Solar Wind Effect on Planetary Wave Propagation and Synoptic-scale Rossby Wave Breaking

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British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

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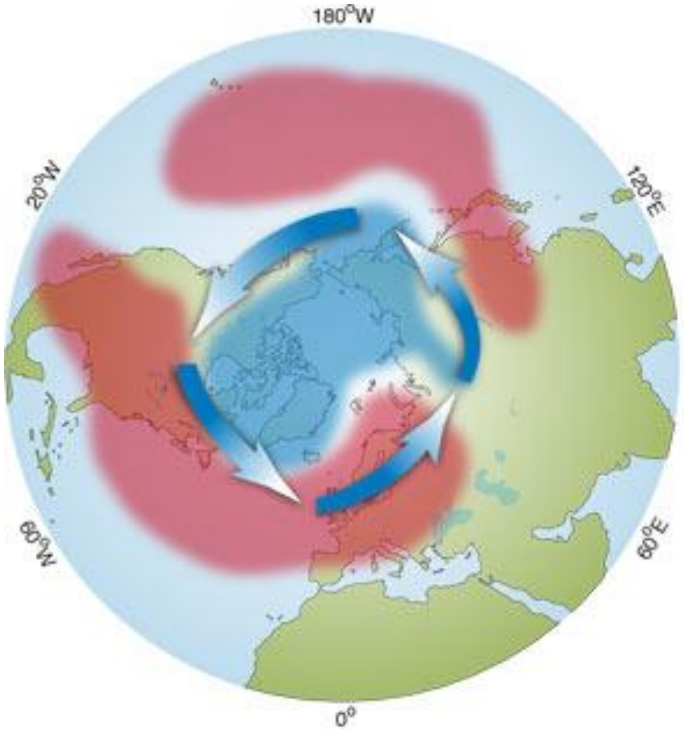
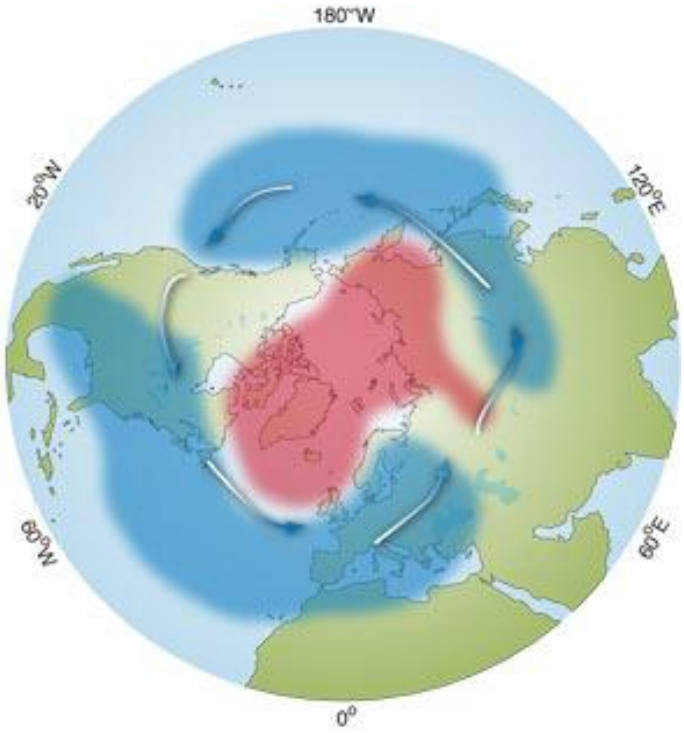
The Northern Annular Mode (NAM)

positive phase of NAM



negative phase of NAM



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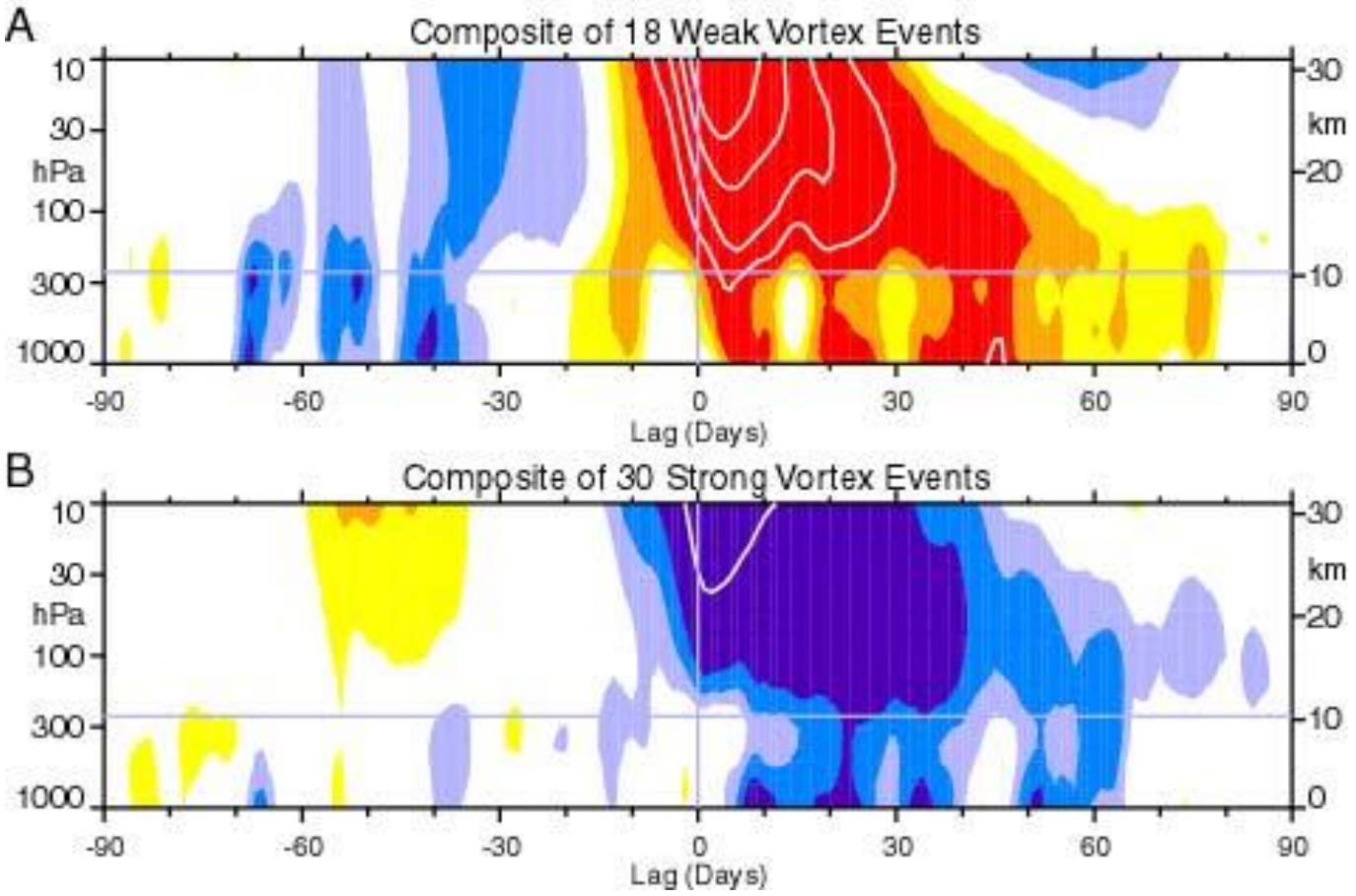
(From Jason Goodman)

