Asymmetries in seasonal stratosphere-troposphere interaction

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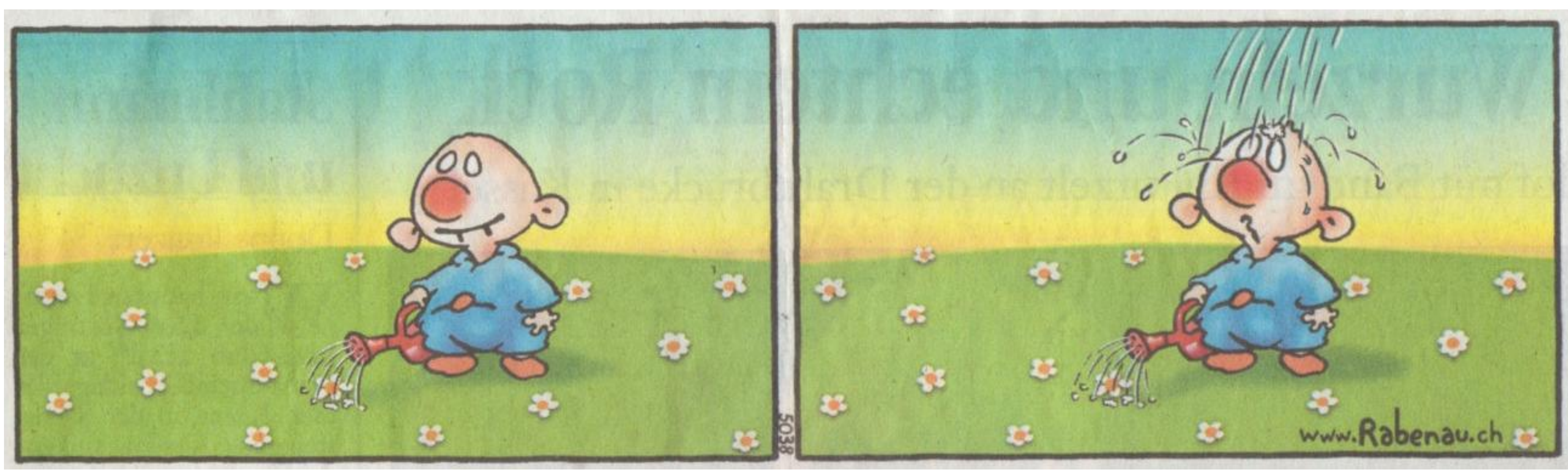
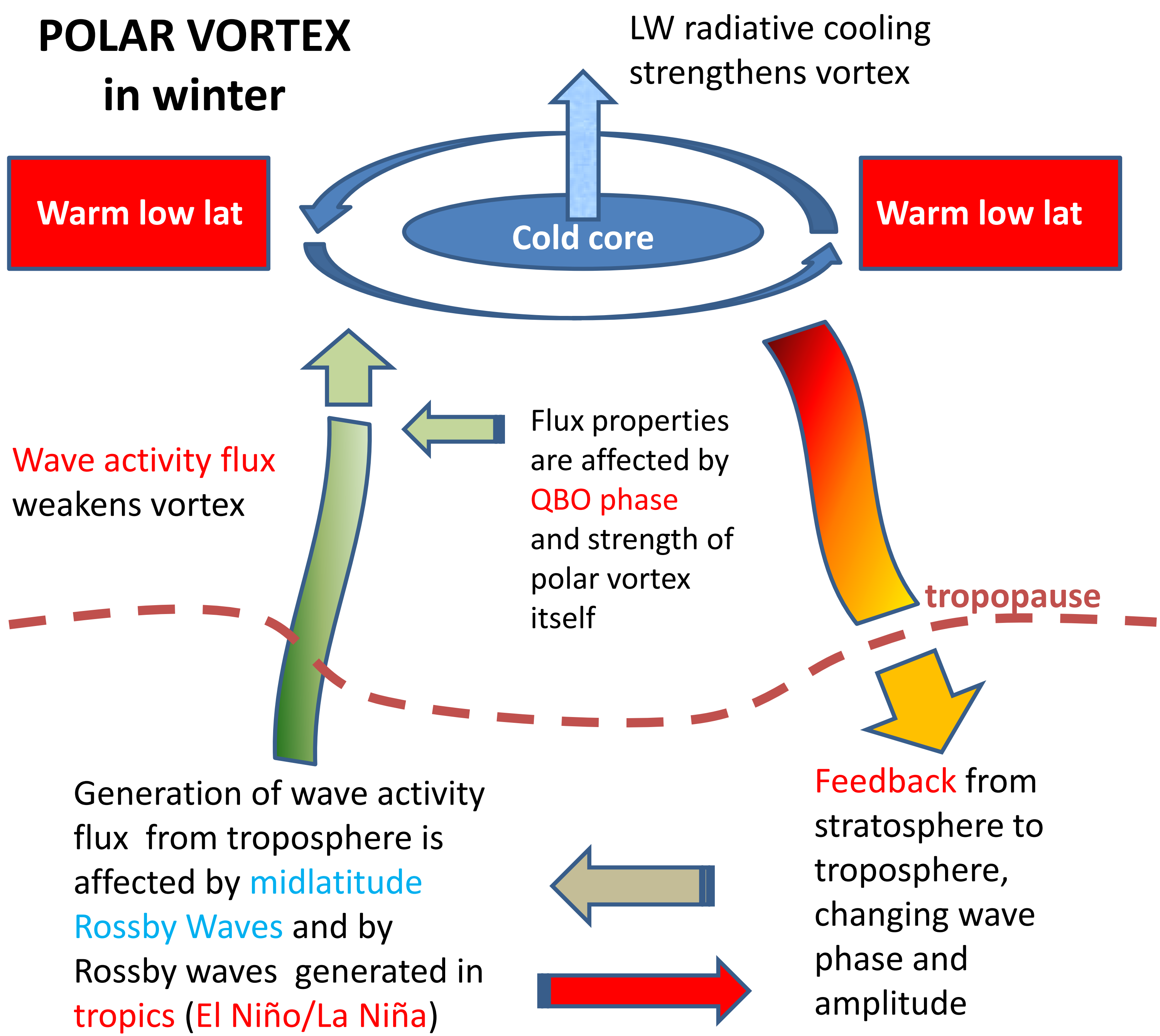



