AGU23

Investigating Energy Transfer in the Atmosphere: Evaluating Gravity Wave Spectral Estimation Methods for Sparse Observational Datasets

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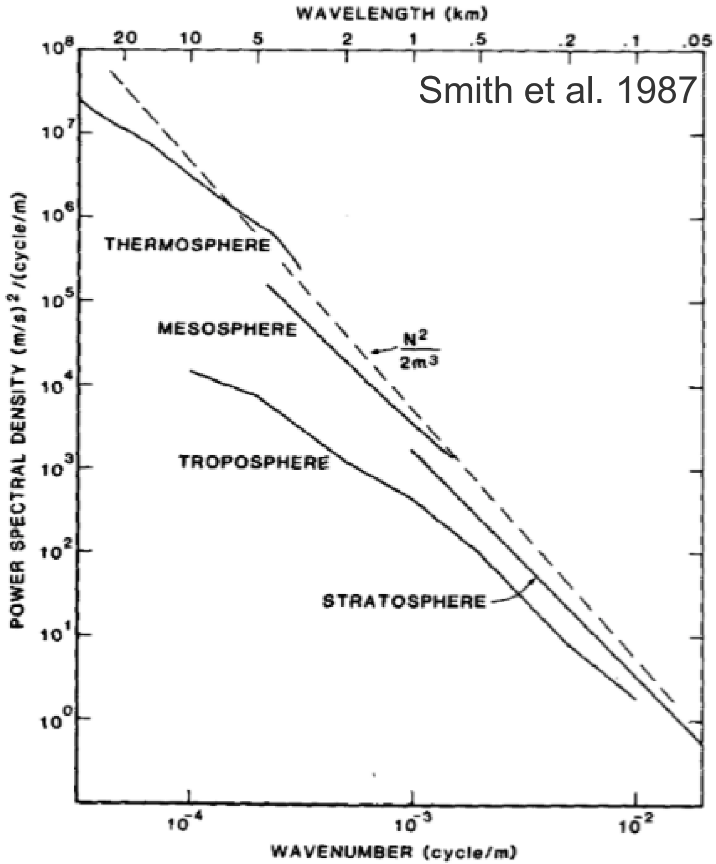
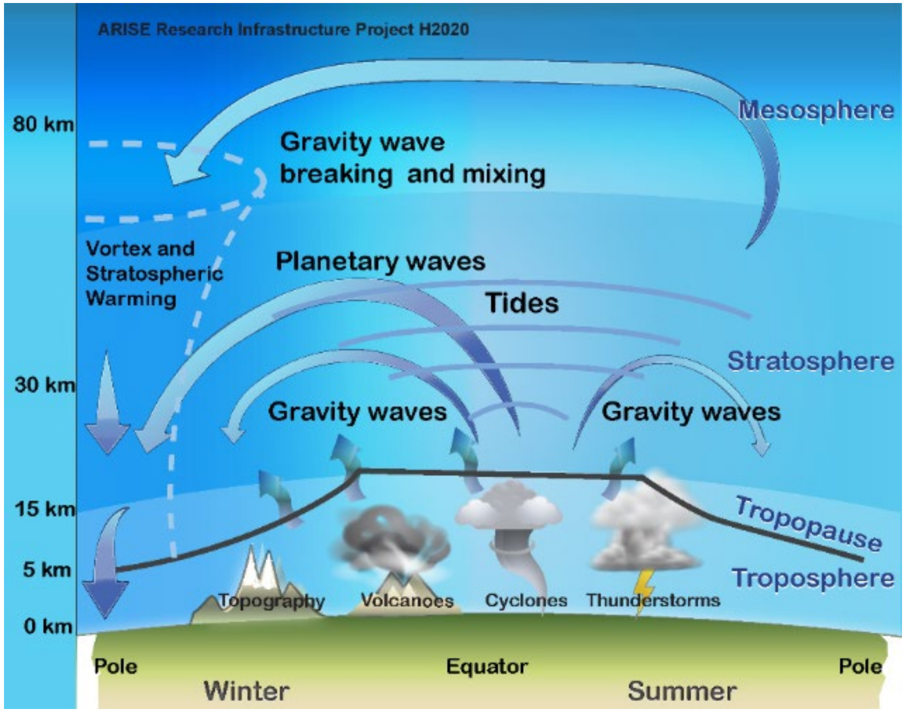
Atmospheric Gravity Waves

- Gravity waves (GWs) have a significant impact on atmospheric dynamics.

