Special Climate Summary

April-July 2004

Hot in Alaska, Cool over Central North America, Wet in South-Central U.S.

by

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1. Overview

The period April-July 2004 featured exceptionally warm and dry conditions from Alaska to California and below-normal temperatures across the eastern half of Canada and the central United States. It also featured above-average precipitation from Texas northeastward to New England (Fig. 1). These conditions were associated with a persistent blocking ridge over Alaska and northwestern Canada, and a westward shift and strengthening of the mean trough over central/ eastern Canada.

Three factors that contributed to the longevity of these conditions are discussed. These include 1) A persistent zonal wave-3 pattern at high latitudes; 2) A pronounced stratospheric extension of the high-latitude height anomalies, with the blocking ridge over Alaska and the downstream amplified trough extending past the 30-hPa level; and 3) Anomalous wave and jet stream conditions over the western North Pacific, including a reduced eastward extent of the East Asian jet core.

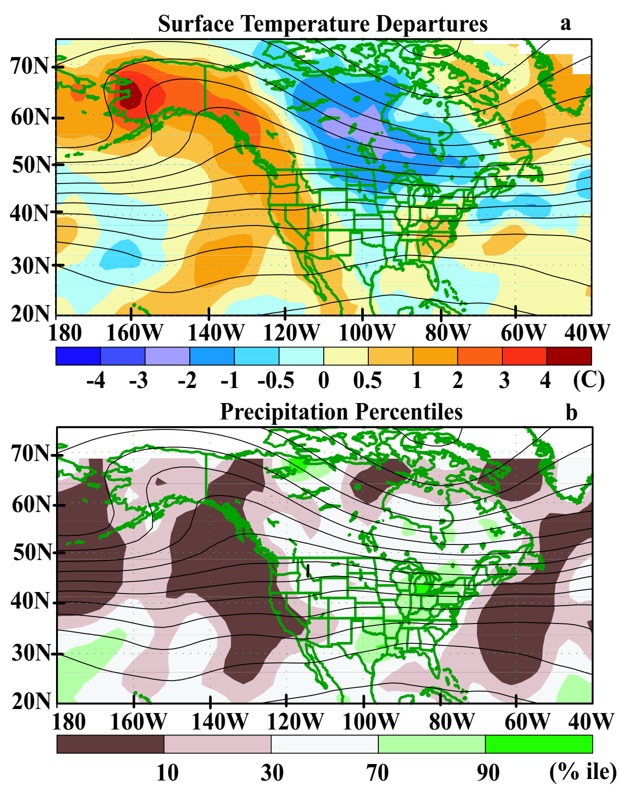

Fig. 1. April-July 2004: mean 300-hPa heights (contour interval is 60 m) overlayed with (a) surface temperature departures (°C) and (b) precipitation percentiles.

2. Surface temperatures and precipitation during April-July 2004

Most of western North America experienced exceptionally warm (Fig. 1a) and dry (Fig. 1b) conditions during April-July 2004, while central North America experienced unusually cool conditions and the eastern United States experienced above-average precipitation. The most anomalously warm and dry conditions were observed in Alaska, northwestern Canada, and the Pacific northwestern United States. In Alaska daily mean surface temperatures averaged 2°-5°C above normal, and precipitation totals were generally in the lowest 30th percentile of occurrences. In northwestern Canada and southeastern Alaska temperatures averaged 2°-3°C above normal, and precipitation totals were in the lowest 10th percentile of occurrences.

Mean temperatures during April-July 2004 were among the warmest in the 1950-2004 record for much of Alaska and western Canada (Fig. 2). For Alaska as a whole area-averaged temperature departures reached 1.8°C, exceeding the previous record departure of 1.5°C observed in 1993 (Fig. 3a).

Time series of daily temperatures (Fig. 4) and precipitation (Fig. 5) at Fairbanks in south-central Alaska and Yakutat in southeastern Alaska illustrate the persistence of the exceptionally warm and dry conditions. Above-normal temperatures first appeared at Fairbanks in early April 2004 (Fig. 4a), and at Yakutat in early February 2004 (Fig. 4b). This anomalous warmth continued at both stations through early August, with no substantial cold-air outbreaks during the period.

Significant precipitation deficits began in September 2003 at both stations (Fig. 5), with Fairbanks receiving no measurable precipitation for the 7 ½ month period from mid-September 2003 through early May 2004 (Figs. 5a, b). Beneficial rains were then observed during May, and again in late July and early August (Fig. 5b).

At Yakutat, the total September 2003-July 2004 precipitation deficit was 1400 mm (Fig.

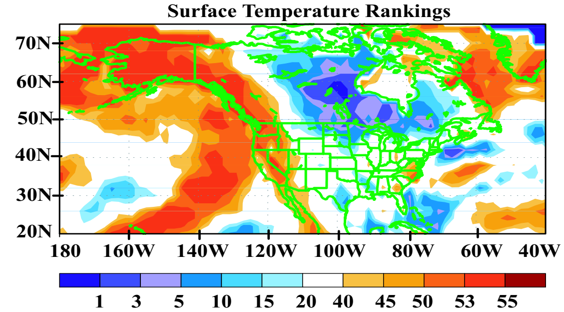

Fig. 2. April-July 2004 surface temperature rankings. A ranking of 1 indicates that April-July 2004 is the coldest such period, and a ranking of 55 indicates that it is the warmest such period, in the 55-year record 1950-2004.

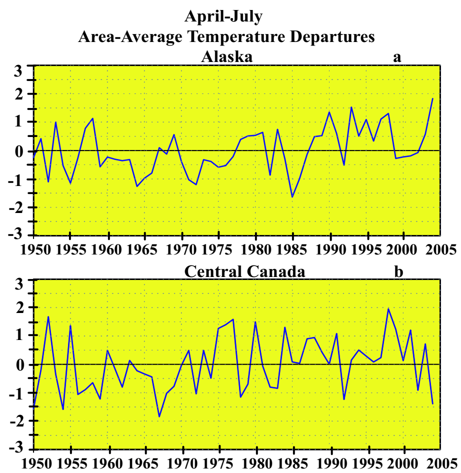

Fig. 3. Time series of April-July surface temperature deparures (°C) from 1950-2004 in (a) Alaska and (b) central Canada. Departures are calculated from the 1950-2004 base period means.

