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Covarying modes of the Pacific SST and northern hemispheric midlatitude atmospheric circulation anomalies during winter

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Abstract

The interannual-to-interdecadal relationship between the Pacific sea surface temperature (SST) and the northern hemispheric midlatitude's atmosphere represented by the circumpolar vortex was documented with the global oceanic and atmospheric reanalysis data of recent 50 years. Two covarying modes of the Pacific SST and northern circumpolar vortex anomalies during winter were examined using the singular value decomposition and wavelet analysis techniques. One is the interannual, ENSO-related mode and the other is the interdecadal, North Pacific SST-related mode with a period of around 20 years. The two modes exhibit distinct spatial structures. For the interannual mode, the SST anomaly is characterized by a typical ENSO pattern with the principal signature in the tropical eastern Pacific and secondary one in the central North Pacific, while the atmospheric anomaly is regional, characterized by a Pacific-North American pattern. For the interdecadal mode, large SST anomaly is located in the central North Pacific, while the atmospheric anomaly is zonally global, associated with the midlatitute's standing long-wave variations. When the central North Pacific is colder, the long-wave is stronger, and vice versa. Further investigations suggest that the interdecadal mode could involve an interaction between "two oceans and an atmosphere".

Keywords: Sea surface temperature; Atmospheric circulation; ENSO; Decadal variability

1. Introduction

Seasonal-to-interdecadal climate variability is inherently related to air–sea interaction. As a result of air–sea interaction in the tropic Pacific, El Niño/Southern Oscillation (ENSO) is the strongest interannual variability in global climate system. ENSO has a significant climate impact not only on the tropics but also on the midlatitude atmosphere via Pacific-North American (PNA) teleconnection, which has been proved by many observational analysis and modeling simulations [1–4]. The Pacific ocean–atmosphere system manifests not only predominantly interannual variability but also decadal-to-interdecadal variability. With observations of a major climatic regime shift around 1976/1977 [5–8], the North Pacific has attracted more and more attention. The evidence show that for the ocean, the sea surface temperature (SST) tends to be anomalously cool in the central-western North Pacific but anomalously warm along the North American coast and the central-eastern tropical Pacific. For the atmosphere, the sea level pressure (SLP) and 500 hPa geopotential height are lower than normal, and the Aleutian low is anomalously strengthened and shifts southeastward. Similar regime shifts also occurred in the 1920s and 1940s. Such regime shifts are closely associated

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with the decadal-to-interdecadal variability in the North Pacific as well as in the tropical Pacific [9–11], which is commonly called the Pacific Decadal Oscillation (PDO) [10]. Recent researches have revealed the joint spatio–temporal structures of the Pacific decadal variability [12] and its association with the climate variability on North America [10] and East Asia [13]. The mechanism responsible for the existence and origin of ENSO is relatively well understood [14–17]. However, the exact cause of the decadal variability and its impact remain unclear and is an area of very active research. Most prior researches have simply regarded the Pacific decadal variability as a local air–sea interaction mode and attributed its impact to downstream effects on circulation over the PNA region [10]. However, recent observational evidence [13] has shown that PDO is closely related to the upstream atmospheric circulation over Eurasia, indicating the potential relationship between Pacific decadal variability and the midlatitude atmospheric circulation of the entire Northern Hemisphere. The purpose of the present study is to reveal the abovementioned connection which is crucial to investigate the causes of Pacific decadal variability.

The spatio–temporal structures of the covarying modes of the Pacific SST and northern hemispheric midlatitude atmospheric circulation anomalies during winter are revealed by using the techniques of Singular Value Decomposition (SVD) and wavelet analysis. Significant differences between the interannual mode and the interdecadal mode and possible physical mechanisms are also discussed. A unique feature of this research is using the representative contour of 500 hPa geopotential height to characterize midlatitude atmospheric circulation. Some previous studies have used such an approach to define the circumpolar vortex and to discuss its linear trend, interannual-to-interdecadal variability [18–21]. This approach provides a visualized but complete representation of the characteristics of midlatitude circulation, such as the ridges and troughs in westerly, shape, location and amplitude of the waveform, as well as the familiar teleconnection pattern.

2. Data and methods

The datasets used in the present work include the 48-year monthly SST taken from the 1°×1° gridded global ice and sea surface temperature data set (GISST) [22,23] and the SLP, 500 hPa geopotential height derived from the NCEP/NCAR atmospheric reanalysis [24] with a grid resolution of 2.5°×2.5°. All these data cover the period of 1951–1998.

Singular value decomposition is an effective diagnostic technique to extract coupled signal and spatio–temporal relation between two meteorological fields. In this study, SVD analysis is used to reveal the covarying modes. The time fluctuation of covarying modes is represented by the SVD time series coefficients, while the time scale of variation is further examined by using the wavelet transform to the SVD time series. The spatial patterns of the covarying modes are depicted by the regressions of oceanic and atmospheric values upon the SVD time series.

To represent the Northern Hemisphere midlatitude atmospheric circulation anomaly, a representative contour of 500 hPa geopotential height (5400 gpm) is selected to define the circumpolar vortex [18–21]. The representative geopotential height contour for each winter is converted into a series of 144 latitudinal and longitudinal intersections along each 2.5° meridian, thus the circumpolar vortex is characterized by a series of 144 straight-line segments connecting the intersections [20]. The circumpolar vortex, which represents the location of the central core of the Northern Hemisphere midlatitude westerly, has been used effectively to provide a flexible measure of atmospheric midlatitude long-wave wind flow. The 5400 gpm contour is selected as a representative contour of circumpolar vortex based on the two considerations, i.e., firstly, providing a fairly well complete representation of the primary characteristics of hemispheric circulation in boreal winter, and secondly, falling within the main belt of the maximum westerly flow (or the region of strongest meridional height gradient) [20] extending from 30°N to 60°N.

3. Spatio–temporal structure of covarying modes

The Pacific SST (30°S–60°N) and circumpolar vortex anomalies in winter are analyzed using SVD technique. The results show that the dominant SVD modes are the first and the second modes which together account for 76.4% of the total variance, while other residual modes merely explain below 10%. Therefore, these prior two SVD modes are discussed in the following.

3.1. Spatial pattern

The first SVD mode (SVD1) accounts for 50.2% of the total variance. The associated SVD1 heterogeneous correlation pattern and temporal coefficient of the Pacific SST and circumpolar vortex are shown in Fig. 1(a)–(c), respectively. Fig. 1(a) shows a typical ENSO pattern, with the SST warm anomalies in the central to eastern tropical Pacific while the cool anomalies in the central North Pacific, Kuroshio and along the North American coast, and vice versa. The corresponding circumpolar vortex variabilities shown in Fig. 1(b) are predominantly confined to the PNA region while much lower in other regions. Associated with the El Niño (La Niña)-like SST anomalies, the circumpolar vortex anomalously expand southward (contract northward) in the central North Pacific while contract northward (expand southward) in the northwestern North America. As being shown in the next section, such circumpolar vortex variabilities are consistent with the PNA pattern in 500 hPa geopotential height.

The second SVD mode (SVD2) explains 26.2% of the total variance. The associated SVD2 heterogeneous correlation pattern and temporal coefficient of the Pacific SST and circumpolar vortex are shown in Fig. 1(d)–(f), respec-