

# Cooling of the wintertime Arctic stratosphere induced by the Western Pacific teleconnection pattern

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## Western Pacific (WP) pattern

- Dominant teleconnection pattern in the wintertime troposphere, with substantial impact on weather and climatic conditions over the Far East and North Pacific, including storm-track activity and cold-air outbreaks [Nakamura *et al.*, 1987]
- Meridional dipole of anomalies over the Far East and North Pacific
- In positive phase, a blocking-flow configuration tends to occur more frequently over the North Pacific

## Stratospheric influence of the WP pattern

- Orsolini *et al.* [2009] revealed that an extremely cold Arctic stratosphere (and elevated Polar Stratospheric Clouds volume) tends to follow a tropospheric event of the positive WP pattern that occurs about one month earlier.
- This occurs in correlation with the reduction of upward injection of planetary-wave activity into the stratosphere
- The aim of this study is to present typical daily evolution of the positive WP pattern and the subsequent cooling in the Arctic stratosphere through composite analysis. We also perform a case study for the 1995/96 winter.
- A mechanism is proposed from a viewpoint of interactions between the climatological-mean planetary waves and an anomalous Rossby wave packet.

## Method and data

- The Japanese 25-year Reanalysis (JRA-25) [Onogi *et al.*, 2007] from 1979 through 2008.
- Anomalies are departures of the 8-day low-pass-filtered daily fields from the daily climatology.
- WP pattern is leading sectorial (20°N-70°N, 120°E-180°) EOF of monthly anomaly fields at 500-hPa (NDJFM) from 1979/1980 through 2007/2008.
- On the basis of the daily index, the 18 strongest positive events (> 3 std dev) have been selected.
- We estimated the heat flux anomaly ( $[V^*T^*]_a$ ) from the low-pass-filtered fields of meridional wind velocity ( $V$ ) and temperature ( $T$ ) with a subscript  $a$  for anomaly. An asterisk signifies the eddy component and square bracket the zonal averaging.

