Inertial Gravity Waves in the Antarctic Stratosphere

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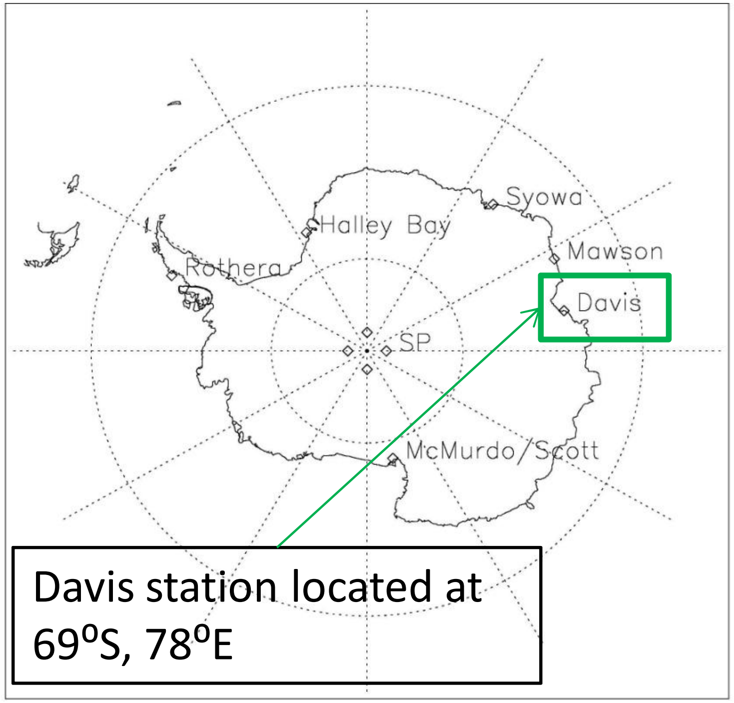
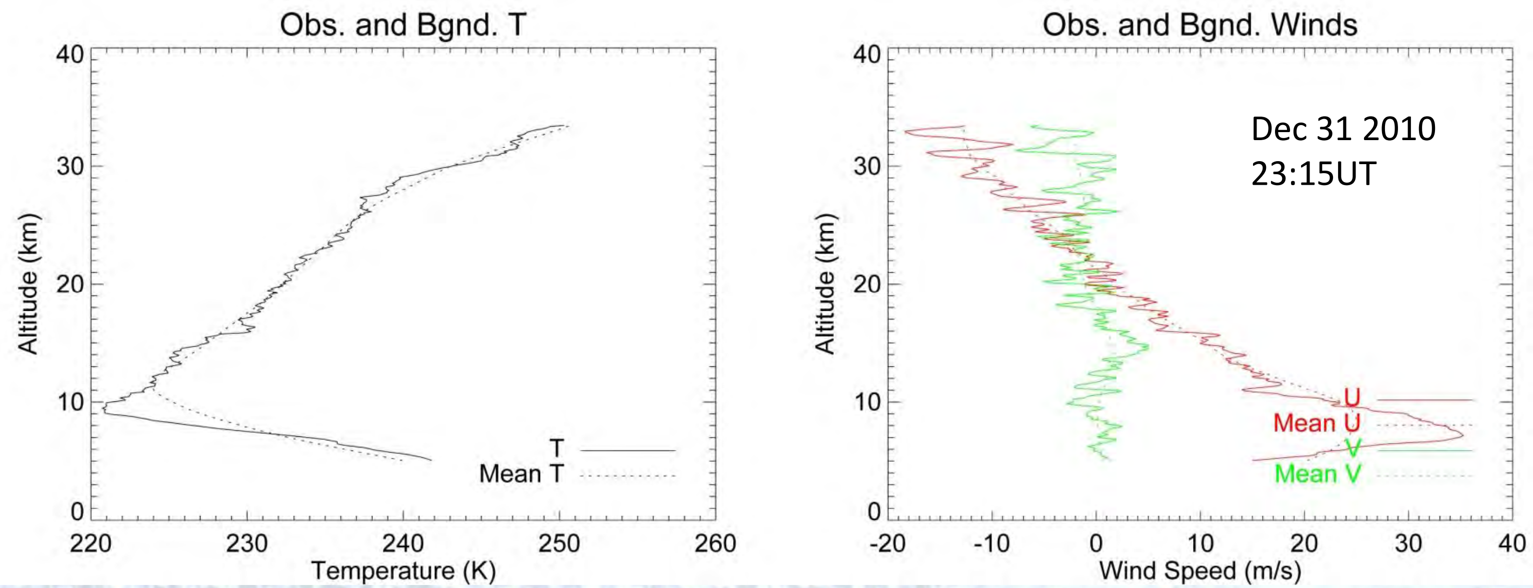
Outline

- Describe analysis method applied to Davis radiosonde observations;
- Consider which portions of the gravity wave spectrum are visible with this technique;
- Describe some of the characteristics of the waves observed over multiple years;
- Investigate the reasons behind these characteristics;
- Consider the relationship between these waves and parameterization schemes.



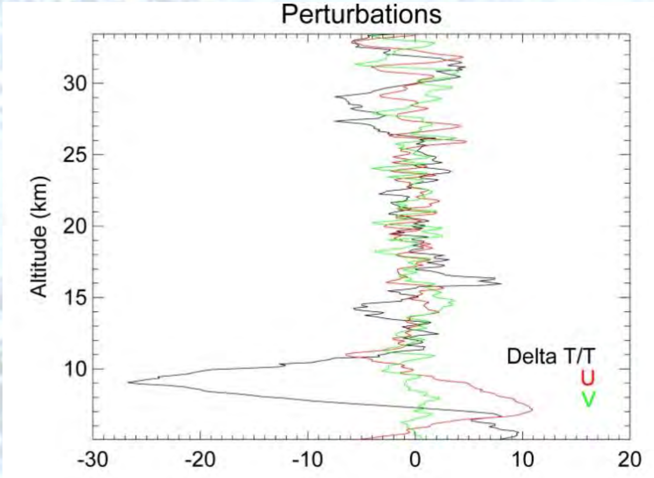
Gravity wave parameter extraction

Primary data obtained from operational radiosonde flights launched between 2001-2012.



Parameter extraction starts with the removal of a background profile.

A simple smoothing is used (potentially problematic near the tropopause).

