Stratospheric Influence on the Troposphere by Planetary Wave Reflection

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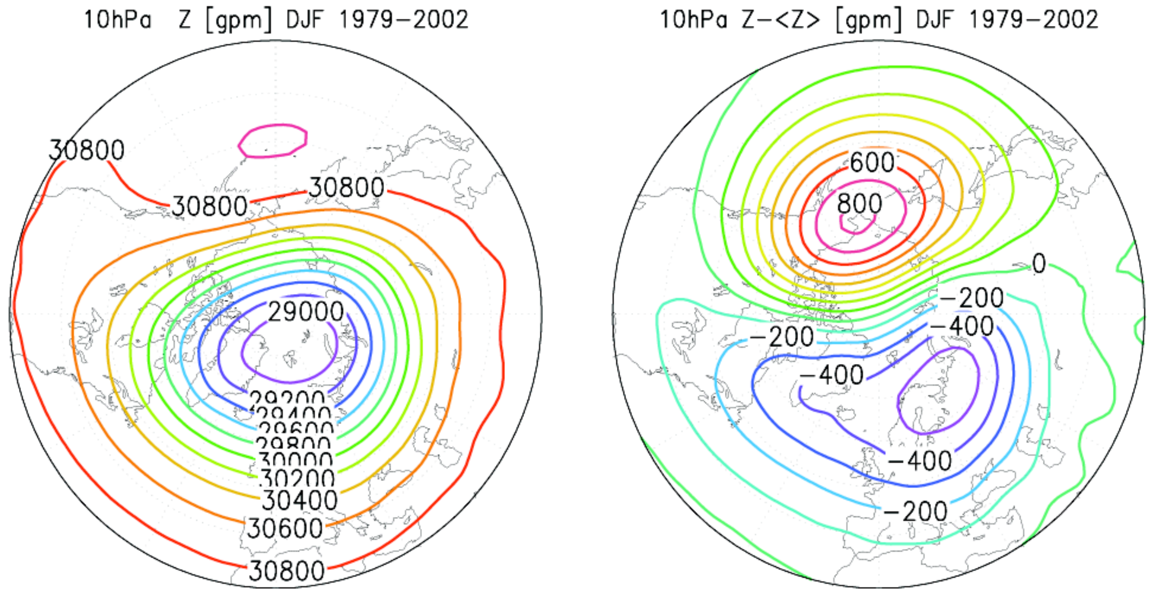
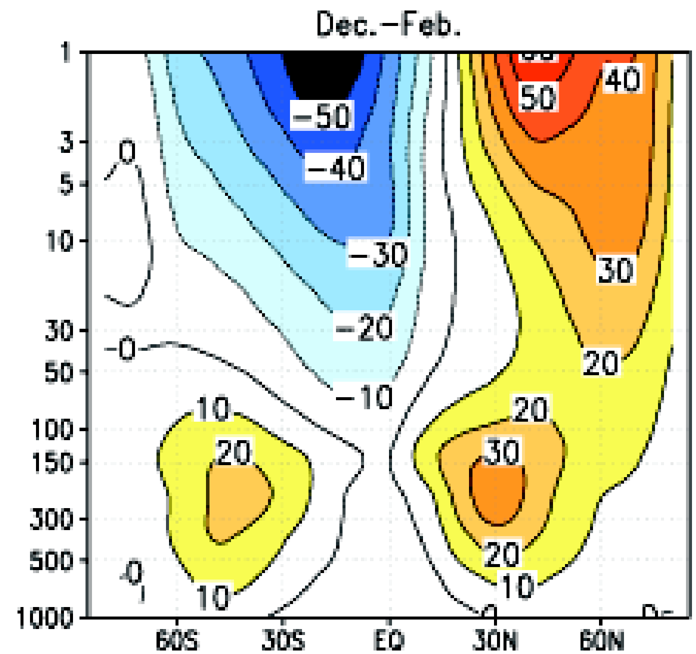
Outline

1. **Introduction**
2. **Downward reflection of planetary waves - evidence that it occurs with a statistical significant signal in the troposphere, during about half of the Northern Hemisphere winters.**
    - Diagnostics: SVD analysis, wave geometry
    - The reflective basic state configuration
3. **Summary and implications**

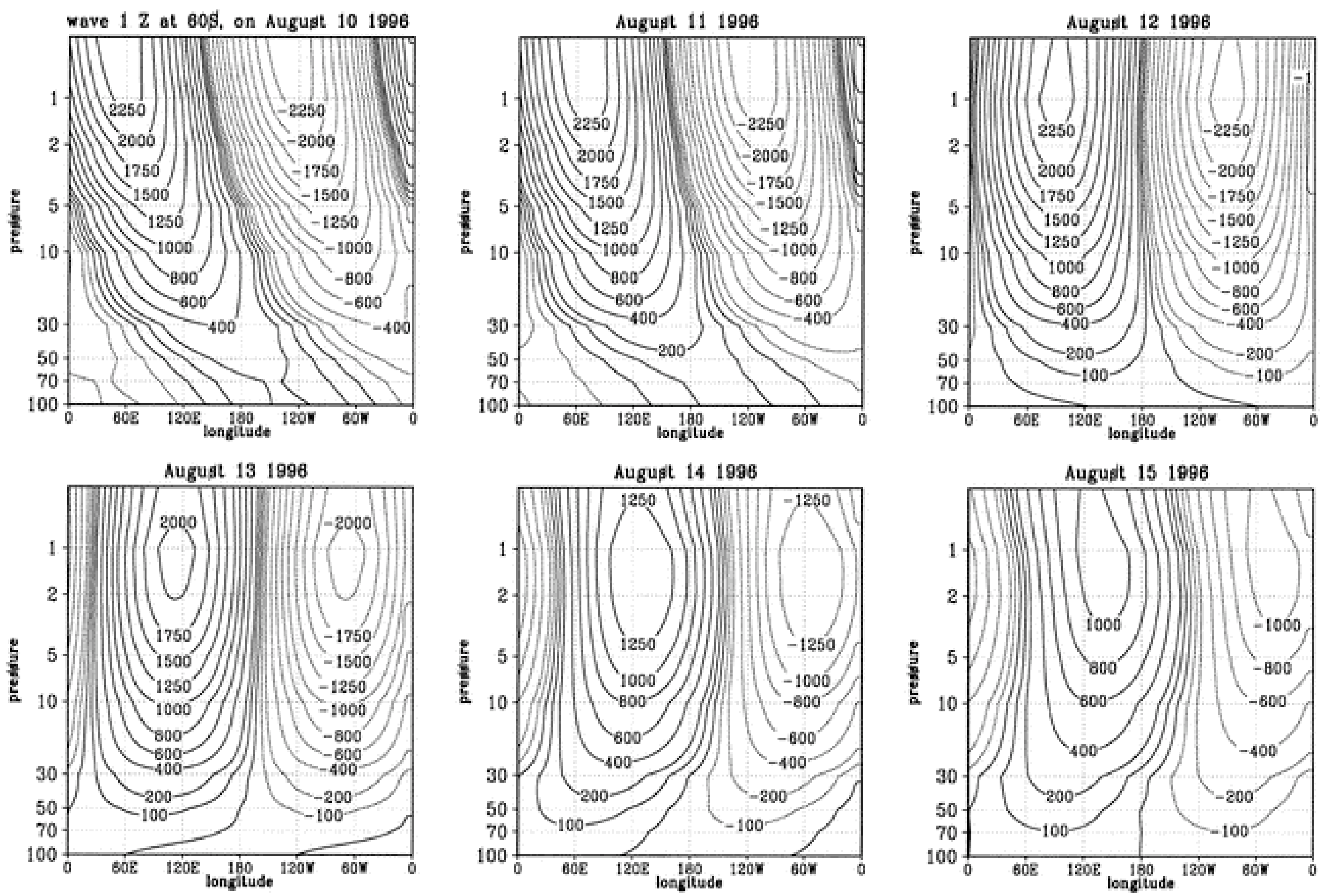
Z 10hPa [gpm]



