Quantifying Atmospheric Gravity Wave Momentum Flux Using Data from the Atmospheric Waves Experiment (AWE)

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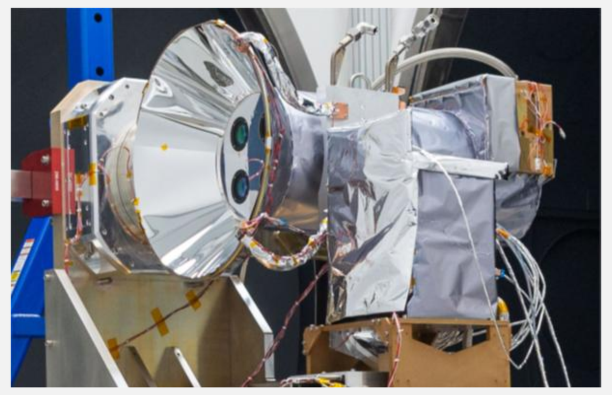
Introduction

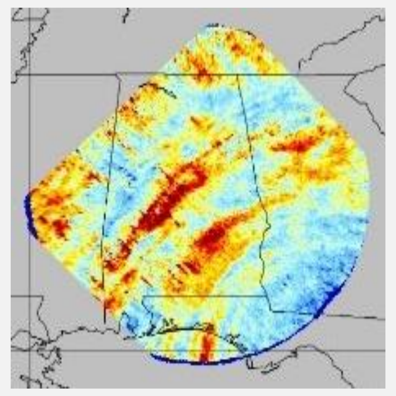
Atmospheric gravity waves (AGWs) transport energy and momentum from the lower atmosphere to the mesosphere and lower thermosphere, where they influence atmospheric circulation. Quantifying the global momentum transport is essential for understanding upper-atmospheric dynamics.

The Atmospheric Waves Experiment (AWE) aboard the International Space Station (ISS) provides near-global observations of AGWs using an Advanced Mesospheric Temperature Mapper (AMTM). By measuring OH airglow emissions near 85 km altitude, AWE produces high-resolution temperature maps over a field of view of approximately 600 km (Figure 1).

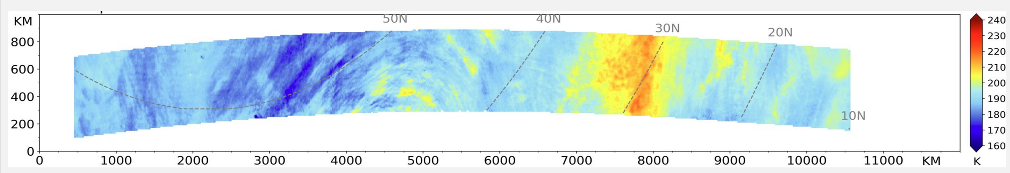
In this study, we combine AWE observations with background atmospheric conditions from the Naval Global Environmental Model (NAVGEM) to retrieve wave phase speeds and estimate momentum flux associated with individual gravity wave structures.



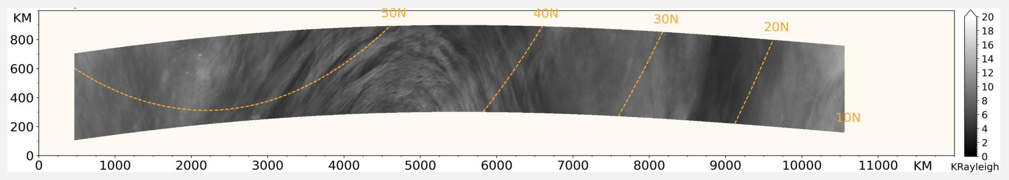
(a) AWE AMTM instrument



(b) Temperature map (L2A)



(c) Temperature swath (L3A)



(d) OH (2,0) band $Q_1(1)$ line brightness swath (L3C)

Figure 1: AWE AMTM instrument (a), and examples of AWE data levels: L2A (b), L3A (c), and L3C (d)

References

- Fritts, D. C., et al. (2014), *Quantifying gravity wave momentum fluxes with Mesosphere Temperature Mappers and correlative instrumentation*, J. Geophys. Res. Atmos.
- Ungermann, J., and Reichert, R. (2025), *JuWavelet – Continuous Wavelet Transform and Stockwell-transform for gravity wave analysis.*

