Gravity Waves in the Stratosphere and Lower Mesosphere above McMurdo & Potential Link to Persistent GWs in the MLT

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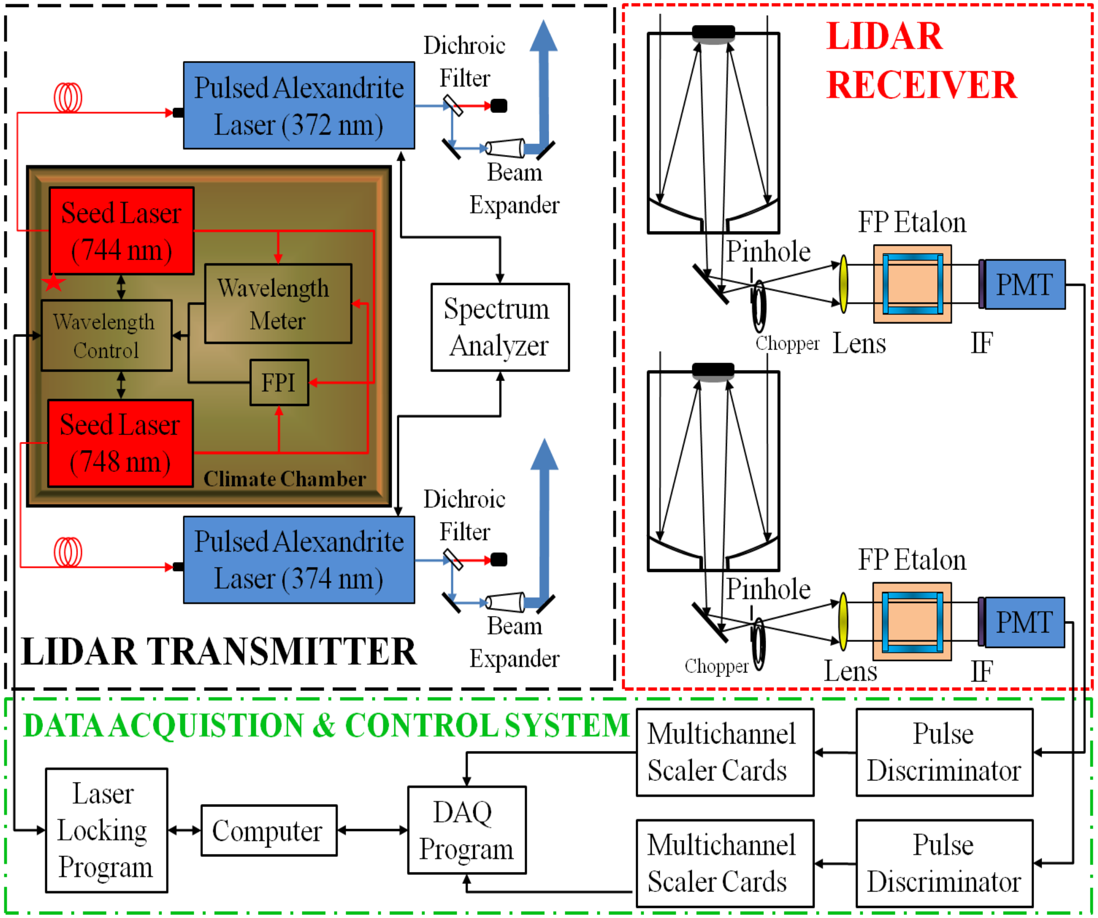
McMurdo Fe Boltzmann Lidar Campaign



[*Chu et al.*, 2002; *Wang et al.*, 2012]

Boltzmann Technique

$$\frac{P_2(J=3)}{P_1(J=4)} = \frac{\rho_{Fe(374)}}{\rho_{Fe(372)}} = \frac{g_2}{g_1}\exp(-\Delta E/k_B T)$$

Rayleigh Technique

$$T(z_1) = \frac{T(z_2)\rho(z_2)}{\rho(z_1)} + \frac{M}{R}\int_{z_1}^{z_2}\frac{g(z)\rho(z)}{\rho(z_1)}\,dz.$$

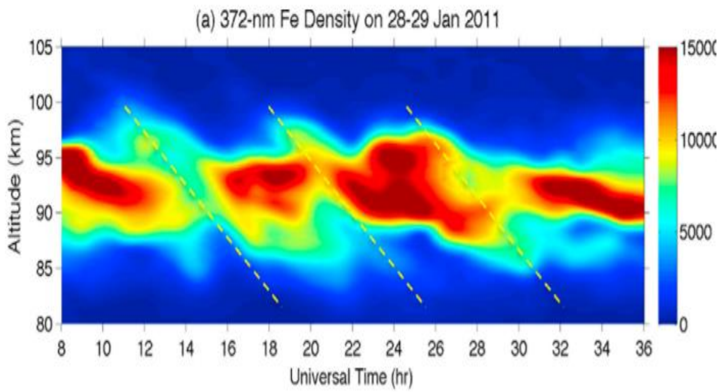
[*Hauchecorne and Chanin*, 1980]

