Buoyancy Frequency

What is buoyancy frequency

- Natural frequency at which an air parcel will vertically oscillate given an initial displacement
- Typical values correspond to a period of 5-10 min
- Brunt–Väisälä frequency
- Gravity waves oscillate from buoyancy force

Hydrostatic Equilibrium

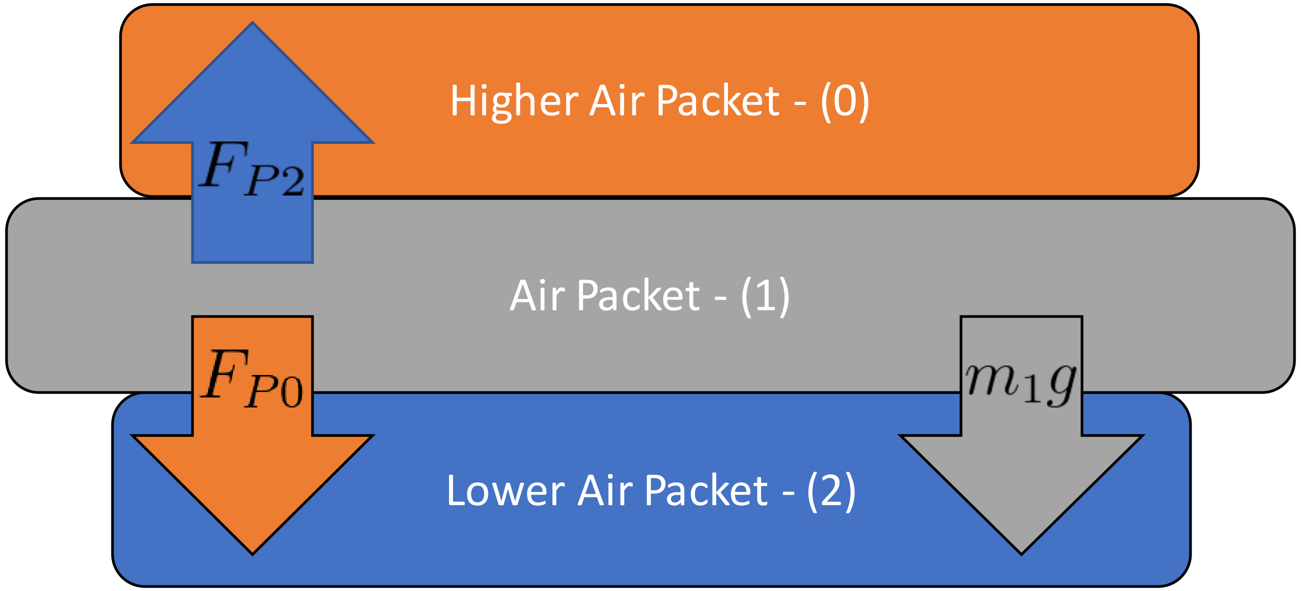
