On the plane wave perspective of the tropospheric Kelvin waves

Ahmed Shaaban[1] and Paul Roundy[2]
2) University at Albany – State University at New York
1) Egyptian Meteorological Authority

EGU General Assembly
Tropical meteorology and Tropical Cyclones
May 2022

The vertical structure of the Kelvin waves
Regressed Zonal wind

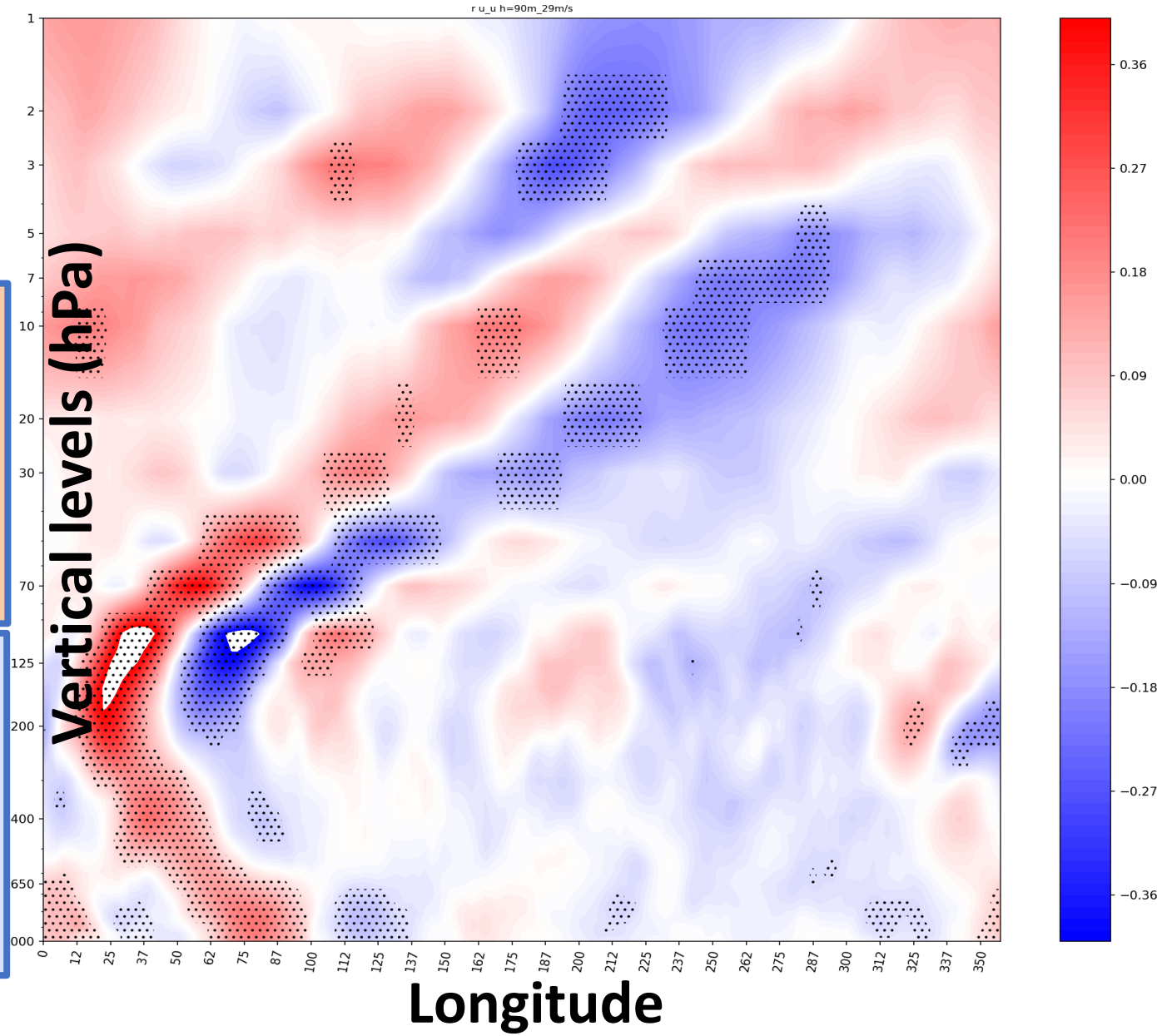
Regressed zonal wind associated with Kelvin waves (wavenumber 4) localized over the Indian Ocean.

Stratospheric

The vertical eastward tilt of Stratospheric Kelvin waves is usually understood in terms of plane gravity waves, with upward propagating energy and downward phase.

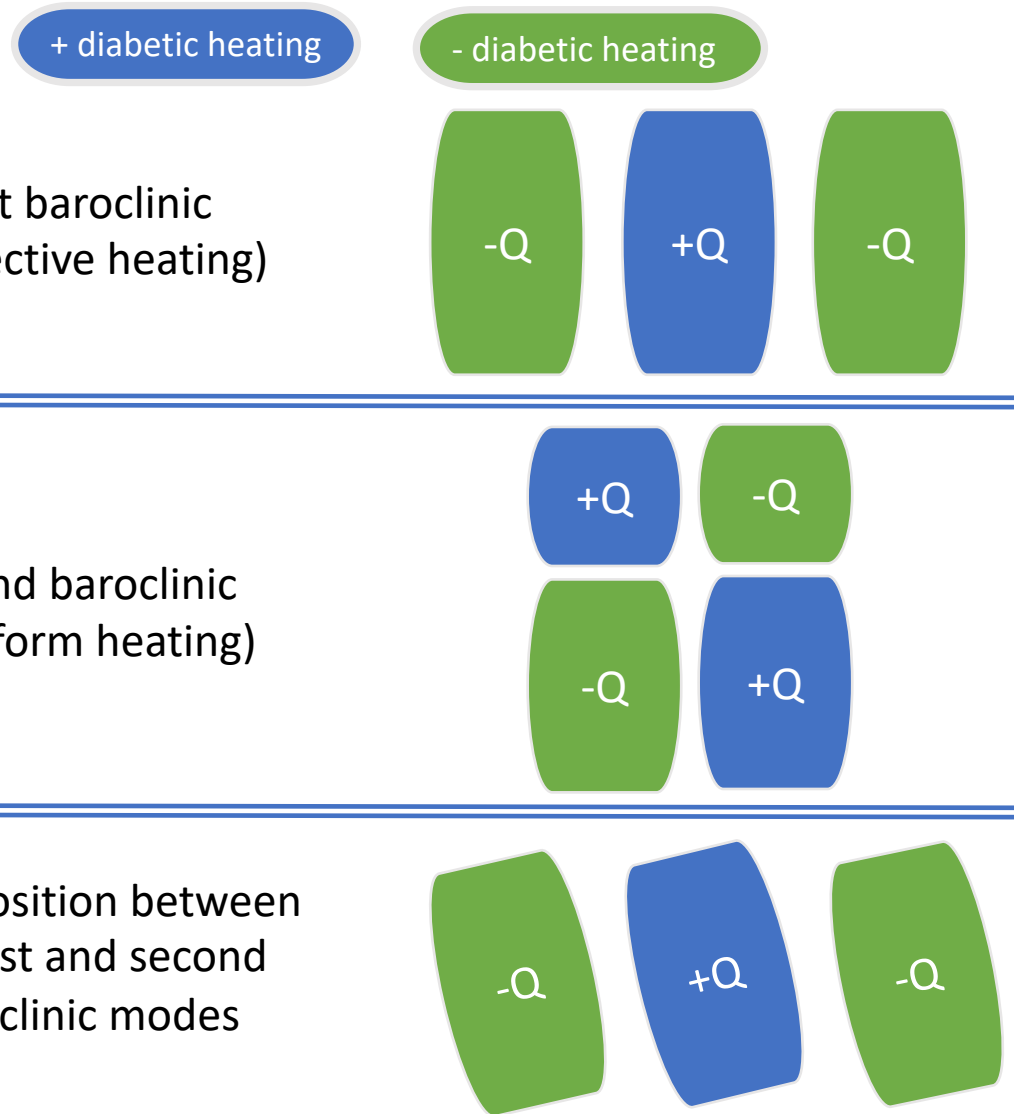
Tropospheric

The vertical westward tilt of the tropospheric Kelvin waves is often described as superposition between baroclinic modes, to meet surface boundary condition.