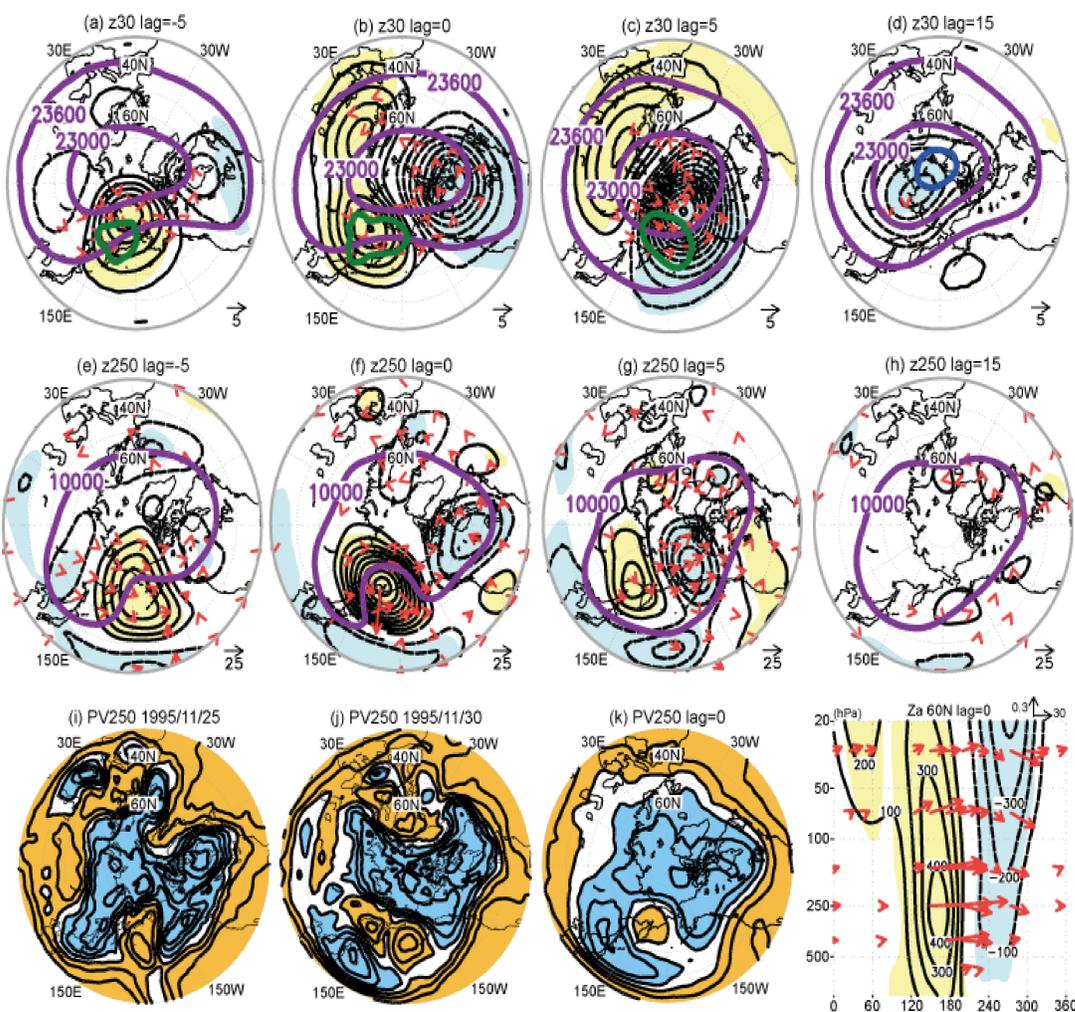


Figure 2. (a-d) Maps (poleward of 30°N) of 30-hPa height anomalies composited for the positive events of the WP pattern events (black lines) with lags of (a) -5, (b) 0, (c) +5 and (d) +15 days relative to the peak time. Contour interval is 50 m (dashed for negative). Yellow and blue shading denotes positive and negative anomalies. The composited 30-hPa height of 23000 and 23600m (purple lines) represent the total field. Arrows represent the 30-hPa horizontal component of Rossby wave-activity flux (unit;  $m^2s^{-2}$ ), and its 100-hPa upward component exceeds  $0.005 m^2s^{-2}$  within the areas encircled by green contours. In the area encircled by the blue contour in (d), 50-hPa temperature composited for the 8 events of the positive WP pattern observed in the October-January period is below 195 K. (e-h) As in (a-d), but for the 250-hPa height anomalies. Purple contours represent composited 250-hPa height of 10000m. (i) Ertel's potential vorticity observed at the 250-hPa level on November 30, 1995 (black; contour interval is 1 PVU) with blue shading for 4 PVU or higher and yellow shading for 3PVU or lower. (h) As in (i), but for PV composited for the peak times of the 18 positive WP events. (j) A zonal height cross-section of height anomalies composited for the peak times of the positive WP events along 60°N.

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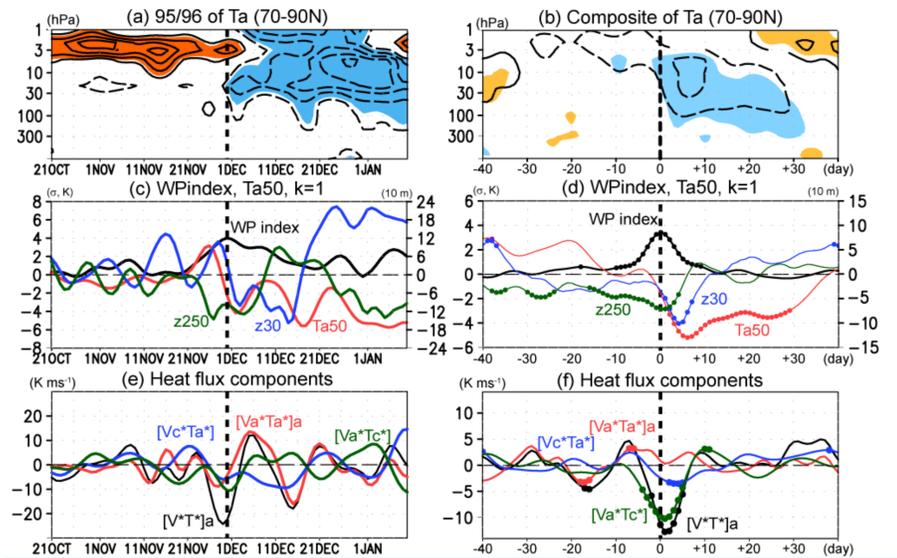


