Analysis of Arctic Oscillation Simulated by Global Warming Prediction Models

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1. INTRODUCTION

The Arctic Oscillation (AO) is a dominant atmospheric phenomenon characterized as opposing atmospheric pressure patterns between the middle and high latitudes. It is defined as a leading mode of an empirical orthogonal function (EOF1) of the sea-level pressure (SLP) in winter Northern Hemisphere by Thompson and Wallace (1998). Since a long-term variability of surface air temperature associated with the Arctic Oscillation Index (AOI) shows high correlation with the recent global warming, it attracts more attention that the AO is an important research problem in the study of global warming.

Miller et al. (2006) analyzed data sets of 14 Atmosphere-Ocean General Circulation Models (AOGCM) for the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC-AR4), indicated that the AOI exhibits a positive trend in response to increasing concentrations of greenhouse gases and tropospheric sulfate aerosols. Hori et al. (2007) also exhibited that the gradual trend in the AO is not a result of enhanced natural variability of the AO dynamics itself, but rather a result of the large anthropogenic forced liner trend projected onto the mean climatological state of the Arctic region. Meanwhile, Tanaka and Matsueda (2005) concluded that the AO is a physical mode of a dynamical system for the global atmosphere using the barotropic general circulation model.

It was reported by Yukimoto and Kodera (2005) that the ensemble mean of the Meteorological Research Institute (MRI) climate model experiments in the 20th century reflects a response to external forcing, while the deviations from the ensemble mean for each member are considered as internal variability.Interestingly, both of internal variability and the response to external forcing show the AO as the most dominant mode.

In this study, we analyze the AO simulated by the dataset of 10 AOGCM for IPCC-AR4 referring to Hori et al. (2007), and reveal features and factors of the AO with global warming conducting the similar analysis as Yukimoto and Kodera (2005).

2. DATA AND METHOD

We used monthly sea level pressure (SLP) and surface air temperature outputs of 10 AOGCM for IPCC-AR4. The control scenarios used the 20th Century Climate in Coupled Model (20C3M) for1901-2000 and Special Report on Emission Scenarios-A1B (SRES-A1B) for 2001-2100. For comparison purposes, the monthly SLP and surface air temperature from the HadSLP2 (Allan and Ansell 2006) and the HadCRUT3 (Brohan 2006) observed dataset are used for the 1901-2000 period.

First we calculate the EOF1 of the winter (DJF) mean SLP anomaly northward of 20N to compare models with the observation. We also illustrate the time series of the global mean surface air temperature anomaly to confirm the reproducibility of the climate change simulated by IPCC-AR4 models.

Then, we analyze decadal variations separated in the internal variability and the response to external forcing using 4 models that have sufficient ensemble members. Each member of the same climate model is integrated using the same external forcing such as increased greenhouse gases, solar constant variation, and volcanic impact but with slightly different initial data. So external forcing and internal variability can be separated by calculating EOF1 of the SLP anomaly for the ensemble mean and for the residual from it. The SLP data are smoothed by the 11-yaer running mean low-pass filter.

Finally, we calculated the EOF1 of the 10 model ensemble mean in order to examine how the AO simulated by model ensemble mean is reproduced in the 20th century and is predicted in the 21th century.

3. RESULTS

3.1 Reproducibility of the AO in winter

Figure 1 shows the spatial pattern and the time series of score of the EOF1 for SLP for 20C3M by the MRI model. The spatial pattern exhibits similar AO pattern, with a negative anomaly in the Arctic region and surrounding positive anomalies in the middle latitude with maxima in the North Atlantic and the North Pacific. But its score time series, called the AOI, disagree with the observed AOI.

All the other IPCC-AR4 models also represented the AO pattern unexceptionally, on the other hand, none of the models could accurately simulates the observed AOI in the 20th century run.

