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SUPERTYPHOON DALE (1996): A REMARKABLE STORM FROM BIRTH THROUGH EXTRATROPICAL TRANSITION TO EXPLOSIVE REINTENSIFICATION THAT IMPACTED THE TROPICS, MIDLATITUDES AND THE ARCTIC

by

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1. INTRODUCTION:

Supertyphoon Dale (1996) was born as a tropical depression (TD) in the tropical northwestern Pacific Ocean on 2 November 1996 and dissipated three weeks later as an extratropical cyclone (EC) in northern Russia just south of the Kara Sea (Fig. 1). Dale tracked westward around a subtropical high, became a typhoon on 6 November and then a supertyphoon (estimated peak intensity of 140 kt) just before it turned to the northwest three days later. Dale recurved to the northeast around the east side of a strong polar vortex as it entered the influence of a strong subtropical westerly jet and underwent extratropical transition (ET; e.g., Jones et al. 2003) over the Bering Sea. Dale rapidly reintensified into a powerful EC as it turned northwestward, making its first landfall in Siberia, and then slowly died as it moved westward along the north coast of Russia. This presentation will focus on the synoptic scale aspects of Dale's life cycle with emphasis on noteworthy aspects that include: 1) environmental sea level pressure (SLP) perturbations of 12 hPa in 10 days over the tropical western Pacific during genesis, 2) the relationship between Dale and a powerful 200 hPa East Asian jet during ET, and 3) a surge of modified tropical air ahead of Dale that crossed the North Pole and reached northern Greenland during the EC phase.

2. DATA AND METHODOLOGY:

ECMWF ERA-40 2.5 gridded reanalyses were used for diagnostic calculations (Gibson et al. (1997). Joint Typhoon Warning Center (JTWC) best track and intensity estimates were obtained for Dale during its tropical phase. Ship reports from the Comprehensive Ocean-Atmosphere Data Set at NCAR were used to refine Dale analyses during its lifetime.

3. RESULTS:

Results indicate that the interactions of three different upper tropospheric (200-400 and 400-600 hPa layer averaged, not shown) potential vorticity (PV) anomalies that broke away from the midlatitudes provided favorable conditions for tropical cyclogenesis. The first PV anomaly (PV1) slowly weakened as it drifted into the tropics and initiated minimal convection by itself in the tropics. A second PV anomaly (PV2) reenergized PV1 by the inertial advection of stronger easterly winds on the north side of PV1 as their respective shear-line axes aligned. The reenergizing sparked deep convection, leading to the formation of two low-level mesoscale convective vortices (MCVs) and a TD on 2 November (Fig. 2). A third PV anomaly (PV3) that fractured from the midlatitudes moved toward this TD and increased the upper-tropospheric southeasterly winds just north of the TD. As a result, a 200-850 hPa thermal jet north of the development region intensified. The entrance regions of this jet and a second thermal jet set up near the development region and combined to create strong upper-level divergence of greater than 8 x 10^{-5} s^{-1} that helped lead to the organization of the MCVs on 4 November (Fig. 3) into TS Dale on 5 November.

On 4 November during Dale's formation, SLP fell below 1003 hPa across a common shipping lane in the tropical western Pacific (Fig. 4). According to a climatology of SLP in a 4^o by 4^o box centered on the equator and 150^{o}E during the 1900-1979 period (Morrisey 1990), these SLP observations of 1000.5-1003.0 hPa are record low values for this region. The record low SLP values occurred in conjunction with intense upper-tropospheric divergence of 12 x 10^{-5} s^{-1} that was associated with a third 200-850 hPa thermal jet that had developed just south of the equator on 4 November (Fig. 5). Some type of propagating wave-like feature may have also played a role in the significant SLP perturbations. A Hövmöller diagram of 24-hour SLP tendency averaged between 20^{o}S and 20^{o}N indicates a region of negative values propagating westward through 150^{o}E in the days leading up to 4 November (Fig. 6). Remarkably, the SLP rebounded to record high values, 1013.0-1015.2 hPa, only 10 days later in this same area. Again, a wave-like feature may be

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responsible with positive values of 24-hour SLP tendency propagating westward through the region just prior to 14 November. A more in depth analysis is needed to determine the mechanisms for this unprecedented swing from record low to record high SLP in the western tropical Pacific.

