Stratospheric planetary wave reflection and its influence on the troposphere

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The following short presentation summarizes results of the following papers

- Shaw, T. A., J. Perlwitz and N. Harnik, 2010: Downward wave coupling between the statosphere and troposphere: The importance of meridional wave guiding and comparison with zonal-mean coupling. *J. Climate*, **23**, 6365-6381.
- Harnik, N., J. Perlwitz and T. A. Shaw, 2011: Observed decadal changes in downward wave coupling between the stratosphere and troposphere in the Southern Hemisphere. *J. Clim.*, **24**, 4558-4569.
- Shaw, T. A., J. Perlwitz, N. Harnik, P. A. Newman, and S. Pawson, 2011: The impact of stratospheric ozone changes on downward wave coupling in the Southern Hemisphere. *J. Clim.*, **24,** 4210-4229.

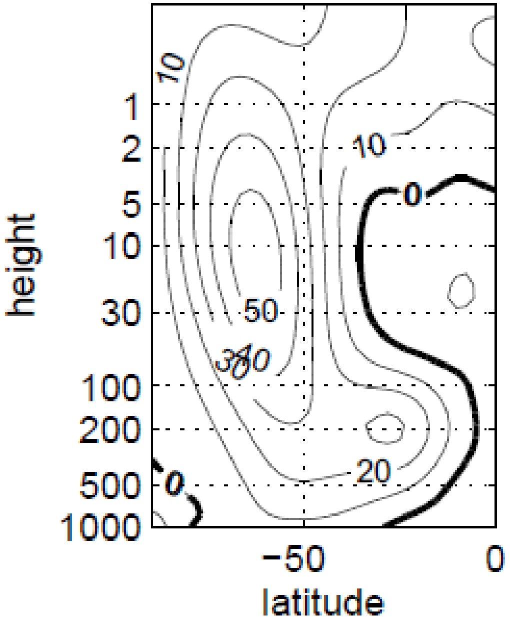
The diagnostics are used and described in detail in:

- Harnik, N., and R. S. Lindzen, 2001: The effect of reflecting surfaces on the vertical structure and variability of stratospheric planetary waves. *J. Atmos. Sci.*, 58, 2872-2894.
- Perlwitz, J., and N. Harnik, 2003. Observational Evidence of a Stratospheric Influence on the Troposphere by Planetary Wave Reflection. *J. Clim.*, 16, 3011-3026.
- Perlwitz, J., and N. Harnik, 2004. Downward coupling between the stratosphere and troposphere: The relative roles of wave and zonal mean processes. *J. Clim.*, 17, 4902-4909.

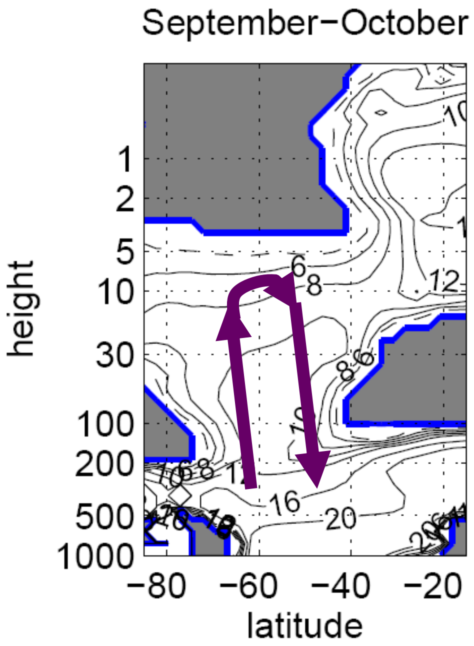
Certain configurations of the stratospheric polar night jet can cause stratospheric waves coming up from the troposphere to get reflected back down to the troposphere. A nice example is the climatological Sep-Oct mean jet in the Southern Hemisphere:

A wave geometry diagnostic – example from Southern Hemisphere Sep-Oct climatology