Zonal mean zonal wind [m/s]



Longitude-height section of Wave 1 at 60^{o}S (Harnik and Lindzen 2001)



Hines, 1974: A possible mechanism for the production of sun-weather correlations.

"*If, as has been alleged, variations in the outflow of solar plasma have some effect on our weather, then the relevant coupling mechanism must be sought. It is suggested here that planetary waves, which may be subjected to variable* ***reflection in the upper atmosphere*** *and so may induce variable interference patterns in the lower atmosphere, constitute a potential candidate.*"

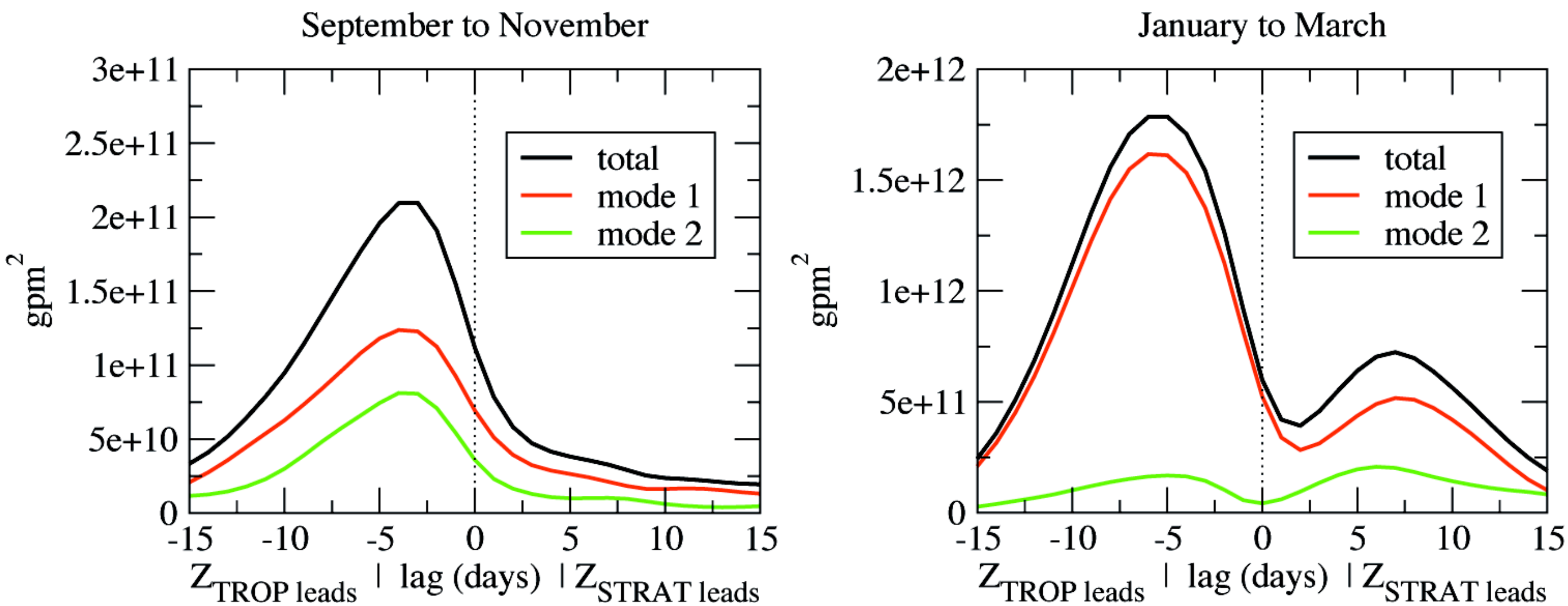
Our approach

- Combine a statistical diagnostic which shows the relationship between the wave fields in the stratosphere and troposphere with a direct diagnostic of reflecting surfaces in the stratosphere
- Use to determine the conditions under which downward reflection of waves back into the troposphere occurs
- Study Northern Hemisphere winter, using daily NCEP/NCAR reanalysis data and daily satellite based analyses of wind and temperature from NASA/GSFC (1979-2002)