Dale strengthened into a supertyphoon on 9 November then recurved to the northeast from the increasing influence of the midlatitude westerlies. Dale began to interact with an upper-tropospheric PV anomaly embedded within a strong westerly jet on the dynamic tropopause (DT, PVU = 2.0) on 13 November. This interaction intensified the jet to over 100 m s^{-1} and led to the ET of Dale within a highly baroclinic environment consistent with typical processes of ET (Jones et al. 2003).

On 14 November, a south to north oriented jet streak developed downstream of Dale. This meridional jet structure developed largely in response to Dale and its warm outflow at upper levels that strengthened a preexisting ridge. Pressures on the DT in this ridge decreased to near 160 hPa while they increased to near 460 hPa in the trailing powerful shortwave disturbance at 12 UTC 14 November (Fig. 7). Strong divergence (greater than 8 x 10^{-5} s^{-1}) associated with the right-entrance region of this meridionally oriented jet streak helped to facilitate mass removal while Dale underwent ET. The aforementioned poleward flux of modified tropical air ahead of Dale also led to an amplification of a preexisting downstream ridge toward the North Pole. As Dale crossed the strong jet axis, explosive reintensification occurred as attested by a central pressure decrease of about 24 hPa in 24 hours on 14 November (Fig. 8).

Dale continued to intensify as an EC to about 943 hPa at 6 UTC 17 November. The 500-1000 hPa thickness over the North Pole increased 30 dam to 532 dam in 24 hours on 16 November as the modified tropical air crossed the Pole (Fig. 9). While still a strong storm, Dale tracked north to 82^{o}N, further north than any other intense transitioned EC on record. Dale then turned west along the north coast of Russia before finally dissipating on 22 November.

4. SUMMARY:

From the tropics to the midlatitudes to the North Pole, Dale produced a sequence of powerful events. The development of Dale was associated with the drop of SLP to record low values in the equatorial western Pacific. Subsequently, the SLP values rose to record high values, indicative of a major perturbation to the tropical circulation in the western Pacific associated with the genesis of Dale. After achieving supertyphoon strength, Dale recurved to merge with the midlatitude westerlies. During ET, the upper-tropospheric jet intensified to over 100 m s^{-1}. Dale's amplification of a downstream ridge allowed it to move northward to an unprecedented 82^{o}N. Modified tropical air ahead of Dale tracked across the North Pole then back to the south over northern Greenland and northern North America. The passage of this modified tropical air over the North Pole resulted in an upward spike of 1000-500 hPa thickness values of close to 30 dam.

3. ACKNOWLEDGEMENT:

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4. REFERENCES:

Gibson, J. K., S. Kallberg, A. Hernandez, S. Uppala, A. Nomura, and E. Serrano, 1997: *ERA Description.* ECMWF Re-Analysis Project Report Series, Vol. 1, European Centre for Medium-Range Weather Forecasts, 72 pp.

Jones, S. C., et al., 2003: The extratropical transition of tropical cyclones: Forecast Challenges, current understanding, and future directions. *Wea. Forecasting*, **18**, 1052-1092.

