18 December 2004- 17 January 2005:

# U.S. Storms and Flooding in the West and Midwest Exceptional Warmth in the Midwest and East

Gerald D. Bell and Wayne Higgins
Climate Prediction Center/NOAA/NWS/NCEP

**Contents:**



## 1. Introduction

The period 18 December – 17 January 2004-05 featured a series of major winter storms that produced 300%-400+% of normal precipitation in the western and midwestern United States (Fig. 1). Periods of exceptional warmth were also observed across the central and eastern United States. These conditions were related to a large-scale upper-level circulation pattern characterized by a blocking ridge in the Gulf of Alaska, an amplified trough over the southwestern U.S., and a broad ridge in the East. Associated with this circulation, the jet stream and storm track in the West were shifted well south of normal and entered the United States over southern California, as compared to their climatological mean position over the Pacific Northwest. For both the West

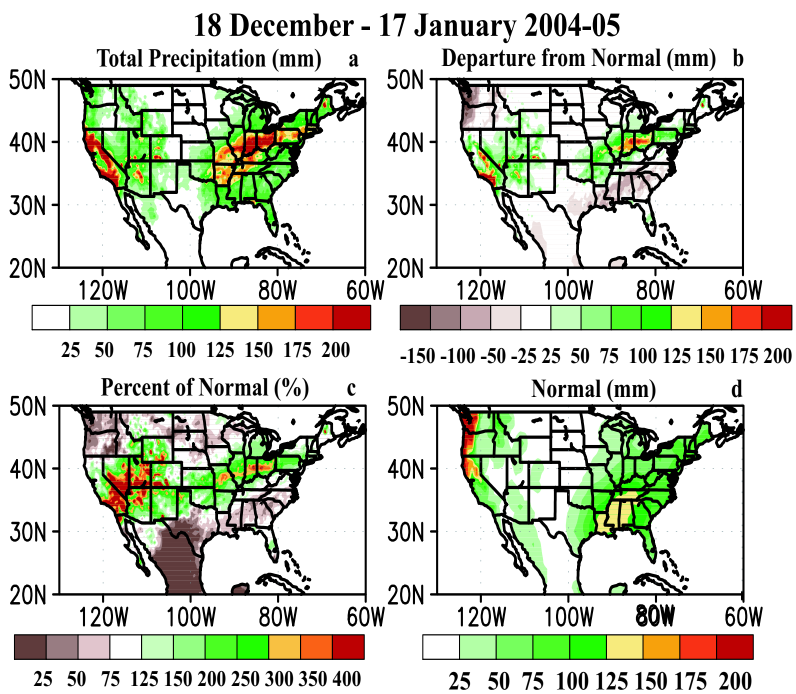


Fig. 1. Precipitation during the 30-day period 18 December – 17 January 2004-05: (a) total (mm), (b) departure from normal (mm), (c) percent of normal, and (d) normal (mm).

and Midwest, the heavy precipitation events were also associated with deep moisture supplied from the tropical North Pacific and Gulf of Mexico, respectively.

In the West, the enhanced precipitation was partly related to a strong Madden-Julian Oscillation (MJO), a tropical disturbance that influences tropical rainfall patterns on time scales of 30-60 days. At times the MJO produces ENSO-like features that cause large-scale circulation anomalies over the Pacific Ocean and western U.S. such as those observed during the period of interest, and can trigger extreme precipitation events in the western United States.

## 2. Precipitation

*a. Southwest*

For the 30-day period 18 December - 17 January 2004-05 precipitation totals were 200+ mm (8+ inches) across California (Fig. 1a). In southern California and the southern Sierra Mountains these amounts were generally 150-200 mm (6 to 8 inches) above average (Fig. 1b), and more than four times the normal for the period (Figs. 1c, d). Large precipitation totals of 75-150 mm (3 to 6 inches) were also observed across much of the Southwest and Inter-Mountain region of the West during the period, with northern Arizona, Utah, Nevada, southern Colorado and southern Wyoming all recording more than 400% of normal precipitation.

This excessive precipitation resulted from a focused storm track that led to the same areas being hit by several major storms. For example, San Diego, located in the southwestern part of the California, received almost 200 mm (7.8 inches) during the 30-day period (Fig. 2a). This amount is more than four times the normal of 46 mm (less than 2 inches), indicating a surplus of 153 mm (6 inches). All of this precipitation occurred between 27 December and 11 January (Fig. 2b). Two-day totals of more than 75 mm (3 inches) were recorded during 28-29 December, followed by 15 mm (more than ½ inch) during 31 Dec.-1 January. The period 3-4 January brought an additional 45 mm (almost 2 inches), followed by 71 mm (almost 3 inches) during five straight days of rain between 7-11 January.