$$F_{Net} = 0 = (P_2 - P_0)A - m_1 g$$

$$m_1 g = -dP \cdot A$$

$$(\rho_1 \cdot V)g = -dP \cdot A$$

$$\rho_1(Adz)g = -dP \cdot A$$

$$\boxed{\frac{dP}{dz} = -\rho g}$$



Buoyancy Frequency

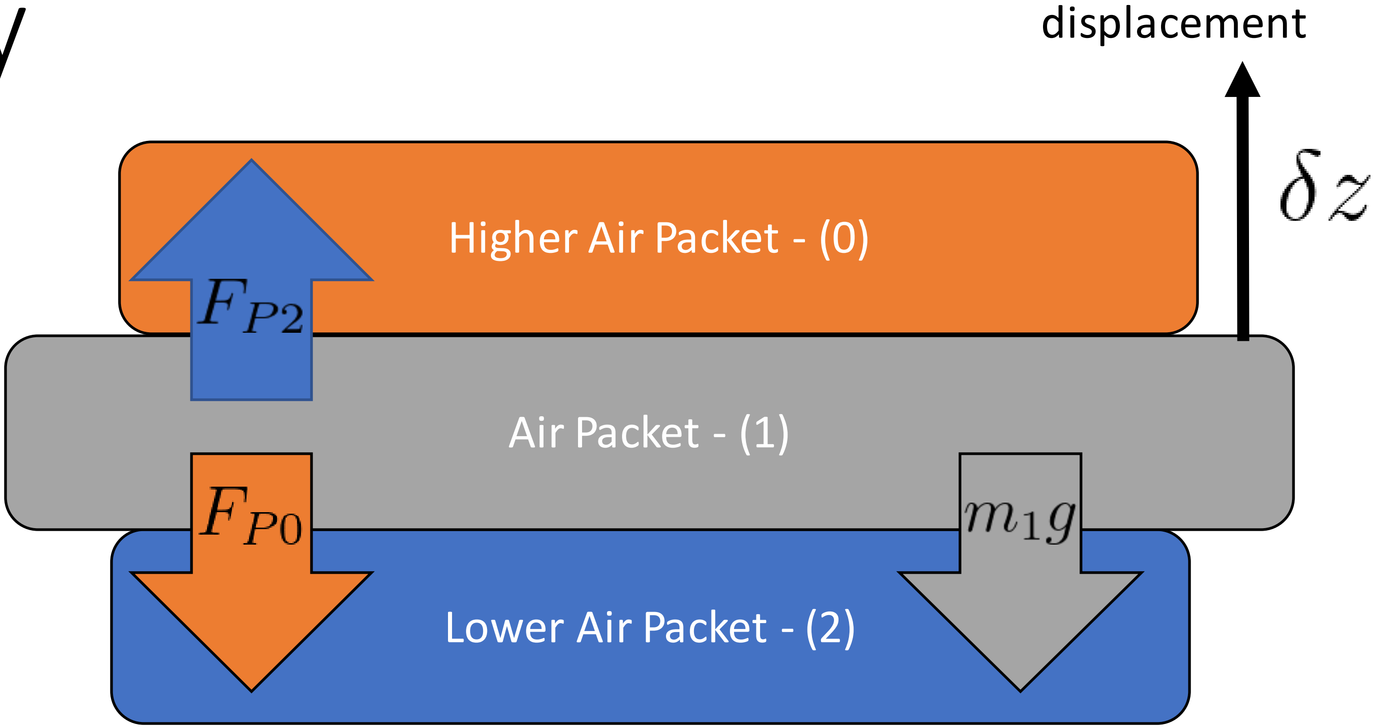
$$m_1 a = (P_2 - P_0)A - m_1 g$$

$$m_1 \frac{d^2(\delta z)}{dt^2} = -dPA - m_1 g$$