Acknowledgement

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Method

Workflow

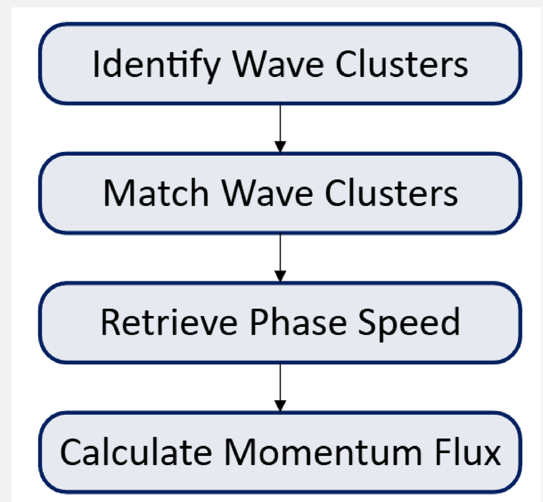


Figure 2: Workflow for estimating gravity wave momentum flux from AWE observations.

1. Wave Identification

- A two-dimensional wavelet transform is applied to identify gravity wave structures and retrieve horizontal wavelength and propagation direction (Figure 3).

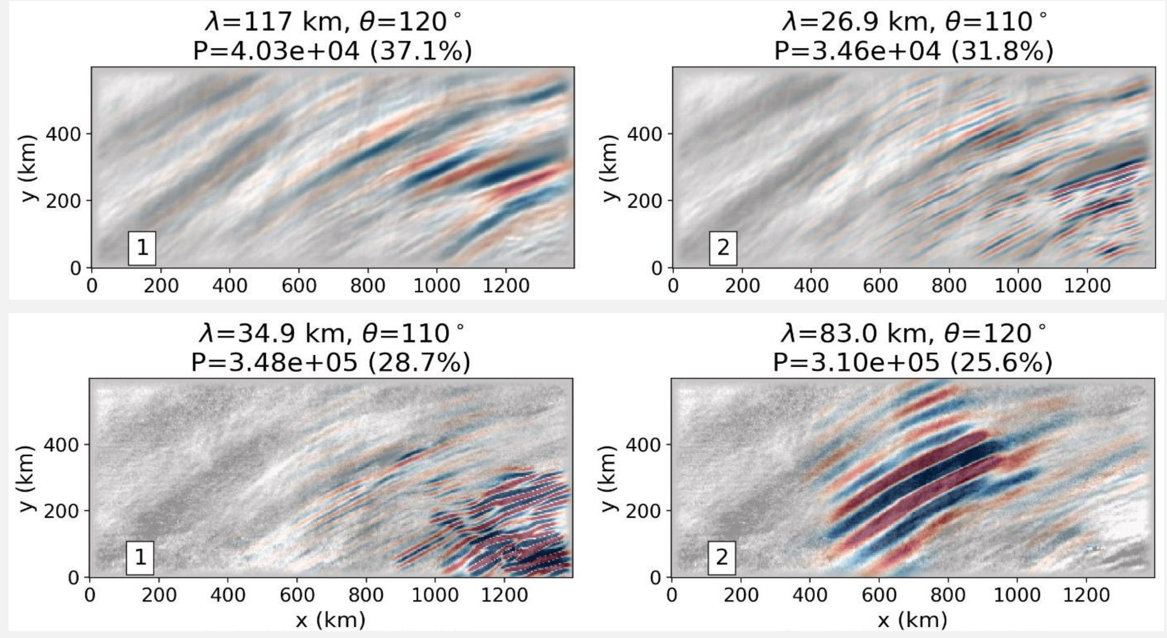


Figure 3: Examples of gravity wave clusters identified in L3C radiance (top) and L3A temperature (bottom).

- Temperature and radiance clusters are matched based on wavelength, propagation direction, and spatial overlap (Figure 4).

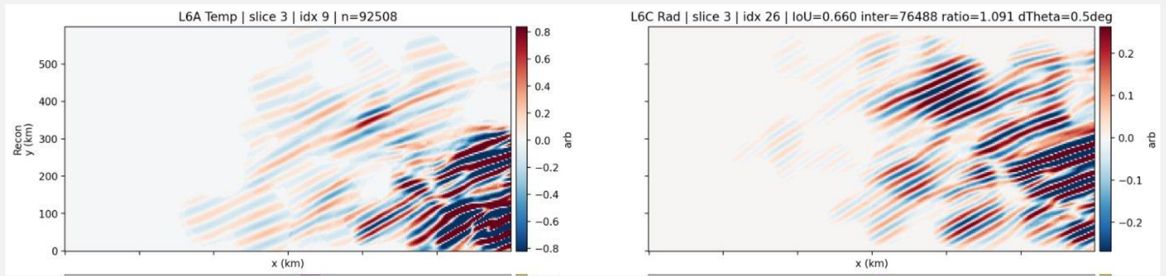


Figure 4: Example of a matched L3A temperature cluster (left) and L3C radiance cluster (right).