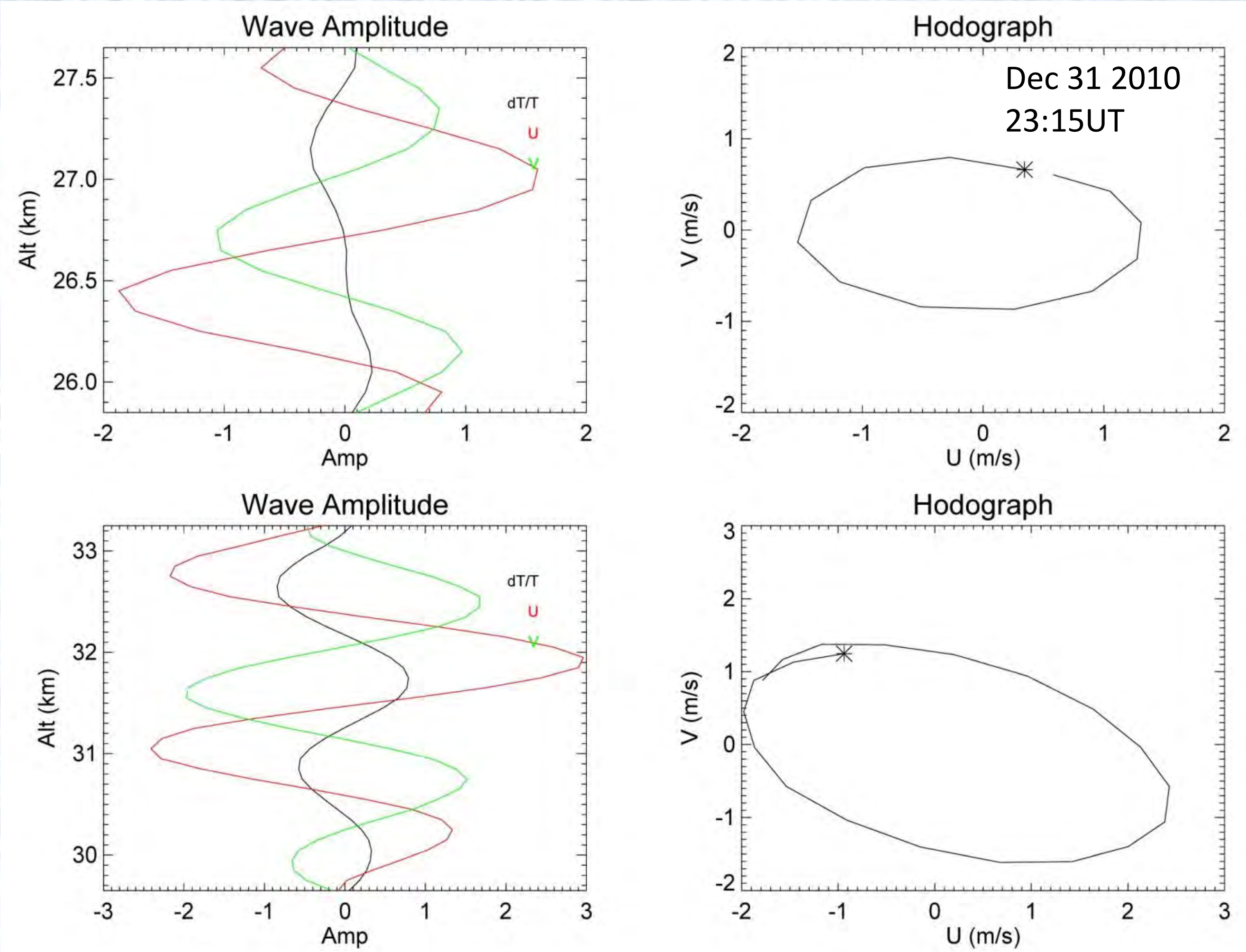


Gravity wave parameter extraction

Wavelet analysis then extracts waves of various vertical scales in wind components and temperature.

Displaying the winds in a ‘hodograph’ shows distinct characteristics of long period (‘inertial’) gravity waves.

The direction of rotation tells us if the wave is propagating upward or downward.



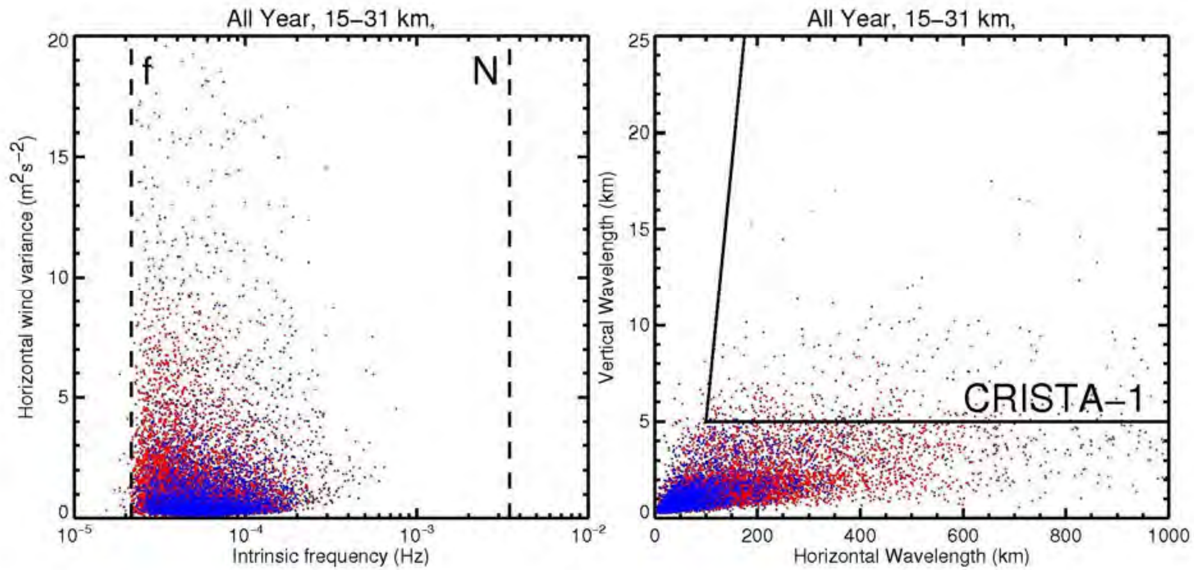
Orientation and axial ratio give the direction of propagation and the intrinsic frequency. Vertical wavelength available from profile.

Which waves are we seeing?

The analysis technique implicitly applies an observational filter [Alexander, 1998].

<u>We do not see the full gravity wave spectrum.</u>

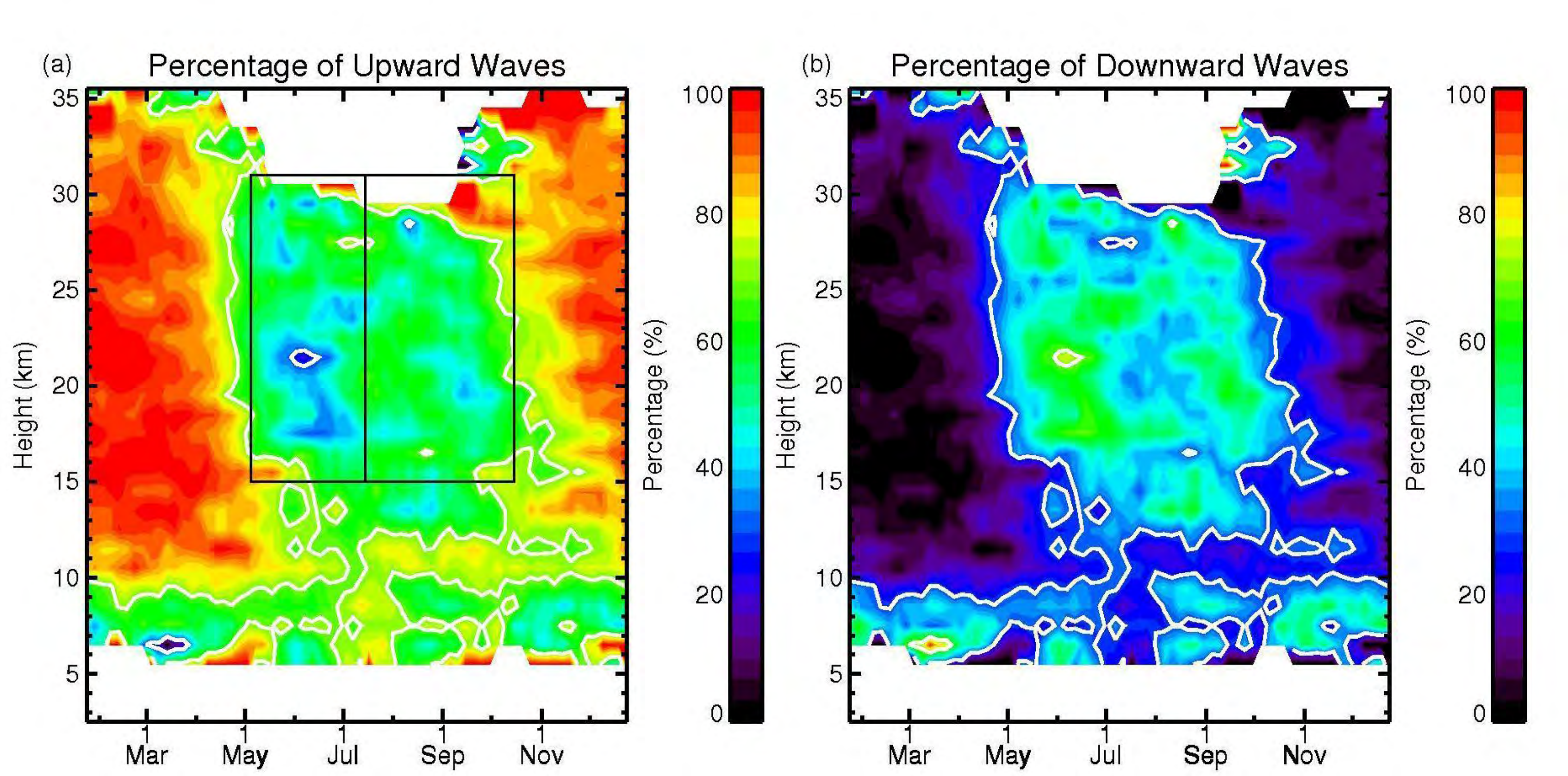
A good depiction of this filtering was presented in Hertzog et al. [2008] for Antarctic super-pressure balloon observations:



Similar plots (but using variance in left hand panel) for Davis radiosonde observations.
Large vertical wavelengths precluded by the sonde height range and wavelet characteristics.

Gravity Wave Characteristics

The sense of rotation of the hodograph ellipse is used to compile a 12 year climatology of upward and downward wave percentages.



Wintertime increases in downward propagating waves over Antarctica have been previously identified [Sato & Yoshiki, 2008; Moffat-Griffin et al., 2011] but without the height structure shown here.

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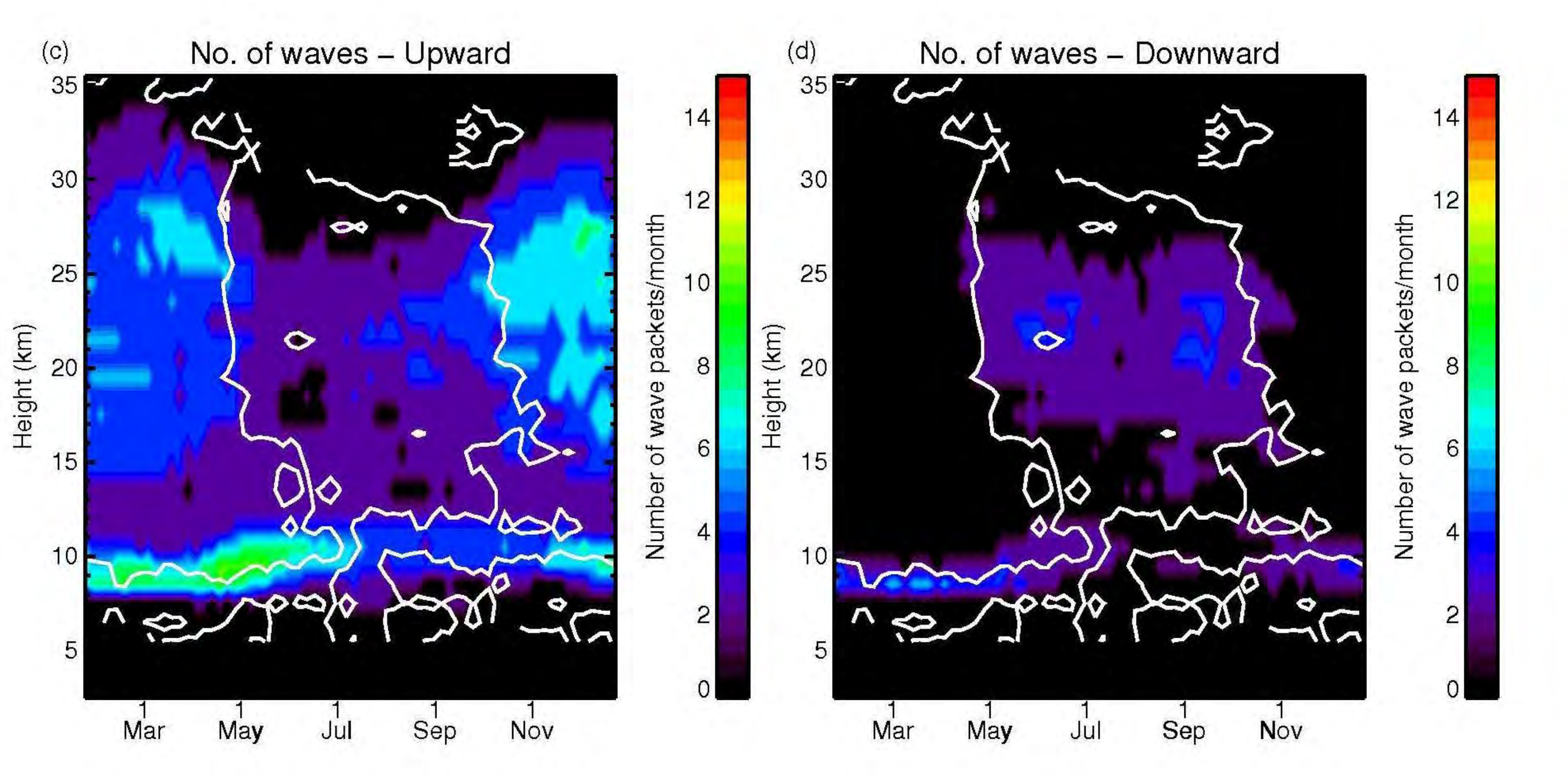