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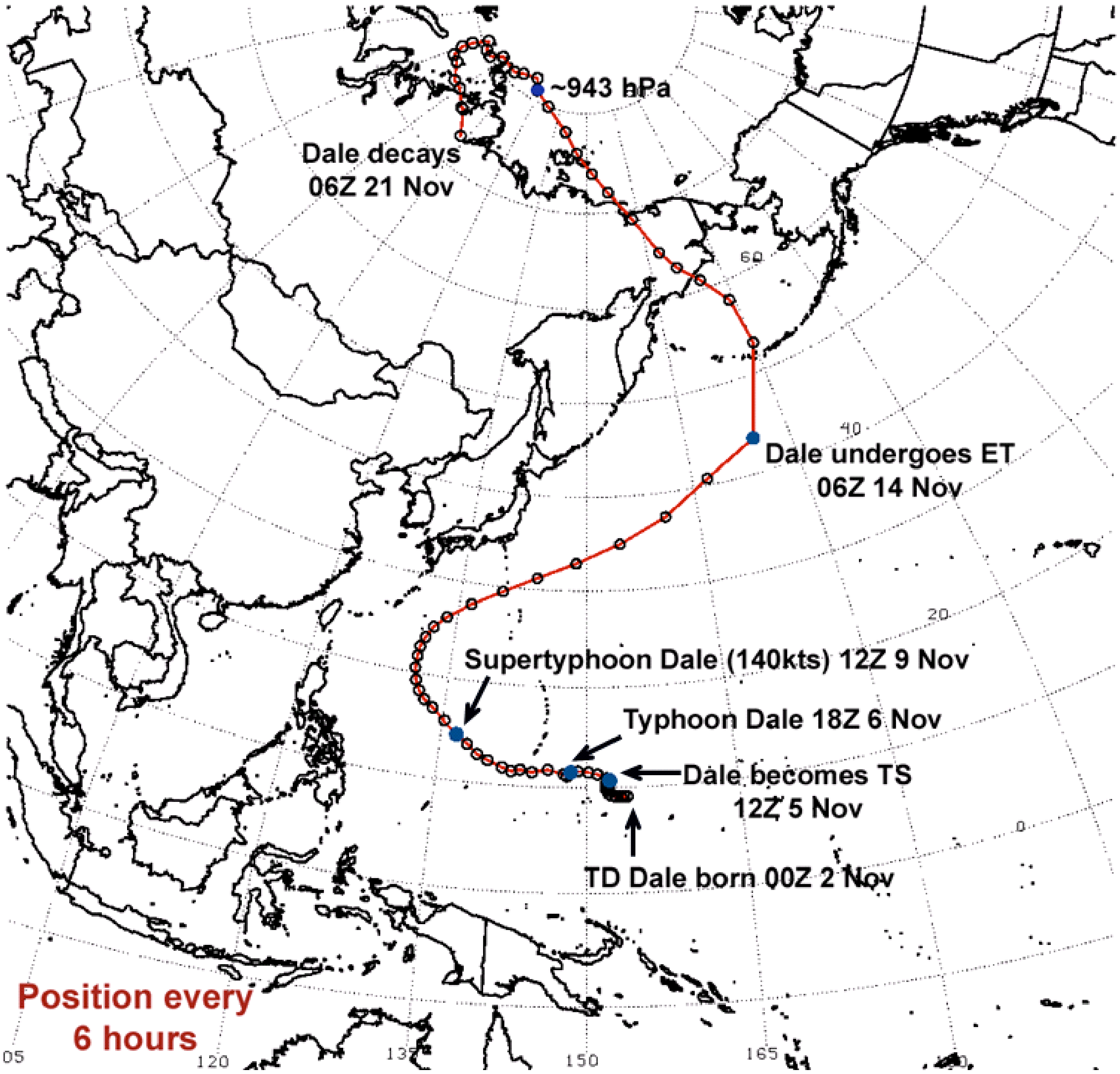

Fig. 1. The track of STY Dale (1996) before and after extratropical transition. Each dot represents the location of Dale every six hours.

