Climate predictability in the second year

BY LEON HERMANSON* AND ROWAN T. SUTTON

Department of Meteorology, Walker Institute, University of Reading, Reading RG6 6BB, UK

In this paper, the predictability of climate arising from ocean heat content (OHC) anomalies is investigated in the HadCM3 coupled atmosphere–ocean model. An ensemble of simulations of the twentieth century are used to provide initial conditions for a case study. The case study consists of two ensembles started from initial conditions with large differences in regional OHC in the North Atlantic, the Southern Ocean and parts of the West Pacific. Surface temperatures and precipitation are on average not predictable beyond seasonal time scales, but for certain initial conditions there may be longer predictability. It is shown that, for the case study examined here, some aspects of tropical precipitation, European surface temperatures and North Atlantic sea-level pressure are potentially predictable 2 years ahead. Predictability also exists in the other case studies, but the climate variables and regions, which are potentially predictable, differ. This work was done as part of the Grid for Coupled Ensemble Prediction (GCEP) eScience project.

Keywords: Grid for Coupled Ensemble Prediction; climate prediction; decadal predictability; general circulation model; initial conditions

1. Introduction

It is well established that, based on knowledge of the initial conditions, important aspects of climate are predictable up to a year ahead. This predictability is primarily associated with the El Niño Southern Oscillation (ENSO). But is climate predictable further ahead? To what extent does the knowledge of the initial conditions constrain longer term climate forecasts?

Previous work (Griffies & Bryan 1997; Grötzner et al. 1999; Boer 2000; Collins 2002; Smith et al. 2007; Keenleyside et al. 2008) has shown evidence that the initial state of the ocean can influence forecasts a decade or more ahead. However, evidence of decadal predictability is clearest for ocean rather than for atmospheric climate variables, especially on annual time scales. In this study, we investigate whether there is evidence that atmospheric climate variables are potentially predictable in the second year, i.e. beyond the generally accepted limit of ENSO-related predictability (although Luo et al. (2008) show evidence for ENSO being predictable more than a year ahead). Recognizing that predictability is likely to be dependent on the initial conditions, we consider model-based case studies rather than measures of average predictability.

* Author for correspondence (k.l.hermanson@reading.ac.uk).

One contribution of 24 to a Discussion Meeting Issue ‘The environmental eScience revolution’.
2. Model set-up and methodology

The Hadley Centre HadCM3 model (Gordon et al. 2000; Pope et al. 2000) was used in this work. It is a coupled model and so has interactive ocean (1.25°×1.25°), atmosphere (2.5°×3.75°), land surface and sea-ice components. The initial conditions for the case studies are taken from an ensemble of five 50-year integrations started in 1950 from a single transient integration that was started in 1860. This ensemble is forced by observed changes in greenhouse gases (GHGs), volcanic aerosols and the solar cycle. Within 10 years, the members have become independent of each other with respect to the important climate variables (not shown).

A case study consists of two further ensembles that are set up as a forecast and integrated for 10 years. Following Smith et al. (2007), the external forcing, the solar cycle, is a repeat of the previous 11 years, there are no volcanic eruptions and historical estimates of GHGs are used. The volcanic aerosols that exist at the beginning of the experiment are decreased exponentially as the integration progresses. Within all ensembles, the initial conditions between the members differ only by small random global perturbations to the sea surface temperatures (SSTs) of the order of 0.01°C. A summary of the experimental set-up can be found in table 1.

The initial conditions for the case-study ensembles are taken from two members of the 50-year ensemble that show large, persistent, regional differences in ocean heat content (OHC). This paper focuses on one case that started on 1 December 1981. The initial conditions were chosen on the basis of large differences in North Atlantic OHC.

Figure 1a shows the difference in the ensemble mean annual mean 500 m OHC of the first year. There are large positive anomalies in the North Atlantic, the Southern Ocean and parts of the West Pacific. There are large negative anomalies in the Indian Ocean and parts of the Pacific. The SST average difference over the North Atlantic (20° N–66° N) is 0.28°C. Predictability in the second year is assessed by examining the difference between the ensemble means for the second-year annual mean. The level of confidence in the differences is measured using a t-test.

