atlantic Niño
[e.g., Zebiak 1993, Keenlyside & Latif, 2007, Ding et al. 2010]

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The Atlantic Niño

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Consistently with the warm bias, coupled models underestimate the thermocline feedback
[e.g., Nnamchi et al. 2015, Deppenmeier et al. 2015, Ding et al. 2015a,b]

Chang et al. 2006
A methodology to correct mean state biases: Anomaly coupled model

Correction added to quantities exchanged between atmosphere and ocean

Courtesy: Thomas Toniazzo
Anomaly coupling captures Atlantic cold tongue

NorESM annual mean SST (ocean model) bias, 1980-2000

Standard

Anomaly coupled

Courtesy: Teferi Demissie
Seasonal predictions – With and without mean state bias

Norwegian Earths System Model with and without anomaly coupling (Toniazzo & Kosseki 2018)

Reanalysis

– 30 member ensemble
– Assimilation of anomaly SST, and T,S profiles, 1980-2010

Retrospective forecasts

– 1985 to 2010 with 9 members and 4 start date per year
Reduced biases enhances seasonal prediction skill for the Atlantic Niño

Norwegian Climate prediction Model, Correlation skill for ATL3 region 1985-2010, 4 starts per year (Feb. May, Aug. Nov.), 9 ensemble members

Courtesy: Francois Counillon
Reduced bias \(\rightarrow\) better equatorial variability

Standard deviation of SST along the equator, January - December

Observations

Standard

Anomaly coupled

Courtesy: Shunya Koseki
Reduced bias enhances ocean analysis

Correlation (1980-2010), 200m heat content
EN4 objective analysis with
Norwegian Climate Prediction Model ocean reanalysis

Standard (biased) model

Anomaly coupled model

Courtesy: Francois Counillon
... but skill remains poor, and not better than other models

Correlation skill for ATL3 region, NorCPM anomaly coupled and North American Multi-Model Ensemble 1985-2010, 4 starts per year (Feb. May, Aug. Nov.), 9 ensemble members

NorESM ACPL – thick black solid
NNME – coloured lines
Persistence – dashed black

Courtesy: Francois Counillon
Supermodelling reduces the Pacific double Inter-tropical Convergence Zone bias

(Shen et al. 2016, 2017)
Synchronising complex systems to compensate systematic errors

Lorenz attractor (1963)

\[ M_1^{*} = M_1 + a_{12} M_2 + a_{13} M_3 \]

\[ M_2^{*} = \ldots \]

\[ M_3^{*} = \ldots \]

Approach successfully applied to simple models (e.g., Van den Berge et al. 2011) and to quasi-geostrophic models (e.g., Selten et al. 2017)

Constants \( a_{12} \) and \( a_{13} \) trained to reproduce truth
Super model versus standard approach

Results from simplified ECHAM5/MPIOM super model

Climatological Precipitation in Tropical Pacific

(Shen et al. 2016, 2017)
Three synchronized Earth System Models

Current stage: Ocean models coupled by assimilating SST

\[
SST_{SuperModel} = \frac{1}{3}SST_{EcEarth} + \frac{1}{3}SST_{MpiEsm} + \frac{1}{3}SST_{NorEsm}
\]

Ocean connection

F. Counillon, M. Devilliers
Three synchronized Earth System Models

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Ocean connection

F. Counillon, M. Devilliers
Two alternative approaches

1. Anomaly coupling → Improved seasonal prediction in the Tropical Atlantic
   - Improved simulation of ocean-atmosphere interaction
   - Better initial conditions
   (Counillon et al. to be submitted)

2. Supermodelling → Reduces the Pacific double Inter-tropical Convergence Zone bias
   - Synchronized models can achieve greater bias reduction, because of non-linearity in the climate system
   - First steps towards 3D coupled Earth System Models
   (Shen et al. 2016, 2017)
Reducing biases enhances Atlantic Niño prediction

Predictions of ATL3 SST anomalies at two months lead
4 starts per year (Feb. May, Aug. Nov.), 9 ensemble members

Anomaly coupled model
Correlation = 0.5

Standard model
Correlation = 0.33

Courtesy: Francois Counillon
Super model strategy – Interactive Ensemble

Coarse resolution model: T31L19 atmosphere, 3 degree ocean,
Differing in the atmospheric convection scheme

Momentum flux:
\[ H = \alpha H_{\text{Nordeng}} + (1 - \alpha) H_{\text{Tiedtke}} \]

Heat flux:
\[ Q = \beta Q_{\text{Nordeng}} + (1 - \beta) Q_{\text{Tiedtke}} \]

Extension of Kirtman et al., 2003.
Standard coupled model

Quantities exchanged between atmosphere and ocean

Courtesy: Thomas Toniazzo