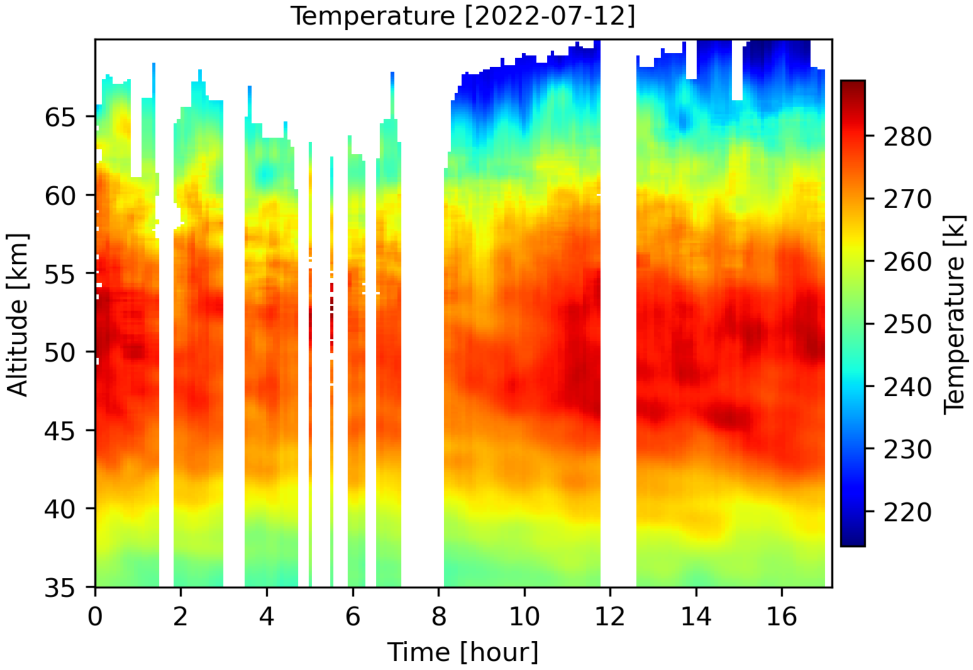




- GW spectra are necessary for efficient parameterizations of how they affect the mean atmospheric state.

Observations are never perfect!

ALOMAR Observatory (69°N, 16°E)



- Rayleigh/Mie/Raman (RMR) twin-lidar observations.

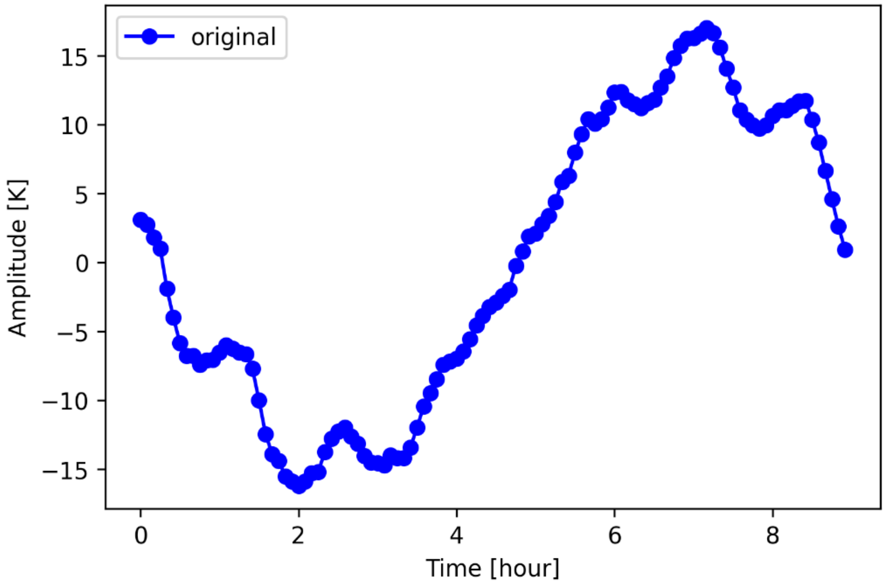
- Gap percentage: 22% = 3.8h
- 98% of lidar measurements in 2021 & 2022 are gapped.

Simulation of 1D time series with a known power-law spectrum

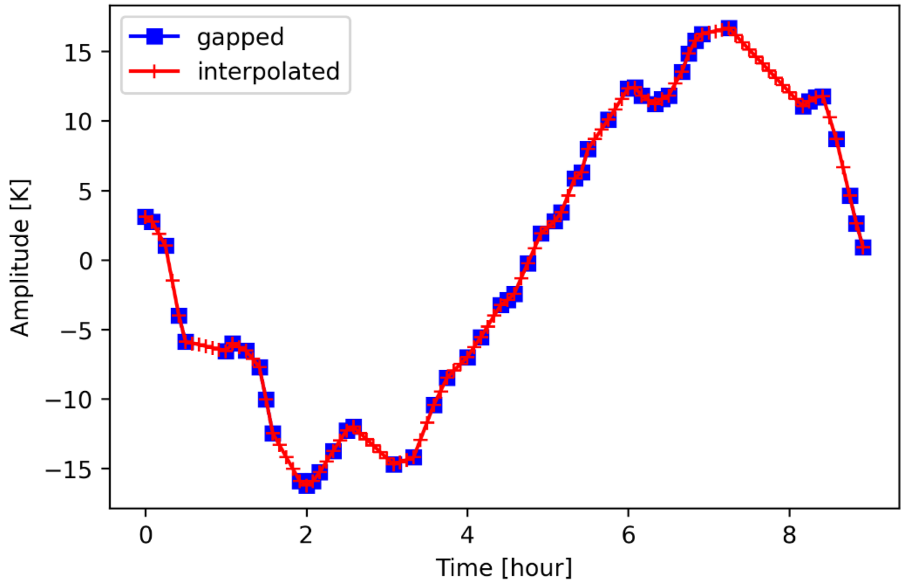
- Superposition of waves with power-law amplitudes [see Mossad et al. 2023]

$$A(f) \propto f^{-\beta}\,.$$

- Random gaps are introduced.