$$\rho_1 V \frac{d^2(\delta z)}{dt^2} = \rho_0 g(\delta z)A - \rho_1 V g$$

$$\frac{d^2(\delta z)}{dt^2} = \left(\frac{\rho_0 - \rho_1}{\rho_1}\right) g$$

$$\frac{d^2(\delta z)}{dt^2} = \frac{g}{\rho_1}\frac{dp}{dz}\delta z$$

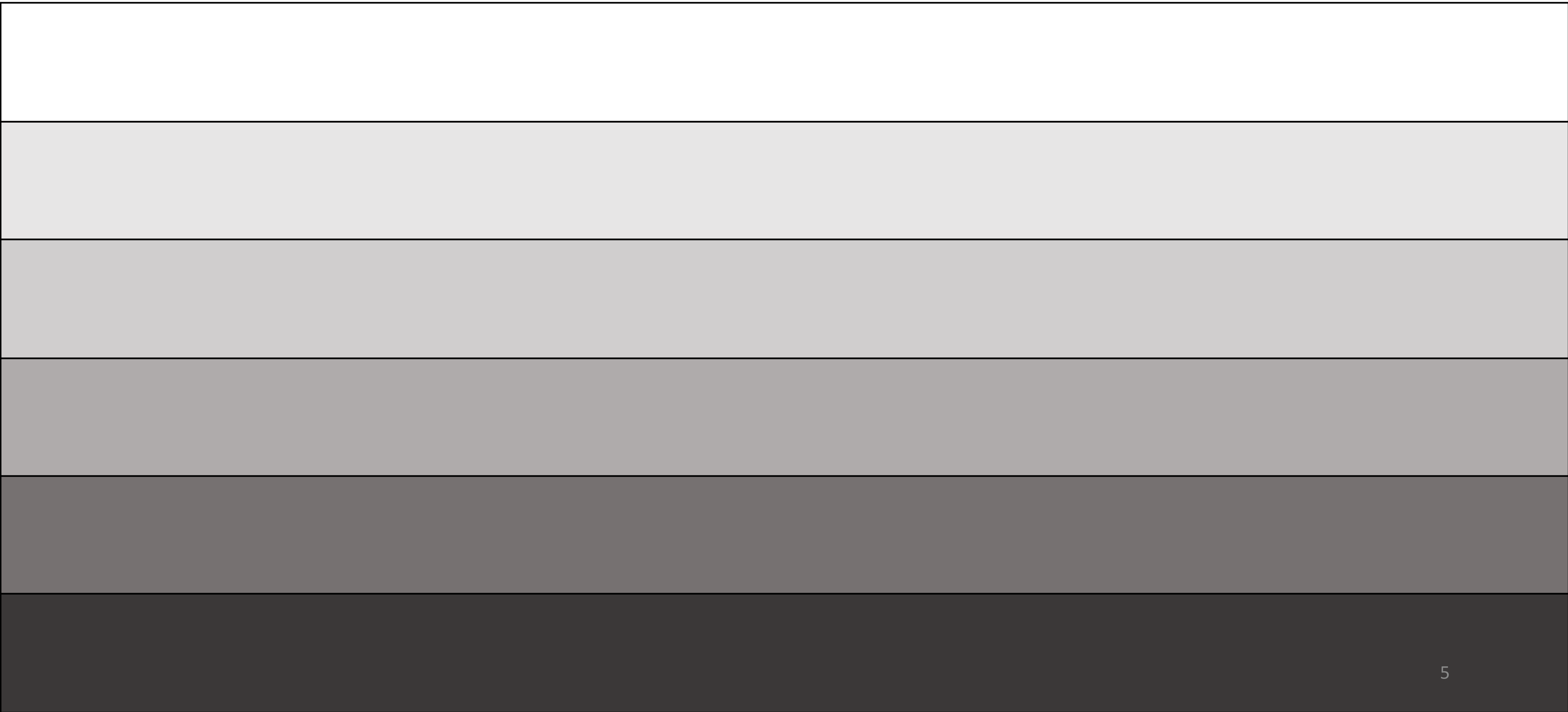


$$\frac{d^2(\delta z)}{dt^2} + \left(-\frac{g}{\rho_1}\frac{dp}{dz}\right)\delta z = 0$$