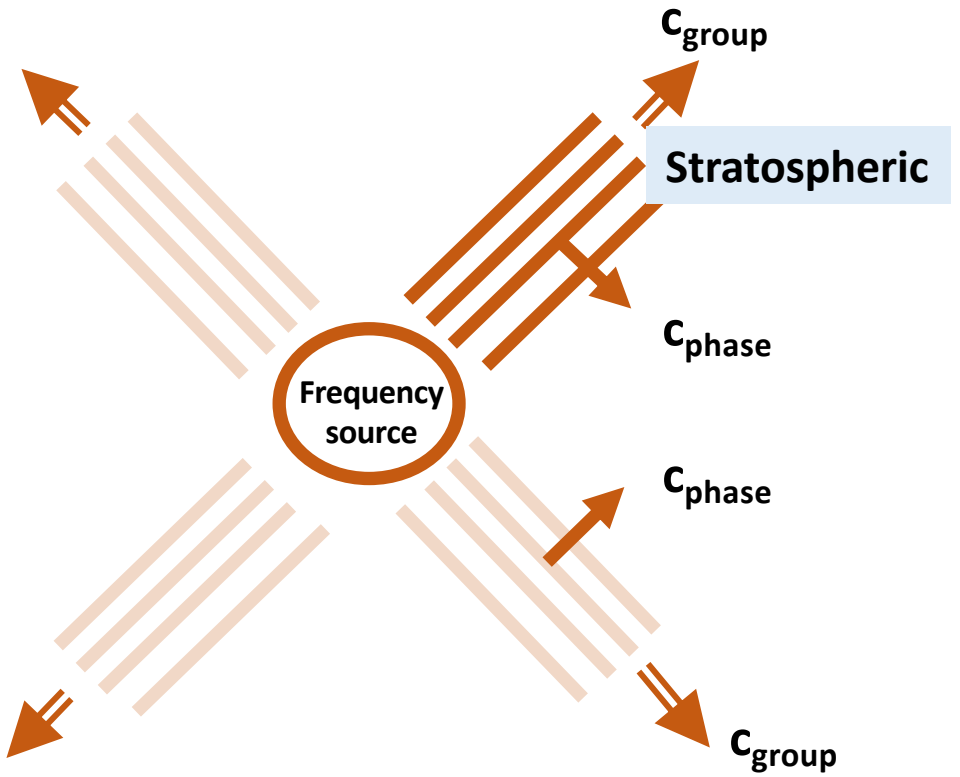


The vertical structure of the Kelvin waves: Two schools of thought

Normal modes (tropospheric Kelvin wave)



Radiative structure (stratospheric structure)



Spatial-temporal Wavelet-based Index

- 2D Wavelet kernel enables us to target localized eastward travelling waves in contrast to the discreate Fourier technique

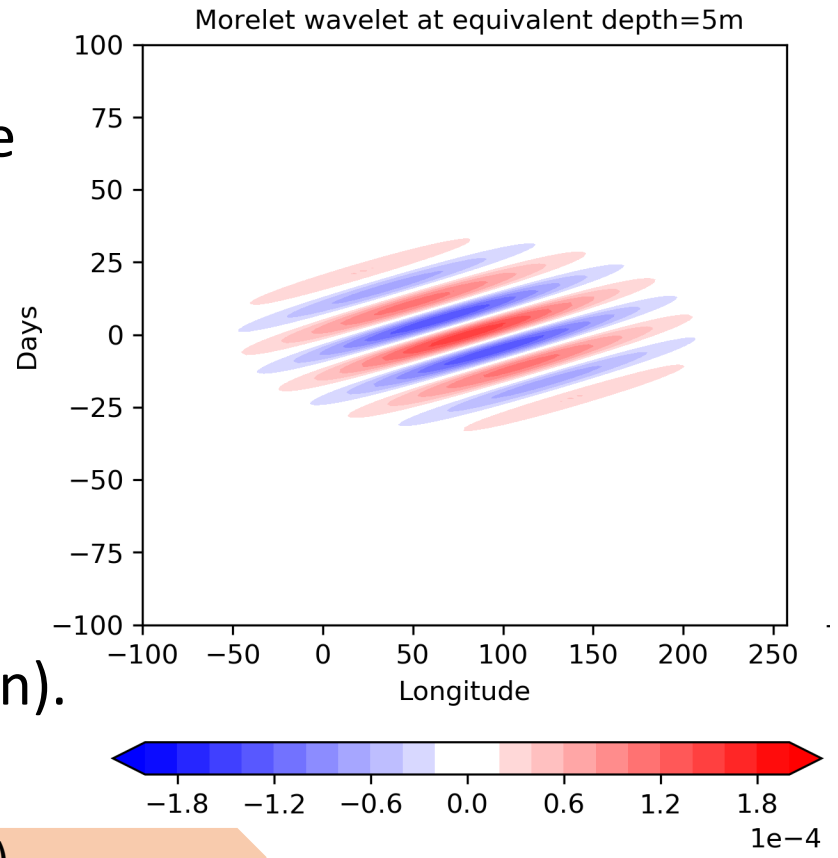
- Wavelet kernel is a tapered sinusoidal in space and time.

$$\psi(x,t) = \frac{1}{\sqrt{a\pi}}\frac{1}{\sqrt{b\pi}}\cos(2\pi(f_x x - f_t t))\exp(-\frac{x^2}{b})\exp(-\frac{t^2}{a})$$