*b. Midwest*

For the 30-day period 18 December - 17 January 2004-05 precipitation totals were 150+ mm (6+ inches) from Arkansas and Missouri northeastward to Pennsylvania. At Indianapolis, Indiana, a representative station within the axis of heaviest precipitation, total precipitation during the

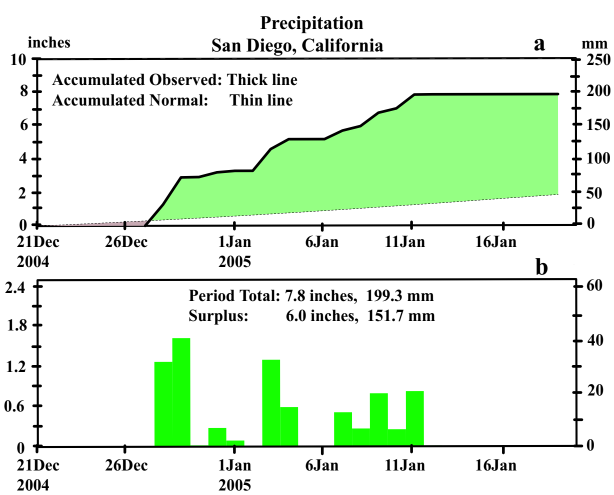


Fig. 2. San Diego, California daily (a) accumulated precipitation (solid) and accumulated normals (dashed), and (b) total precipitation. In (a) accumulated precipitation departures are shaded, with green indicating a surplus.

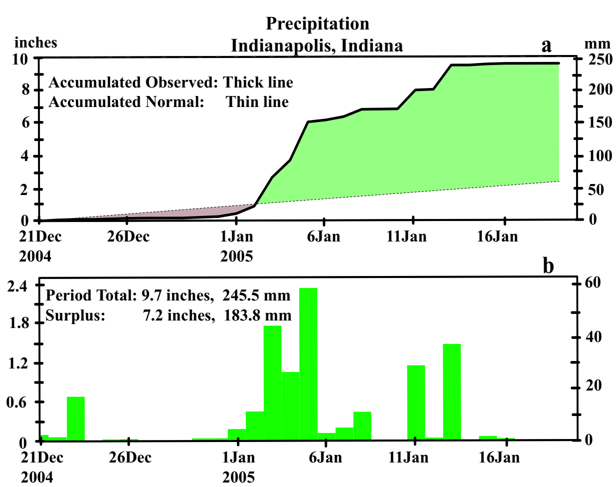


Fig. 3. Indianapolis, Indiana daily (a) accumulated precipitation (solid) and accumulated normals (dashed), and (b) total precipitation. In (a) accumulated precipitation departures are shaded, with green indicating a surplus.

period was 245 mm (9.7 inches) (Fig. 3a). This amount is almost four times the normal of 62 mm (2 ½ inches), indicating a surplus of 183.8 mm (7.2 inches). Nearly all of this precipitation resulted from three major storms that occurred on 23 December, and 2-6 and 11-13 January (Fig. 3b). All of the precipitation fell as snow during the first storm, which produced snowfall totals of 10-20 inches throughout the Ohio Valley region. The second and third storms occurred during a major warm-up, and produced 160 mm (more than 6 inches) of rain and 70 mm (almost 3 inches) of rain at Indianapolis, respectively. This excessive rainfall combined with rapid snow melt to produce significant flooding throughout the region (Fig. 4, see also section 4).

## 3. Snowfall in the West

The heavy precipitation in the West led to extreme snowfall totals in areas such as the Sierra Nevada Mountains and western Nevada. National Weather Service reports from Reno, Nevada indicate that during 28 Dec. – 11 January, 13 feet of snow fell at the Sierra Storm Lab and 10 feet fell in Tahoe City. Snowfall was 6-7.5 feet at Reno, and 14-19 feet at ski resorts.

For the major winter storm during 7-11 January, the Sierra Nevada Mountains below 7000 ft recorded an average of 4-6 feet of snow, while Tahoe City recorded 4 ½ feet. Snowfall was 2-3.5 feet at Reno, and 6-8 feet at ski resorts.

## 4. Flooding in the West and Midwest

The large precipitation totals in the Southwest led to isolated river flooding. According to a flood summary issued 13 January by NOAA's Hydrologic Information Center "record high flows on the Santa Clara River in Arizona and Utah caused substantial damage around St. George and Santa Clara." The Virgin River in Nevada and Arizona also flooded, washing out many roads and damaging or destroying approximately 100 homes in Overton, Nevada.

In the Midwest, river flooding occurred from northeastern Oklahoma and southeastern Kansas

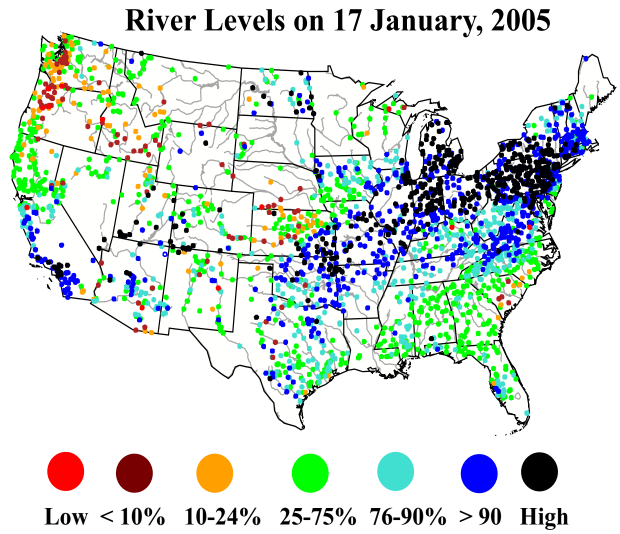


Fig. 4. Streamflows at United States Geological Survey (USGS) station gauges, expressed as percentiles of historical daily streamflow for the day of the year. Stations with at least thirty years of data are used. Locations where data was unavailable have no dot. Black dots indicate the highest streamflows in the record, and dark blue dots indicate flows in the highest 90% percentile of occurrences. Red dots indicate the lowest streamflows in the record, and burgundy dots indicate flows in the lowest 10% percentile. Figure courtesy of the USGS.

northeastward to include nearly all of Pennsylvania and much of Ohio and Wisconsin, with major flooding observed in parts of Indiana (Fig. 4). Some examples included minor to moderate flooding along the Ohio River from West Virginia to Cairo, Illinois. Also in Illinois, major flooding occurred along parts of the Wabash and White Rivers, with record flooding seen at Mount Carmel. In Indiana major flooding also occurred along the Mississinewa River in Marion, and along the Tippecanoe River in Lafayette. In Ohio major flooding occurred along the Auglaize, Maumee, and St. Mary's Rivers, while in Pennsylvania flooding was seen along the Allegheny and Monongahela Rivers.