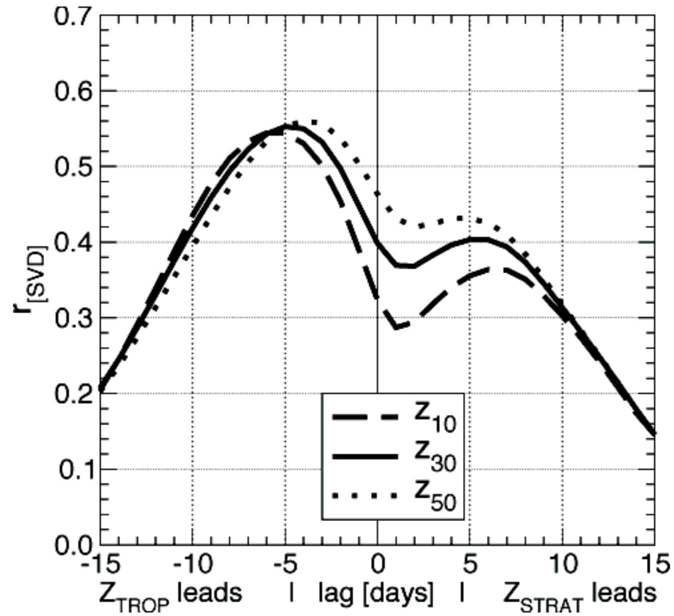
Time-lagged SVD analysis

- Isolate coupled modes between two fields that describe maximum covariance
- Apply SVD analysis to the wave 1 gepotential height fields at two levels, 500hPa (troposphere) and various stratospheric levels
- Carry out series of SVD analysis at various time lags (-15 to 15 days)
- Compare results
  - Squared covariance between the two fields
  - Correlation coefficients between temporal expansion coefficients
  - Associated patterns

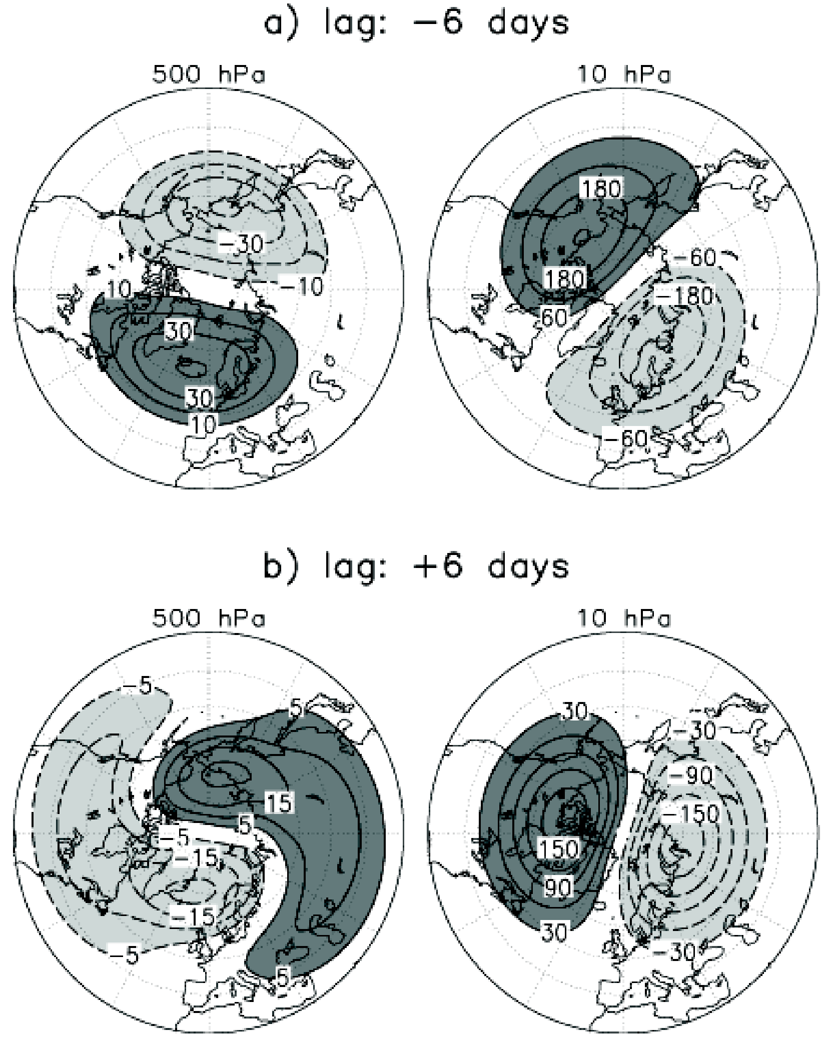
Total squared covariance between Northern Hemisphere 10 and 500hPa wave 1 height fields



Correlation Coefficients



Associated Patterns



Phase shift with height □E

SVD analysis	$rmax_{SVD\,(lag<0)}$ lag [days]	$rmax_{SVD\,(lag<0)}$ $d\lambda$ (65°N)	$rmax_{SVD\,(lag>0)}$ lag [days]	$rmax_{SVD\,(lag>0)}$ $d\lambda$ (65°N)
[500 hPa;10 hPa]	-6	-132.5	6	107.5
[500 hPa;30 hPa]	-5	-105.0	5	85.0
[500 hPa;50 hPa]	-4	-80.0	4	62.5

Diagnosing reflecting surfaces (Harnik and Lindzen, 2001)

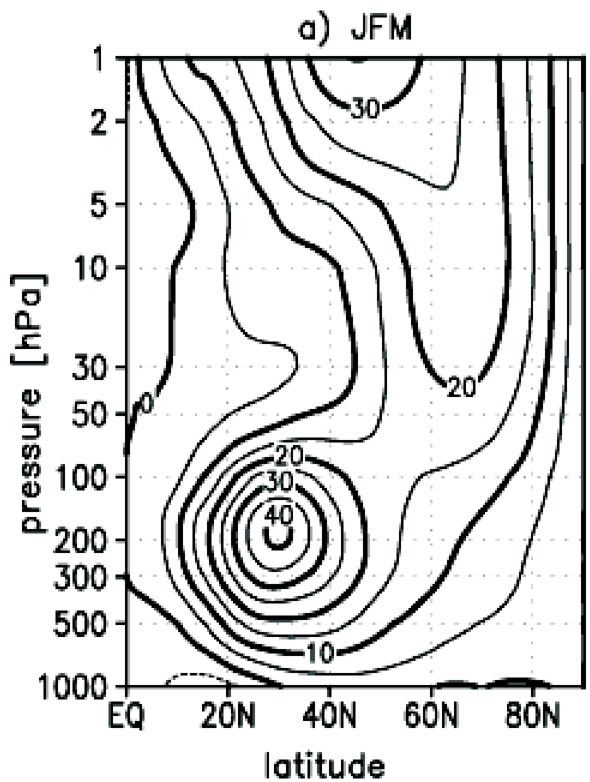
- For a given basic state, zonal wave number and phase speed
- Separate the index of refraction into vertical and meridional wave numbers