$$\boxed{\omega^2 = N^2 = -\frac{g}{\rho_1}\frac{d\rho}{dz}}$$

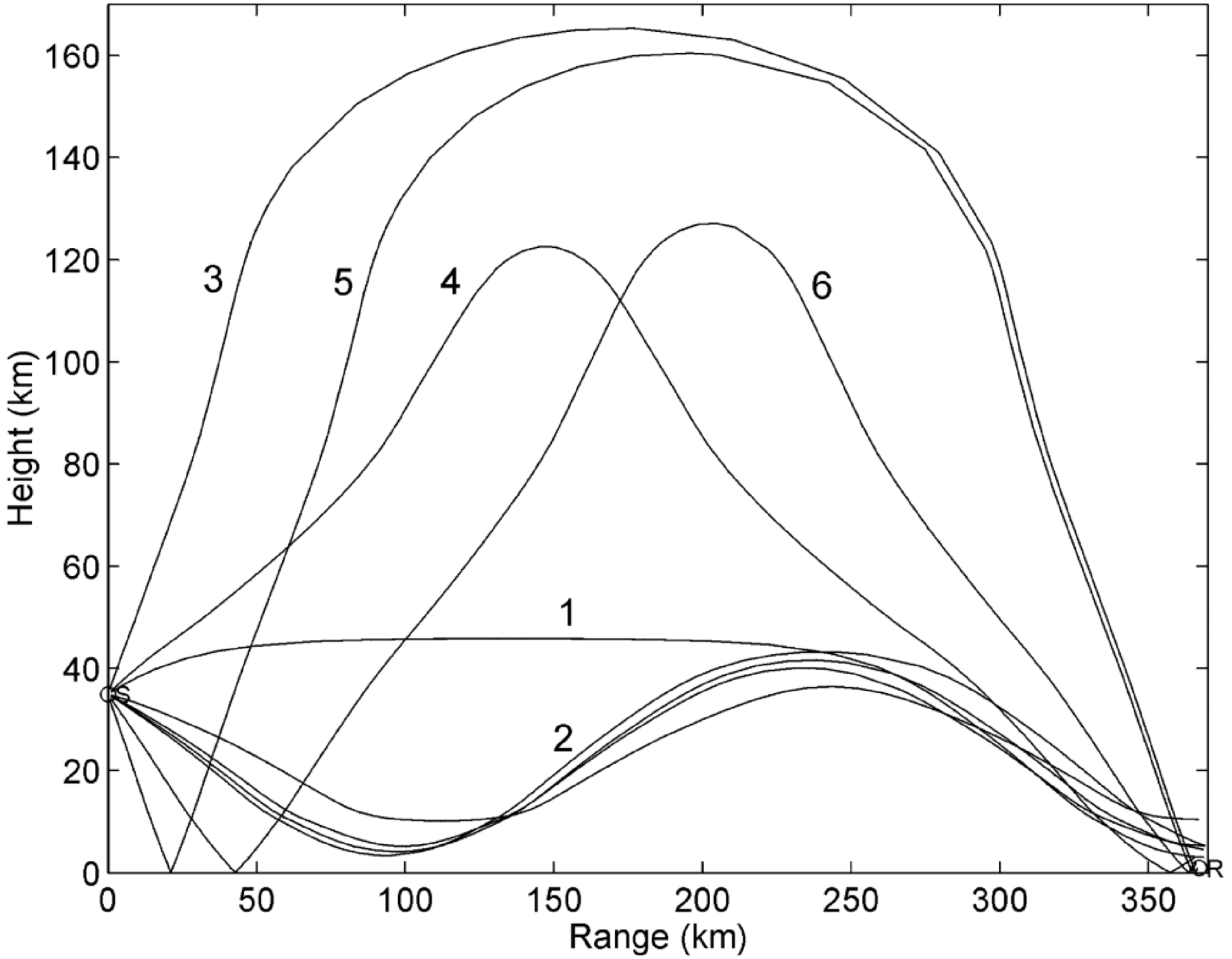
(Nappo 2012), (Sutherland 2010)

Stratification



Ray-Tracing

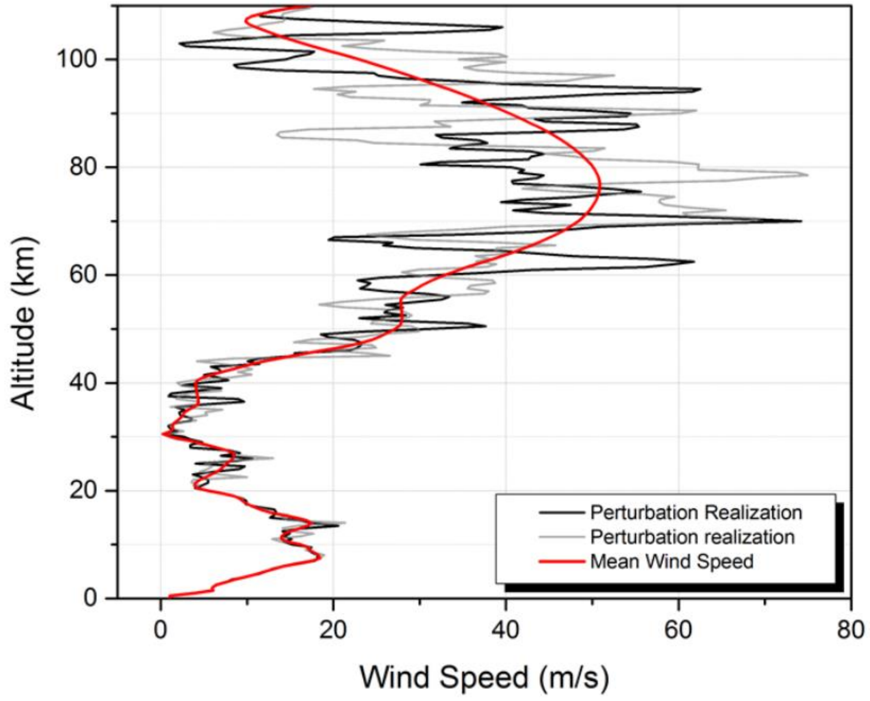
- Near-field (< 150 km) - direct arrivals
- Far-field (> 150 km) - "ducted" arrivals
- Airborne explosion causes long-period wave together with a short-period wave (Taun, 1975)



