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Article

Improved decadal climate prediction in the North Atlantic using EnOI-assimilated initial condition

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ABSTRACT

Decadal prediction experiments of Beijing Climate Center climate system model version 1.1 (BCC-CSM1.1) participated in Coupled Model Intercomparison Project Phase 5 (CMIP5) had poor skill in extra-tropics of the North Atlantic, the initialization of which was done by relaxing modeled ocean temperature to the Simple Ocean Data Assimilation (SODA) reanalysis data. This study aims to improve the prediction skill of this model by using the assimilation technique in the initialization. New ocean data are firstly generated by assimilating the sea surface temperature (SST) of the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) dataset to the ocean model of BCC-CSM1.1 via Ensemble Optimum Interpolation (EnOI). Then a suite of decadal re-forecasts launched annually over the period 1961–2005 is carried out with simulated ocean temperature restored to the assimilated ocean data. Comparisons between the re-forecasts and previous CMIP5 forecasts show that the re-forecasts are more skillful in mid-to-high latitude SST of the North Atlantic. Improved prediction skill is also found for the Atlantic multi-decadal oscillation (AMO), which is consistent with the better skill of Atlantic meridional overturning circulation (AMOC) predicted by the re-forecasts. We conclude that the EnOI assimilation generates better ocean data than the SODA reanalysis for initializing decadal climate prediction of BCC-CSM1.1 model.

1. Introduction

Near-term climate prediction has been studied extensively using the models participated in the decadal prediction experiments of the Coupled Model Intercomparison Project Phase 5 (CMIP5) [1]. The North Atlantic is one of the regions that have shown improved skill due to initialization in most models [2–6]. The Atlantic multi-decadal oscillation (AMO) was a benchmark to assess the capability of decadal forecast systems, which impacts temperature and precipitation over the land [7]. The prediction skills in AMO and climate over the land associated with the AMO are, however, model dependent [8]. Still, some models, such as the Beijing Climate Center climate system model version 1.1 (BCC-CSM1.1), had poor prediction skill in the AMO although they are skillful in the tropical Pacific and tropical Atlantic oceans [9,10].

Decadal climate predictability depends on both initial conditions and external forcings arising from changes in atmospheric composition [11,12]. Since the external forcing is the same for all CMIP5 models [13], different prediction skills of these models may mainly originate from their initial conditions. Currently, modeling groups use different techniques and methodology to initialize decadal climate prediction, as summarized in Meehl et al. [6]. It is hard to identify which technique is better through comparing these model outputs. Carrying out re-forecasts using one model and different techniques of initialization is a good approach, although it is a huge task for any modeling group.

In the ongoing CMIP6, one of the grand science challenges is to improve near-term climate predictions. It is urgent to study how to improve the prediction skill of BCC-CSM climate model. This paper aims to investigate the influence of assimilated data used in the initialization upon the prediction skill of BCC-CSM1.1. First, we

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generate a new dataset through assimilating the sea surface temperature (SST) of the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) dataset [14] via the Ensemble Optimum Interpolation (EnOI). Then a suite of re-forecasts was carried out with the new assimilated data used in the initialization. Results of the re-forecasts will be compared with the previous CMIP5 forecast focusing on the North Atlantic.

2. Model, experiments and methodology

2.1. Model

Climate model BCC-CSM1.1 was developed by Beijing Climate Center (BCC) of China Meteorological Administration (CMA). The horizontal resolution of the atmospheric model BCC_AGCM2.1 is about 2.8° (T42), and there are 26 layers in the vertical [15,16]. The ocean component is based on the Modular Ocean Model version 4.0 (MOM4) [17], which has 40 levels in the vertical and is hence abbreviated as MOM4_L40 [18]. The horizontal resolution of the ocean model is 1° longitude by 1/3° latitude with tripolar grid. Detailed description about BCC-CSM1.1 was provided by Wu et al. [19].

