重力波鉛直伝播の簡便な表現方法
-Gravity wave transmission diagram-

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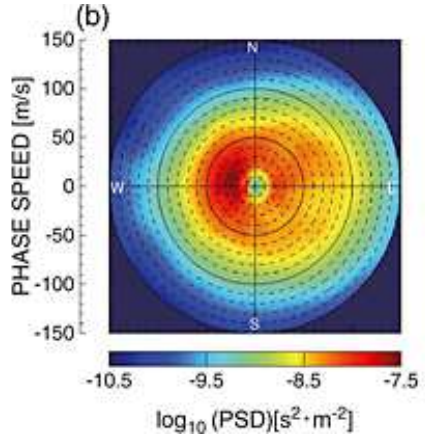
Tomikawa, Y., Gravity wave transmission diagram, Ann. Geophys., 33, 1479-1484, 2015.

Motivation



Power spectrum in horizontal phase velocity domain (Matsuda et al., 2014)

How well is the power spectrum of gravity waves in horizontal phase velocity domain explained by critical level filtering?

It is important in order to

- distinguish contributions of wind filtering and wave generation
- interpret vertical distributions of momentum and energy deposit

Critical Level Filtering

Waves are absorbed at a critical level, where the background horizontal wind velocity parallel to the horizontal wave vector equals to the horizontal phase velocity of the wave (Booker and Bretherton, 1967).

$$\text{background horizontal wind}: (u, v)$$

$$\text{ground-based horizontal phase velocity}: c_h \geq 0$$

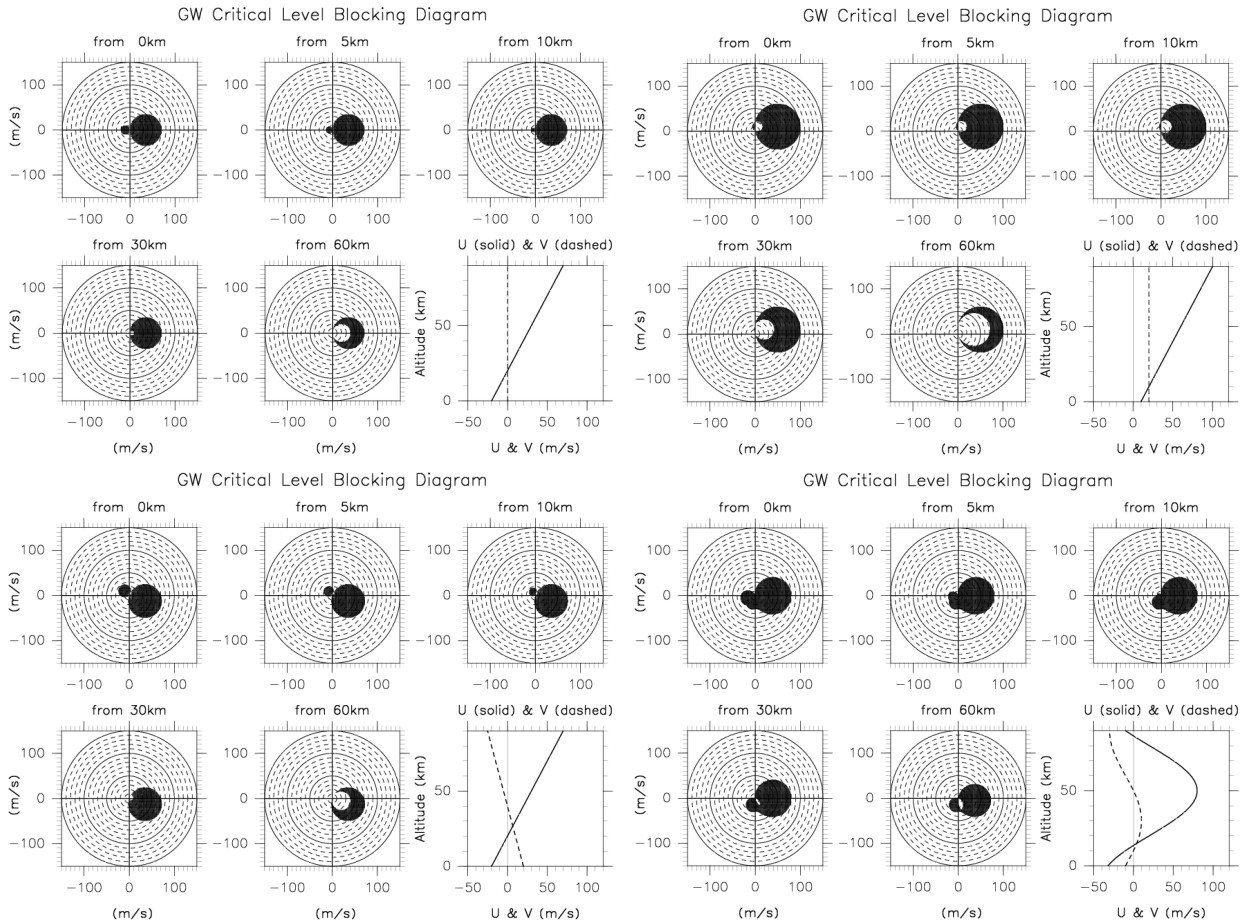
$$\text{direction of ground-based horizontal phase velocity}: \theta$$