- For each matched cluster, a representative wave point is selected near the location of highest wave amplitude.

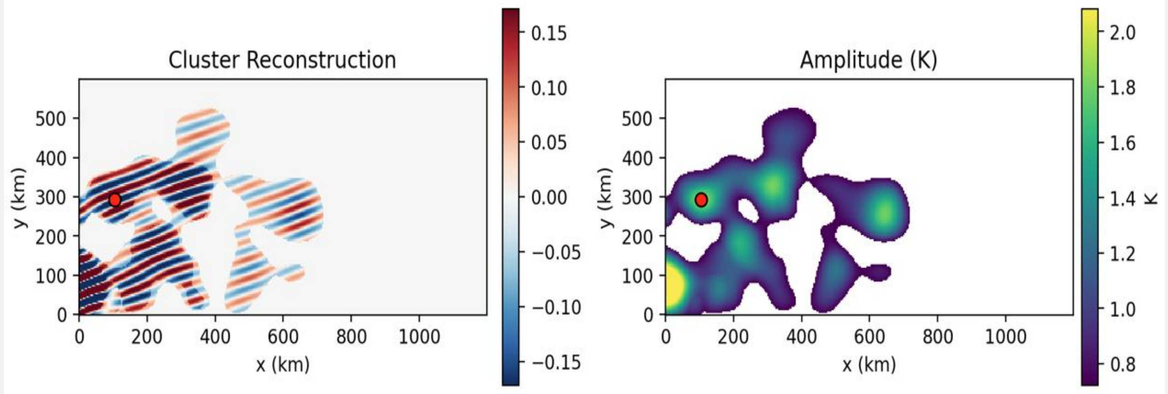


Figure 5: Representative wave point (red marker) used for phase speed retrieval.

2. Phase Speed Retrieval

- Extract a sequence of 25 AWE images centered on the selected (representative) point.
- Apply wavelet transform and filtering to isolate the target gravity wave.
- Sample the wave relative amplitude at multiple points along the propagation direction (Figure 6).
- Track the temporal evolution of the wave phase (Figure 7).
- Retrieve phase speed and propagation direction from the phase progression.

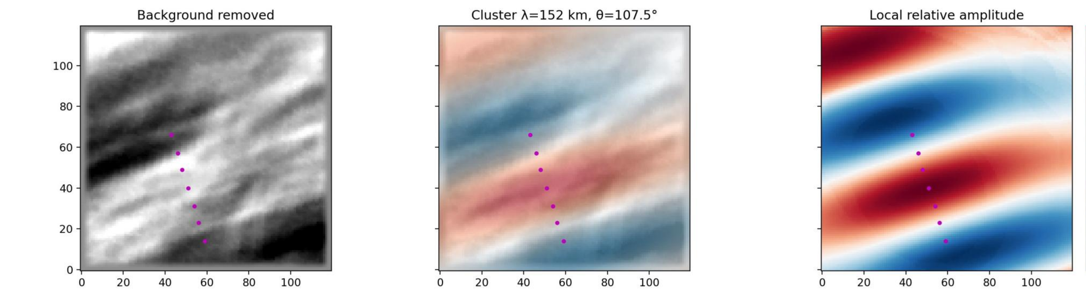


Figure 6: Example of tracking relative amplitude for 7 points in a frame.

Calculate phase speed:

$$c = \lambda \left(\frac{a}{360}\right) \frac{1000}{\Delta t}$$

where:

- c = phase speed (m/s)
- λ = wavelength (km)
- a = phase change per frame (degrees/frame)
- Δt = frame cadence (1.1 s)

Output: Phase speed magnitude and propagation direction.