Zonal wind

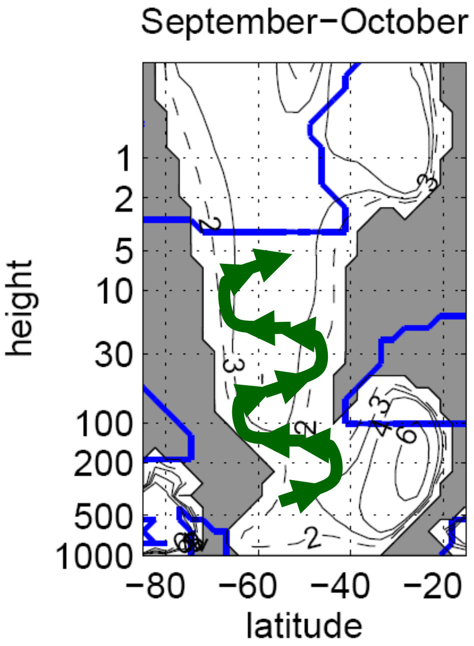


Vertical wavenumber



Waves reflected down from 5hPa

Meridional wavenumber



Waves confined between 40-70^{o}S

MERRA data

The combination gives a vertically bounded high-latitude meridional waveguide

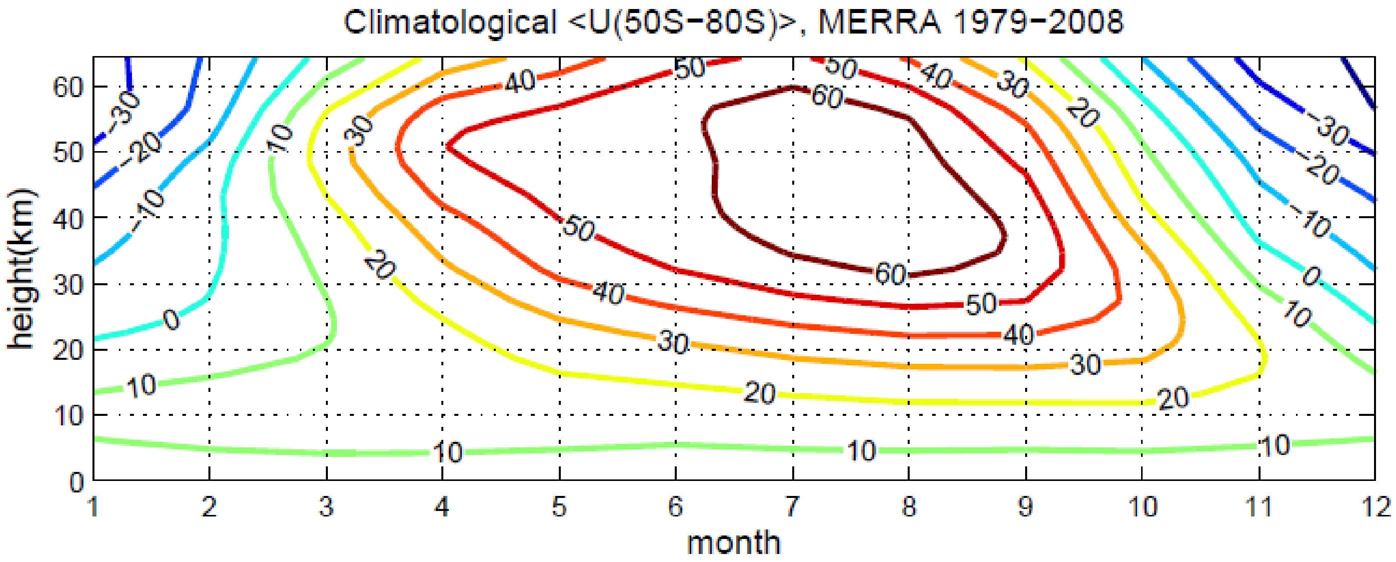
A main form of downward coupling between the stratosphere and troposphere is through the downward propagation of zonal mean wind anomalies on a time scale of a few weeks. This coupling is driven by downward absorption of planetary wave activity in the stratospheric jet. Downward wave reflection excludes wave absorption, thus it also affects the downward coupling to the troposphere.

Next we examine the climatological seasonal cycle of wave geometry in the Southern Hemisphere, and see how it affects downward coupling to the troposphere

Seasonal climatology in the Southern Hemisphere

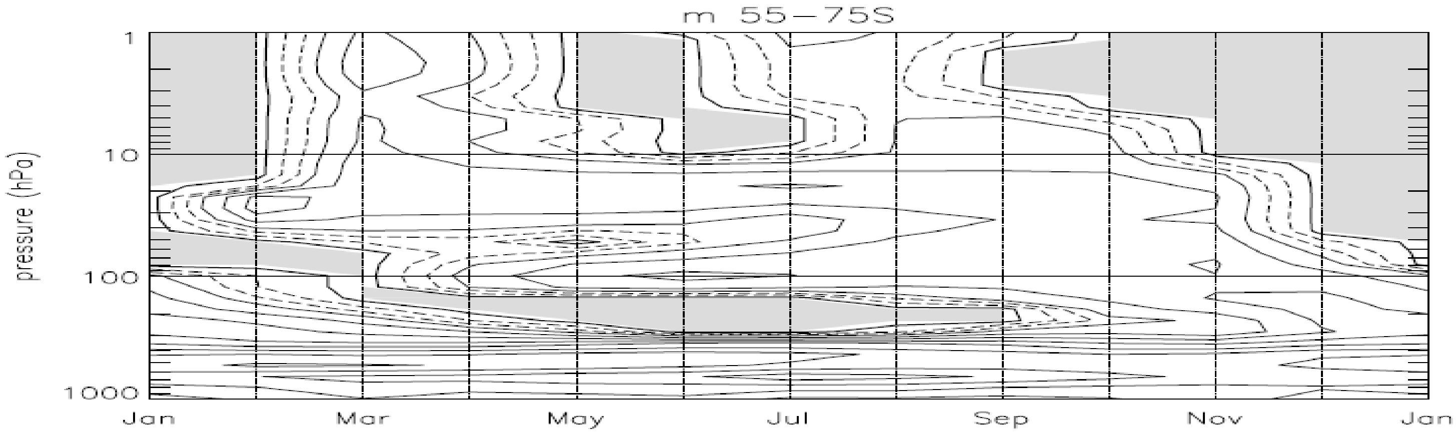
The jet peak moves downwards (and polewards).