Downward Propagation of the NAM

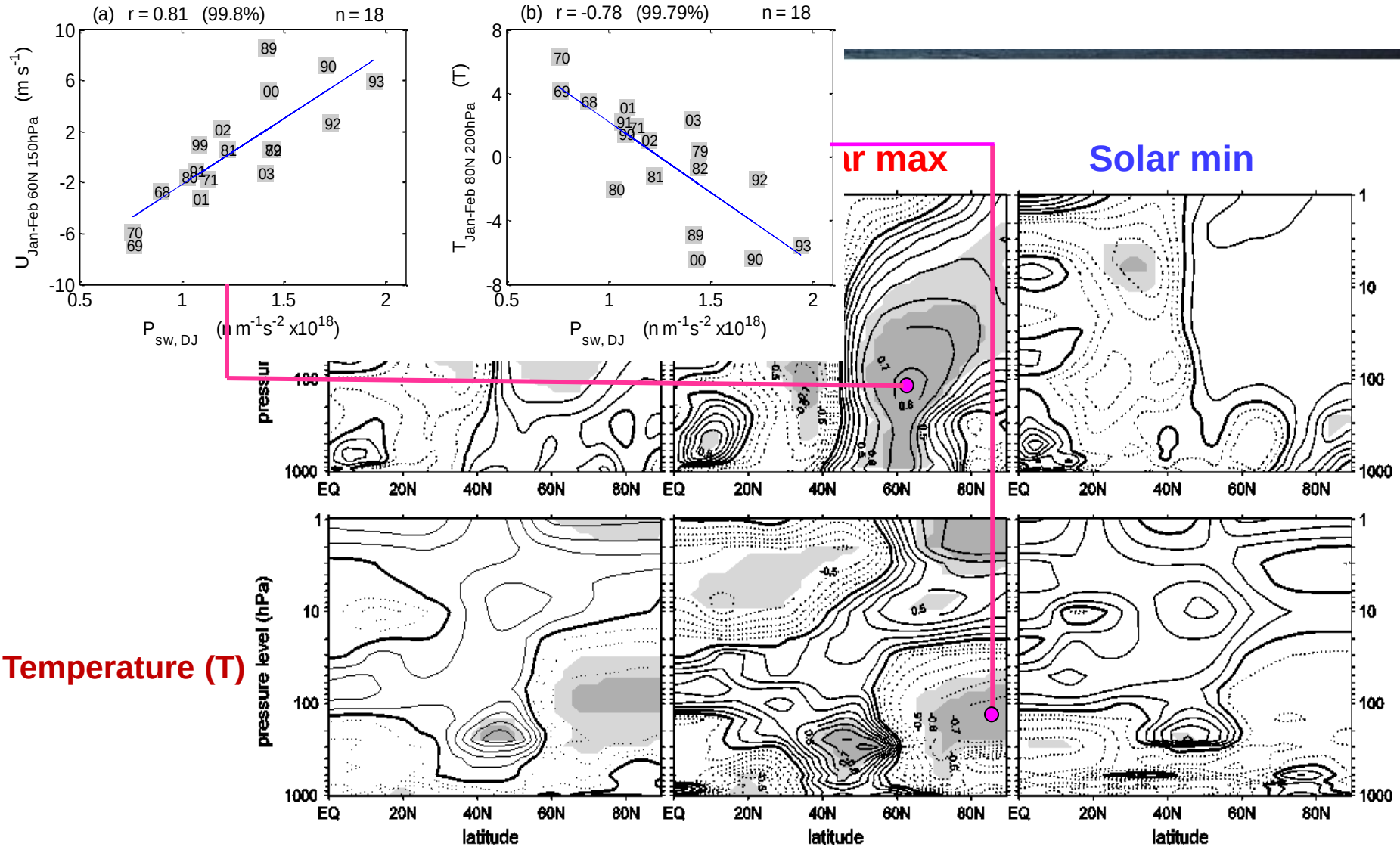
A dynamic phenomenon due to wave mean flow interaction



Baldwin and Dunkerton (2001): Science

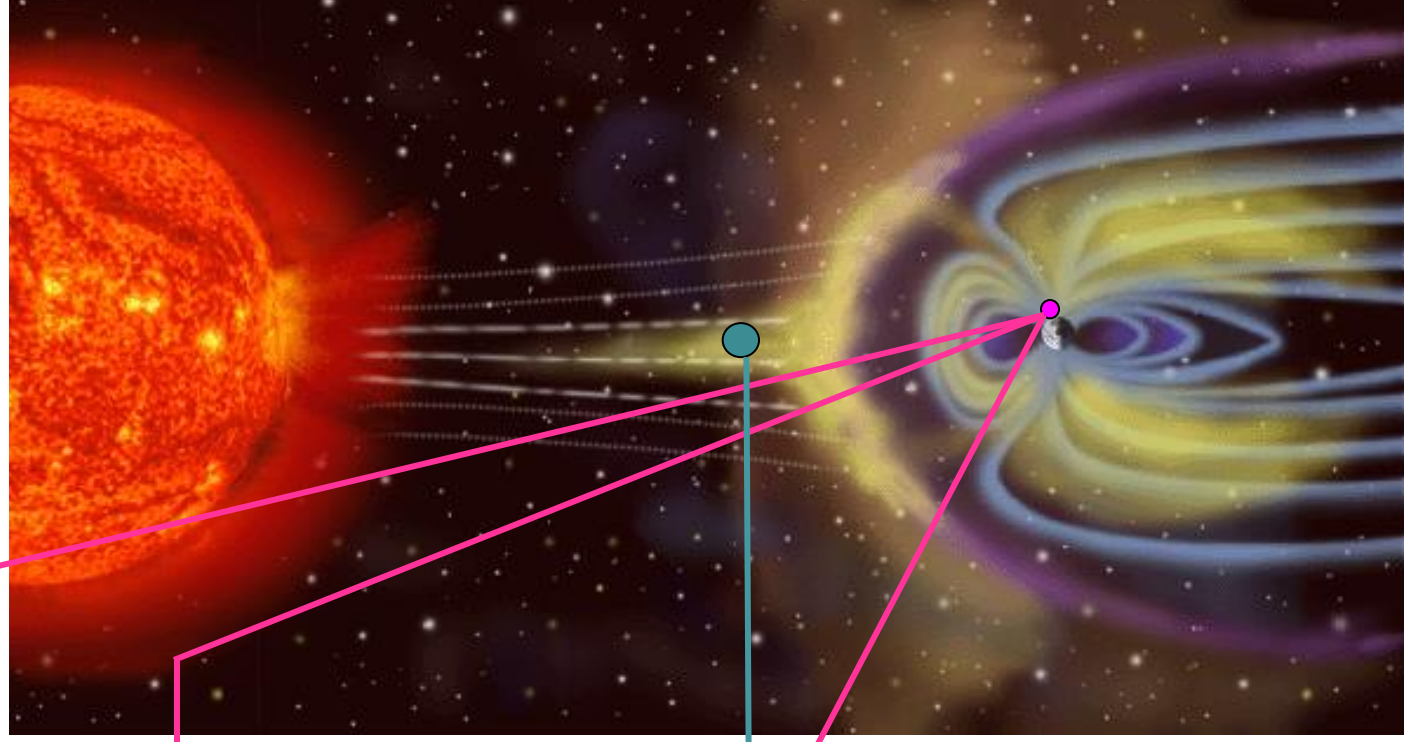
Correlations with zonal-mean zonal wind and temperature

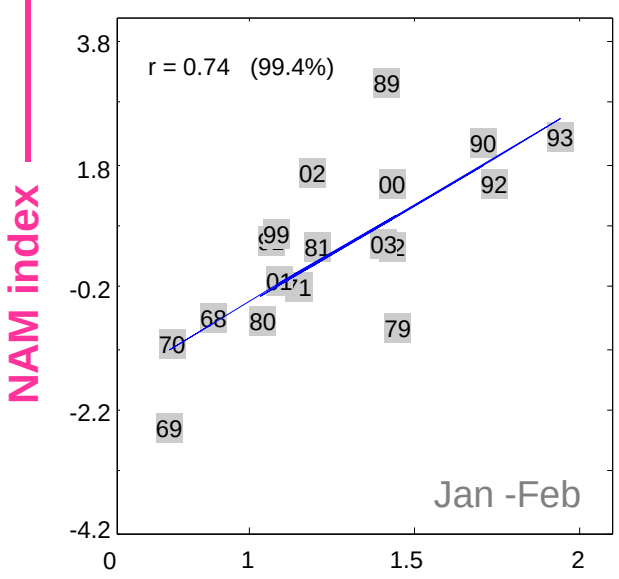
Signals in January-February mean (Lu et al. 2008)

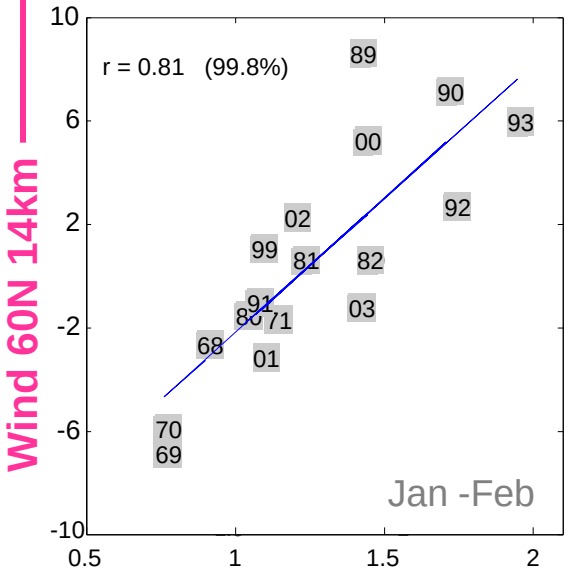


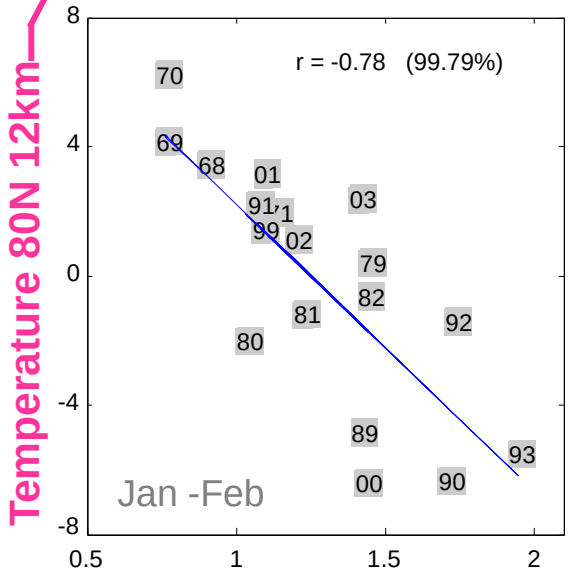
Q: How does the solar wind dynamic pressure link to the NAM and weather?