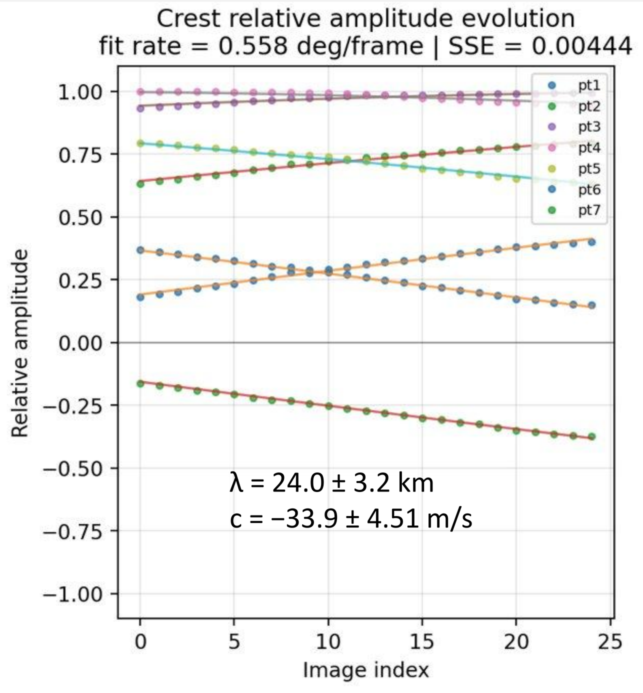


Figure 7: Example of the phase progression determination by minimizing the fitting error (SSE).

3. Momentum Flux Estimation

- Retrieve phase speed c from Section 2.
- Estimate vertical wavelength λ_z using phase speed and NAVGEM background wind.

$$m^2 = \frac{N^2}{(c-u)^2} - k_h^2 \qquad \lambda_z = \frac{2\pi}{m}$$

- Calculating momentum flux (Fritts et al., 2014)

$$MF = \frac{1}{2}\frac{g^2}{N^2}\left(\frac{\lambda_z}{\lambda_x}\right)\left(\frac{T'}{T}\right)^2 \frac{1}{C_f^2}$$

Where:

- N = buoyancy frequency
- λ_z = vertical wavelength
- λ_x = horizontal wavelength
- c = phase speed
- T' = wave amplitude
- T = background temperature
- C_f = cancellation factor
- u = projected background wind

Results

Momentum Flux Using Fixed Vertical Wavelength

- Using fixed λ_z = 10 km and applied to 2024–2025 AWE observations.
- Figure 8 shows enhanced zonal momentum flux over the Andes in June 2024, consistent with mountain waves generated by strong tropospheric eastward winds.

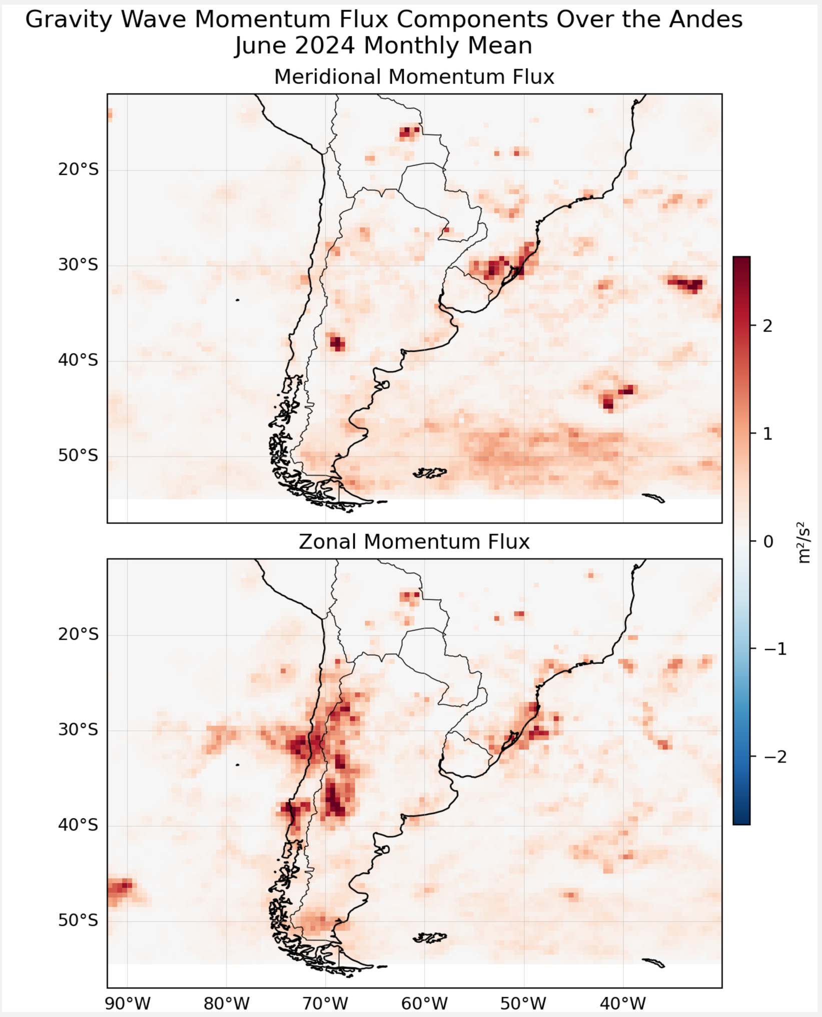
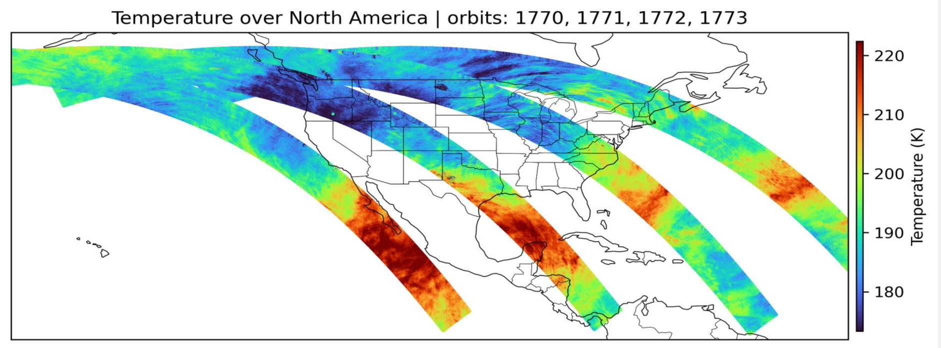