## 5. Exceptionally warm temperatures in the Midwest and East

From 26 Dec. – 13 January much of the eastern U.S. experienced exceptionally warm wintertime temperatures. During the week ending 3 January mean temperatures were well above freezing for almost the entire country east of the Rocky Mountains (Fig. 5a), with departures in most areas exceeding 4°C (7°F) (Fig. 5b). The most anomalous warmth was centered in the southern Plains and Midwest, where mean temperatures were 8°-12+°C (14°-22°F) above average. This exceptional warmth then progressed eastward during the next week ending 11 January (Fig. 6a), with the largest departures exceeding 8°C (14°F) centered over the southeastern and eastern United States (Fig. 6b).

This anomalous warmth is summarized at three representative stations: Chicago, Illinois (Fig. 7a), Albany, New York (Fig. 7b), and Washington, D. C. (Fig. 7c). At all three stations, daily mean temperatures were above average from late December through 13 January, followed by a drop to below-average temperatures in mid-month. Daily mean temperatures often reached 5°C (41°F) at both Chicago and Albany during the period, and 10°-14°C (50°-57°F) at Washington D. C. Also at Washington, daily maximum temperatures often reached 15°-20°C (59°-68°F) during the period.

In the Ohio Valley region this anomalous warmth was accompanied by a pronounced northward surge of moist air from the Gulf of Mexico (refer ahead to Fig. 10). These conditions led to a rapid snowmelt in late December, and to excessive rainfall (8-9 inches) in association with two major winter storms during early January. This combination of conditions produced significant flooding throughout the region (Fig. 4, see also section 4).

## 6. Atmospheric Circulation

The highly anomalous temperatures and precipitation amounts during 23 December-14 January 2004-05 were related to an exceptionally amplified circulation pattern at jet stream level that spanned North America (Fig. 8a). This pattern featured a

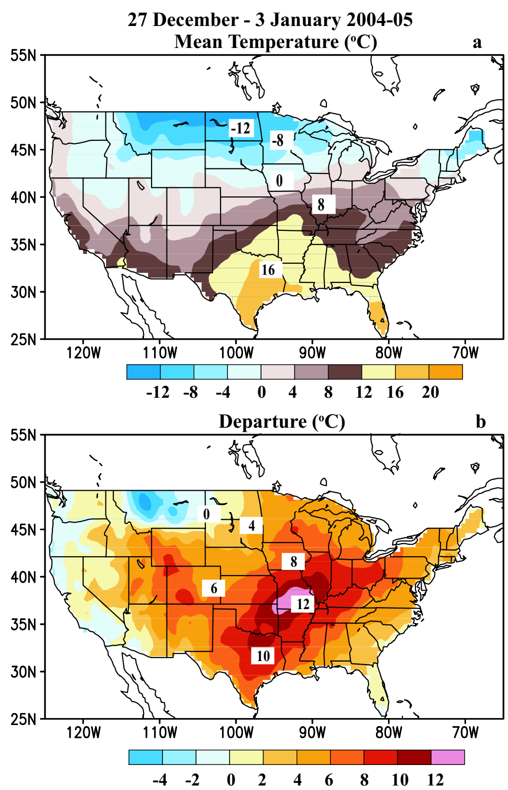


Fig. 5. Mean surface temperatures (°C) (a) and departures from normal (b) during the 7-day period ending 3 January 2005. Departures are calculated from the 1971-2000 base period daily means.

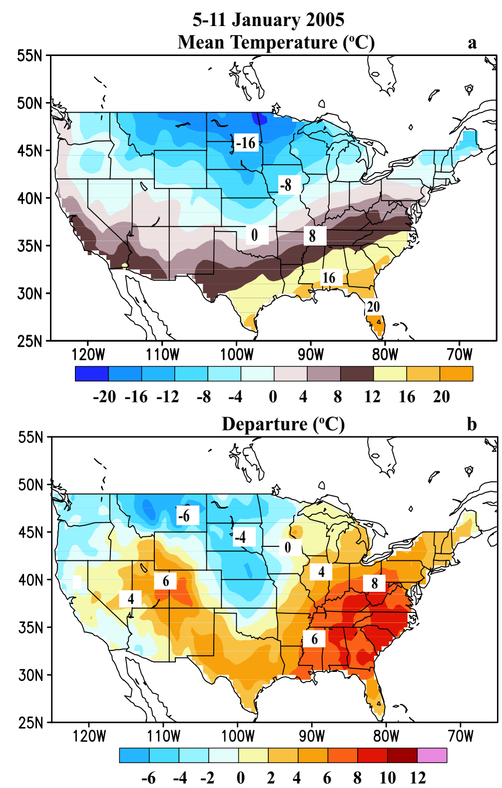


Fig. 6. Mean surface temperatures (°C) (a) and departures from normal (b) during the 7-day period ending 11 January 2005. Departures are calculated from the 1971-2000 base period daily means.