(Lu et al. 2008)

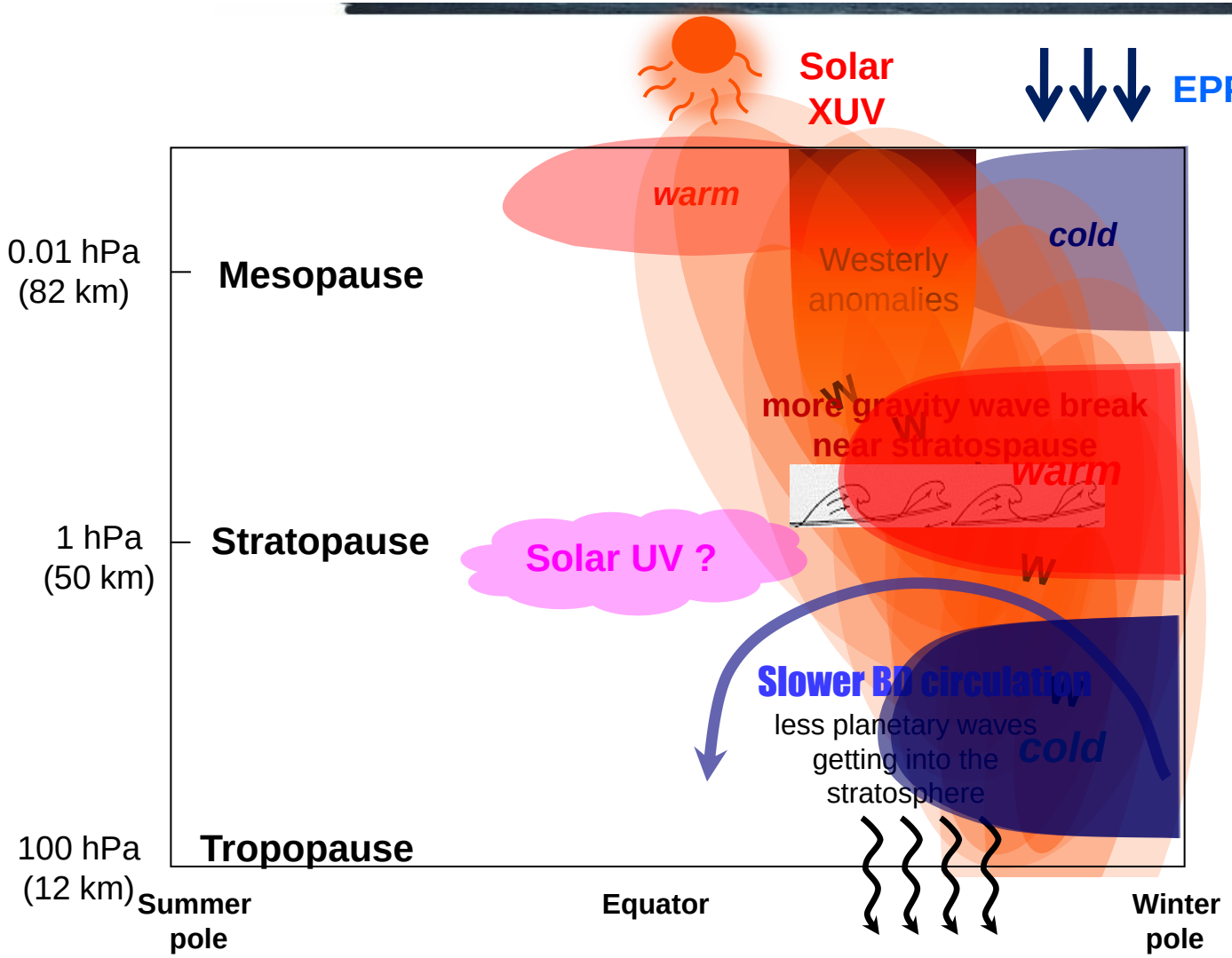








Hypothesis: Dynamical Coupling



The Objectives, Data and Methods

Objectives: **to examine whether or not the solar wind dynamic pressure has a detectable effect on Rossby wave breaking/propagation**

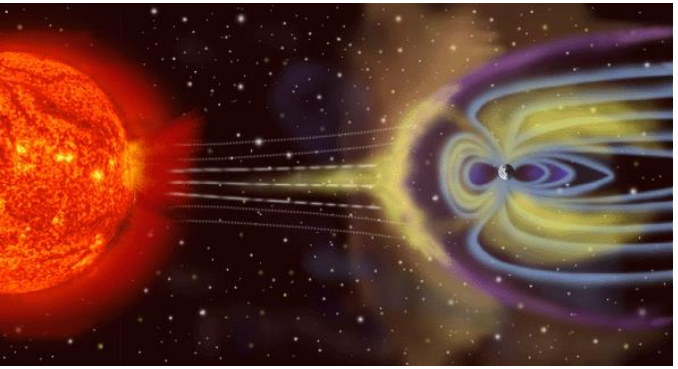
- ✓ effect on wave-mean flow interaction
- ✓ temporal variation -> downward propagation of the signature?
- ✓ insight into the dynamic processes

Data

- ✓ 6-hourly *u*, *T*, and *v* from ERA-40 (1958-2001) + ERA-Interim (2002-2009)

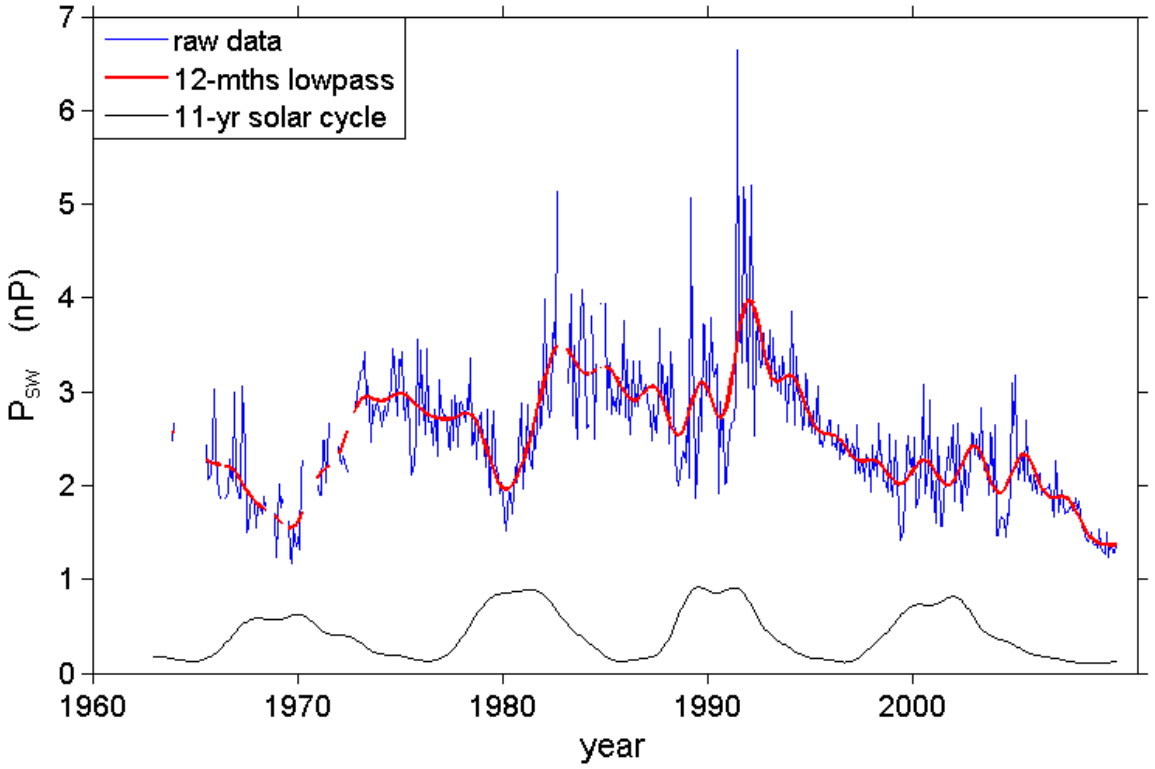
Methods

- ✓ moving regression between atmospheric variables and solar wind dynamic pressure
- ✓ the transformed Eulerian-mean equations & Eliassen-Palm (EP) fluxes & divergence



Solar wind Dynamic Pressure

- Solar wind and solar F10.7 radio flux are not well correlated
- 12-mths lowpass filtered solar wind dynamic pressure (P_{sw}) is used here
- All the analyses are performed for all data, high solar (HS) and low solar (LS) conditions in order to include the effect of solar UV in the stratosphere