$$\underbrace{\frac{a_e^2 f^2}{N^2}\frac{\partial^2 \Phi}{\partial z^2}}_{-\Phi m^2} + \underbrace{\frac{f}{\cos\varphi}\frac{\partial}{\partial \varphi}\left(\cos\varphi \frac{\partial}{\partial \varphi}\left(\frac{\Phi}{f}\right)\right)}_{-\Phi l^2} + \underbrace{\left(\frac{a_e^2 q_y}{U} - \frac{1}{\cos^2\varphi} + a_e^2 f^2 F(N^2)\right)\Phi}_{\Phi\times(index\ of\ refraction\ squared)} = damp$$

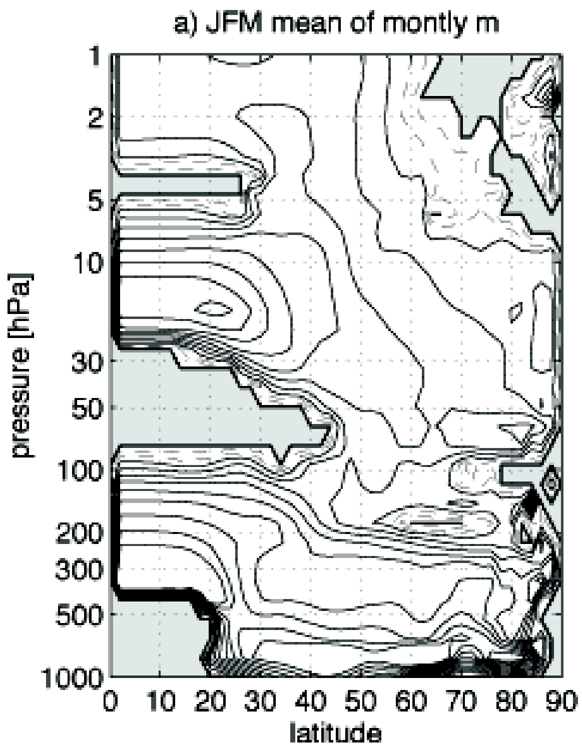
- Use the solution of a Quasi Geostrophic spherical model with the observed state to diagnose m and l

- Regions of $m^2>0$ ($l^2>0$) ->vertical (meridional) wave propagation.
- Regions of $m^2<0$ ($l^2<0$) -> vertical (meridional) wave evanescence.

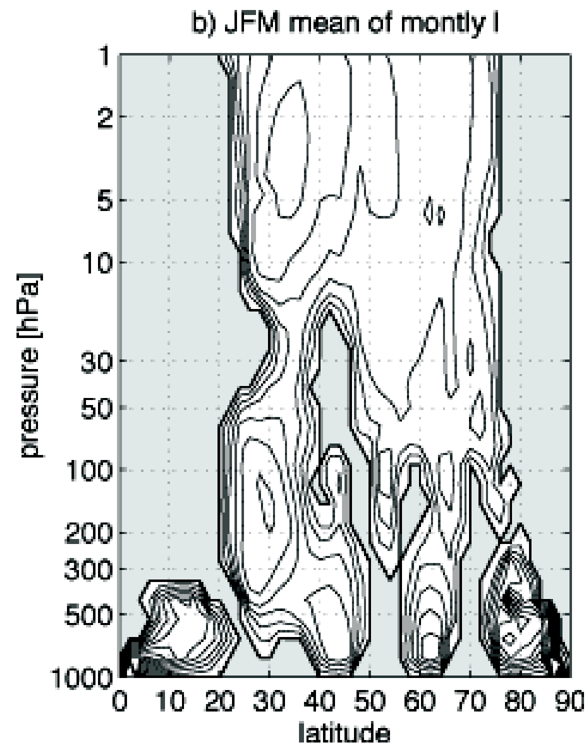
January to March
zonal mean wind and wavenumbers