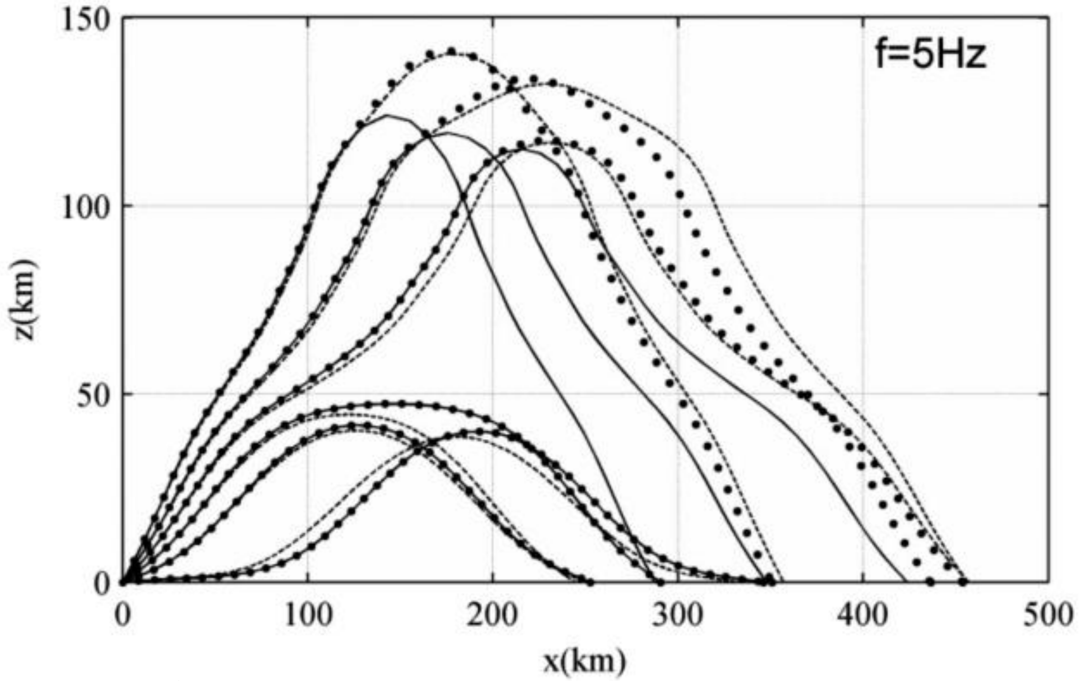
(Brown et al. 2003)

Gravity Waves on Propagation

- Rays will reflect if their frequency is less than buoyancy frequency (Sutherland 1999, Kalashnik 2013)
- Monte-Carlo Wind Perturbations to estimate winds from buoyancy frequency (Stratosphere and lower atmosphere) (Silber 2014)
- Attenuation effects usually ignored for shorter periods (Groot-Hedlin 2006), or at lower altitudes (Song et al, 2014)



(Silber 2014)