POLAR VORTEX
in winter
LW radiative cooling
strengthens vortex
Warm low lat
Cold core
Warm low lat
Wave activity flux
weakens vortex
Flux properties
are affected by
QBO phase
and strength of
polar vortex
itself
tropopause
Generation of wave activity
flux from troposphere is
affected by midlatitude
Rossby Waves and by
Rossby waves generated in
tropics (El Niño/La Niña)
Feedback from
stratosphere to
troposphere,
changing wave
phase and
amplitude

Castanheira et al. JAS 2009: Baroclinic Rossby wave forcing and barotropic Rossby wave response to stratospheric variability **(individual SVE and WVE)**

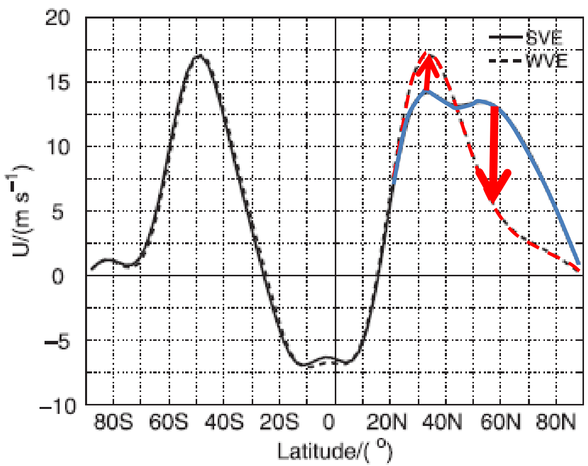


FIG. 5. Composites of the barotropic component of zonal mean zonal wind for strong and weak vortex events. The barotropic component has been rescaled to represent a vertical average weighted by the vertical structure function $G_0(p)$.

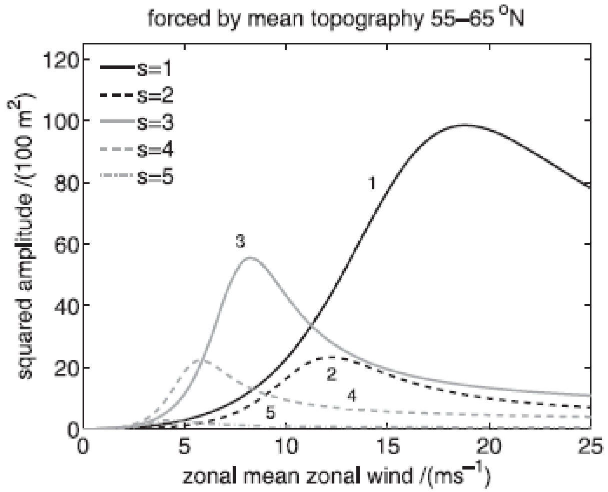
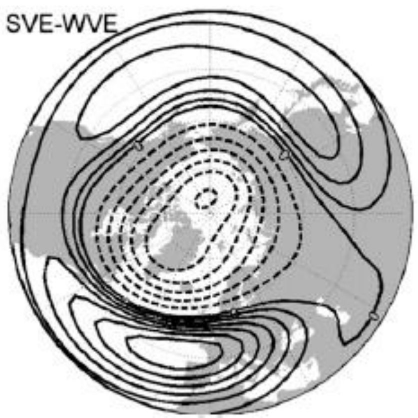


FIG. 7. Squared amplitudes of topographic waves as computed by the model of Charney and Eliassen [Eq. (7)] forced with the Fourier components of the mean topography in the latitudinal band 55°–65°N.



Composites of barotropic geopotential differences (SVE - WVE). Zonal mean plus Rossby wave numbers 1 -3.

- Stronger (weaker) barotropic component of zonal mean wind at SVE (WVE) and its interaction with topography at 55-65 N mainly leads to ZWN 1 and 3 response in midlatitudes, ZWN2 forces a pattern that projects on NAO.
- Over the polar cap barotropic response with lower pressure at SVE.

Different mechanisms at different latitudes!