- Gap Percentage 0%

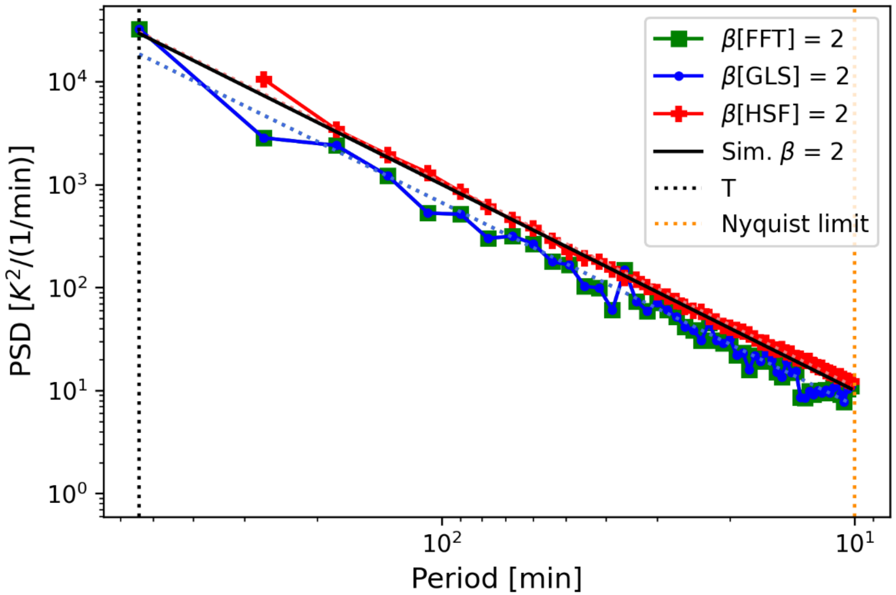


Gap Percentage 50%

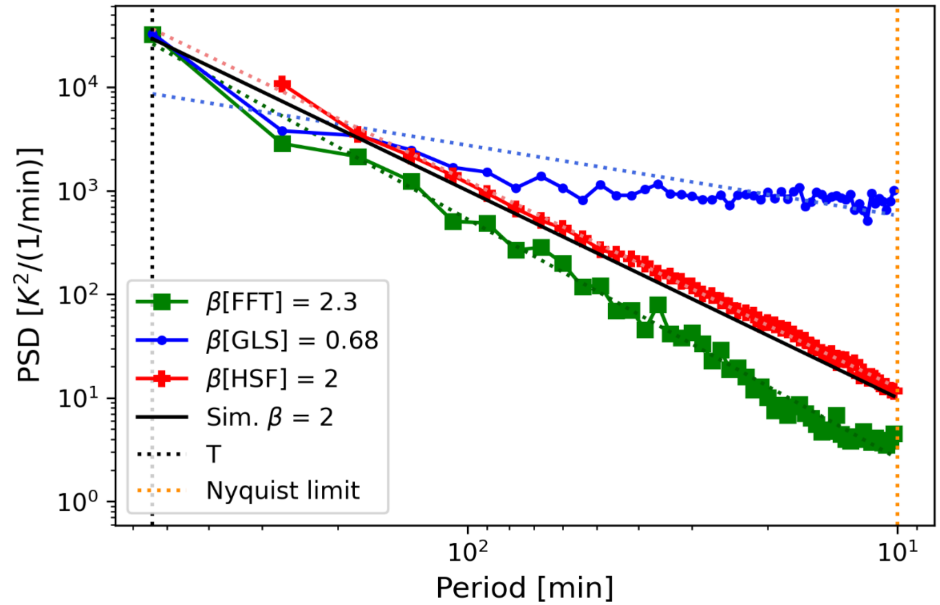
Effect of gaps [idealized]

Spectral methods include:

- Fast Fourier Transform (FFT)
- Generalized Lomb-Scargle Method (GLS)
- Haar Structure Function (HSF) [Lovejoy 2012]