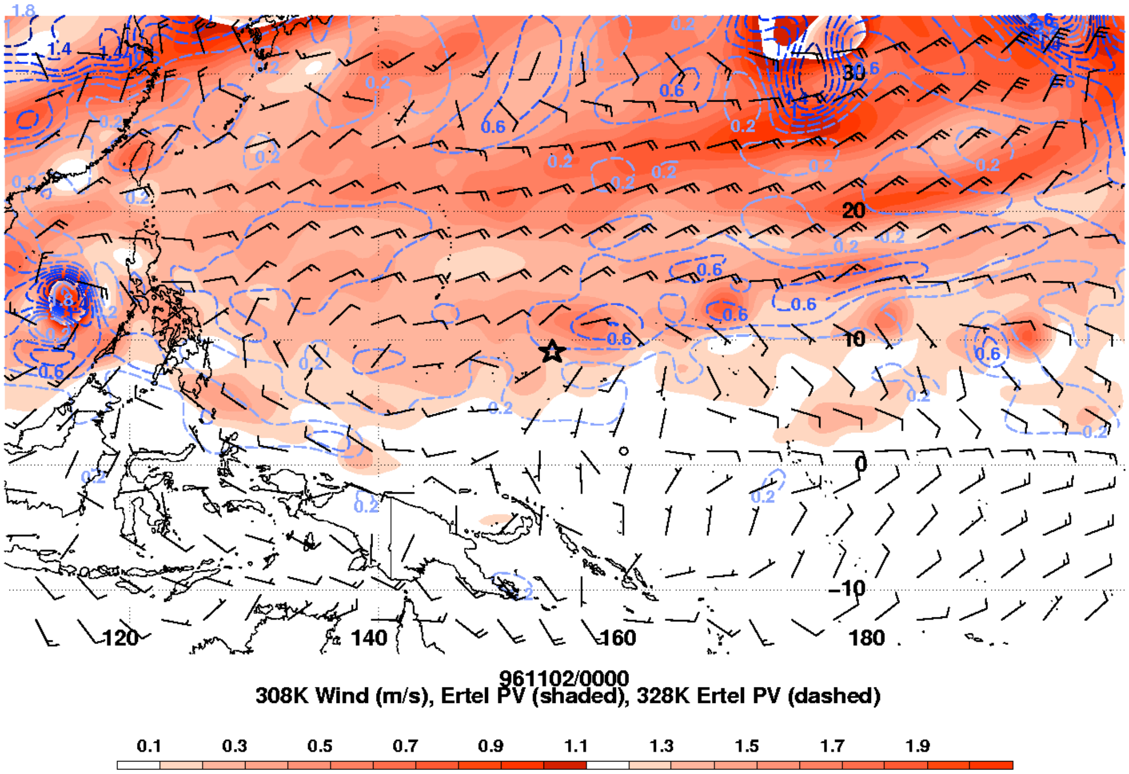

Fig. 2. Ertel PV on the 328K _-surface (PVU, blue dashed) and 308K _-surface (PVU, red shaded ≥ 0.1 PVU), and wind (ms^{-1}) on the 308K _-surface at 00 UTC 2 November.

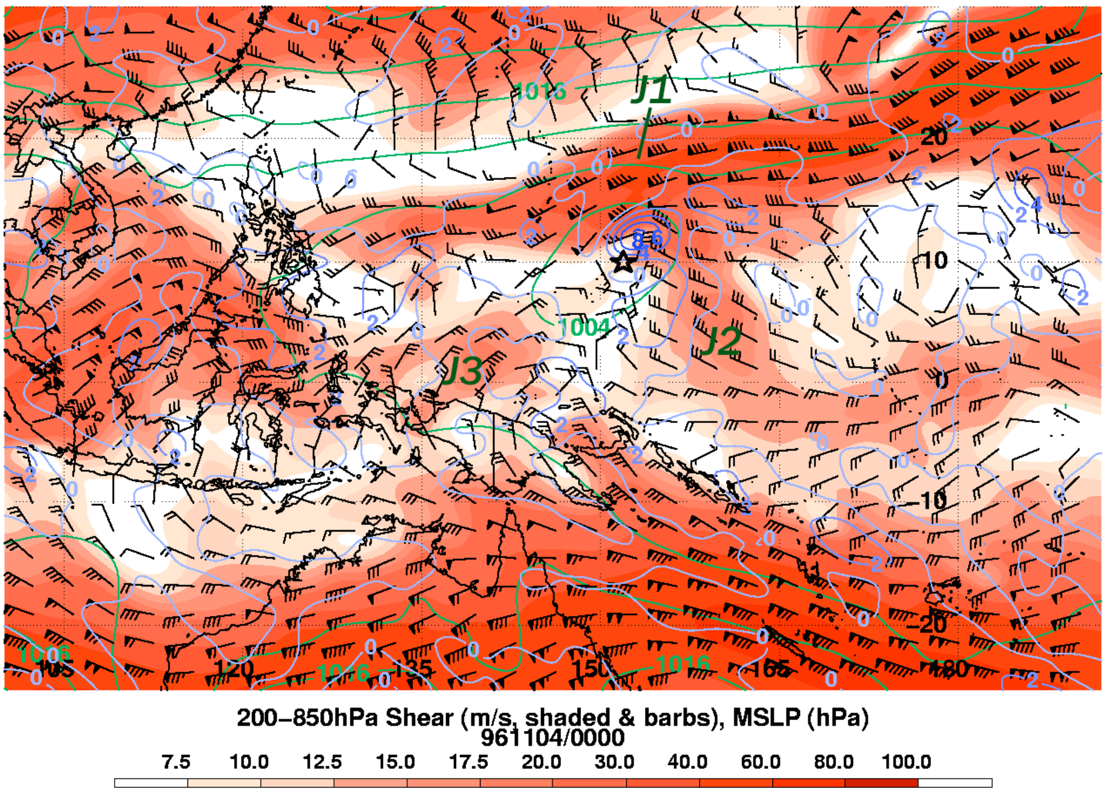

Fig. 3. 200-850 hPa shear wind barbs (ms^{-1}) and magnitude (red shaded), 200 hPa divergence (blue contours, x 10^{-5}) and sea-level pressure (green contours). The star denotes the location where the TD that becomes Dale forms at 00 UTC 2 November 1996 and the location of TD Dale thereafter.