Strategy of the analysis: quasi-seasonal, not individual events

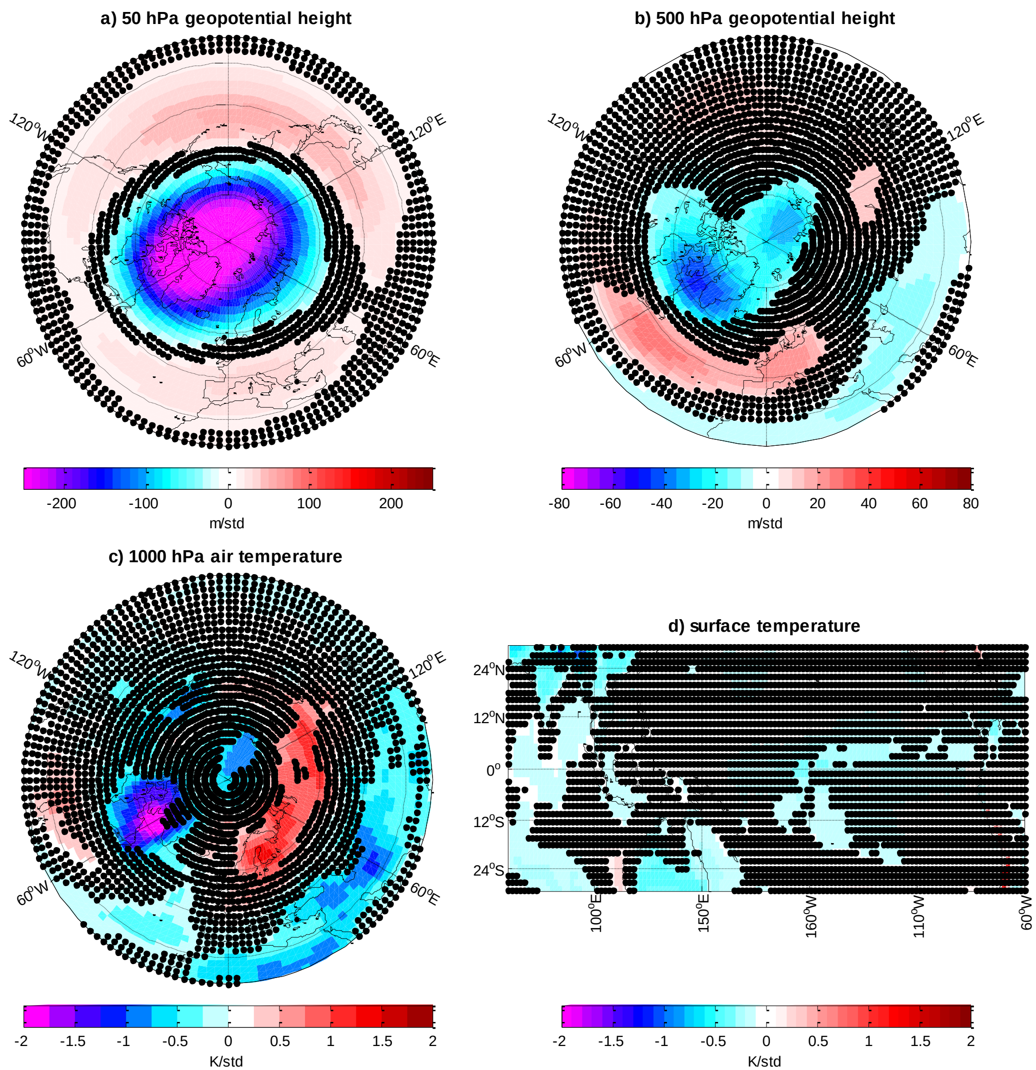
NCEP reanalysis (Kalnay et al., 1996) for the period 1948/01 until 2012/09, thus covering winters from 1948/49 to 2011/12. The data were provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA. Detrended locally.

The strength of the stratospheric polar vortex is calculated as the normalized geopotential height anomaly at the 50 hPa level during mid winter (January and February) over the northern polar cap (north of 65^{o}N).

A Polar Vortex Index (PVI) is defined as the inverted and linearly detrended standardized time series of the so-defined geopotential height data.

Winters characterized by strong and weak polar vortex correspond to those years when PVI is, respectively, above 1 and below -1.

Linear regression of the Polar vortex index January-February with the average 50 hPa and 500 hPa geopotential heights, 1000 hPa air temperatures and Pacific sea surface temperatures. All winters included.



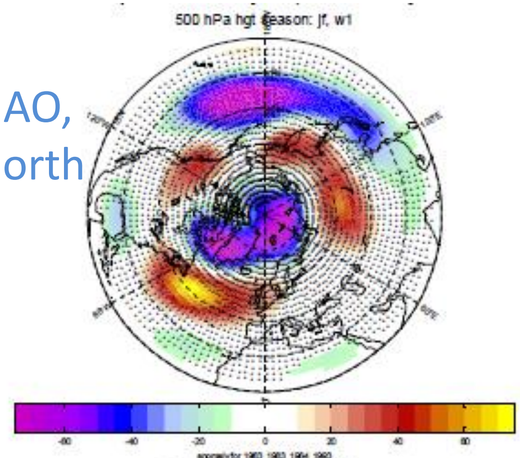
There are other processes with low frequency variability like:
Volcanic eruptions, El Niños and La Niñas, Quasi Biennial Oscillation, solar activity.