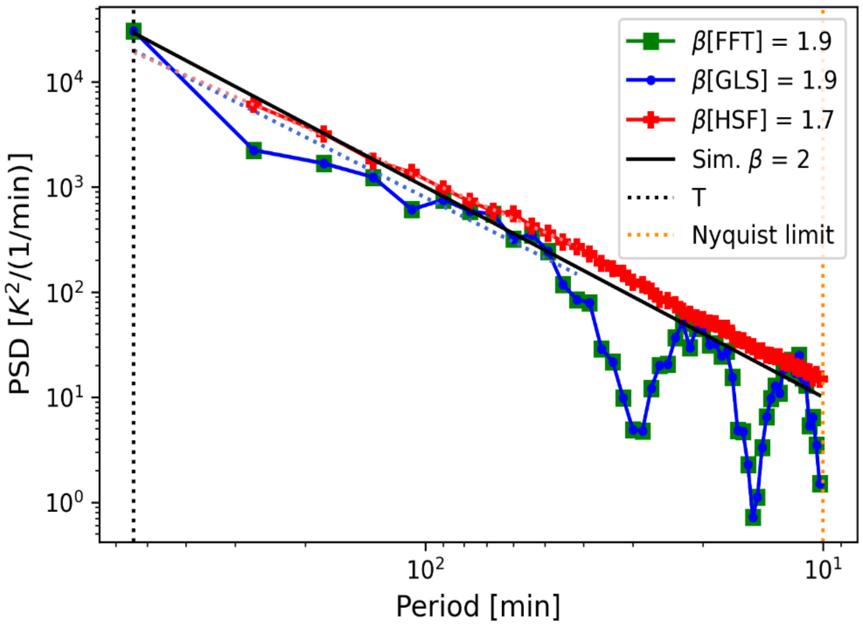
Gap Percentage 0%



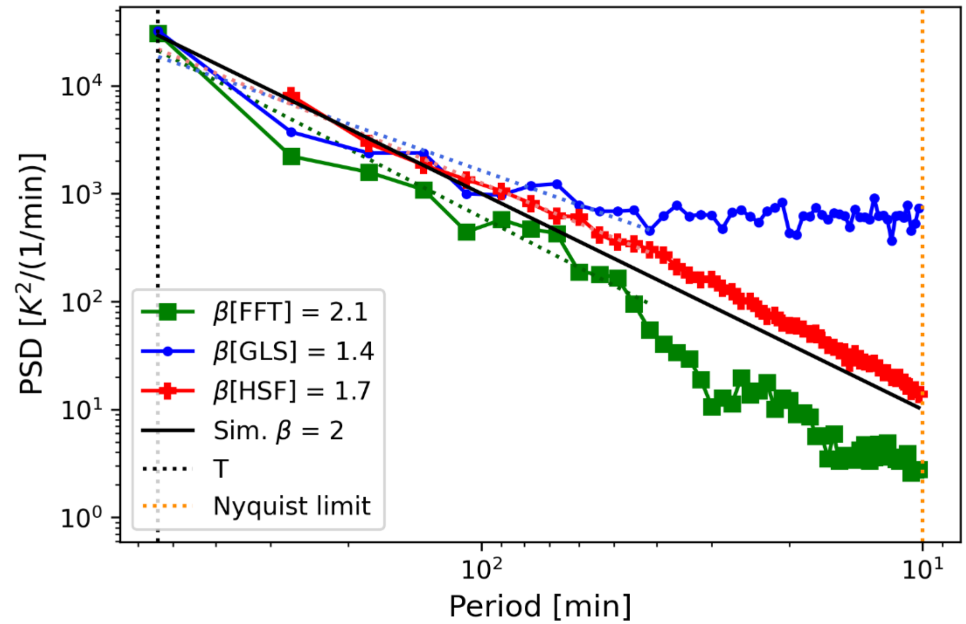
Gap Percentage 50%

- Different responses to gaps by different methods.

Effect of gaps [+noise + smoothing]