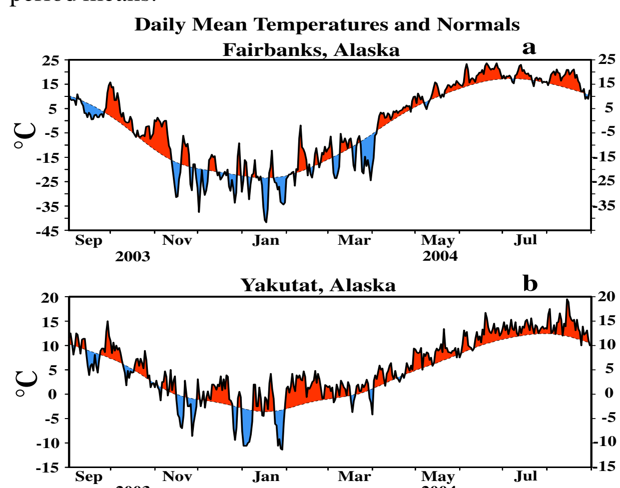

Fig. 4. Daily mean temperatures and normals at (a) Fairbanks and (b) Yakutat, Alaska during September 2003 - July 2004. Temperatures are shown by thin solid line and normals are indicated by dashed line. Departures from normal are shaded, with red (blue) indicating above (below) normal temperatures.

5c). Rainfall was particularly suppressed during May-July, when daily totals reached 25 mm on only three occasions (Fig. 5d).

Looking at longer time scales, April-July surface temperatures in Alaska have exhibited considerable low-frequency variability since 1950. For example, during the 19-yr period 1959-1977 only one season (1969) was above average and sixteen seasons were below average. During the following 27-yr period (1978-2004) sixteen seasons (59%) were above-average and nine seasons were below average.

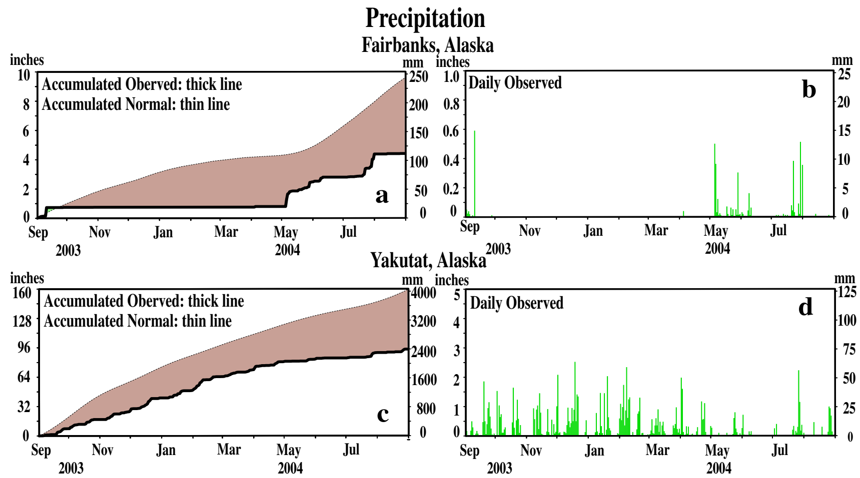

Fig. 5. Daily and accumulated precipitation at (a, b) Fairbanks and (c, d) Yakutat, Alaska during September 2003 - July 2004. Accumulated departures from normal are shaded, with brown shading indicating precipitation deficits.

In contrast to the exceptionally warm and dry conditions in Alaska during April-July 2004, daily mean temperatures were well below average across central North America. The largest temperature departures were observed across central Canada (2°-3°C below normal) and the north-central United States (1°-2°C below normal). The largest southward extent of the cool conditions occurred during June and July, when maximum temperatures were below average across nearly the entire United States (Fig. 6).

In central Canada, many regions experienced their coldest April-July period in the 1950-2004 record (Fig. 2). Overall, area-average temperatures in central Canada were 1.4°C below normal during April-July 2004, making this the coldest such period since 1967 and the third coldest since 1950 (Fig. 3b).

A time series of temperature departures at Waco, Texas (Fig. 7) illustrates the character of the cold conditions over the south-central United States during June and July. Temperatures at this station were below-average throughout the period, with the cold conditions even extending into mid-August.

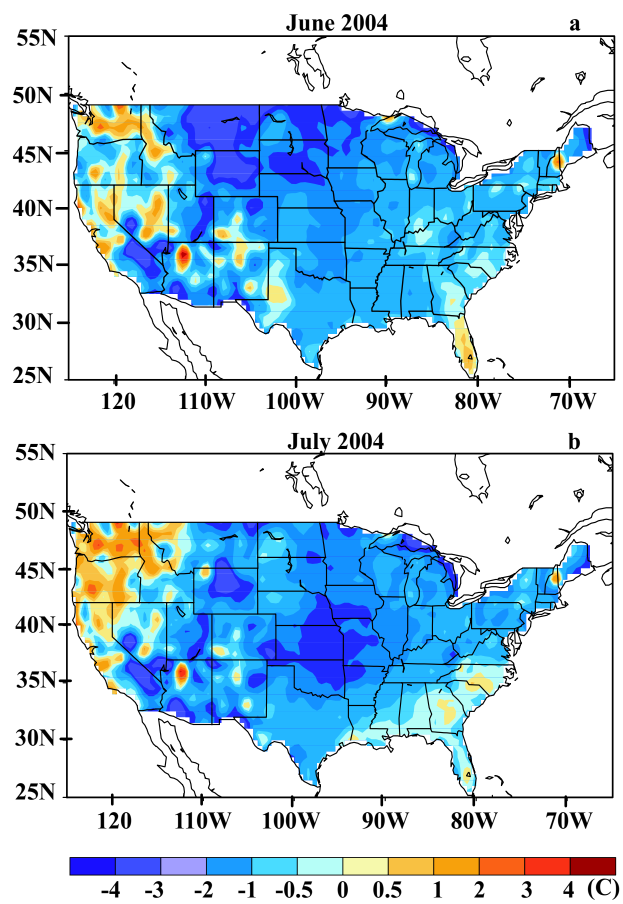

Fig. 6. Mean maximum temperature departures (°C) during (a) June and (b) July, 2004. Departures are calculated from the 1971-2000 base period normals.

Several significant cold-air outbreaks occurred during mid-June through mid-August, as cold fronts penetrated into the deep south. These events also brought well below-average temperatures to much of the eastern United States (shading, Fig. 8).