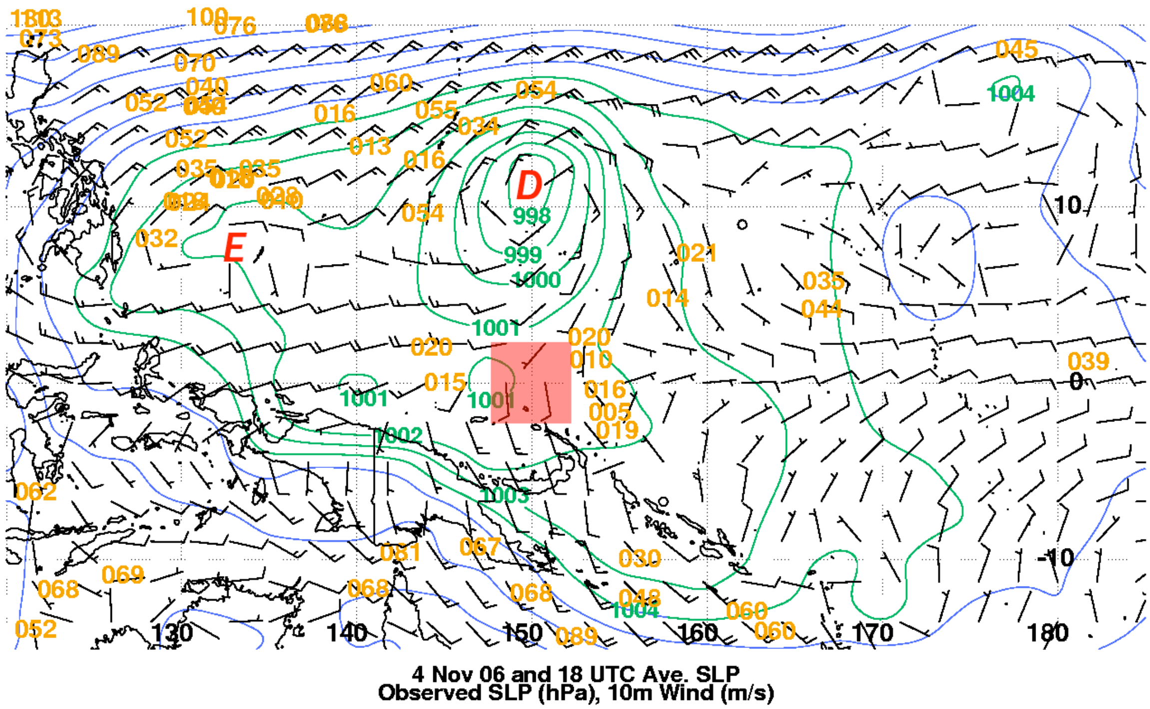

Fig. 4. Sea-level pressure averaged for 06 and 18 UTC 4 November (contoured every 1 hPa, green ≤ 1004 hPa), ship observations for both 06 and 18 UTC 4 November (gold), and 10 m wind for 06 UTC 4 November. The red shading covers the box bounded by 2°S, 2°N, 148°E and 152°E.

