Cross-isentropic mixing: A DEEPWAVE case study

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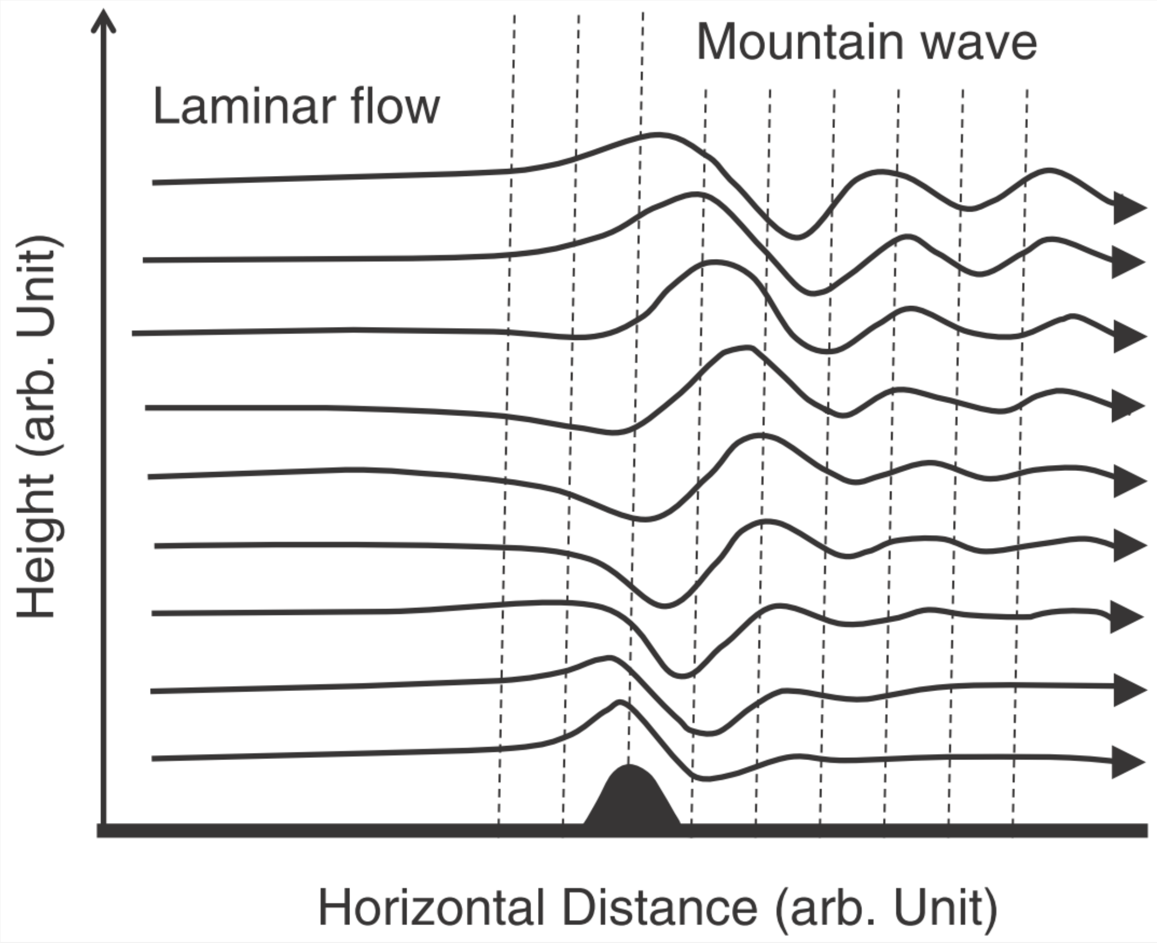
Introduction and motivation

Introduction and motivation

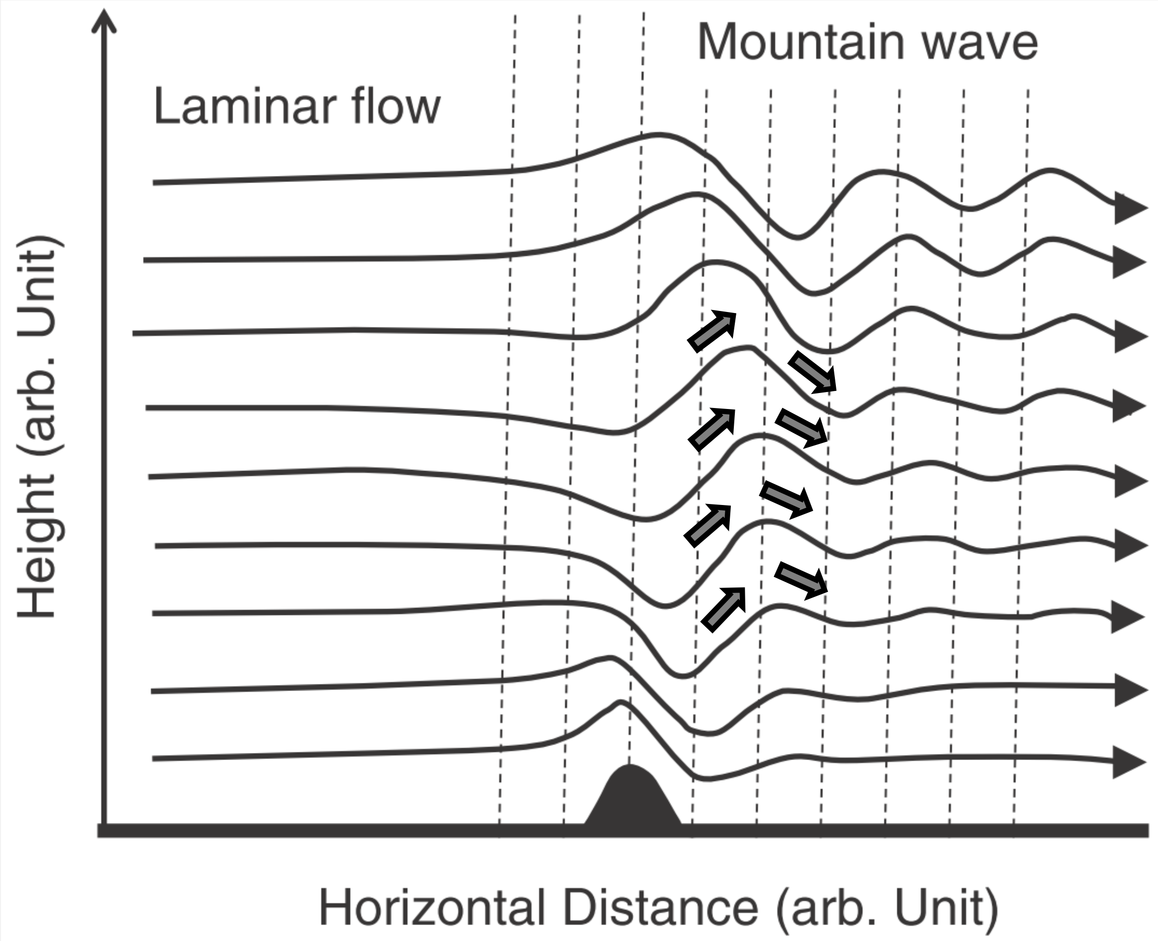
- orographic waves transport energy and momentum in the atmosphere



Tsuda (2014)