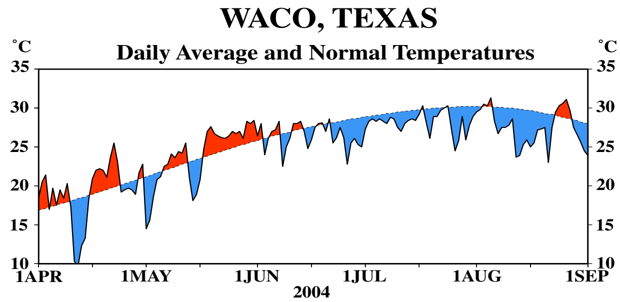

Fig. 7. Daily mean temperatures and normals at Waco, Texas during Apr.-Aug. 2004. Temperatures are shown by thin solid line and normals are indicated by dashed line. Departures from normal are shaded, with red (blue) indicating above (below) normal temperatures.

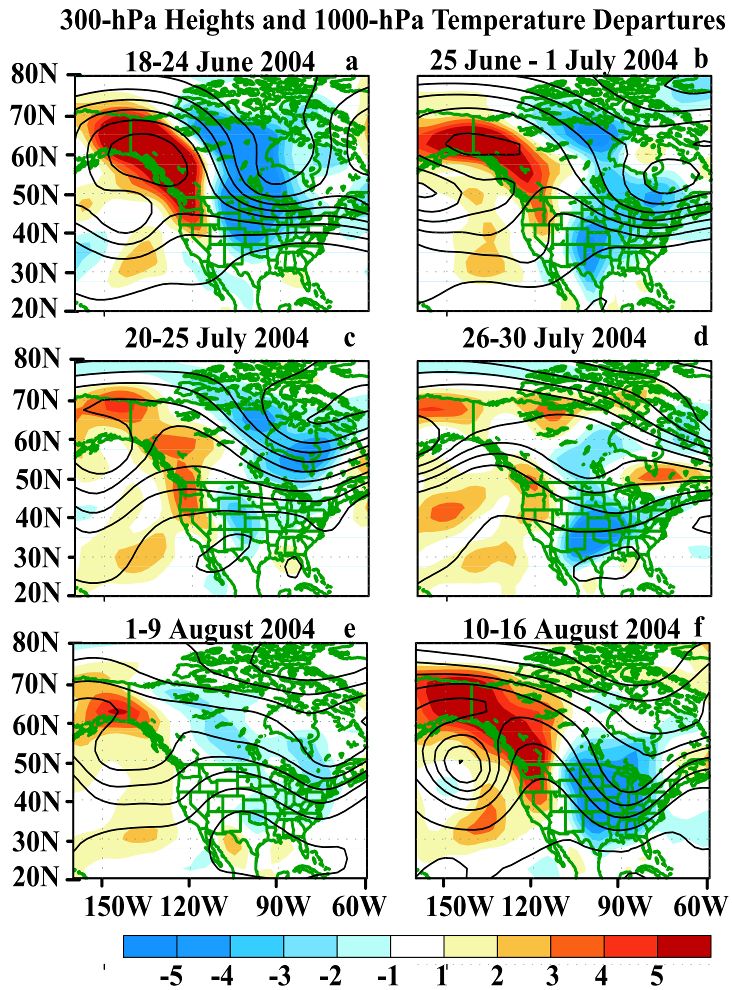

Fig. 8. 300-hPa heights (contour interval is 60 m) and 1000-hPa temperature departures during selected periods from mid-July through mid-August 2004. Anomalies are departures from the 1971-2000 base period means.

These cold-air outbreaks were associated with an amplified upper-level ridge (contours) over western North America and an amplified trough extending southward into the central or eastern United States. In Texas, the exceptional southward penetration of the cold fronts during these periods was also related to a strong southward funneling of cold air along the eastern slopes of the Rocky Mountains. This funneling is related to up-slope flow along the southern (or leading) edge of the surface pressure ridge, which is generally located upstream of the mean trough axes.

This combination of vigorous upper-level troughs and strong cold frontal passages also contributed to above-average precipitation from Texas northeastward to New England during June and July. During June Texas recorded its wettest such month in the historical record dating back to 1895.

These conditions, especially during the second half of June (Figs. 8a, b) and the latter part of July (Figs. 8c, d), were associated with a westward shift of the mean summertime ridge that normally extends from Texas northward to south-central Canada. This mean ridge not only influenced the summertime temperature and precipitation patterns over North America, but also helped to regulate the stength of the Southwest U.S. monsoon system. During June and July the anomalous upper-level ridge was associated with a below-average strength of this monsoon system (not shown).

3. Mean Atmospheric Circulation over North America during April-July 2004

The mean upper-level circulation over North America during April-July 2004 featured a blocking ridge over Alaska and northwestern Canada, an amplified trough over Hudson Bay, and above-average heights over the southwestern North Atlantic (Fig. 1). Each of these features was quite persistent, with the associated 500-hPa height anomalies evident during 65%-80% of the 4-month period (Fig. 9). Also during the period a very persistent jet stream was centered over the Great Lakes region within the base of the amplified upper-level trough (Fig. 10a).

The warm and dry conditions from Alaska to southern California coincided with the anomalous upper-level ridge, while the cool conditions over central North America were associated with the anomalous northwesterly flow between the ridge and downstream trough axes. In the United States the below-average temperatures were related to periodic significant southward penetrations of the anomalous upper-level trough and the associated surface cold fronts during June and July (Fig. 8).

Also during June and July the above-average precipitation from Texas northeastward to New England coincided with the region upstream of the mean ridge axis situated over the southeastern U.S., and with the right entrance region of the mean jet stream located over the Great Lakes (Fig. 10b). For many areas the periods of sgnificant precipitation were related to the strong cold frontal passages and the associated southward penetrations of the amplified upper-level trough/ jet system discussed in section 3.

4. Mean jet stream over North America

A series of diagnostics have been performed to better understand the relationships between the mean jet and wave features over North America during April-July 2004. Similar

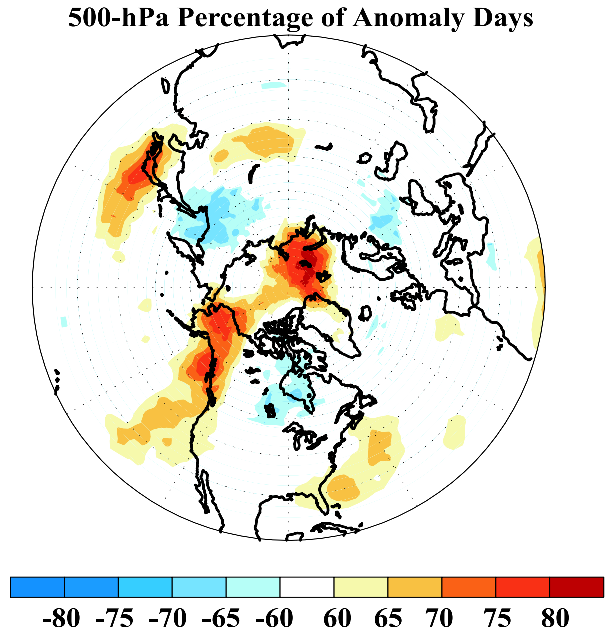

Fig. 9. Percentage of days during April-July 2004 that 500-hPa height anomalies were positive (red) and negative (blue). Anomalies are departures from the 1971-2000 base period means.