U (50-80S)
MERRA data, 1979-2008

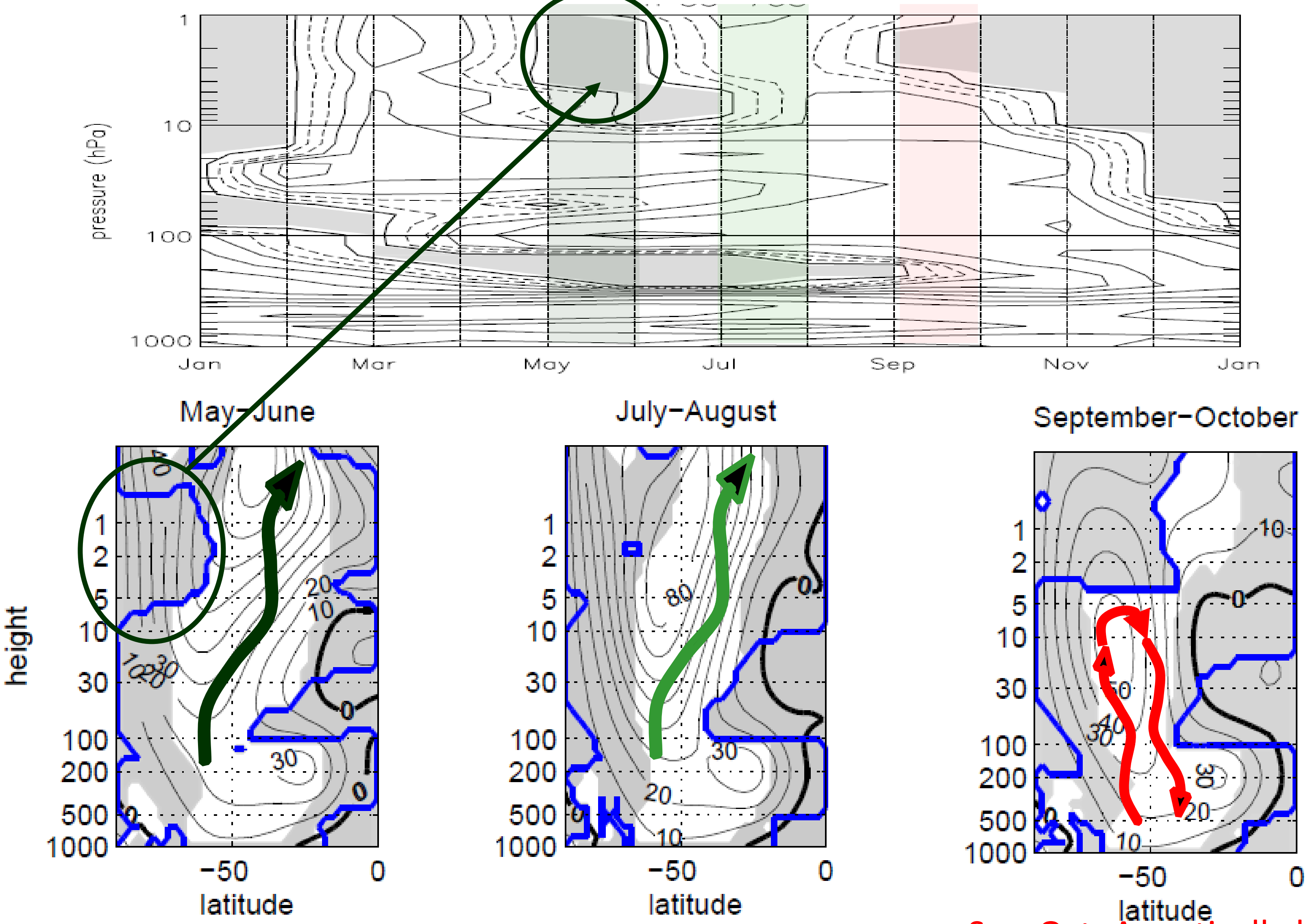


A vertical reflecting surface forms in May-Jun and Sep-Dec (Jan there is no more vortex)

55-75 S Vertical wave # (Shaw et al, 2010)



55-75 N Vertical wave number (Shaw et al, 2010)