Introduction and motivation

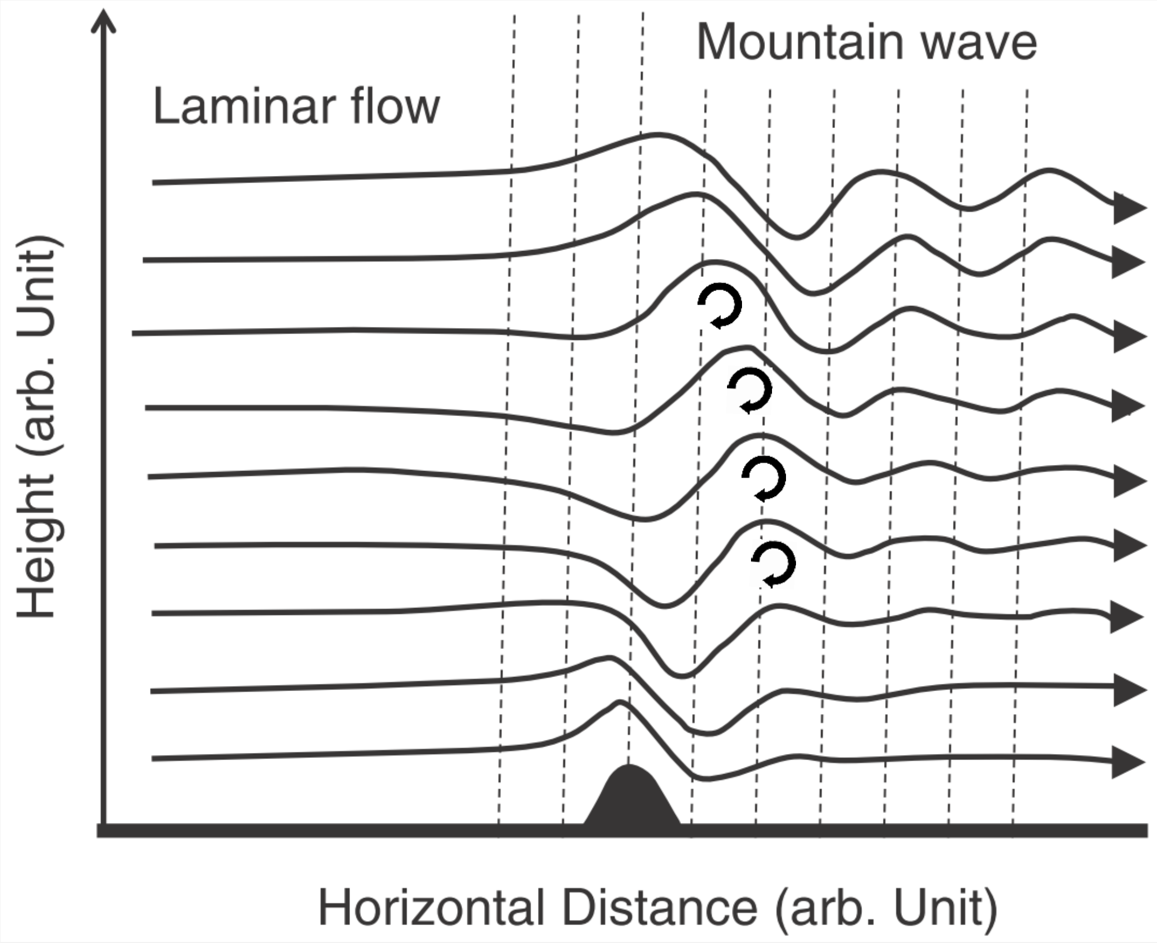
- linear waves induce no mixing



Tsuda (2014)

Introduction and motivation

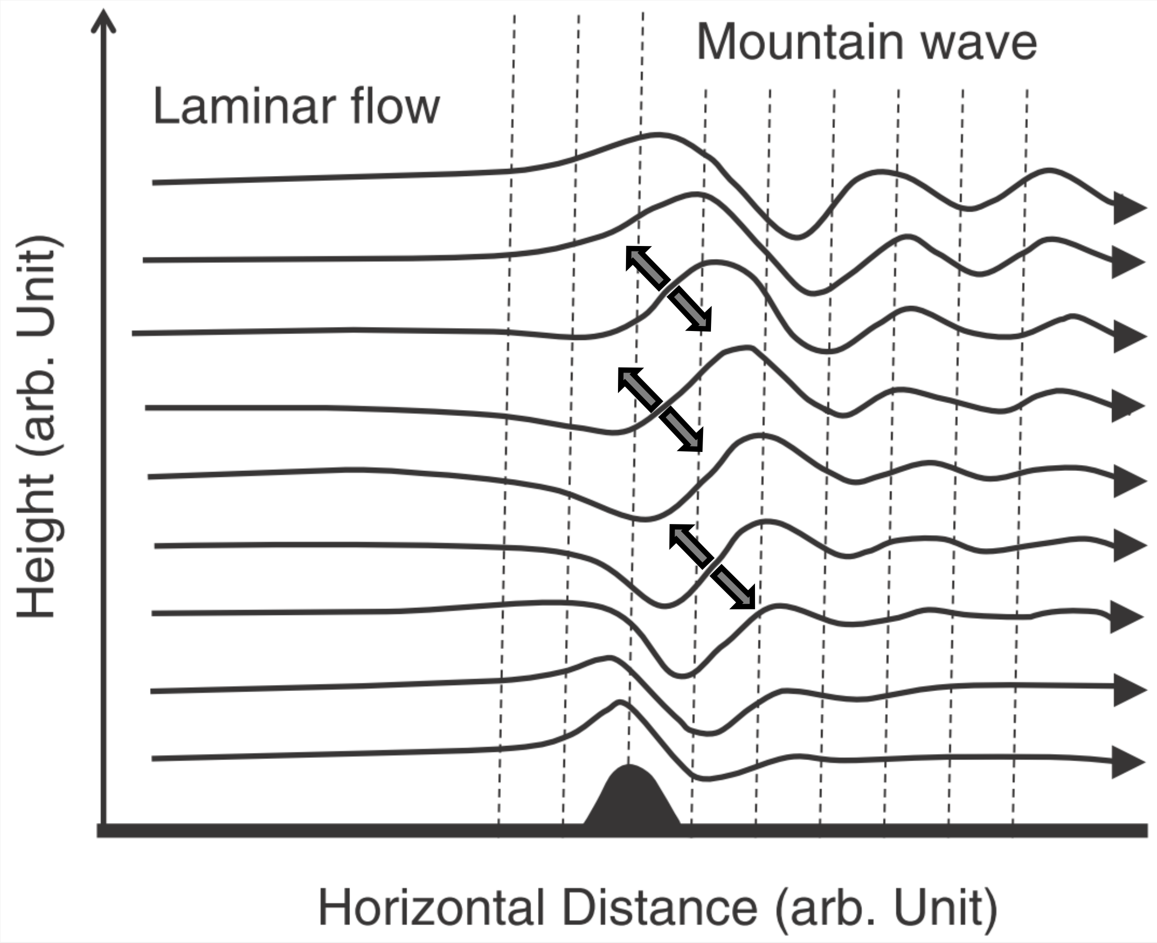
- mountain waves could induce turbulence and instabilities locally



Tsuda (2014)

Introduction and motivation

- a possible consequence is cross-isentropic transport



Tsuda (2014)