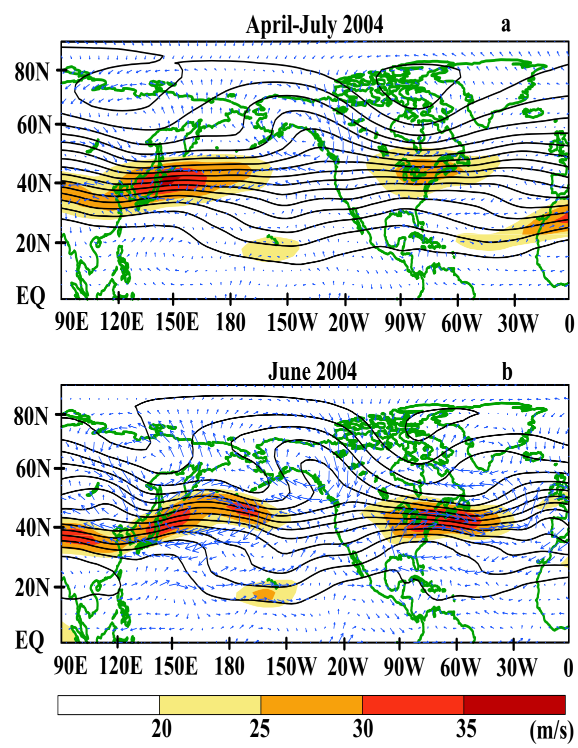

Fig. 10. 200-hPa heights (contour interval is 60 m), wind speeds (shading, m/s), and anomalous wind vectors, during (a) April-July 2004, and (b) June 2004. Anomalies are departures from the 1971-2000 base period means.

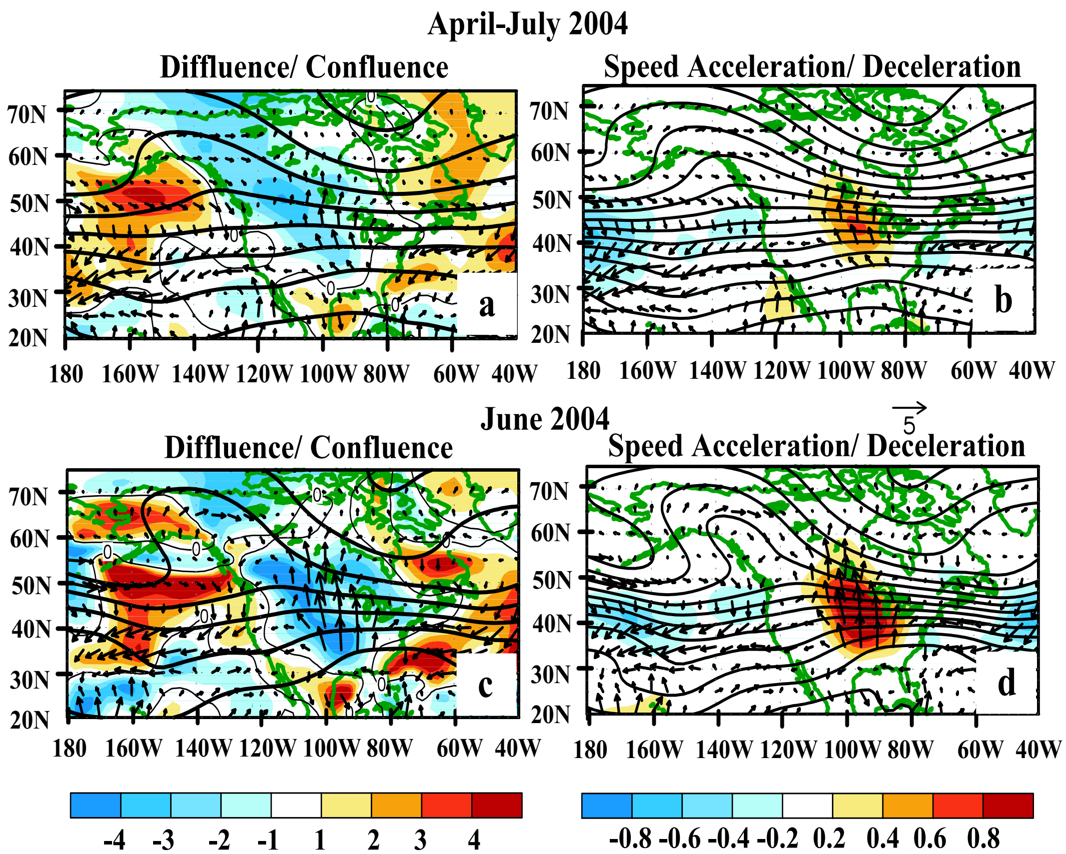

Fig. 11. Mean 200-hPa heights (contour interval is 120 m) and ageostrophic wind vectors overlayed with (Left) mean diffluence (shading, x 10^{-5} s^{-1}) and (Right) mean parcel speed accelerations (shading, x 10^{-2} m s^{-2}) during (a, b) April-July 2004 and (c, d) June 2004. In (a) and (c) diffluence is shown red and confluence is blue. In (b) and (d) speed accelerations are shown red and decelerations are blue. Vector scale (m s^{-1}) is shown on right between panels (b) and (d).

