Available online at www.sciencedirect.com
ScienceDirect
Dynamics of Atmospheres and Oceans
43 (2007) 151–170
dynamics of atmospheres and oceans
www.elsevier.com/locate/dynatmoce

The North Atlantic Oscillation as a source of stochastic forcing of the wind-driven ocean circulation

Kettyah C. Chhak [a,*], Andrew M. Moore [b]

[a] School of Earth and Atmospheric Sciences, Georgia Institute of Technology, 311 Ferst Drive, Atlanta, GA 30332, United States
[b] Department of Ocean Sciences, 1156 High Street, University of California, Santa Cruz, CA 95064, United States

Received 25 July 2006; accepted 22 December 2006
Available online 9 January 2007

Abstract

Observations show that at middle and high latitudes, the magnitude of stochastic wind stress forcing due to atmospheric weather is comparable to that of the seasonal cycle and will likely exert a significant influence on the ocean circulation. The focus of this work will be the contribution of the North Atlantic Oscillation (NAO) to the stochastic forcing in the North Atlantic and its influence on the large-scale, wind-driven ocean circulation. To this end, a QG model of the North Atlantic Ocean was forced with the stochastic component of wind stress curl associated with the NAO signal. The ocean response is localized primarily in the western boundary region and can be conveniently understood using generalized stability analysis. Much of the variability is associated with the nonnormal influence of the bathymetry and inhomogeneities in the western boundary flow on the large-scale circulation. A more traditional statistical analysis of the circulation, however, reveals that there are very small and insignificant correlations between the NAO forcing and the ocean response within the western boundary region. This suggests that the dynamics of the ocean response to stochastic forcing may obscure any obvious coherence between the forcing and the response which is equally difficult to identify from observations.

Keywords: Stochastic forcing; Wind-induced variability; Teleconnections

1. Introduction

Identified as a high-frequency atmospheric teleconnection pattern (vanLoon and Rogers, 1978; Wallace and Gutzler, 1981), the North Atlantic Oscillation (NAO) is one of the dominant modes

* Corresponding author. Tel.: +1 404 894 4008.
E-mail address: kettyah.chhak@eas.gatech.edu (K.C. Chhak).

0377-0265/$ – see front matter
doi:10.1016/j.dynatmoce.2006.12.002

of atmospheric and climate variability at middle and high latitudes. The NAO is a meridional oscillation in atmospheric air mass between the Arctic and subtropical Atlantic and is sometimes considered a regional expression of the hemispheric mode of variability, the Arctic Oscillation (AO) (Thompson and Wallace, 1998; Marshall et al., 2001). The positive phase of the NAO is characterized by a deeper than normal low pressure anomaly over the Arctic and Icelandic regions (the Icelandic low), and a stronger than normal high pressure anomaly across the subtropical Atlantic (the Azores or Bermuda high). The resulting redistribution of air masses produces stronger than normal westerlies, typically resulting in more frequent and stronger storms that travel in a northeasterly direction along the North Atlantic storm track. This contributes to winters that are anomalously warm and wet in Europe, anomalously cold and dry in Canada and Greenland and anomalously mild and wet along the Eastern United States. The negative phase of the NAO is similar to the positive phase but with considerably weaker pressure anomalies. Therefore, during a negative phase of the NAO there are less frequent and weaker storms along the North Atlantic storm track (Hurrell, 1995).

The NAO is often defined in several ways, most typically as an index of normalized, time-averaged pressure differences between two stations that represent the two centers of action of the NAO such as the Azores and Iceland (Hurrell, 1995; Marshall et al., 2001). An obvious drawback of such an approach is that it does not take into account the possibility that the centers of action may not actually overlap the station locations. An alternative method for computing an NAO index is therefore to compute principle component (PC) timeseries of the leading EOF of wintertime sea level pressure (SLP) anomalies over the Atlantic sector (Branstator, 2002). On seasonal timescales, both definitions of the NAO index give qualitatively similar results with correlations between the two index timeseries around 0.90 (Hurrell, 1995), and both indicate that the NAO has largest amplitude and areal coverage during the December–March period (Hurrell, 1995; Marshall et al., 2001).

The NAO has been observed to exhibit variability on a wide range of timescales ranging from a few days to decades. During the last 25 years or so, the NAO has exhibited primarily decadal variability, and relatively high values compared to the previous century (Hurrell, 1995; Greatbatch, 2000). Through observational and modeling studies, decadal variability in the NAO has been linked with decadal variability in North Atlantic sea surface temperatures (Deser and Blackmon, 1993; Hanse and Bezdek, 1996; Sutton and Allen, 1997), climate patterns of temperature and precipitation in Europe and North America (Hurrell, 1995; Hurrell and van Loon, 1997), and mode water formation in the western North Atlantic (Paiva and Chassignet, 2002).

Although decadal variability of the NAO has been most prominent during the last 25 years, it also displays distinct interdecadal and interannual variability (Bjerknes, 1964; Hurrell, 1995; Eden and Jung, 2001). Wunsch (1999) found, through a spectral analysis of a timeseries containing 100 years of station based NAO indices, a weakly red spectra of the NAO index with weak peaks near periods between 2–3 years and 8–10 years. Observational studies of Frankignoul et al. (2001) and Joyce et al. (2000) found interannual shifts in the Gulf Stream position associated with the NAO, while Curry and McCartney (2001) present observational evidence of interannual variability in the intensity of the North Atlantic subtropical and subpolar ocean gyres associated with the NAO.

It is still a matter of current debate whether the NAO is a coupled ocean-atmosphere phenomenon or whether the ocean response to the NAO is passive. However, dynamical coupling with the ocean is not an essential feature of NAO dynamics as noted by Greatbatch (2000). The longer timescales of variability observed in the NAO are, however, linked to climate variability and are therefore most likely due to coupled ocean-atmosphere phenomena. In this study, we are primarily interested in the stochastic or high frequency component of the NAO variability so the