Figure 1. (a) Height-time section of temperature anomaly averaged over the Arctic (poleward of 70°N) from October 20, 1995 through January 10, 1996. Orange and blue shading exceed 4 K. (b) As in (a), but for the composite for the 18 positive WP pattern events. (c) Daily time series of the WP pattern index (black; left axis), 50-hPa temperature anomaly averaged over the Arctic (red; left axis), anomalous amplitude of the  $k=1$  component in the 250-hPa height (green; right axis) and 30-hPa height (blue; right axis) along 50°N in the 1995/96 winter. (d) As in (c), but for the corresponding daily time series based on the composite for the positive WP pattern events. (e) Daily time series of 100-hPa eddy heat flux  $[V^*T^*]$  (black),  $[V_a^*T_c^*]$  (green),  $[V_c^*T_a^*]$  (blue) and  $[V_a^*T_a^*]$  (red) averaged poleward of 45°N ( $Kms^{-1}$ ) for the 1995/96 winter. (f) As in (e), but for the corresponding time series based on the composite for the positive WP

## Composite of strong events and a case study for the 1995/96 winter

- Compositing relative to the peak times of the individual events shows a height-time section of polar temperature anomalies similar to the corresponding evolution in the 1995/96 winter. This cold stratospheric anomaly persists for about one month
- In the composite evolution, the rapid stratospheric cooling occurs concurrently with a significant reduction in the upward flux of planetary wave activity at the 100-hPa level
- In the troposphere, the positive WP pattern accompanies a dipolar height anomaly pattern with an anticyclonic blocking ridge that evolves westward. This evolution corresponds to cyclonic breaking of the planetary-wave trough over the North Pacific, most striking in the PV maps.
- The high in the total planetary wave field is initially recognized as a poleward meander of geopotential height contours (purple). For the next five days, the high in the total field breaks down through its destructive interference with the westward-developing cyclonic anomaly. Although the stratospheric anomaly field is dominated by the  $k=1$  component, its zonal phase is such that it weakens the total planetary wave field. The polar vortex thus becomes remarkably zonally symmetric under suppressed planetary-wave forcing, and correspondingly a cool anomaly develops rapidly in the Arctic stratosphere and persist for 1 month.

## Conclusions

- A positive event of the WP pattern in winter can be a precursor for the one-month lasting polar stratospheric cooling (up to 6 K)
- It weakens upward propagation of planetary waves into the stratosphere through the destructive interference between the climatological planetary waves and wavy anomalies associated with the WP pattern
- This study confirms the findings in Orsolini *et al.* [2009], that monthly events of the largest PSC volume tend to be observed in the following months of the positive WP pattern.
- The daily evolution of the positive WP pattern is quite similar to the development of a blocking high over the Pacific. It presents a unique case where a blocking high can induce cooling in the polar stratosphere rather than warming. The positive contribution  $[V_a^*T_a^*]$ , which is consistent with a general tendency for blocking anticyclones to act as precursors of stratospheric sudden warming events (e.g., Martius *et al.* [2009]), is here rather weak. As their unique dynamical characteristic, the contribution is overwhelmed by the destructive interference between the blocking anomaly and climatological-mean planetary waves.

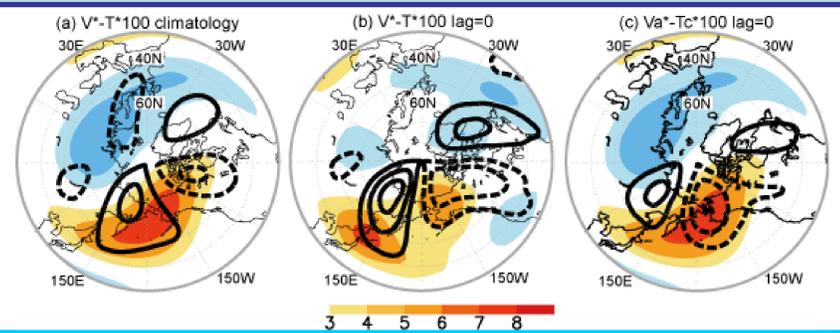


Figure 3. (a) Winter-mean (NDJFM) climatology of eddy components of 100-hPa meridional wind velocity ( $V_c^*$ ; contoured for every 5  $ms^{-1}$ ; dashed for the northerlies) and temperature ( $T_c^*$ ; shaded as indicated below if warmer and cooler, respectively, than the longitudinal average; interval: 2 K). (b) As in (a), but for the composite fields for the peak times of the 18 positive WP event. (c) As in (b), but for anomalous meridional wind ( $V_a^*$ ) and climatological-mean temperature ( $T_c^*$ ) that contribute to  $[V_a^*T_c^*]$ .

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