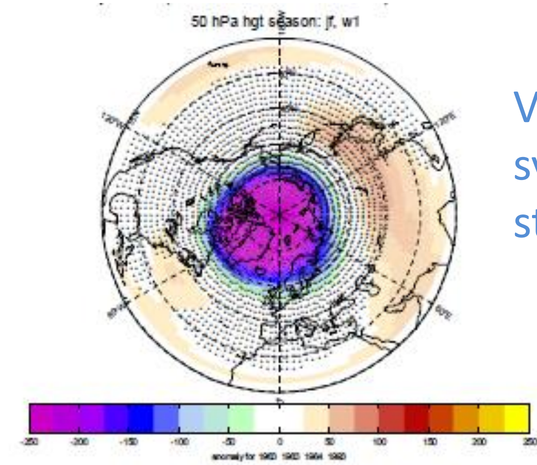
Could these have an impact on the linear regression results just by sampling biases?

Volcanos:

Composite of all volcanic winters with very strong polar vortex (1963, 1983, 1984, 1993) against all other winters that do not have very strong polar vortex and are not volcanically influenced.

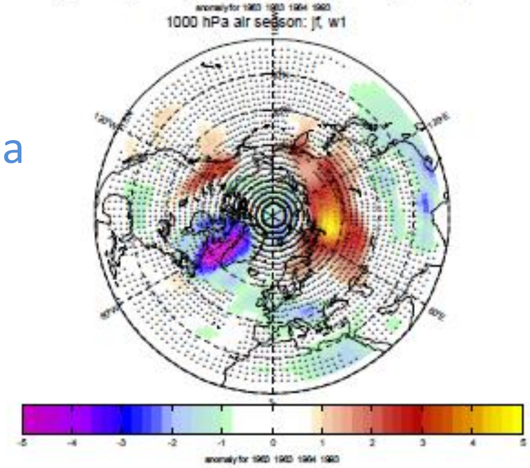
Strong positive NAO, but also strong North Pacific Low.

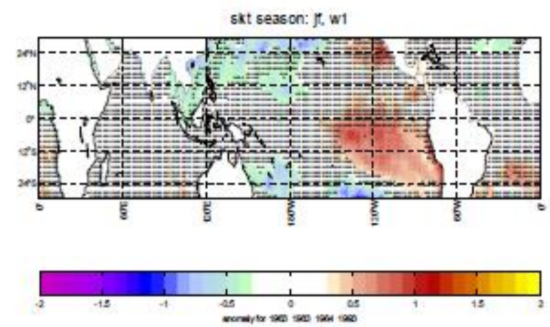




Very strong, polar symmetric stratospheric vortex

Cold Davis Strait and warm Siberia





Warm tropical East Pacific

Are these volcanically impacted winters dominating the signal of strong polar vortex?

Strong and weak polar vortices and how they are aligned with the phase of ENSO (defined by EMI index), QBO and solar activity.

Polar vortex		ENSO: warm	ENSO: cold/neutral
	strong	-05	+67 **-72** **-74** -**76** **+89** +<u>*90*</u> **-96** -97 +**00**
	weak	**+58** 69 *+70* *-77* **-87** *+04* **-10**	*60* -85 +01 *-06* *-09*

QBO phase in <u>Nov before</u> (i.e. Year -1!)

East West Neutral

Small italic numbers mean that ENSO index is only weakly positive or negative, bold numbers indicate ENSO index exceeds 1 stdv, Strong (+) and weak (-) solar activity is quite equally distributed!

The six volcanically impacted winters are neglected!

Strong polar vortices (10) are nearly all (9) during cold/neutral ENSO and dominated by WQBO (6)!
Weak polar vortex (12) for both, warm (8) and cold/neutral (4) ENSO, also, while dominated by EQBO (8), for both QBO phases.

Composite analysis for the well populated sectors in the previous matrix

Significance of the anomalies is assessed based on random occurrence (500 surrogate data sets) as in Graf and Zanchettin (2012). In all figures statistically non-significant (p>0.05) local anomalies are indicated by dots.

In all following analyses the colour code is the same!

In all cases we suffer from small ensembles!

	warm	cold
strong	-05	+67 **-72** **-74** -**76** **+89** +*90* **-96** -97 +**00**
weak	**+58** 69 *+70* -*77* -**87** +*04* -**10**	*60* -85 +01 -*06* *-09*