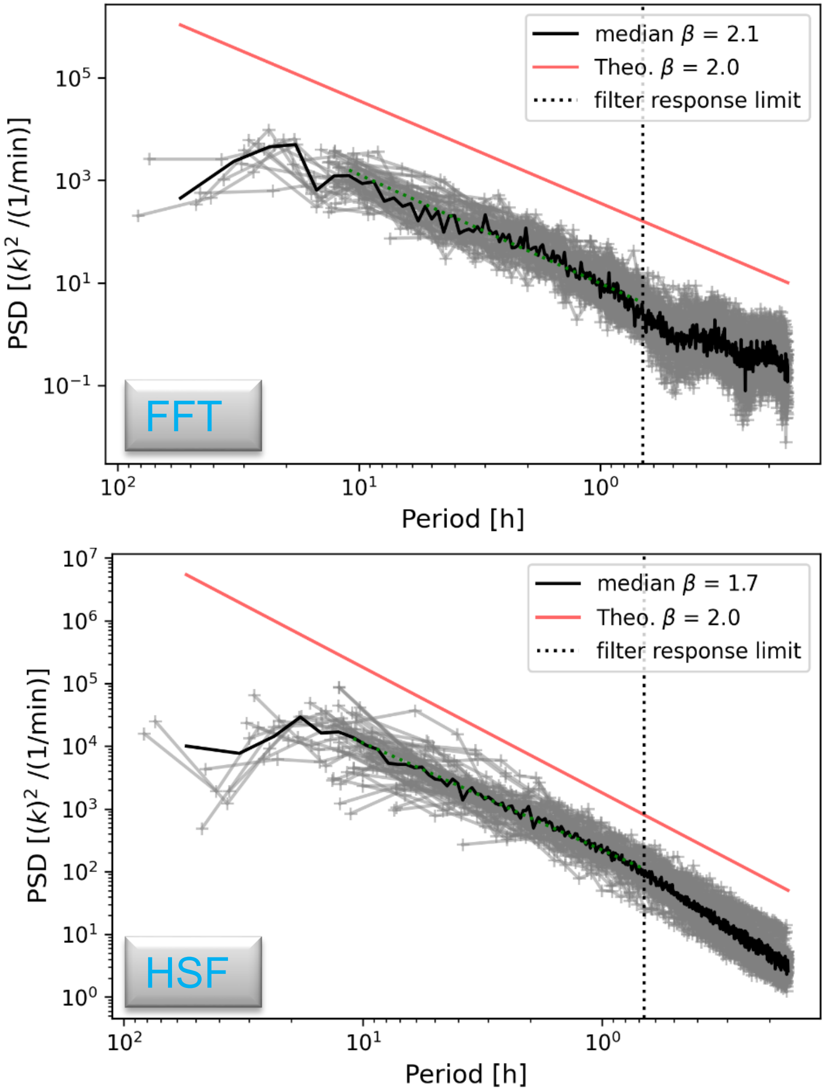


Gap Percentage 0%



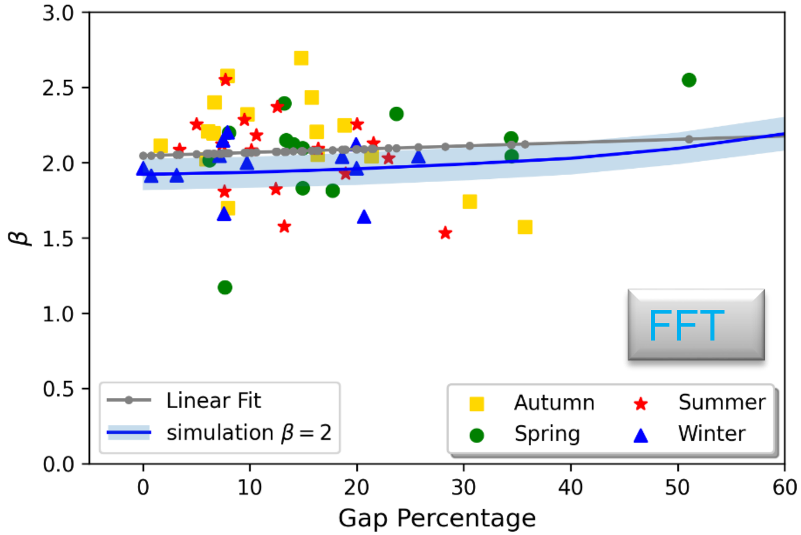
Gap Percentage 50%

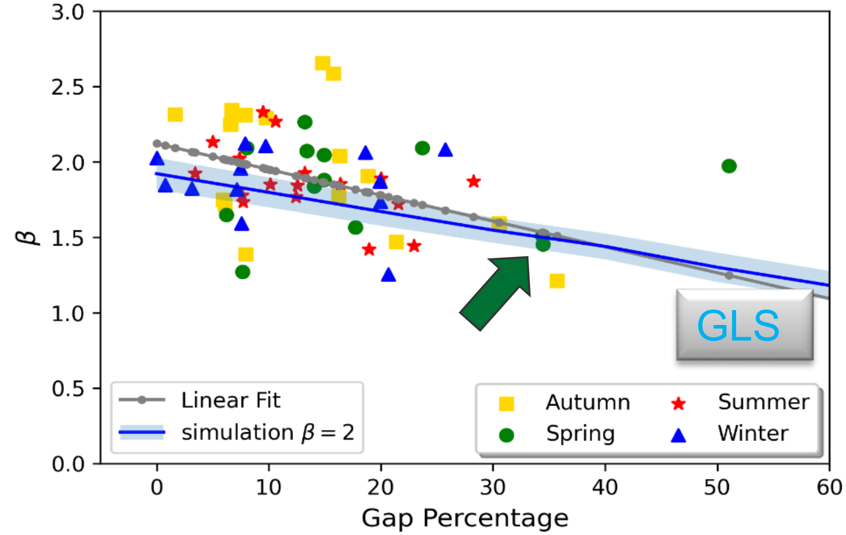
Spectra of ALOMAR lidar measurements

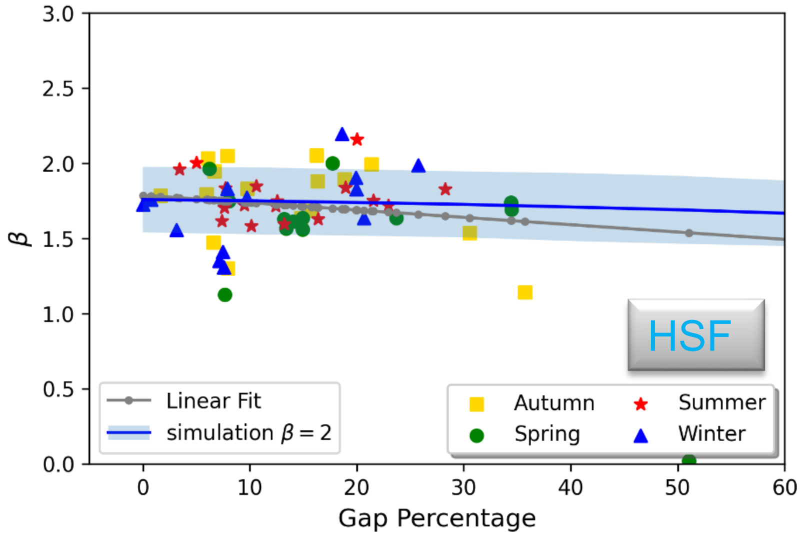


- Temperature fluctuations from 2021-2022.
- Altitude: 35 to 45km.
- Resolution: 5 min and 150m.
- Span: Longer than 8 hours.