wavenumber and temporal frequency

Scale factor in space and time

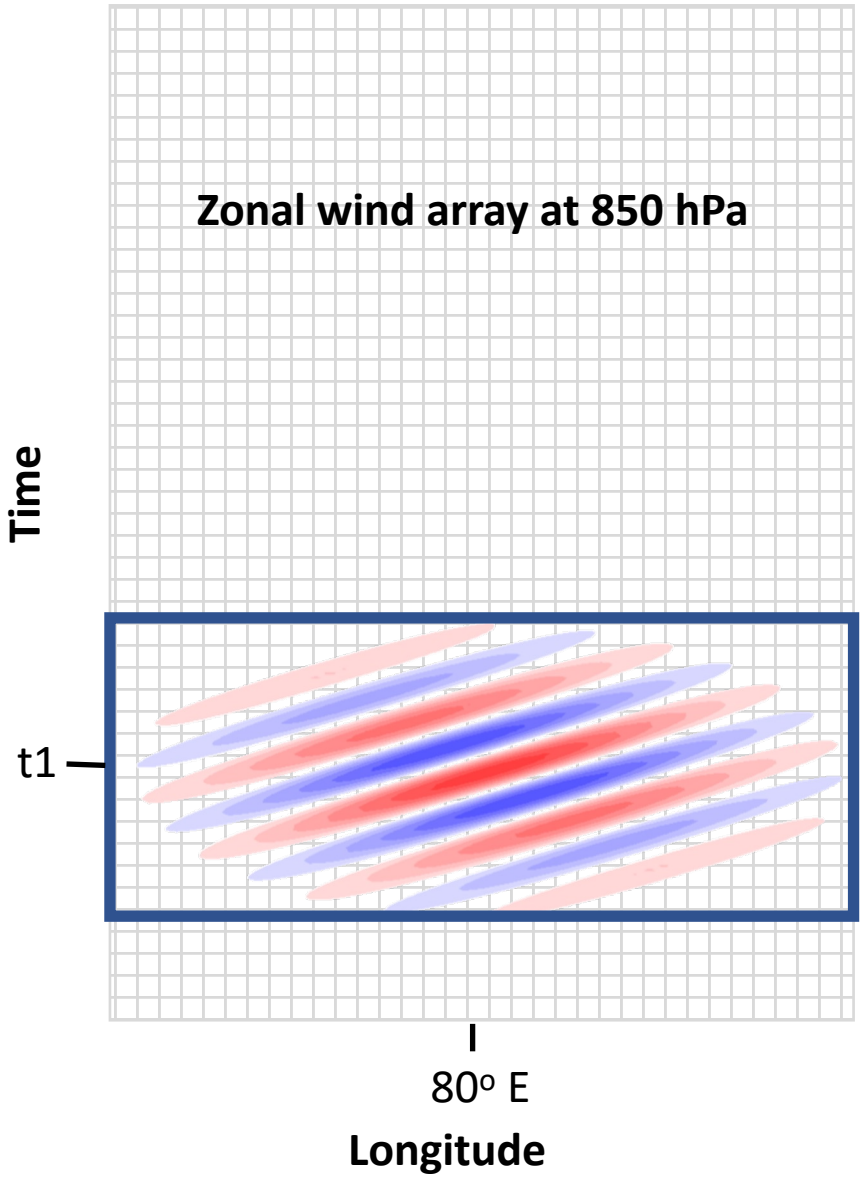
$$a = 8(\frac{2\pi f_t}{2\pi})^{-3/2}$$



- Horizonal global wavenumber 4 localized at 80ºE (Indian ocean).
- Travelling waves at specific horizontal phase speed.

	Slow (Moist)					Fast (Dry)				
Equivalent depth (m)	5	12	20	25	40	60	80	90	100	200
speed (m s^{-1})	7	11	14	16	20	24	28	30	31	44
period (days)	16.5	10.6	8.2	7.3	5.8	4.7	4.1	3.9	3.7	2.6

Constructing Kelvin wave index



- The Index based on zonal wind at 850 hPa.
- Choose wavelet kernel at certain speed.
- Center the wavelet at the base longitude (80E) and at t1.

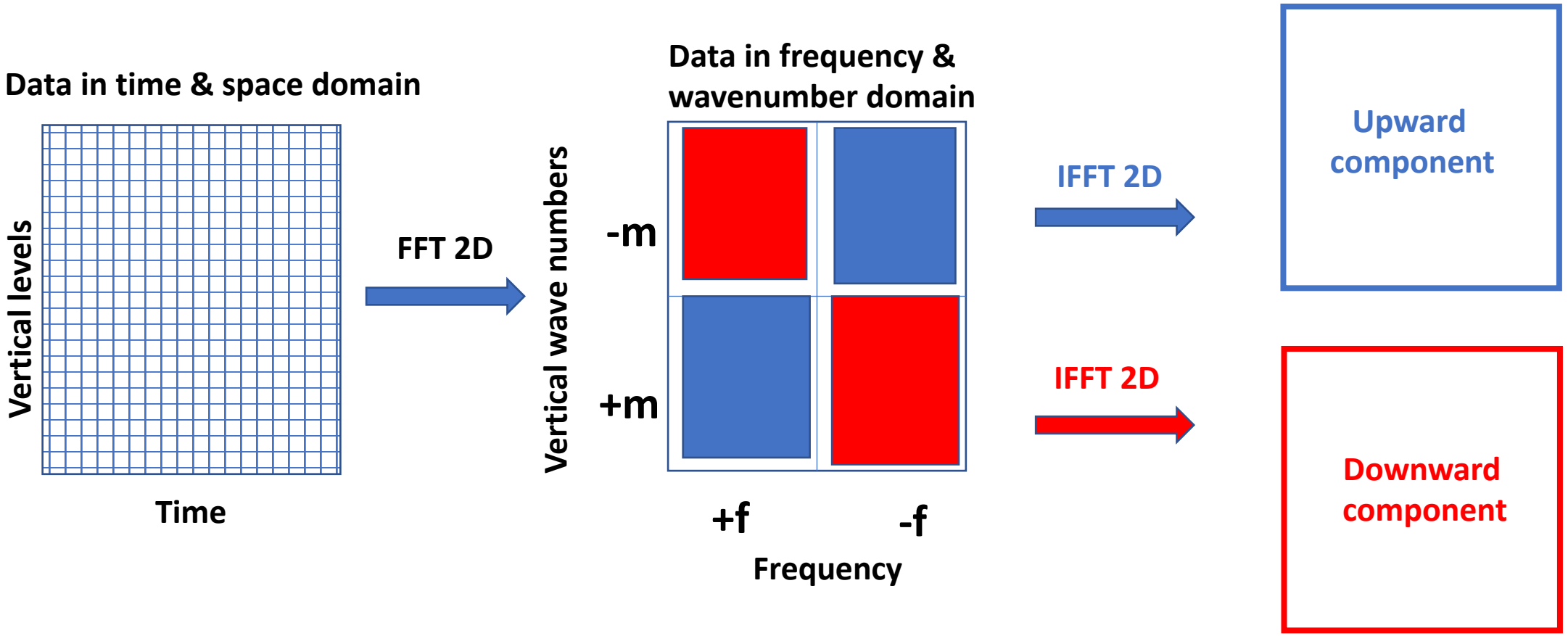
2D average of the pointwise multiplication between the wavelet kernel and the data

X1

Kelvin wave Index based on zonal wind at 850 hPa

Filtering data into Upward and Downward components.

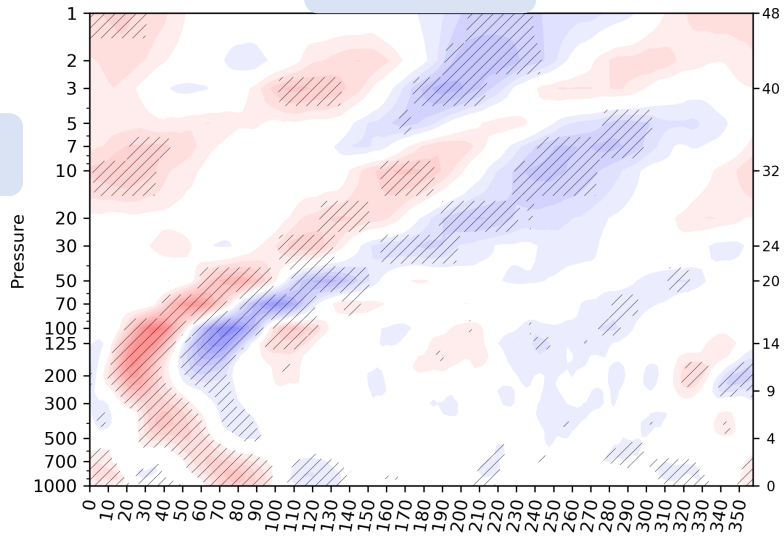
We used complex FFT in time and vertical levels to decompose the data into upward and downward components.



