Examining Tropospheric Precursors to the October 2016 Stratospheric Weak Vortex Event from an Ensemble Forecast Perspective

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Introduction / Background

- Weak vortex (WV) events occur when there is a warming of the polar stratosphere and an accompanying deceleration of the zonal mean winds at 60ºN at 10-hPa. If the zonal mean zonal wind at 10-hPa and 60ºN reverses direction, it is considered a major sudden stratospheric warming event (SSW).
- WV events often follow periods of anomalously large meridional eddy heat flux, which indicates upward wave activity flux (WAF) from the troposphere to the stratosphere. WAF convergence in the stratosphere will decelerate the stratospheric polar vortex (SPV) (Martius et al. 2009).
- There was a WV event during October–November 2016 following the extratropical transition (ET) of Hurricane Nicole in the North Atlantic and Typhoon Haima in the Pacific. Both ETs led to an increase in upward WAF from the troposphere to the stratosphere.

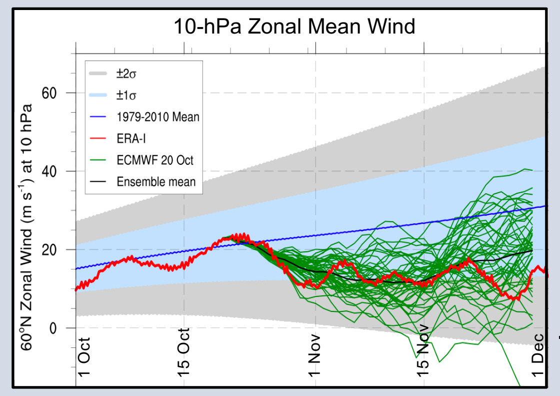

Figure 1. ERA-I (red) and ECMWF ensemble (green) 10-hPa $\bar{u}$ at 60°N

- Tyrrell et al. (2019) argue that upward WAF and the resulting WV event were the result of anomalously cold temperatures over Siberia. They concluded that the climatological and anomalous waves in this region constructively interfered, increasing the amplitude of wavenumber one planetary scale waves, which led to enhanced WAF into the stratosphere and therefore a decelerated SPV.

Methodology

- Reforecast data obtained from WCRP/WWRP S2S Prediction Project database.
- Analyzed ECMWF ensemble initialized 0000 UTC 20 October 2016
  - Calculated zonal mean eddy heat flux at 50-hPa from 25 October–3 November for each of the 51 ensemble members.
  - Composited ensemble members with the five largest (T5) and five smallest (B5) zonal mean eddy heat flux values during this period to evaluate:
    - Sources of variability of upward WAF between ensemble members
    - Impacts of forecast evolution on ET of Typhoon Haima
    - Impacts that differences in the ET play in the evolution of the SPV
- ERA-Interim data used for verification.
- Zonal mean momentum budget used to quantify deceleration of the SPV.
  - Acceleration of Zonal mean wind
  - Momentum flux term
  - Vertical derivative of heat flux scaled by static stability
  - Vertical derivative of static stability scaled by heat flux

$$\frac{\partial u}{\partial t} \approx \frac{\partial\left(\overline{v'u'}\right)}{\partial y} + f_0 \left[\frac{\frac{\partial\left(\overline{v'T'}\right)}{\partial z}\frac{\partial\bar{\theta}}{\partial z} - \frac{\partial^2\bar{\theta}}{\partial z^2}\overline{v'T'}}{\left(\frac{\partial\bar{\theta}}{\partial z}\right)^2} \right]$$