Fe density, Temperature, Air density

Persistent Gravity Waves Challenge Understanding

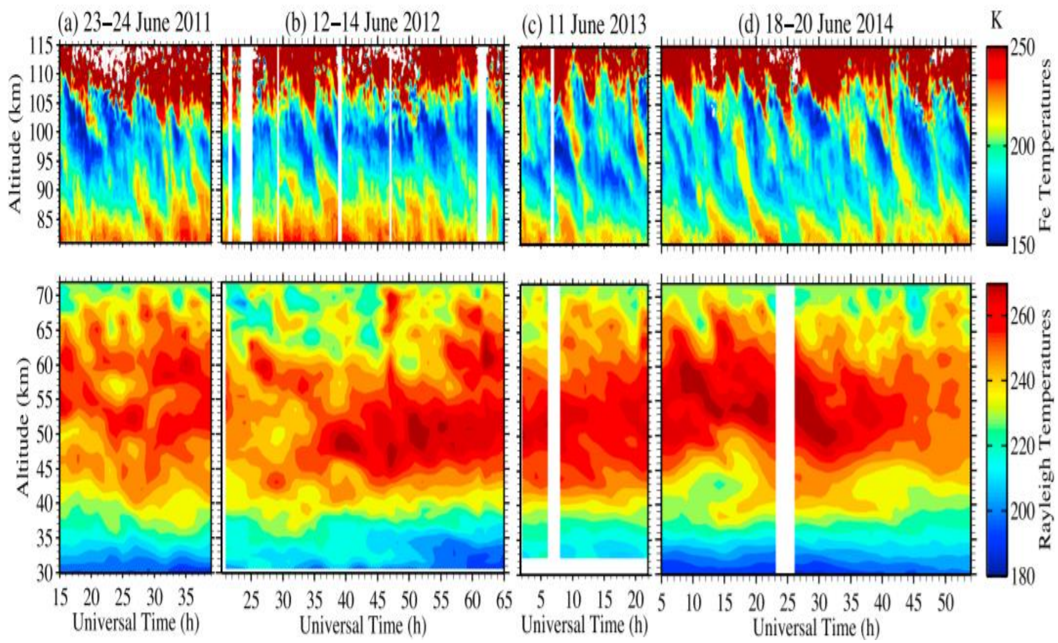
Persistent GWs in McMurdo MLT

Fe Density



[*Chen et al.*, 2016; *Chen and Chu*, 2017; Chu et al., 2011]

Temperature



Signatures:

Large amplitude (±20K)

Dominate temperature variations

Perpetually exist summer winter

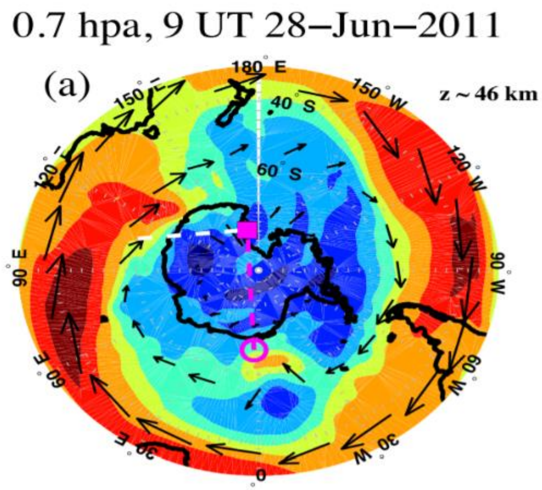
τ: 3-10 h, λ_z: 20-30 km

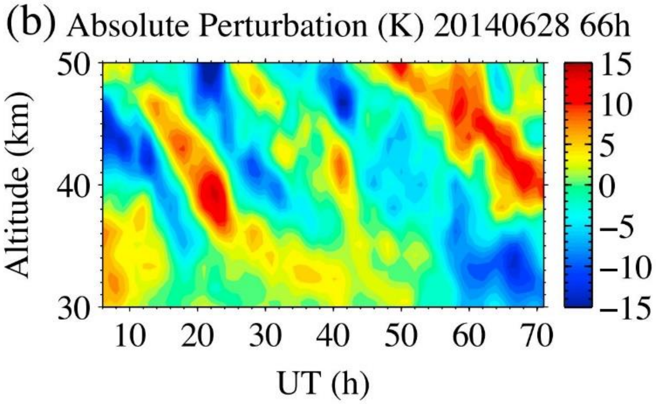
Constituent concentration, PMC, GCMs, etc.

Potential sources for persistent GWs in MLT

Persistent GWs in MLT
[*Chen et al*, 2013, 2016]

Possible wave source in stratosphere
[*Chen et al*, 2013]





[*Zhao et al*, 2017]

Urge the characterization of GWs in the stratosphere
Search for wave sources for MLT persistent waves and stratospheric GWs

Stratospheric and MLT GWs: τ, λ_z, c_z

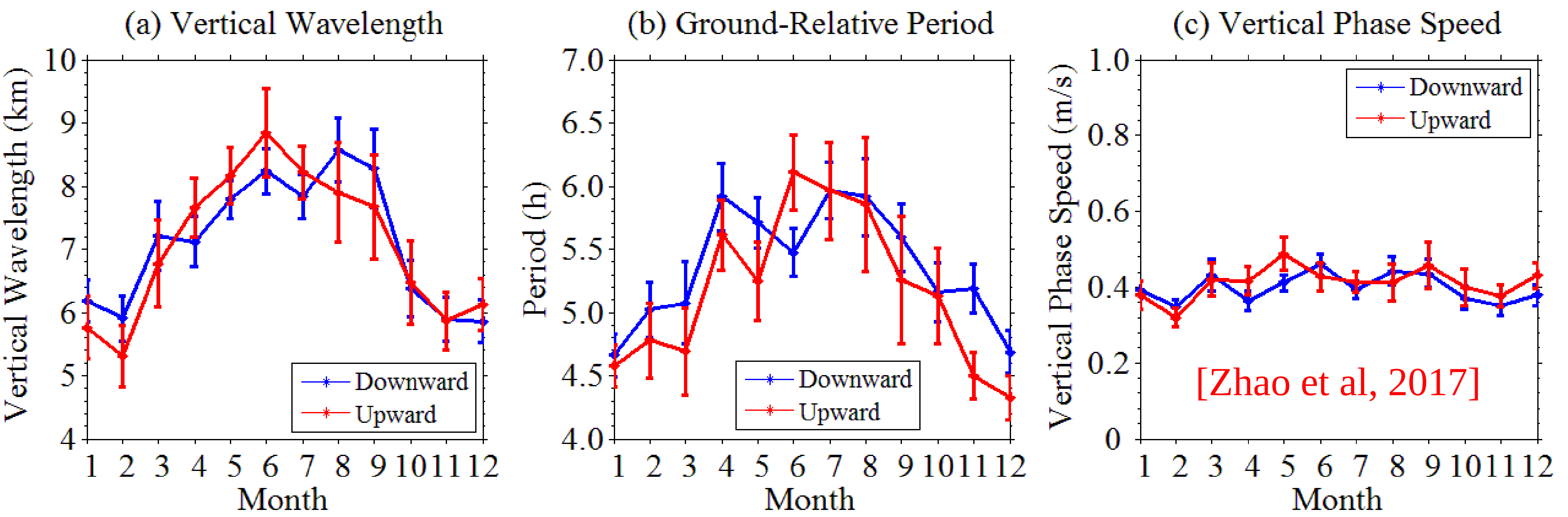
MLT persistent waves τ: 3-10 h, λ_z: 20-30 km