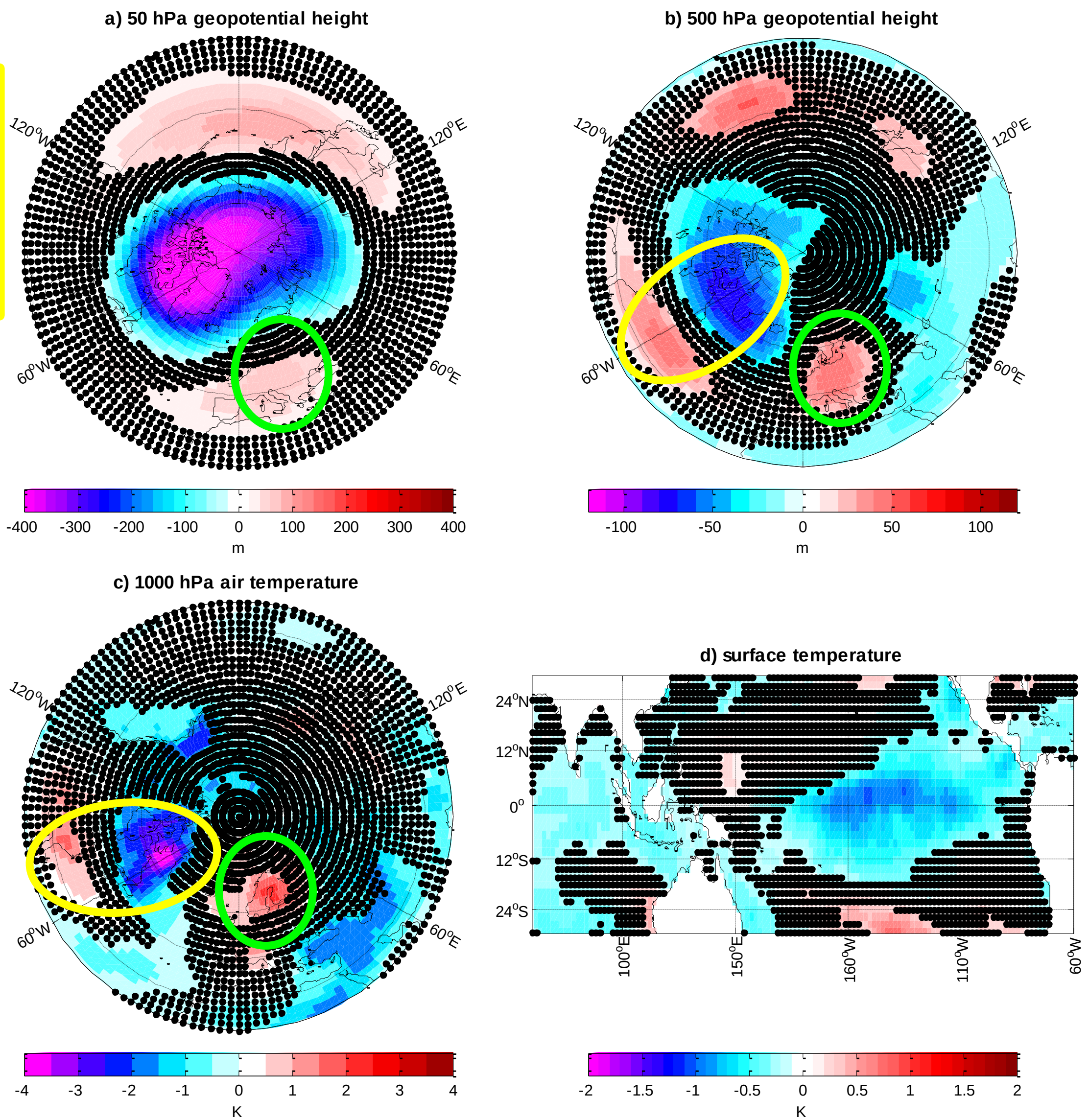
The six volcanically impacted winters are neglected!

Strong polar vortex and cold-to-neutral ENSO conditions
(years: 1967 1972 1974 1976 1989 1990 1996 1997 2000)

The clear "NAO" response we had in the linear regression is gone and something projecting on –PNA and the West Atlantic pattern appears.

Over Europe we find pattern with high pressure, high Scandinavian temperatures that imprints on the stratosphere.
Siberia is no longer warm.

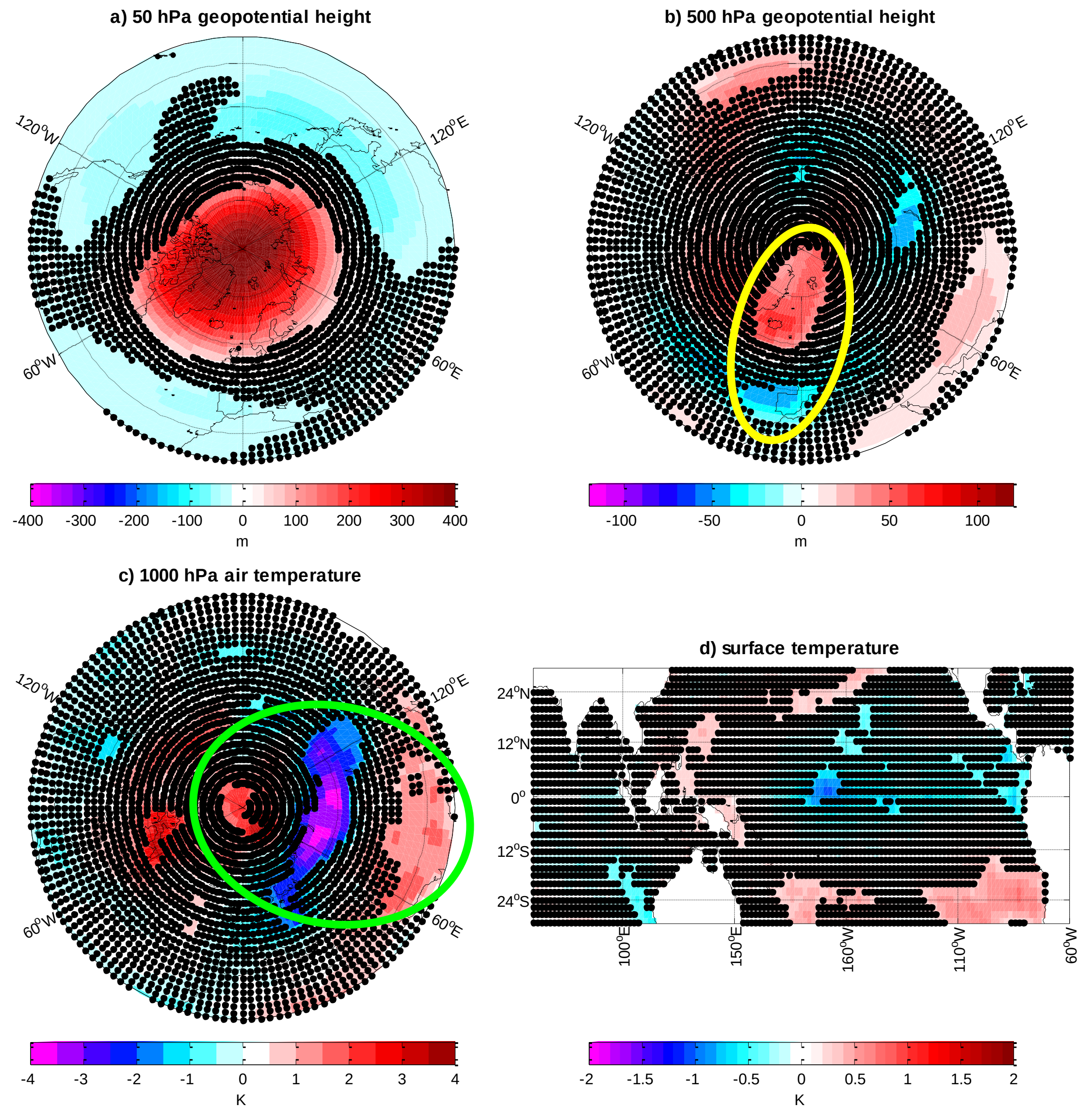
Clearly bias towards cold conditions in central tropical Pacific affecting the North Pacific (-PNA)