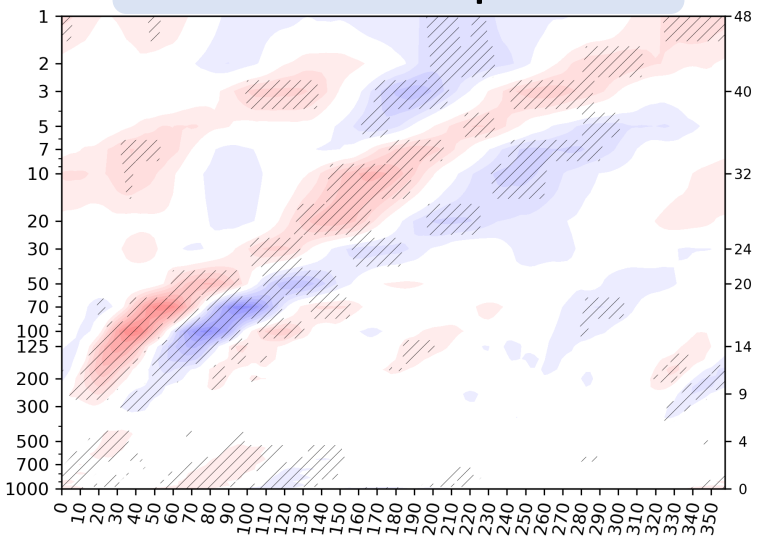
Upward and downward-phase Kelvin waves : Regressed zonal wind based on 850 hPa wavelet index

30 m s^{-1}

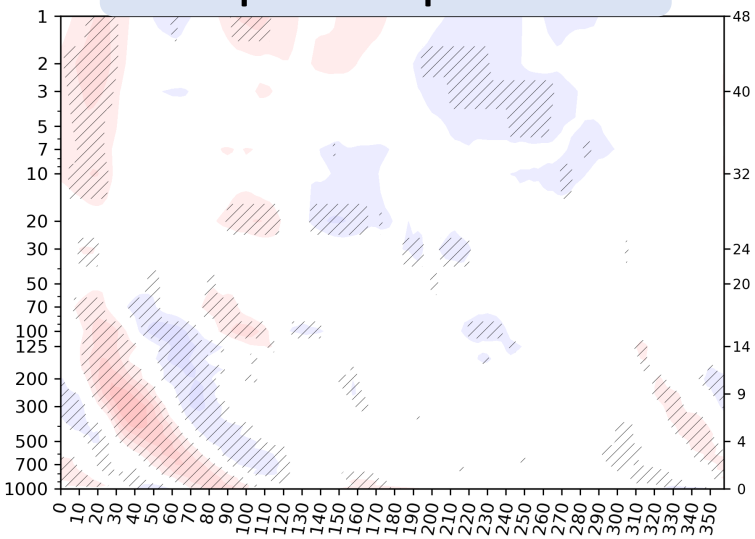
Total



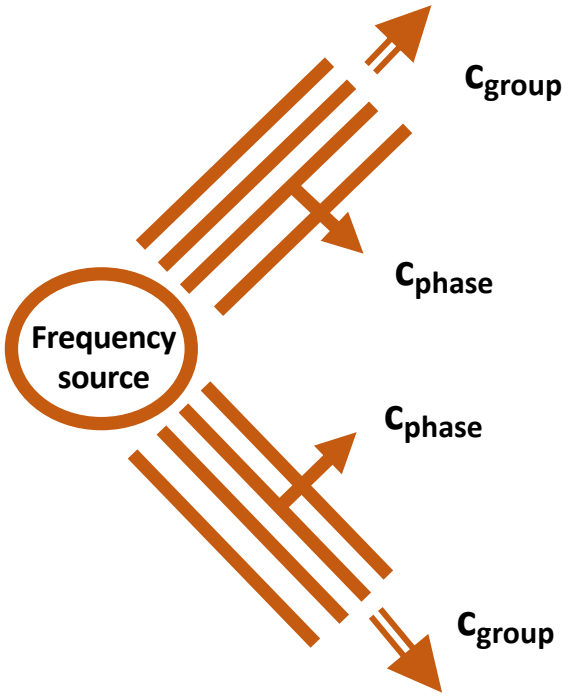
Downward-phase

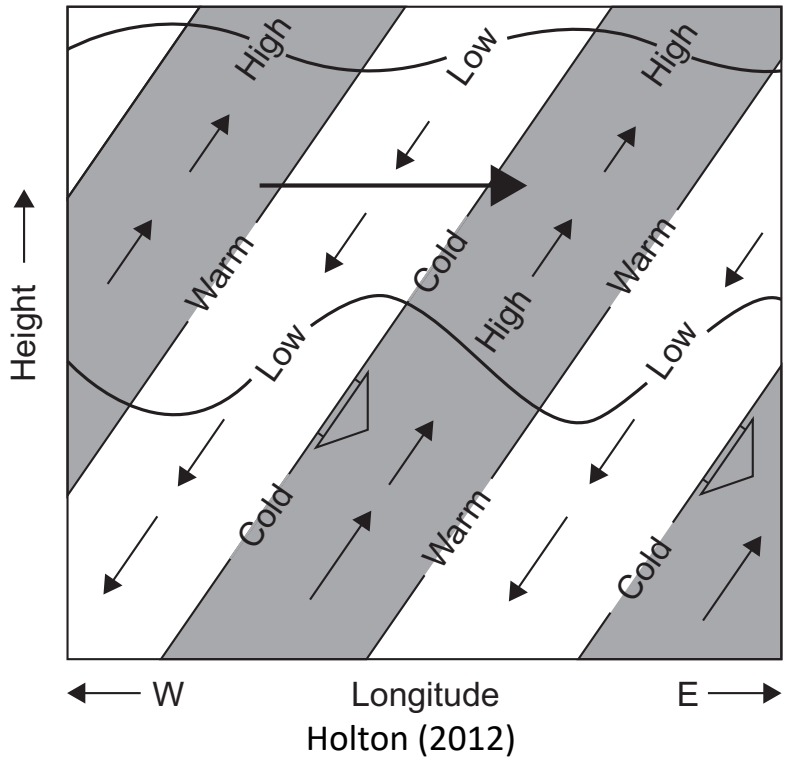


Upward-phase



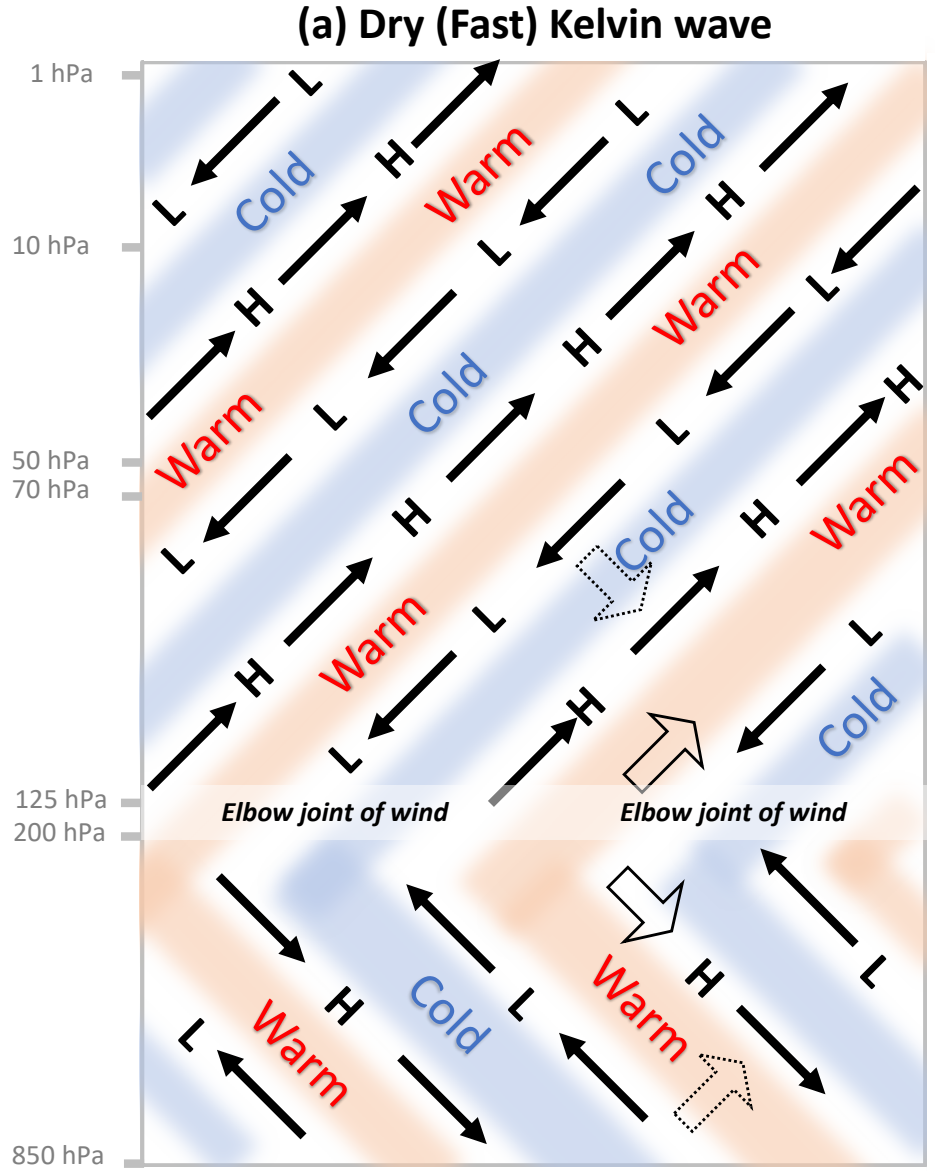
Vertical Structure of the Upward and Downward-Phase Kelvin waves