Validation of simulation results by lidar data

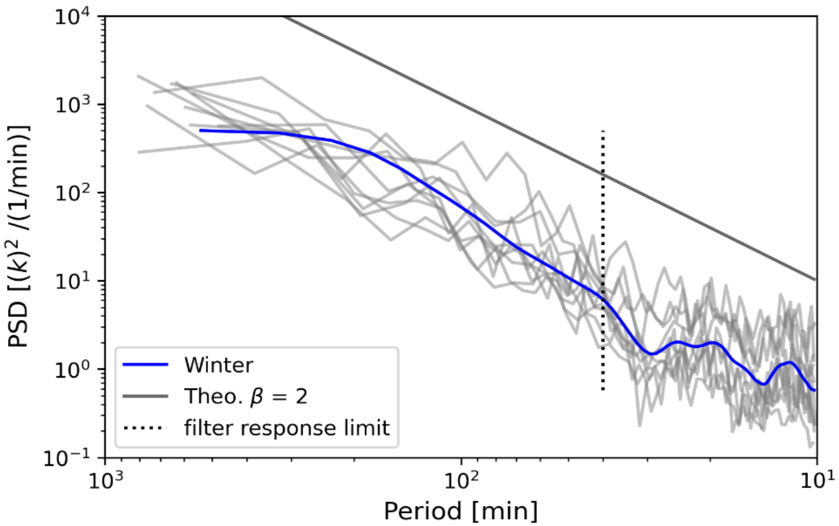


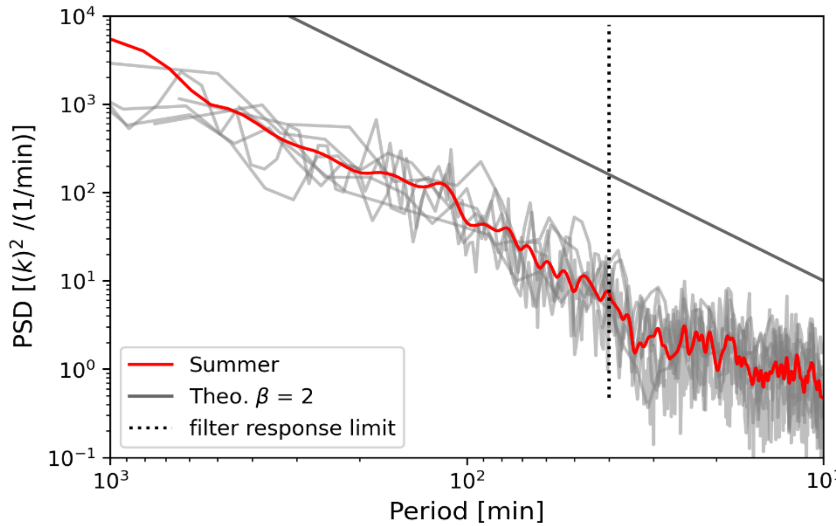


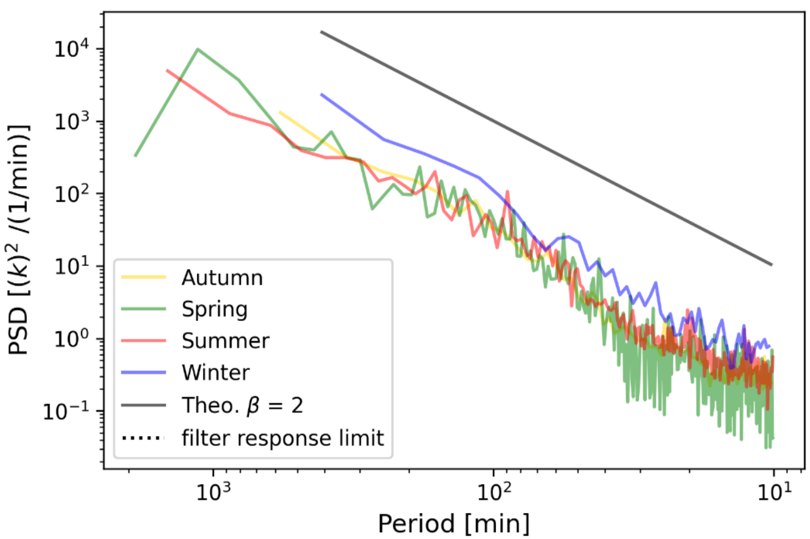


- The tendency of the mean slope is similar to what we simulated.
- Seasonal variation of β values.
- Clear gap % dependence of GLS.

Seasonal Variation







- More variation in amplitude in Winter.
- Winter also has more power on average than other seasons.
- Shorter measurements in Winter.

Summary:

- **Effects of gaps.**
- **Different methods have different bias.**
- **Take-Home Message**:
  By comparing different methods on our simulation, we can account for the gap effects in lidar data.