Results

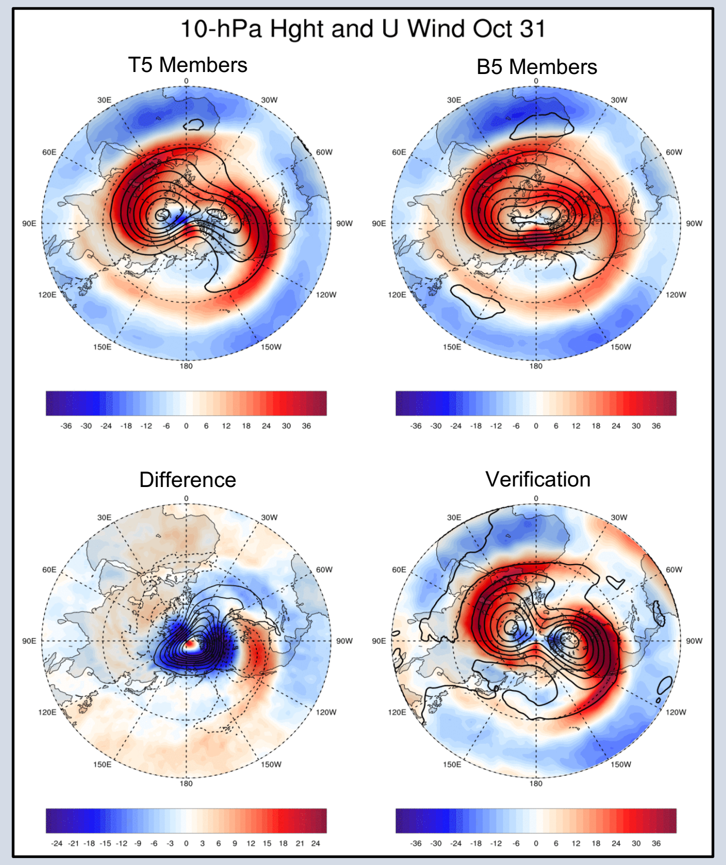

Figure 2. 10-hPa winds (shaded) and geopotential heights (contoured)

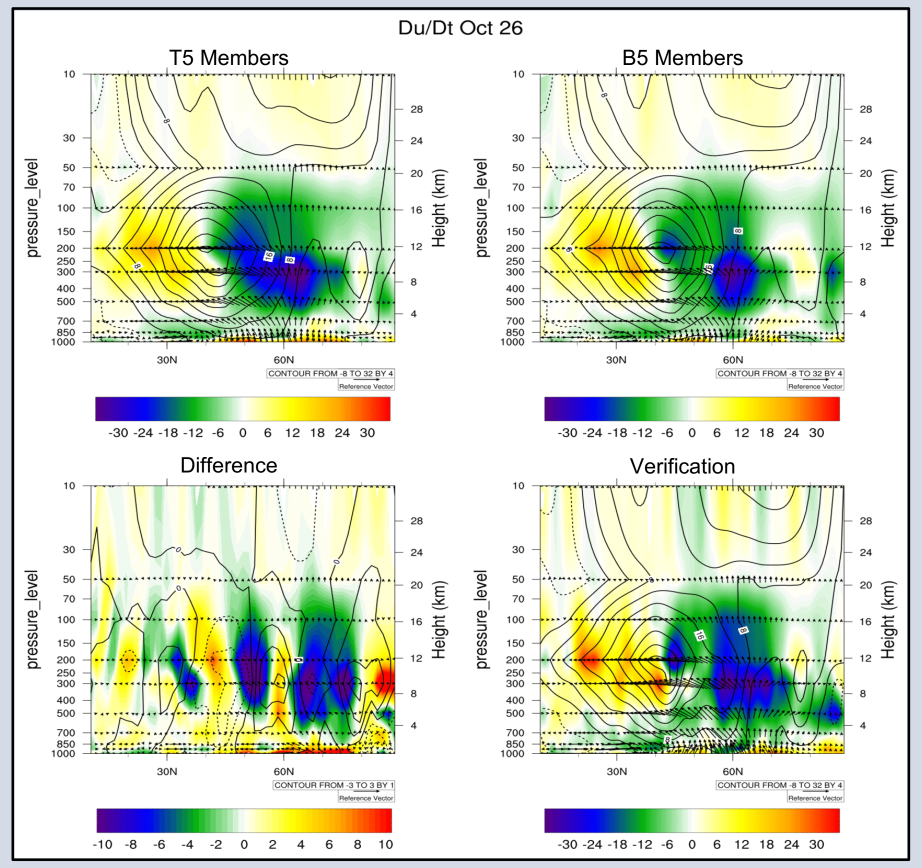

Figure 3. Acceleration of the wind (shaded), zonal mean winds (contoured) and EP flux vectors