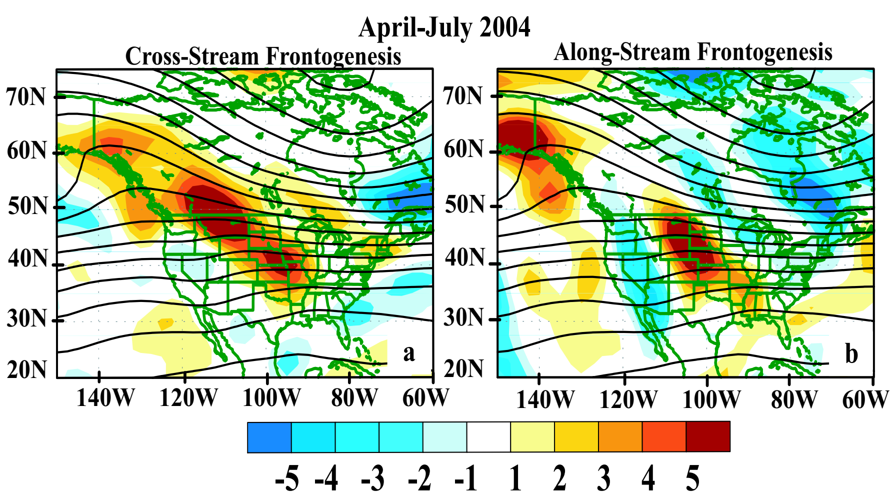

Fig. 12. April-July 2004: Mean 200-hPa frontogenesis in the (a) cross-stream and (b) along-stream directions (shading, x 10^{-11} K $(ms)^{-1}$). The mean 200-hPa heights (contour interval is 120 m) are overlayed in both panels . Frontogenesis is shown red and frontolysis is blue.

diagnostics are used in section 5 to examine the anomalous East Asian jet stream and its relationship to the persistent blocking ridge over Alaska.

Over North America a prominent indicator of a link between the mean jet and wave features is the highly confluent (blue shading) mean northwesterly flow between the upper-level ridge and downstream trough axes (Fig. 11a). The associated ageostrophic wind vectors are directed toward lower heights, indicating strong speed accelerations ocurring in the mean just upstream of the trough axis (Fig. 11b). These conditions coincide with the left entrance region of the mean jet core situated over the Great Lakes. Similarly the right jet entrance region is situated in the southwesterly flow immediately upstream of the mean upper-level ridge axis over the southeastern United States. These conditions are especially evident during June (Figs. 11c, d), when the south-central U.S. recorded well above-average precipitation.

During April-July 2004 the confluent flow between the mean ridge and trough axes was highly frontogenetical (red shading) in both the cross-stream (Fig. 12a) and along-stream directions (Fig. 12b). This circulation forced an anomalous descent of stratospheric air in the northwesterly flow over west-central Canada and along the jet axis (Fig. 13). The large values of cyclonic vorticity produced by this descending motion were then advected into the downstream trough axis, thereby helping to maintain both the mean jet itself and the enhanced trough over Hudson Bay.

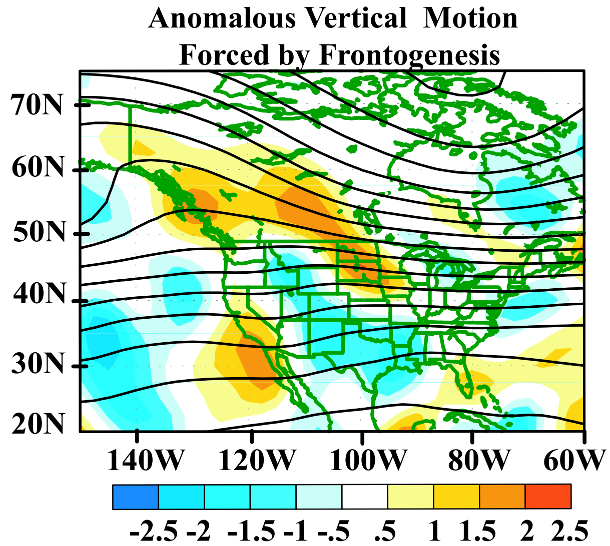

Fig. 13. April-July 2004: Anomalous 300-hPa quasi-geostrophic vertical motion (shading, x10^{-4} hPa s^{-1}) overlayed with mean 200-hPa heights (contour interval is 120 m). Anomalous ascending motion is shown blue and anomalous descending motion is red.

Over the south-central United States the mean upper-level frontogenesis forced anomalous ascending motion, which helps to account for the above-average precipitation in that region. These conditions were particularly prominent during June (Fig. 14), when strong frontogenesis in the jet

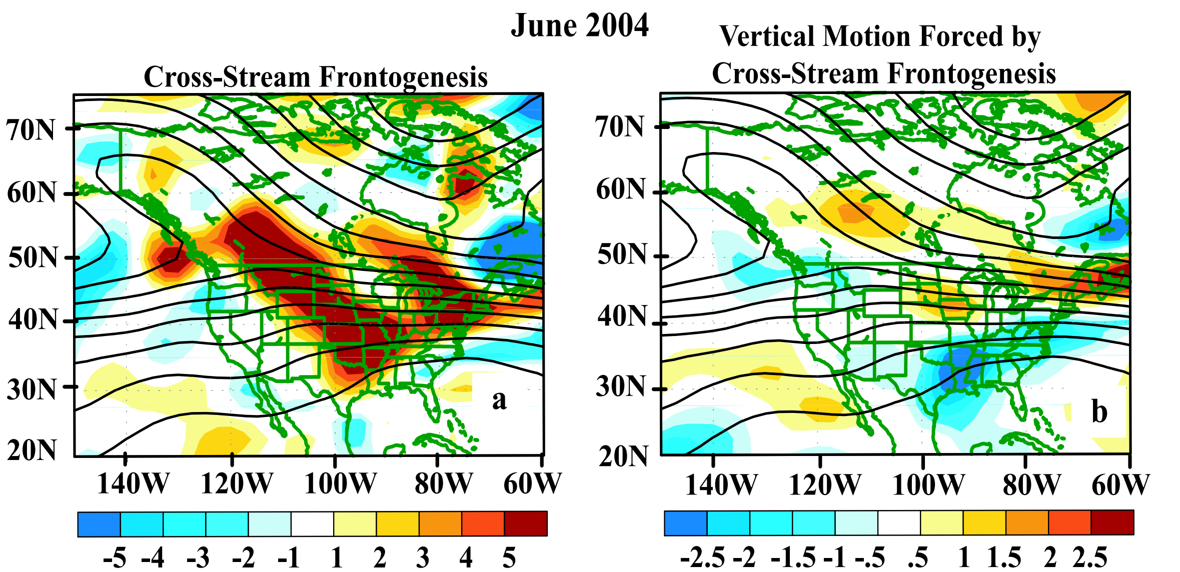

Fig. 14. June 2004: 200-hPa heights (contour interval is 120 m) overlayed with (a) frontogenesis calculated along mean parcel trajectories in the cross-stream direction at 200-hPa (shading, x 10^{-11} K $(ms)^{-1}$), and (b) the associated mean quasi-geostrophic vertical motion at 300-hPa (shading, x10^{-4} hPa s^{-1}). In (a) frontogenesis is shown red and frontolysis is blue. In (b) ascending motion is shown blue and descending motion is red.

entrance region covered the central United States and the resulting ascending motion extended from Texas northeastward to the mid-Atlantic region (blue, Fig. 14b).