Stratosphere Dominant GWs

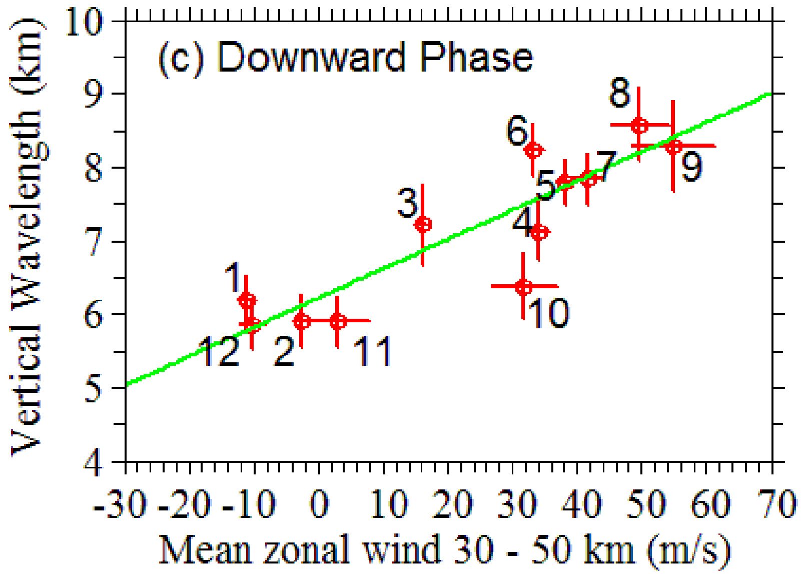
Vertical wavelength: ~5.5 km (summer) to ~8 km (winter)

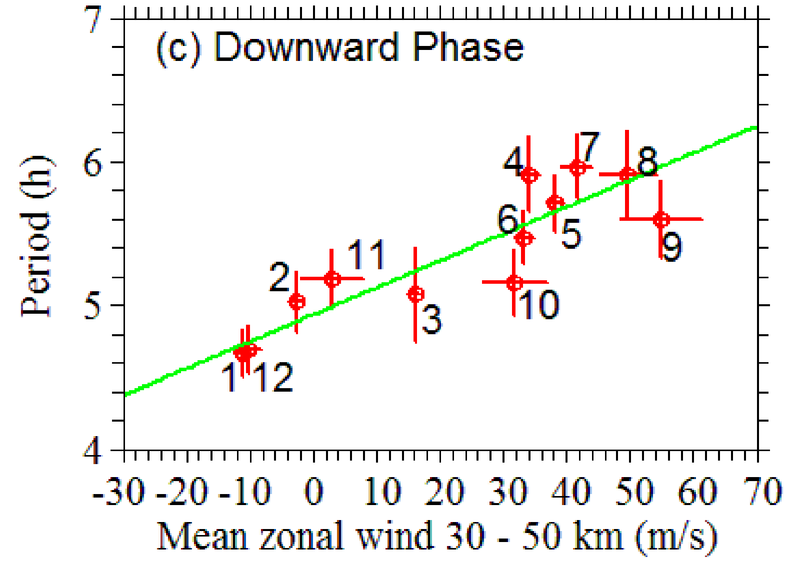
Ground-relative period: ~4.5 h (summer) to ~5.7 h (winter)

Vertical phase speeds: constant (~0.4 m/s) throughout the year



Stratosphere: Linear Correlation of λ_z, τ with Bkg Wind





GW dispersion relation

$$\hat{\omega} = N\left|\frac{k_h}{m}\right|$$

$$\lambda_z \cong \frac{2\pi}{N}\left(c_h - \bar{u}_h \cos\theta\right)$$

$$S_{\lambda_z} = -\frac{2\pi\cos\theta}{N}$$

Doppler shift effect

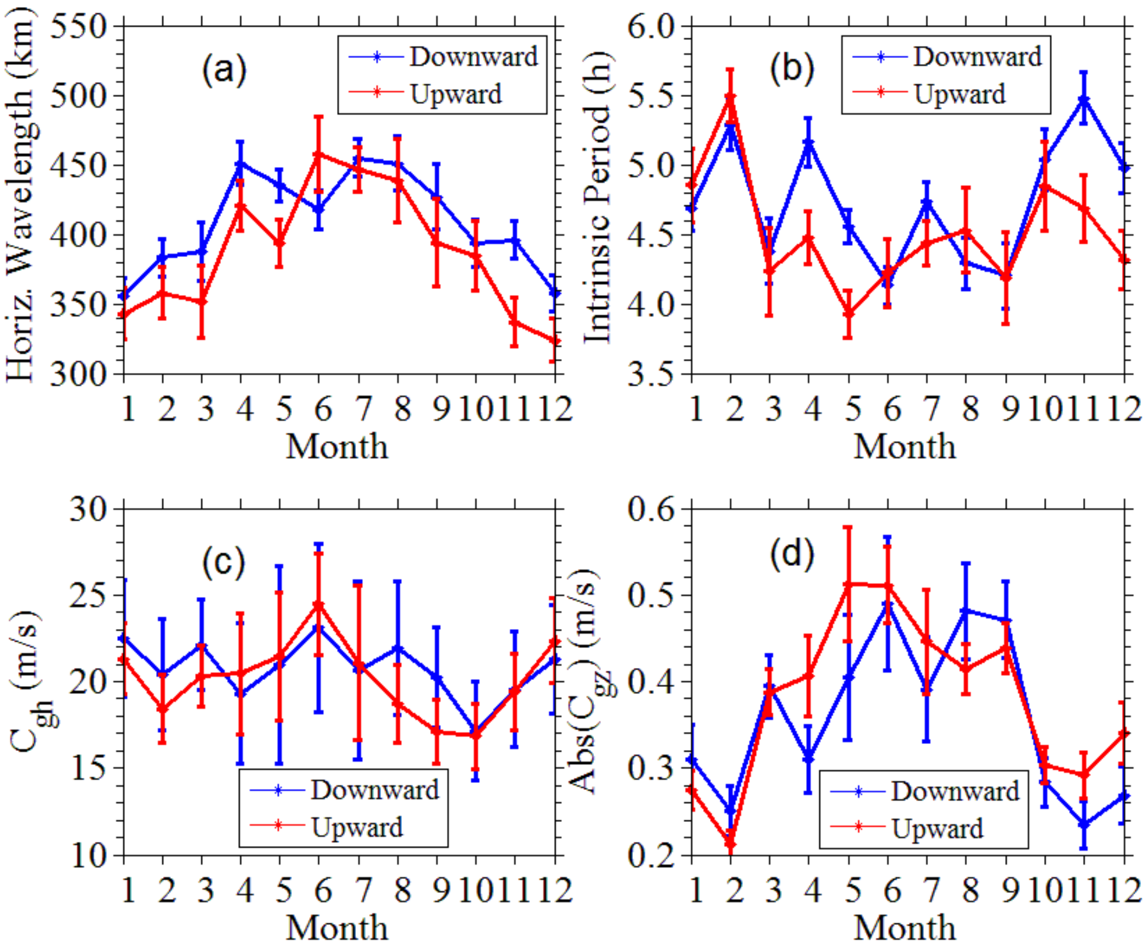
$$\hat{\omega} = \omega - \vec{k}\cdot\vec{\bar{u}} \cong \omega - k_h\bar{u}_h\cos\theta = \omega\left(1 - \frac{\bar{u}_h\cos\theta}{c_h}\right)$$