$$\text{intrinsic horizontal phase velocity}: \hat{c}_h$$

$$\hat{c}_h = c_h - (u\cos\theta + v\sin\theta)$$

If $\hat{c}_h$ changes its sign with height, it is the critical level for the wave.

See also Taylor et al. (1993)



Assumptions

- Only vertical propagation is assumed.
- Ground-based horizontal phase velocity is constant, which is corresponding to that the background horizontal wind does not change with time for a timescale of vertical propagation
- Wave reflection at a turning level and wave breaking are not taken into account.

The first assumption may break in case of gravity waves with fast ground-based horizontal phase speeds.

$$C_{gh} \approx C_h \quad \Rightarrow \quad \text{360km horizontal propagation for GWs with } C_h = 50 \text{ m/s}$$

Additional Filtering

- Strictly speaking, the critical level filtering should occur where

$$\hat{C}_h = \pm \frac{f}{k_h}, \text{ not where } \hat{C}_h = 0.$$

Additional critical level filtering

- Gravity waves are reflected at a turning level where $m^2=0$.

$$m^2 = \frac{k_h^2\left(N^2 - \hat{\omega}^2\right)}{\hat{\omega}^2 - f^2} - \frac{1}{4H^2}$$

Turning level reflection

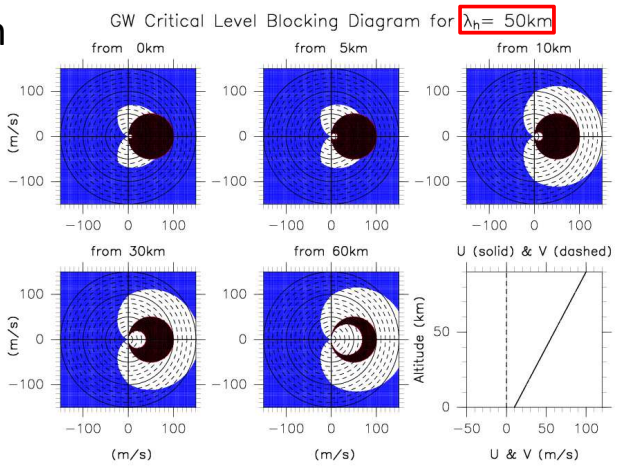
⇒In order to take these effects into account, a horizontal wavelength of the gravity wave must be specified.

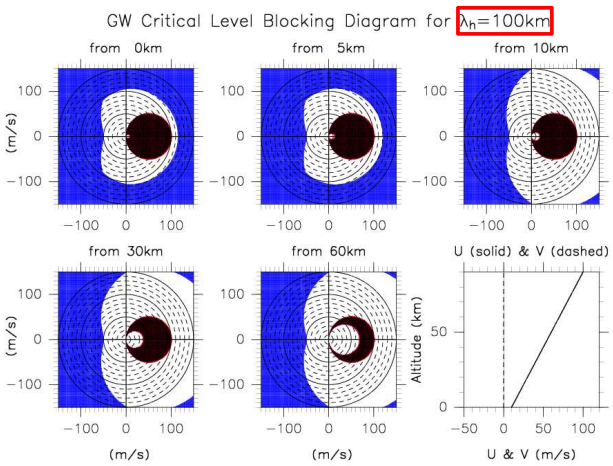
In other words, additional filtering depends on the horizontal wavelength of the gravity wave.