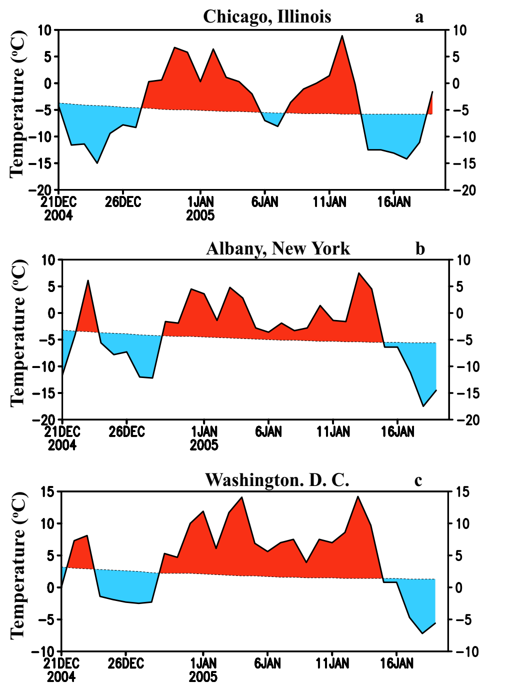


Fig. 7. Daily mean surface temperatures (solid line) and normals (dashed line) at (a) Chicago, Illinois, (b) Albany, New York, and (c) Washington, D.C. In all panels, above-normal temperatures are shaded red and below-normal temperatures are shaded blue.

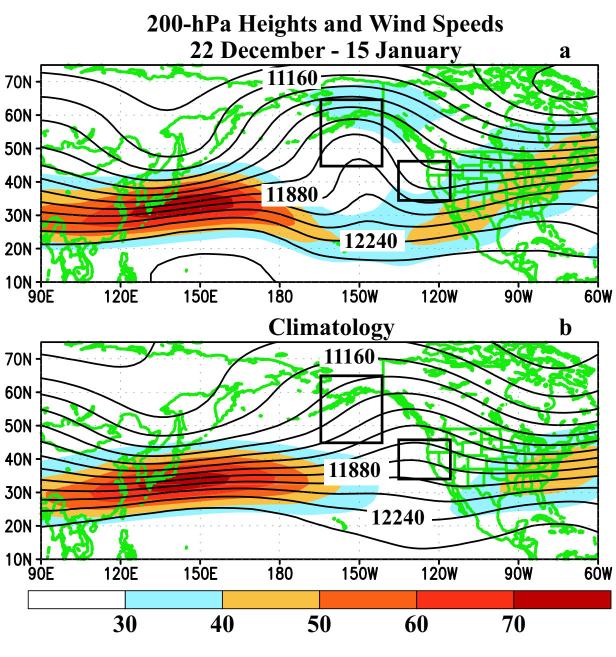


Fig. 8. Mean 200-hPa heights (contour interval is 120 m) and wind speeds (shading, $ms^{-1}$) during 25 December – 15 January (a) observed during 2004-05 and (b) climatology. Black boxes denote the regions used to calculate height anomaly indices (see Fig. 11). The climatological means are calculated from the 1979-1995 base period daily means.

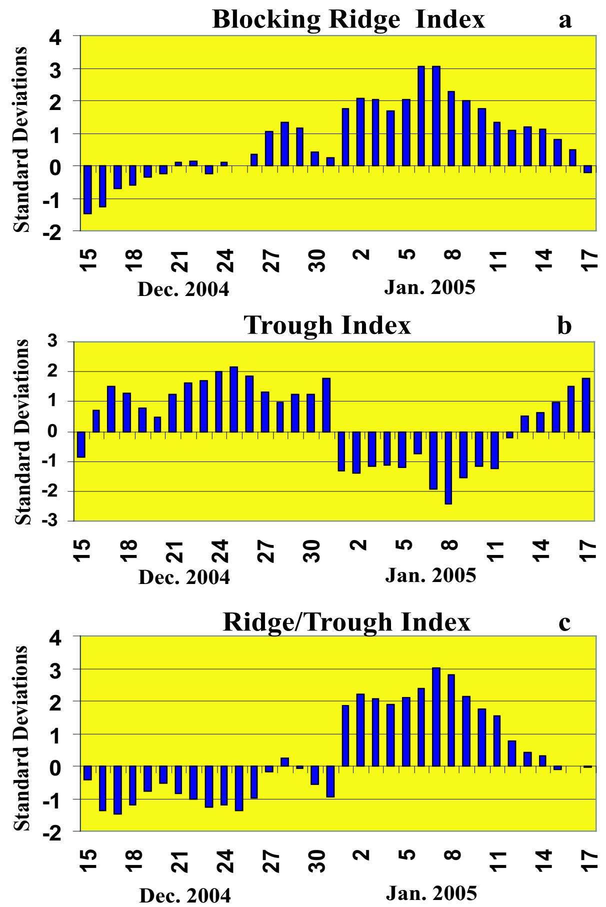


Fig. 9. Standardized, area-averaged 500-hPa height anomalies centered on (a) the blocking ridge (140°W-165°W, 45°N-65°N), and the (b) the trough upstream of California (115°W-135°W, 35°N-45°N). Panel (c) shows the standardized height anomalies for the combined regions, calculated as the standardized difference of Panel-a minus Panel-b. Anomalies are standardized based on the 1948-2004 period daily means.

blocking ridge in the Gulf of Alaska, an amplified trough over the southwestern U.S., and a broad ridge in the East. Both the blocking ridge and the mean upper-level trough axes were centered 30°-40° of longitude west of the climatological ridge and trough positions (Fig. 8b), meaning that the western U.S. was situated downstream of a mean upper-level trough instead of beneath the climatological mean ridge. Farther east, the mean Hudson Bay trough was notably weaker than normal, as an upper-level ridge dominated the entire eastern United States.