$$\tau = \hat{\tau}\left(1 - \frac{\bar{u}_h\cos\theta}{c_h}\right)$$

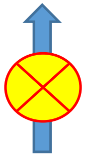
$$S_\tau = -\frac{\hat{\tau}}{c_h}\cos\theta = -\frac{2\pi k_h\cos\theta}{\hat{\omega}\cdot\omega}$$

[Zhao et al, 2017]

Stratospheric & MLT GWs: Inferred λ_h, c_h, τ_I, c_{gh}, c_{gz}



MLT persistent waves
λ_h:1000-3000 km;
λ_z: 20-30 km
[*Chen et al., 2012; 2013*])



Not Direct Source

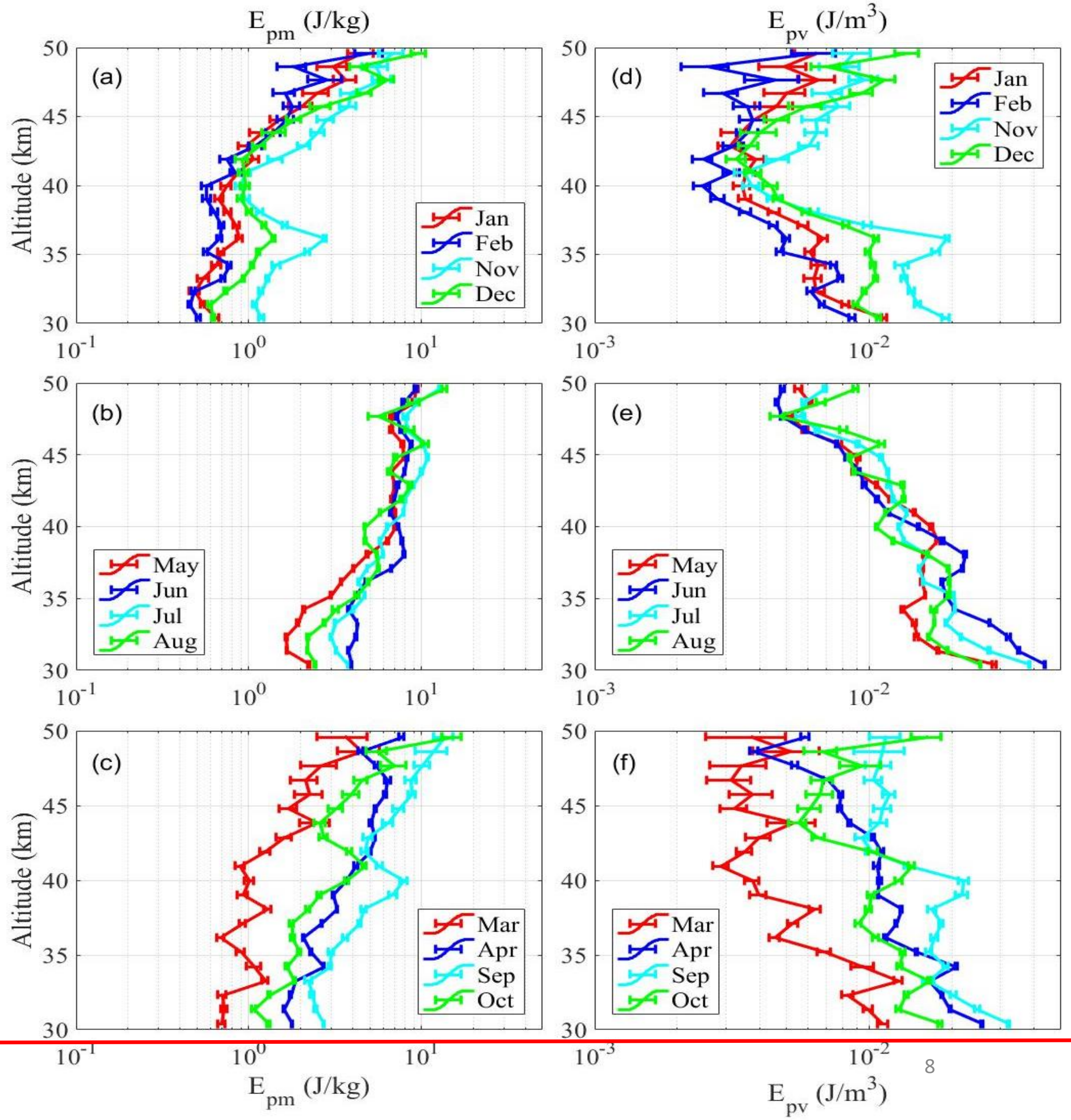
Stratosphere Dominant GWs:
λ_h: ~400 km; λ_z: 5-8 km
Elevation angle: ~1°
Propagating along North-South