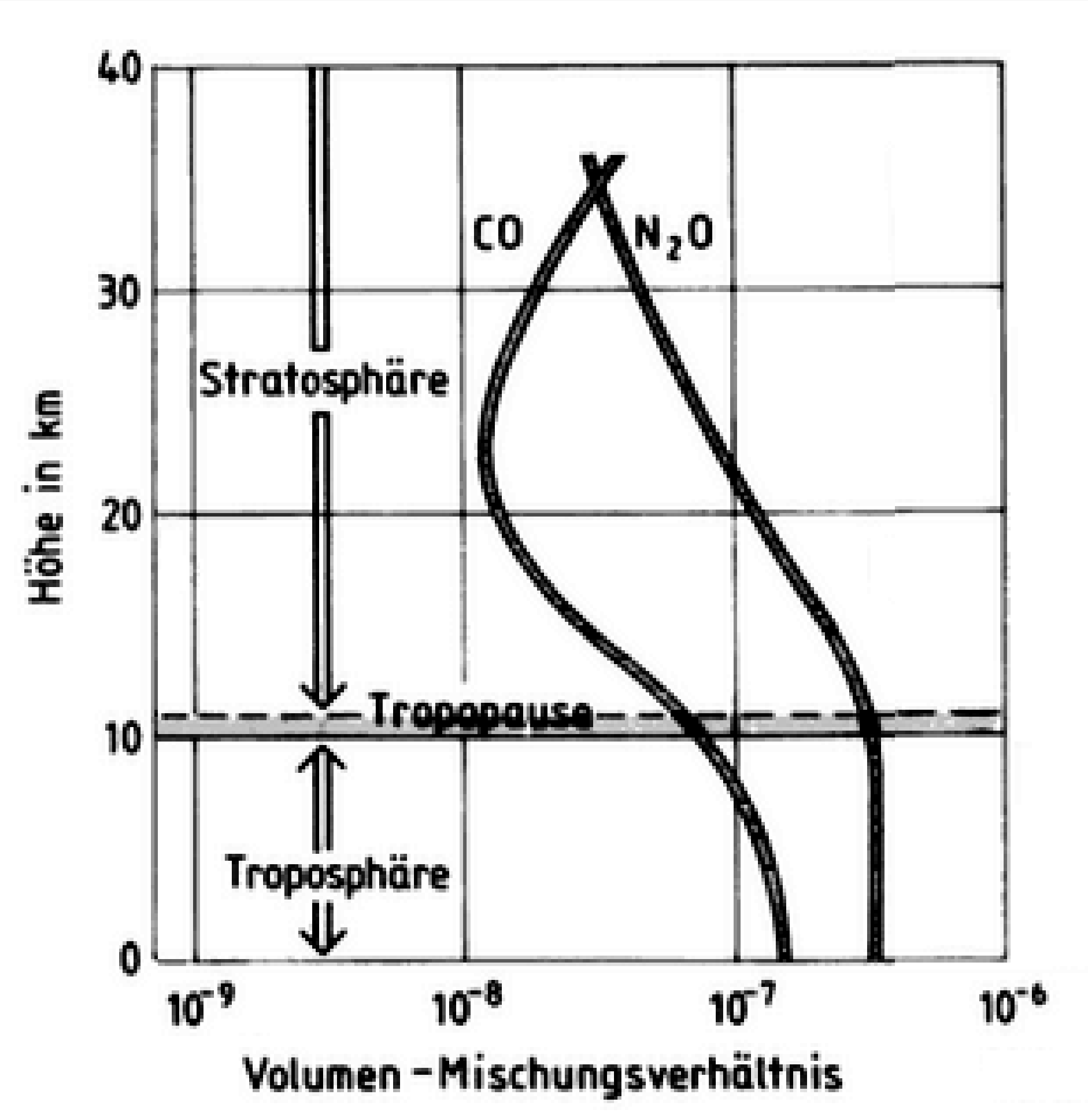
Introduction and motivation

Question:

- Is it possible to identify cross-isentropic mixing processes during a mountain wave event based on the distribution of trace gases?

Tracers: N_2O and CO

- N_2O and CO are tracers for diagnosing mixing
- both having a vertical gradient in the lower stratosphere

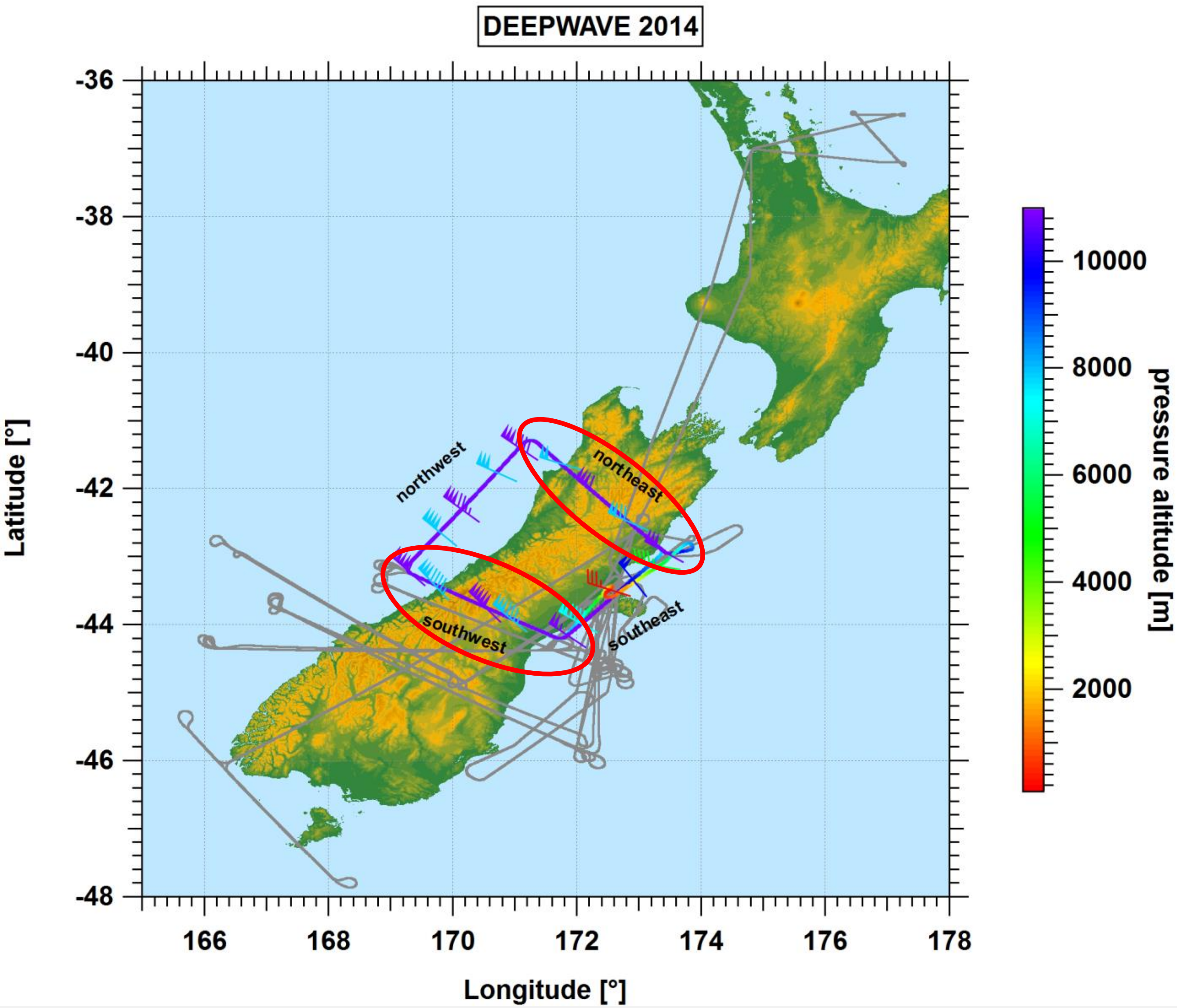


Görner, Hübner „Umweltschutztechnik“ (1999)