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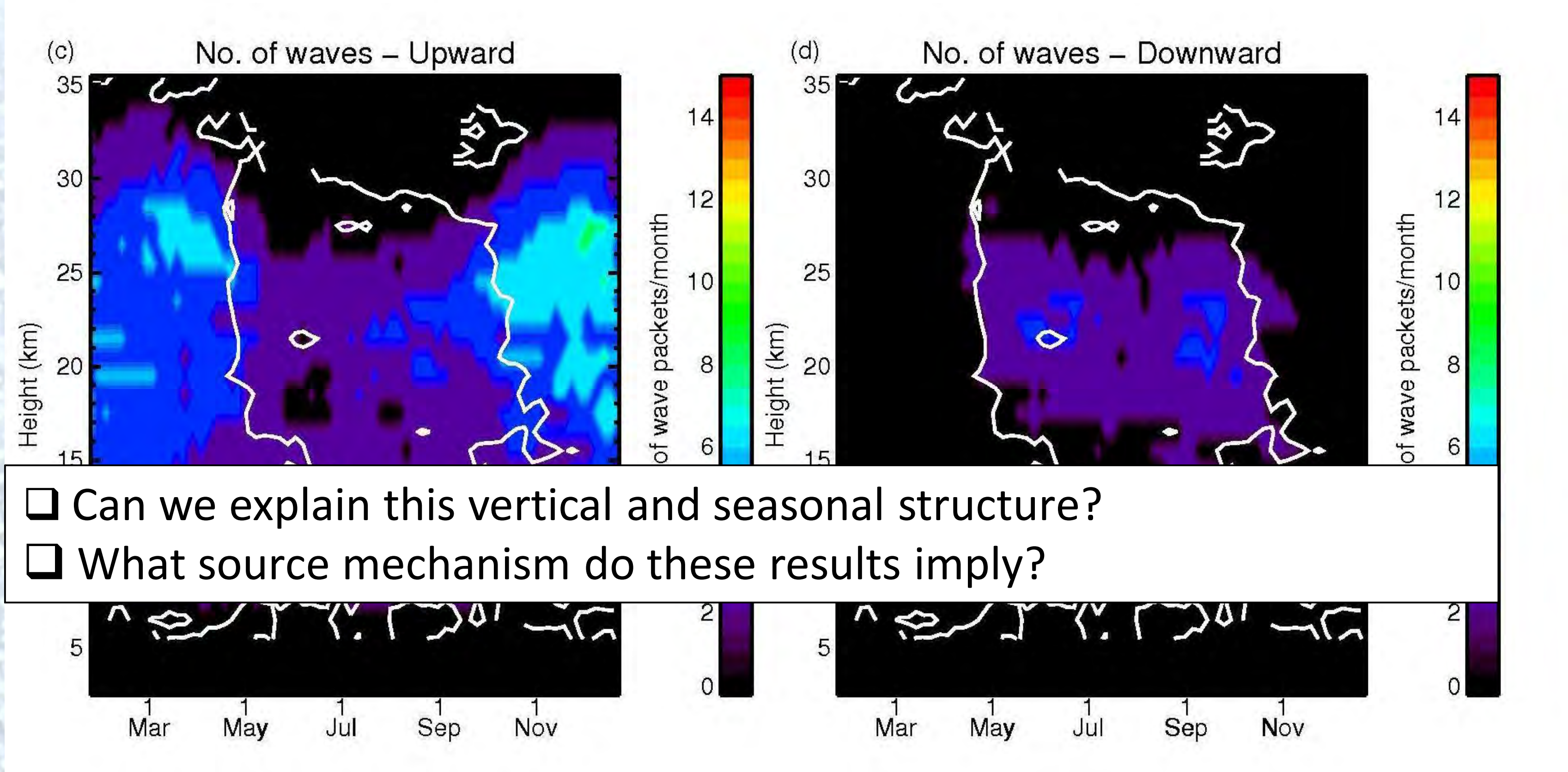

- ❑ Can we explain this vertical and seasonal structure?
- ❑ What source mechanism do these results imply?

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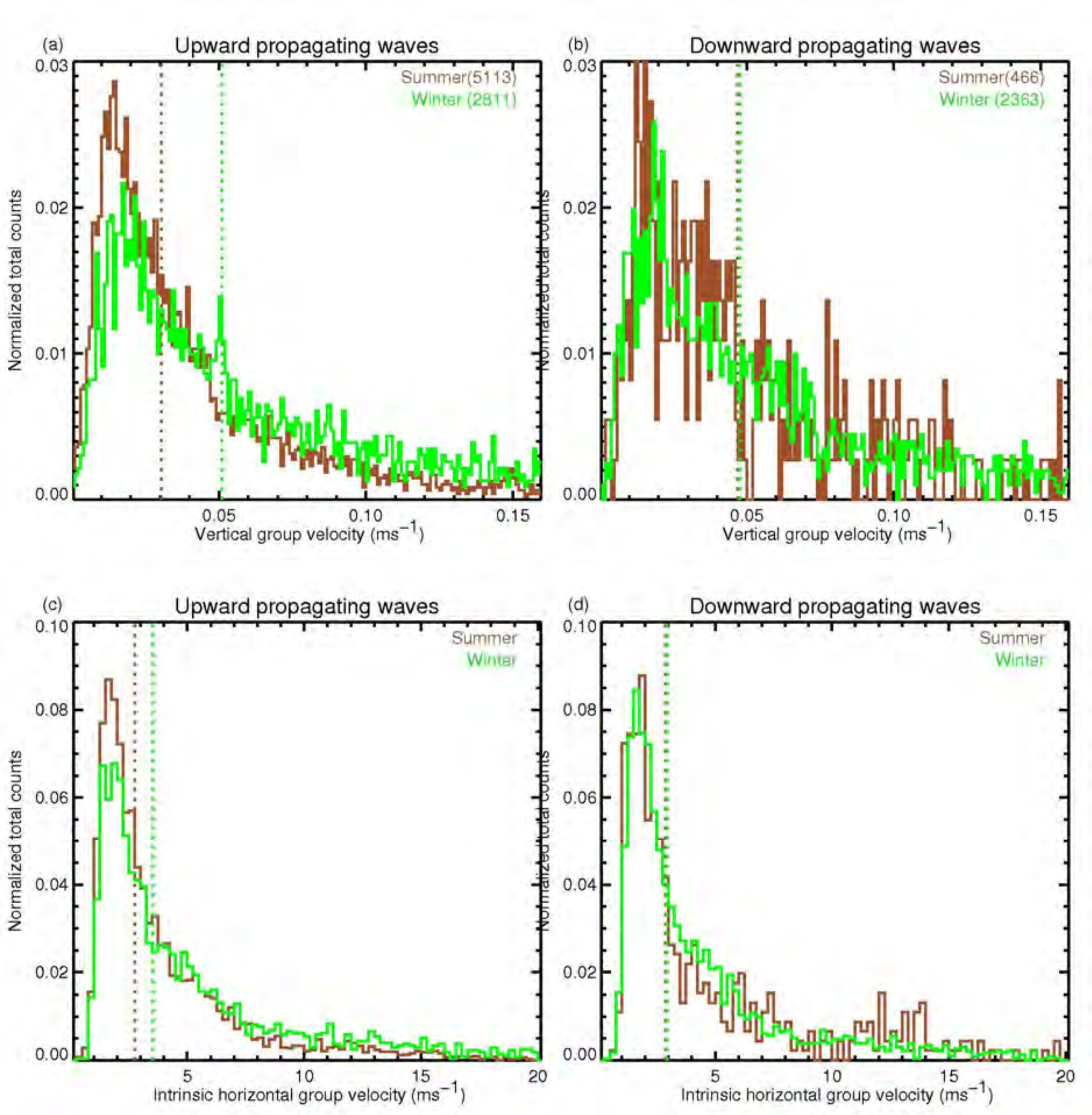
Gravity wave characteristics