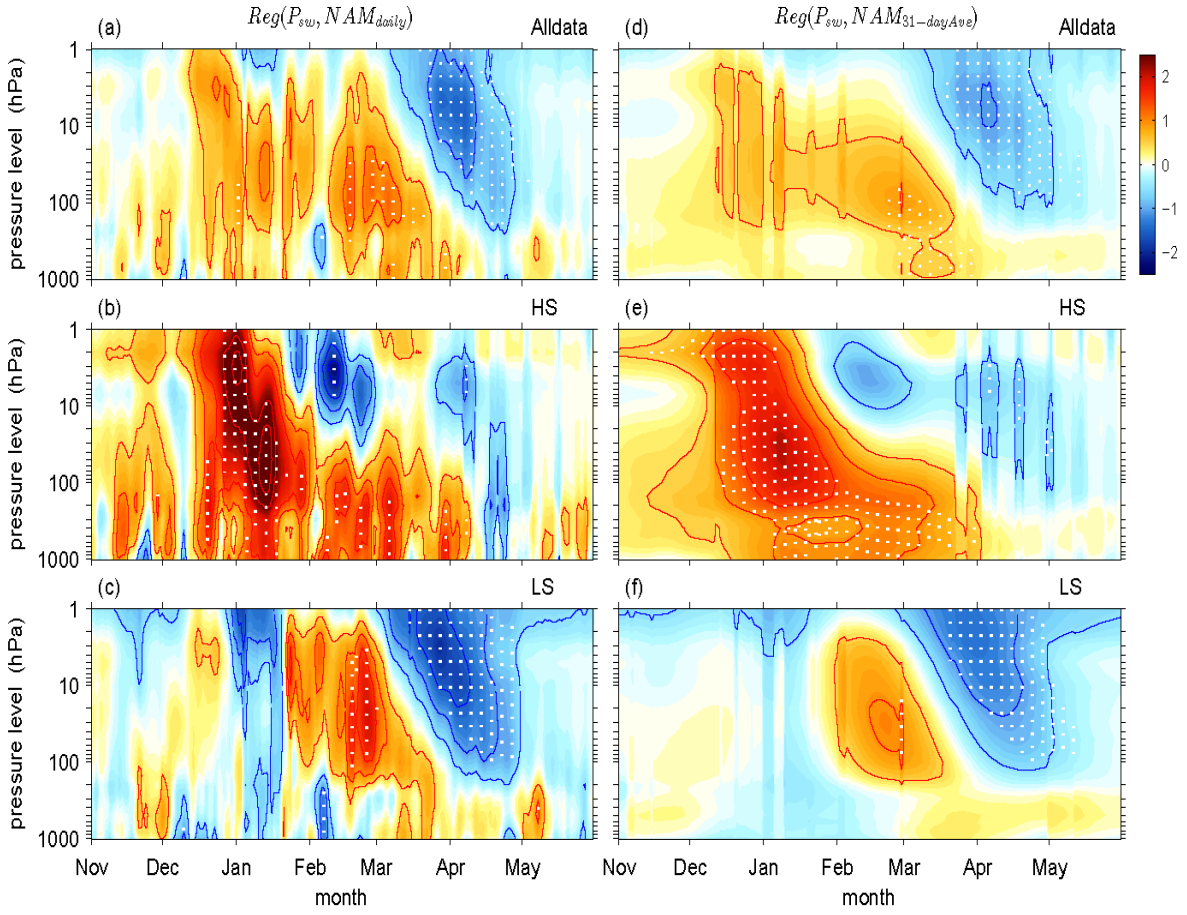


Solar Wind Dynamic Pressure Signal in the NAM

All data

HS

LS



signal propagates from the stratosphere to the troposphere under high solar condition or solar UV is high

earlier & stronger responses under HS than under LS

apparently opposite effect under HS and LS condition

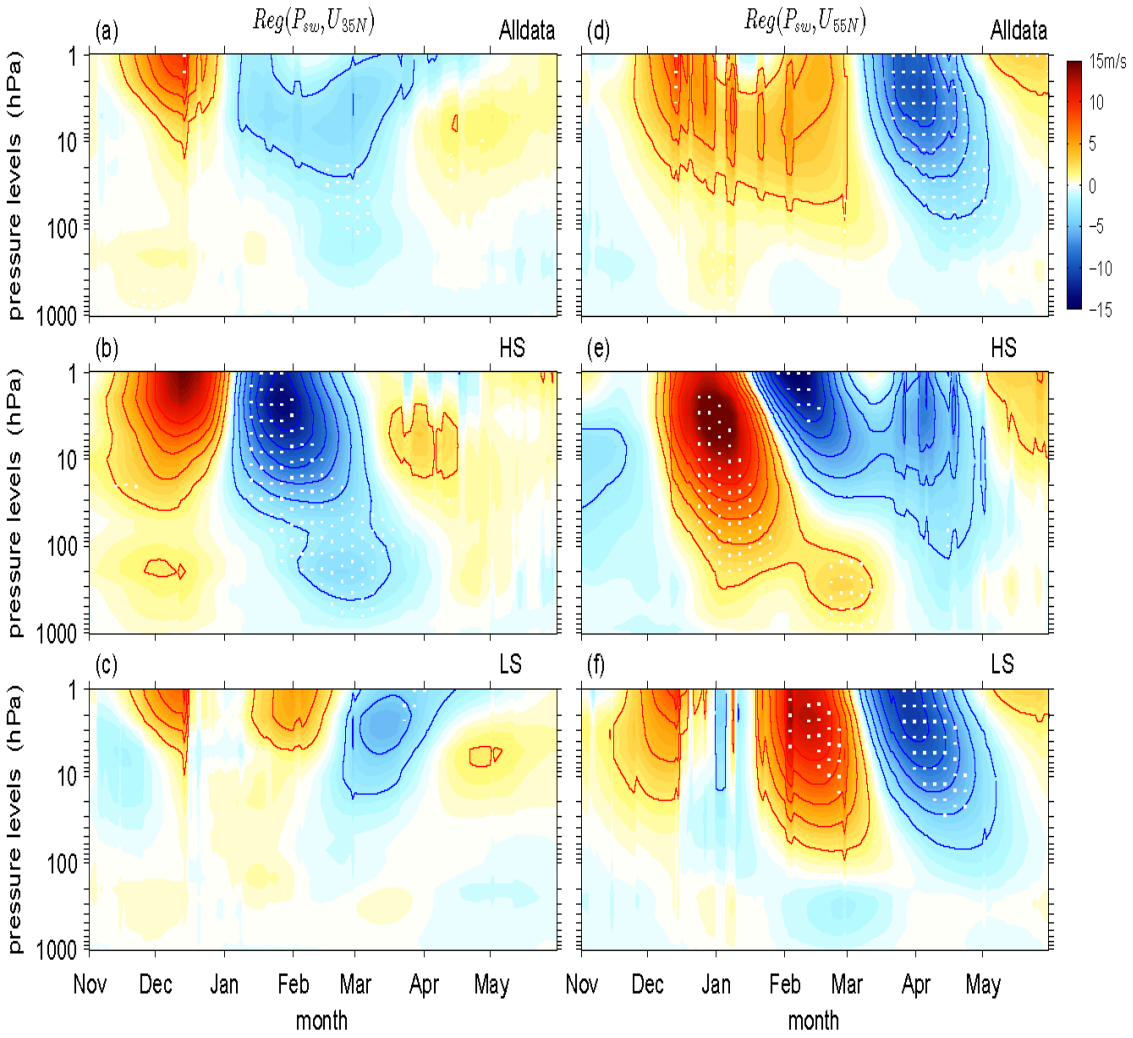
Signal in Zonalmean Zonal Wind

$\overline{u}_{35N}$ $\overline{u}_{60N}$

All data

HS

LS



Westerly anomalies in winter follow by easterly anomalies in spring

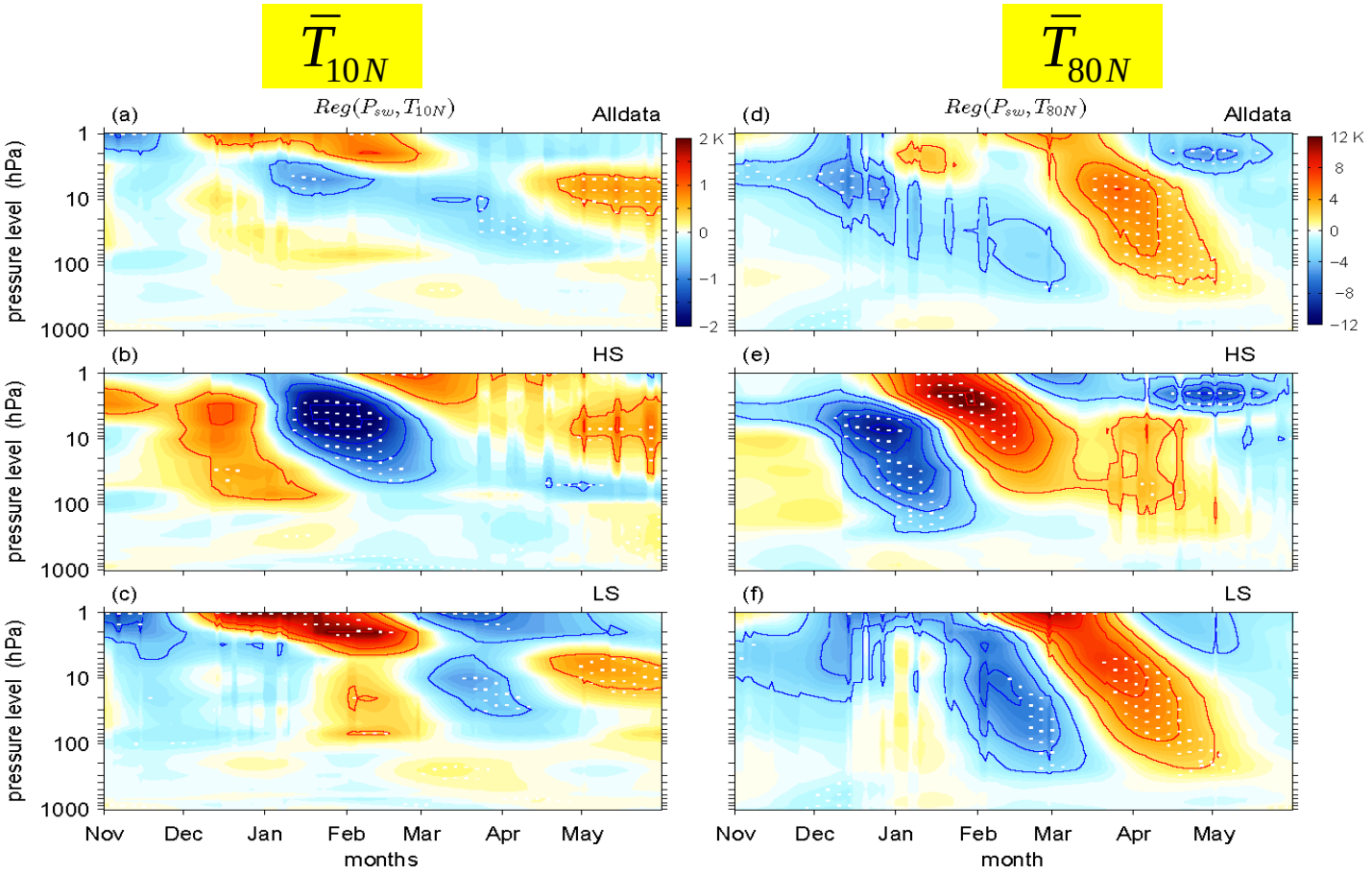
Signal descent from the upper stratosphere to the lower stratosphere

