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Influence of the subarctic front intensity on the midwinter suppression of the North Pacific storm track

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ABSTRACT

Influence of the subarctic front zone (SAFZ) intensity variation on the midwinter suppression of the North Pacific storm track (NPST) is investigated based on reanalysis datasets in centennial period. It is found that when the late-autumn SAFZ intensity is stronger, the midwinter suppression of the NPST is more pronounced. Lagged regression analysis shows that there exist distinct subseasonal changes in the NPST response to the late-autumn SAFZ intensity variation, with significantly intensified NPST in late autumn but weakened NPST in midwinter. The difference in the NPST response between November and January is presumed to be responsible for the larger suppression of the NPST in midwinter. Analysis on the local energetics reveals that changes in the baroclinic energy conversion (BCEC) associated with the late-autumn SAFZ intensity variation are similar to the NPST response pattern, indicating that the BCEC plays a crucial role in determining the distinct subseasonality in the NPST response.

1. Introduction

Daily weather variability in the midlatitudes is closely related to synoptic-scale high and low pressure systems. Regions corresponding to active synoptic atmospheric eddies are referred to as storm tracks (Blackmon, 1966; Blackmon et al., 1966), which is one of the most important atmospheric circulation systems. By transporting large amounts of heat, momentum and moisture from the subtropics to high latitudes, storm tracks not only affect daily local weather events such as strong winds (Booth et al., 2010), extreme precipitation (Salathé and Eric, 2006; Kunkel et al., 2012) and heat/cold events (Liao and Zhang, 2013; Chang et al., 2016), but also influence the planetary-scale flow and the climate in the midlatitude (Chang et al., 2002; Rivière and Orlanski, 2007; Wettstein and Wallace, 2010). Therefore, it is of great significance to investigate the subseasonal changes in storm tracks.

There exist two zonally-elongated storm tracks in the Northern Hemisphere; one is over the Pacific and the other over the Atlantic. While the North Atlantic storm track (NAST) shows a single maximum in midwinter, the North Pacific storm track (NPST) is characterized by distinctive double peaks in late autumn and early spring with a minimum in midwinter in spite of the strong baroclinicity (Nakamura, 1992; Lee et al., 2011). The latter is called the NPST midwinter suppression, which is not in accordance with the linear theory of baroclinic instability (Charney, 1946; Eady, 1949). Previous studies have explored the mechanisms for this counterintuitive phenomenon, and found that the subtropical jet stream in winter (Chang,

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2001; Nakamura and Sampe, 2002; Harnik and Chang, 2004), diabatic heating (Chang, 2001; Chang and Song, 2006), and upstream seed disturbances (Orlanski, 2005; Penny et al., 2010) are all possibly related to the NPST midwinter suppression.

The warm water from the Kuroshio and the cold water from the Oyashio currents converge in the North Pacific along ~40°N, leading to the formation of the zonally-elongated domain with a prominent sea surface temperature (SST) meridional gradient, which is referred to as the subarctic front zone (SAFZ, Nakamura and Kazmin, 2003; Taguchi et al., 2012; Kida et al., 2015). Observational analyses (Nakamura et al., 2004; Yao et al., 2017), dynamical diagnoses (Fang and Yang, 2016; Wang et al., 2016a) and numerical simulations (Yao et al. 2016) have indicated that the midlatitude oceanic front and associated atmospheric transient eddy activities play a crucial role in the midlatitude air-sea interaction. Nakamura et al. (2004) indicated that the midlatitude SST front could anchor storm tracks through maintaining the near-surface baroclinicity. Nakamura et al. (2007) and Sampe et al. (2010) found that the sensible heat flux differences across the midlatitude oceanic front could restore the strong near-surface baroclinicity against the relaxing effect by the poleward heat transport, which is called the "oceanic baroclinic adjustment". The storm-track activities would be reduced significantly when the midlatitude SST fronts are smoothed (Taguchi et al., 2009; Small et al., 2013).

Although many previous studies have discussed the factors regarding the NPST midwinter suppression, the impact of the SAFZ intensity on the degree of the NPST midwinter suppression is still unclear. Considering the close relationship between the NPST and the SAFZ (Nakamura et al., 2004, 2007), it is of great interest to investigate whether the SAFZ intensity has an impact on the degree of the NPST midwinter suppression. In this study, an index is defined to quantify the SAFZ intensity variation. With this index, the influence of the SAFZ intensity on the degree of the NPST midwinter suppression is investigated using reanalysis datasets in centennial period.