May-Jun: Vertical reflecting surface “misses” meridional waveguide

Jul-Aug: Waves propagate up unhindered

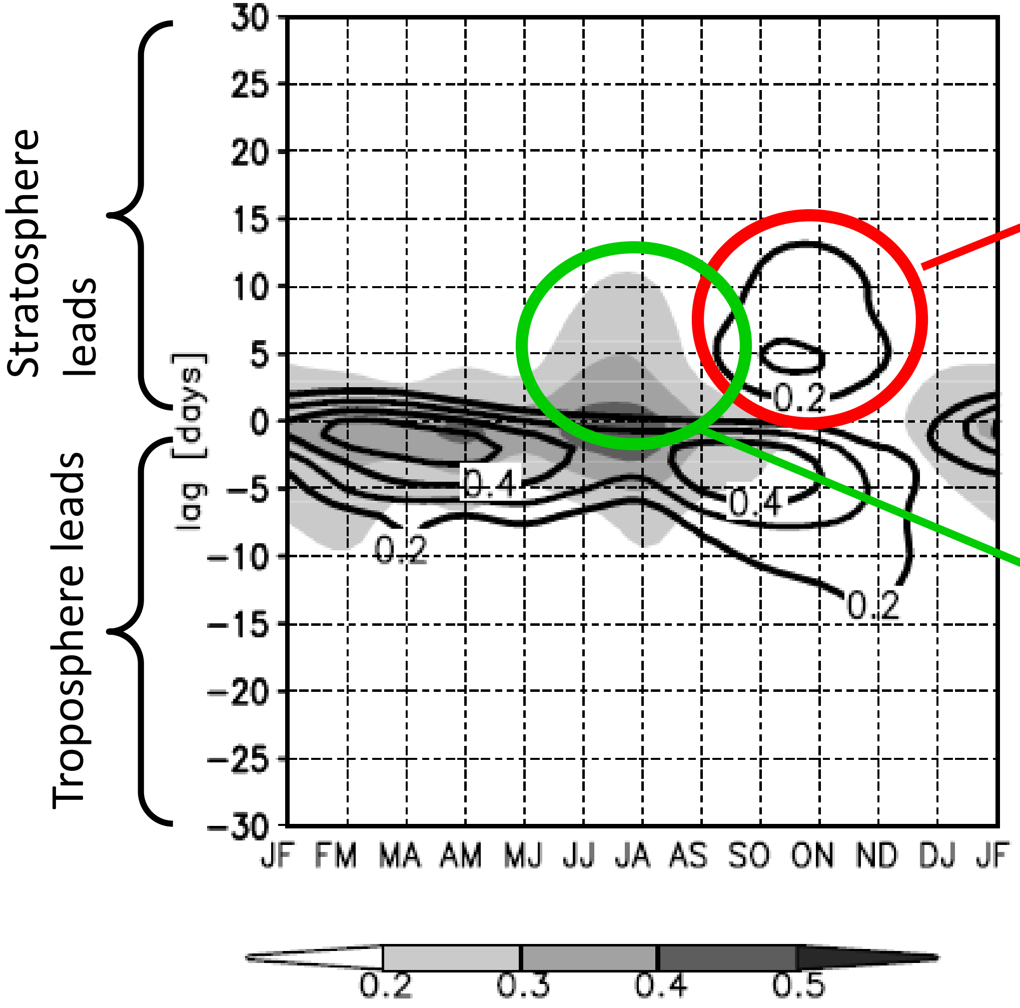
Sep-Oct: A vertically bounded waveguide forms – best conditions for downward wave reflection. Holds through Dec.

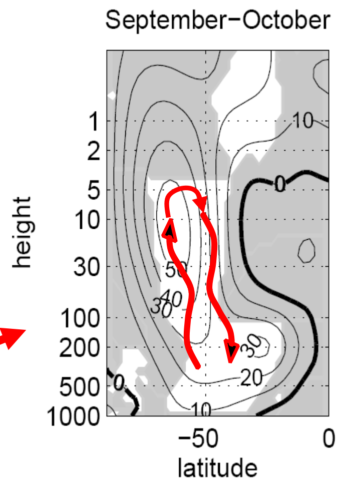
Downward dynamical coupling varies seasonally, consistent with the variations of downward reflection.

Time lagged cross correlations of:

20-1000hPa SAM (zonal mean coupling)

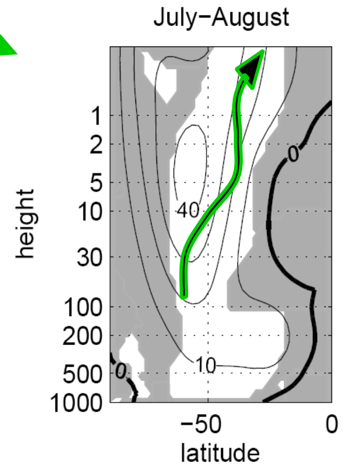
20-500hPa wave 1 (follwing Randel 1987)





Wave reflection dominates the downward dynamical coupling during Sep-Dec, when bounded wave geometry forms

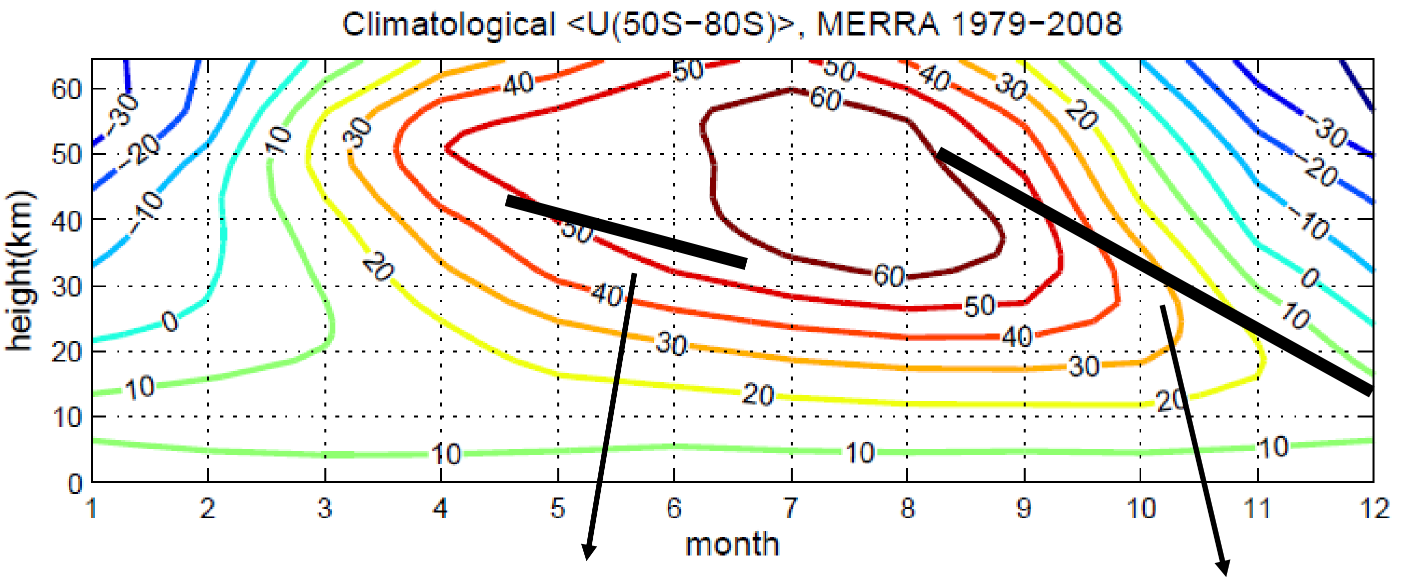
Zonal mean coupling dominates when waves are not reflected