5. Links to Hemispheric-Scale Circulation

The North American circulation during April-July 2004 was linked to a persistent hemispheric-scale pattern of height anomalies characterized by an anomalous zonal wave-3 pattern at high latitudes, and by above-average heights near Japan (Fig. 9). The positive anomalies over the Gulf of Alaska, the polar region, and near Japan, were the most persistent of these circulation features, and were evident for 75%-80% of the period.

The hemispheric scale of this anomalous circulation likely contributed to its persistence. Another factor that likely contributed to the persistence of the anomalous circulation over North America is the deep stratospheric penetration past the 30-hPa level of the positive height anomalies over Alaska and the polar region, and the negative anomalies over Hudson Bay (Fig. 15).

A third contributing factor to the persistent North American circulation was the anomalous jet and wave structure over the western North Pacific. This relationship is examined for the

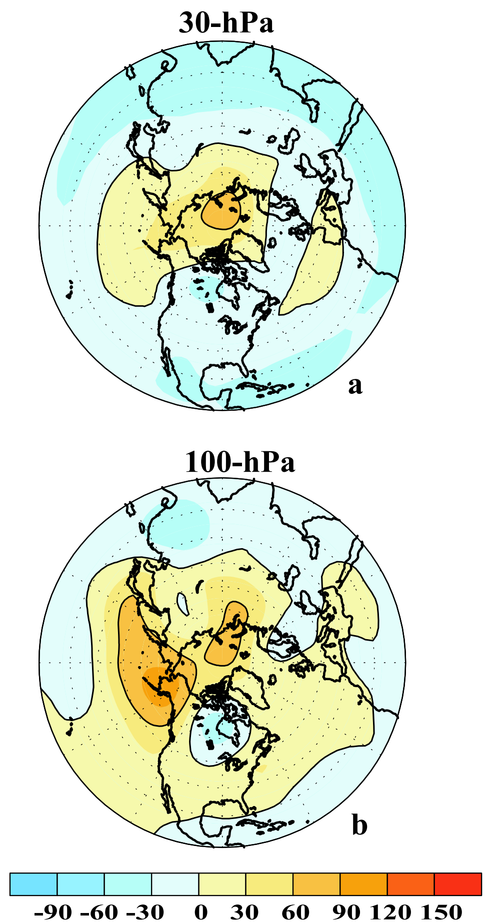

Fig. 15. April-July height anomalies (m) at (a) 30-hPa and (b) 100-hPa. Positive anomalies are shown orange and negative anomalies are blue. Anomalies are departures from the 1971-2000 base period means.

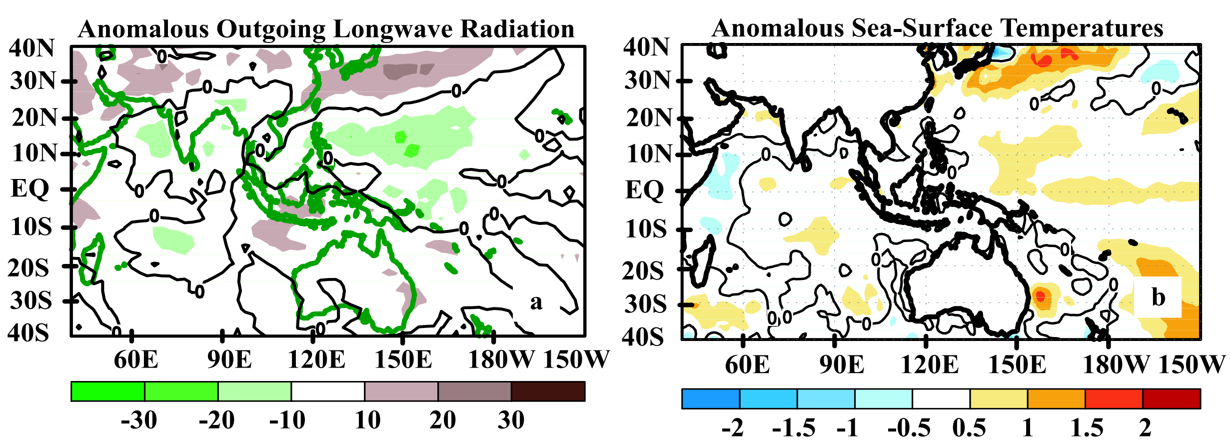

Fig. 16. April-May 2004 anomalous (a) Outgoing Longwave Radiation (OLR, W m^{-2}) and (b) sea-surface temperatures (SSTs, °C). For OLR, green (brown) at low latitudes indicates enhanced (suppressed) tropical convection. OLR (SST) anomalies are departures from the 1979-1995 (1971-2000) base period means.

April-May 2004 period, when enhanced convection (Fig. 16a) and above-average sea surface temperatures (Fig. 16b) over the western tropical Pacific also likely influenced the East Asian jet.

During April-May a diffluent trough was situated over eastern Siberia (contours, Fig. 17a), well west of its climatological position over the Aleutian Islands. This trough and the persistent positive height anomalies over Japan were associated with above-average winds speeds (exceeding 40 m s^{-1}) in the core of the East Asian jet (Fig. 17b).

