Horizontal Wavenumber Spectra Across the Middle Atmosphere From Airborne Lidar Observations During the 2019 Southern Hemispheric SSW

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INTRODUCTION

- Nastrom and Gage (1983): the horizontal wavenumber spectrum of the troposphere exhibits a power-law behavior of approximately $k^{-5/3}$ on the mesoscales (2.6 km $< \lambda <$ 400 km)
- Previous airborne lidar observations covered only parts of the middle atmosphere (e.g. Kwon et al., 1990, Hostetler et al., 1991, Hostetler et Gardner, 1994, Gao and Meriwether, 1998)
- First observations from 20 km to 80 km altitude by the Airborne Lidar for Middle Atmosphere reserach (ALIMA) operated during the SouthTRAC-GW campaign September 2019 (Rapp et al., 2021)
- Prevalent theories for the generation of a canonical horizontal spectrum on the mesoscales are stratified turbulence (e.g. Lilly, 1983; Lindborg, 2006; Li and Lindborg, 2018) or interacting Gravity Waves (GW)s (e.g. Dewan, 1979; VanZandt, 1982; Bacmeister et al., 1996)
- A Southern Hemisphere Sudden Stratospheric Warming (SSW) started on 30 August 2019 with a displacement of stratospheric polar vortex towards South America (Fig. 1).
- The critical level for propagting MWs descended to approx. 40 km due to the SSW (Fig. 2).

RESEARCH QUESTIONS

1) What is the shape of the horizontal wavenumber spectrum throughout the middle atmosphere in the vicinity of the mountain wave (MW) hotspot above the Southern Andes?
2) How is the horizontal wavenumber spectrum in the middle atmosphere affected by GWs and the SSW?

DATA

- 43 straight flight legs with lengths from 150 km to 2400 km
- Range-corrected photon counts $\gamma(t,z)$ with a resolution of $\Delta t = 1$ min and $\Delta z = 900$ m
- Monte-Carlo experiment: photon noise spectra calculated based on $\overline{\gamma(z)}$ and assumption that photon noise follows a Poisson distribution

METHOD

- Flight leg normalization: $\gamma'(t,z) = \frac{\gamma(t,z)}{\overline{\gamma(z)}}$ (1)
- Power spectral density (PSD): $PSD_\gamma(k) = \left|\widehat{\gamma'}(k)\right|^2 * \frac{\Delta x^2}{X}$ (2)
- $\lambda_k = k * \Delta x, \quad k = [1, 2, \dots, n], \quad k = \frac{2\pi}{\lambda_k}, \quad n = \frac{X}{\Delta x}, \quad \Delta x = \tau * \overline{GS_{HALO}}$

Horizontal wavelength; Horizontal wavenumber; Length of flight leg; Horizontal bin size; Ground speed of HALO

RESULTS

- Derived horizontal wavelengths range from 22 km to 2000 km (Fig. 3 and 4)
- Below 70 km altitude, most horizontal wavenumber spectra are well above the noise floor (except ST10 due to icing of the laser window; Fig. 3 and 4)
- $\overline{PSD_\gamma}$ is reduced by approximately 25 % at $\lambda_k = 200$ km during flights ST09, ST10, ST11, ST12 and ST14 compared to ST08 (Fig. 3)
- Largest values and variability of $\overline{PSD_\gamma}$ over the ocean, while on average values larger over land than over the ocean (especially in the mesosphere; Fig. 5)

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CONCLUSIONS

- Averaged horizontal wavenumber spectra are statistically robust, rather smooth and exhibit slopes close to $k^{-5/3}$ in stratosphere; slopes deviate from $k^{-5/3}$ for $\lambda_k < 200$ km in the mesosphere
- Influences by horizontally and vertically propagating MWs and potentially non-orographic GWs apparent
- The SSW caused an attenuation of spectral power

Altitude dependent horizontal wavenumber spectra changing for the different research flights