Associated with this circulation, the mean jet stream was exceptionally strong across the lower latitudes of the eastern North Pacific and significantly under-cut the blocking ridge. A second jet core extended northeastward from the central Baja Peninsula to New England, well north of its climatological mean position. This anomalous jet stream is consistent with the axis of heavy precipitation that extended through the Midwest.

A time series showing the daily mean strength of the blocking ridge (Fig. 9a) and downstream trough (Fig. 9b) indicates that both features reached peak amplitude between 1-11 January. During this period the 500-hPa heights associated with the ridge often reached two standard deviations above normal, while those associated with the trough were more than one standard deviation below normal. The strength of the combined ridge-trough system averaged 2-3 standard deviations above normal during the period.

These conditions were associated with a series of moisture-laden, major winter storms in the Southwest and Midwest. The first storm featured a broad upper-level trough over the western U.S., with a jet core embedded in southwesterly flow extending from Texas to New England (Fig. 10a). This storm was associated with a strong surface frontal boundary and surface pressure trough that extended northward through the Ohio Valley (Fig. 10b), where it produced an average of 10-20 inches of snow on

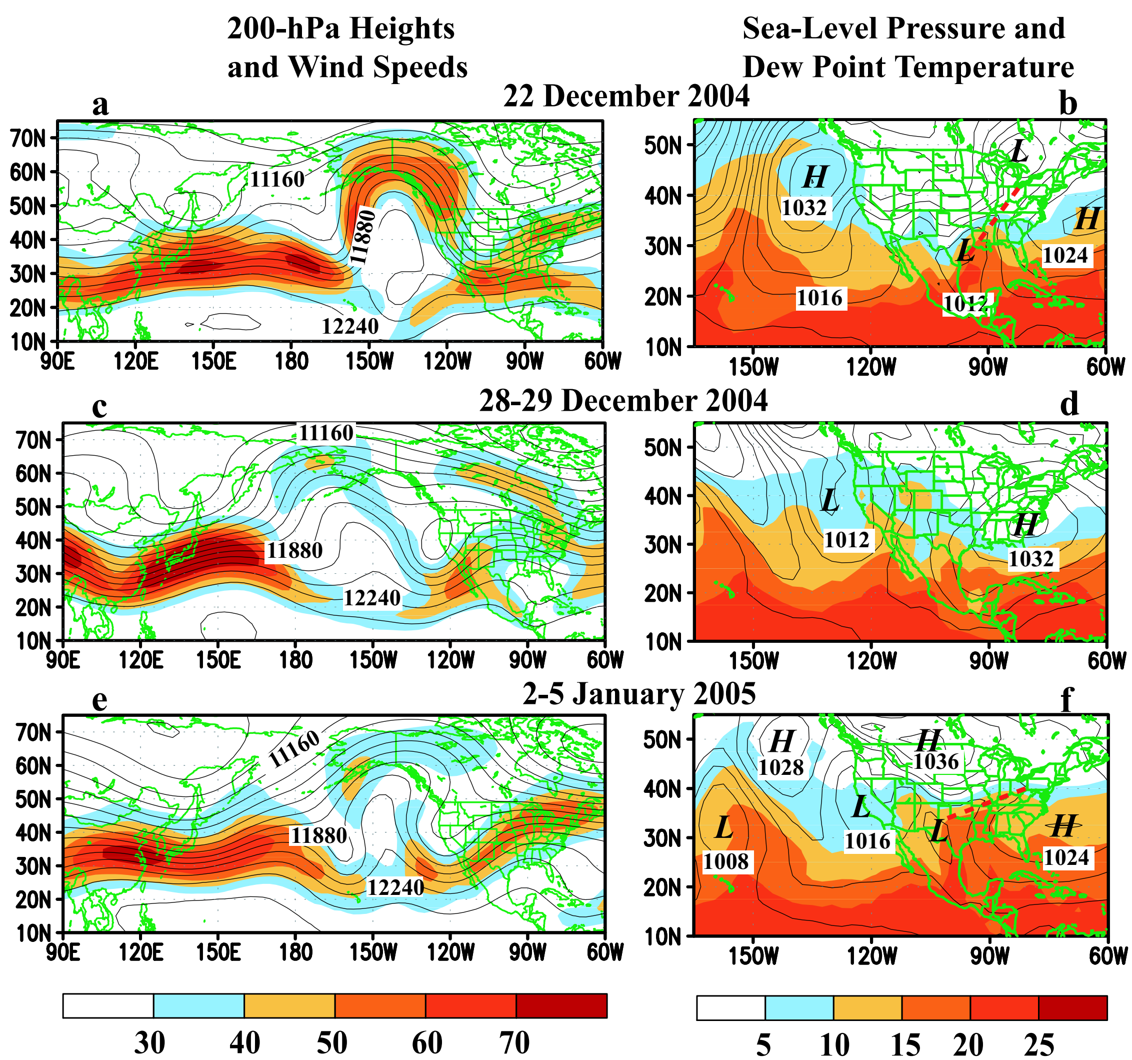


Fig. 10. Left: Mean 200-hPa heights (contour interval is 120 m) and wind speeds (shading, $ms^{-1}$), and Right: Mean sea-level pressure (contour interval is 2 hPa) and surface-based dew-point temperature (shading, °C), during (a, b) 22 December 2004, (c, d) 28-29 December 2004, and (e, f) 2-5 January 2005. Red dashed line indicates frontal boundary.