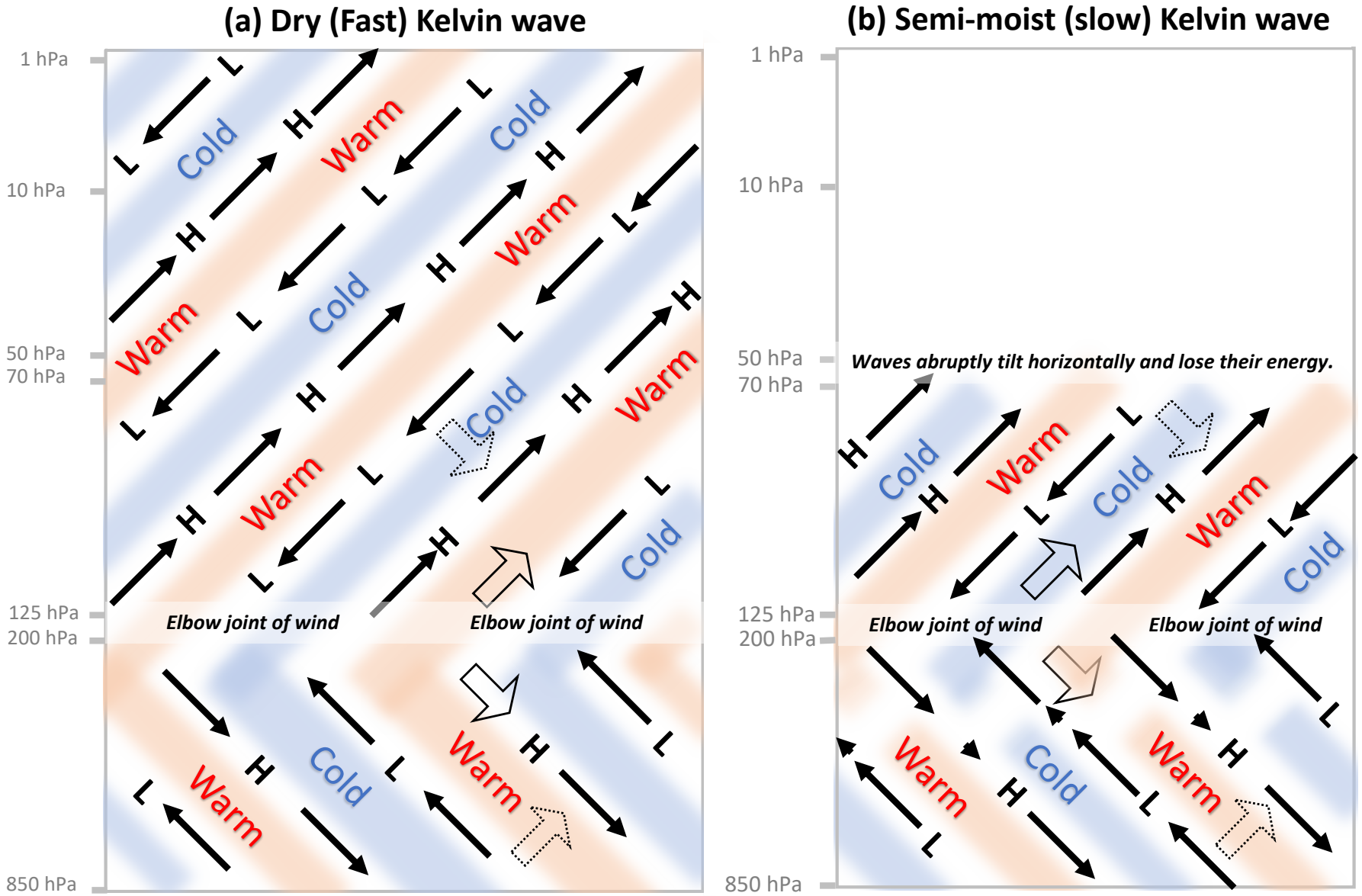


Holton (2012)

We observed one wave component (upward-phase), with no reflection.



Fast and slow upward and downward-phase Kelvin waves



Conclusion

The vertical structure of the Kelvin waves over Indian ocean moving at particular phase speeds could be interpreted in terms of plane wave dynamics similar to that at the stratosphere.

Received: 8 April 2020 | Revised: 15 June 2021 | Accepted: 1 July 2021

DOI: 10.1002/qj.4122

Quarterly Journal of the Royal Meteorological Society RMetS

RESEARCH ARTICLE

Upward and downward atmospheric Kelvin waves over the Indian Ocean

Ahmed A. Shaaban | **Paul E. Roundy**

Department of Atmospheric and Environmental Sciences, University at Albany, State University of New York, Albany, New York

Correspondence
A.A. Shaaban, Department of Atmospheric and Environmental Sciences, University at Albany, State University of New York, Albany, NY, USA.
Email: alasheen@albany.edu

Funding information
U.S. National Science Foundation, Grant/Award Number: 1560627

Abstract

Stratospheric Kelvin waves are often understood as plane gravity waves, yet tropospheric Kelvin waves have been interpreted as a superposition between the baroclinic modes. Fourier filtering is used to decompose the ECMWF-Interim reanalysis dynamical fields into upward and downward propagating components. Then wavelet regression is used to isolate the propagating Kelvin waves over the Indian Ocean across different speeds at zonal wavenumber 4. Results for fast waves show dry upward-phase signal in the troposphere, while downward-phase Kelvin waves occupy most of the stratosphere. The presence of upward-phase tilted waves in the troposphere suggests that the tropospheric Kelvin wave is not a superposition of the upward and downward components, as one might expect in a normal mode. We found that propagating Kelvin waves in the troposphere obey gravity wave dynamics with geopotential height in phase with the zonal wind, the vertical velocity out of phase with the zonal wind, and the temperature in quadrature with the zonal wind. Both dry and moist tropospheric Kelvin waves show a westward vertical tilt, suggesting that tilt probably cannot be a superposition between baroclinic modes coupled to convective and stratiform heating. In the context of radiating gravity waves, results suggest that faster tropospheric Kelvin waves appear to be associated with higher Brunt–Väisälä frequencies, and waves maintain similar vertical tilt across a wide range of phase speeds.

Caveats and future work

- The Kelvin waves discussed here represent a tiny fraction of the bulk Kelvin wave variance. The structure of the tropospheric Kelvin wave filtered at bulk of wavenumbers and frequencies resembles an overturning circulation. It is not yet clear how superposition of downward phase wave could yield an overturning circulation.