ERA-40 reanalysis data, Shaw et al, 2010

What causes the vertical reflecting surface to form? Varies seasonaly

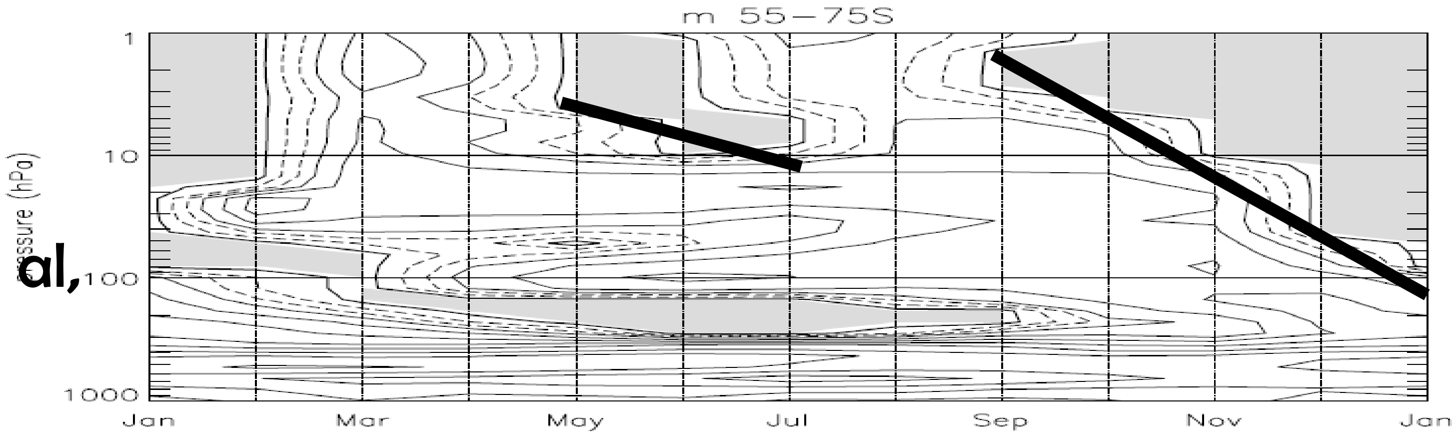
U (50-80S)



Charney and Drazin critical wind value

Small q_y

55-75 S Vertical wave # (Shaw et al, 2010)



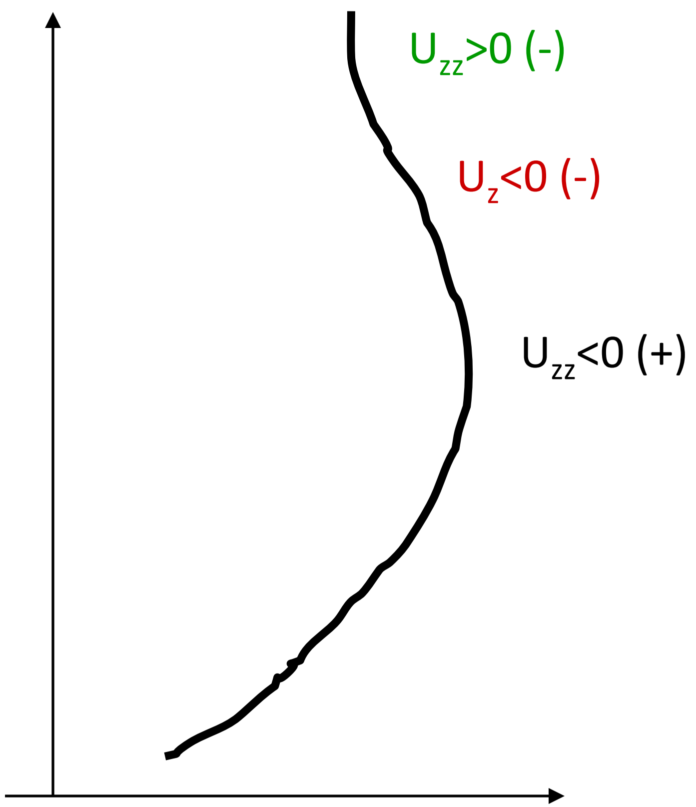
In late-winter spring, a small q_y is the cause of formation of a vertical reflecting surface (m^2=0). What causes q_y to be small?

$$n_{ref}^2 = \frac{N^2}{f^2}\left[\frac{\bar{q}_y}{U} - k^2\right] - \frac{1}{4H^2}$$

$$q_y \approx \beta - U_{yy} + \frac{f^2}{N^2}\frac{U_z}{h} - \frac{f^2}{N^2}U_{zz}$$

$$\longrightarrow \quad m^2 \approx \frac{N^2}{f^2}\frac{\beta}{U} + \frac{U_z}{hU} - \frac{U_{zz}}{U}$$

