NOTES AND CORRESPONDENCE

Apparent Vertical Propagation of the NAM Index Due to an Embedded Wave Structure

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Abstract

The leading empirical orthogonal function (EOF) of the geopotential height is called the Northern Annular Mode (NAM). Stratosphere-troposphere connections seen in the multilevel NAM signal are often considered as due to a propagation of the annular structure. However, the tropospheric leading EOF contains not just an annular structure, but also a wave structure. This indicates that the NAM index is sensitive to changes in wave activity.

A previous study showed that an apparent downward propagation of the NAM index can appear as a result of a reflection of wave 1 due to a stratospheric sudden warming. If this result is correct, we may also expect to find a reverse case. Here we show a case when an amplification of a tropospheric wave 1 leads to a stratospheric warming, an apparent upward propagation of the “Annular” mode signal, i.e., change in the amplitude of the NAM index appears due to a projection on the wave component of the tropospheric NAM.

1. Introduction

To emphasize the zonal structure of the Arctic Oscillation (AO), the loading pattern of the leading empirical orthogonal function (EOF) of sea level pressure (SLP) in the northern hemisphere, Thompson and Wallace (2000) renamed it as the “Northern Annular Modes (NAM).”

The AO, or NAM, is usually qualified as a seesaw pressure between the polar region and midlatitudes. However, it also contains a wave structure: the polar signal is larger in the Atlantic sector, and midlatitude anomalies are prominent over the North Atlantic and North Pacific Oceans.

The spatial structure of the NAM over the Atlantic sector is similar to the North Atlantic Oscillation (NAO), a seesaw of the SLP between the Icelandic Low and Azores High. Some people (e.g., Deser 2000) consider that the Pacific signal in the NAM has no physical significance but is due to the use of a hemispherical EOF. However, Honda et al. (2001) consider that the Pacific signal is real and that

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a seesaw between the Icelandic and Aleutian Lows is an essential feature of the NAM. This means that the annular mode, in spite of the nomenclature, contains a large wave component in the troposphere.

An aspect of the NAM that is often emphasized is an equivalent barotropic structure extending from the surface to the stratosphere. Baldwin and Dunkerton (1999) demonstrated a downward propagation of the NAM signal from the stratosphere based on the projection of the multilevel NAM pattern onto the geopotential height of the corresponding level. The time series of the NAM index at each pressure level was shown to sometimes contain a time lag of surface anomalies from stratospheric anomalies. This is usually interpreted as a vertical propagation of “the annular” structure from the stratosphere to the troposphere.

The multilevel NAM is, in fact, the leading EOF at each pressure level. The spatial structures are rather different between the stratosphere and troposphere. The stratospheric NAM is mostly zonal, whereas the tropospheric NAM has a large wave component added to the zonal one. (Note some people continue to call the “surface NAM” by its original name, the “AO” to distinguish from the stratospheric NAM.) The variability of the stratospheric NAM practically coincides with that of polar night jet, but the variation of the tropospheric NAM can also be caused from a change in wave component.

In fact, Coughlin and Tung (2005) showed that an apparent propagation of the NAM signal during the winter 1998/99 does not necessarily mean a propagation of the annular structure, but the tropospheric NAM signal is due to the projection of the wave 1 structure in the leading EOF. They showed that an apparent downward propagation of the NAM can appear due to a reflection of wave 1 in the stratosphere due to a stratospheric warming. If their argument is correct, we may also expect to find a reverse case, where an amplification of the tropospheric wave number 1 leads to a stratospheric warming. In this case an apparent upward propagation of the NAM signal appears due to the projection onto the wave component in the troposphere and zonal component in the stratosphere.

Inspection of Fig. 2 in Coughlin and Tung

(2005) reveals that prior to the change in the stratospheric NAM index, the NAM index in the troposphere changes due to the wave 1 component. However, during the winter, variability is large both in the stratosphere and troposphere so that it is difficult to see a causal relationship between them. Usually the stratosphere is not perturbed in October because the tropospheric planetary wave amplitude is still small. Interestingly, a very large amplification of the wave 1 for this season occurred in October 2006. In the present study, this example is used to examine the role of wave propagation in a framework of the stratosphere-troposphere connection by the annular mode.

Operational meteorological centers are monitoring the weather and climate by calculating different indices. At NOAA Climate Prediction Center (CPC) the AO index is calculated based on the EOF 1 of 1000-hPa geopotential height. The polar vortex strength from the troposphere and stratosphere is monitored by polar geopotential height (averaged north of 65°N) at each level as a simplified multilevel NAM index. We will show how the October 2006 event is captured in a NAM framework and it will be compared with a more classical monitoring of

Fig. 1. (top) Normalized geopotential height anomalies over the polar region (65°N–90°N) at each pressure level as a simplified multilevel NAM index and (bottom) AO (1000 hPa NAM) index in October 2006 analyzed by NOAA/CPC.