Weak polar vortex and cold-to-neutral ENSO conditions (years: 1960 1985 2001 2006 2009)

In the troposphere we find some significant anomaly pattern in 500 hPa height that resembles the negative phase of NAO.

The only larger scale significant temperature anomalies are the cold northern Siberia and warm northern India/Tibet as well the North Pole.



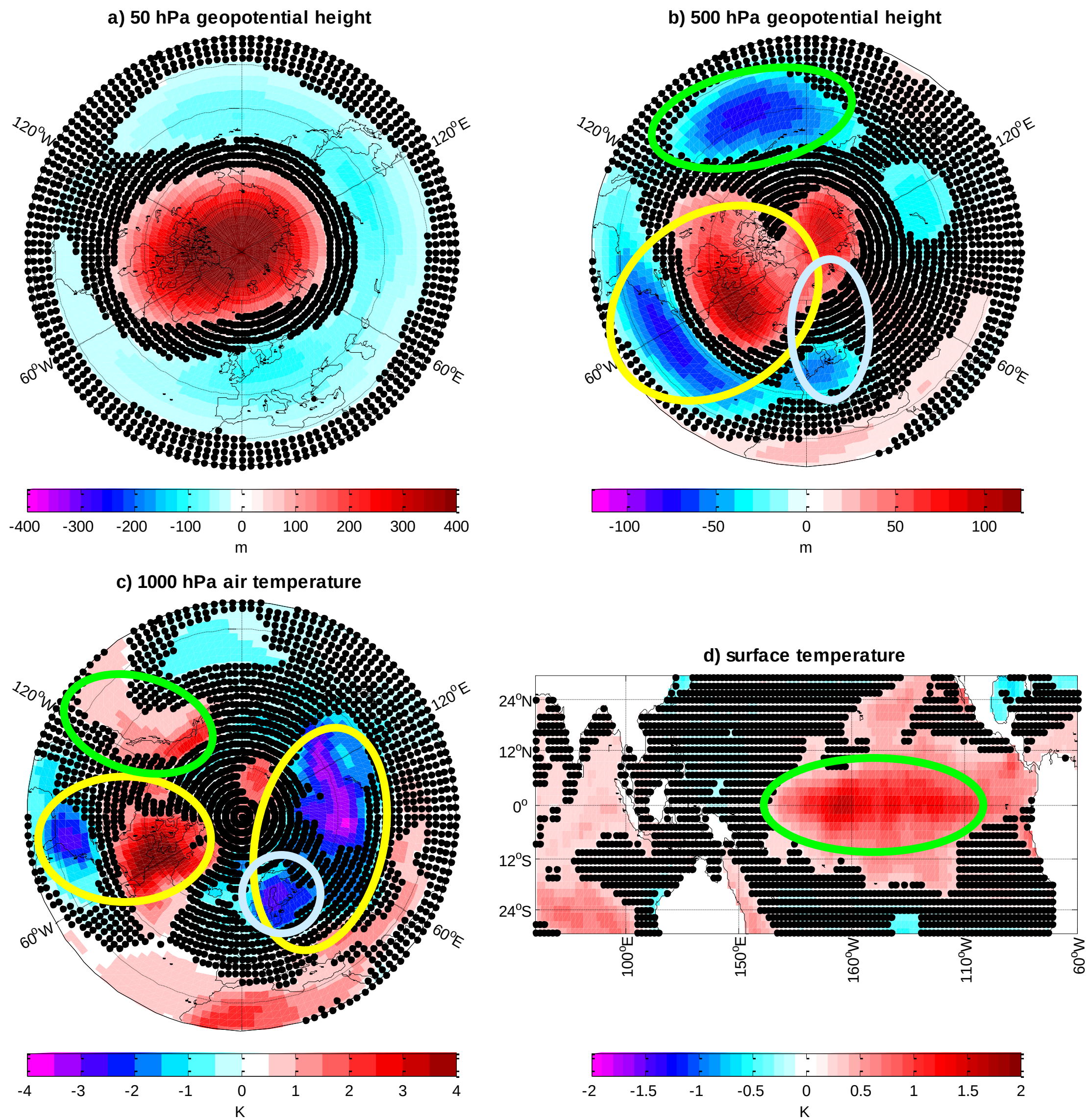
Weak polar vortex and warm ENSO conditions
(years: 1958 1969 1970 1977 1987 2004 2010)