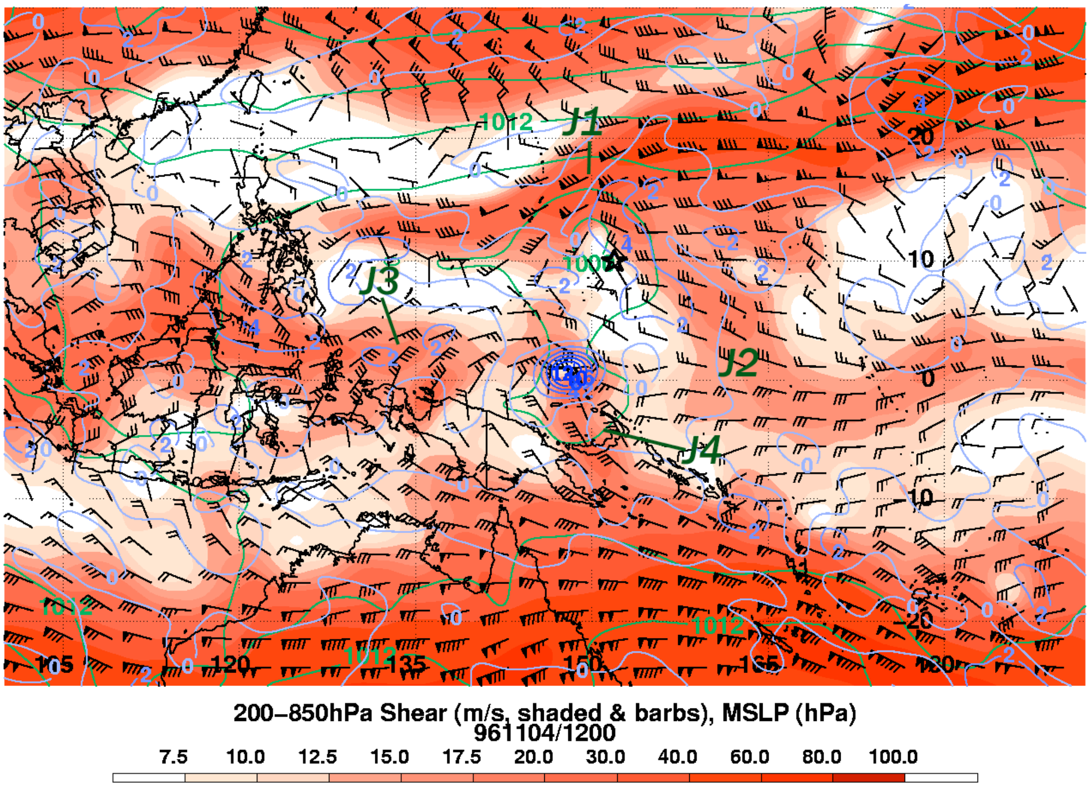

Fig. 5. As in Figure 3, but for 12 UTC 4 November.

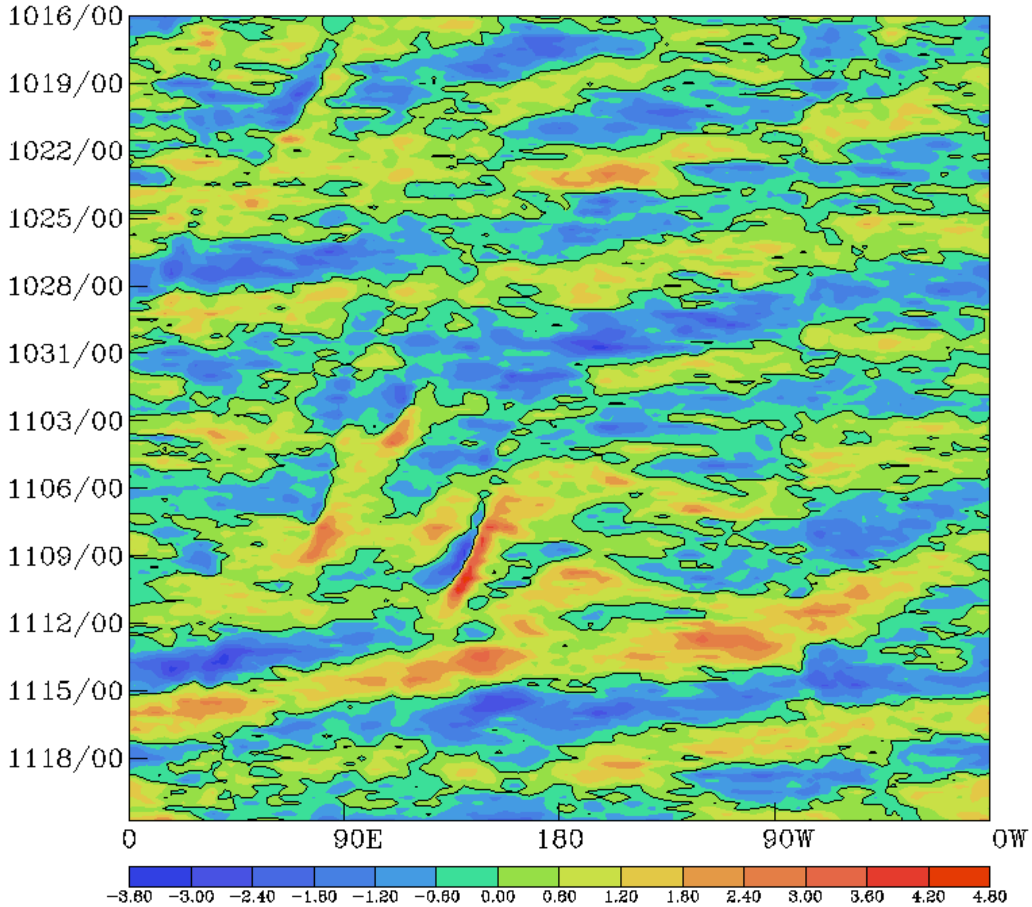

Fig. 6. A Hövmöller diagram of 24-hour sea level pressure tendency averaged between 20ºS and 20ºN.