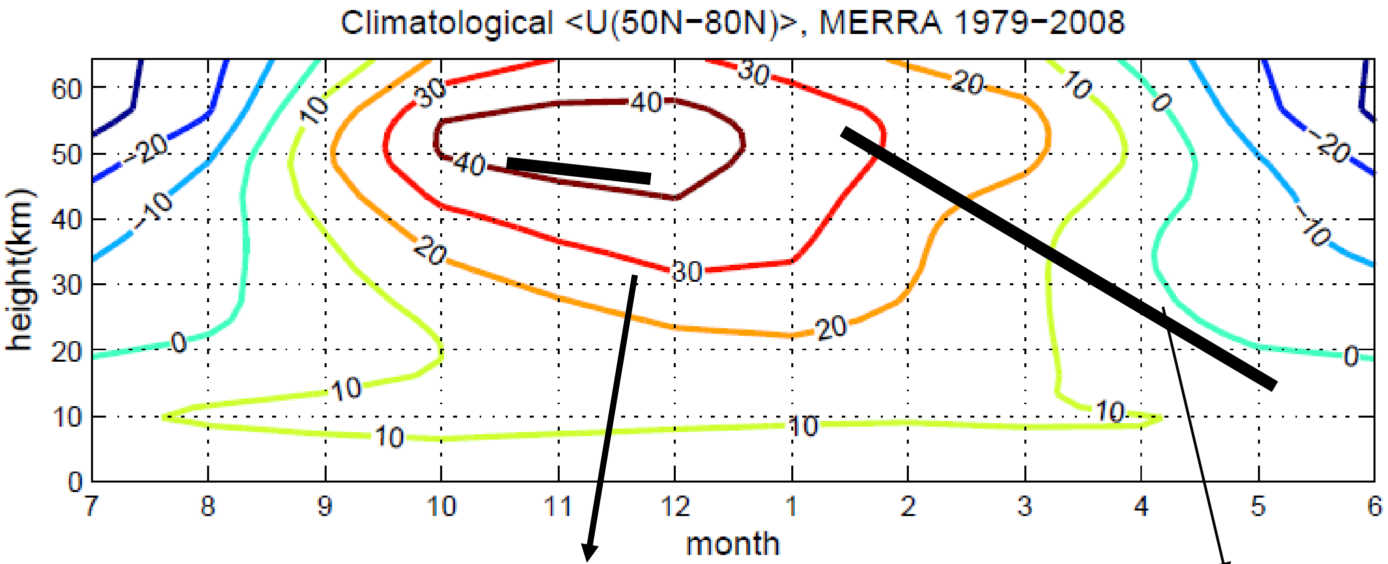
Characteristic reflective high latitude U profile



In climatology- U_z<0
Inter-annual variability of upper stratospheric m^2 correlates best with $-U_{zz}$, and βN^2 in SH Sep-Oct , and with U_z in NH Jan-Mar

Next we will examine the climatological seasonal cycle of wave geometry in the Northern Hemisphere. Vertical reflecting surfaces also form in late fall and toward the end of winter/spring. The jet weakens towards end of winter but peak does not shift down as in SH.

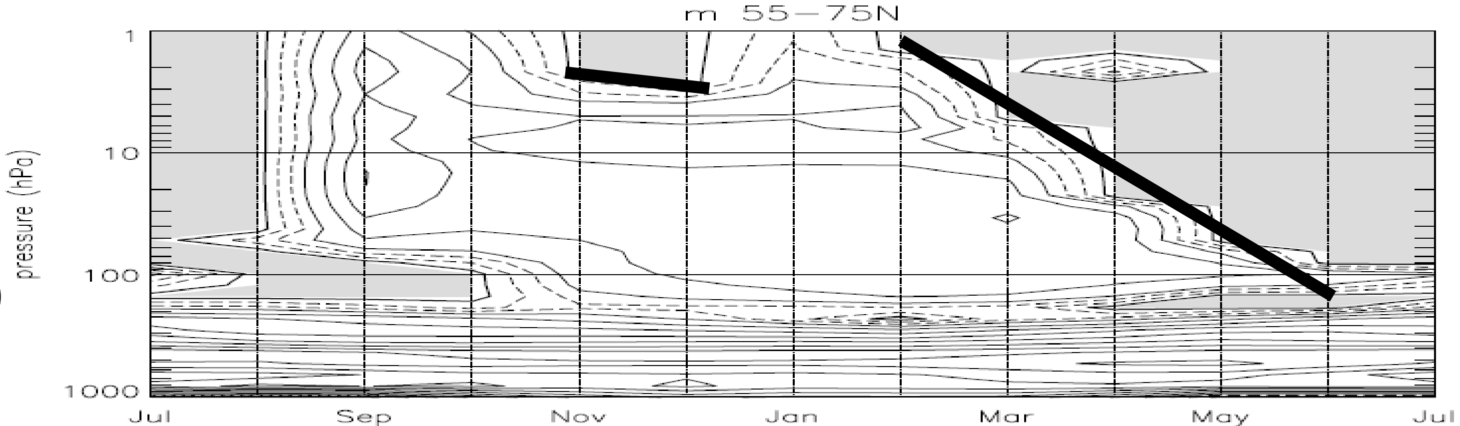
U (50-80N)



