A Siberian Precursor to Midwinter Intraseasonal Variability in the North Pacific Storm Track

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ABSTRACT

An observational diagnostic analysis is performed to study variations in the behavior of upper tropospheric Rossby waves prior to intraseasonal variability in the North Pacific storm track. The research is motivated from considerations of the midwinter suppression of the North Pacific storm track. During midwinter strong upper tropospheric cyclone events in the North Pacific storm track are preceded 7 days by a large-scale cyclonic circulation anomaly located over Siberia. The Siberian precursor anomaly is found to be strongly linked to one of the primary modes of upper tropospheric intraseasonal variability over Asia. More generally, this Asian mode is determined to provide a substantial modulation in the structure and amplitude of the North Pacific storm track at lead times of $+5$ to $+8$ days. This downstream influence is concentrated during midwinter and is likely related to intraseasonal variations in the East Asian winter monsoon.
1. Introduction

Synoptic-scale transient eddies strongly influence daily weather and regional patterns of temperature and precipitation. The preferred migratory paths in which synoptic eddies attain their largest magnitude are known as storm tracks. The two main storm tracks in the Northern Hemisphere are located downstream and slightly poleward of the North Pacific and North Atlantic jet streams. The synoptic eddies comprising storm tracks are often referred to as baroclinic waves, since they are thought to arise from baroclinic instability. Nakamura [1992] found that seasonal variations in the storm track magnitudes do not always follow variations in baroclinic forcing. More specifically, the North Pacific storm track attains a relative minimum during midwinter (the midwinter suppression) even though the associated baroclinic forcing simultaneously peaks during midwinter.

Previous studies of the North Pacific midwinter suppression have mainly studied the structure and mean flow interaction of baroclinic waves within or downstream of the East Asian jet [e.g., Chang et al. 2002]. However, Nakamura [1992] originally suggested that a potential contributor to the Pacific midwinter suppression is an alteration in upstream sources of upper tropospheric Rossby wave activity. The upper-level synoptic waves that “seed” the Pacific storm track emanate from two Asian waveguides: a northern branch over Siberia and a southern branch over Southeast Asia [e.g., Chang, 2005]. Although the northern branch is considered the key source of upper-tropospheric short level waves for the Pacific storm track [Hakim, 2003], both Nakamura and Sampe [2002] and Chang [2005] have demonstrated that waves from the southern branch also strongly influence Pacific cyclogenesis. Chang further demonstrated that waves from the two branches can constructively interfere leading to enhanced North Pacific cyclogenesis.
The comparative study of general circulation models by Robinson and Black [2006] provides circumstantial evidence at short (one day) lead times consistent with Nakamura’s seeding hypothesis. We extend their analysis with an observational study of the seasonally-stratified wave behavior that occurs upstream of the North Pacific storm track. We begin by studying the evolution of Rossby wave packets traversing Asia several days prior to the genesis of strong upper tropospheric synoptic-scale cyclonic circulation anomalies (“cyclone events”) over the Pacific storm track. The goal is to ascertain variations in the upstream circulation behavior associated with different stages of the cool season, focusing on the cyclone events studied by Robinson and Black [2006]. The deduced large-scale behavior is then contrasted with the primary modes of intraseasonal variability over East Asia.

2. Data and Methodology

The results in this study are derived from the ERA40 reanalysis dataset provided by the European Centre for Medium-Range Weather Forecasts. We use 45 years of daily-averaged data from September 1958 through August 2002 focusing on the extratropical Northern Hemisphere. We first define a daily climatology as the sum of the first 6 Fourier harmonics of a seasonal cycle derived from the calendar time-series of long-term daily averages. Daily intraseasonal anomalies are then computed by subtracting both the daily climatology and interannual variability (seasonal anomalies) from unfiltered daily averages. High-pass (synoptic scale; periods of 2.5-6 days) and low-pass (low frequency; periods of 10-90 days) components of the intraseasonal anomaly field are isolated using 151-point Lanczos filters. The total (unfiltered) intraseasonal anomaly field is the sum of time scales less than 90 days.

To study seasonal variations in the wave packet behavior found upstream of the
Pacific storm track, we follow Robinson and Black [2006] and first stratify the boreal cool season into three stages: an early stage taken as November and December, a middle stage taken as January and February, and a late stage of March and April. The early and late (middle) stages correspond to maxima (a relative minimum) in synoptic eddy activity over the North Pacific. Taking into account the seasonal migration of the storm track, we next select a geographical “core” point marking the local relative maximum in wave activity for each stage. We then regress the intraseasonal anomaly fields against normalized time-series of high-pass filtered 300 hPa geopotential height at each core point for each stage. The lag regression approach follows that of Lim and Wallace [1991]. To focus on strong cyclone events, we perform regressions relative to times marking relative minima in the time-series that exceed -1σ. This provides about 300 separate events for each stage over the 45 year period. Due to the marked symmetry of the early and late stages, for the brevity of presentation we combine the results of these two stages into one (early/late winter period or EL) and contrast them with that of the middle stage (midwinter or MW).

