

# Aircraft observations of gravity waves, turbulence and clouds in the tropical tropopause layer

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*Learn more:* Atlas and Bretherton 2023, ACP

<https://doi.org/10.5194/acp-23-4009-2023>

# Small-scale vertical motions and TTL cirrus

Research article | 31 Jul 2018

**Geophysical Research Letters\***

Research Letter | Free Access

**Ubiquitous influence of waves on tropical high cirrus clouds**

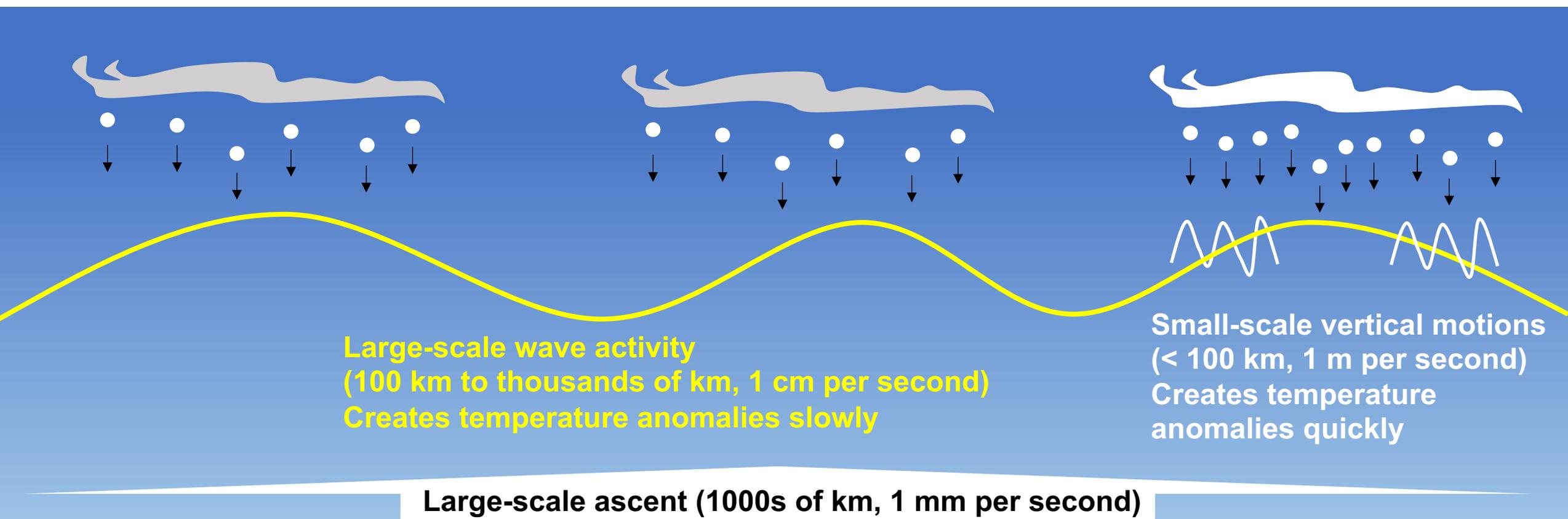
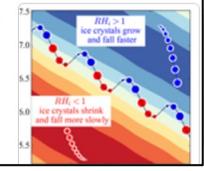
Ji-Eun Kim, M. Joan Alexander, T. Paul Bui, Jonathan M. Dean-Day, R. Paul Lawson, Sarah Woods, T. P. Dinh, D. R. Durran, T. P. Ackerman, Mark R. Schoeberl, Eric J. Jensen, Sarah Woods

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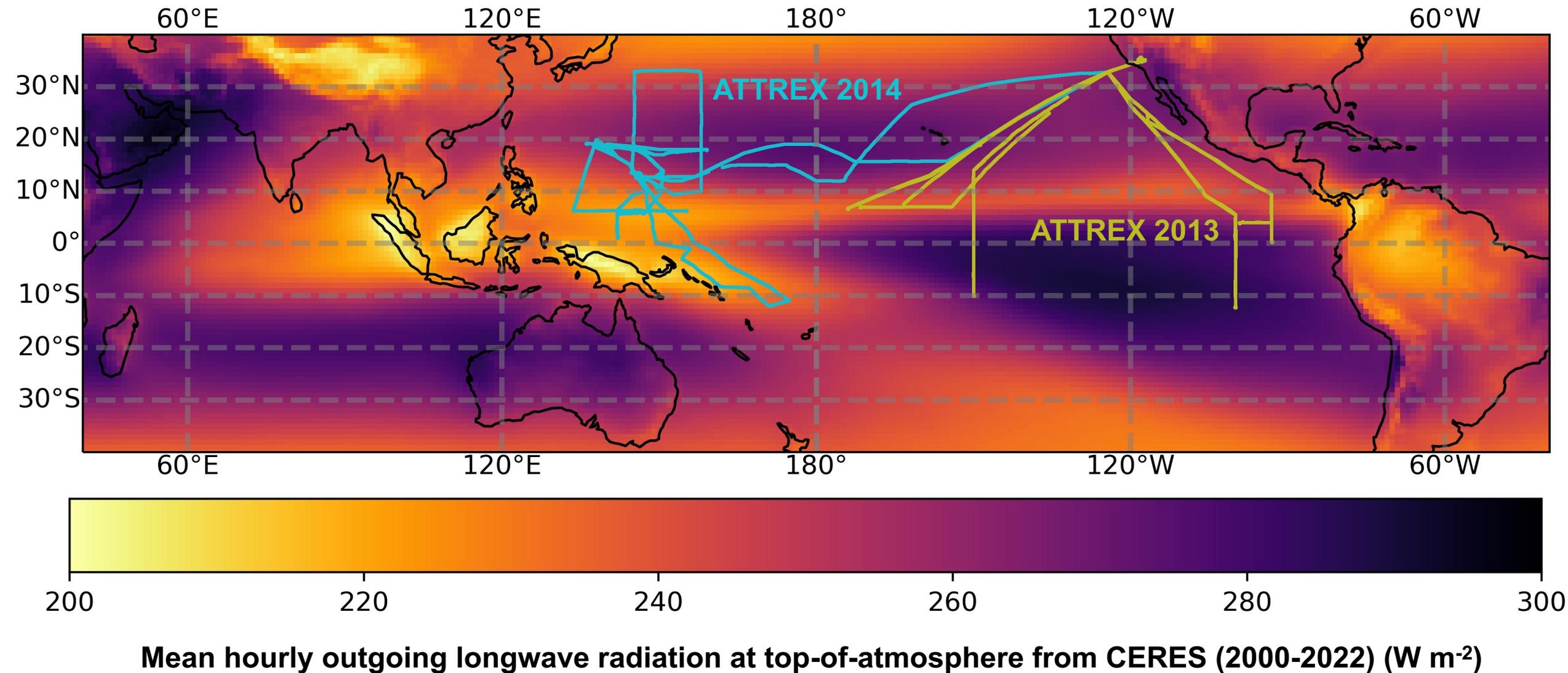
Effect of gravity waves on the motion and distribution of atmospheric ice particles in tropical tropopause layer cirrus

Aurélien Podglajen<sup>1,a</sup>, Riwal Plougonven<sup>1</sup>, Albert Hertzog<sup>2</sup>, and Eric Jensen<sup>3</sup>