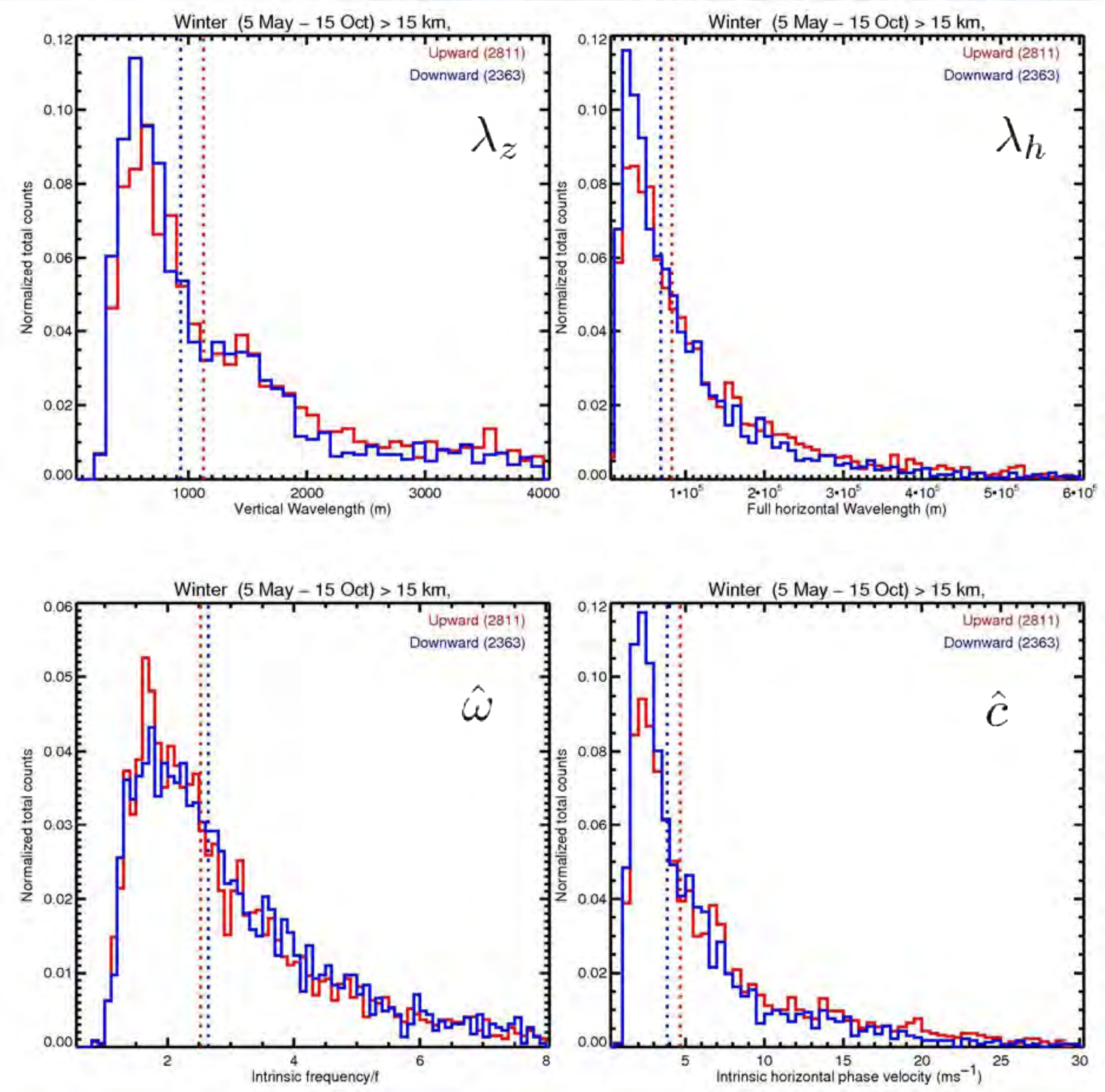
Vertical group velocity is small: ~0.05ms^{-1} for winter, up and down.

Horizontal group velocity is larger: ~3ms^{-1} for winter, up and down.

These imply an elevation angle of around 1^{o}:

Propagation is very close to horizontal. (Expected for inertial GWs.)

Comparing upward and downward wintertime waves



The distributions of gravity-wave characteristics of wintertime upward and downward propagating waves are very similar.

- Vertical wavelength
- Horizontal wavelength
- Intrinsic frequency and
- Intrinsic phase speed

are shown here but this is true of almost all GW parameters.

Potential source models (1)

Tropospheric source

Åt common to attribute tropospheric processes to gravity wave generation.

ÅThis cannot explain the high percentage of downward propagating waves in winter.

Noting that the upward and downward propagating waves are very similar in their characteristics, is it possible that the downward propagating waves are reflected versions of the upward ones?

Tropospheric source with reflection

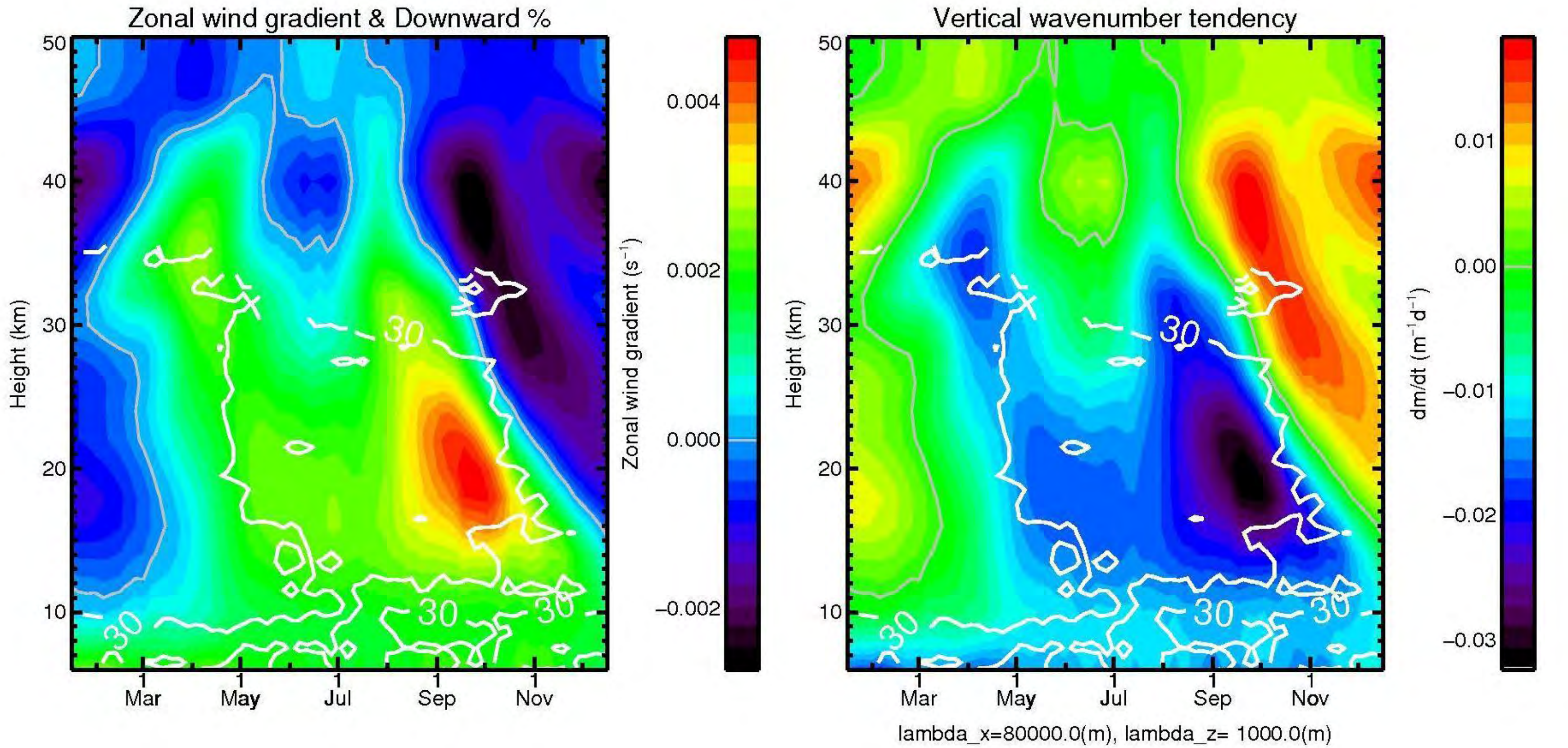
This can be investigated using a gravity wave ray tracing equation...

Tendency in *m* following the wave depends on vertical shear in zonal and meridional wind, and in Brunt-Vaisalla frequency squared.

$$\frac{d_g m}{dt} = \frac{(k^2+l^2)(N^2)_z}{2\hat{\omega}(k^2+l^2+m^2)} - k\bar{u}_z - l\bar{v}_z$$

Horizontal wavenumbers *k* and *l* can vary with propagation but an estimate of wave propagation behaviour can be obtained by using typical values (from observations) and background wind and temperature fields (from reanalysis – here UKMO).