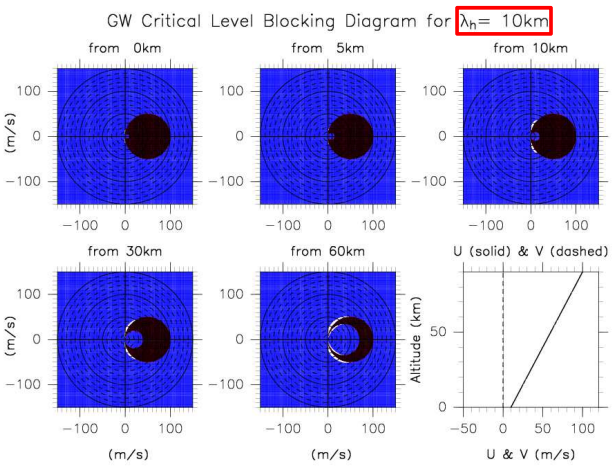
Gravity wave transmission diagram

Red: blocked by $\hat{C}_h = \pm \frac{f}{k_h}$

Blue: blocked by turning levels



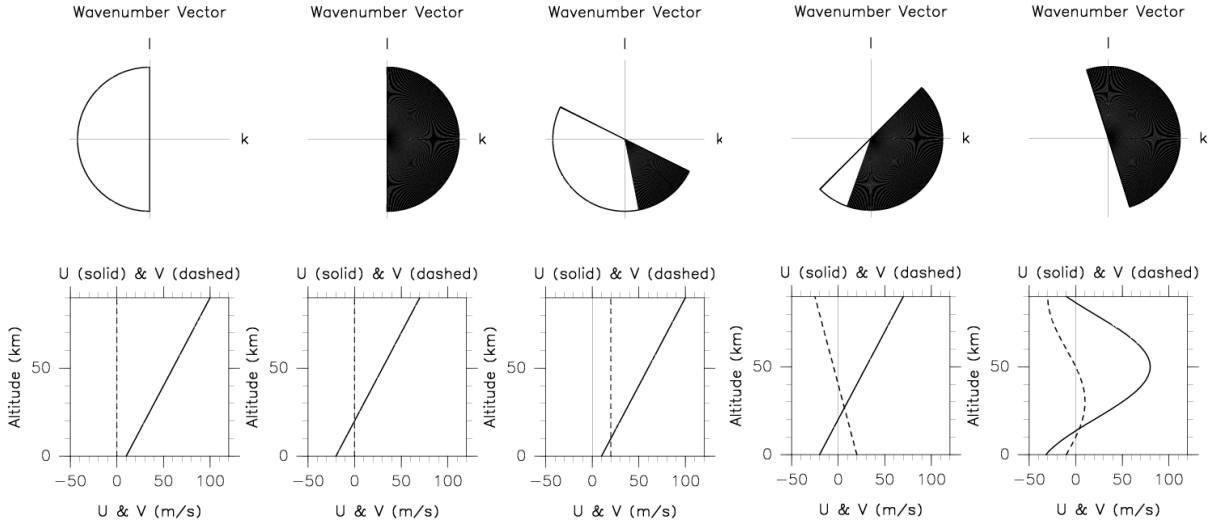




Special Attention for Mountain Waves

Stationary waves such as mountain waves are expressed as one point at the origin in horizontal phase velocity domain. However, stationary waves can have various angle of wavenumber vector. The critical level filtering depends on the angle of wavenumber vector. Thus the critical level filtering for stationary waves cannot be expressed at one point in horizontal phase velocity domain.

Blocking Diagram for Mountain Waves



Semicircle : horizontal wavenumber vector of mountain waves which can be excited by the wind at the ground

Shades : mountain waves blocked by critical level filtering

Concluding remarks

- Gravity wave transmission diagram can diagnose what horizontal phase velocity GWs need to have for vertical propagation.
- Mountain waves cannot be described in GW transmission diagram, and need special treatment.
- In order to consider a GW turning level, horizontal wavelengths of GWs (and N^2) must be specified.
- Reflection at a turning level strongly depends on GW horizontal wavelength, and can strongly restrict vertical propagation of GWs.