	Down	**Up**
C_h(m/s)	21.2	20.8
cos(θ)	-0.14	-0.16

[Zhao et al, 2017]

MLT persistent GWs vs stratospheric GW strength: E_{pm}

MLT persistent waves:
±20 K large amplitude
E_{pm} of persistent waves was not characterized in Chen et al. [2016]

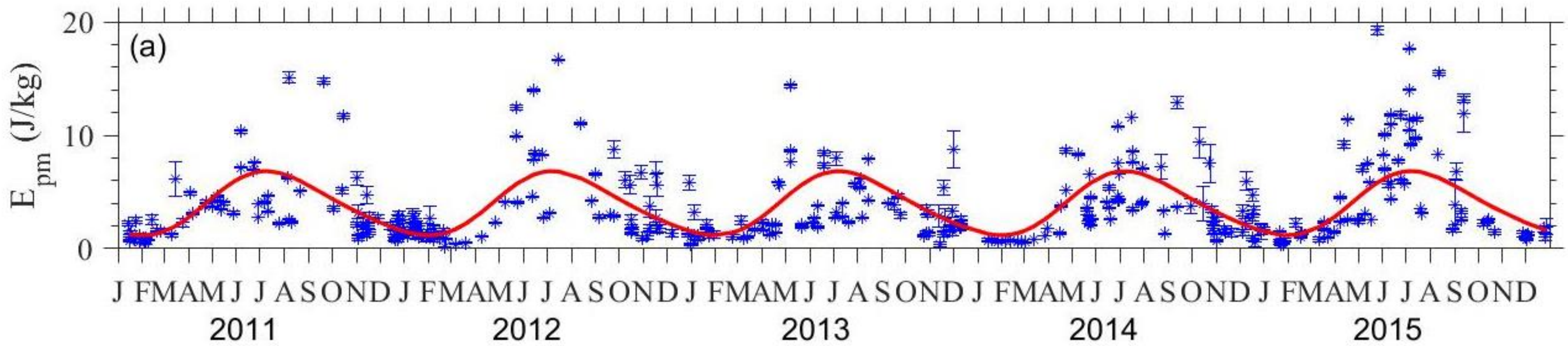


Stratosphere GWs

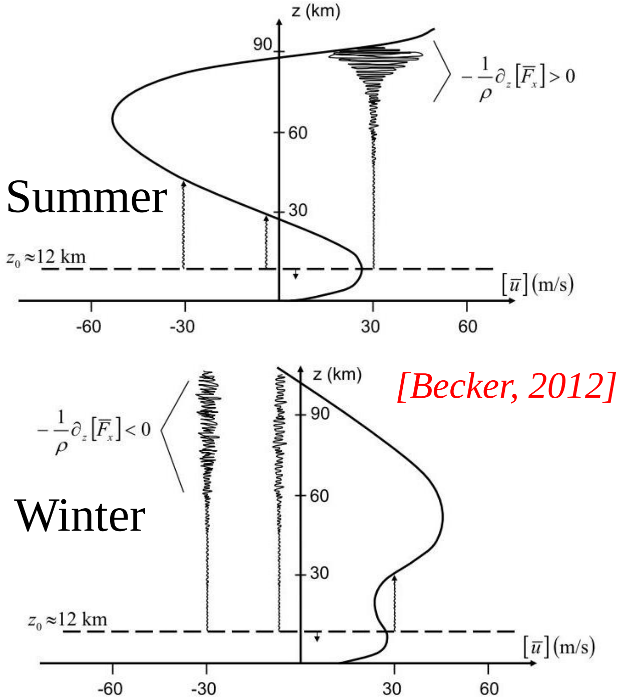
- E_{pm} winter > summer
- Critical level filtering from lower atmosphere