Outlook:

- **Expanding Data Analysis.**
- **Climatology of spectra of GWs**.
- **Model validation.**

Thank you for listening.
You are welcome to ask questions.
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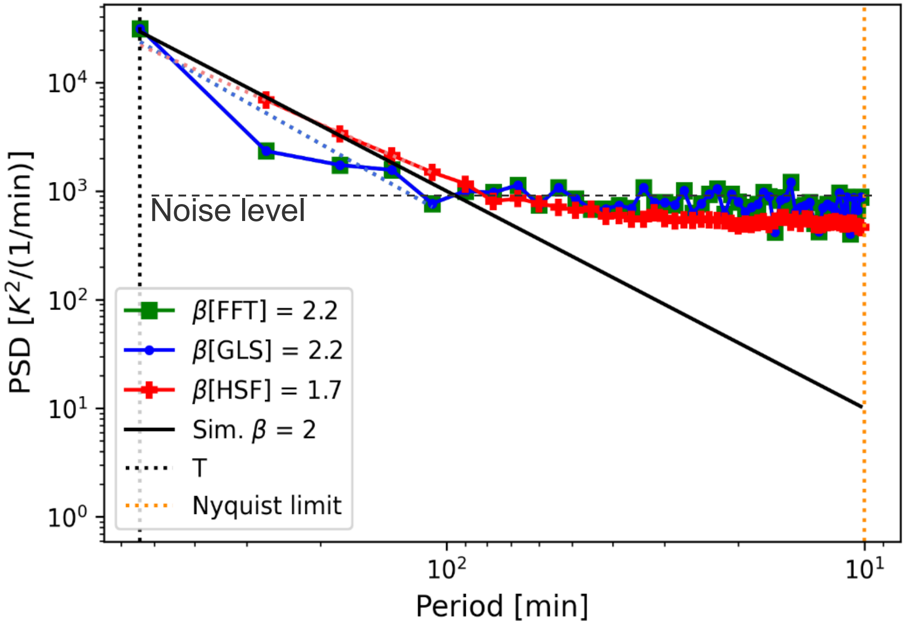
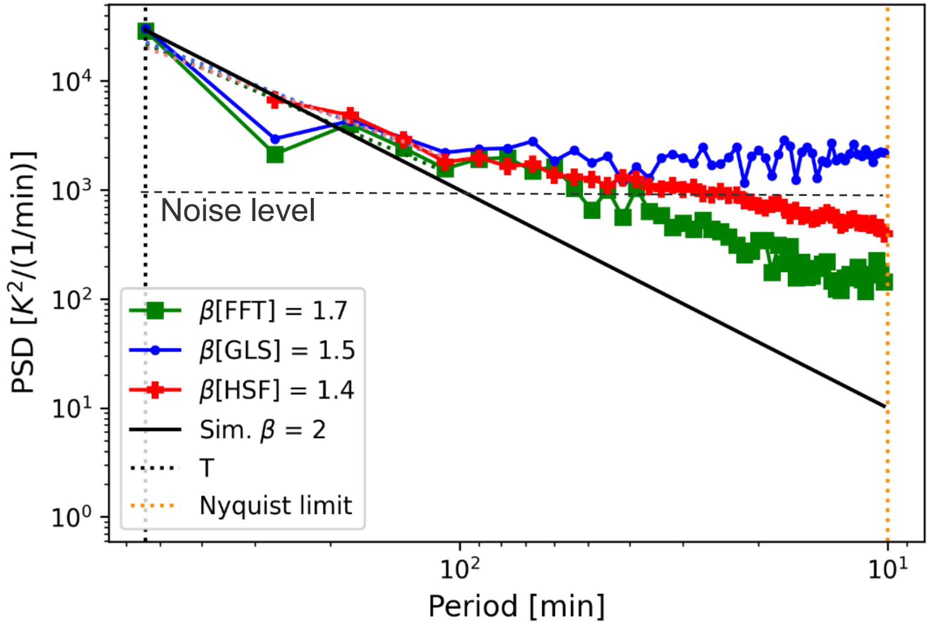
Effect of gaps [+noise]

- A more realistic approximation.
- Both gaps and noise affect high frequency components.



Gap Percentage 0%



Gap Percentage 50%

Literature:

- Lovejoy, S. and Schertzer, D.: Haar wavelets, fluctuations and structure functions: convenient choices for geophysics, Nonlinear Processes in Geophysics, 19, 513–527, https://doi.org/10.5194/npg-19-513-2012, 2012.
- VanZandt, T. E. "A universal spectrum of buoyancy waves in the atmosphere." *Geophysical Research Letters* 9.5 (1982): 575-578.
- Mossad, M., Strelnikova, I., Wing, R., and Baumgarten, G.: Assessing Atmospheric Gravity Wave Spectra in the Presence of Observational Gaps, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-1598, 2023.
- Smith, Steven A., David C. Fritts, and Thomas E. Vanzandt. "Evidence for a saturated spectrum of atmospheric gravity waves." *Journal of Atmospheric Sciences* 44.10 (1987): 1404-1410.