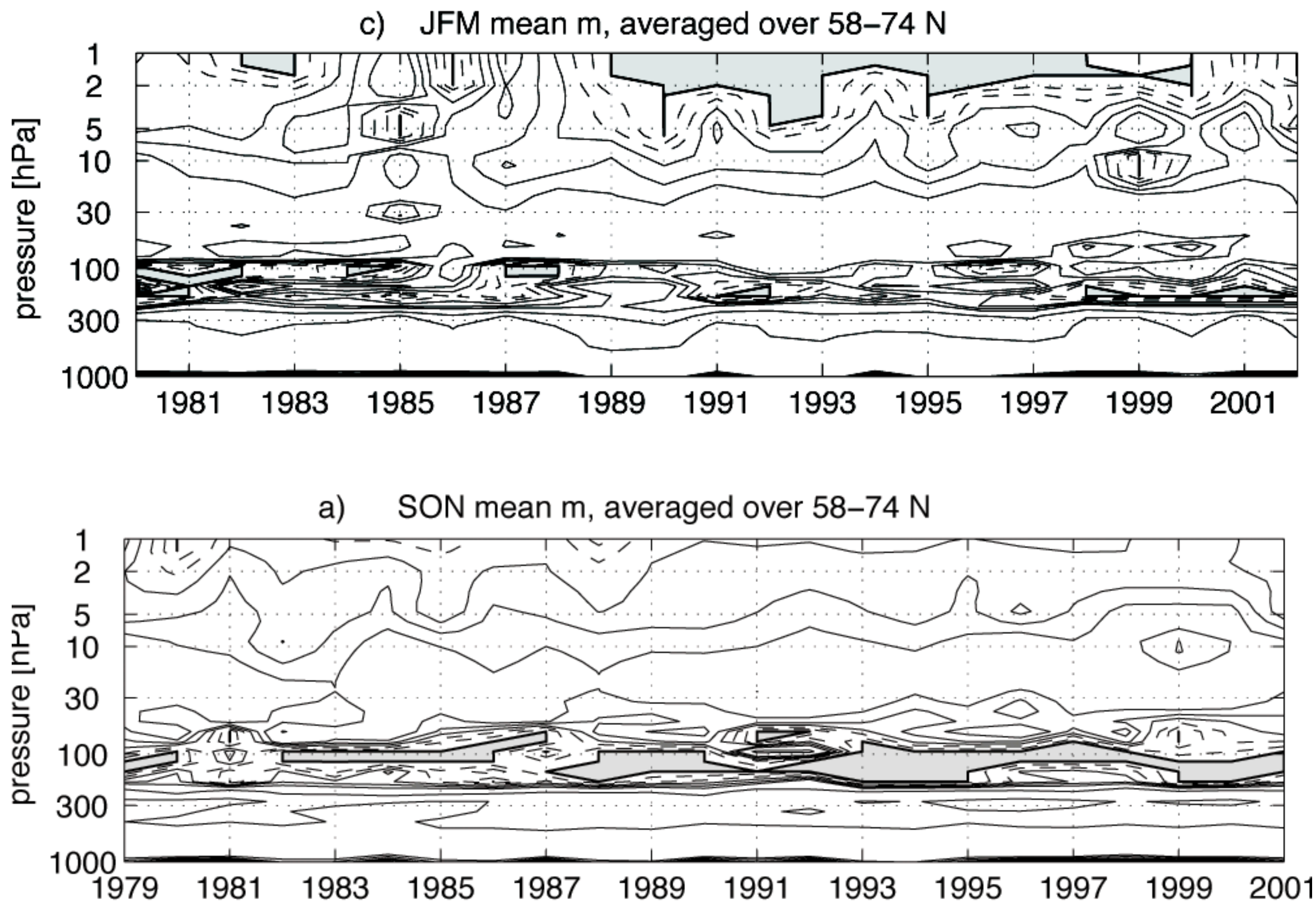
vertical wavenumber



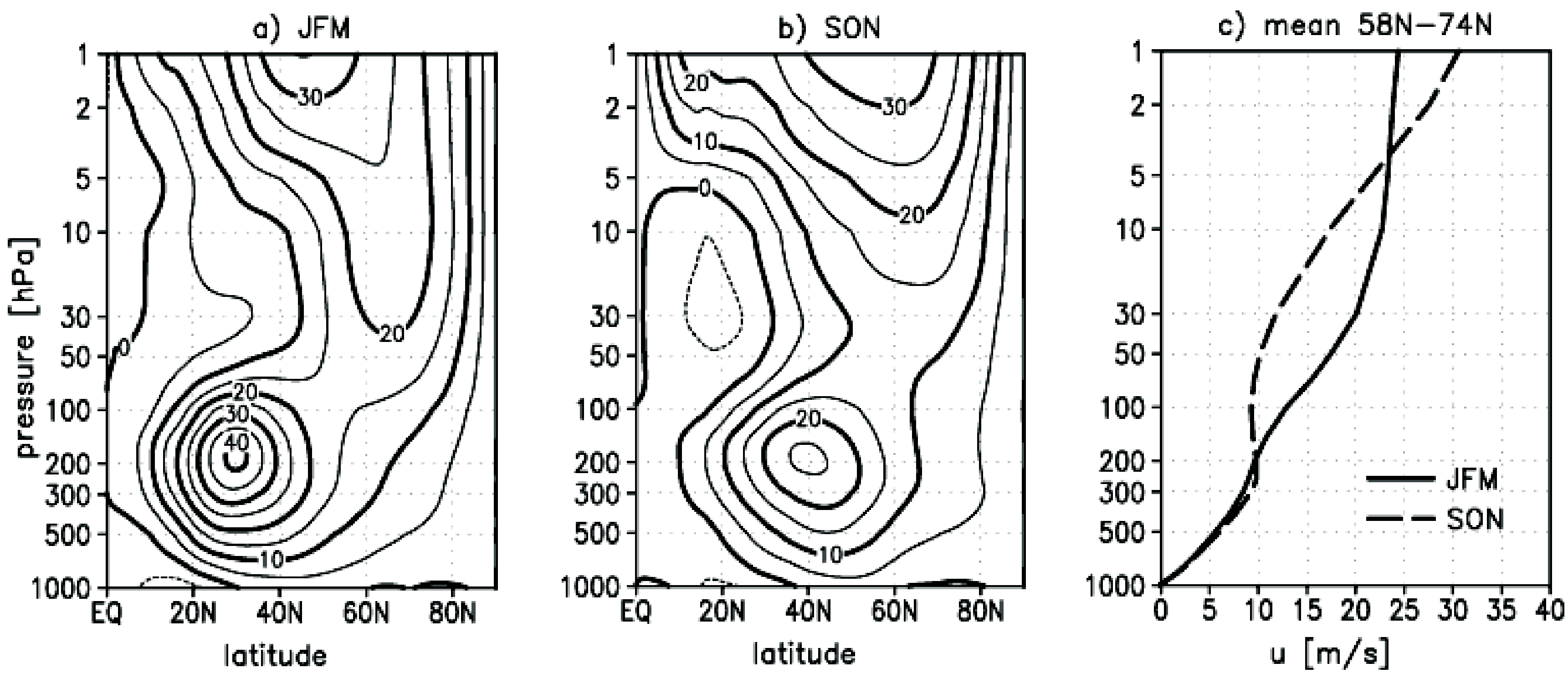
meridional wavenumber



Vertical wavenumbers
Interannual variability



JFM versus SON
Zonal mean zonal wind [m/s]

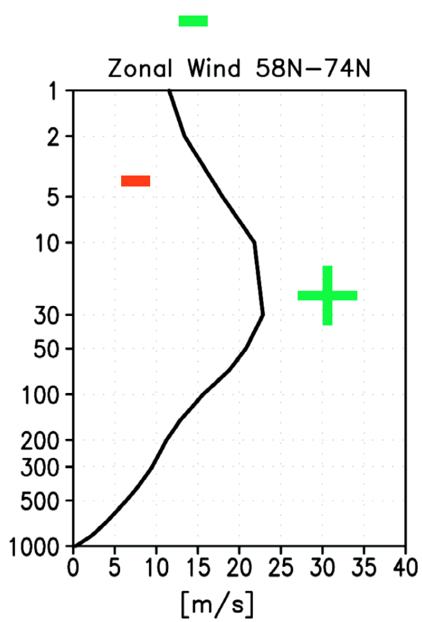


When does reflection occur?