- E_{pm} grow slower in winter
- More wave dissipation

Seasonal Variations of E_{pm} in the stratosphere

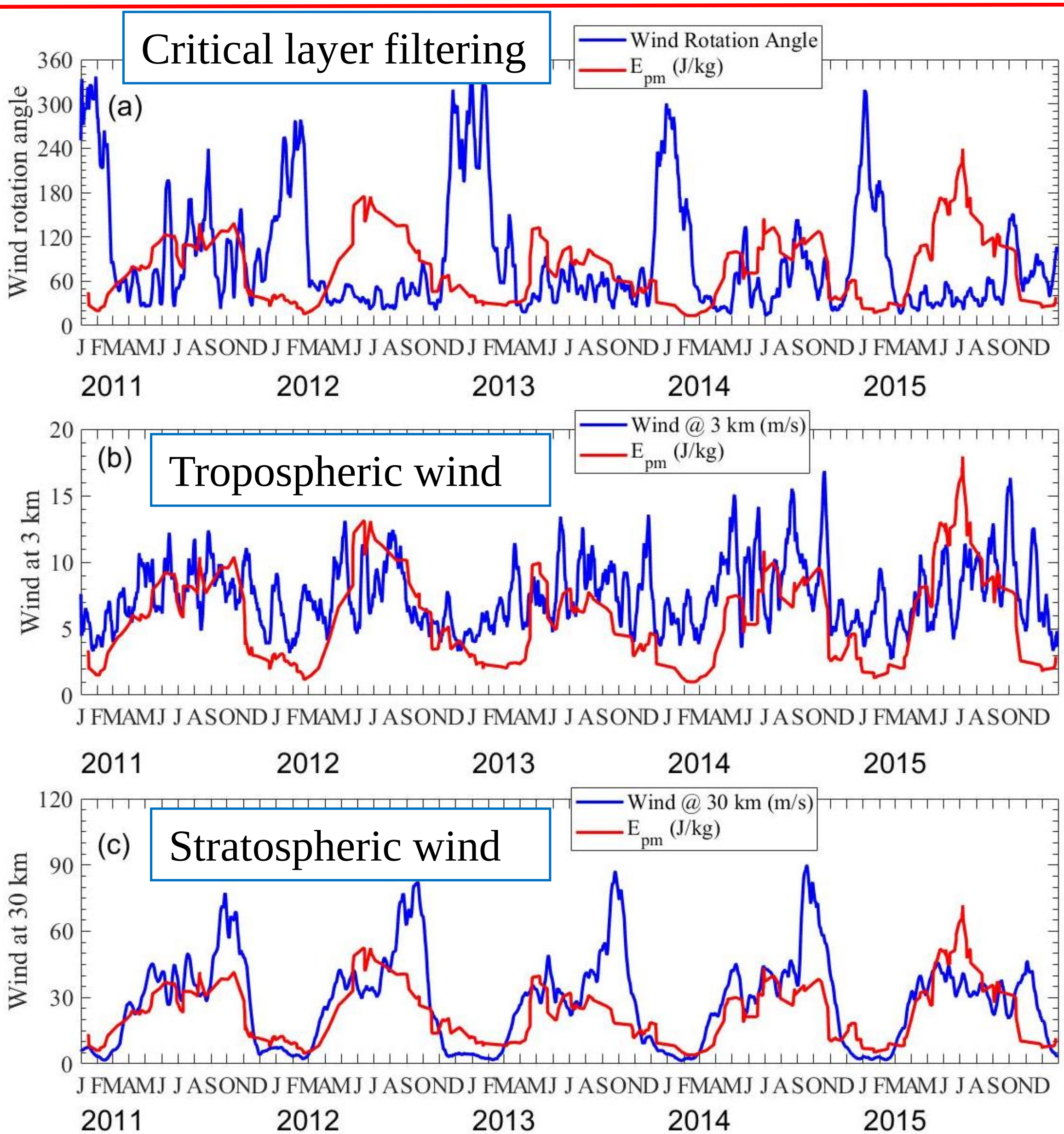


E_{pm} vary substantially from Obs. to Obs.
Quite large year-to-year variability
Summer minima (Feb) and winter maxima (Jun)
Indicating the critical level filtering due to Bkg. wind



[Becker, 2012]

E_{pm} vs Wind Rotation and Wind Speeds (ECMWF)

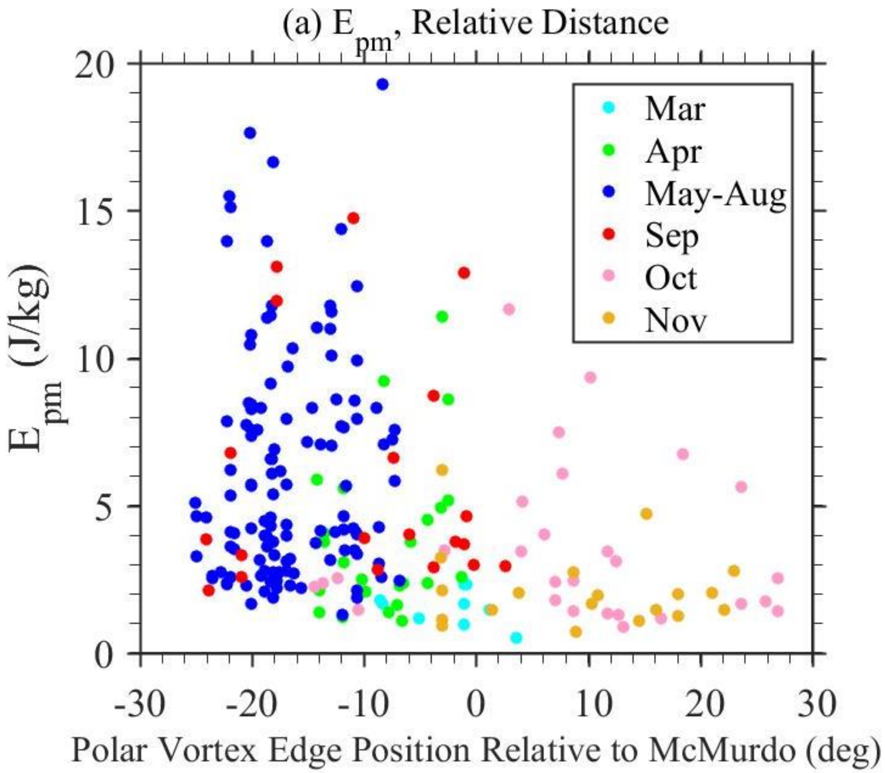


Large increase in E_{pm} in winter

More likely due to:

1) More waves propagate into stratosphere due to less critical level filtering
2) More orographic waves generated in the troposphere
3) In-situ wave source in the stratosphere
4) Doppler shift theory [Whiteway et al.,1997]

In-Situ Source: Polar Vortex (MERRA) vs E_{pm}



Small E_{pm} occurs all year round

Large E_{pm} happens:

- McMurdo is inside the jet stream core 8° to 23° towards the pole
- Wind is strong

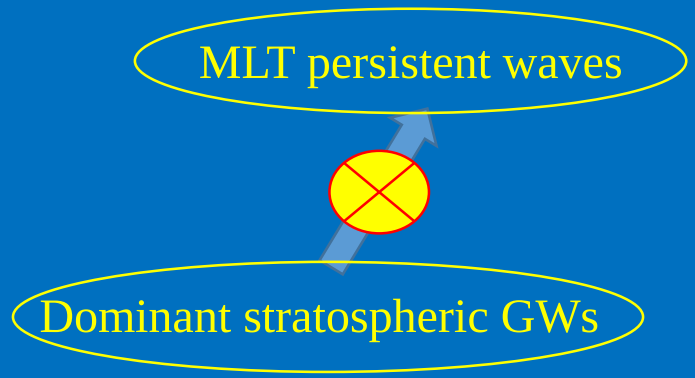
Possible sources for stratospheric and MLT waves

Stratosphere GWs

- GWs (mainly orographic GWs) from lower atmosphere modulated by critical level filtering
- In-situ wave source due to strong polar vortex

MLT persistent GWs

λ_h: Dominant stratospheric GWs << MLT persistent GWs



How about secondary gravity wave generation?