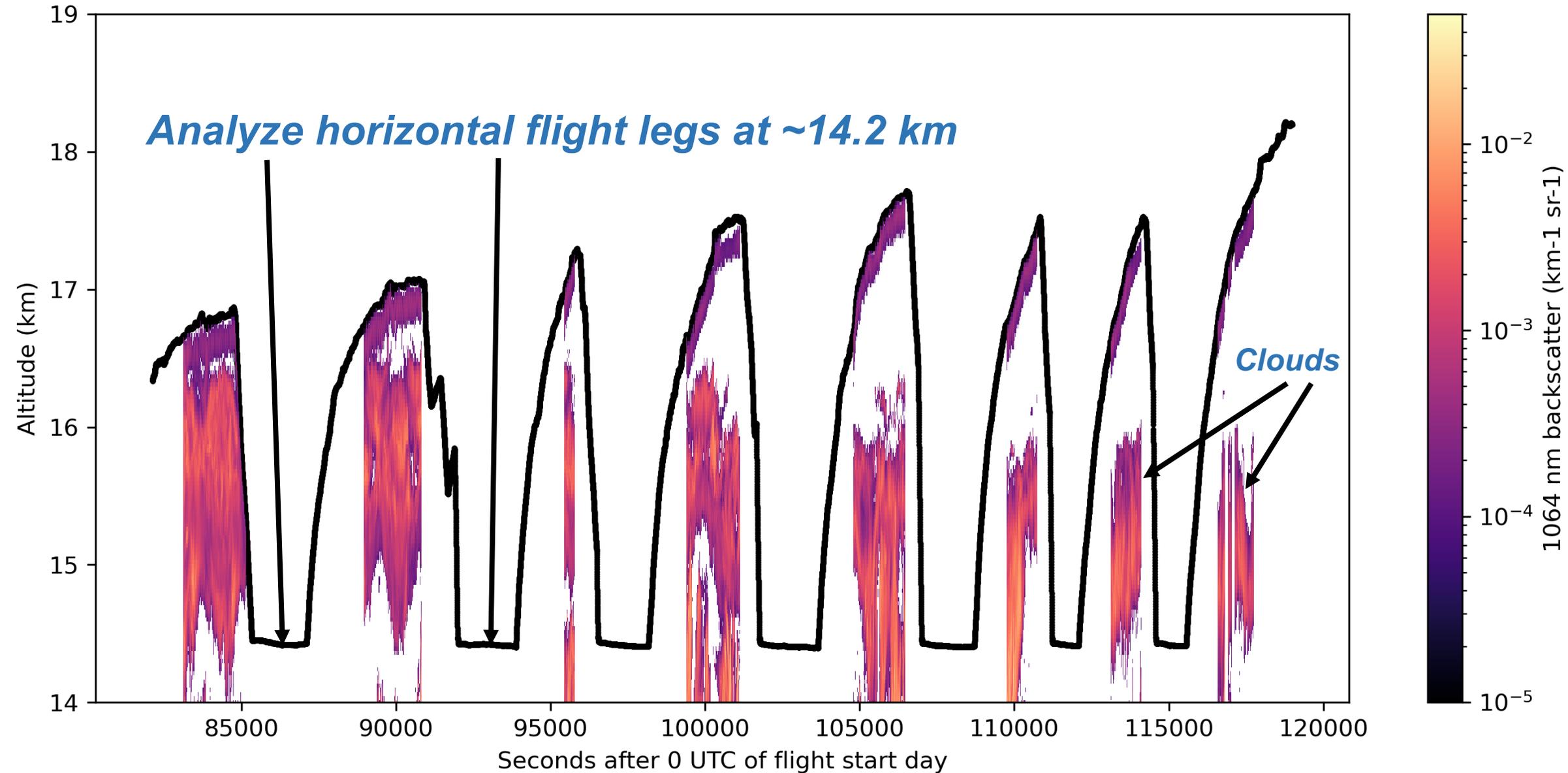
Eric J. Jensen, Rei Ueyama, Leonhard Pfister, Theopaul V. Bui, M. Joan Alexander, Aurélien Podglajen, T. Dinh<sup>1</sup>, A. Podglajen<sup>2</sup>, A. Hertzog<sup>2</sup>, B. Legras<sup>2</sup>, and R. Plougonven<sup>1</sup>



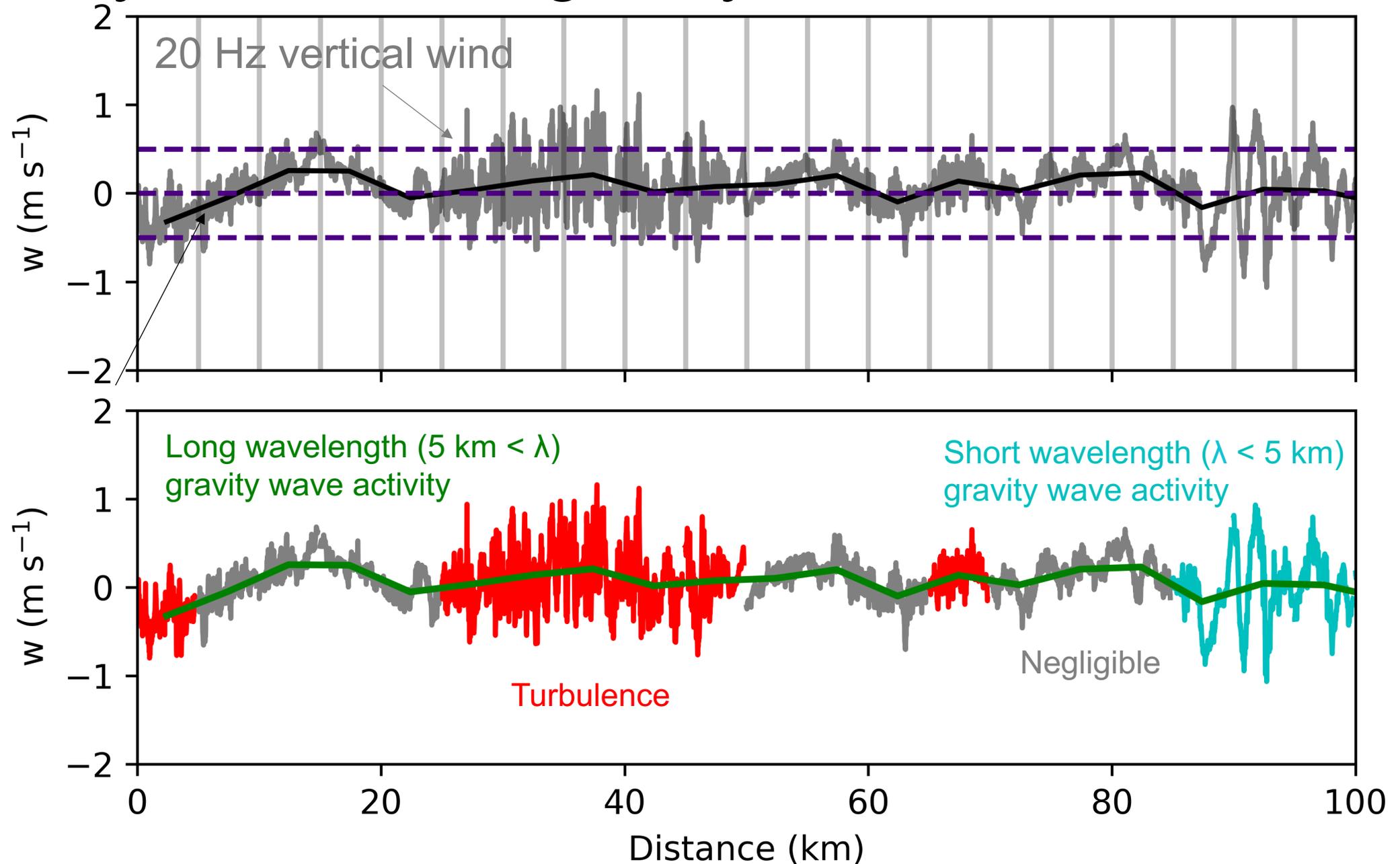
# Flight tracks from ATTREX 2013 and 2014