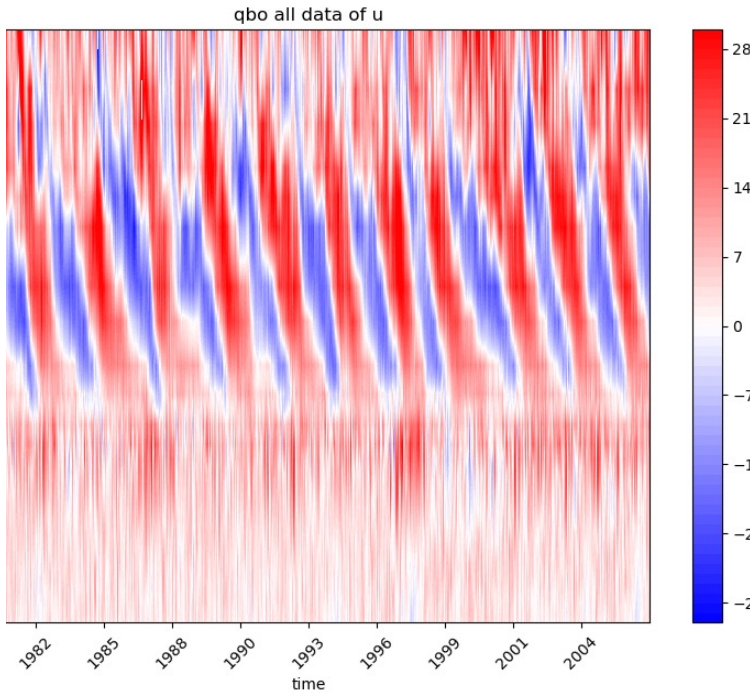
- The height of the Elbow joint, which is thought to be the source of the radiative upward and downward waves, is higher than that of the diabatic heating in the Indian ocean.

- The quick fading of the slow stratospheric Kelvin wave with respect to the dry wave.

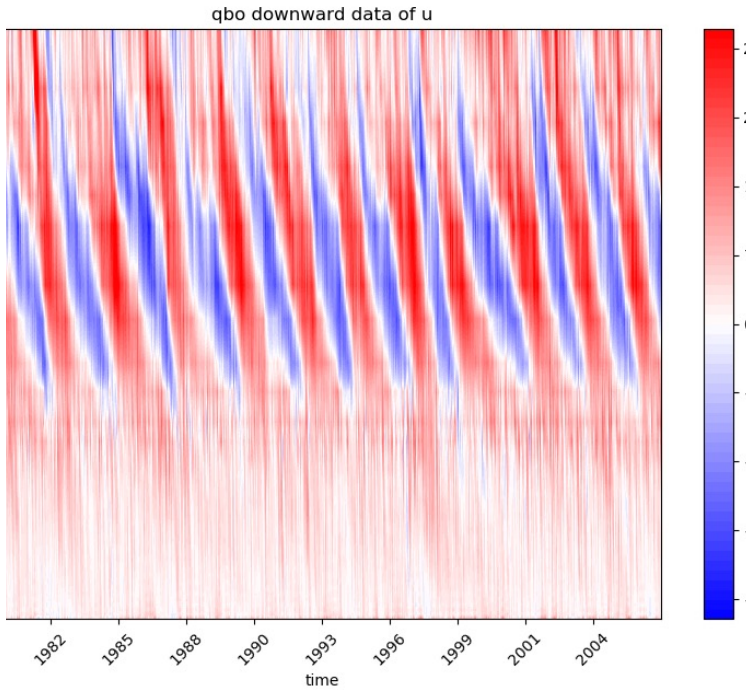
More Slides

Decomposing the Quasi Biennial Oscillation (QBO) into upward and downward components

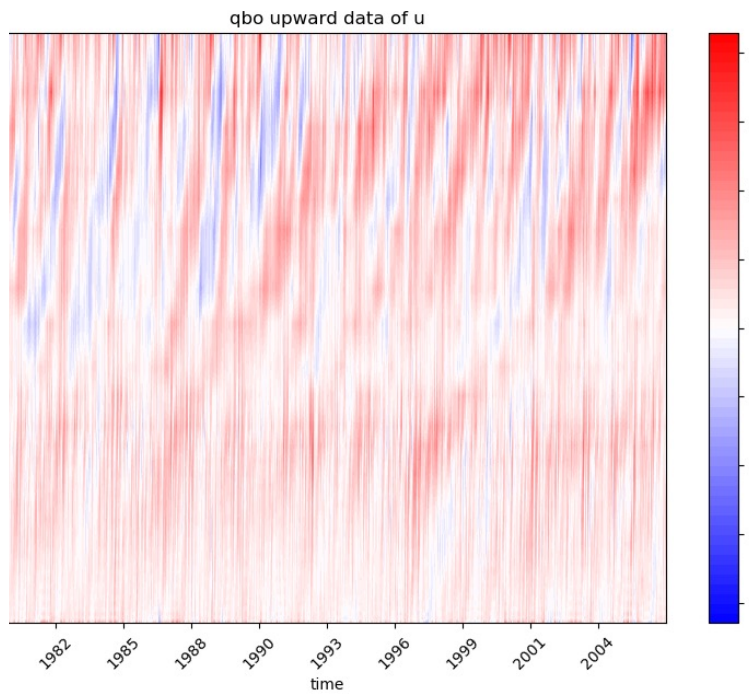
Unfiltered Zonal wind



Downward component



Upward component

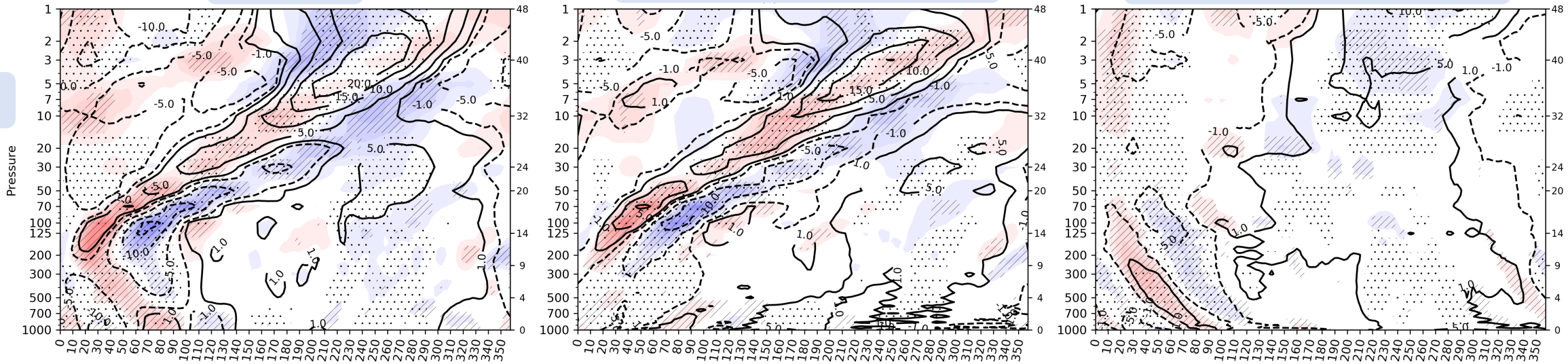


Most of the QBO amplitude appears in the downward component.