Case study: DEEPWAVE flight 9

DEEPWAVE flight 9

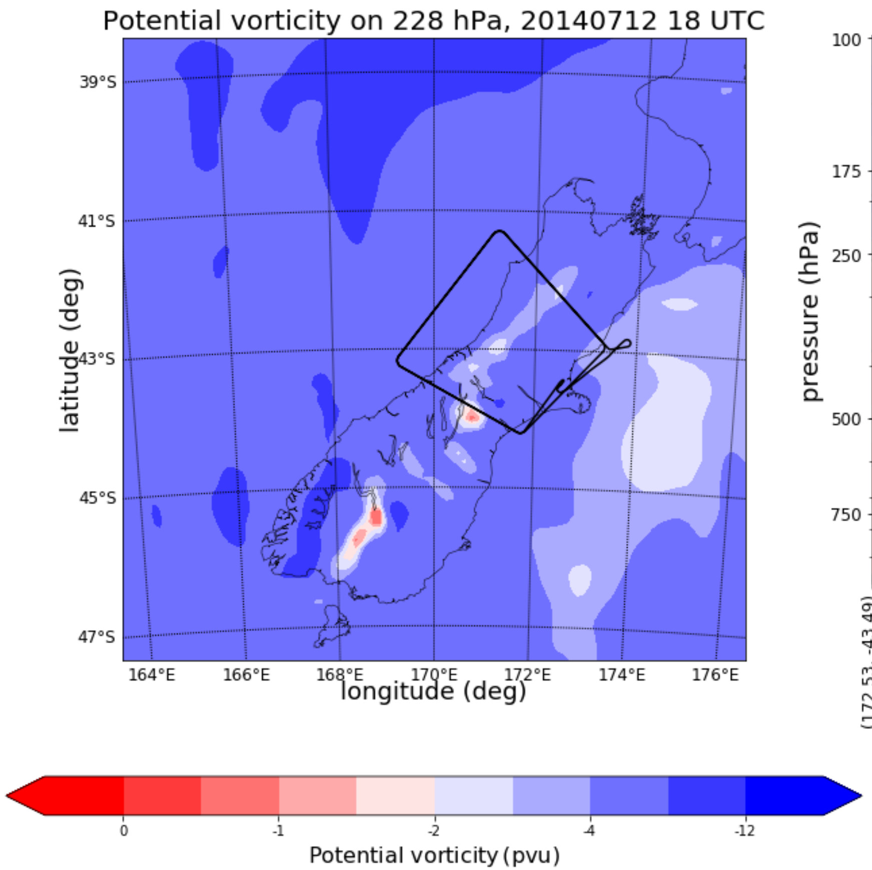
preliminary data

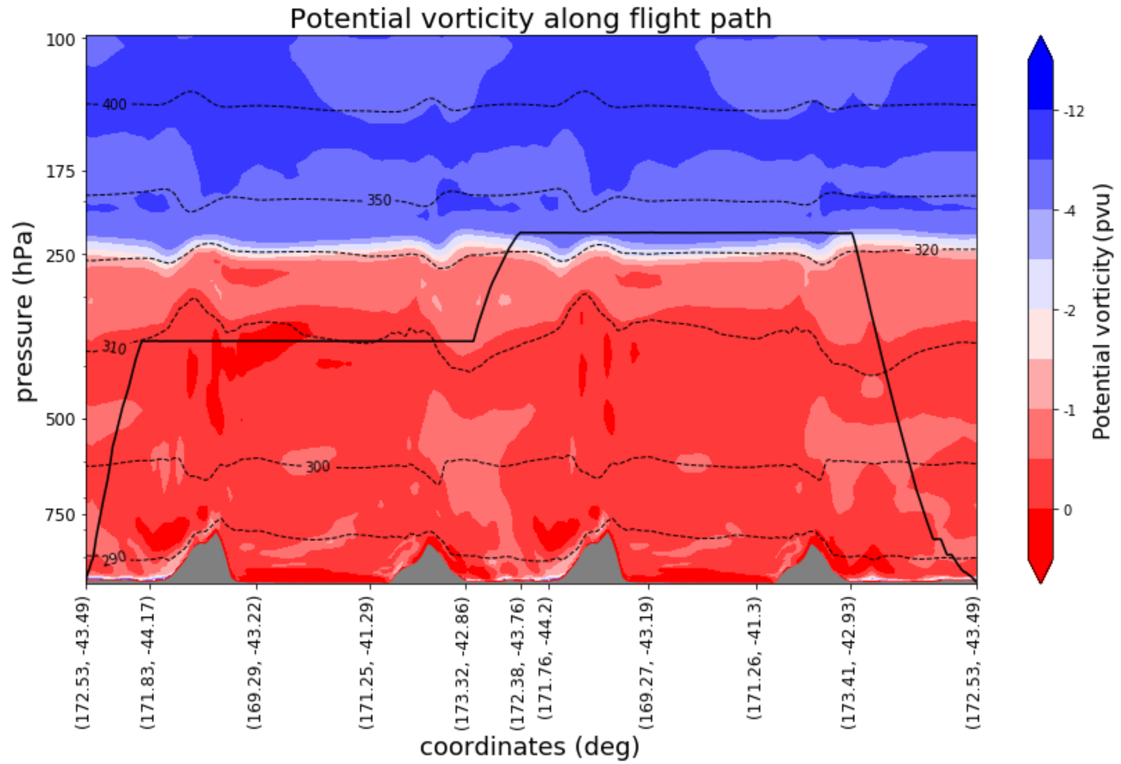


- flight paths during DEEPWAVE 2014
- measuring waves: flight legs parallel to the wind and cross to the mountains