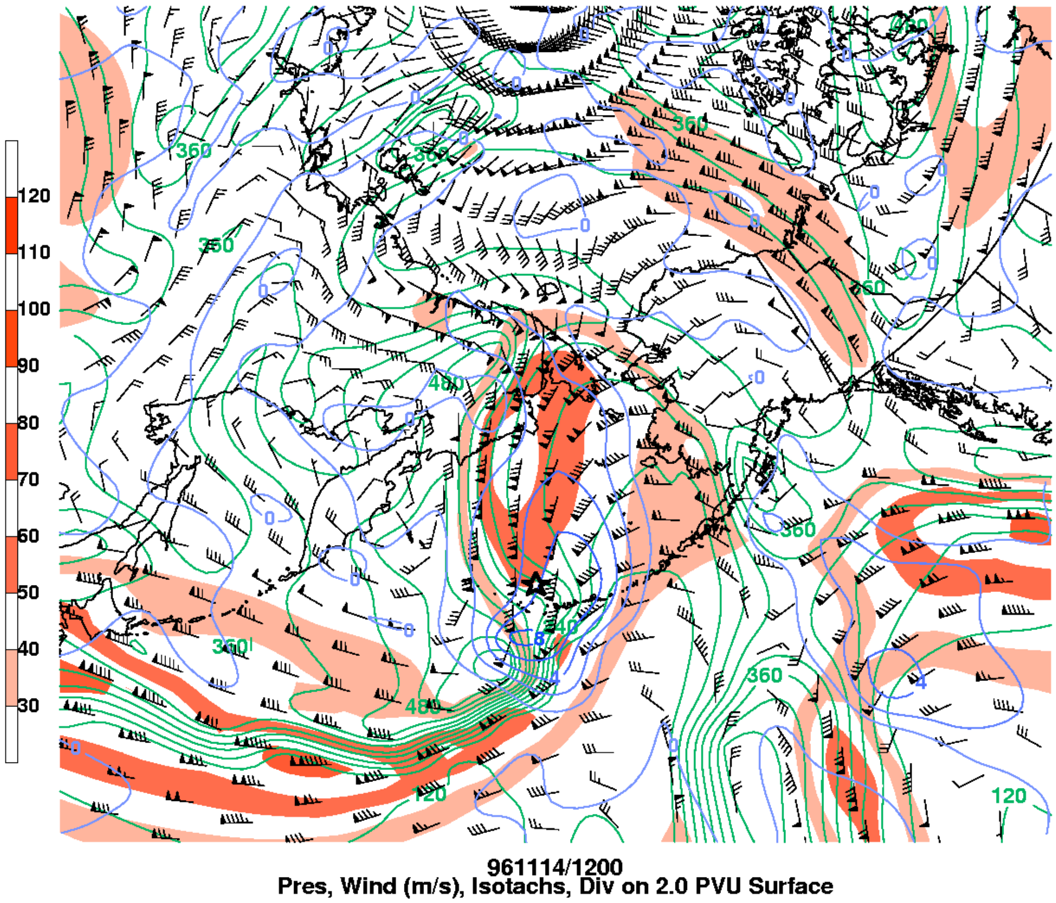

Fig. 7. Pressure (green contours, every 40 hPa), isotachs (shaded, every 10 m s^{-1} starting at 30 m s^{-1}), wind barbs (m s^{-1}), and divergence (blue contours, x 10^{-5} s^{-1}, starting at 0 s^{-1}) on the dynamic tropopause (PVU = 2.0) at 12 UTC 14 November. The black star indicates the location of Dale.