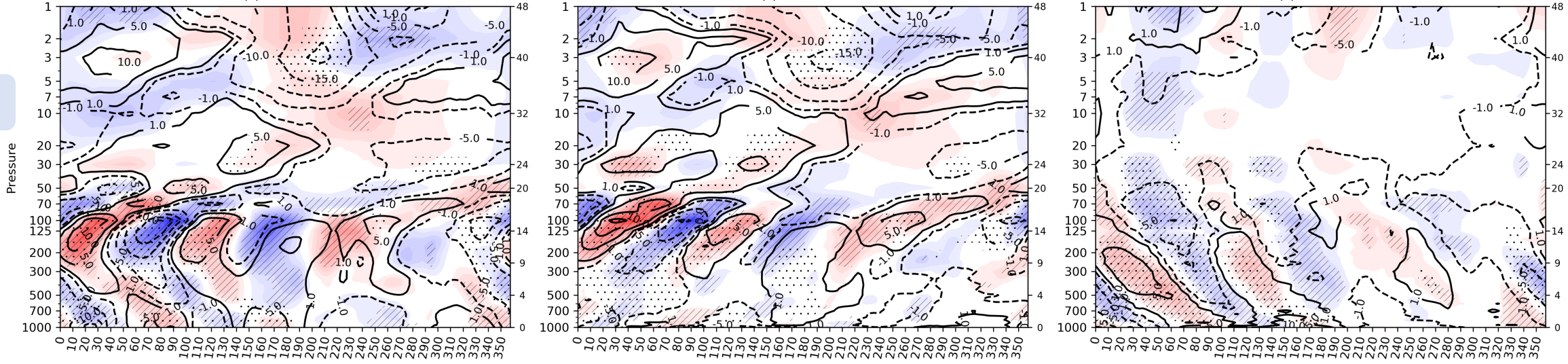
Upward and downward-phase Kelvin wave
Regressed zonal wind (shaded) & geopotential (contour)

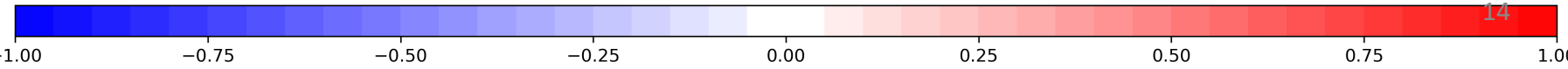
Total | **Downward-phase** | **Upward-phase**

30 m s^{-1}



16 m s^{-1}





Upward and downward-phase Kelvin wave
Regressed temperature (shaded) & zonal wind (contour)