Secondary Wave Generation & Signature

Larger Scale secondary GWs

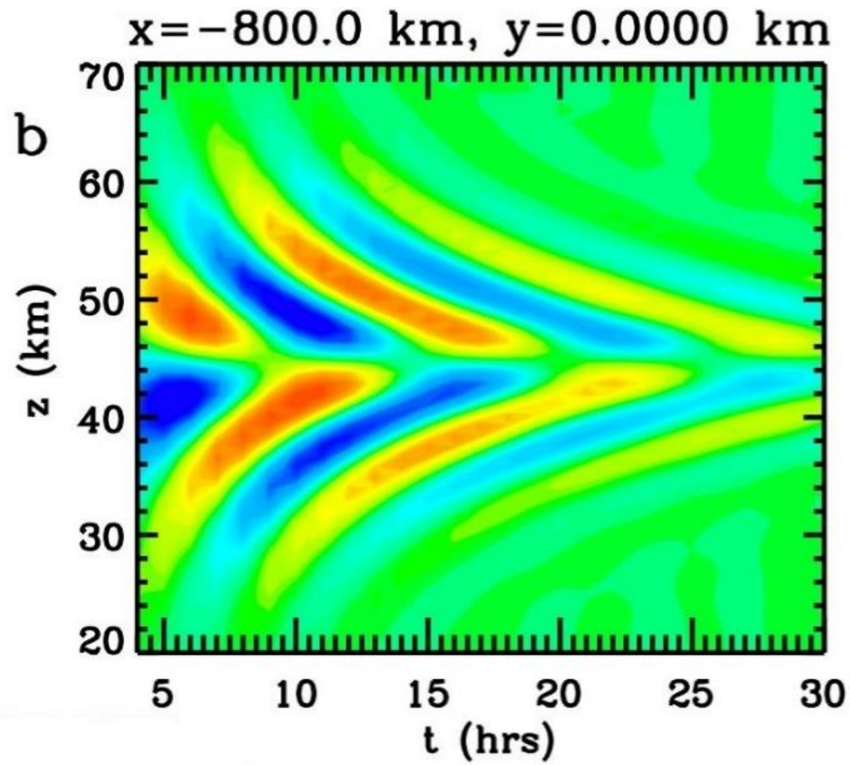
“Fishbone” signatures

Smaller Scale GWs
Cascades of energy

body force

break ~ 45 km

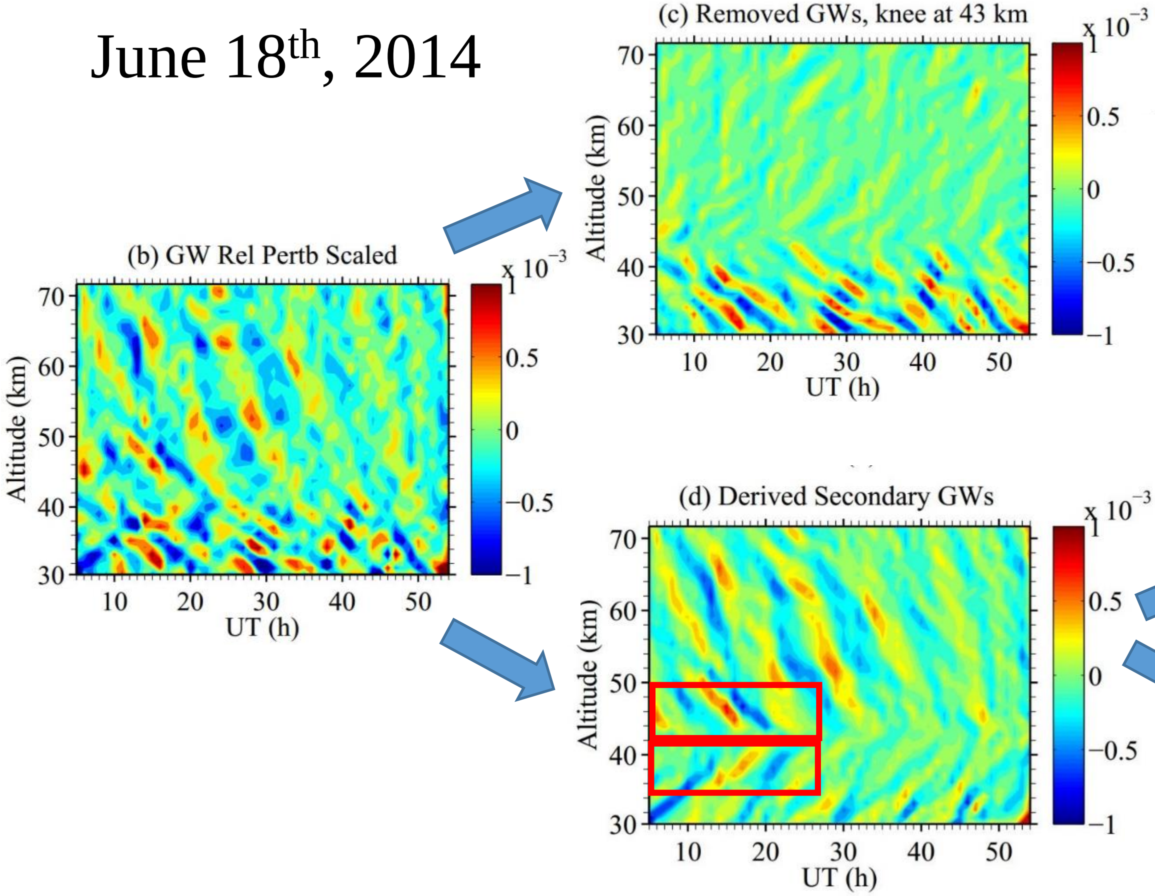
Primary GW(orographic)