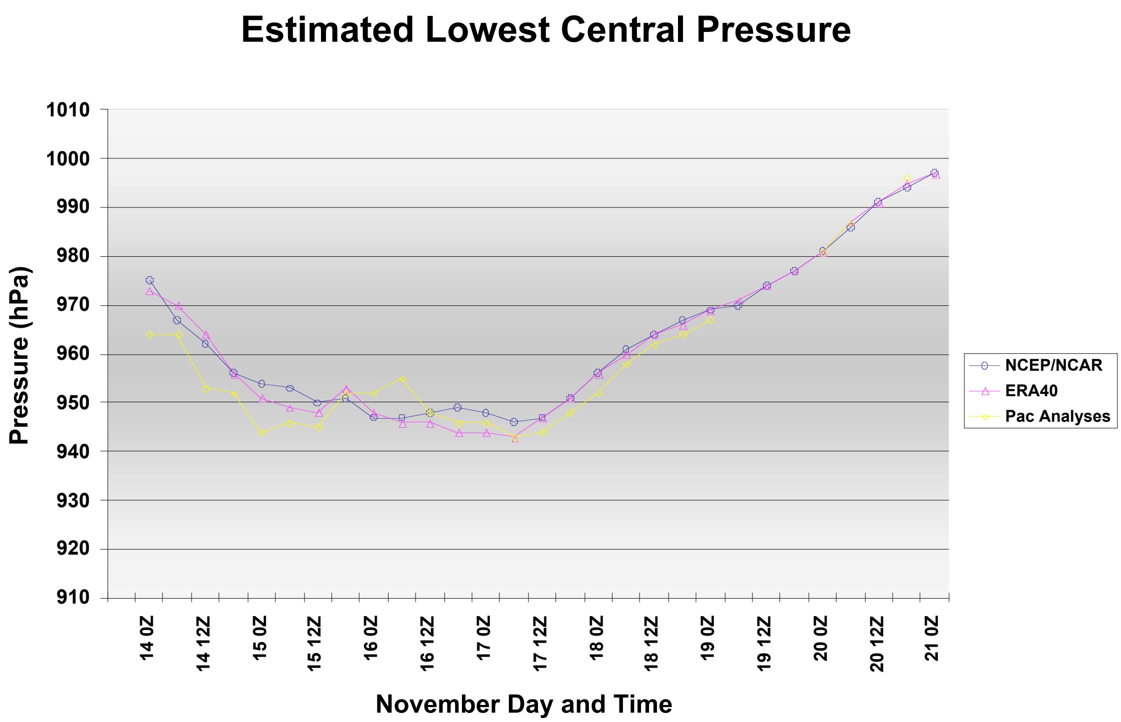

Fig. 8. Time series of Dale's minimum sea level pressure as analyzed by the NCEP/NCAR Reanalysis, ERA-40 reanalysis, and operational human analyses.

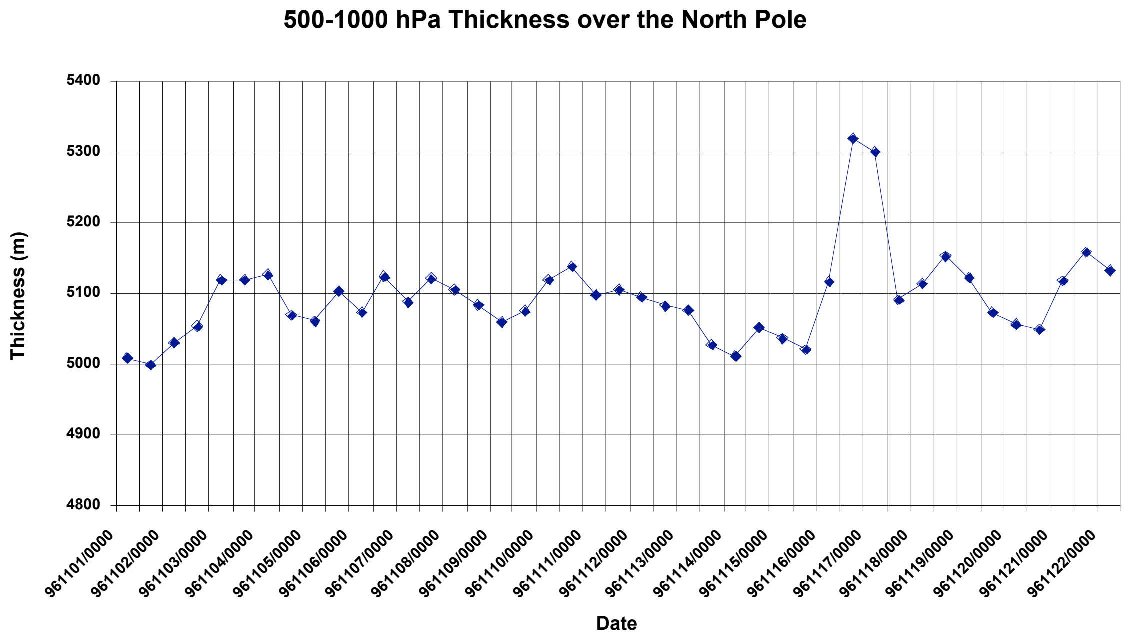

Fig. 9. Time series of 500-1000 hPa thickness (m) over the North Pole.