# Example flight from ATTREX

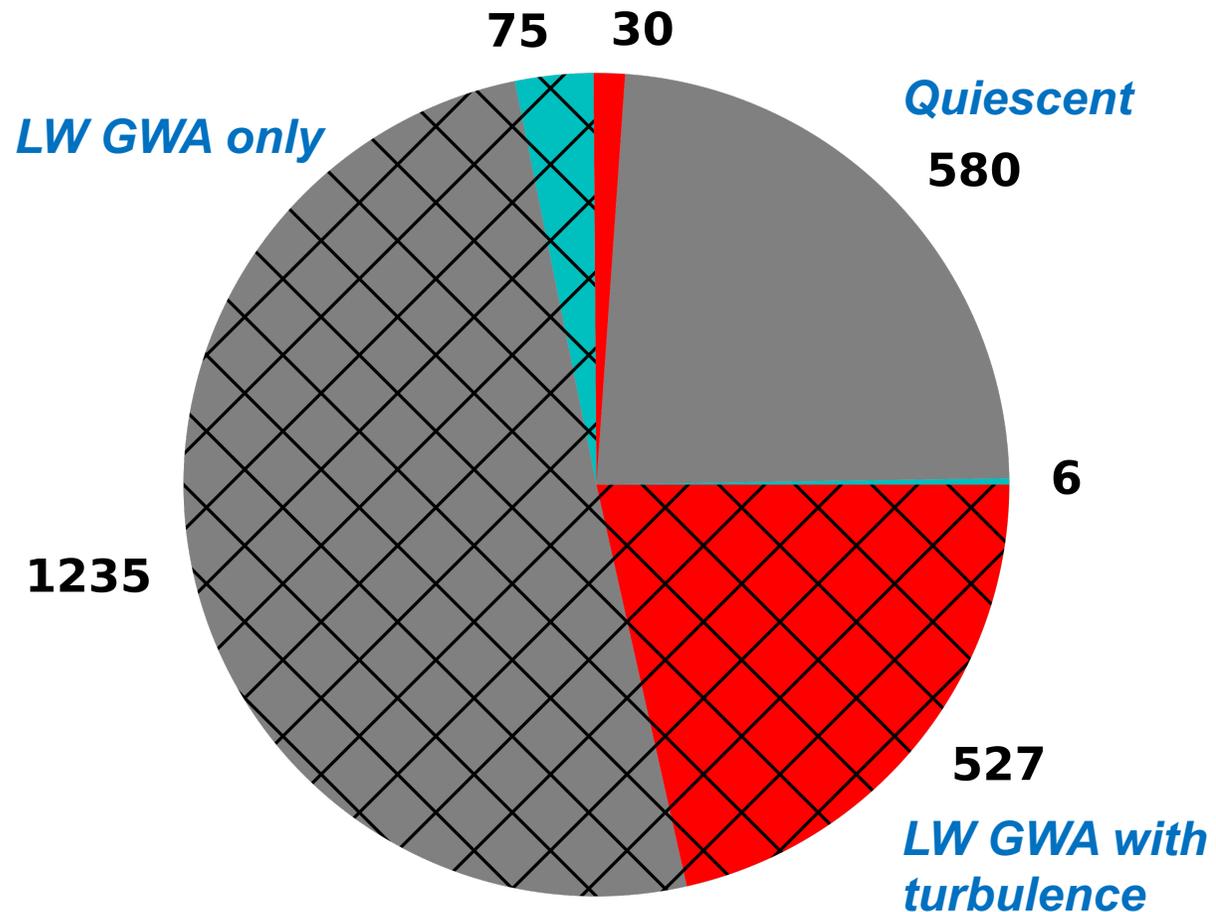


# Identify small-scale gravity waves and turbulence



# How common are gravity waves and turbulence?

## Classifications of all 5 km segments



- Long wavelength gravity wave activity is detected 75% of the time
- Turbulence co-occurs with gravity wave activity 95% of the time
- Three situations are dominant

 Long wavelength gravity wave activity

Negligible

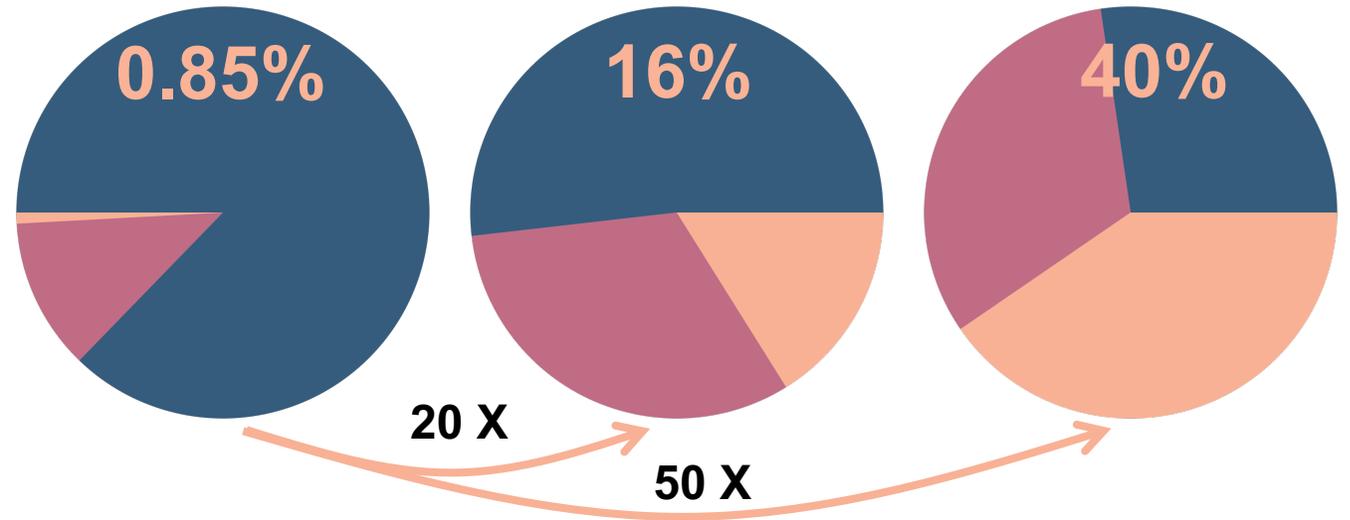
Short wavelength gravity wave activity

Turbulence

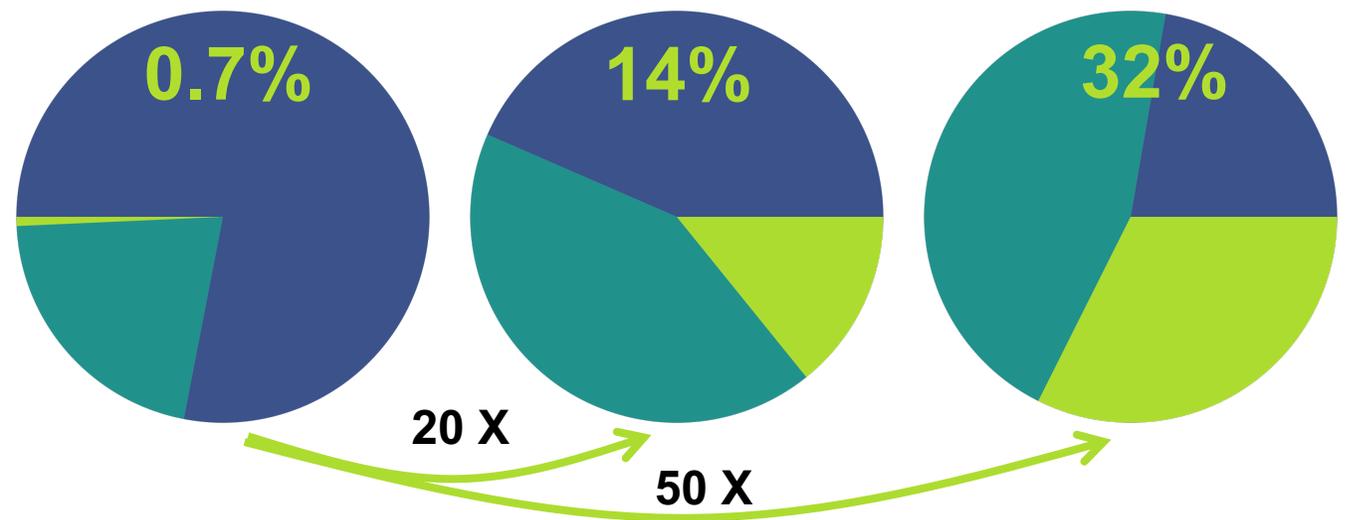
# How do they affect cirrus clouds?

**Clear-sky (NI = 0)**  
**Low-NI (NI < 20 L<sup>-1</sup>)**  
**High-NI (NI > 20 L<sup>-1</sup>)**

■ *Quiescent*    ▣ *LW GWA only*    ▣ *LW GWA with turbulence*

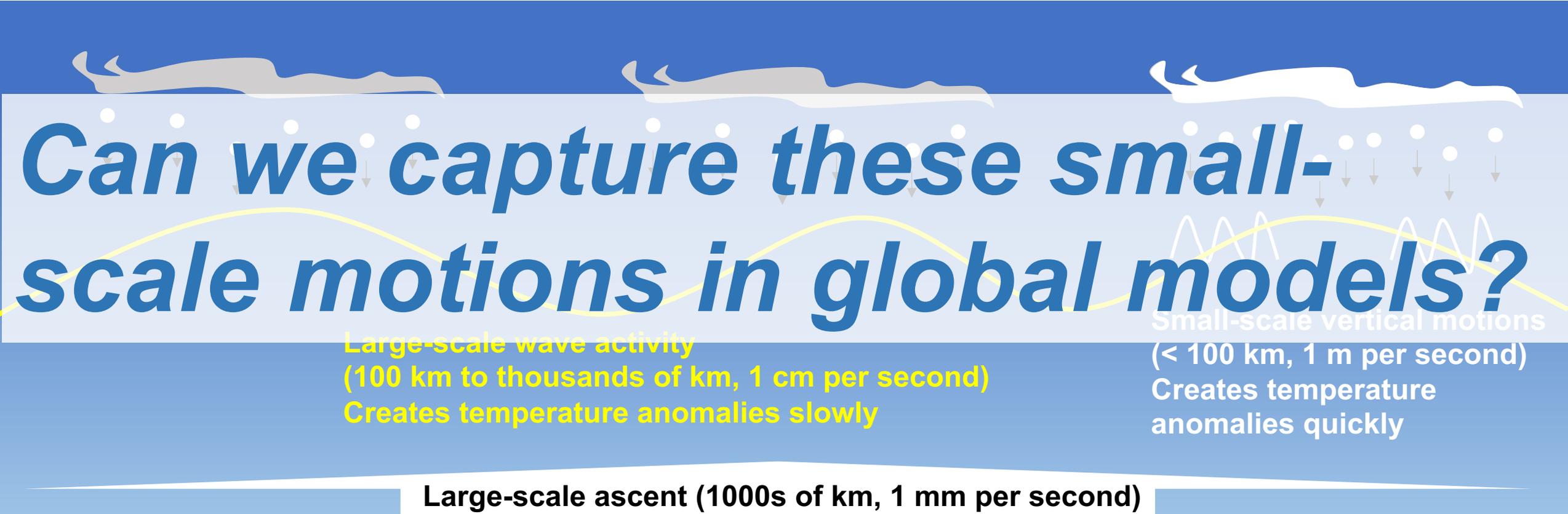


**Clear-sky (IWC = 0)**  
**Low-IWC (IWC < 1 mg m<sup>-3</sup>)**  
**High-IWC (IWC > 1 mg m<sup>-3</sup>)**



# Small-scale vertical motions and TTL cirrus

*We found the first observational evidence that small-scale motions are key to forming high-NI and high-IWC TTL cirrus!*



The diagram illustrates the relationship between different vertical motions and cloud formation. At the top, a dark blue band represents the tropopause. Below it, three layers of cirrus clouds are shown: a thin grey layer, a thicker grey layer, and a white layer. A yellow wavy line represents large-scale wave activity, with arrows pointing down from it to the middle grey cloud layer. A white wavy line represents small-scale vertical motions, with arrows pointing down from it to the white cloud layer. The central text asks, 'Can we capture these small-scale motions in global models?'.