PV cross-sections

preliminary data

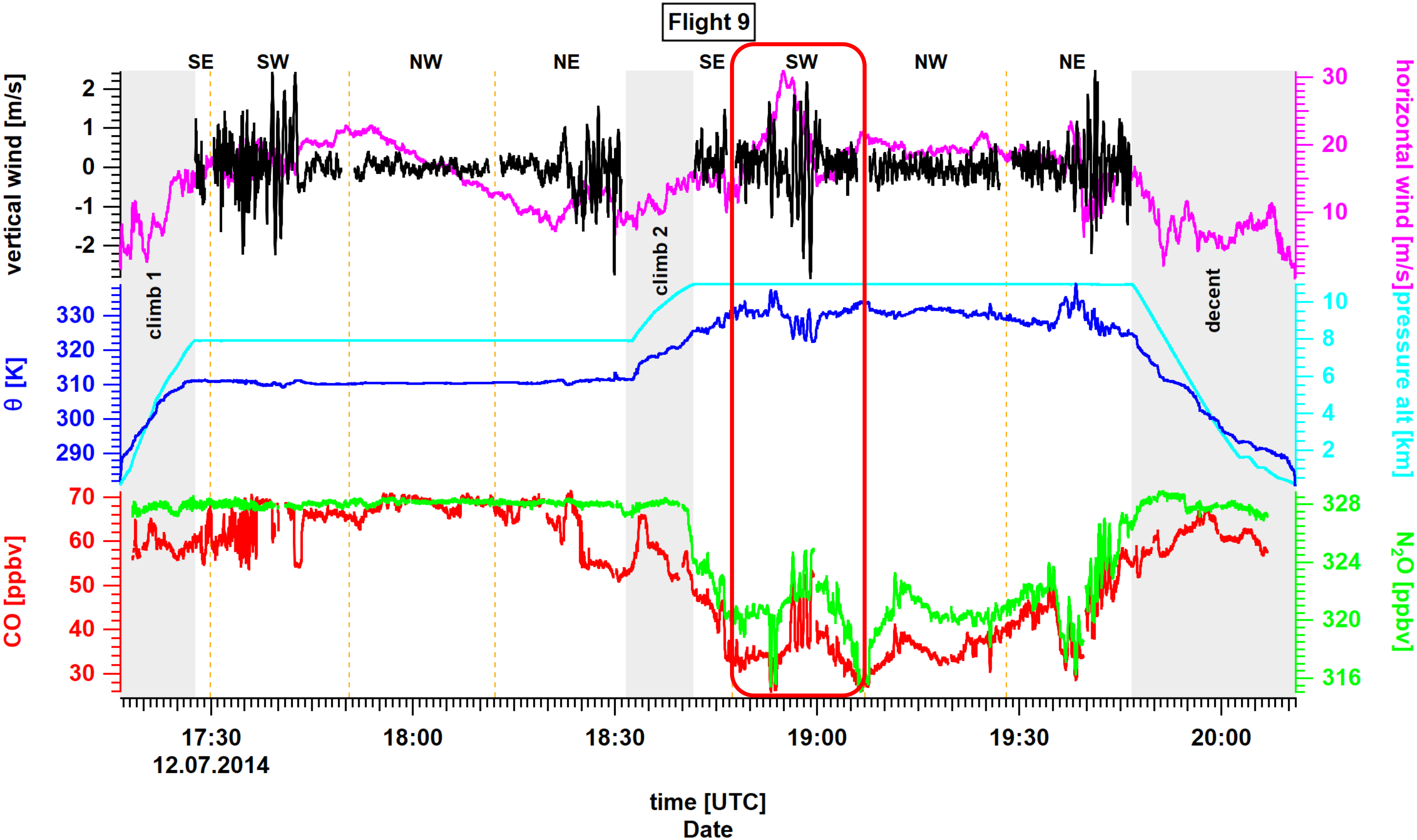




- upper flight legs close to the dynamical tropopause

Time series of flight 9

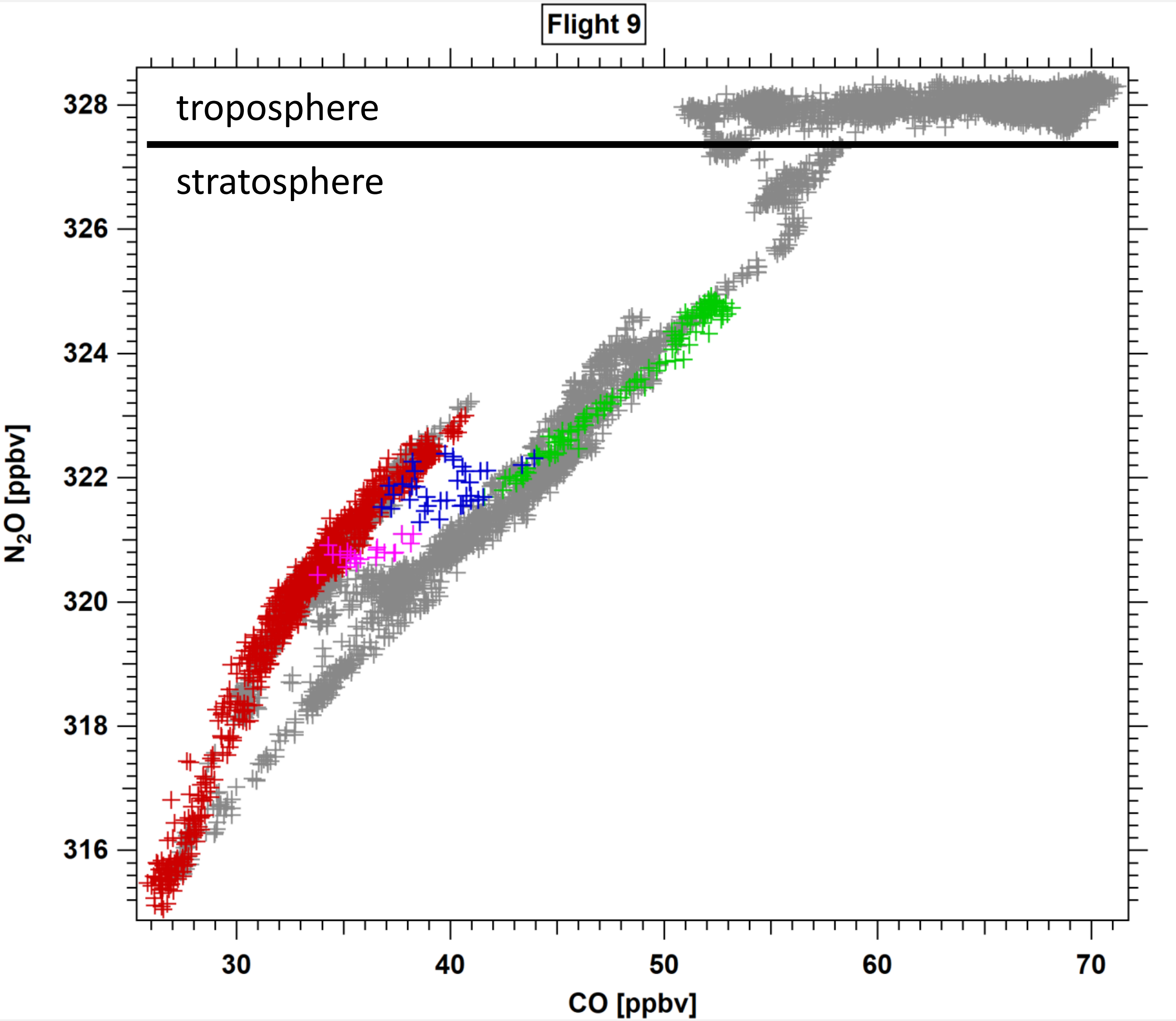
JG|U
preliminary data