Signal in Zonalmean Temperature

All data

HS

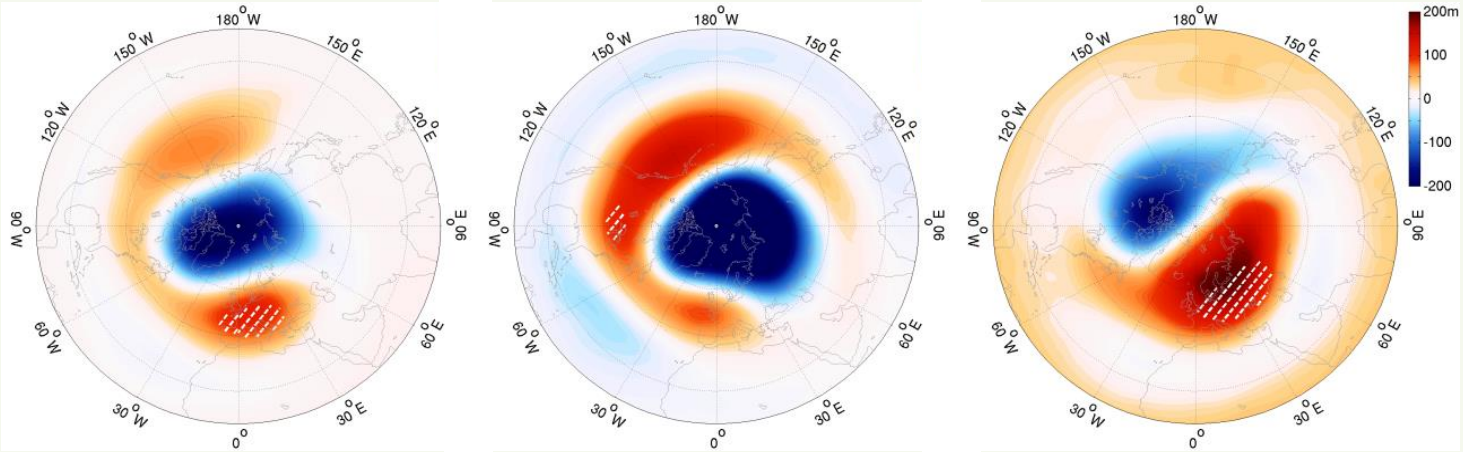
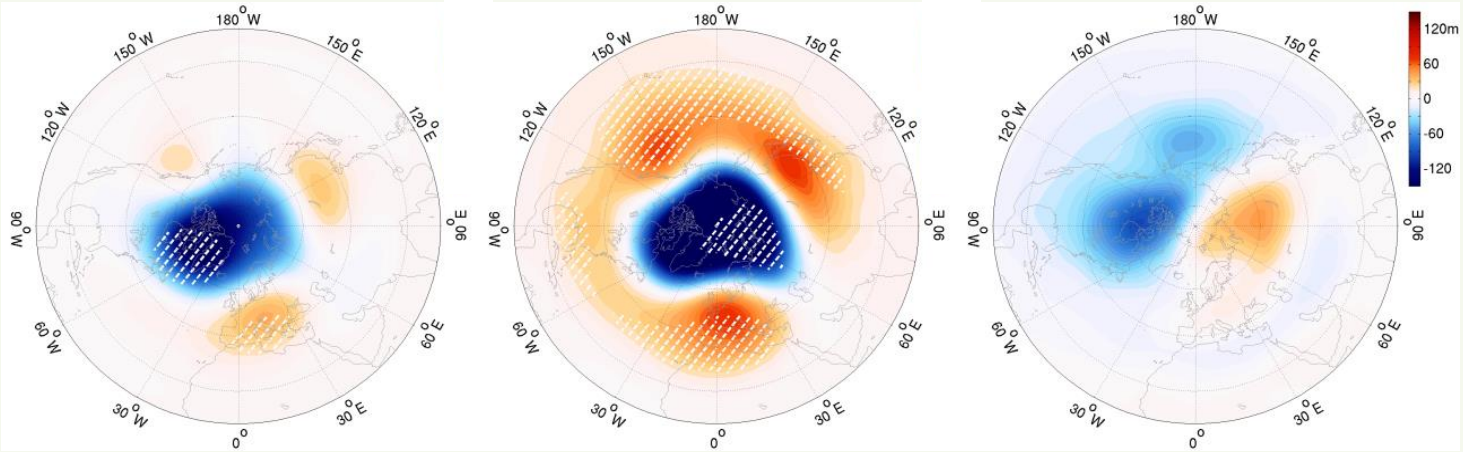
LS



- Opposite responses at high and low latitudes in the upper to mid- stratosphere
- signal again descends from the upper stratosphere to the upper troposphere
- Signal occurs earlier under HS than under LS

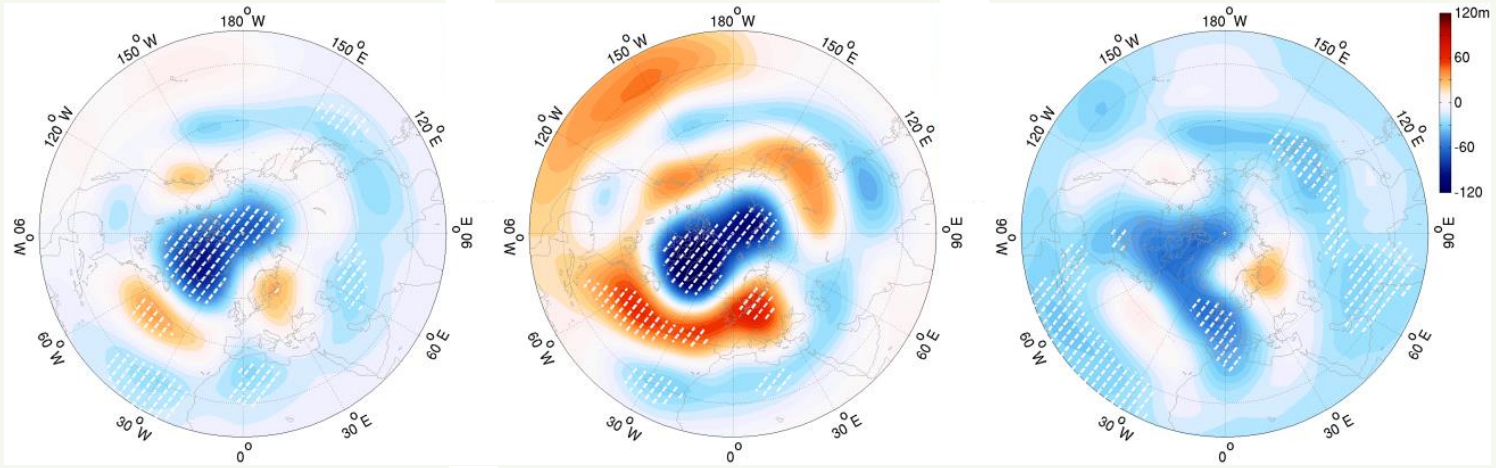
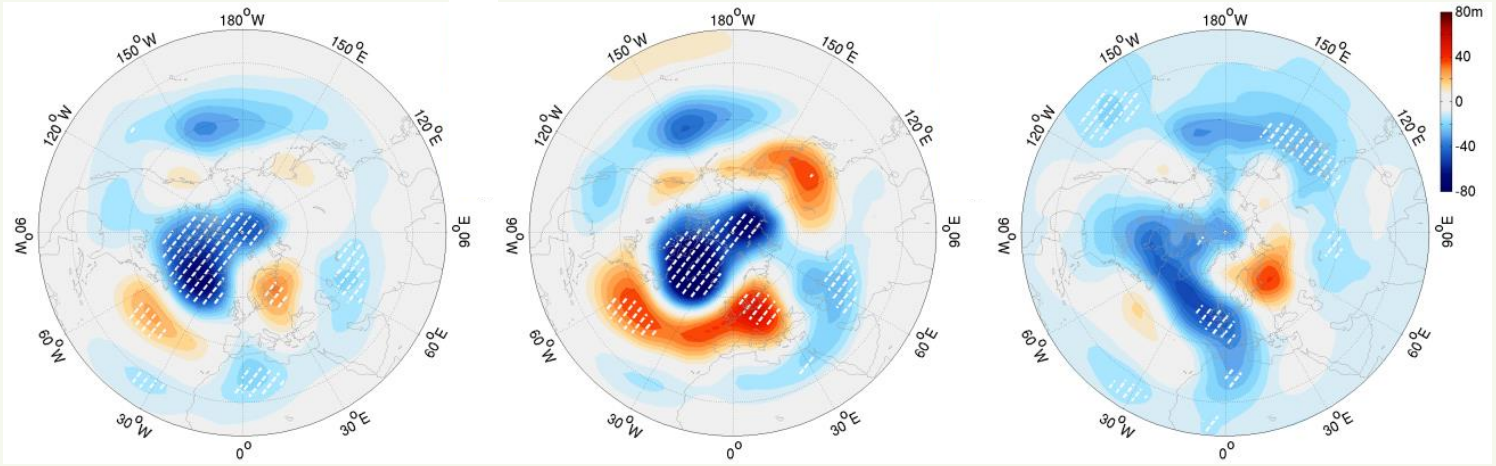
Composite differences of Dec-Jan mean geo-potential height