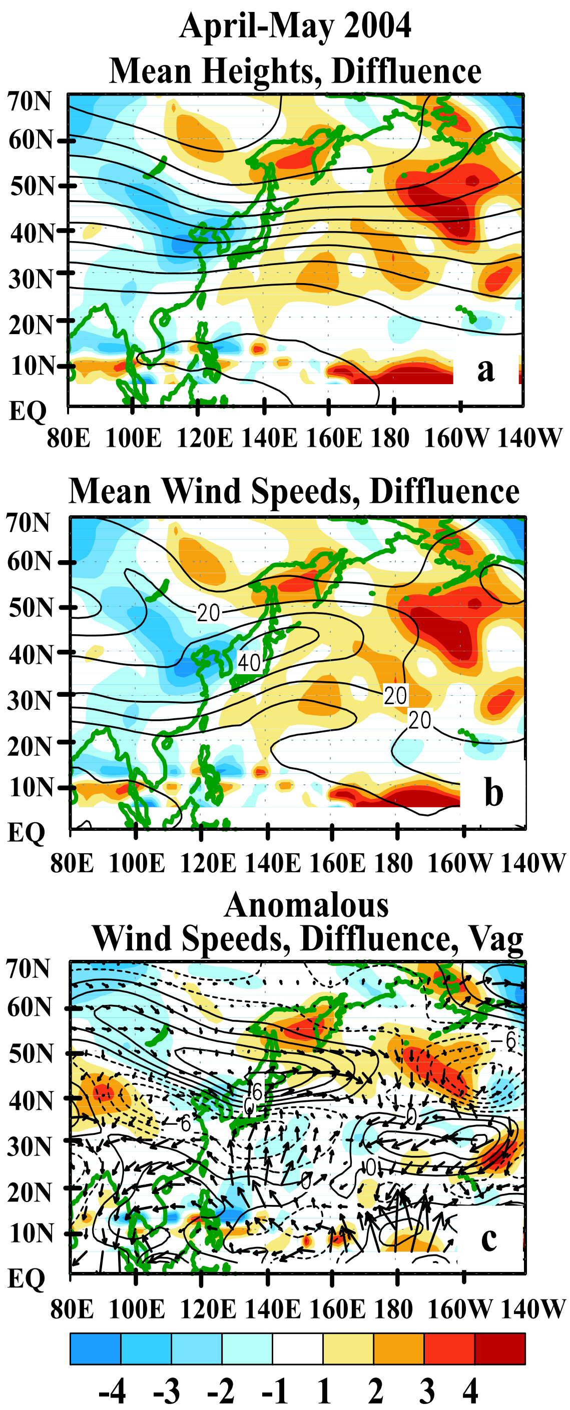

Fig. 17. April-May 2004: 200-hPa mean (a), (b) diffluence (shading, x 5 x 10^{-5} s^{-1}) overlayed with (a) heights (contour interval is 120 m) and (b) wind speeds (contour interval is 10 m s^{-1}). (c) Anomalous diffluence (shaded), anomalous wind speeds (contour interval is 2 m s^{-1}) and anomalous ageostrophic wind vectors. Diffluence is shown red and confluence is blue.

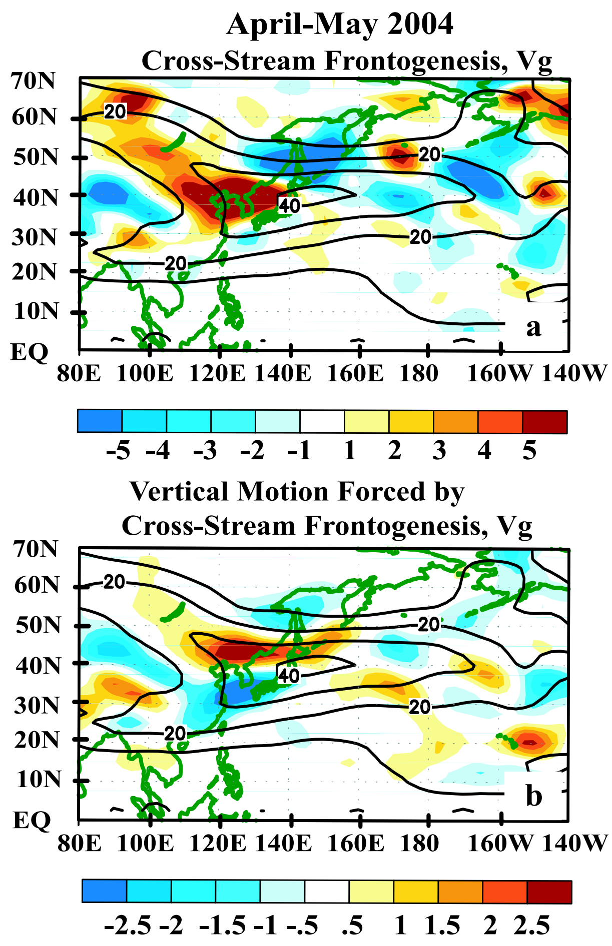

Fig. 18. April-May 2004: Anomalous (a) 200-hPa geostrophic frontogenesis in the cross-stream direction (shading, x 10^{-11} K $(ms)^{-1}$), and (b) the associated anomalous quasi-geostrophic vertical motion at 300-hPa (shading, x10^{-4} hPa s^{-1}). The mean 200-hPa geostrophic wind speeds (contours, interval is 10 m s^{-1}) are overlayed in both panels. In (a) frontogenesis is shown red and frontolysis is blue. In (b) ascending motion is shown blue and descending motion is red.

These increased wind speeds were associated with an enhanced jet entrance region, indicated by anomalous confluence along the jet axis (blue, Figs. 17b, c) and anomalous southerly ageostrophic flow extending from the deep Tropics northward to 45°N. The enhanced jet entrance region also featured anomalous upper-level frontogenesis in the cross-jet direction (red, Fig. 18a), which produced anomalous descending motion north of the jet axis and ascending motion south of the jet axis (Fig. 18b).

In the subtropics the anomalous southerly ageostrophic flow was also partly related to divergent outflow from enhanced convection over the western tropical North Pacific (Fig. 16a). In the mean this outflow is seen to accelerate northward into the mean jet entrance region, thereby helping to maintain the above-average wind speeds in the jet core. This anomalous outflow also represents a source of anticyclonic vorticity for the amplified subtropical ridge, which likely helped to maintain the ridge during the period.

However, the East Asian jet core only extended to 155°E, which is approximately 40 degrees of longitude shorter than its normal length. This significantly reduced eastward extent of the jet core was linked to upper-level diffluence throughout the Pacific basin (red, Figs. 17a, b), with the most anomalous diffluence observed downstream of the Siberian trough and in the mean jet exit region (Fig. 17c).

This combination of high-latitude diffluent flow and a westward retraction of the East Asian jet core and jet exit region is known to favor a westward shift in the positions of the mean ridge and trough axes over North America, as is typically seen during the winter season in association with Pacific cold episodes (La Niña).