- strongest wave signals within the south-western leg

N_2O - CO correlation

preliminary data

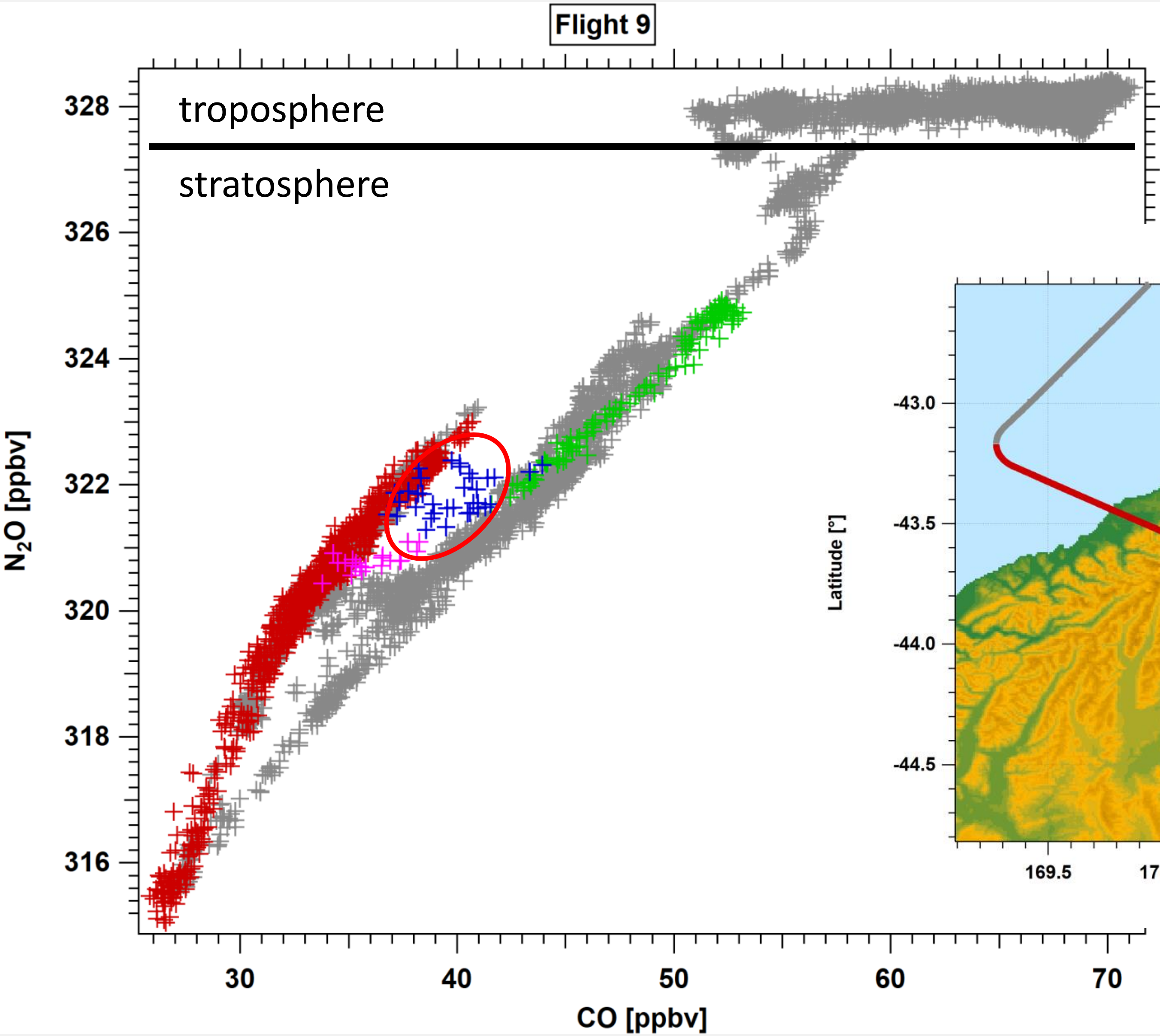


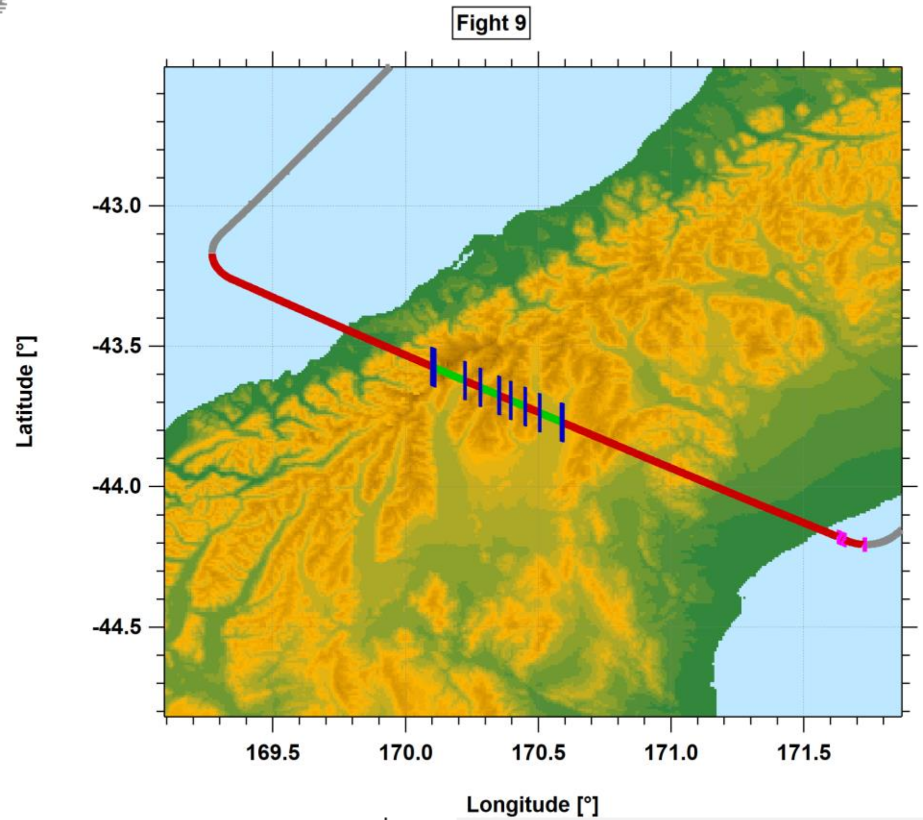
- points (blue) between two stratospheric air masses (red, green) indicate mixing