Haar structure function (HSF) [Lovejoy and Schertzer 2012]

- Performs the scaling analysis in real space, i.e. without performing a Fourier transform.
- Haar wavelets are appropriate for estimating the scaling exponent of processes with $\beta \in [3,-1]$
- This range of exponents covers all expected slopes for geophysical process.
- Implemented numerically:
  - The 1st order Haar fluctuation at lag dt is given by the relation:

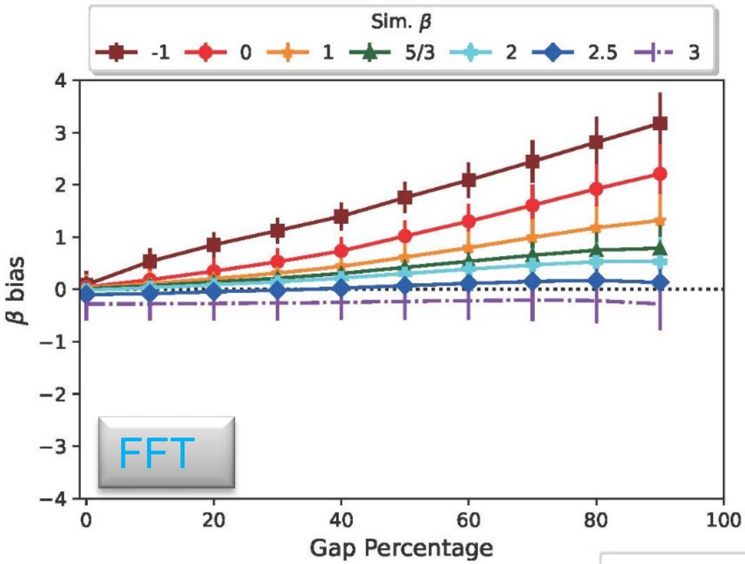
$$\mathcal{H}_\tau(x(t')) = \frac{2}{\tau}\left| \sum_{t+\frac{\tau}{2}<t'<t+\tau} x(t') - \sum_{t<t'<t+\frac{\tau}{2}} x(t') \right|$$

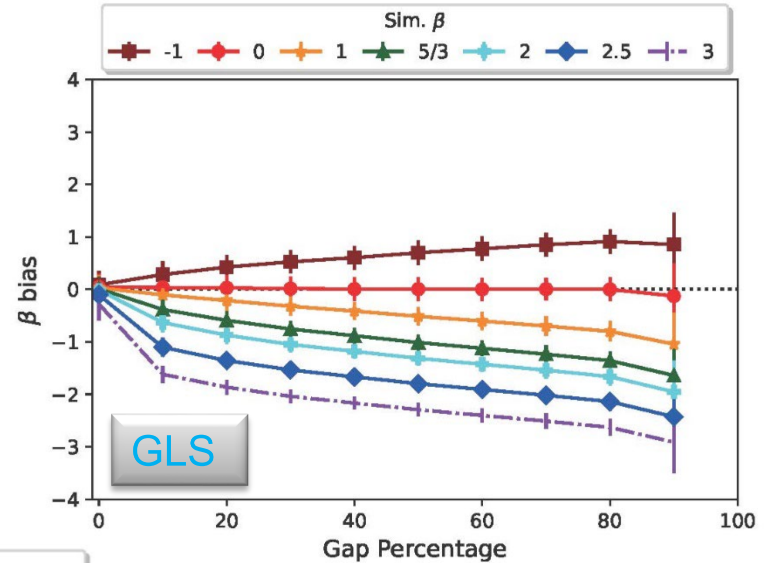
  - The structure function is then equal to the ensemble average of all fluctuations:

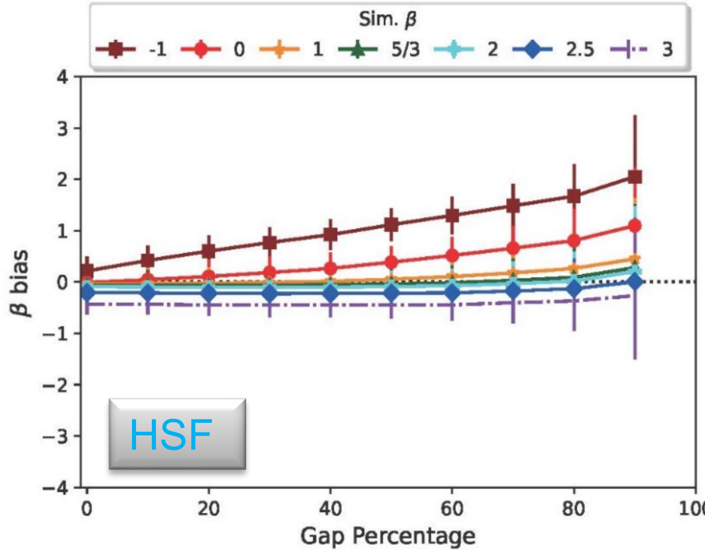
$$S_{\mathcal{H},q=1}(\tau) = \langle \mathcal{H}_\tau(x(t)) \rangle \approx \tau^{qH-K(q)}$$

- HSF works well with irregularly sampled data.

Simulation results (different β)







- The HSF is the least biased for $\beta \in [1,3]$.
- The GLS is the least biased for $\beta \in [0,-1]$.