As in SH, this downward reflecting surface does not coincide with the meridional waveguide- no downward reflection

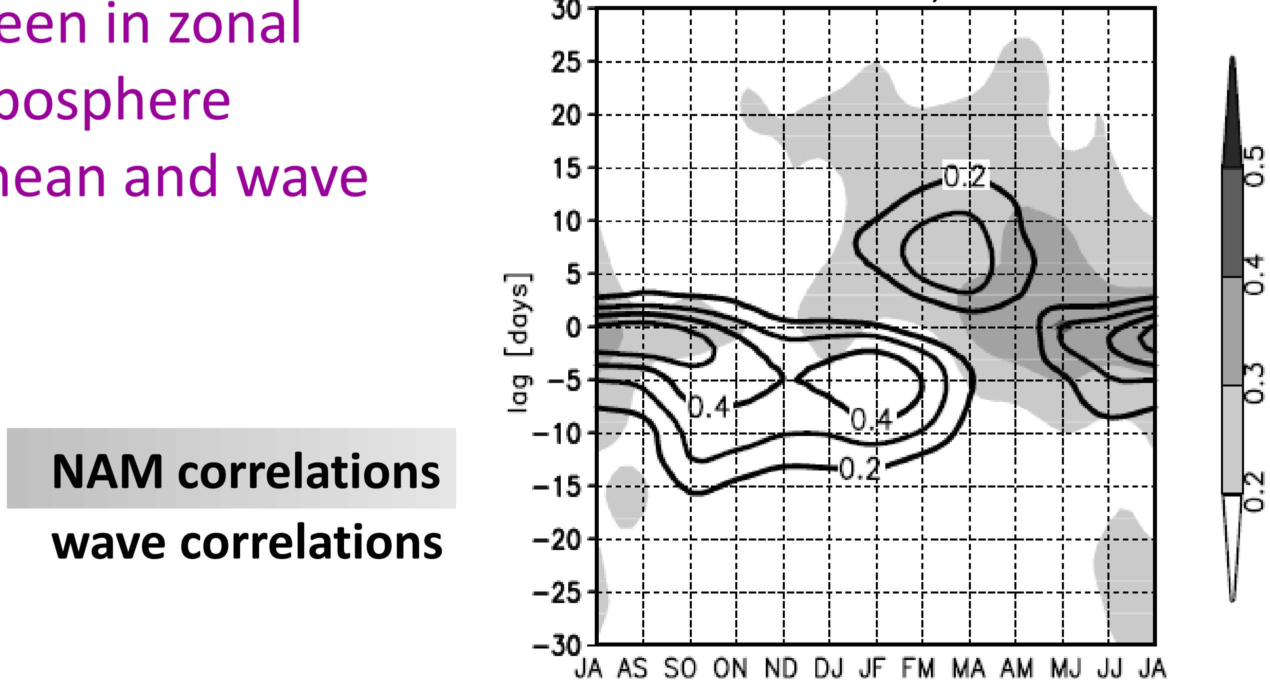
What causes reflection in late winter/spring?

55-75 N Vertical wave #
(Shaw et al, 2010)



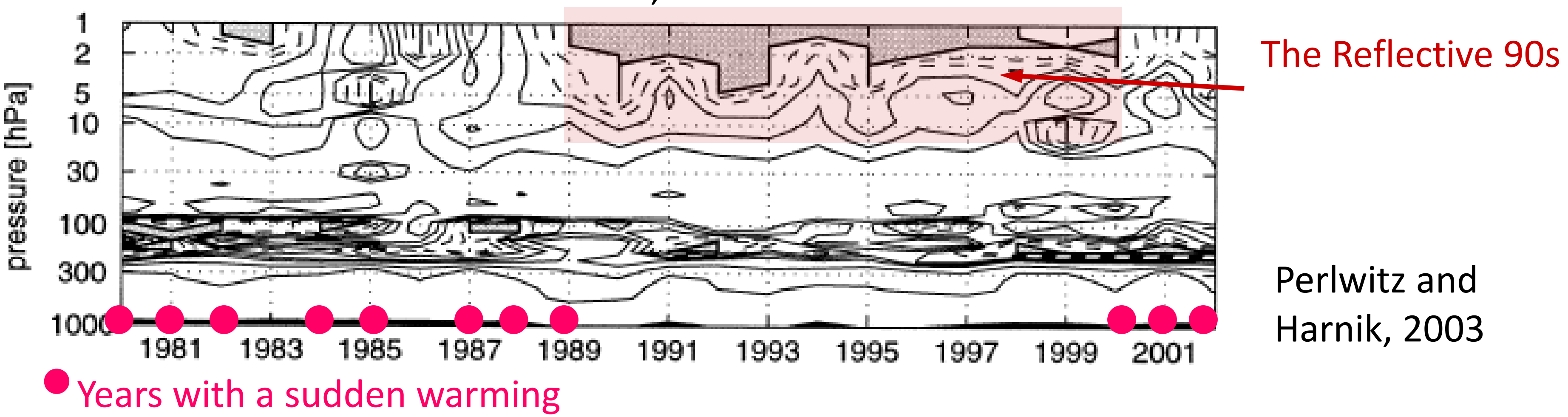
The donward wave coupling, as seen in zonal mean and wave stratosphere-troposphere correlations suggest both zonal mean and wave couplings exist in NH winter