Stratosphere

	Alldata	HS	LS
10hPa			
50hPa			

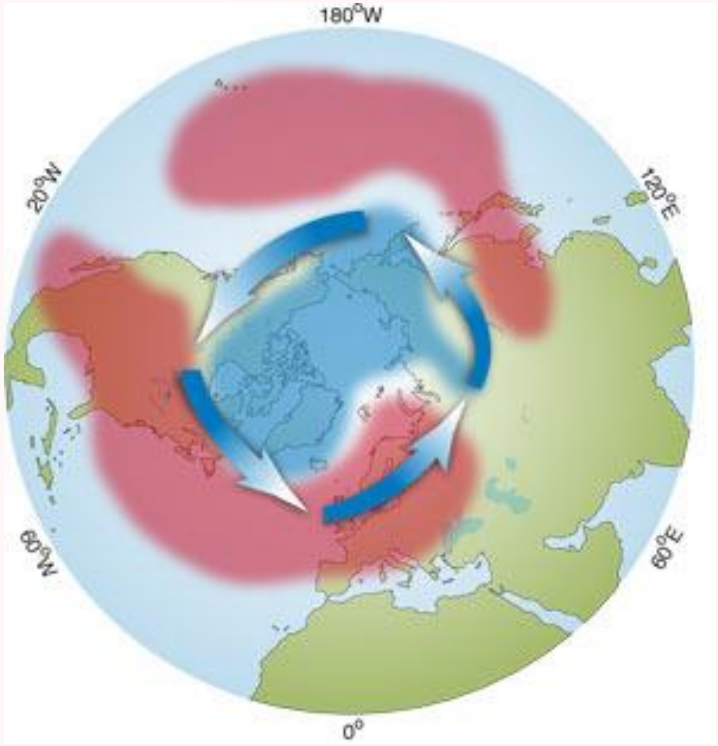
Composite differences of Dec-Jan mean geo-potential height

Troposphere

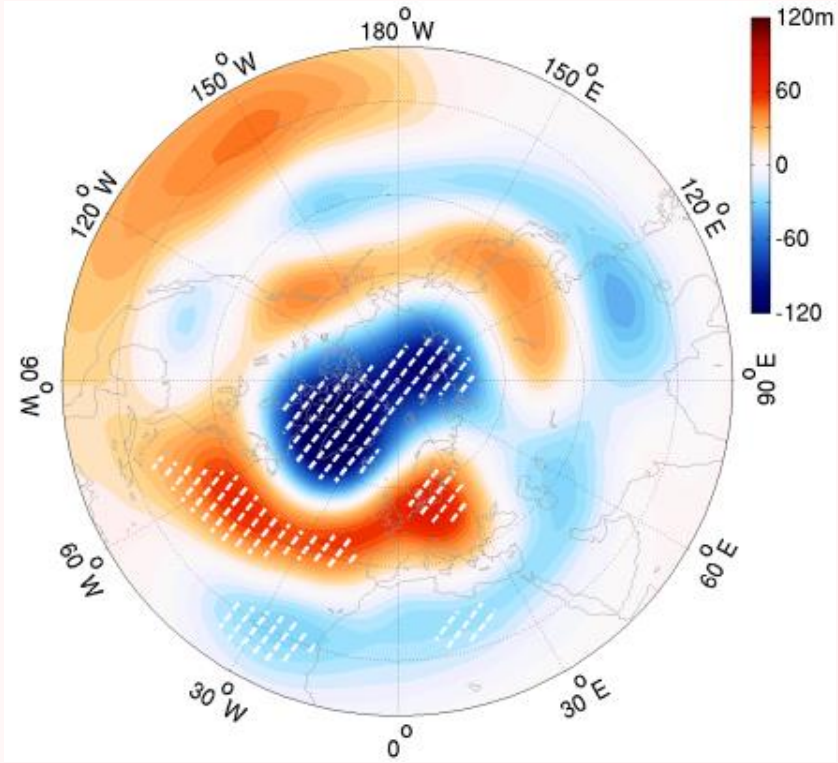
	Alldata	HS	LS
200hPa			
500hPa			

A Comparison between the NAM Pattern and that of Solar wind Dynamic Pressure Signature

positive phase of NAM



Psw signal under HS



Mechanism From a Transformed Eulerian-Mean Viewpoint

$$\frac{\partial \bar{u}}{\partial t} = f\bar{v}^{*} + \frac{\nabla \cdot \mathbf{F}}{\rho_0 a \cos\phi}$$

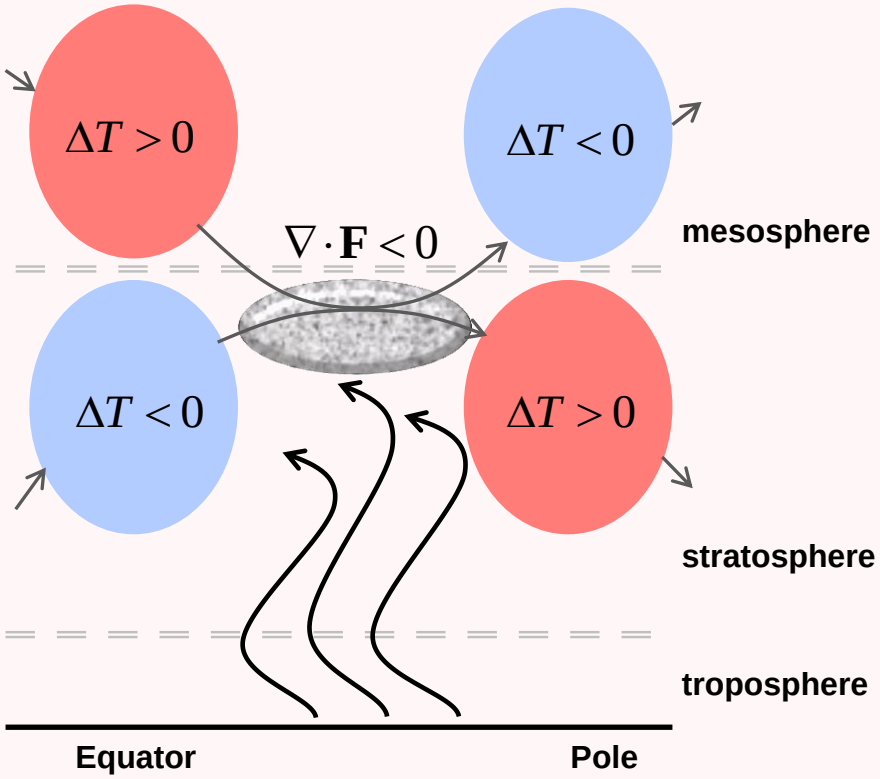
$f\bar{v}^{*}$ — Residual mean meridional circulation

$\dfrac{\nabla \cdot \mathbf{F}}{\rho_0 a \cos\phi}$ — wave forcing

$$\nabla \cdot \mathbf{F} = (a\cos\phi)^{-1} \frac{\partial}{\partial \phi}\left(F^{(\phi)} \cos\phi\right) + \frac{\partial F^{(z)}}{\partial z}$$

Northward mumentum flux term

Upward heat flux term



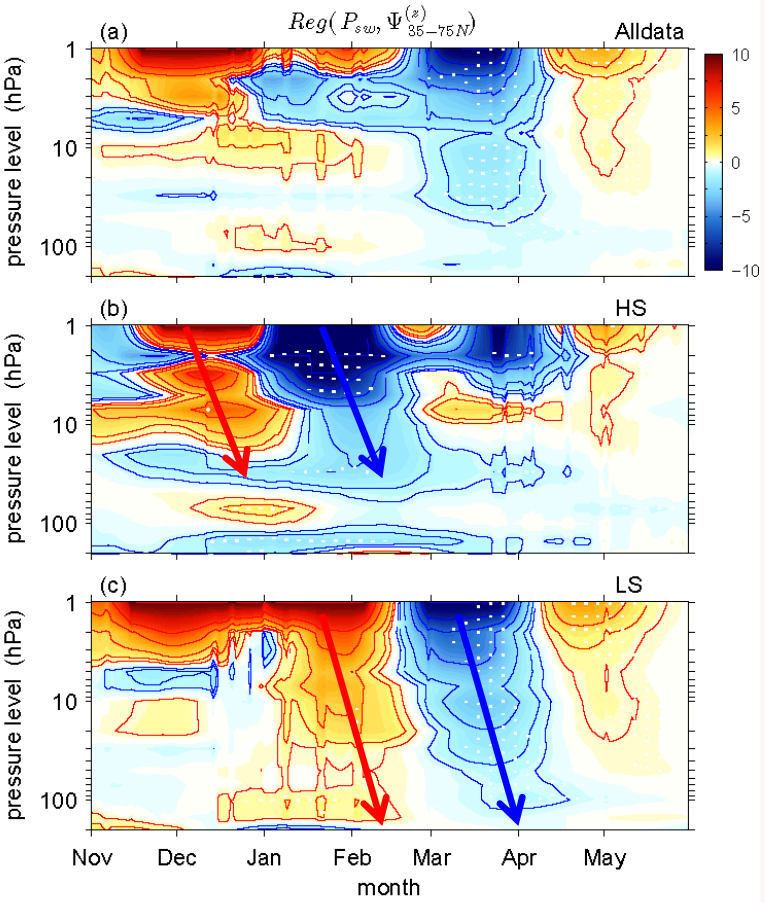
Signal in Vertically Propagating Wave Breaking & Meridional Circulation