In this case we find the strongest tropospheric anomalies.
While the stratosphere anomaly is comparable with the previous, in the troposphere it is very different!

A strong Aleutian Low and warm anomalies at west coast North America is linked to the positive SST in central Pacific.

The negative NAO-like pressure anomaly is linked to very cold temperatures over Europe and Siberia as well as over the south-eastern US and positive temperature anomalies prevail over the Canadian Arctic.

Low pressure over Europe and high Arctic pressure → cold Scandinavia



Preliminary conclusions

- Very strong polar vortex nearly exclusively develops during cold ENSO, hence tropospheric anomalies potentially are not solely due to polar vortex, but are biased by the cold ENSO conditions.

- Weak polar vortex can develop under both, warm and cold ENSO. The strongest tropospheric anomalies develop at weak polar vortex and warm ENSO.

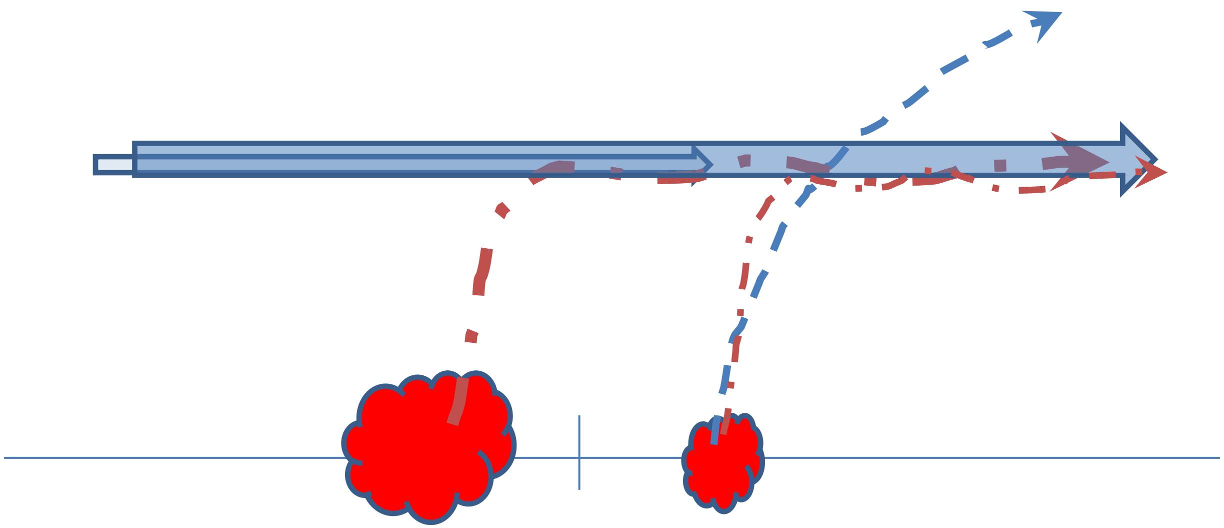
- QBO phase possibly modulates the strength of polar vortex (WQBO – strong vortex, EQBO – weak polar vortex) in the development phase, but does not determine it in mid-winter.

- ENSO phase is strongly modulating the stratospheric polar vortex effects on troposphere

How is the warm ENSO phase affecting tropospheric climate and why is this effect so strong?

All the warm ENSO cases we have studied were either Central Pacific or “hybrid” warm events (see Johnson, 2013). They lead to enhanced rainfall at and to the west of the date line.

The resulting strong Aleutian Low enhances westerlies around 30°N, which helps to activate the tropospheric “subtropical bridge” (Graf and Zanchettin, JGR 2012) into an efficient zonal wave guide for tropically induced waves.



The result is a very weak Azores High in the subtropical Atlantic that enhances the negative NAO phase.