*Can we capture these small-scale motions in global models?*

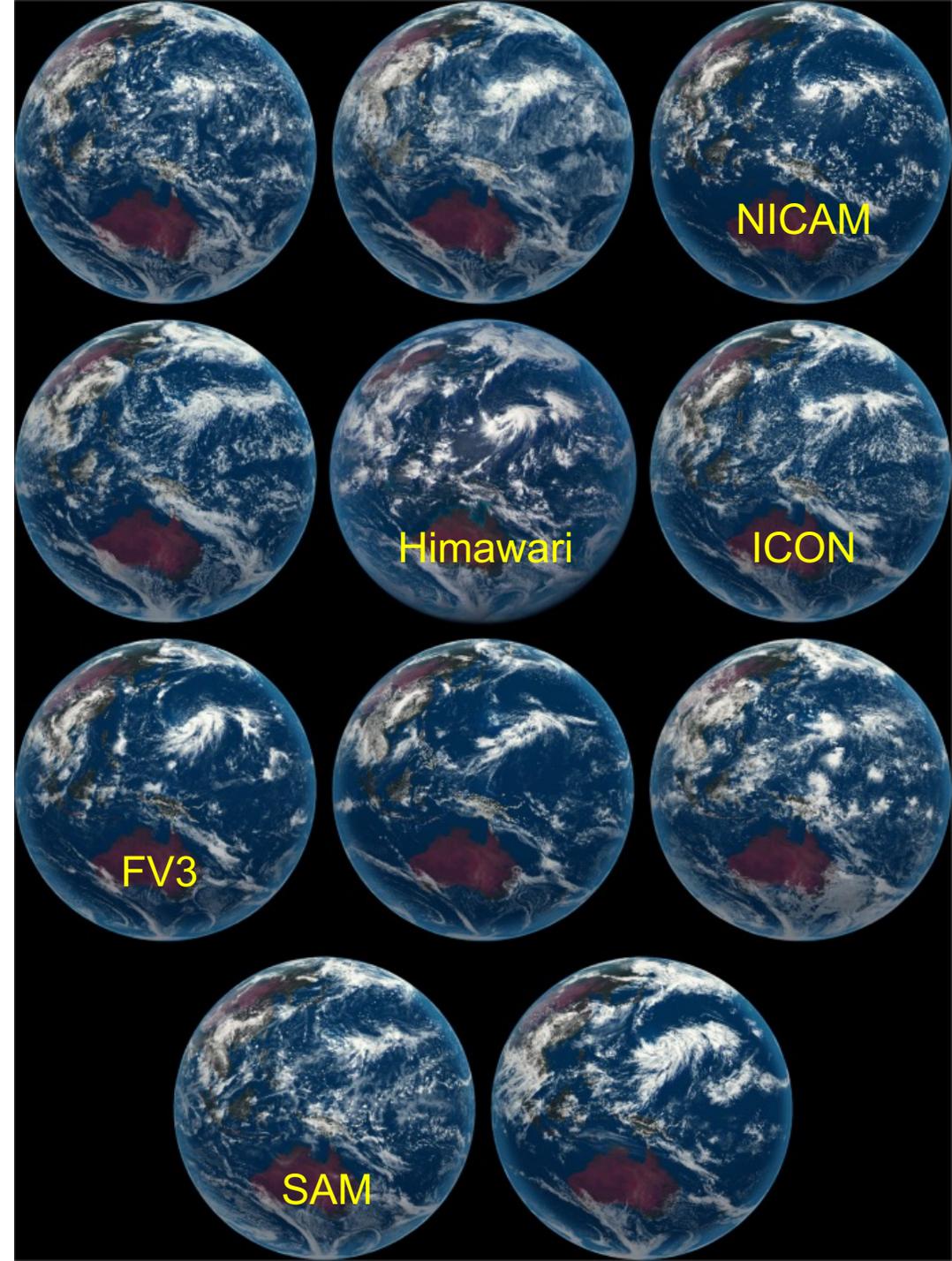
Large-scale wave activity  
(100 km to thousands of km, 1 cm per second)  
Creates temperature anomalies slowly

Small-scale vertical motions  
(< 100 km, 1 m per second)  
Creates temperature anomalies quickly

Large-scale ascent (1000s of km, 1 mm per second)

## *Evaluate small-scale vertical winds in four simulations from DYAMOND-1*

- Horizontal grid spacings  $< 5$  km
- Explicit deep convection (no parameterization)
- Turbulence is unresolved so we only evaluate small-scale gravity wave activity