Shaw et al, 2010



A closer look shows large interannual and decadal variability of downward reflection during Jan-Mar

JFM Vertical wavenumber, 58-74N mean



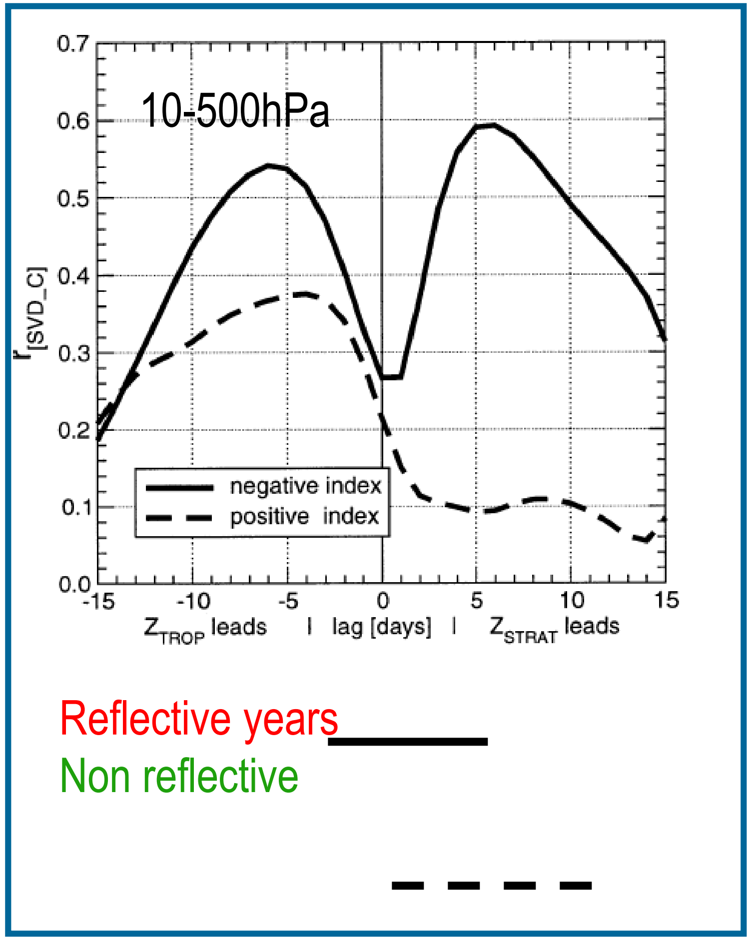
Perlwitz and Harnik, 2003

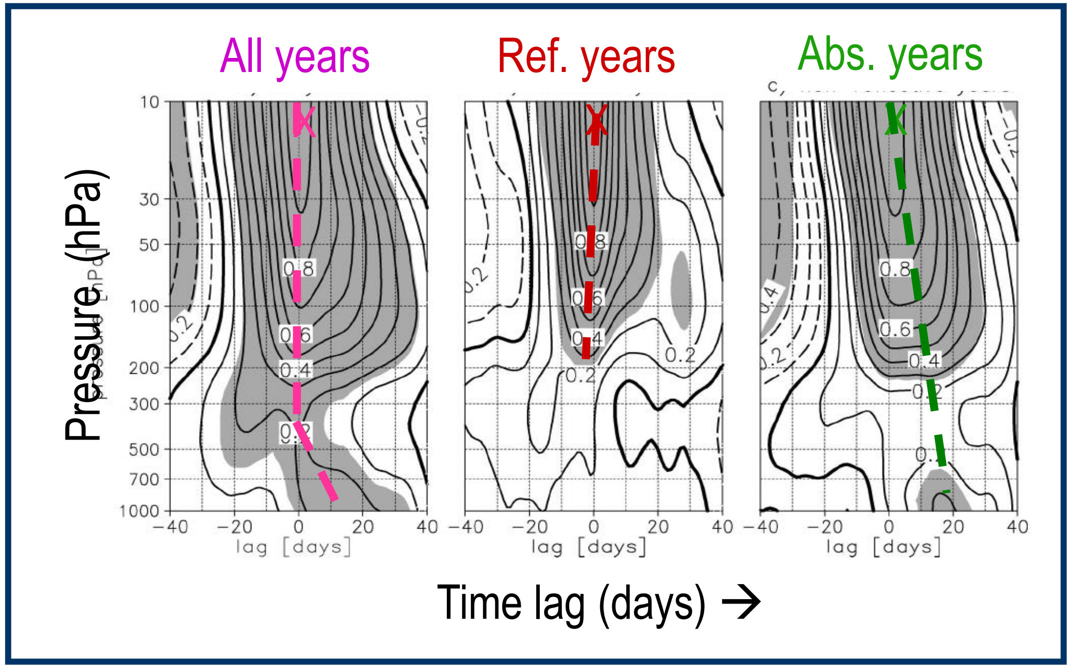
Examining reflective and non reflective years separately shows downward coupling varies correspondingly

Downward wave coupling only during reflective years

Perlwitz and Harnik, 2003, 2004

Downward NAM correlations only during non reflective years





→ An indirect effect of reflection: the downward progression of NAM correlations disappears during reflective years

Summary:

Reflection and downward coupling occur when a bounded wave geometry forms, towards end of winter:

- In SH as part of climatological seasonal cycle
- In NH during some years (inter-annual variability), with strong wave absorption and sudden warmings during other years

An indirect influence on the troposphere – reflection excludes a zonal mean downward influence.