23 December.

The second storm during 28-29 December featured a vigorous upper-level trough/ jet stream system immediately upstream of southern California, which amplified in the northwesterly flow downstream of the blocking ridge (Fig. 10c). This storm was associated with a deep surface low and a strong southerly flow of moisture into California and Arizona, as indicated by dew point temperatures of 10°-15°C throughout the region (Fig. 10d).

The third storm occurred during 2-5 January and brought several days of exceptionally heavy precipitation to the Midwest. This storm was again associated with a very strong jet stream embedded in southwesterly flow (Fig. 10e), and also featured a strong frontal boundary in the upper Midwest with moisture-laden air extending from the Gulf of Mexico northward to the frontal boundary (Fig. 10f). During this period, another upper-level trough over the eastern North Pacific brought two days of precipitation to southern California.

During the fourth storm, which hit the Southwest during 7-11 January, the mean upper-level circulation featured a continuous East Asian jet from Japan to southern California (Fig. 11a). This anomalous jet stream, combined with the amplified trough off the coast, brought five straight days of precipitation to southern California and portions of the Southwest. During this period, moisture-rich air again covered the southwestern U.S. (Fig. 11b), and contributed to significant snowfall totals at higher elevations in areas such as the Sierra Nevada Mountains and western Nevada.

The third period of very heavy precipitation in the Midwest occurred during 11-13 January, and was triggered by a strong upper-level disturbance

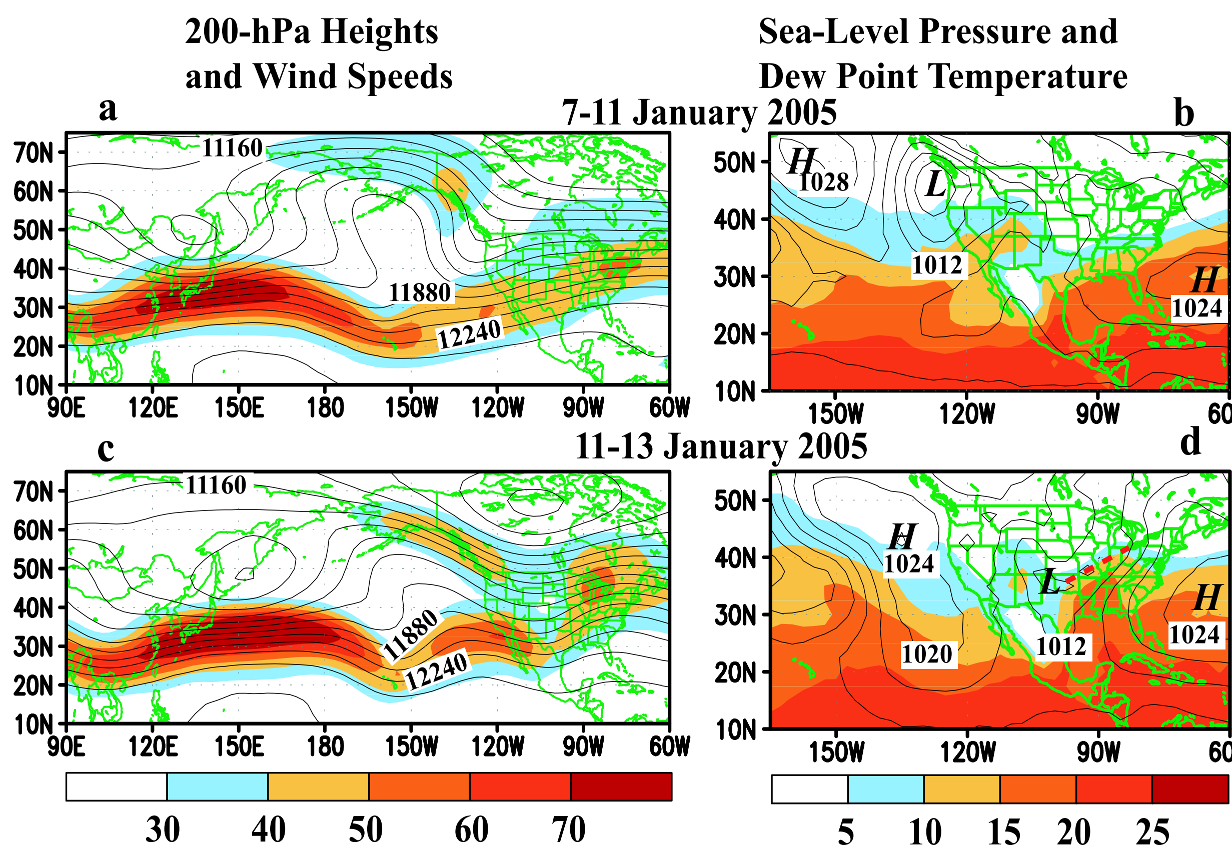


Fig. 11. Left: Mean 200-hPa heights (contour interval is 120 m) and wind speeds (shading, $ms^{-1}$), and Right: Mean sea-level pressure (contour interval is 2 hPa) and surface-based dew-point temperature (shading, °C), during (a, b) 7-11 January 2005, and (c, d) 11-13 January 2005. Red dashed line in (d) indicates frontal boundary.

moving across the South (Fig. 11c). This disturbance also tapped into the extensive area of moisture-rich air extending from the Gulf of Mexico to the Ohio Valley (Fig. 11d).