# Can we model small-scale gravity waves?

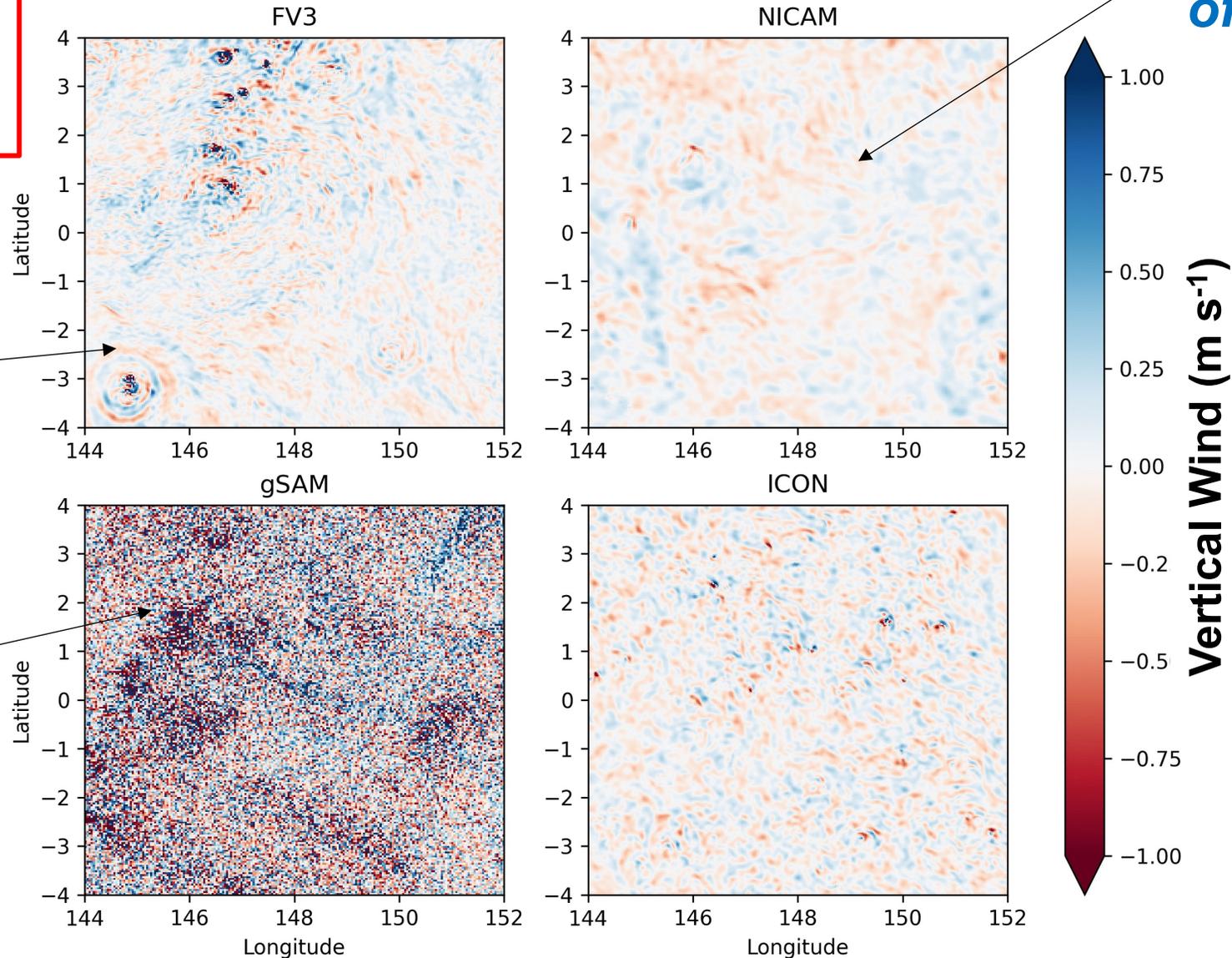
DYAMOND-1 hour = 048

**Simulated vertical winds at ~14.2 km over the tropical West Pacific**

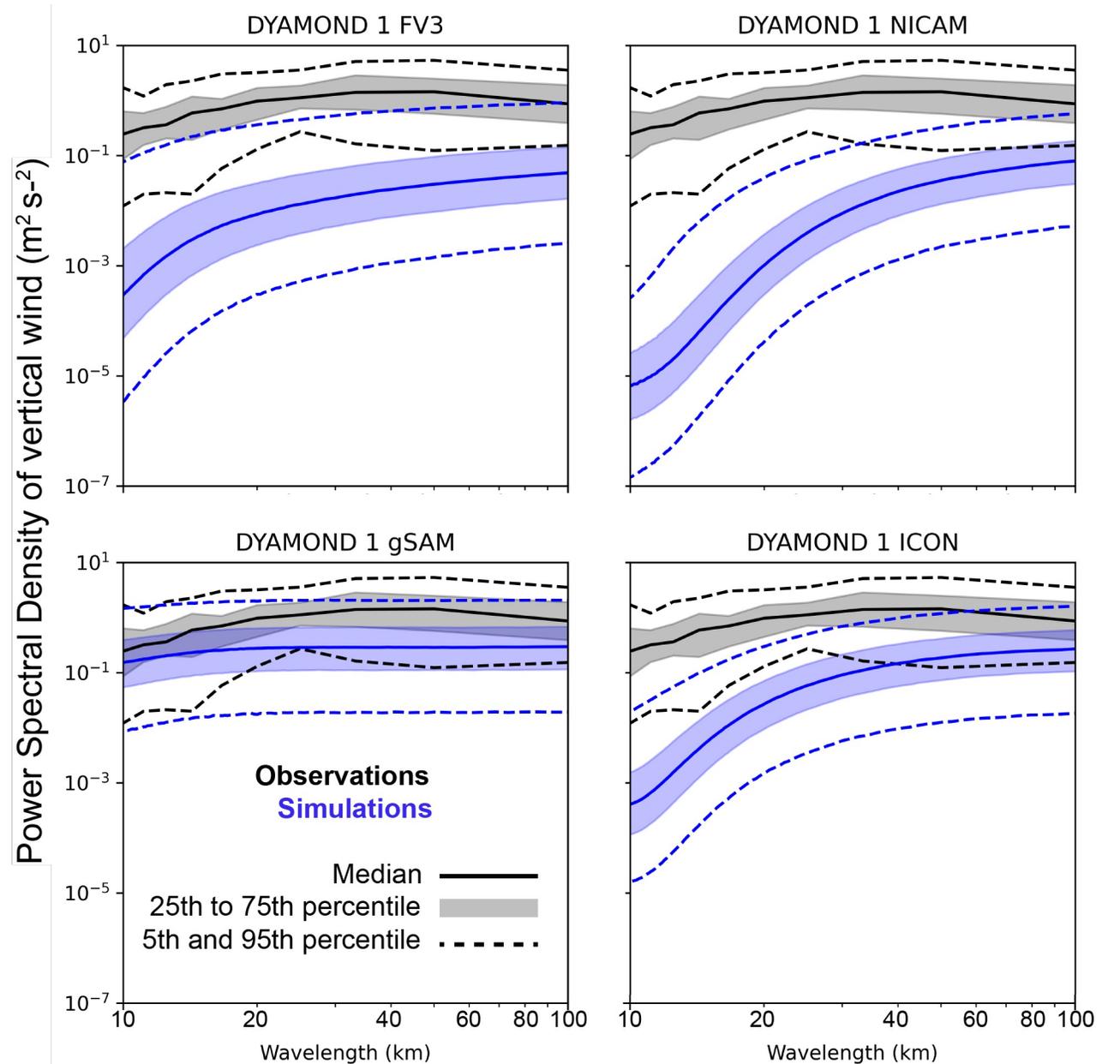
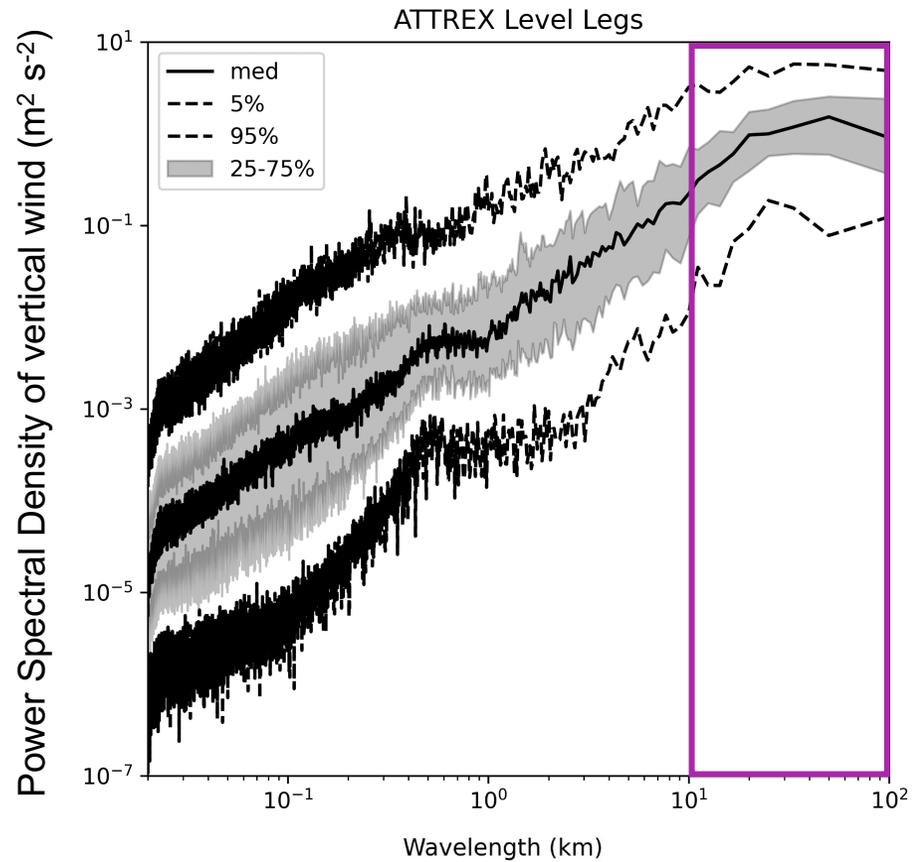
*Strong gravity waves around deep convection*