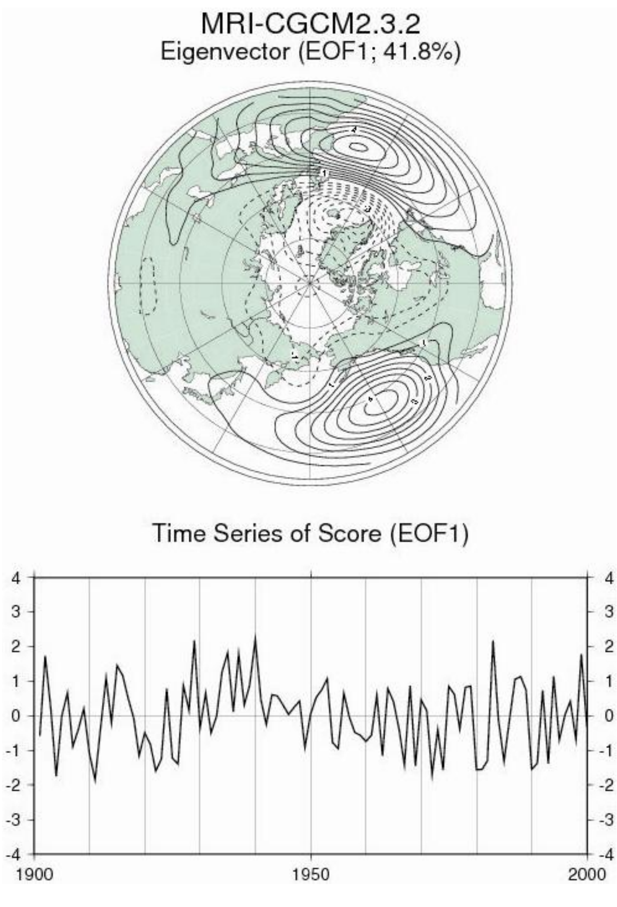


Fig. 1. Spatial pattern and time series of score of the EOF1 for SLP for 20C3M by the MRI model.

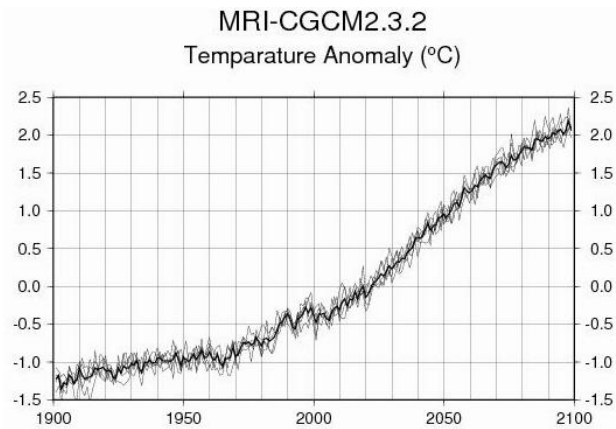
3.2 Reproducibility of the surface temperature

Figure 2 shows the time series of global mean surface air temperature anomaly for the 20C3M and SRES-A1B for the 5 ensemble members (thin lines) and the ensemble mean (thick line), simulated by the same MRI model. In the 20th century, the temperature increases 1℃ and its tendency is remarkable after 1970s. The amount of change and its tendency correspond to the observation. For the 21th century run, the increase of temperature continues monotonically, and the model projects 2.5℃ warming during the 100 years.

The variation range of the ensemble members included in the internal variability is as same as the range of the ensemble mean resulted form the external response. The result suggests that the temperature change may be regarded mostly as the response to the external forcing.

3.3 Internal variability and external response

The spatial patterns of the EOF1 of SLP for the decadal (by 11-year low-pass filter) internal variability and the response to external forcing for 20C3M and SRES-A1B by the same MRI model are shown in Figure 3, and their score time series are shown in Figure 4. Internal variability exhibits the AO pattern for the 20th and 21th century run. However, external forcing cannot reproduce the AO pattern completely,



high

Fig. 2. Time series of global mean temperature anomaly for 20C3M and SRES-A1B by the MRI ensemble model.

contributing ratio of 77.1 %.

On the other hand, the score of EOF1 for external response (thick line) in the 20th century run shows notable increasing trend after 1970s. In the 21th century, it shows a monotonic increasing trend, which is likely to be caused by the monotonic increase of greenhouse gases. But unlike temperature, each independent score of the internal variability is so large that the AOI may be determined by the natural variability.

In the other models, the internal variability appears commonly as the AO pattern, however, the response to the external forcing varies widely depending on the models and scenarios. The time series of the score represents a monotonic positive trend superimposed on the substantially large internal variability after the late 20th century with the increase of greenhouse gases.