3. Predictability in the second year

Figure 1b–d shows ensemble mean anomalies in 1.5 m surface temperature, precipitation and sea-level pressure, respectively, all for the second-year annual mean. From figure 1b it is clear that the large differences in OHC from the first year in the North Atlantic still influence surface temperatures in the second year. There are also significant temperature anomalies of more than half a degree over central Europe. The warm SSTs appear to alter the local circulation and bring
more southerly winds to central Europe, as shown in figure 1. The low pressure over the North Atlantic also brings wetter weather, as shown in figure 1d, to the southern Iberian Peninsula.

In the tropics, there are significant anomalies in precipitation, closely correlated with significant anomalies in SST. The South Atlantic shows a southward shift of the intertropical convergence zone with large anomalies over northeast Brazil. In the West Pacific, precipitation is reduced at the eastern edge of the maritime continent, while, in the subtropics, the South Pacific convergence zone has moved south and west bringing large changes in precipitation to South Pacific island nations. These changes in tropical precipitation are likely to be associated with changes in the Walker circulation, as is also suggested by the anomalies in tropical sea-level pressure.

Other case studies (not shown here) also show evidence of climate predictability in the second year. For example, in some cases, precipitation is found to be potentially predictable in the Sahel and India. There are also cases where surface temperatures in southeast USA are potentially predictable.

4. Conclusions

This work has shown evidence that knowledge of the initial conditions can constrain predictions of climate variables in the second year ahead. In the particular case study considered, North Atlantic SSTs, central European temperatures, tropical and subtropical precipitation in the Pacific and tropical precipitation in the Atlantic appear to be predictable.
However, predictability of climate variables in the second year is strongly dependent on the initial conditions. Other case studies show predictability in different regions. Further work will involve understanding the mechanisms that give rise to these predictable signals and examining the predictability of climate variables beyond the second year.

References

Boer, G. J. 2000 A study of atmosphere–ocean predictability on long time scales. *Clim. Dyn.* **16**, 469–477. (doi:10.1007/s003820050340)

Collins, M. 2002 Climate predictability on interannual to decadal time scales: the initial value problem. *Clim. Dyn.* **19**, 671–692. (doi:10.1007/s00382-002-0254-8)

Gordon, C., Cooper, C., Senior, C. A., Banks, H., Gregory, J. M., Johns, T. C., Mitchell, J. F. B. & Wood, R. A. 2000 The simulation of SST, sea ice extent and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Clim. Dyn.* **16**, 147–168. (doi:10.1007/s003820050010)

Griffies, S. M. & Bryan, K. 1997 A predictability study of simulated North Atlantic multidecadal variability. *Clim. Dyn.* **13**, 459–487. (doi:10.1007/s003820050177)

Grötzner, A., Latif, M., Timmermann, A. & Voss, R. 1999 Interannual to decadal predictability in a coupled ocean–atmosphere general circulation model. *J. Clim.* **12**, 2607–2624. (doi:10.1175/1520-0442(1999)012!2607:ITDPIA2.0.CO;2)

Keenleyside, N. S., Latif, M., Jungclaus, J., Kornblueh, L. & Roeckner, E. 2008 Advancing decadal-scale climate prediction in the North Atlantic sector. *Nature* **453**, 84–88. (doi:10.1038/nature06921)

Luo, J. J., Masson, S., Behera, S. K. & Yamagata, T. 2008 Extended ENSO predictions using a fully coupled ocean–atmosphere model. *J. Clim.* **21**, 84–93. (doi:10.1175/2007JCLI11412.1)

Pope, V. D., Galiani, M. L., Rowntree, P. R. & Stratton, R. A. 2000 The impact of new physical parametrisations in the Hadley Centre coupled model without flux adjustments. *Clim. Dyn.* **16**, 123–146. (doi:10.1007/s003820050009)

Smith, D. M., Cusack, S., Colman, A. W., Folland, C. K., Harris, G. R. & Murphy, J. M. 2007 Improved surface temperature prediction for the coming decade from a global climate model. *Science* **317**, 796–799. (doi:10.1126/science.1139540)