3. Results

Figure 1 displays the regression results for the total intraseasonal anomaly field at Days -7, -5, and -3 for the EL period (top row) and the MW period (bottom row), respectively. Day 0 represents the time lag at which the upper level cyclone event is mature within the core of the climatological storm track (~175°E). Contours are the regressed geopotential height anomalies at 300-hPa, while shaded regions indicate statistical significance at the 95% level based on a two-tailed t-test. The associated ageostrophic geopotential flux vectors, computed following Orlanski and Katsfey [1991], are also plotted. The ageostrophic geopotential flux is a measure of the downstream dispersion of eddy
kinetic energy (relative to the background mean flow) in a Rossby wave packet.

The upper tropospheric cyclonic disturbance, which ultimately initiates cyclone development, enters the baroclinic zone of the Pacific storm track at Day -3. The associated negative height anomaly is located over the Sea of Japan (~135°E) at this time. The upstream time evolution during EL consists of the southeastward propagation (in both phase and energy) of a coherent packet of synoptic scale waves from Siberia toward the east coast of Asia. The phase of the precursor cyclonic disturbance can be traced back to west of Lake Baikal at Day -7. This disturbance strengthens via downstream energy dispersion as it propagates southeastward within the wave packet. In accord with Rossby wave theory, the energy of the wave packet moves downstream more quickly than the individual troughs and ridges. There is little or no projection of this wave pattern upon low frequency time scales. The evolution observed during EL corresponds very well to the behavior of synoptic wave packets propagating along the northern branch of the Asian wave guide as in *Chang [2005]*.

The upstream behavior observed during MW is markedly different than EL. First, there is no evidence of a coherent synoptic scale wave packet upstream at Day -7. However, a significant large scale cyclone feature extends over much of central Siberia at this time. This large-scale feature has a substantial low frequency component (not shown) which gradually weakens and moves eastward after Day -7. Significant synoptic-scale wave packets emerge along both the northern and southern branches of the Asian waveguide at Day -5. The two wave packets are longitudinally in phase with one another, favoring strong subsequent cyclogenesis downstream over the Pacific [Chang, 2005]. The large-scale anomaly over Siberia is less evident at this time since it is out of phase with a ridge embedded within the northern synoptic wave packet. By Day -3 all three features have come
into phase with one another resulting in a robust Rossby wave packet located over eastern Asia. Within this packet, the cyclonic circulation anomaly over the Sea of Japan strengthens due to downstream development. Although the juxtaposition of synoptic-scale and large-scale circulation anomaly elements observed at Days -5 and -3 is field significant at the 98% confidence level [Livezey and Chen, 1983], we note that the phase-locking of synoptic wave packets in both branches of the Asian waveguide may not occur in all cases [Chang, 2005].

The above results suggest that during MW the formation of strong upper tropospheric cyclone events in the Pacific storm track is affected by pre-existing large-scale circulation anomalies located upstream over the Asian continent.

To explore the nature and influence of the upstream large-scale variability further, we next perform an EOF analysis of the total 300 hPa height anomaly field over the horizontal spatial domain encompassed in Fig. 1. The EOF analysis is performed separately for the MW and EL periods. In both cases, the spatial pattern associated with the first EOF (not shown), corresponding to the regional manifestation of the Northern Annular Mode and explaining 22% (23%) of the local MW (EL) variance, is largely orthogonal to the Siberian precursor anomaly pattern in Fig. 1d. However, Fig. 2 illustrates that the second EOF pattern (EOF2) derived for each period bears a striking resemblance to the Siberian precursor (SP) anomaly. Further, the respective index time series (obtained by projecting the daily height anomalies upon the three spatial patterns) are strongly related with a correlation of 0.92 (0.90) between the SP time series and the MW (EL) EOF2 time series. The SP anomaly is thereby linked to one of the primary modes of upper tropospheric intraseasonal variability over Asia.

We test the more general nature of the relationship between the large-scale Asian
variability and the Pacific storm track by examining how the Pacific storm track varies in response to episodes of EOF2 during EL and MW (This is effectively the inverse of the problem examined in Fig. 1). More specifically, we perform composite analyses of the Pacific storm track structure that exists during the period +5 to +8 days after large-amplitude episodes of EOF2 (Fig. 3). This is done by analyzing the 300 hPa envelope function [Nakamura and Wallace, 1990] separately for (a) positive and negative phases of EOF2 and (b) EL and MW time periods (The positive phase corresponds to the anomaly patterns displayed in Fig. 2). During EL the impact of EOF2 is relatively weak, with a slight weakening (strengthening) and northwestward (southward) shift of the storm track occurring following positive (negative) EOF2 events (Figs. 3a, 3b).