For reflection, need $n_{ref}^2 = \frac{a_e^2 q_y}{U} - \frac{1}{\cos^2\varphi} + a_e^2 f^2 F(N^2)$ small or negative:

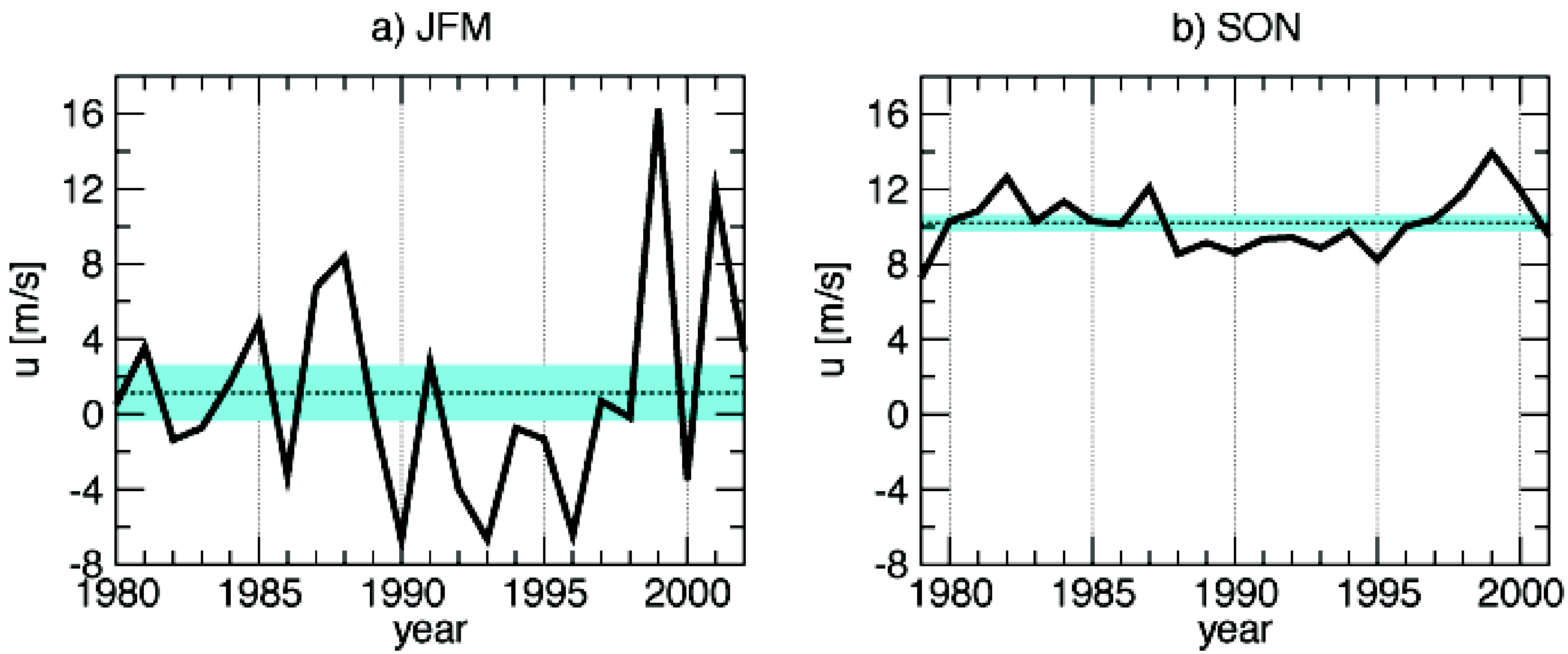
- U large (the Charney-Drazin criterion)
- q_y small or negative

$$q_y = \beta - \frac{1}{a_e^2}\frac{\partial}{\partial\varphi}\left(\frac{1}{\cos\varphi}\frac{\partial(U\cos\varphi)}{\partial\varphi}\right) \underbrace{- \frac{f^2}{\rho_o e^{-z/H} a_e^2}\frac{\partial}{\partial z}\left(\frac{\rho_o e^{-z/H}}{N^2}\frac{\partial U}{\partial z}\right)}_{\frac{f^2}{H a_e^2 N^2}\frac{\partial U}{\partial z} - \frac{f^2}{a_e^2 N^2}\frac{\partial^2 U}{\partial z^2}}$$