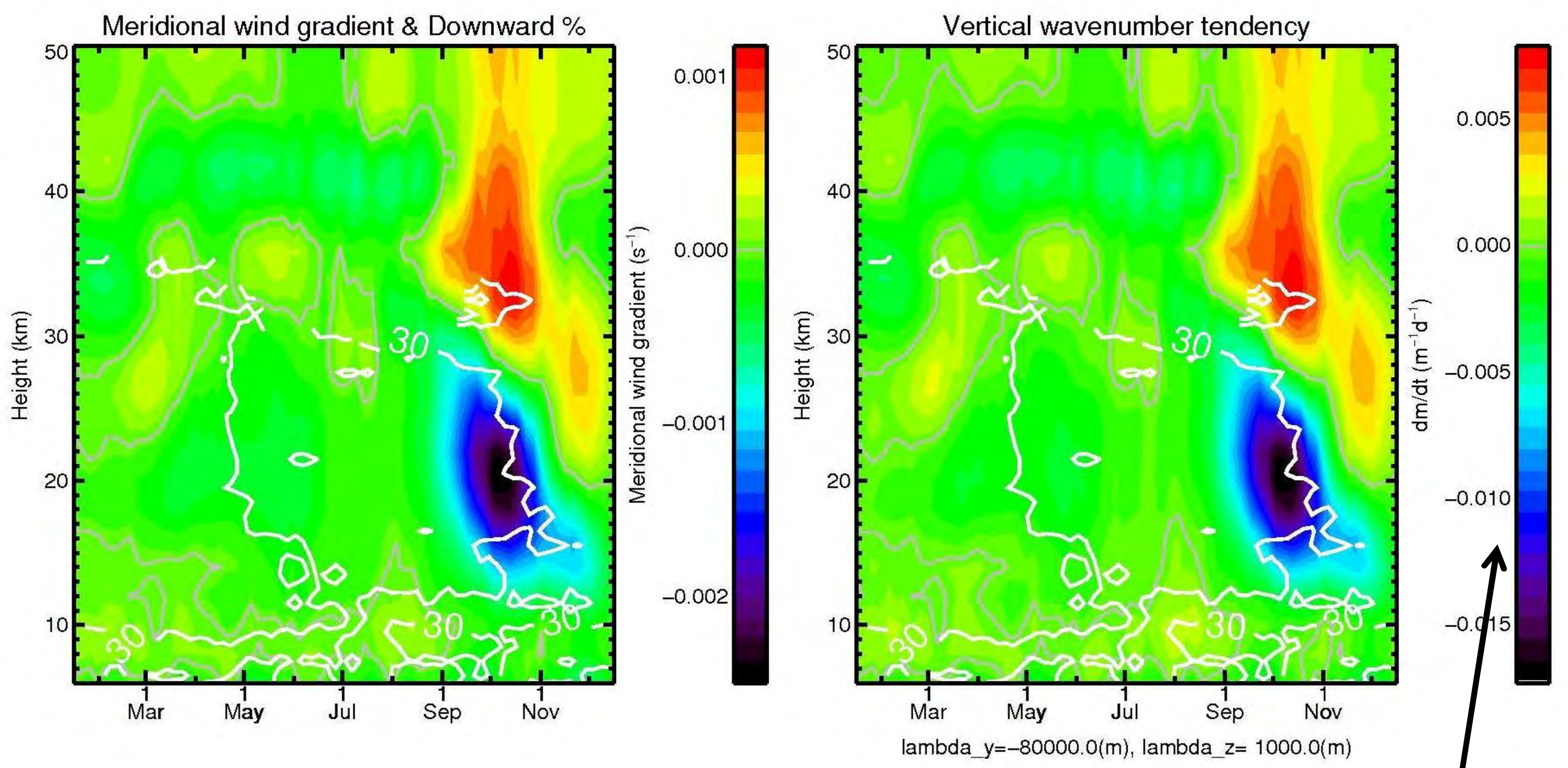
Vertical wavenumber tendency - U_z



$$\frac{d_g m}{dt} = \frac{(k^2+l^2)(N^2)_z}{2\hat{\omega}(k^2+l^2+m^2)} - k\bar{u}_z - l\bar{v}_z$$

Likely influence of U_z on switch on/off but not upper boundary.

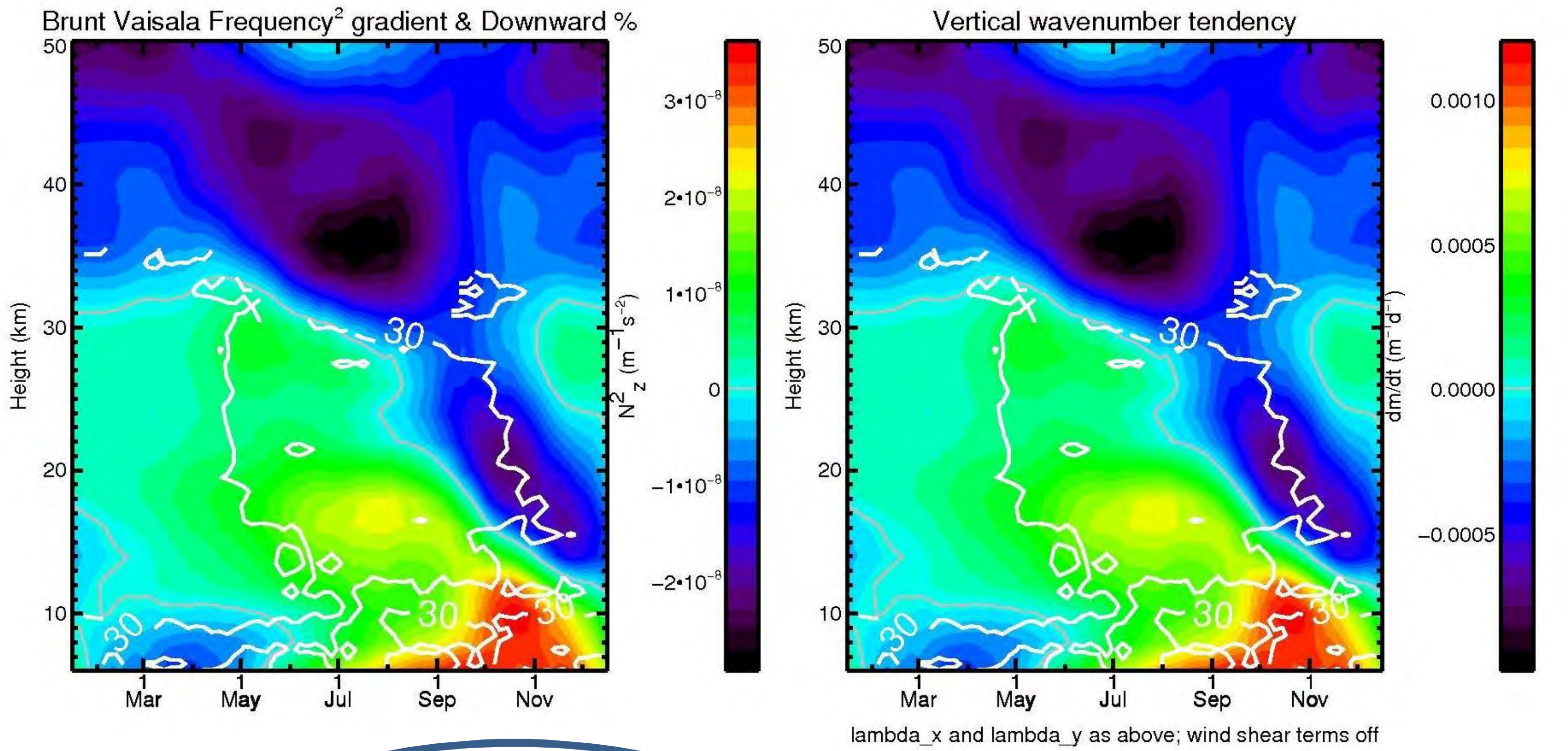
Vertical wavenumber tendency - V_z



$$\frac{d_g m}{dt} = \frac{(k^2+l^2)(N^2)_z}{2\hat{\omega}(k^2+l^2+m^2)} - k\overline{u}_z - l\overline{v}_z$$

These values are smaller than for U_z.