6. No Link to intraseasonal variability associated with the Madden-Julian Oscillation (MJO)

The period April-July 2004 featured strong intraseasonal variability in tropical convection associated with the Madden-Julian Oscillation (MJO) (Fig. 19). The corresponding time-longitude section of 300-hPa height anomalies averaged between 60°N-70°N shows little relationship to the phase of the MJO. Therefore, it appears that the MJO did not have a major influence on

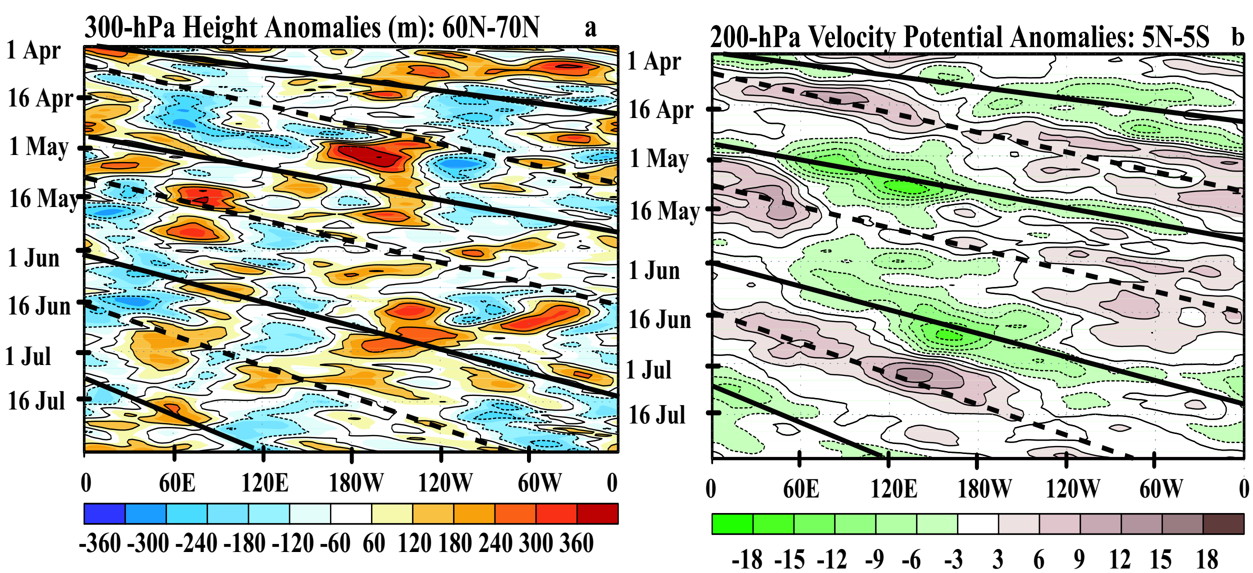

Fig. 19. Time-longitude sections during April-July 2004 of (a) daily 300-hPa height anomalies averaged between 60°N-70°N, and (b) 5-day running mean 200-hPa velocity potential anomalies ($x10^5$ m^2 s^2) averaged between 5°N-5°S. Solid and dashed lines indicate opposite phases of the MJO. In (b) green indicates anomalous ascending motion and brown indicates anomalous descending motion. Anomalies are departures from the 1971-2000 base period daily means.

the persistent North American circulation during the period.

7. Summary

The period April-July 2004 featured exceptionally warm and dry conditions from Alaska to California, with record temperatures set at many locations in Alaska. For the state as a whole, this was the warmest April-July period in the 1950-2004 record.

April-July 2004 also featured well below-average temperatures across the eastern half of Canada and the central/ eastern United States. Central Canada experienced its third coolest such season in the record, with mean temperatures averaging 2°-3°C below normal.

Across the central and eastern U.S., the most significantly below-average temperatures and above-average precipitation occurred during June and July. Several significant cold-air outbreaks occurred during this period, in association with an amplified upper-level ridge over western North America and an amplified trough extending southward into the central or eastern United States. These conditions favored the southward pentration of cold fronts well into the deep south. In Texas, the exceptional southward penetration of the cold fronts was also related to a strong southward funneling of the cold air along the eastern slopes of the Rocky Mountains. These frontal systems also brought below-average temperatures to much of the eastern United States, and contributed to above-average precipitation from Texas northeastward to New England.

In the mean, the anomalous temperature and precipitation patterns over North America during April-July were related to a persistent blocking ridge over Alaska and northwestern Canada, a westward shift and strengthening of the mean trough over central/ eastern Canada, and a persistent jet stream in the Great Lakes region.

While it is not possible to attribute a specific cause or causes of this persistent circulation, three factors that contributed to its longevity have been discussed. These include a persistent zonal wave-3 pattern at high latitudes, and a pronounced stratospheric extension of the high-latitude height anomalies, with the blocking ridge over Alaska and the downstream amplified trough extending past the 30-hPa level. They also include a sharply reduced eastward extent of the East Asian jet core, combined with a highly diffluent trough over eastern Siberia.

Key structural aspects of these circulation features have been examined to better understand their role in maintaining the anomalous circulation over North America. For example, it is shown that the highly confluent flow configuration between the blocking ridge over Alaska and the downstream trough contributed to the persistent trough/ jet steam configuration, and to the anomalous temperature and precipitation patterns over the central and eastern United States.

Farther west, the mean circulation during April-July 2004 featured a highly diffluent trough over eastern Siberia, and a westward retraction of the East Asian jet core and jet exit region. These conditions favored the persistence of a blocking ridge over western North America.

The anomalous East Asian jet stream was also associated with an enhanced jet entrance region over extreme eastern Asia. This feature is related to above-average confluence and upper-level frontogenesis between the Siberian trough and an amplified subtropical ridge over the western North Pacific. In the mean, enhanced speed accelerations in this jet entrance region contributed to super-geostrophic wind speeds in the jet core, which then resulted in an anomalous ageostrophic flow toward higher heights much farther west than normal. This result is consistent with the pronounced westward retraction of the jet core.

It is found that conditions in the anomalous jet entrance region also likely helped to maintain the anomalous East Asian jet/ Siberian trough configuration, as well as the persistent ridge south of the jet core. For example an enhanced descent of stratospheric air in the left jet entrance region, which represents a source of cyclonic vorticity, likely helped to offset the downstream advection of the Siberian trough and jet stream, and therefore aided in the persistence of these features.

As another example, during April and May the divergent outflow from enhanced convection over the western tropical North Pacific is seen to accelerate northward into the mean jet entrance region. This outflow represents a source of anticyclonic vorticity that may have helped to maintain the amplified ridge south of the jet core, and therefore may also have helped to maintain the anomalous East Asian jet during this period.