2.2. Experiments

The initialization of CMIP5 decadal prediction experiments with BCC-CSM1.1 [20] employed a full-field nudging method to relax modeled ocean temperature to Simple Ocean Data Assimilation (SODA) data [21]. The time period for the restoration is one day. This study uses the EnOI method to assimilate the observation data to MOM4_L40, and generates a new dataset for the initialization of decadal prediction experiments. EnOI is a simplified form of the Ensemble Kalman Filter (EnKF) [22,23], which has an advantage in computational cost. In the assimilation, background error covariance controls the magnitude and structure of adjustment to the observations. The background error covariance used in EnOI is estimated from a prescribed static ensemble instead of dynamic ensembles used in EnKF. This ensemble is kept unchanged through the assimilation cycle and is referred as "static ensemble". It is usually generated by using a large historical ensemble composed of model states sampled over a long-time integration.

A control run (CNTR) from 1949 to 2008 is firstly carried out with MOM4_L40 model driven by the daily NCEP/NCAR reanalysis [24]. The instantaneous fields of CNTR on the 15th day of each month from 1990 to 1999 are selected to generate the static ensembles, because previous study indicated that 100 or so static samples are more appropriate than other sample numbers [25]. Then the HadISST data were assimilated to MOM4_L40 model using the EnOI method from January 1949 to December 2008. The time window for assimilation is one month. Outputs generated by the EnOI assimilation are named ASSIM.

The sea surface temperature (SST) bias of ASSIM is compared to that of CNTR to examine the performance of the EnOI assimilation (Fig. 1). The observation data used to estimate the bias is from the Extended Reconstructed Sea Surface Temperature (ERSST) Version 3b (ERSST V3b) dataset [26]. As can be seen in Fig. 1, the SST bias of ASSIM is lowered globally than that of CNTR, especially in the tropical Indian Ocean, the western Pacific Ocean and northward of 40 °N in the North Pacific Ocean, with the bias less than 0.5 °C. In the North Atlantic, the SST bias of CNTR is about 2.0 °C, while the bias of ASSIM is reduced by about 0.5–1.0 °C. So the EnOI assimilation is able to reduce the SST bias simulated by the ocean model.

The ASSIM data are used in the initialization of the re-forecasts of BCC-CSM1.1, while other conditions remain the same as in the CMIP5 forecasts. As the CMIP5 forecasts, the re-forecasts started each year over the time periods of 1961–2005 and predicted the next 10 years. This new suite of decadal forecasts is named as EnOI_HadInit. The CMIP5 decadal prediction using the SODA data in the initialization is referred to as SODAInit, while the historical simulation without initialization is referred to as NoInit. The external forcing of the two suits of forecasts are the same as the NoInit with the greenhouse gases, ozone, aerosols, volcanoes and solar variability evolving with time. The two suites of forecasts and NoInit all have three ensemble realizations with difference in initial states. The ensemble mean of the three realizations for each experiment were used in the analysis.

The ASSIM data have less bias than the modeled SST, and are more coordinated with the ocean component of BCC-CSM1.1 than

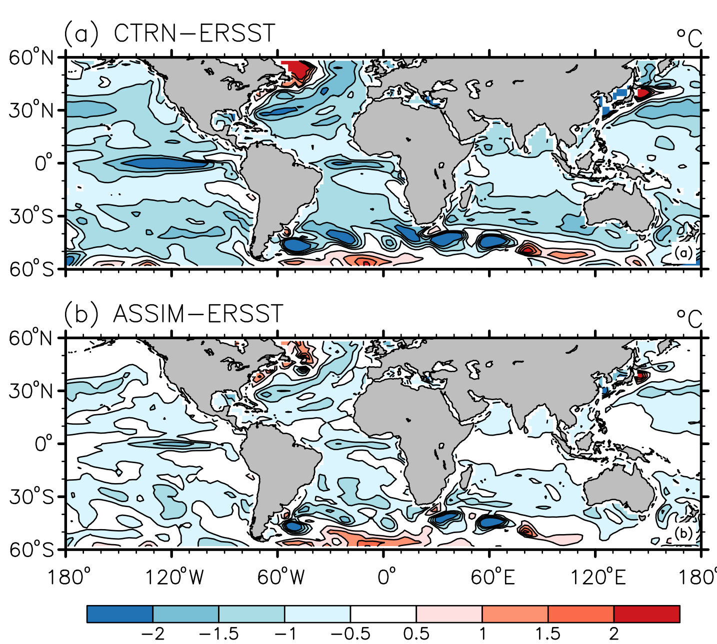

Fig. 1. Biases of SST (°C) climatology (1960–2005) simulated by control run CNTR (a) and ASSIM (b) of MOM4_L40 with respect to the observation.