Wave breaking due to $F^{(z)}$

All data

HS

LS



- Downward decent of the signal in wave breaking due to upward EP flux $F^{(z)}$ under LS
- Consistent with temperature response at high & low latitudes and zonal wind response at high latitude

Why does this general mechanism is weaker for the HS condition, given the fact that the signature in the NAM is stronger under HS than under LS?

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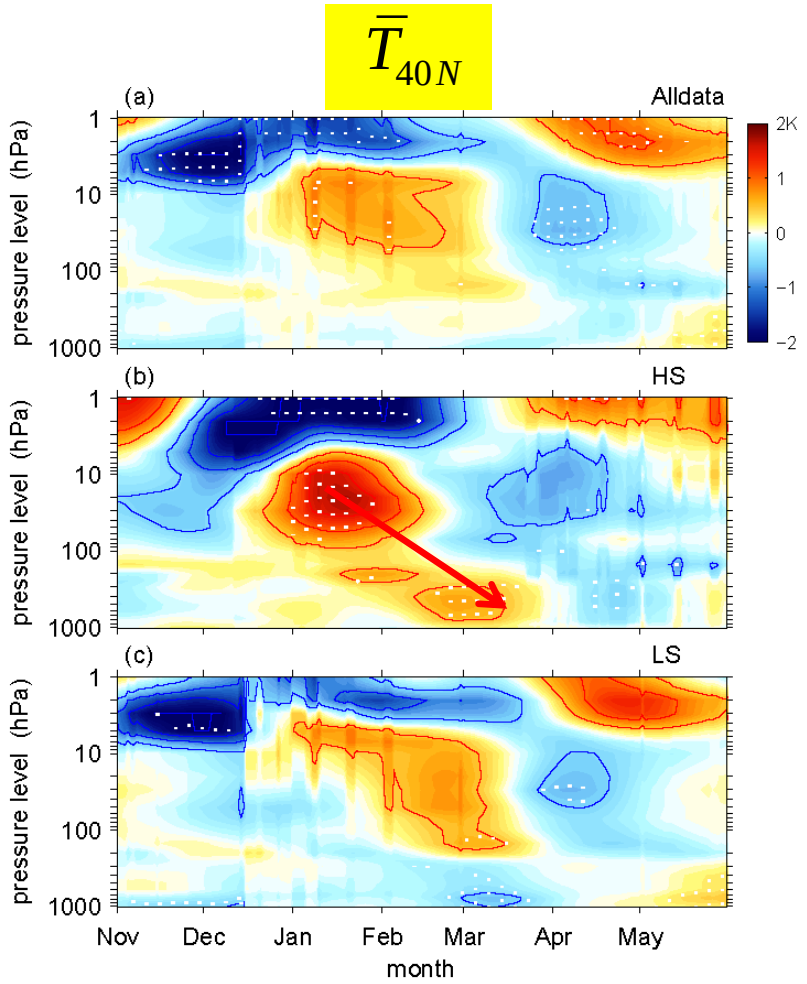
Signal in Mid-lats Temperature