This paper is organized as follows. Section 2 introduces the data and method used in this study. The SAFZ intensity index (I_{SAFZ}) is defined in Section 3. In Section 4, the impact of the SAFZ intensity variation on the degree of the NPST midwinter suppression is investigated. Section 5 analyses the subseasonal changes in the NPST response to the late-autumn SAFZ intensity variation. Conclusions are presented in the final section.

2. Data and method

Monthly mean SST is taken from the Met Office Hadley Center Sea Ice and Sea Surface Temperature version 1 (HadISST1), with 1° spatial resolution (Rayner et al., 2003). Atmospheric variables including wind speed and air temperature are derived from the Twentieth-Century Reanalysis Dataset version 2 (20CRv2) with a horizontal resolution of 2° × 2° (Compo et al., 2011). This study focuses on the cold season (Oct–Mar) from 1911 to 2010.

Here, a 31-point Lanczos bandpass filter is applied to obtain synoptic-scale transient eddies (2–8 days) and the synoptic-scale meridional wind velocity variance ($v'v'$) at 300 hPa is defined as the storm track (Blackmon et al., 1966; Chang and Fu, 2002; Gan and Wu, 2013). Following Deng and Mak (2006), the degree of the NPST midwinter suppression (η) is defined as: $\eta = (\overline{v'v'}_{\text{Nov}} + \overline{v'v'}_{\text{Mar}})/2 - \overline{v'v'}_{\text{Jan}}$, where the overbar denotes the monthly average, and the larger η indicates the larger suppression of the NPST in midwinter.

The lagged regression analysis is used to explore the impact of the SAFZ strength on the NPST. This method has been widely used to evaluate the influence of the midlatitude SST variation upon the overlying atmosphere in the North Pacific basin (Frankignoul et al., 1997; Frankignoul and Sennéchael, 2006; Qiu et al., 2006; Frankignoul et al., 2011; Taguchi et al., 2012; Qiu et al., 2014). The lagged regression coefficient $b(x, y)$ can be expressed as:

$$b(x, y) = \frac{< I_{SAFZ}(t)A(x, y, t+m) >}{< I_{SAFZ}(t)^2 >} \quad (1)$$

where $I_{SAFZ}(t)$ represents the SAFZ intensity index, $A(x, y, t)$ denotes atmospheric anomalies and m (>0) denotes the atmosphere time lag. Angle brackets in Eq. (1) indicate time average.

Atmospheric monthly anomalies are produced by subtracting the climatological monthly means and by removing the linear trend from the monthly atmospheric variables. In addition, we remove the linear regressed Nino-3.4 SST anomaly from both the I_{SAFZ} (t) and the $A(x, y, t)$ time series in order to minimize the low- frequency signals in the tropics (Alexander et al., 2002; Qiu et al., 2006; Qiu et al., 2014). Composite analysis and correlation analysis are also used, and the statistical significance is tested based on the Student's t-test.

3. Definition of the SAFZ intensity index

Following Frankignoul et al. (2011), we firstly calculate the negative meridional SST gradient ($-\partial SST/\partial y$) between 145° and 175°E using monthly-mean SST, then the maximum $-\partial SST/\partial y$ at each longitude between 35° and 47°N is determined as the SAFZ intensity along this longitude. After removing the linear trend, monthly mean, and Niño-3.4 SST anomaly signal at each longitude, Empirical Orthogonal Function (EOF) is applied to monthly SAFZ intensity anomalies. The normalized leading principal component is defined as the SAFZ intensity index (I_{SAFZ}) for each individual month. In order to study the impact of the SAFZ intensity on the degree of the NPST midwinter suppression, particular attention is paid to the SAFZ intensity variation in calendar months before midwinter (from August to subsequent January).

Fig. 1 exhibits the climatological SAFZ and correlation maps of monthly SAFZ anomalies with the I_{SAFZ} in each calendar month from August to subsequent January. The SAFZ gradually intensifies from August to subsequent January and the SAFZ