Vertical wavenumber tendency – N^2_z



$$\frac{d_g m}{dt} = \frac{(k^2+l^2)(N^2)_z}{2\hat{\omega}(k^2+l^2+m^2)} - k\overline{u}_z - l\overline{v}_z$$

These tendencies are much smaller than those due to zonal velocity, but the correspondence between forms warrants further consideration.

Potential source models (2)

A third potential source model is a:

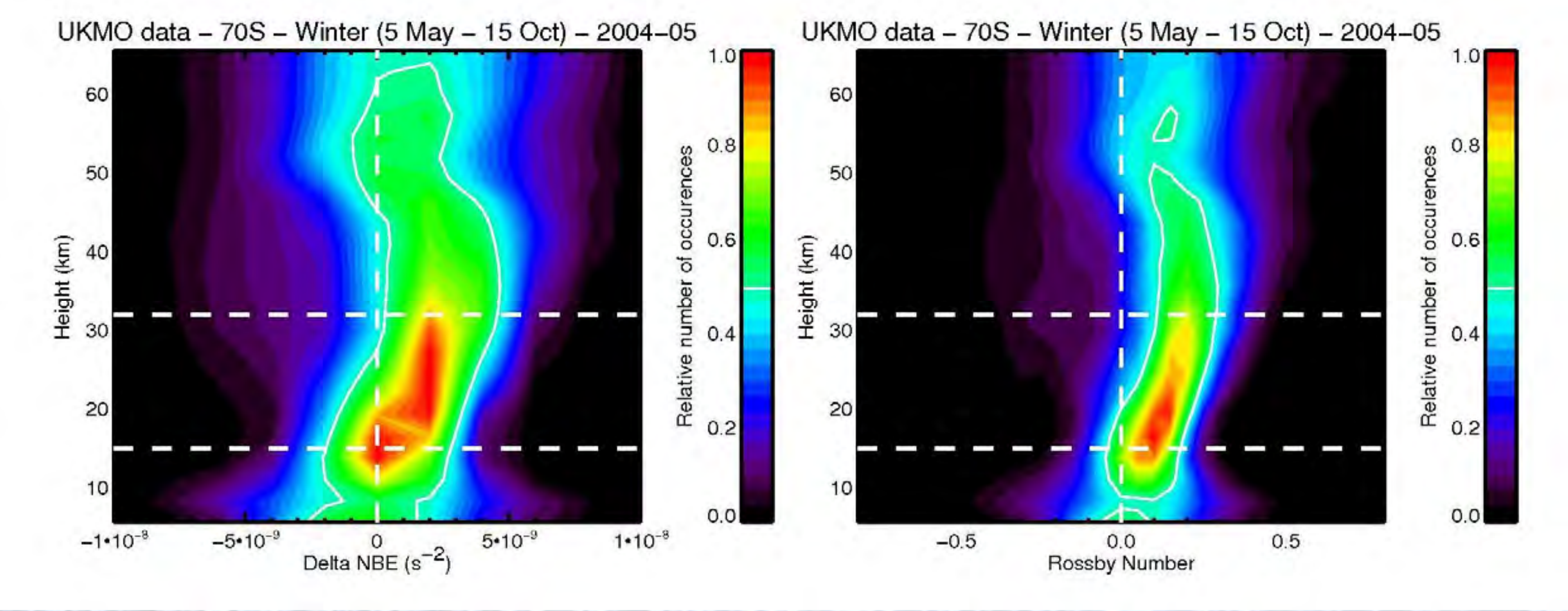
<u>Distributed stratospheric source</u>

1- Source mechanism is in the stratosphere and extends over the height range of our observations;

2- It can equally make upward or downward propagating waves (or both).

1 - Balance adjustment processes have been linked to inertial wave generation. [e.g. Tateno and Sato, 2008; Sato and Yoshiki 2008].

The potential for these processes to occur can be assessed using the residual terms in the non-linear balance equations [Zhang et al., 2001; Zhang, 2004]



From UKMO, 70ºS, all longitudes.

Distributed stratospheric source

2- ‘Creates upward and downward waves’:

This concept is supported by:
Åthe strongly horizontal propagation angles of the waves; there is not much difference between an upward and downward waves ;
Åthe similarity of the GW characteristics of up and downgoing waves (suggesting a common source).

Sato and Yoshiki [2008] provide some observational support.

Modelling required to verify this.

From Sato&Yoshiki [2008] JAS ‘Gravity wave generation around the polar vortex in the stratosphere revealed by 3-hourly radiosonde observations at Syowa station’