Different mechanisms

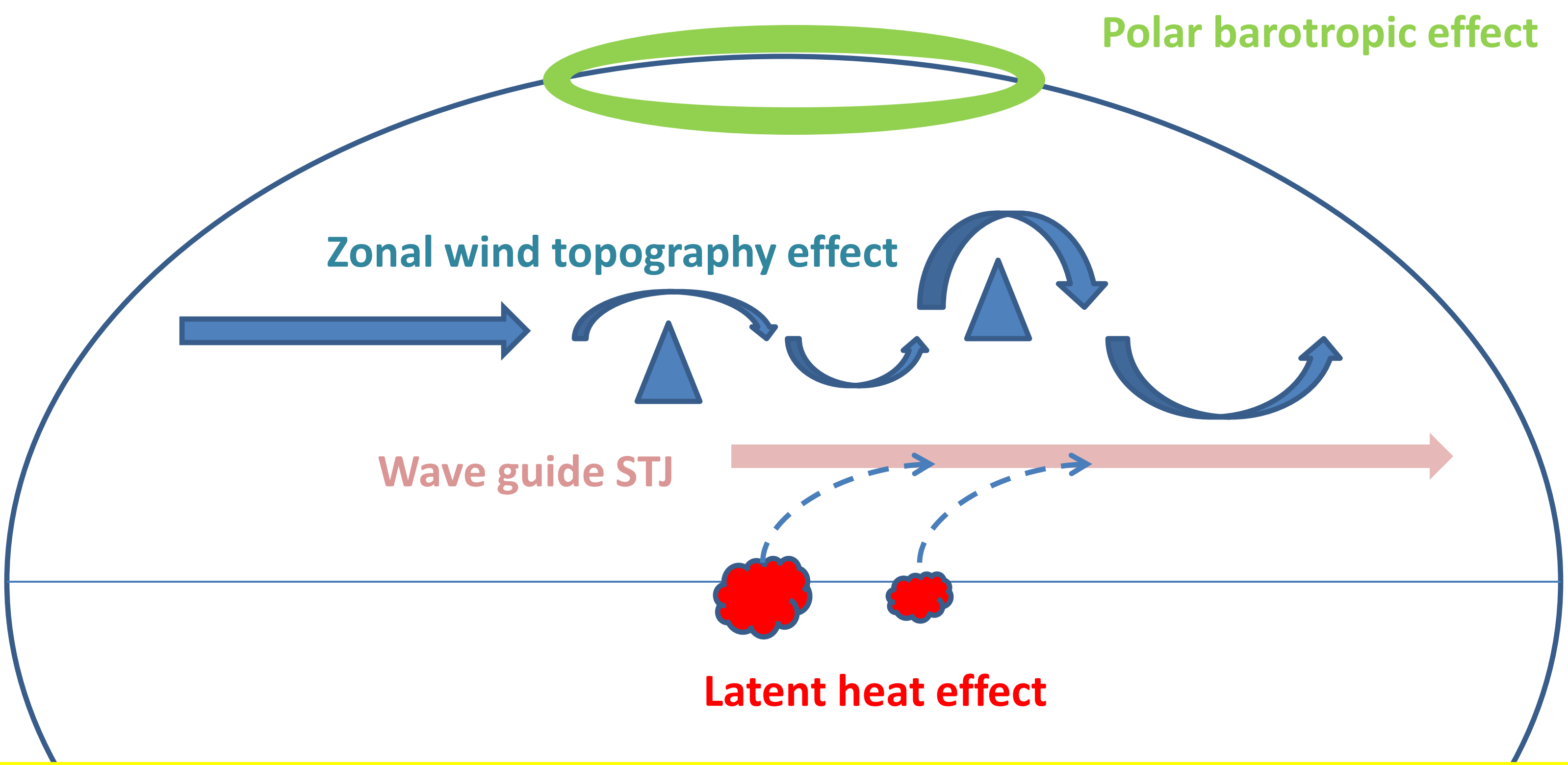
High latitudes: Barotropic effects lead to tropospheric pressure anomalies over the Arctic that are similar in sign as in the stratosphere.

Mid-latitudes: Zonal mean wind anomalies (coming from the stratosphere and penetrating into the troposphere at the edge of the polar vortex) and their interaction with topography lead to wave anomalies.

Subtropics: Subtropical jet can act as active wave guide linking Pacific with Atlantic and Europe. STJ is enhanced at Central Pacific warming.

Tropics: SST anomalies along the Pacific Equator lead to anomalies of precipitation and latent heat release affecting generation of Rossby waves (PNA response). If STJ wave guide is active, strong teleconnection to Atlantic and Europe.

The cartoon:



- Tropospheric anomalies are strongly modulated by the phase of ENSO with warm ENSO enhancing the anomalies dramatically. Superposition of PNA and Arctic pressure anomaly enhances pressure anomaly over Canadian Arctic at strong polar vortex and cold ENSO as well as at weak polar vortex and warm ENSO. At weak polar vortex and cold ENSO anomalies from Arctic pressure anomaly and negative PNA cancel each other out over the Canadian Arctic.

Conclusions forward looking

Tropospheric climate in mid and high latitudes of the Northern Hemisphere is affected by both, polar vortex and tropical rainfall with links to El Niños/La Niñas, hence by pure tropospheric mechanisms and by troposphere-stratosphere interaction.

There are sampling biases such that very strong polar vortex nearly exclusively occurred during La Niñas. How much of the observed anomalies is due to C-Pacific La Niñas?

While very weak polar vortex can develop both, for cold and warm ENSO, the climate effects are much stronger and more large scale when weak vortex coincides with Central Pacific warming and the upper-tropospheric “subtropical bridge” is activated.

The ultimate effect from the tropics is latent heat release from deep convection. This is not necessarily well captured by ENSO indices.

The recent warming that started in the 1980s in the Indian Ocean and expanded in the 1990s and 2000s into the west Pacific warm pool strongly affected rainfall patterns there, but is not fully covered by any of the current ENSO indices.