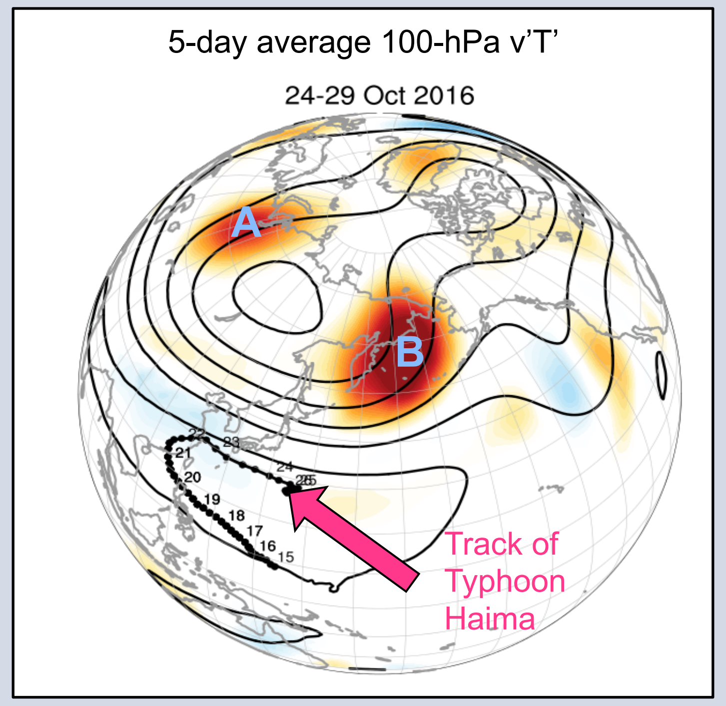

Figure 4. 5-day average heat flux (shaded) and 100-hPa geopotential heights (contoured)

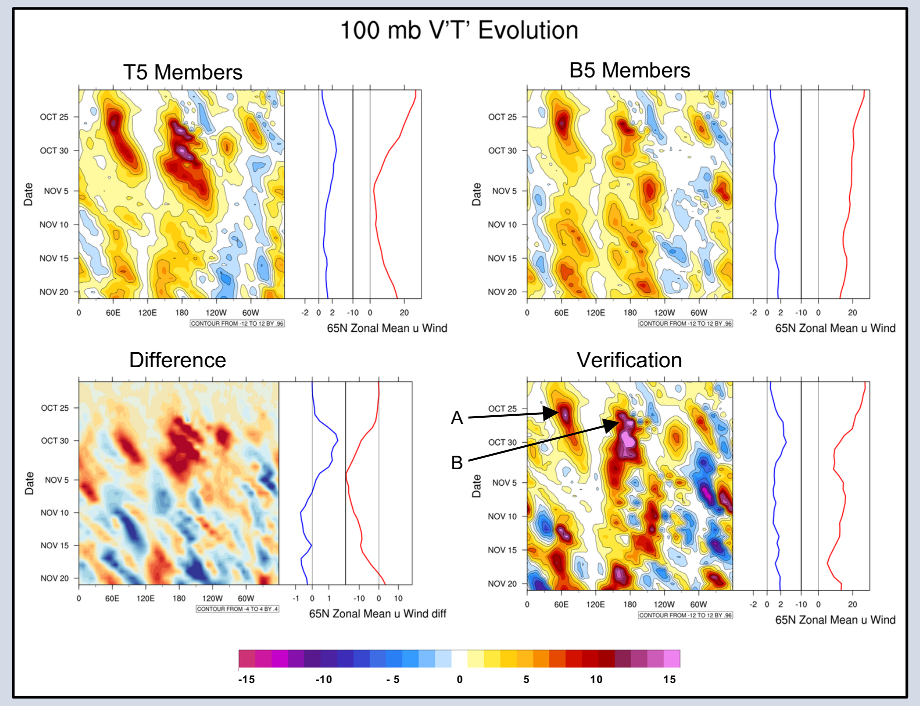

Figure 5. Hovmöllers of heat flux (shaded), zonal mean v'T' (blue line) and 10-hpa $\bar{u}$ at 65°N (red line)