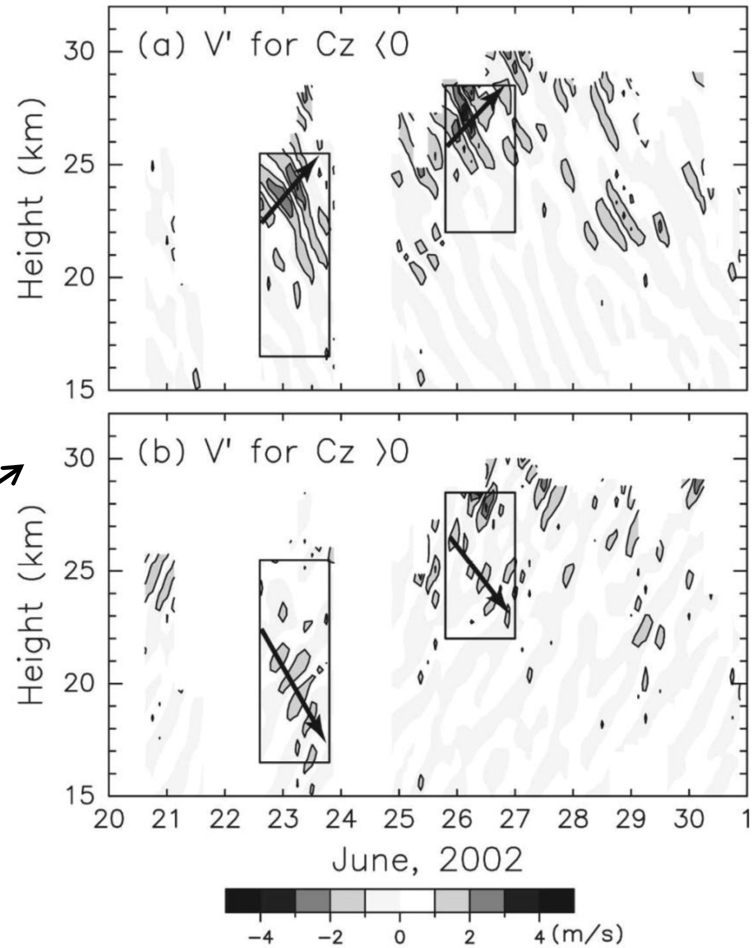
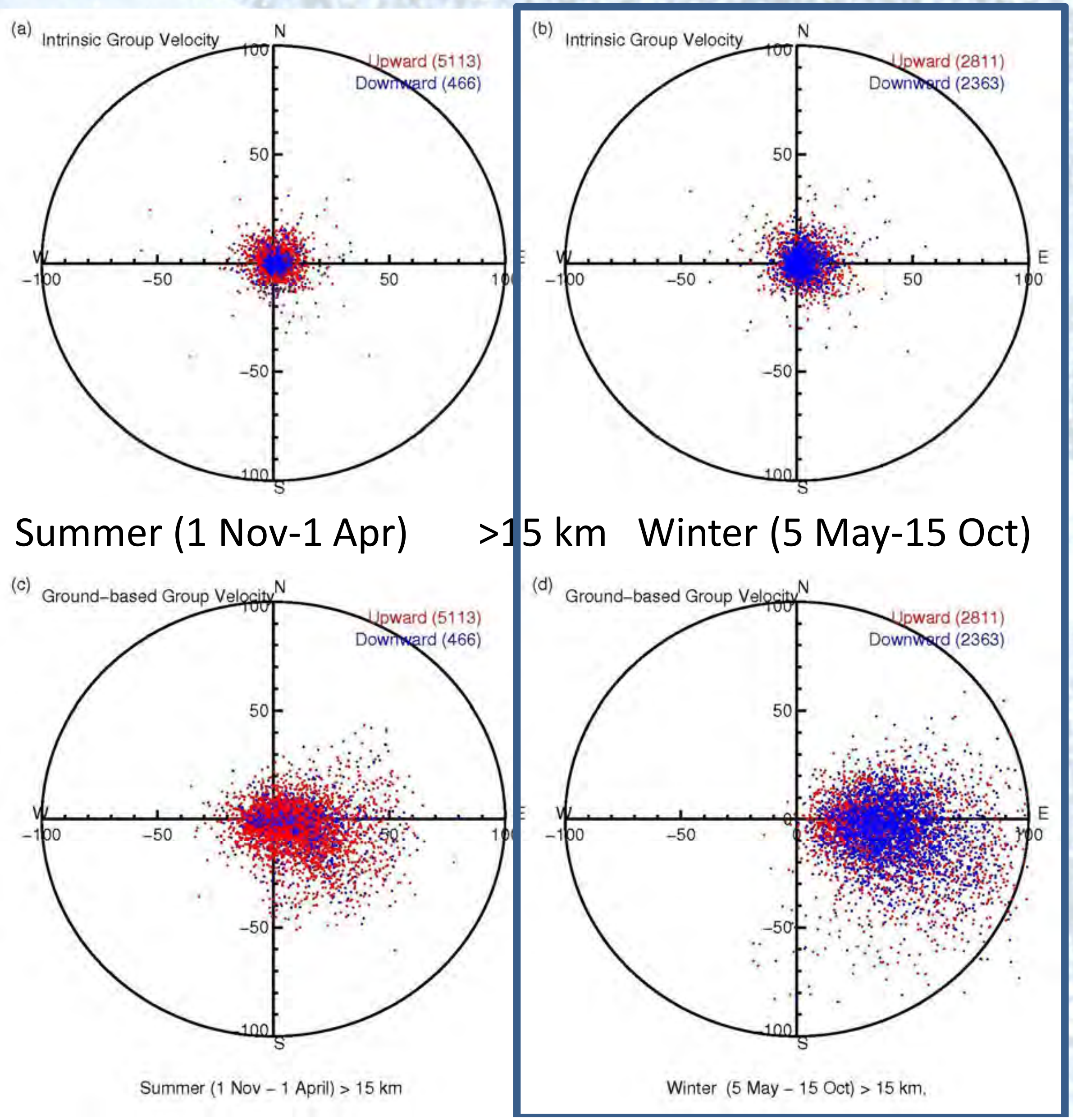


FIG. 8. Time–height sections of (a) upward and (b) downward phase propagation components of meridional wind fluctuations in June. The rectangles denote the regions when and where strong wave packets are observed. Arrows depict the packet propagations.

Implications for modelling



<u>Advection vs propagation</u>

Intrinsic group velocities (i.e. group velocities in the frame of the background wind) are mostly within +/- 5ms^{-1} for summer, winter, up and down.

Ground based group velocities are dominated by the effect of the background winds.

This is particularly true in wintertime.

The waves are being advected more than they are propagating

Implications for modelling

- Waves travel long distances horizontally so do not fit the vertical column GW parameterization schemes in common usage;
- Stratospheric sources are not currently included in models (although the conditions for source switch-on would be resolved and so could be identified);

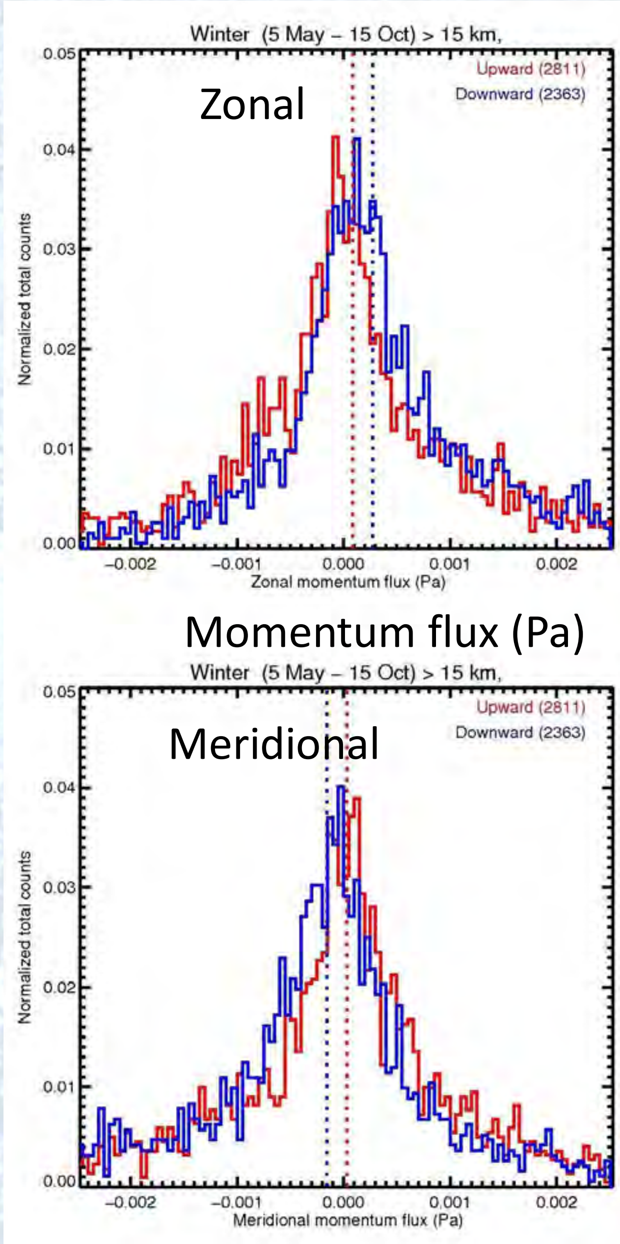
<u>But how much momentum do these waves carry?</u>
This can be calculated from the sonde data using [Zink and Vincent, 2001b]:

$$\overline{u'w'} = -\frac{\rho\hat{\omega}}{N^2}\, g\, \overline{u' \frac{T'_{+90}}{\overline{T}}}$$

and

$$\overline{v'w'} = -\frac{\rho\hat{\omega}}{N^2}\, g\, \overline{v' \frac{T'_{+90}}{\overline{T}}}$$

Most waves have momentum fluxes in the range +/-0.001 Pa, so they have relatively small fluxes.



Summary and conclusions

ÅWavelet analysis of radiosonde observations provides insight into low frequency gravity waves with vertical wavelengths below ~8km;
ÅThere are roughly equal numbers of upgoing and downgoing inertial gravity waves in the winter lower stratosphere at 69ºS;
ÅThis is not easily explained by a tropospheric source or a tropospheric source with vertical reflection;
ÅA source process distributed through the stratosphere that launches up and downgoing waves can explain the observations.