Fig. 2. Anomalous geopotential height at (a) 1000-, (b) 500- and (c) 10-hPa averaged from 15 to 19 October 2006. (d) same as in (c) but for the average from 22 to 26 October 2006. Unit is m and negative values are indicated by dashed lines. Values lower than the area mean (30°N – 90°N) are shaded.

the stratospheric circulation by Japan Meteorological Agency (JMA) to better understand the dynamics.

2. Results

NOAA CPC indices related to the NAM (<http://www.cpc.noaa.gov/>) are reproduced in Fig. 1. During the October of 2006, the AO index showed a clear decrease. It became lower than 2 standard deviations from 15 to 19 October. A height-time section of polar geopotential height shows that following a decrease of the AO index, a weaker polar vortex propagates upward from the troposphere to the stratosphere.

To understand what has actually happened, the spatial structure of the geopotential heights at (a) 1000-, (b) 500- and (c) 10-hPa are shown as departure from a climatology (1968–1996) in Fig. 2 for this period of low AO indices (15–19 October 2006). The height anomaly at 1000-

hPa exhibits a characteristic feature of the negative surface NAM or the AO: an increase of polar pressure, in particular over the Atlantic sector and a decrease of midlatitude pressures over the Atlantic and Pacific sectors. This feature could also be qualified as an Icelandic-Aleutian Low seesaw or the NAO+ Aleutian Low variation. Anomalous geopotential height at 500 hPa shows more or less similar structure as that of 1000-hPa. Although spatial structure in the stratosphere at 10-hPa is largely different, a seesaw pattern between the polar and surrounding region, which is a characteristic feature of the NAM signal, is recognized during a following period of 22–27 October 2006 (Fig. 2d). This does not necessarily mean that the connection between the troposphere and the stratosphere is due to the annular field.

If one looks not at the departure from the

Fig. 3. Same as in Fig. 2 but for the total field.

climatology but at the total field, one observes different features. Figure 3 shows the same 5-day mean values as in Fig. 2, but for total fields. The geopotential height at 1000-hPa pattern is not so different, but the 500-hPa geopotential height pattern exhibits an amplified wavenumber 1 pattern with a blocking situation over the North Atlantic region and a developed Aleutian Low. Wave 1 structure is also prominent at the 10-hPa level, but the phase is shifted to the west: low pressure is located over the European sector and high pressure is now found in the Pacific region (Fig. 3c). Further westward shift of the wave structure in the following period (Fig. 3d) indicates a vertical propagation of planetary waves from the troposphere, which leads to a polar warming and midlatitude cooling in the stratosphere.

Stratospheric warming is monitored by JMA (<http://ds.data.jma.go.jp/tcc/tcc/products/clisys/STRAT/index.html>). The north polar temperature at 10-hPa and the vertical component of the E-P flux averaged over north of 30°N are

reproduced in Fig. 4. Following the amplification of the vertical propagation of planetary wave 1 from the troposphere, an increase in the polar temperature occurred. The warming was not large (about 10 K), but this phenomenon is the same as the stratospheric sudden warmings described by Matsuno (1970).

3. Concluding remarks

The term ‘annular mode’ emphasizes the zonal structure of the EOF pattern. However, as shown here and in the previous paper (Coughlin and Tung 2005), the EOF pattern also contains a wave 1 structure, which gives rise to a change in the tropospheric NAM index. Such examples may be more easily understood with a classical framework of the vertical propagation of planetary waves and wave mean-flow interaction. Therefore caution should be taken to interpret the stratospheric-tropospheric connection in terms of “annular” modes.

Itoh and Harada (2004) showed that the tropospheric teleconnection pattern related to the

Fig. 4. (top) North polar temperature at 10 hPa. (bottom) Vertical component of the EP flux of wavenumber 1 at 100-hPa averaged north of 30°N. The unit is Pa m²s⁻². Blue line is smoothing by 5-day running mean. Analysis by Japan Meteorological Agency.

stratospheric NAM is the North Atlantic Oscillation (NAO) and that related with the stratospheric wave 1 is the Pacific North American (PNA) pattern. In the present study, the geopotential height pattern prior to the warming exhibits a clear wave 1 pattern in the troposphere (Fig. 3b). Interestingly its anomalous field (Fig. 2b) exhibits a similar pattern to that obtained from a regression of NAM index at 30 hPa onto the 500-hPa height by Itoh and Harada (2004). As can be seen in Fig. 4, a warming occurred following a propagation of this wave 1 into the stratosphere. (Note also that this anomalous stratospheric wave 1 pattern has a different phase structure to that associated with the PNA.) To get an insight into a dynamical process of the vertical connection, this case study

on a prominent event should be a very useful addition to the statistical one.

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