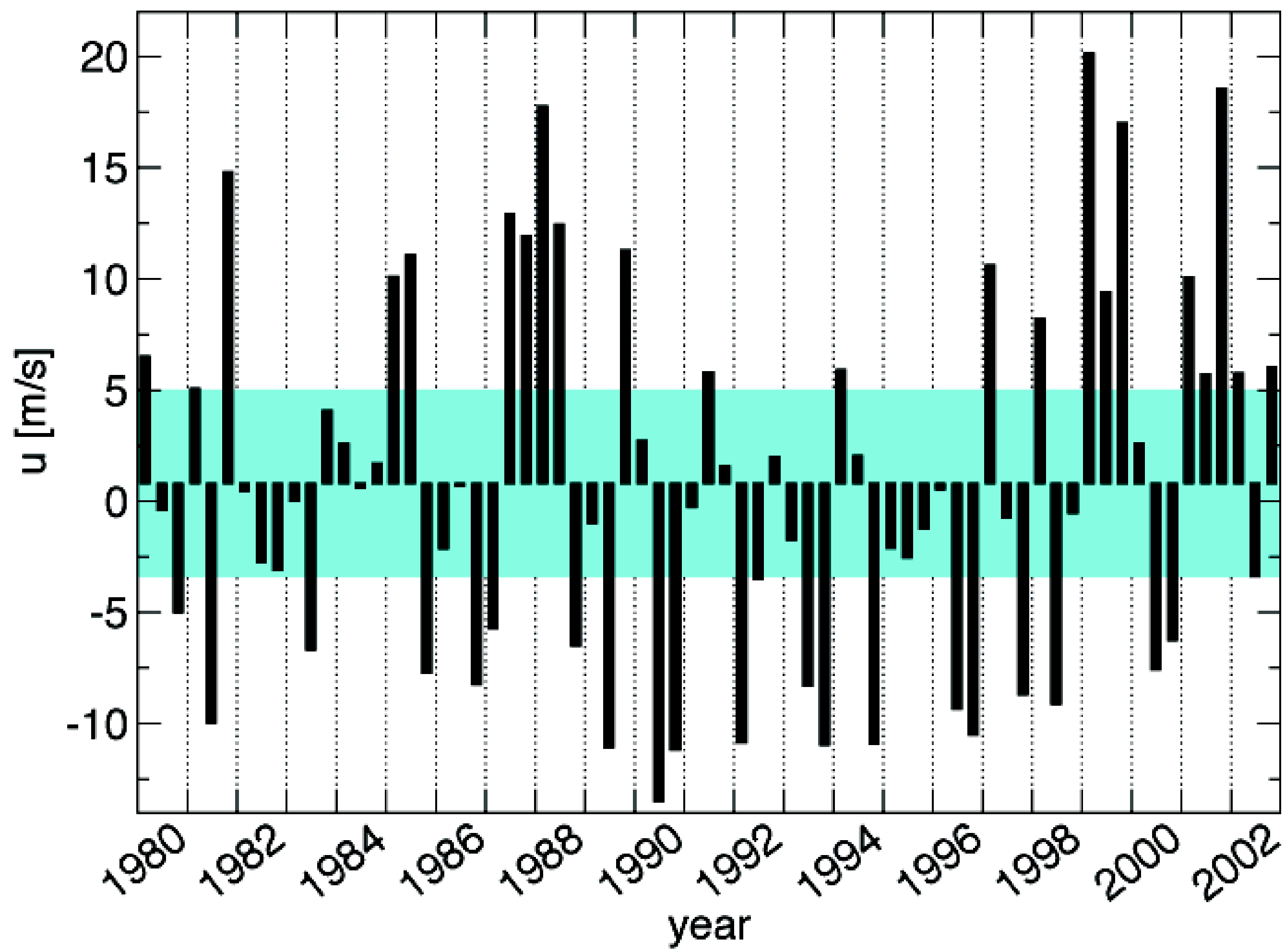


Observations for stationary wave 1:
$U_z < 0$ in upper stratosphere reduces q_y near reflecting surface (5 hPa).

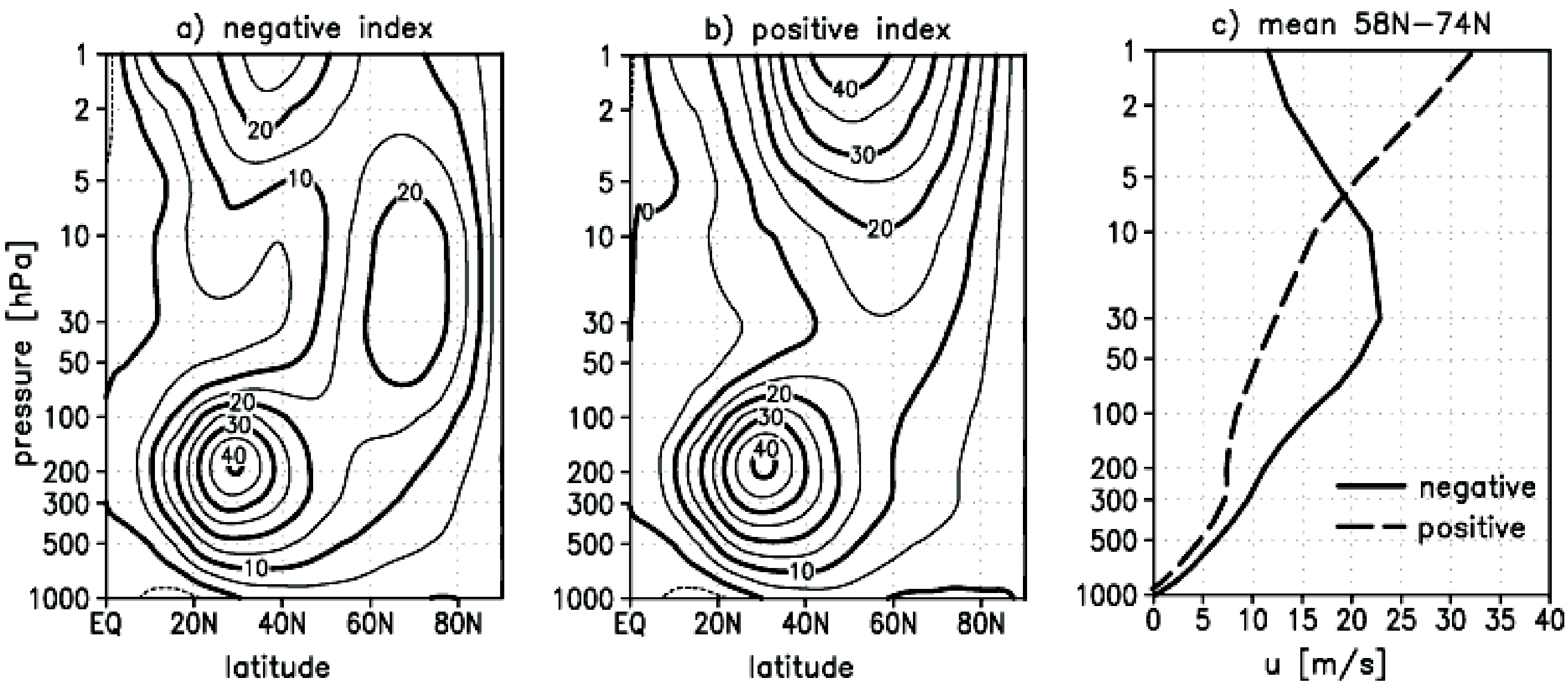
Reflection index:
vertical wind shear at 2 -10 hPa 58^o-74^oN