*Lots of grid scale variability*

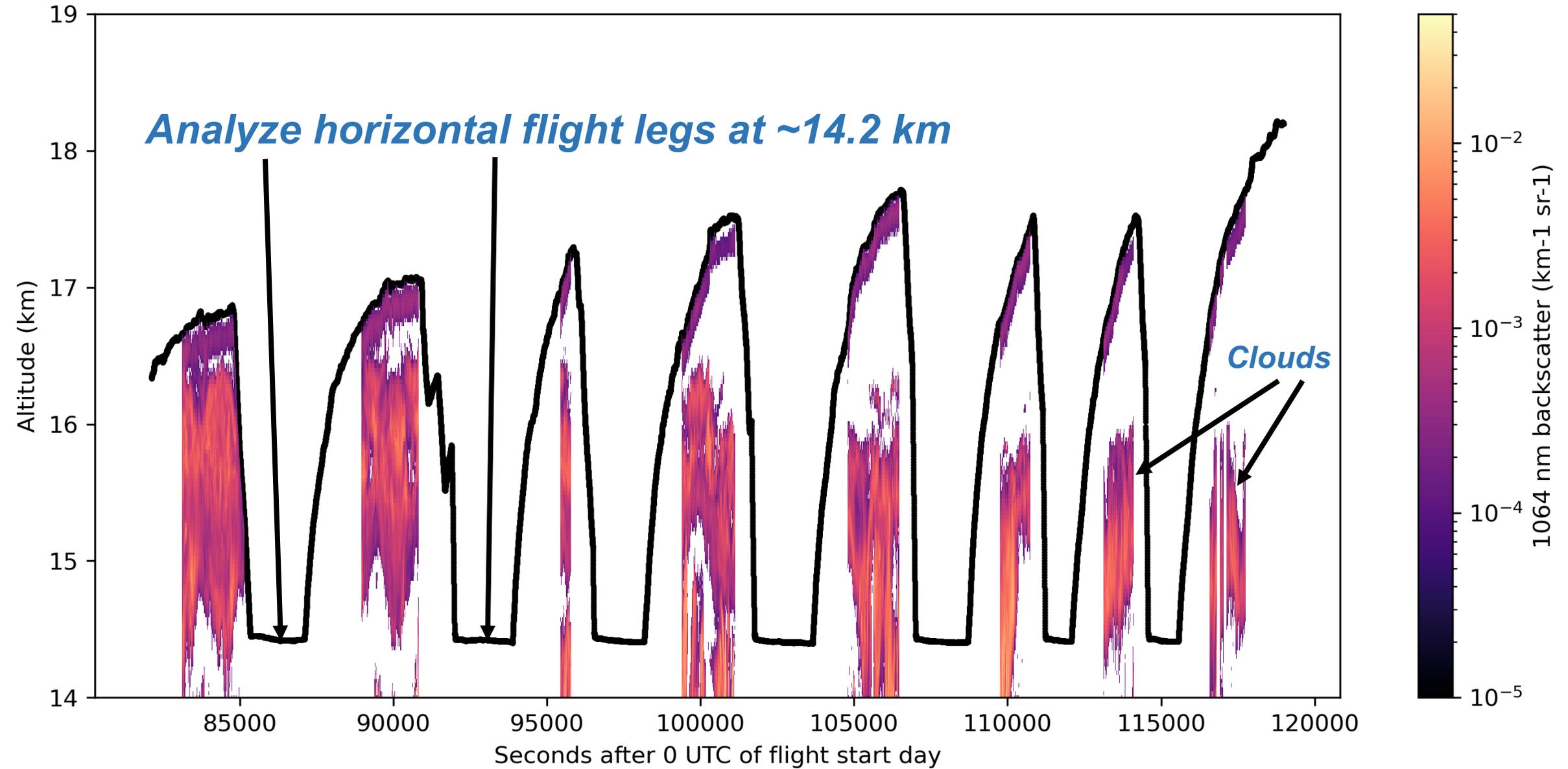
*Larger scales of variability*



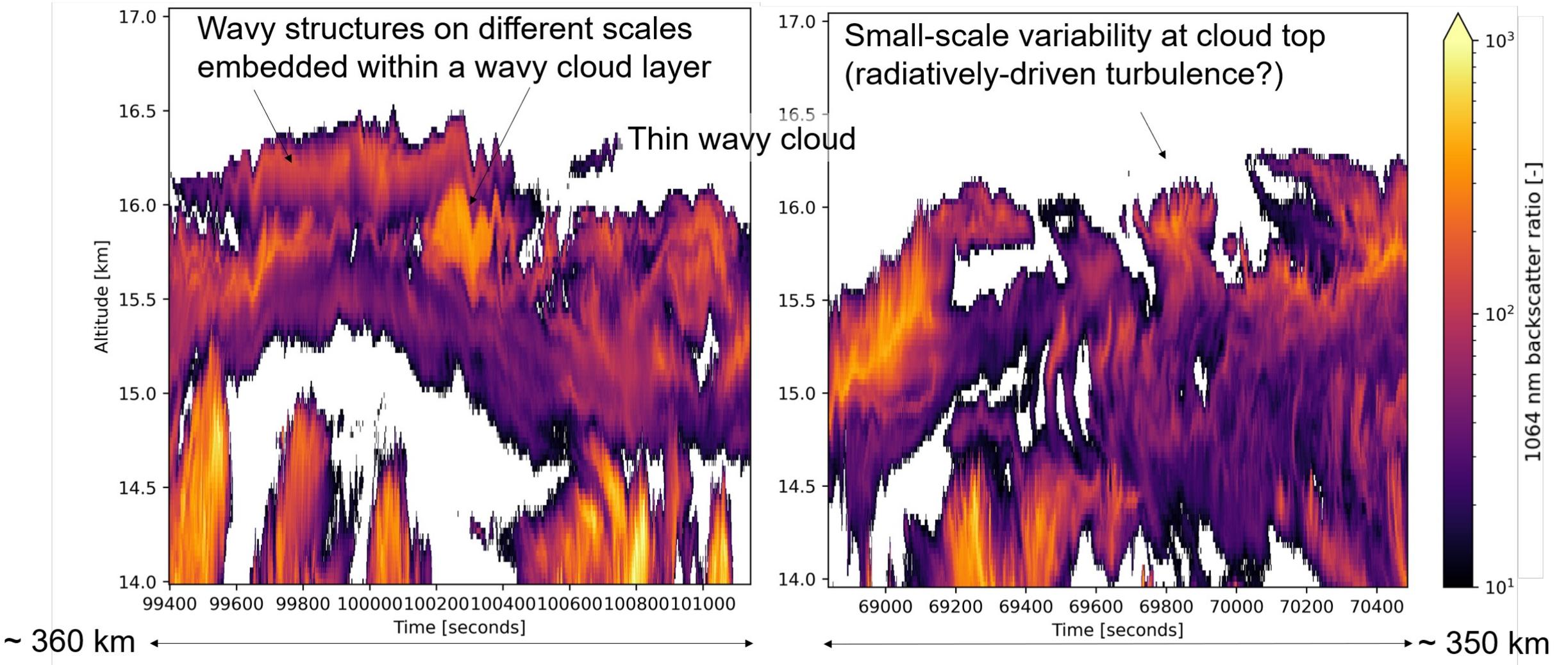
# Can we model small-scale gravity waves?