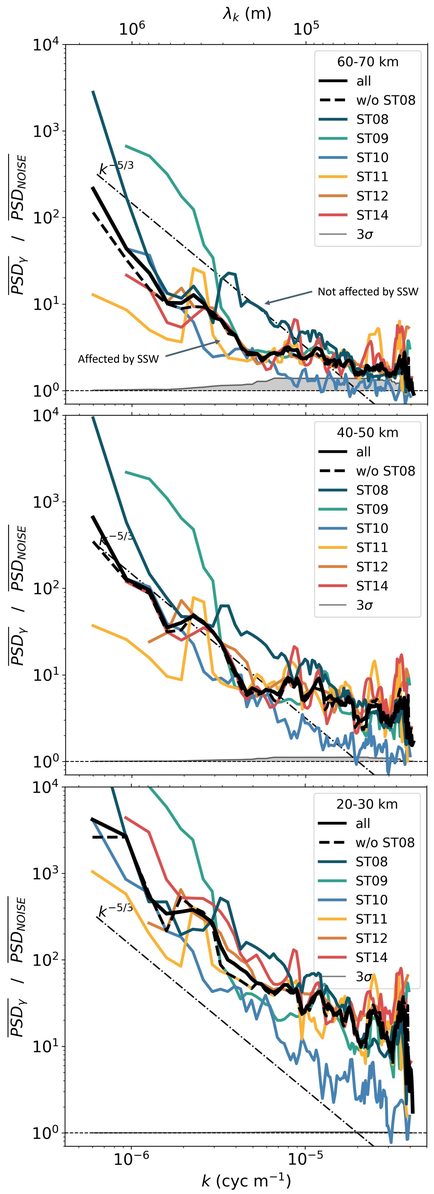


Figure 1 ←: Vertically averaged horizontal wavenumber spectra of all research flights.

Atmospheric Conditions and Mountain wave propagation during the SSSW

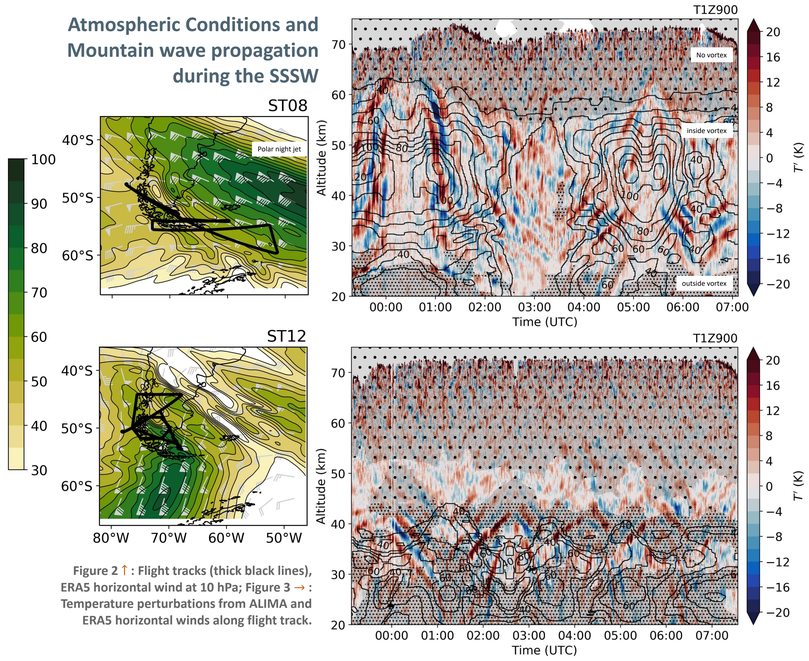
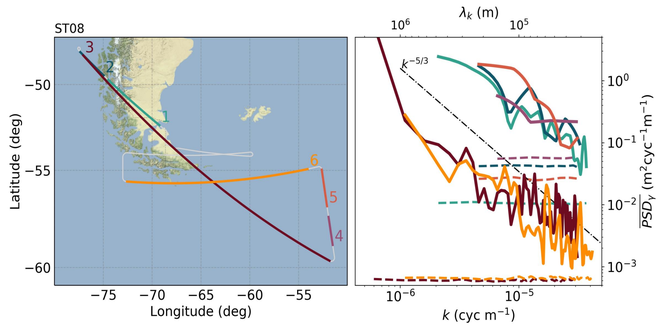


Figure 2 ↑: Flight tracks (thick black lines), ERA5 horizontal wind at 10 hPa; Figure 3 →: Temperature perturbations from ALIMA and ERA5 horizontal winds along flight track.



Individual horizontal wavenumber spectra of ST08 close to $k^{-5/3}$

Figure 4 ←: Flight legs of ST08; Photon noise spectra (colored dashed lines).

Altitude dependent distribution of $\overline{PSD_\gamma}$ pronouced above ocean

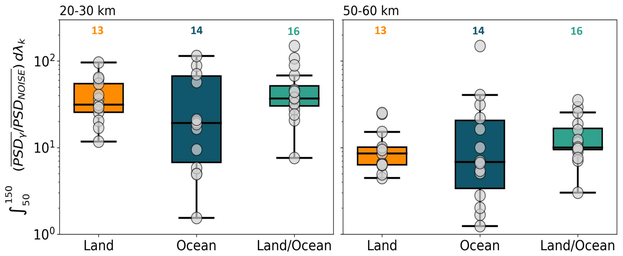


Figure 5 →: Box-whiskers include median, 25- and 75-pertencile, non-outliers, and number of flight legs (colored numbers).

OUTLOOK

Further developement: extention of ALIMA by an iron resonance channel for lower thermosphere and wind measurements

Future application: e.g. ALIMA observations during strong stratospheric polar vortex conditions, investigation of horizontal GW propagation

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