N_2O - CO correlation

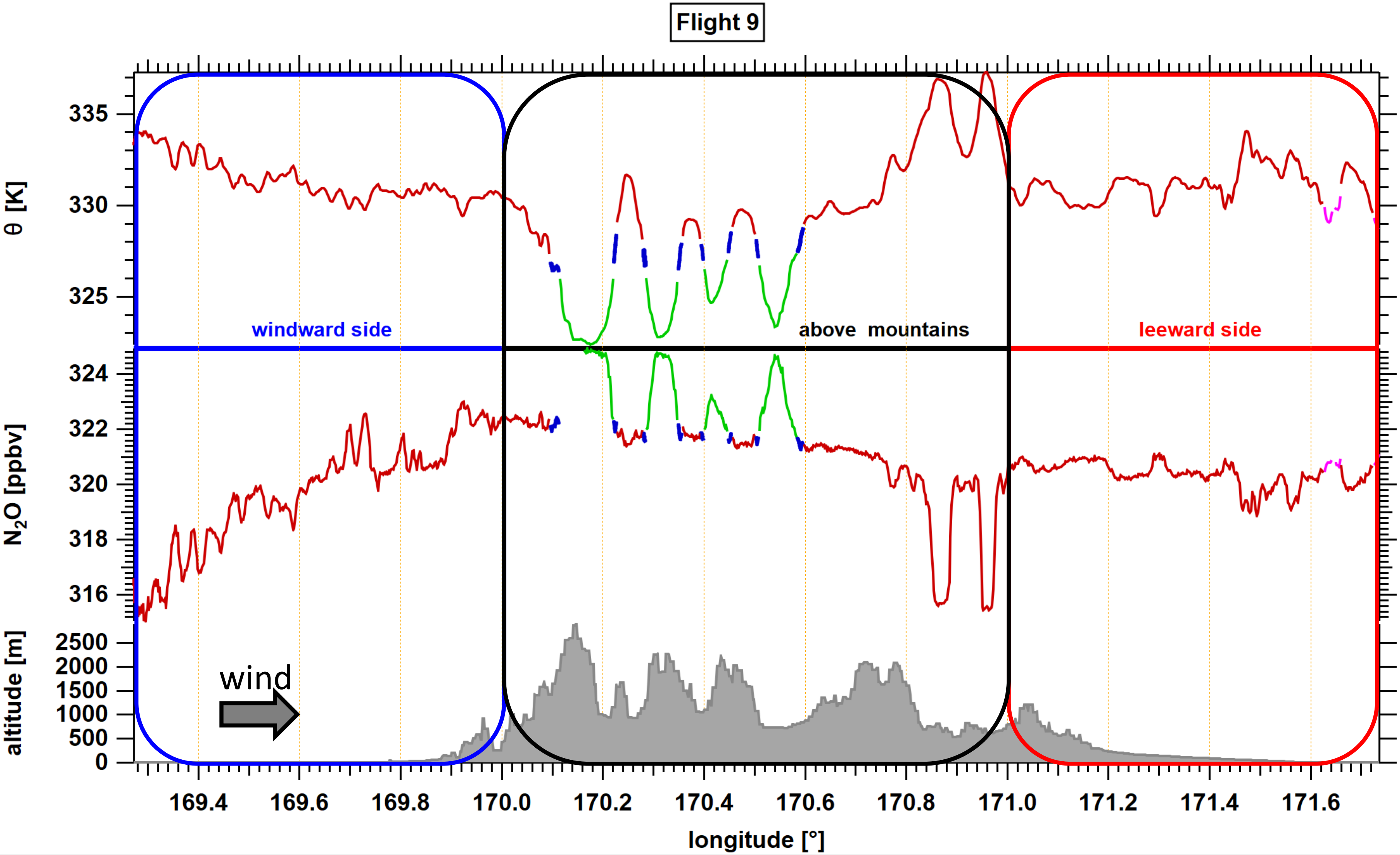
preliminary data

- mixing points above the mountains





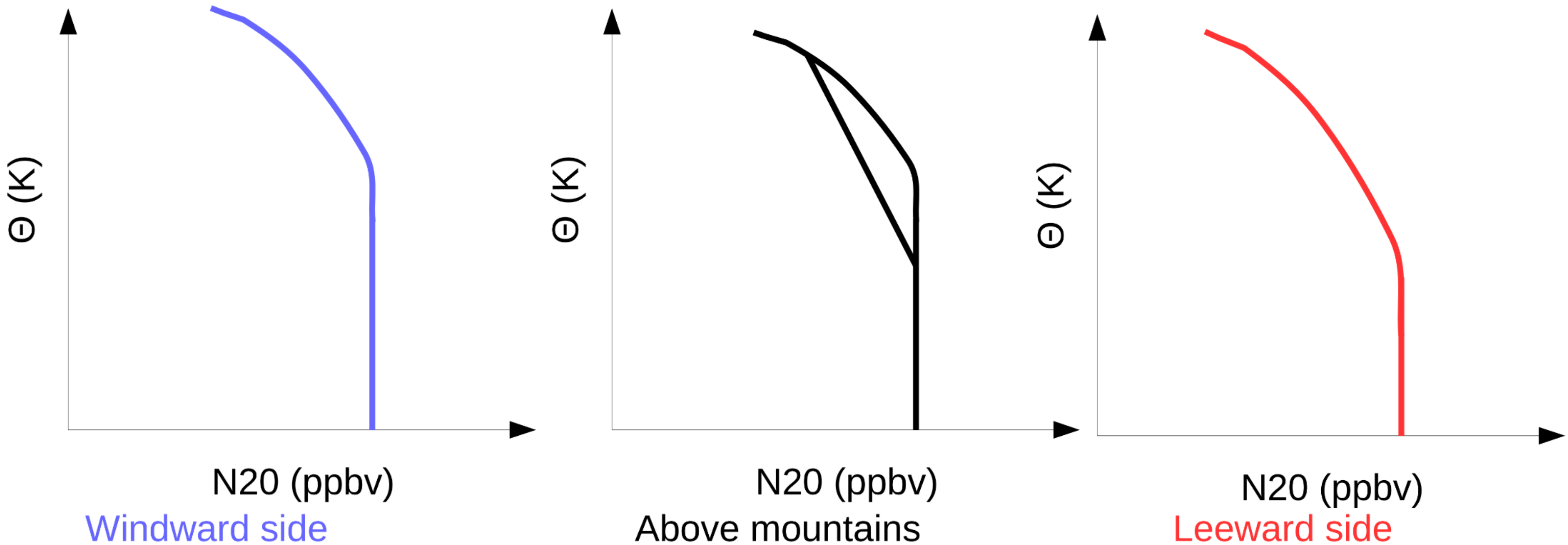
Region of mixing



- separation of the leg in 3 different sectors

Tracer distribution and mixing

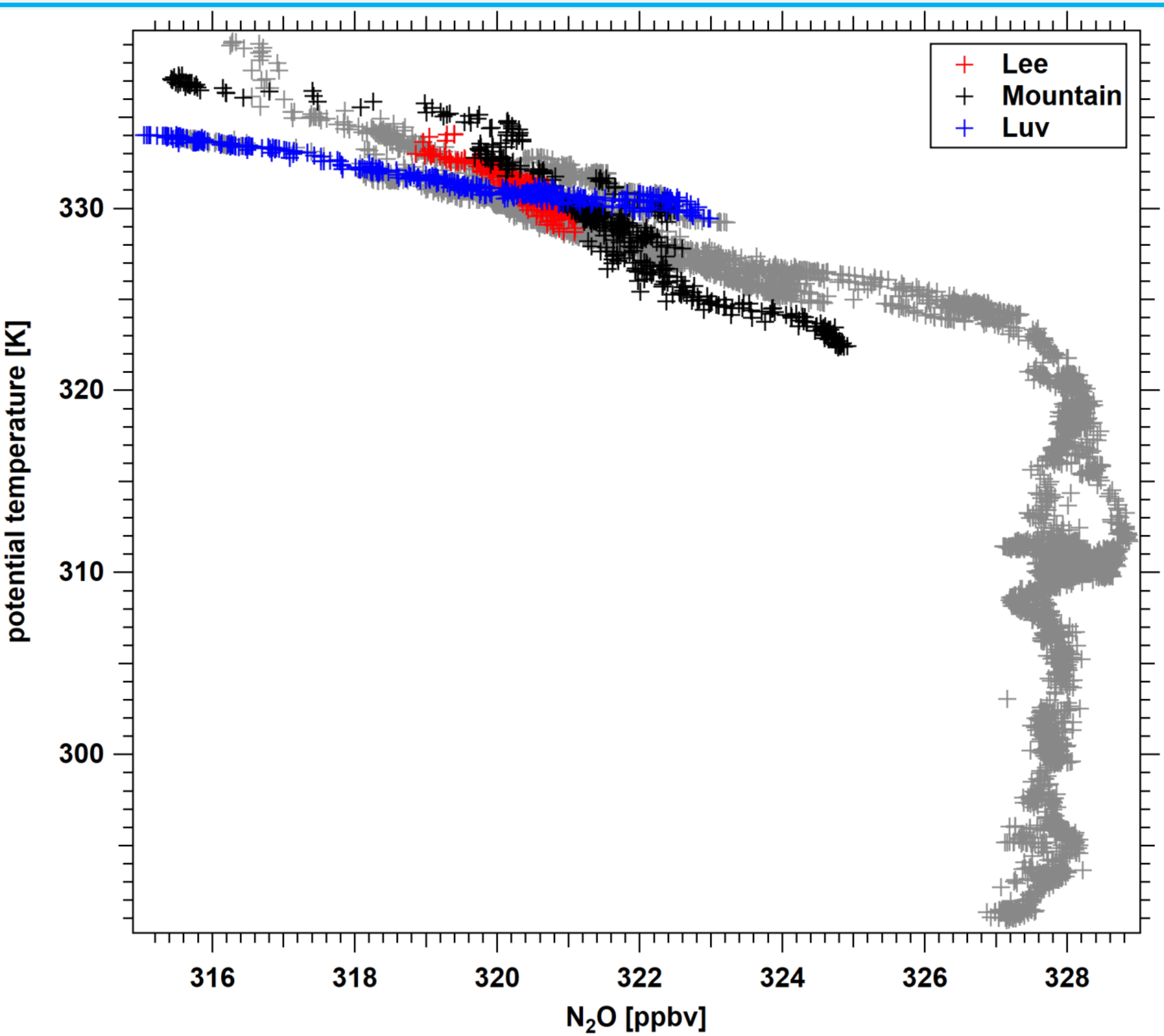
Tracer distribution and mixing



- Hypothesis:
  - windward side: background N_2O profile
  - mixing and turbulence induced by mountain waves change the gradient of N_2O and potential temperature
  - leeward side: new modified N_2O profile