The monthly $U_{2\text{-}10}$ index
Jan,Feb,Mar



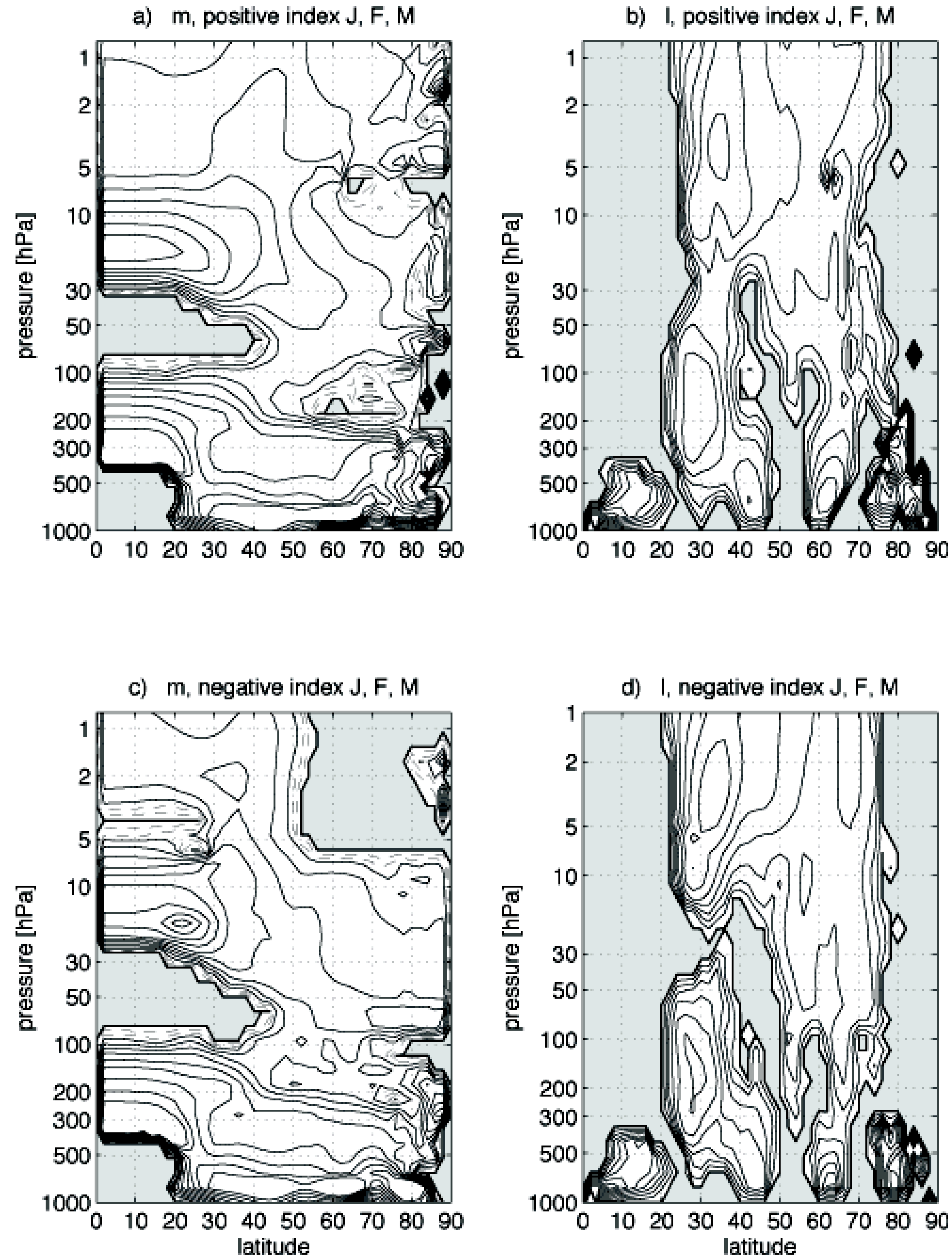
Negative and positive index $U_{2\text{-}10}$ basic state composites



Wavenumbers

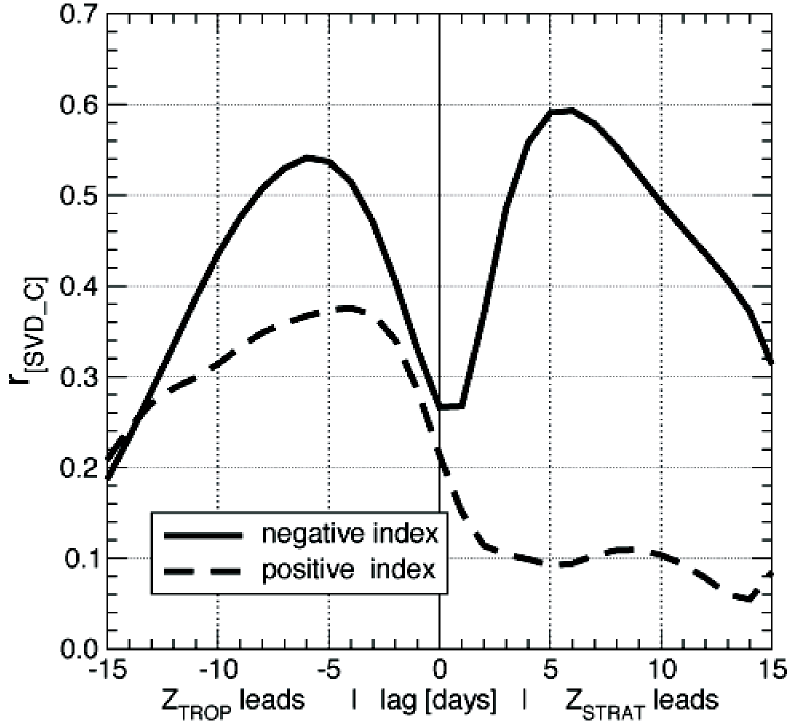
Positive index

Negative index



SVD correlations for negative and positive $U_{2\text{-}10}$ months

500 and 10 hPa wave 1



Summary

- Downward reflection of wave 1 occurs during Northern Hemisphere winter with a statistical significant signal in mid-troposphere
- A significant tropospheric signal is found when
  - A reflecting surface for vertical propagation forms in the upper stratosphere
  - A well defined waveguide forms at high latitudes in the lower middle stratosphere

-> negative shear in the upper stratosphere ($U_{2-10} < 0$)

- The reflective state occurs during JFM during about half the years and not during fall.

Implications

- Effect of planetary wave reflection on the tropospheric flow?
  - Effect on synoptic time scale
  - By changing the longitudinal orientation of the planetary waves and the wave amplitude
  - Anomalies in tropospheric wave structure will further induce zonal mean and eddy anomalies
- Climate change impact on troposphere?
  - By changing the reflective properties of the basic state

Weather forecast models and climate models have to be able to resolve full stratospheric dynamics with a realistic basic state and variability