3.4 The AO simulated by multi-model

Figure 5 shows the spatial patterns of the EOF1

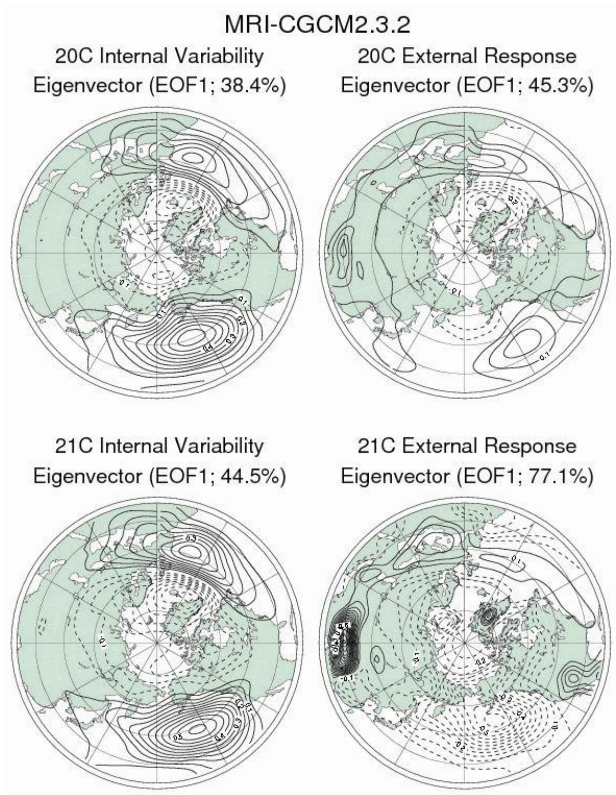


Fig. 3. Spatial patterns of the EOF1 of SLP for decadal internal variability and response to external forcing for 20C3M and SRES-A1B by the MRI ensemble model.

of SLP for decadal (by 11-year low-pass filter) model ensemble mean and the deviation from it for 20C3M and SRES-A1B. Their time series of score are shown in Figure 6. Both the multi-model mean and the deviation from it show AO-like structure in the 20th and 21th century. Especially, for the 21th century, the variance contributionby the external response represents 88.1 % The result suggests that the external response of SRES-A1B is more monotonous than 20C3M and its circulation is determined uniquely.

In the time series of the AOI, model ensemble shows increasing trend after 1970s. However it cannot reproduce the observed AOI completely for 20C3M.

4. DISCUSSIONS

In this study, we analyzed the AO under the global warming for the 20th and 21th century using data sets of 10 AOGCM for IPCC-AR4.

The long-term variability of the atmosphere superficially looks like to correspond with the climate

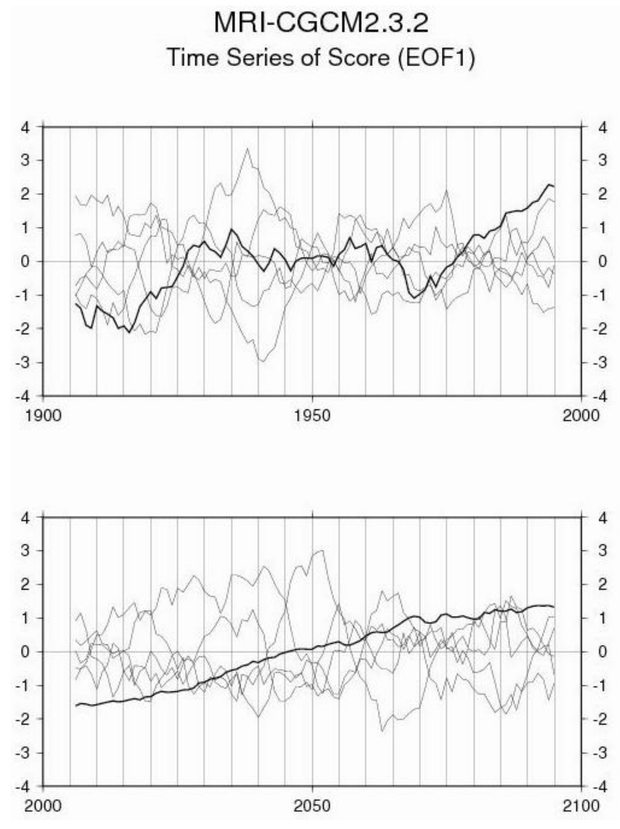


Fig. 4. As in Fig. 3, but time series of the score.

change in the middle and high latitudes on global warming (e.g. increasing of the score of EOF1 for external response with SRES-A1B), However, its spatial pattern didn't necessarily represent the AO. And the global mean surface temperature simulated by the models reproduces the observation responding to external forcing. However, none of the models could reproduce accurately the bserved AOI.