All data

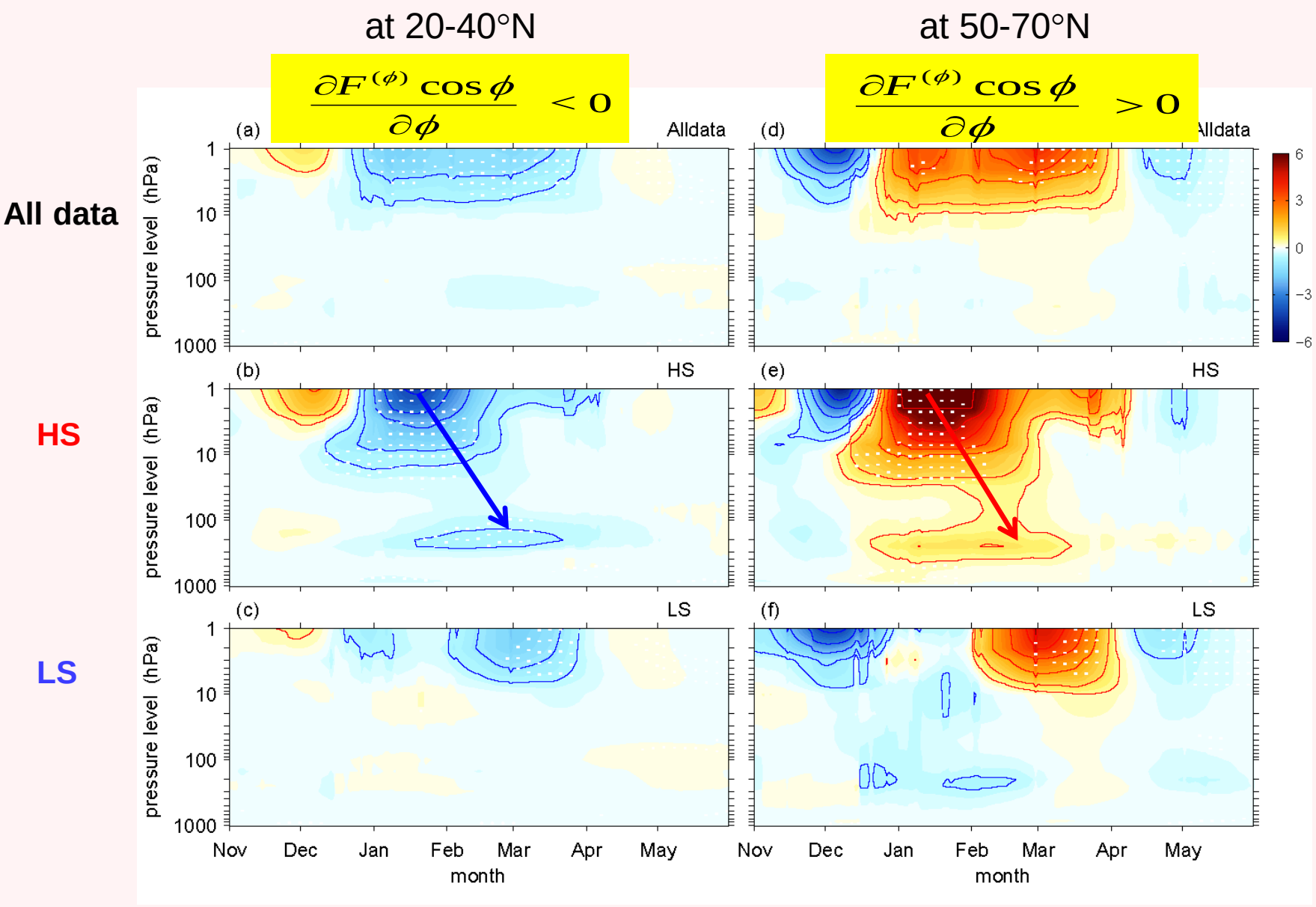
HS

LS

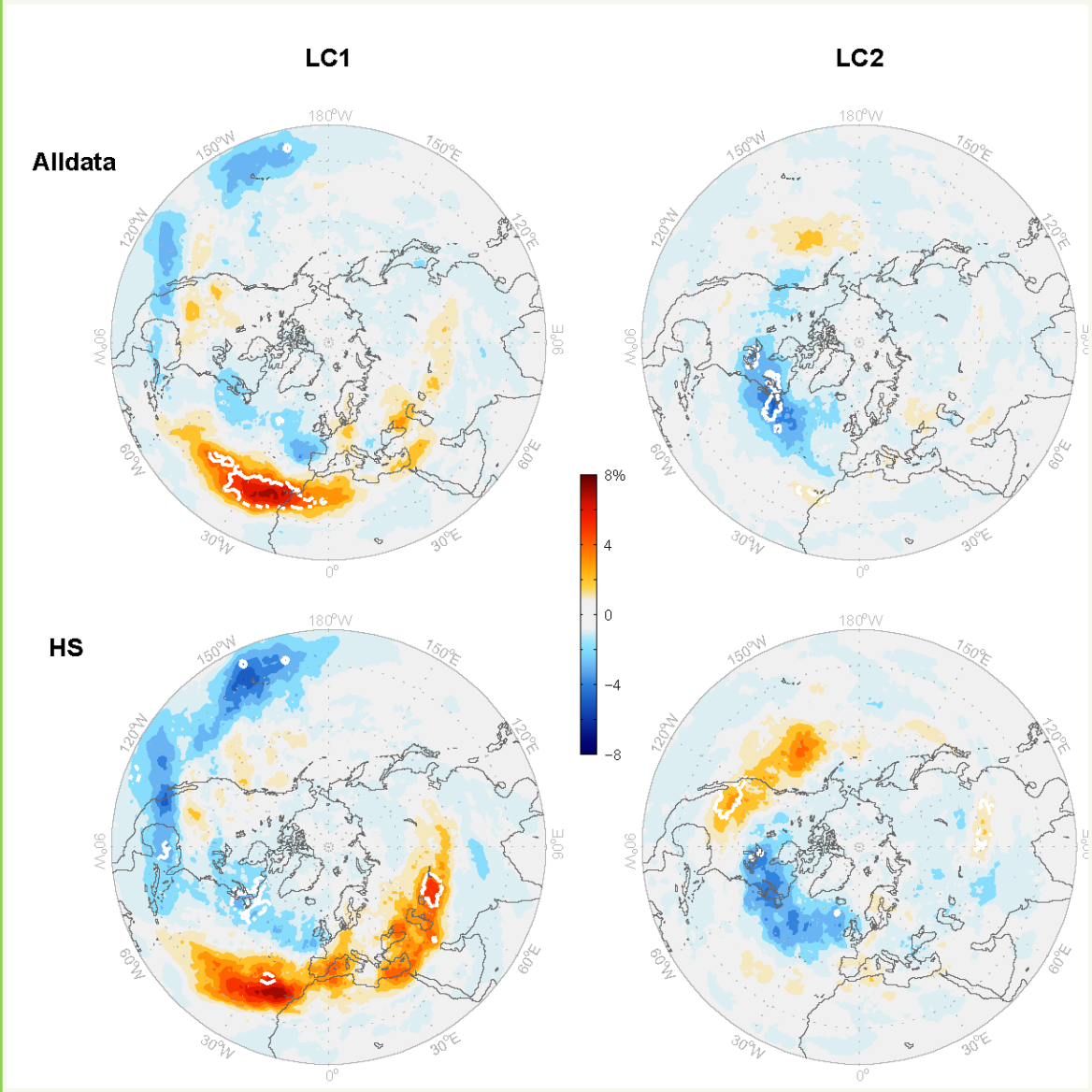


- positive temperature anomalies in the mid-stratosphere to the surface with negative anomalies above
- Signal descent from the upper stratosphere to the surface under **HS** condition but stops at tropopause under **LS** condition

The important role of northward EP flux $F^{(\phi)}$ under HS condition

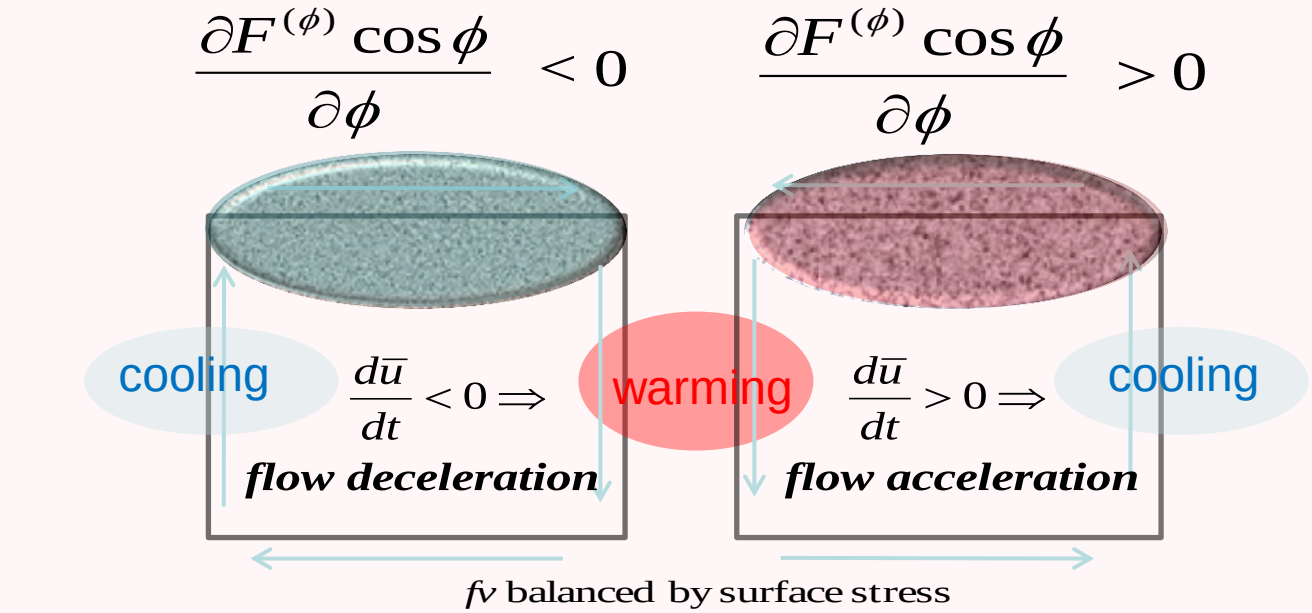


Effect on Synoptic-scale Rossby wave breaking near the tropopause



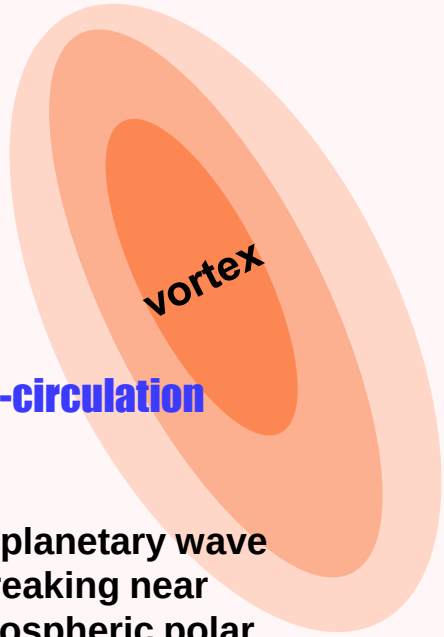
- More anti-cyclonic wave breaking (LC1) at mid-latitudes
- Less cyclonic wave breaking (LC2) at high latitudes
- consistent with EP –flux divergence analysis of $F(\phi)$

The role of northward EP flux $F^{(\phi)}$ / eddy momentum flux ($\overline{u'v'}$) at lower to mid-latitudes under HS condition



The Mechanism

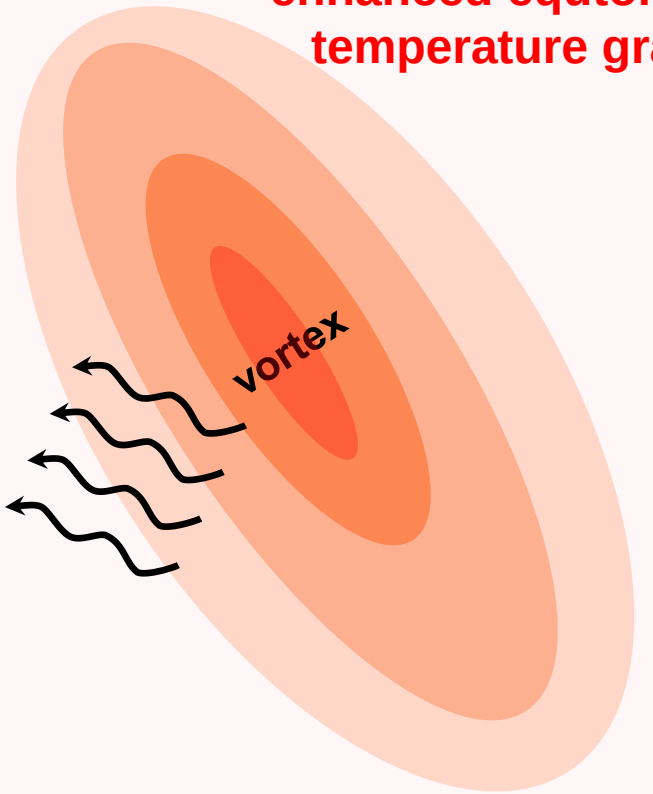
General & LS condition



Altered BD-circulation

Less planetary wave breaking near stratospheric polar vortex in WINTER but more in SPRING

HS condition with enhanced equtor-to-pole temperature gradient



a stronger polar vortex under HS
→ More planetary waves refracted equatorwards
→ even stronger vortex
→ enhanced barotropic instability

Summary

- Solar wind dynamic pressure appears to correlate with Rossby wave propagation & breaking in NH winter & spring
- The Solar wind dynamic pressure signal in the NAM, U and T propagates from the upper stratosphere into the lower atmosphere
- The effect differs according to the level of solar irradiance forcing

Under HS

- the effect is mainly in the winter months at both mid- and high-latitudes
- weaker winds & warming in the mid-latitude under HS is caused by anomalous northward EP flux propagating equatorward at 20-40°N and poleward at 50-70°N

Under LS:

- the effect confines in the spring months at high latitudes only
- warming (cooling) in the low (high) latitude upper stratosphere are responses to the anomalous residual circulation induced by changes of upward EP flux

- The behaviour of synoptic-scale Rossby wave breaking is consistent with classic atmospheric dynamic theory and the signal in the mean flow previously reported by *Lu et al*. (2008)

Thank you !

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