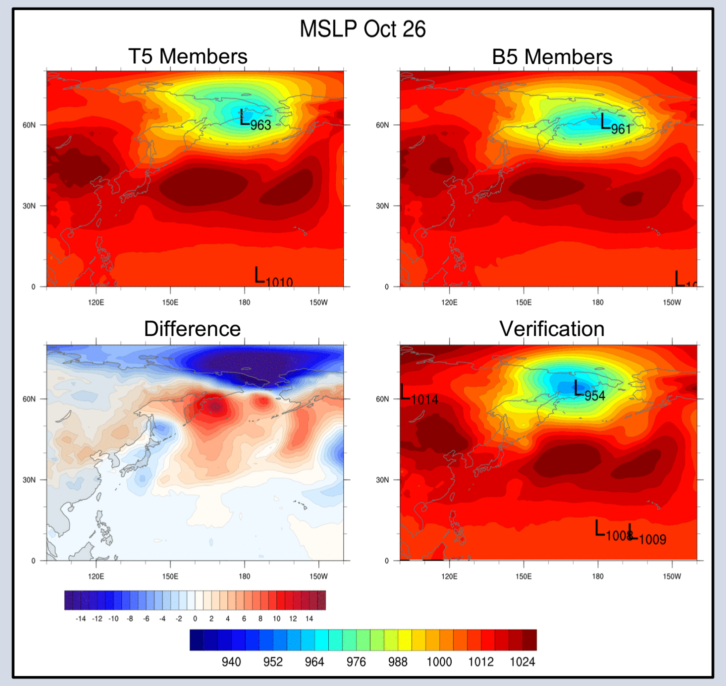

Figure 6. Mean sea level pressure

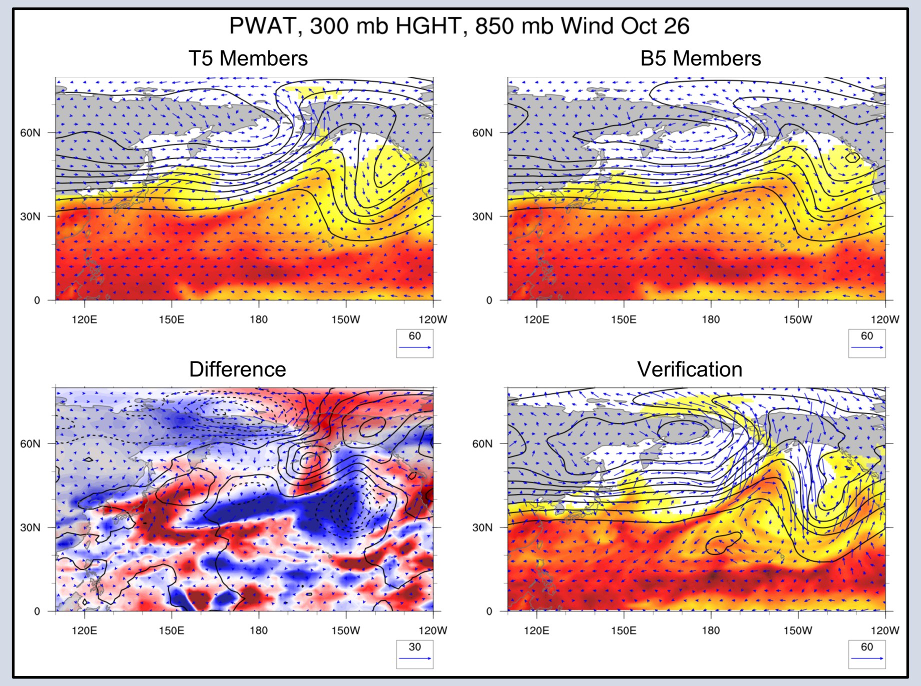

Figure 7. 300-hPa geopotential height (contour), 850-hPa winds (blue vectors), and PWAT (shaded)

Conclusions

- Upward WAF between 25 October–3 November was primarily due to the ET of Typhoon Haima. T5 members show increased heat flux in the North Pacific associated with both the ET event and subsequent cyclogenesis in this region.
- Several synoptic-scale features contributed to the differences in heat flux magnitude:
  - The ET occurred further north in T5 members, leading to the center of low pressure being located further north.
  - Increased ridging downstream of the mid-latitude cyclone following ET in T5 members versus B5 members.
  - Increased moisture flux into the high latitudes in T5 versus B5 members, which contributed to ridge building via diabatic processes.
- T5 heat flux ensemble members have, on average, a roughly 10 ms^{-1} greater deceleration of the SPV than B5 heat flux members.
- Increased upward WAF following the ET of Haima and the resulting differences in forecast evolution between T5 and B5 members suggest that while large-scale conditions were favorable for a decelerated SPV (Tyrrell et al. 2019), this synoptic-scale event played a major role in forcing this weak vortex event.
- Model simulations with the same large-scale conditions, but with Typhoon Haima removed could be used to test this conclusion.

References

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