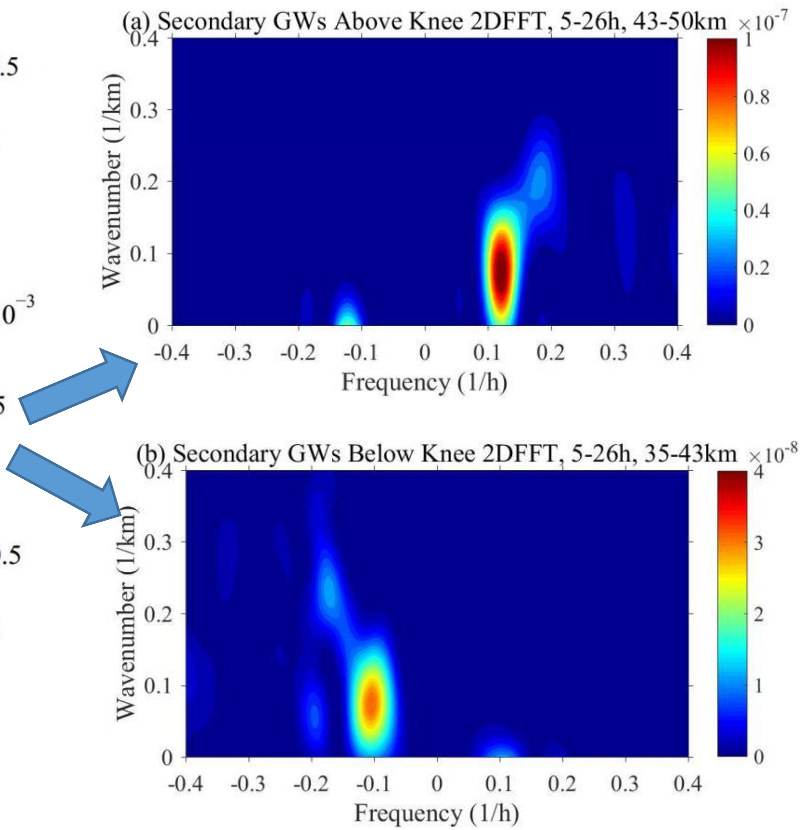
[*Vadas et al., 2003, 2018*]

Secondary Wave Generation at McMurdo

June 18th, 2014

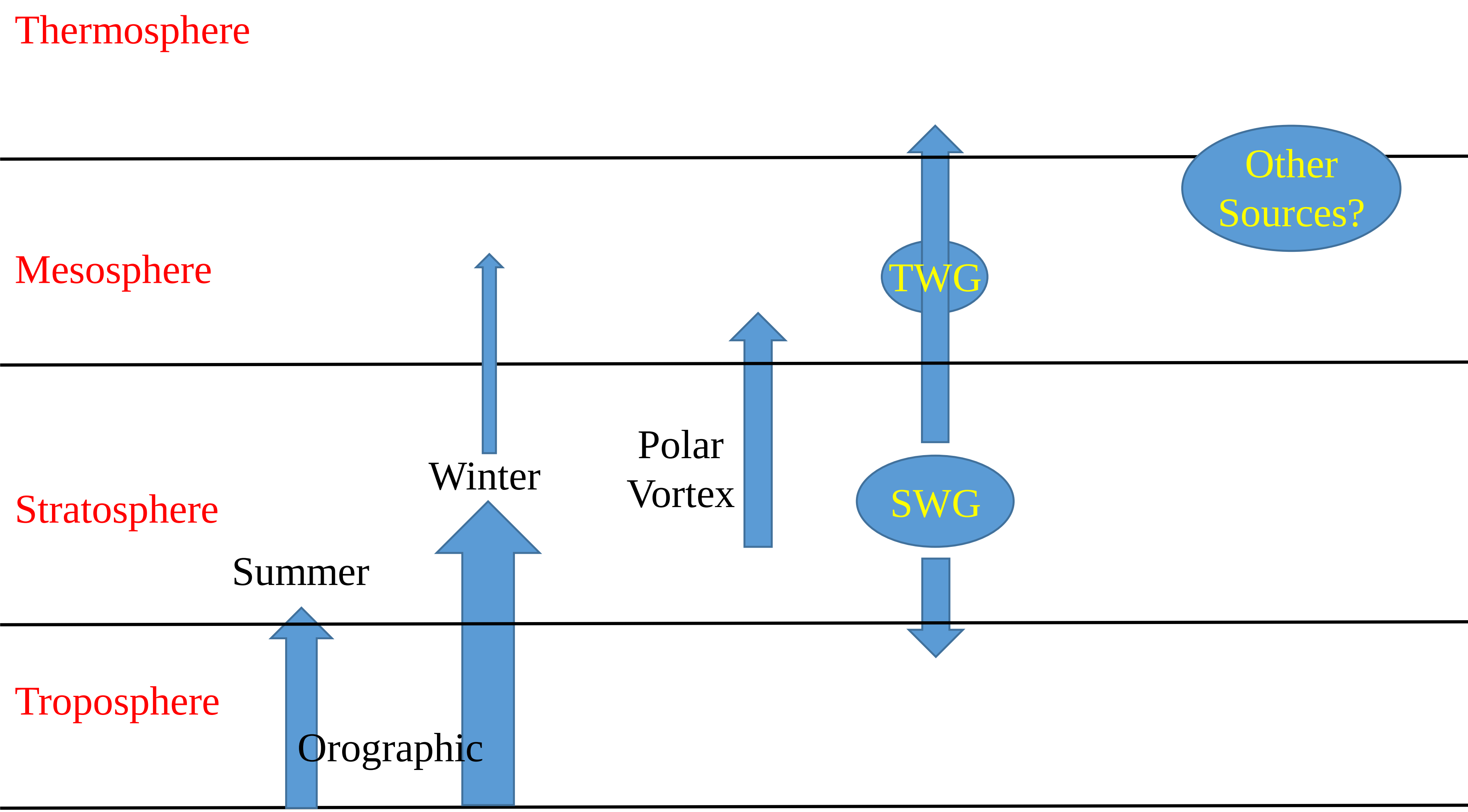


8 criteria



[*Vadas et al., 2003, 2018*]

A potential general picture of GWs above McMurdo



Conclusions

- Compare wave parameters of stratospheric dominant gravity wave and MLT persistent wave
  - Seasonal variations of $\tau, \lambda_z, \lambda_h, E_p, c_z, c_h, \tau_I, c_{gh}, c_{gz}$
  - λ_z and τ are : Linearly correlated with background winds
- Stratospheric GW source:
  - E_{pm}: Critical level filtering of GWs from lower atmosphere, In-situ generation, Doppler shift
- Speculate dominant stratospheric gravity waves are not the waves that propagate into MLT and become the observed persistent GWs
- Possible source of persistent waves in MLT: Secondary gravity wave generation

Thank you!

Questions?