Therefore, it is concluded that the observed decadal variability like the AO is not the forced response, but can be explained mostly by the natural variability of the atmosphere.

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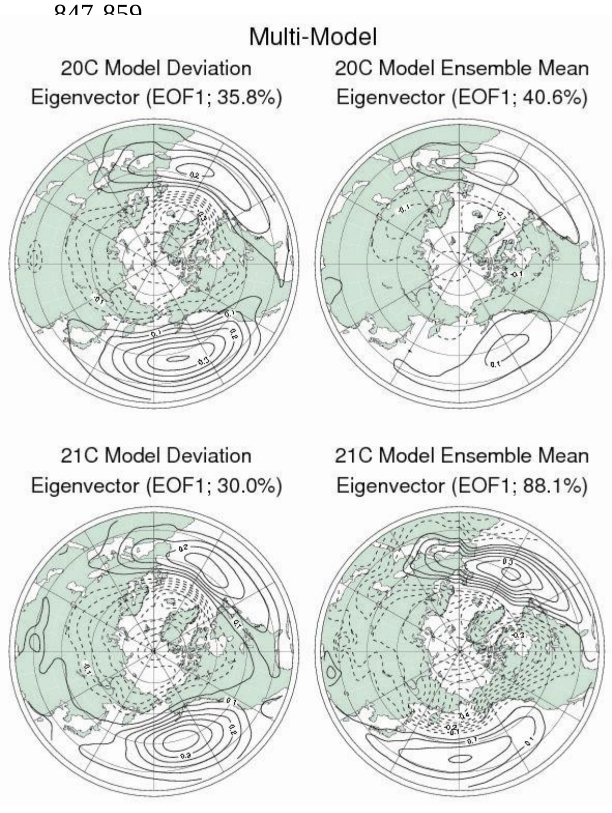

Fig. 5. Spatial patterns of the EOF1 of SLP for decadal model ensemble mean and deviation from it for 20C3M and SRES-A1B.

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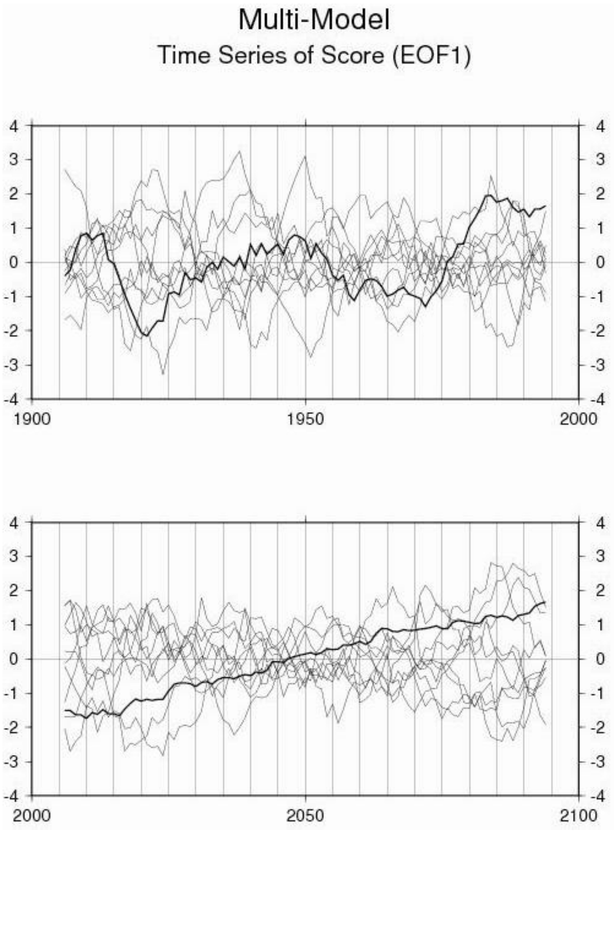

Fig. 6. As in Fig. 5, but time series of the score.