## 7. Links to the Madden-Julian Oscillation (MJO) and anomalous tropical rainfall

The circulation anomalies over the eastern North Pacific and North America are known to be significantly influenced by the East Asian jet stream which, in turn, exhibits large fluctuations in response to anomalous tropical convection over the central equatorial Pacific. The El Niño/ Southern Oscillation (ENSO) phenomenon is one climate factor known to influence the North American wintertime circulation in this manner. For example, tropical convection during El Niño episodes generally extends to well east of the date line, resulting in an eastward extension of the East Asian jet stream and an eastward shift of the jet exit region. During very strong El Niño episodes, the jet exit region and its associated region of strong cyclogenesis often become situated immediately upstream of California, which leads to a southward shift of the mean wintertime storm track and enhanced storminess and precipitation across the Southwest and South.

During La Niña episodes equatorial convection is confined to the western Pacific. As a result the East Asian jet core and jet exit region retract westward, which leads to a westward shift of the mean upper-level ridge and trough positions across the eastern North Pacific and North America.

These same patterns of anomalous equatorial convection are also seen on shorter time scales in association with the Madden-Julian Oscillation (MJO). The MJO is an eastward propagating tropical disturbance that influences equatorial rainfall patterns on time scales of 30-60 days, as opposed to ENSO which influences equatorial rainfall for roughly 12-18 months at a time. Because the MJO is a propagating disturbance, its impacts on the East Asian jet stream and the downstream circulation anomalies over North America depend upon the eastward extent of the enhanced tropical convection (Fig. 12).

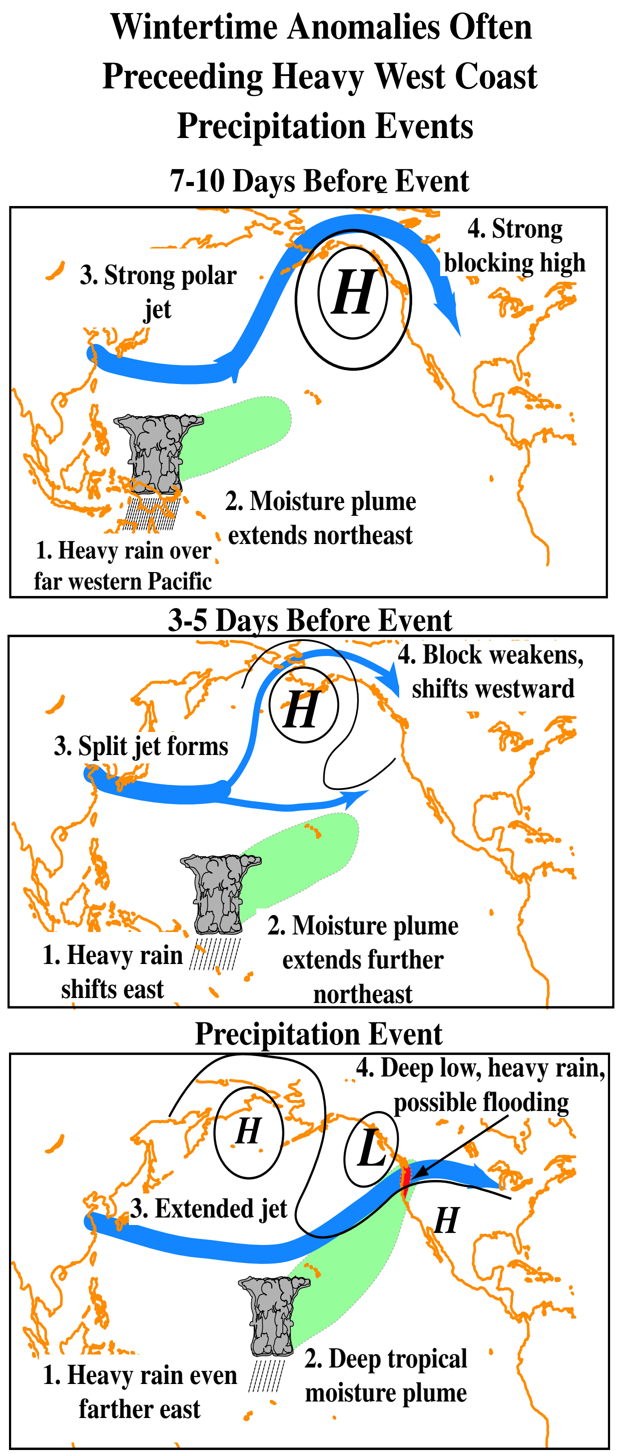


Fig. 12. Schematic representation of conditions associated with the Madden-Julian Oscillation (MJO) leading to major precipitation events in California, (a) 7-10 days before the precipitation event, (b) 3-5 days before the precipitation event, and (c) at the time of the precipitation event.