Figure 8: Meridional (top), and zonal (bottom) momentum flux maps obtained from AWE measurements for June 2024

Momentum Flux Using Retrieved Vertical Wavelength

- Retrieved phase speeds and NAVGEM data were used to estimate λ_z.
- Temperature maps from four consecutive overpasses show concentric gravity wave structures.



- Derived zonal and meridional momentum flux patterns are consistent with the observed wave propagation directions.

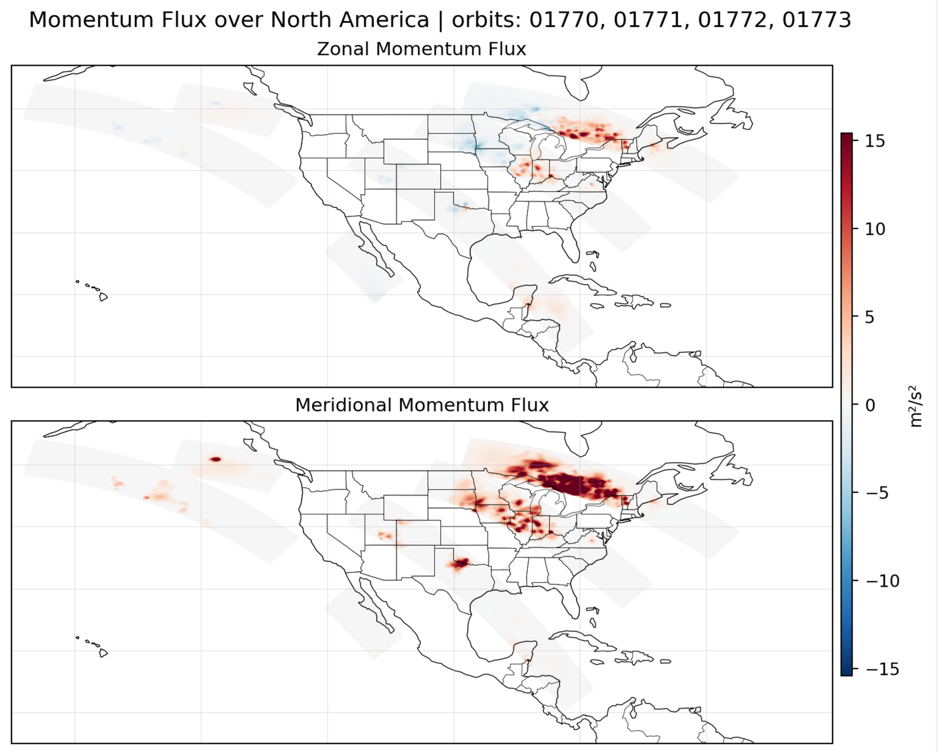


Figure 9: Four consecutive temperature swaths obtained by AWE in March 2024 (top), and corresponding zonal (middle), and meridional (bottom) momentum flux maps.

Future Work

- Improve phase speed and vertical wavelength retrieval accuracy.
- Apply the retrieval method to the complete AWE dataset.
- Investigate seasonal and geographic variabilities of gravity wave momentum flux.
- Identify major gravity wave source regions.