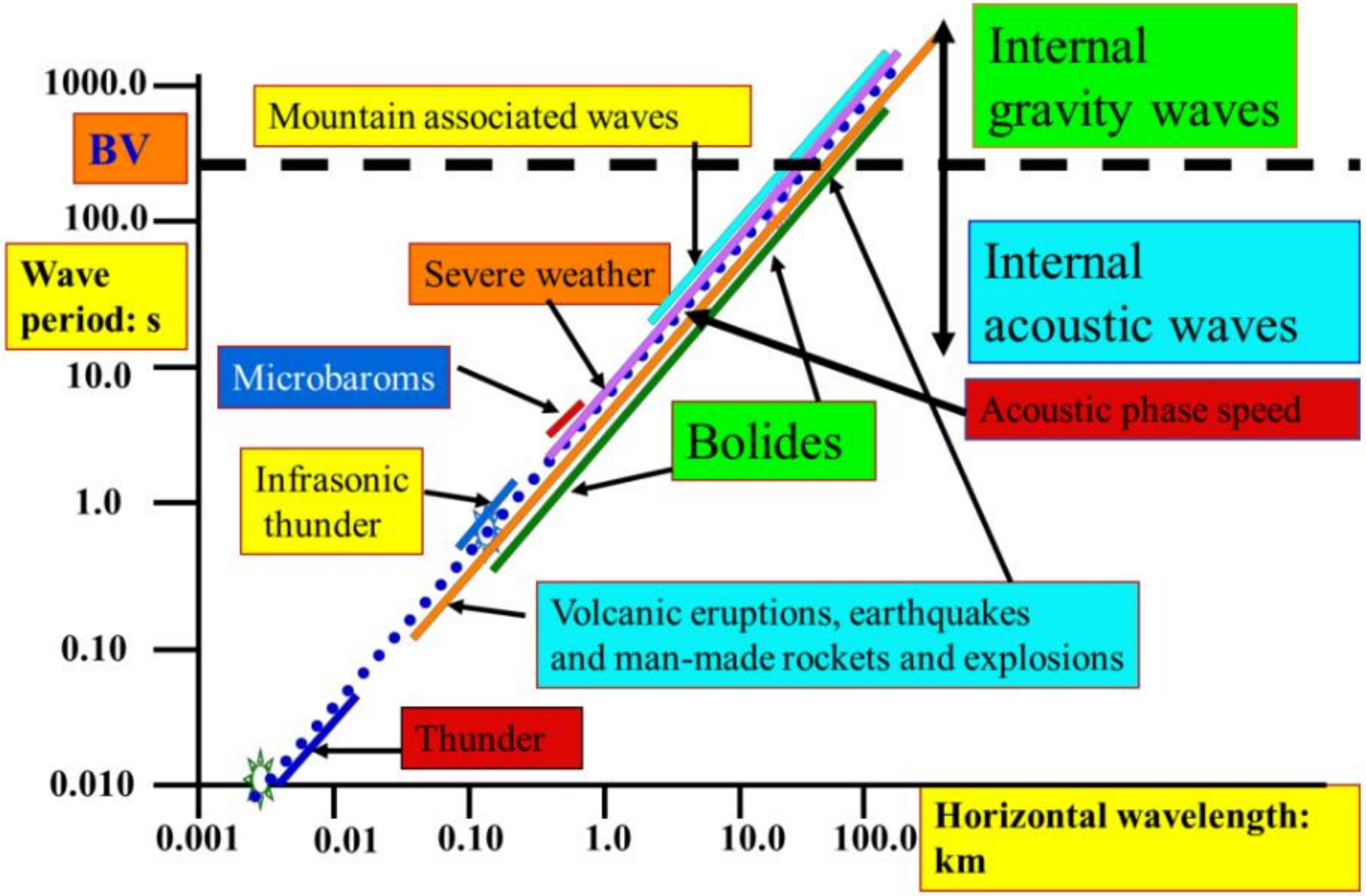
Solid – acoustic rays
Dotted – acoustic gravity wave rays
Dashed – classical rays (no gravity waves or dispersion)

(Song et al, 2014)

Infrasound

- Gravity waves have similar periods to bolide detections – especially at long ranges

- Perturbed atmosphere give uncertainties in ray-tracing travel times and directions
- This also affects yield calculation



Silber (2014)