# Example flight from ATTREX

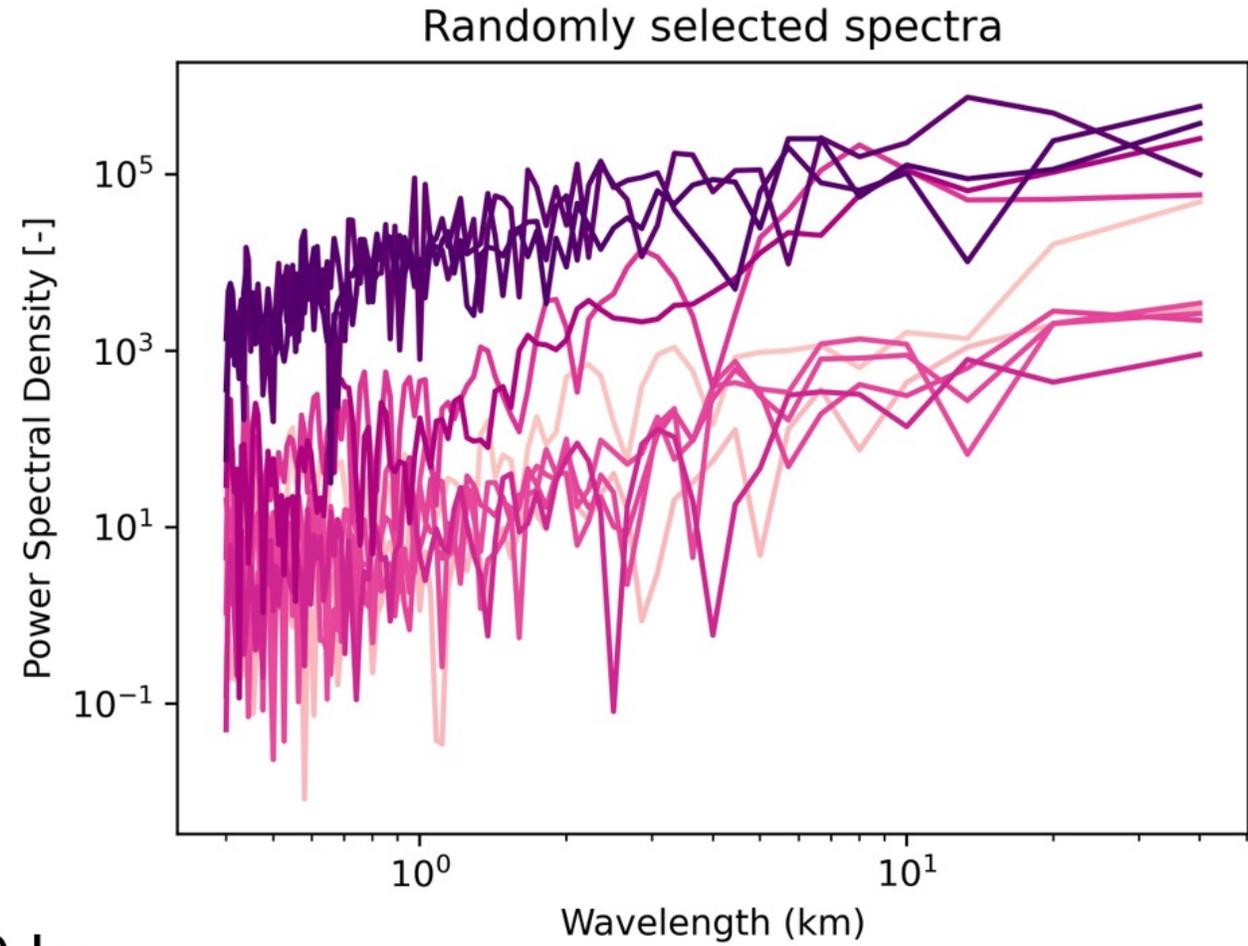
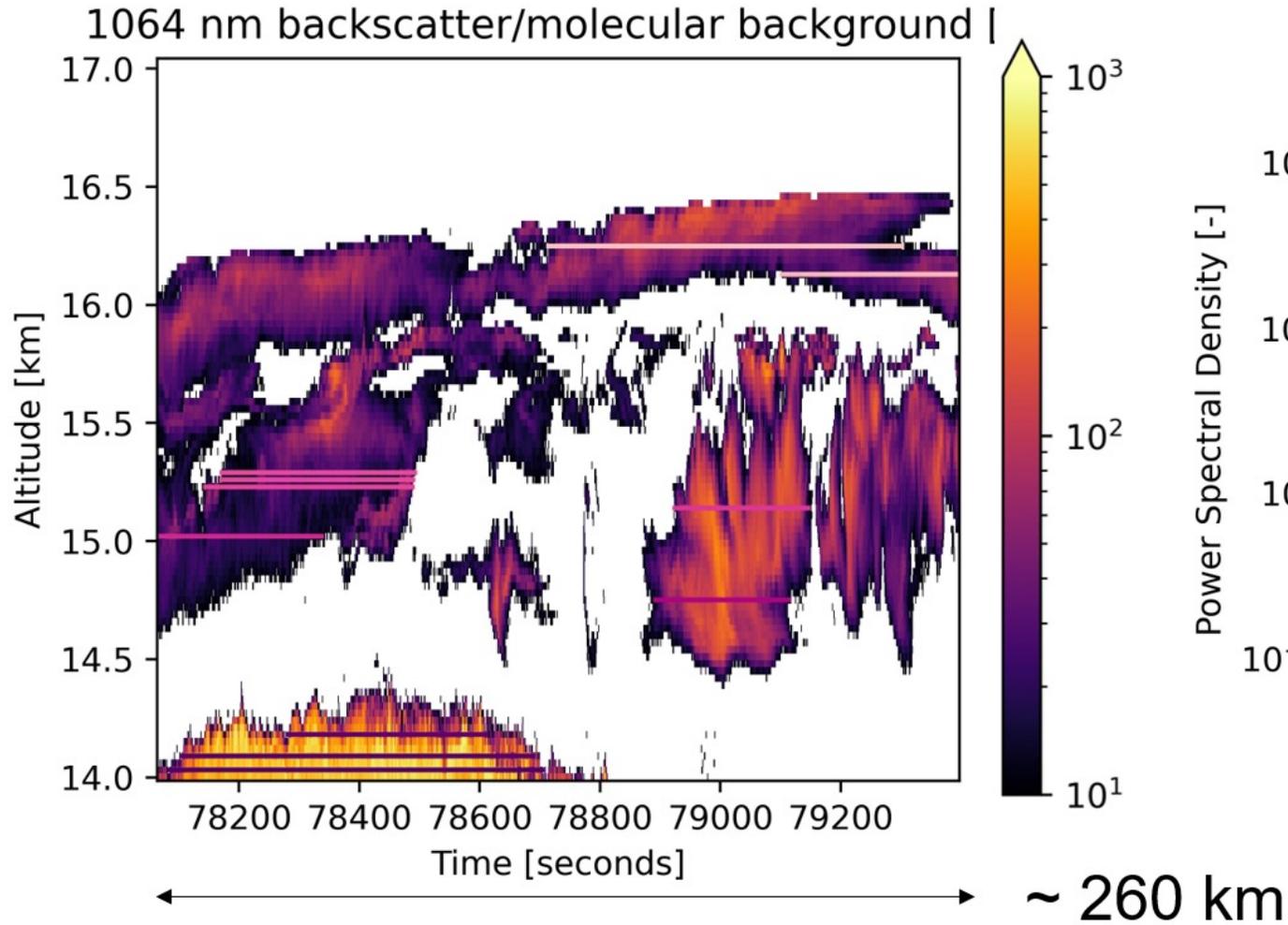


# Close-up on ATTREX lidar images

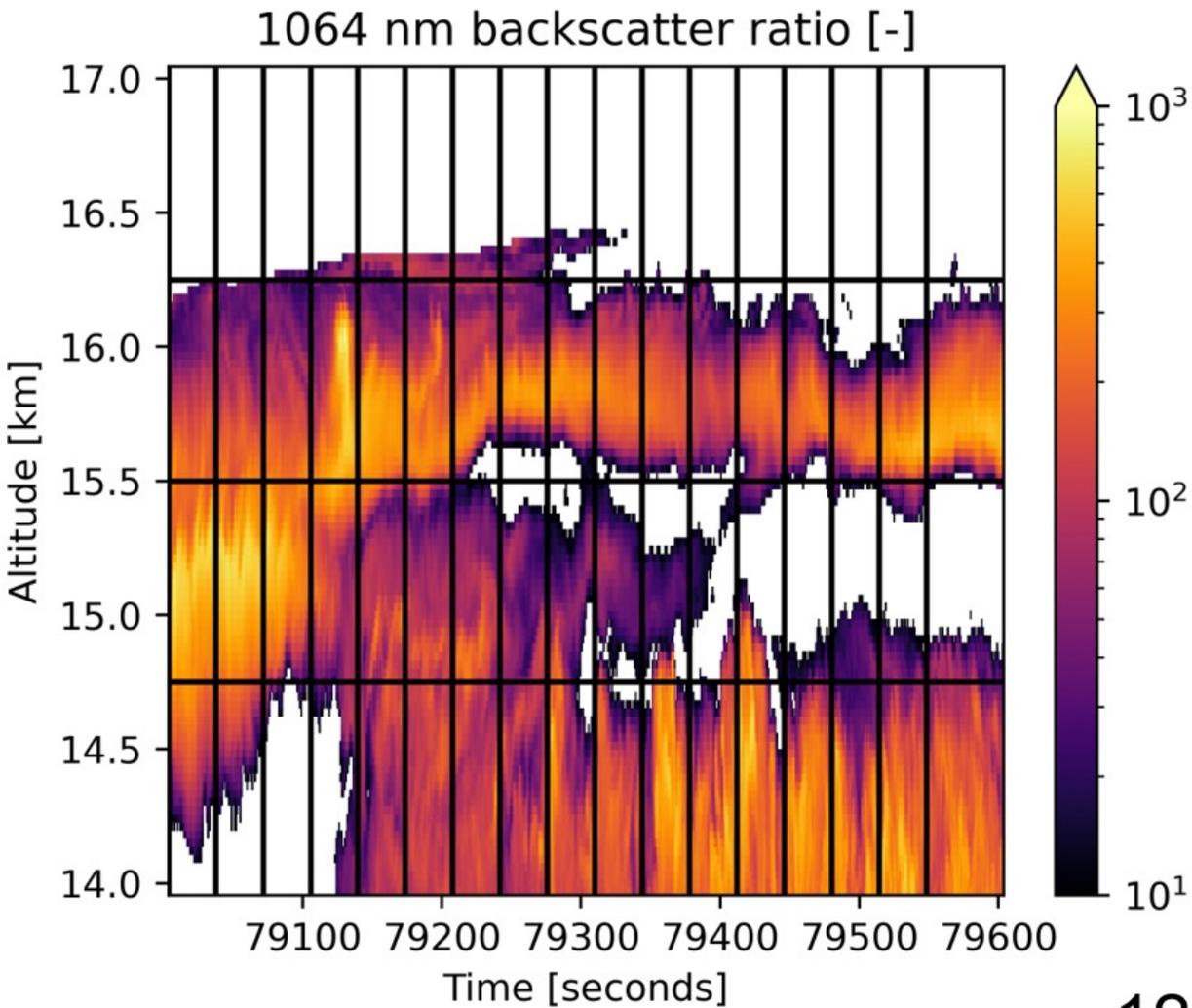


*There is great qualitative information about fine-scale dynamics in these lidar images. How can we get quantitative information from them?*