A much stronger impact is evident during MW, however. In this case, the opposing EOF2 phases are associated with marked differences in the subsequent structure and amplitude of the Pacific storm track. During the positive (negative) phase the core of the storm track has peak values of 1.5 (1.7) x 10^4 m^2 and is located near 42°N/170°E (35°N/165°W), representing a longitudinal shift of 25°. The difference between the two patterns (Fig. 3f) consists of a Northwest-Southeast anomaly dipole with local anomaly magnitudes approaching 50% of the peak regional climatology. The general effect is as follows: The positive phase is associated with a strengthening of the storm track along an axis extending from central Japan northeastward to the Aleutian Islands. The negative phase is linked to a marked southeastward shift and intensification of the storm track. The midwinter differences characterized here are, in fact, considerably larger than the differences between the EL and MW storm track climatologies (not shown).

Interestingly, the impact observed near the climatological core of the storm track
(which was originally used in a case-oriented sense to identify the SP anomaly pattern) is relatively weak. For completeness, we note that similar results are obtained if one constructs composites based upon the index time series associated with the Siberian precursor anomaly, itself (or using the MW EOF2 pattern alone). The composite analyses confirm the existence of a relationship between large-scale Asian circulation anomalies and subsequent midwinter variations in the North Pacific storm track.

4. Concluding Remarks

We perform an observational diagnostic analysis of the linkages between intraseasonal variations in the North Pacific storm track and upstream Rossby wave behavior during different phases of the boreal cool season. During early and late stages of the cool season (EL - when North Pacific storm track is typically strongest), coherent precursor synoptic scale wave packets can be traced upstream to the northern branch of the Asian waveguide as early as 7 days prior to Pacific cyclone events. In contrast, the midwinter (MW) evolution is initially characterized by a large-scale cyclonic flow anomaly over Siberia at Day -7. Synoptic wave packets subsequently emerge from along both the north and south branches of the Asian waveguide. These three synoptic features then merge at Day -3 to form the upper tropospheric precursor to MW Pacific cyclone events. The Siberian precursor (SP) anomaly appears to provide an important contribution to the Rossby wave packet observed at Day -3.

Further study of the MW SP anomaly pattern reveals that it is strongly linked to one of the primary modes (EOF2) of upper tropospheric intraseasonal variability over the Asian continent. An independent analysis based on the EOF2 pattern indicates that this mode provides a strong midwinter intraseasonal modulation of the North Pacific storm track at lead
times close to one week. Following the positive phase of EOF2 the storm track axis lies north of 40°N and peaks west of the Date Line, while after its negative phase the storm track dips southward to near 35°N and peaks 15° east of the Date Line. The negative phase is also associated with local increases in synoptic eddy activity of as much as 50% (compared to climatological values). A second important result is that the linkages observed during the MW period are largely absent during EL, even though the respective EOF2 patterns are quite similar. We speculate that the upper-tropospheric SP identified here is likely linked to intraseasonal variability in the Asian winter monsoon (e.g., Takaya and Nakamura, 2005). Future research will focus on the dynamic mechanisms behind the statistical associations found here and potential connections to the Pacific midwinter suppression phenomenon.

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References


**Figure Legends**

Figure 1. Regressed intraseasonal height anomalies (contour intervals: 10 m) at 300 hPa for the (a)-(c) EL and (d)-(f) MW periods for Day -7 (left), Day -5 (middle), and Day -3 (right). Height anomalies significant at the 95% confidence level are also color shaded. The associated ageostrophic flux vectors are plotted and a scale vector provided.

Figure 2. Spatial patterns derived from an EOF analysis of the total 300 hPa geopotential height over the domain encompassed in the plot. The second EOF is displayed for the (a) EL period and (b) MW period (contour interval: 25 m). The pattern is scaled to represent a +1 standard deviation value of the associated principal component time series.

Figure 3. Envelope function (units: $10^2$ m$^2$) at 300 hPa composite averaged +5 to +8 days after large-amplitude EOF2 events for (a)-(c) the EL period and (d)-(f) the MW period. Left (Middle) Column: Composite for EOF2 events exceeding (falling below) +1 (-1) standard deviation. Right Column: The difference between the fields displayed in the Left and Middle columns. The climatological maxima for EL and MW are indicated by X.
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