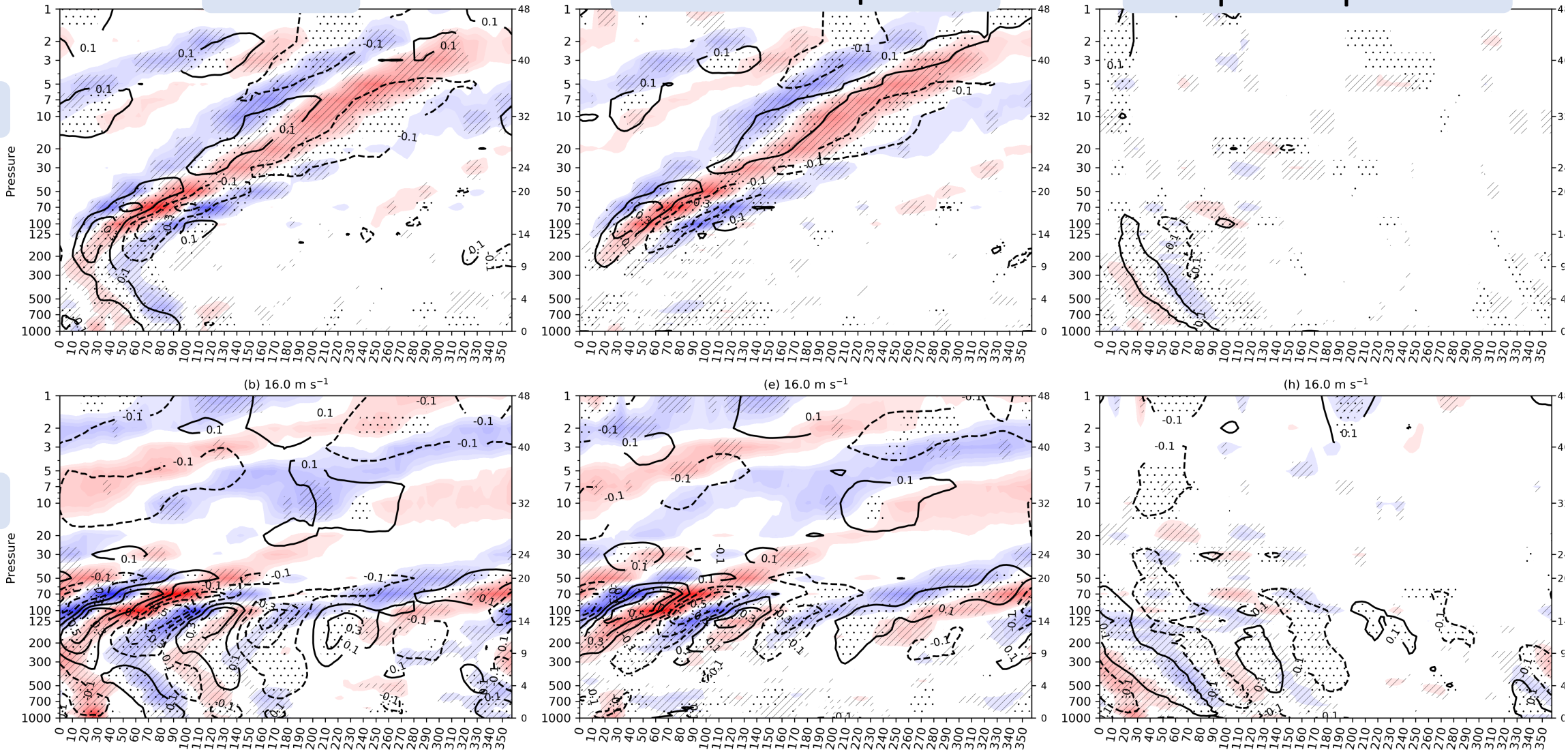
30 m s^{-1}

16 m s^{-1}

Total

Downward-phase

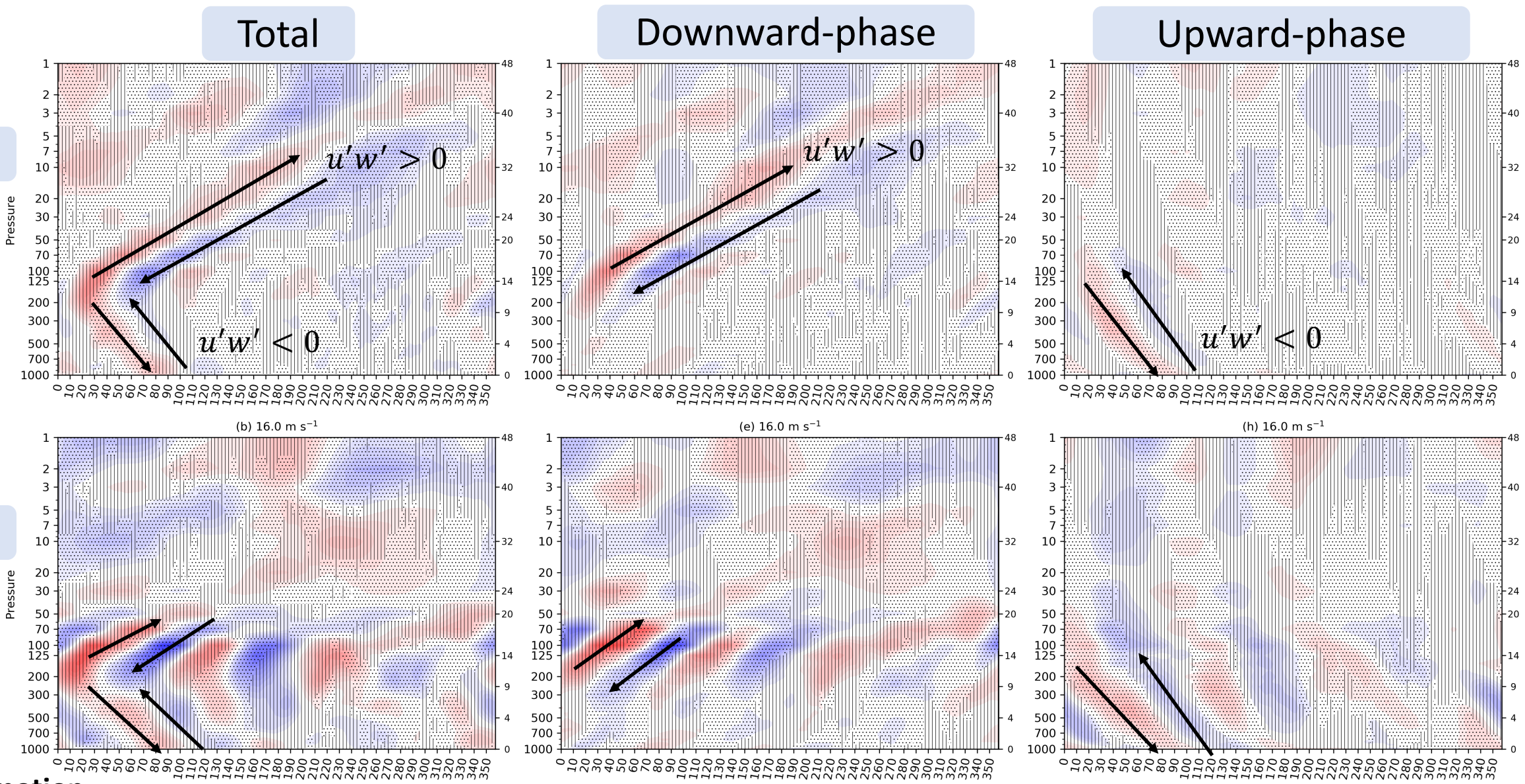
Upward-phase



Upward and downward-phase Kelvin wave
Regressed zonal wind (shaded) & vertical wind (dash)

30 m s^{-1}

16 m s^{-1}

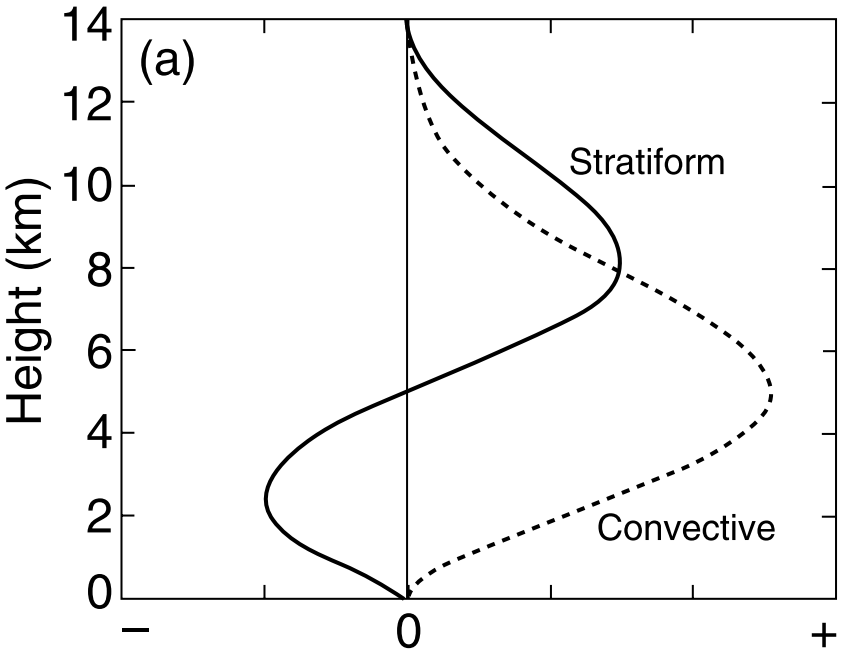


| Upward motion

.. Downward motion

Convective and stratiform modes.

- Convective heating (one signed diabatic heating in the troposphere) is frequently modeled as associated with the first baroclinic mode.
- Stratiform heating (two signed diabatic heating in the troposphere) is frequently modeled as if associated with the second baroclinic mode (Mapes (1999)).
- Superposition between the first and second baroclinic mode yields a top-heavy diabatic heating structure.
- Tilted vertical structure of the dynamics field may be produced by superposition between the two modes.



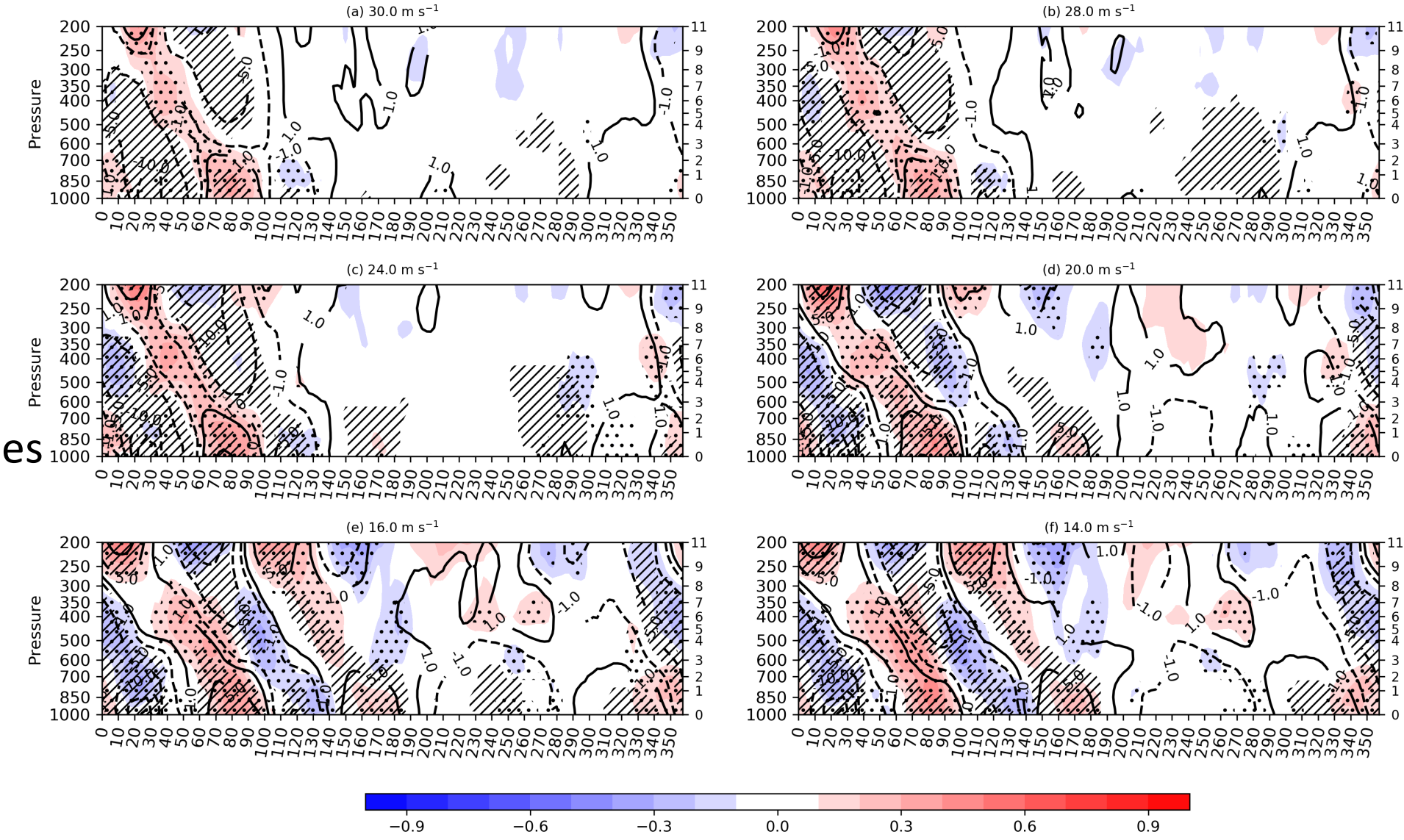
Adapted from Houze (2004)

Reduced phase speeds of the moist waves

Tilt of the waves is almost invariant

$$\frac{\lambda_z}{\lambda_x} = \frac{\omega - k\bar{u}}{N} \approx cons$$

Waves of low frequencies (phase speed) favor environments with low static stability.



regressed zonal wind anomalies

regressed geopotential anomalies