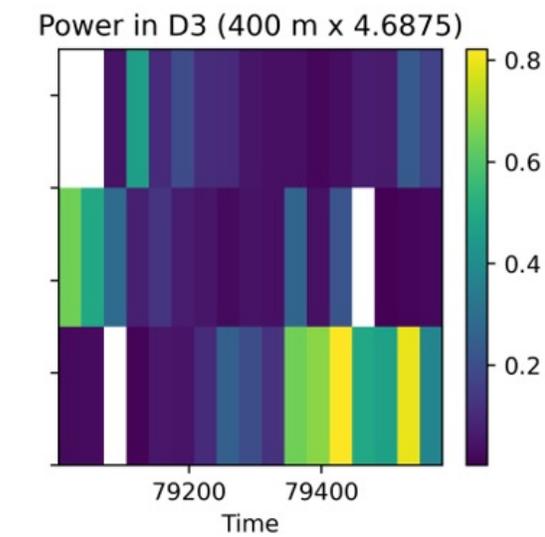
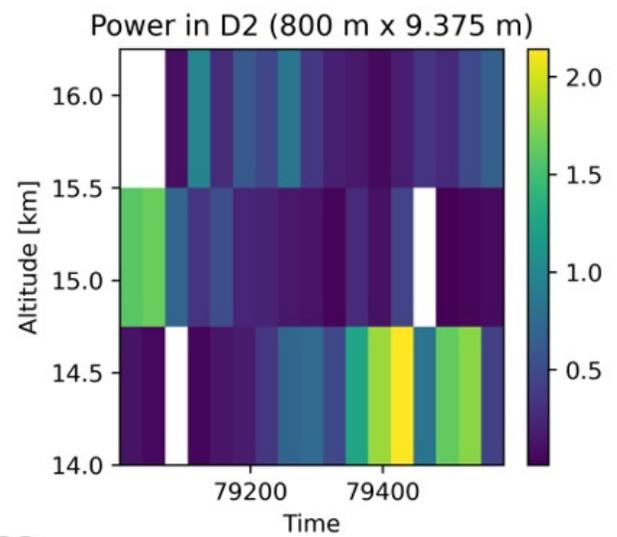
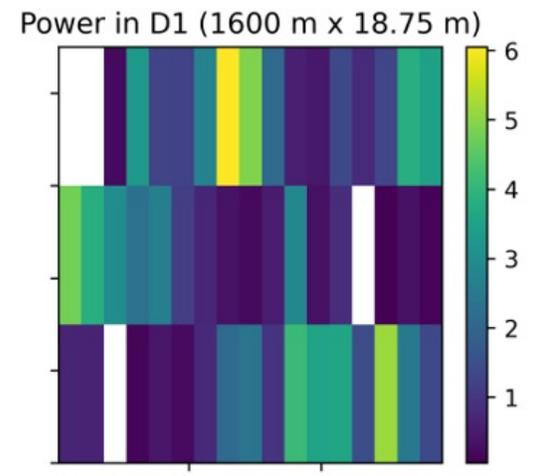
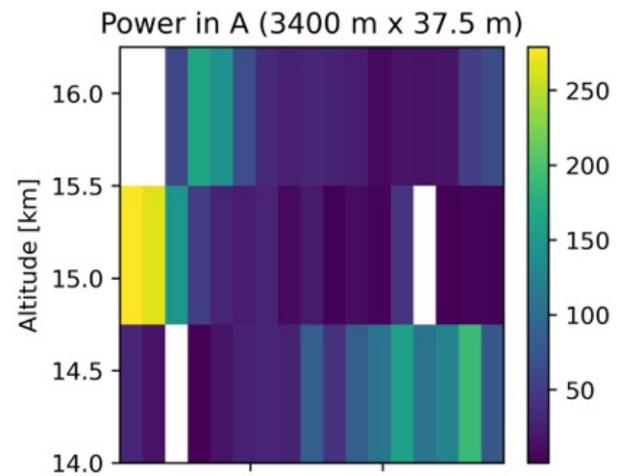
# Fourier spectra on lidar images



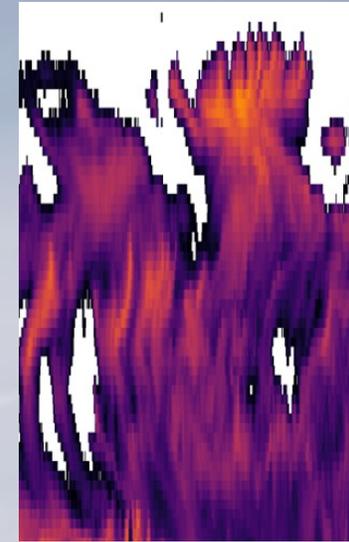
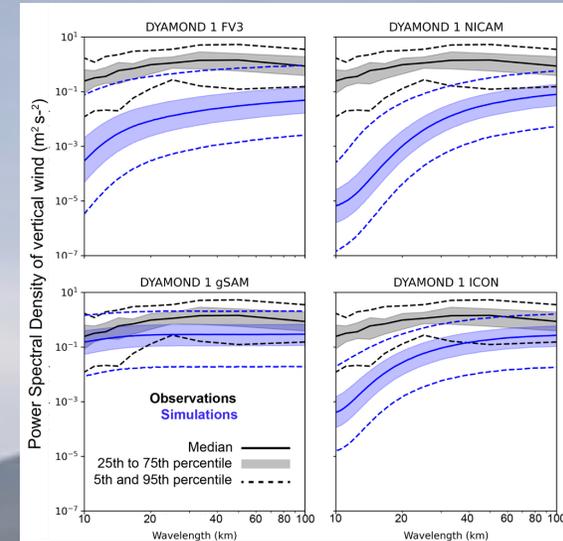
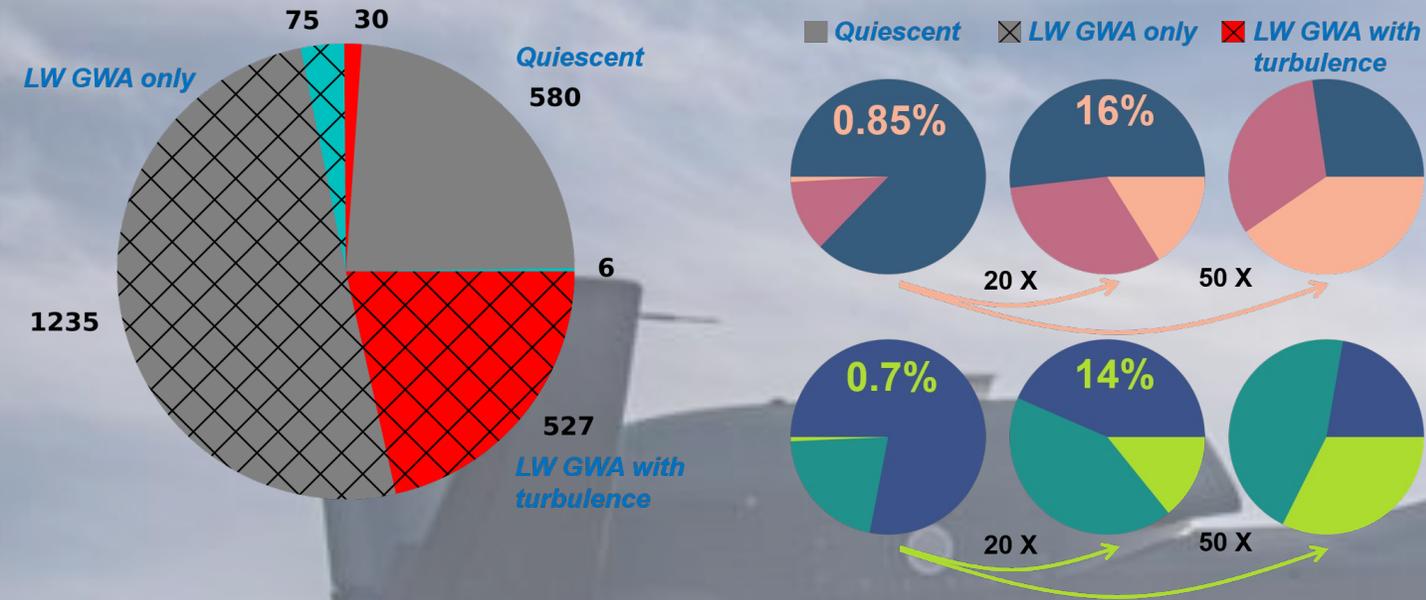
# Wavelet analysis on lidar images



~ 120 km



# Aircraft observations of gravity waves, turbulence and clouds in the tropical tropopause layer



- Gravity wave activity is present 75% of the time
- Turbulence nearly always co-occurs with gravity wave activity

- Small-scale motions (from both turbulence and gravity waves) are key to forming high-IWC and high-NI cirrus
- Found observational evidence to support the result of modelling studies

- Most GSRMs have too little vertical wind between 10 and 100 km
- Horizontal and vertical grid spacing are likely limiting factors

- Fine-scale dynamics are visible by eye in ATTREX lidar images
- Suggestions?