The typical scenario linking tropical rainfall associated with the MJO to extreme precipitation events along the west coast of the United States is shown in schematic form (Fig. 12). The figure depicts changes in the large-scale circulation and moisture patterns that occur over the 10-day period leading up to heavy precipitation events in the West. These are often referred to as "pine-apple express" events, so named because a significant amount of the deep tropical moisture traverses the Hawaiian Islands on its way toward the western United States.

The scenario shown in Fig. 12 is similar to that which occurred during 25 December-15 January. For example, during 22-26 December enhanced convection associated with the MJO was situated over the Indian Ocean, and suppressed convection was seen near the date line (Fig. 13a). During this period the East Asian jet core was retracted westward and high latitude blocking prevailed over the central and eastern North Pacific. The enhanced convection then shifted eastward to Indonesia during the next several days ending 31 December (Fig. 13b), followed by increased precipitation over the Hawaiian Islands and California during the next 10 days as enhanced convection became established as far east as the date line (Figs. 13c, d). The East Asian jet stream extended progressively farther eastward during this period, eventually undercutting the blocking ridge and extending all the way to California. This evolution contributed to the intensity and extended duration of precipitation in the southwestern U.S. during 7-11 January.

## 8. Summary

During 25 December – 14 January 2004-05 the exceptionally wet conditions in the West and Midwest, and near-record warmth in East, all resulted from a persistent large-scale circulation pattern that extended across the eastern North Pacific and North America. During this period, the mean jet stream and associated storm track entered the United States over southern California,

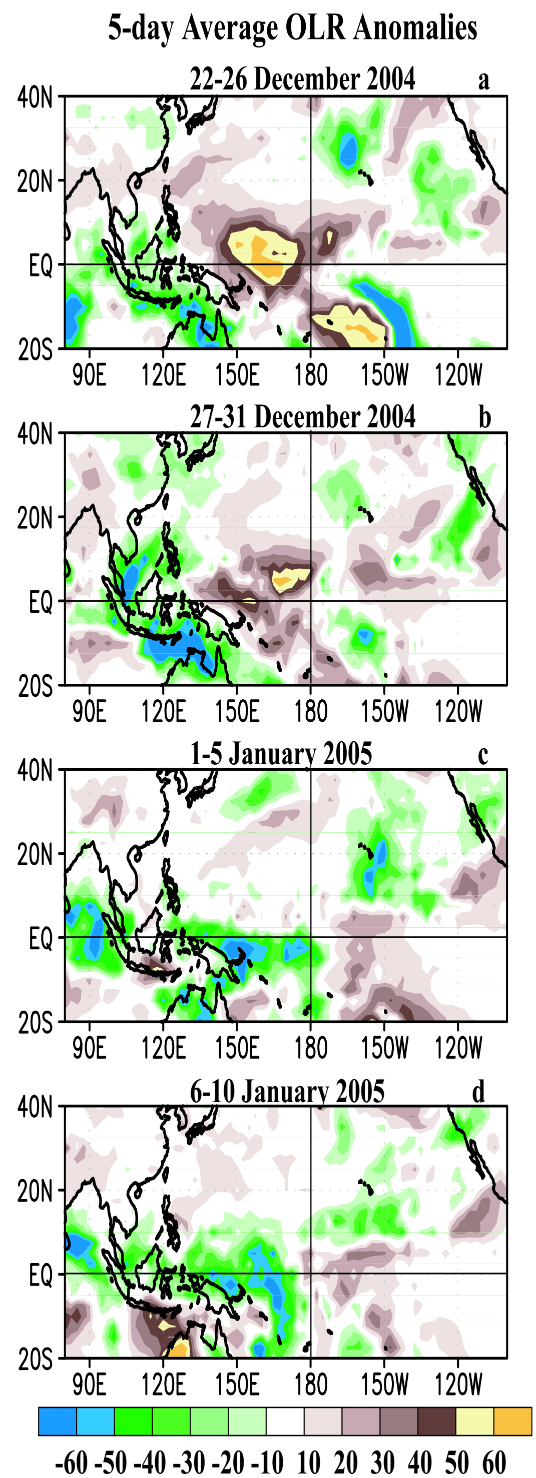


Fig. 13. Outgoing Longwave Radiation (OLR) anomalies for the 5-day periods (a) 22-26 December 2004, (b) 27-31 December 2004, (c) 1-5 January 2005, and (d) 6-10 January 2005. Negative anomalies shown with green-blue shading indicate above-average rainfall. Positive anomalies shown with brown-yellow shading indicate below-average rainfall.

well south of their climatological mean position over the Pacific Northwest.

The enhanced precipitation in California resulted from a series of vigorous upper-level trough/ jet stream systems that ingested significant tropical moisture. For the main 7-11 January event, this tropical moisture was supplied by a pronounced eastward extension of the East Asian jet stream, which under-cut the persistent blocking ridge and brought deep tropical moisture from Hawaii to California. This “Pineapple express” event was linked to an eastward propagation of deep tropical convection to the central Pacific in association with the MJO.

For the Midwest, a northward shift and strengthening of the mean jet stream allowed for a deep layer of moisture originating over the Gulf of Mexico to penetrate well northward into the region. The interaction of this moisture-rich air with vigorous upper-level disturbances and strong frontal boundaries led to three major precipitation events that culminated in significant river flooding in many states. These same circulation anomalies led to periods of extreme warmth across the Midwest and East, with daily mean temperatures in many locations often exceeding 8°C above average.