N_2O profile

preliminary data

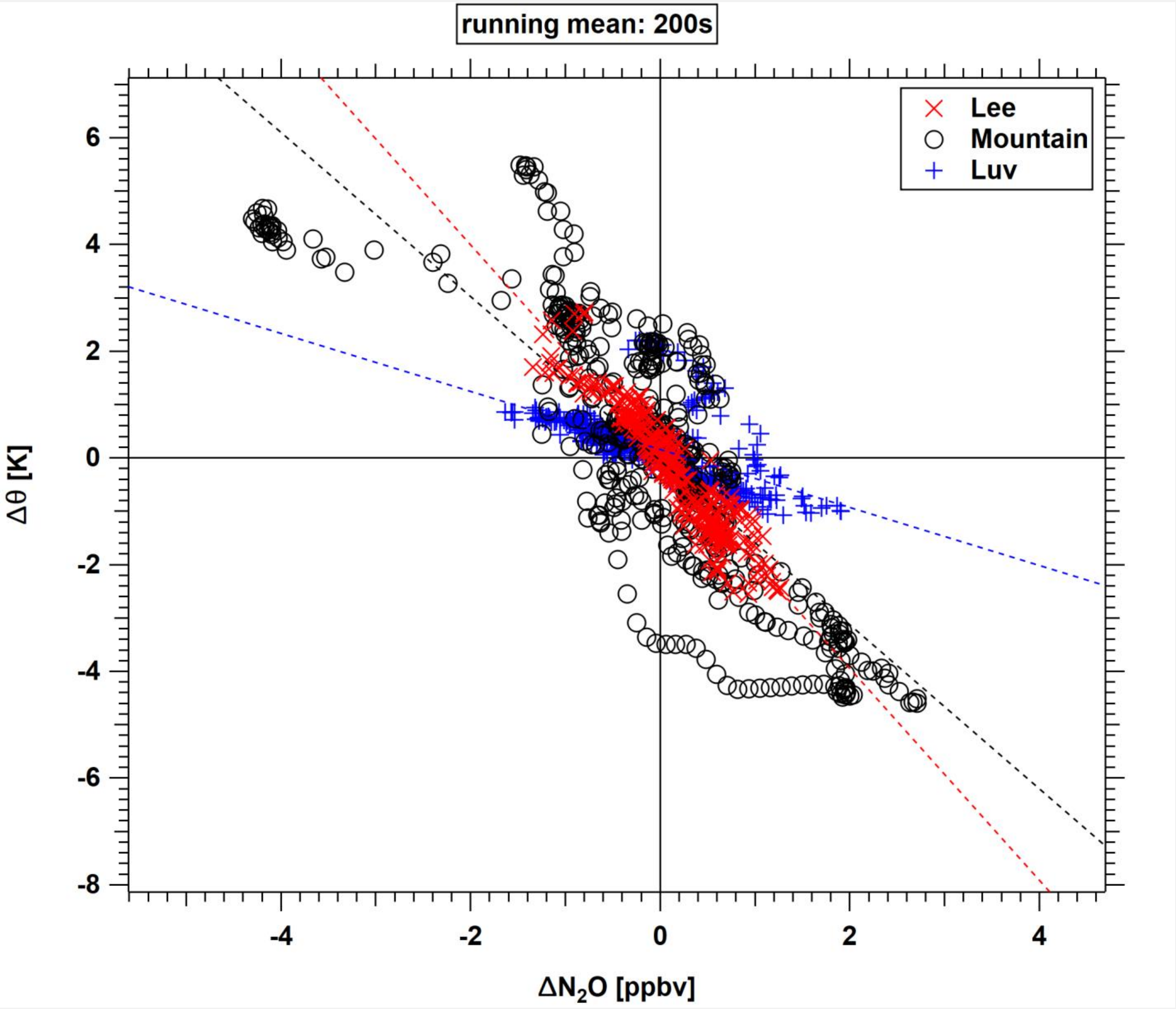


- different slopes on windward and leeward side

⇒ Which wavelengths and scales are relevant for mixing as indicated by the slope change?

Scale analysis

preliminary data



- Reynolds decomposition:

$$q(t) = \bar{q} + q'(t)$$

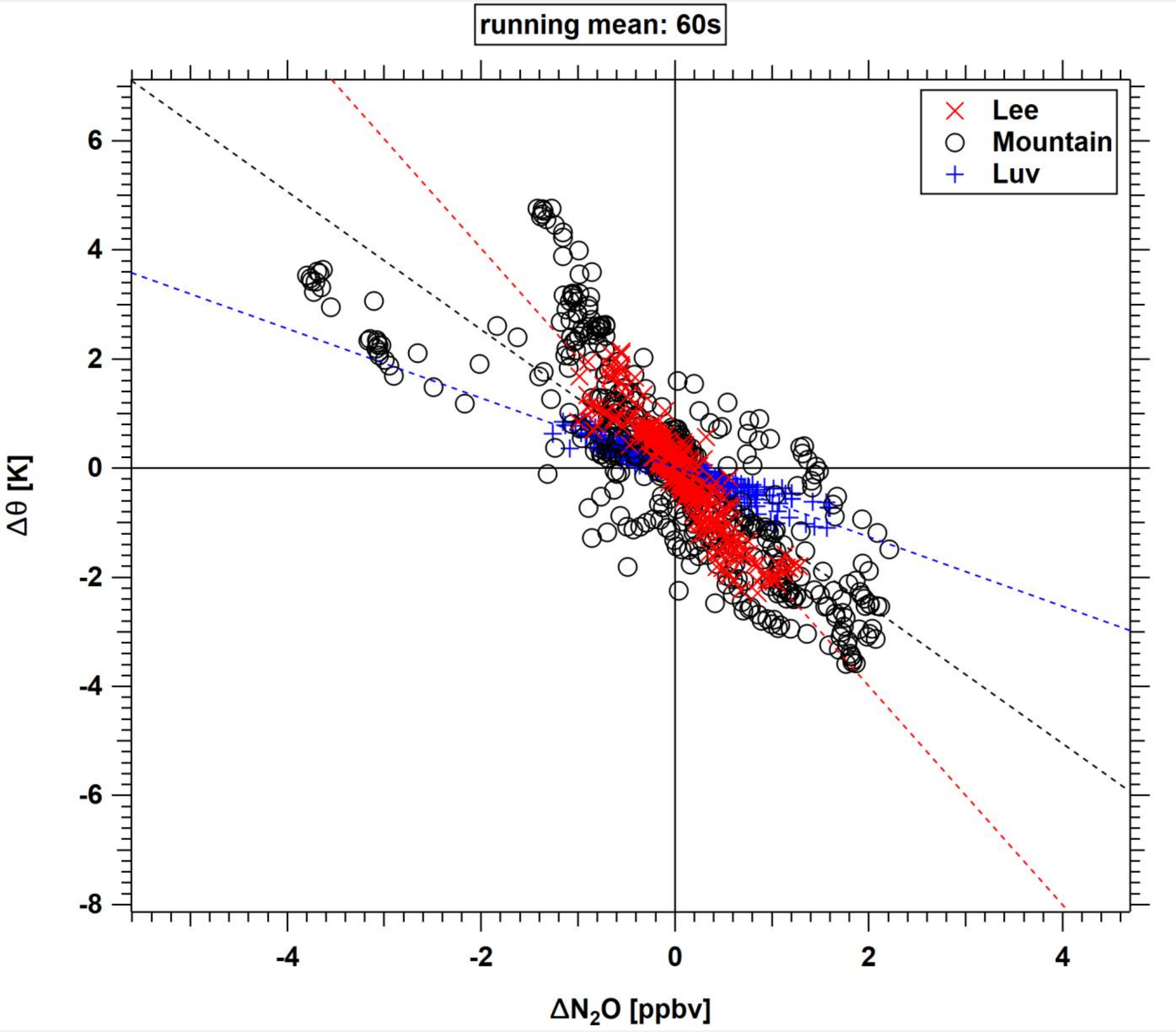
<=>

$$q'(t) = q(t) - \bar{q}$$

- $\bar{q}$ determined from running mean for different values of averaging time (see next slides)
- here: 200s as an example

Scale analysis

preliminary data



- Reynolds decomposition:

$$q(t) = \bar{q} + q'(t)$$

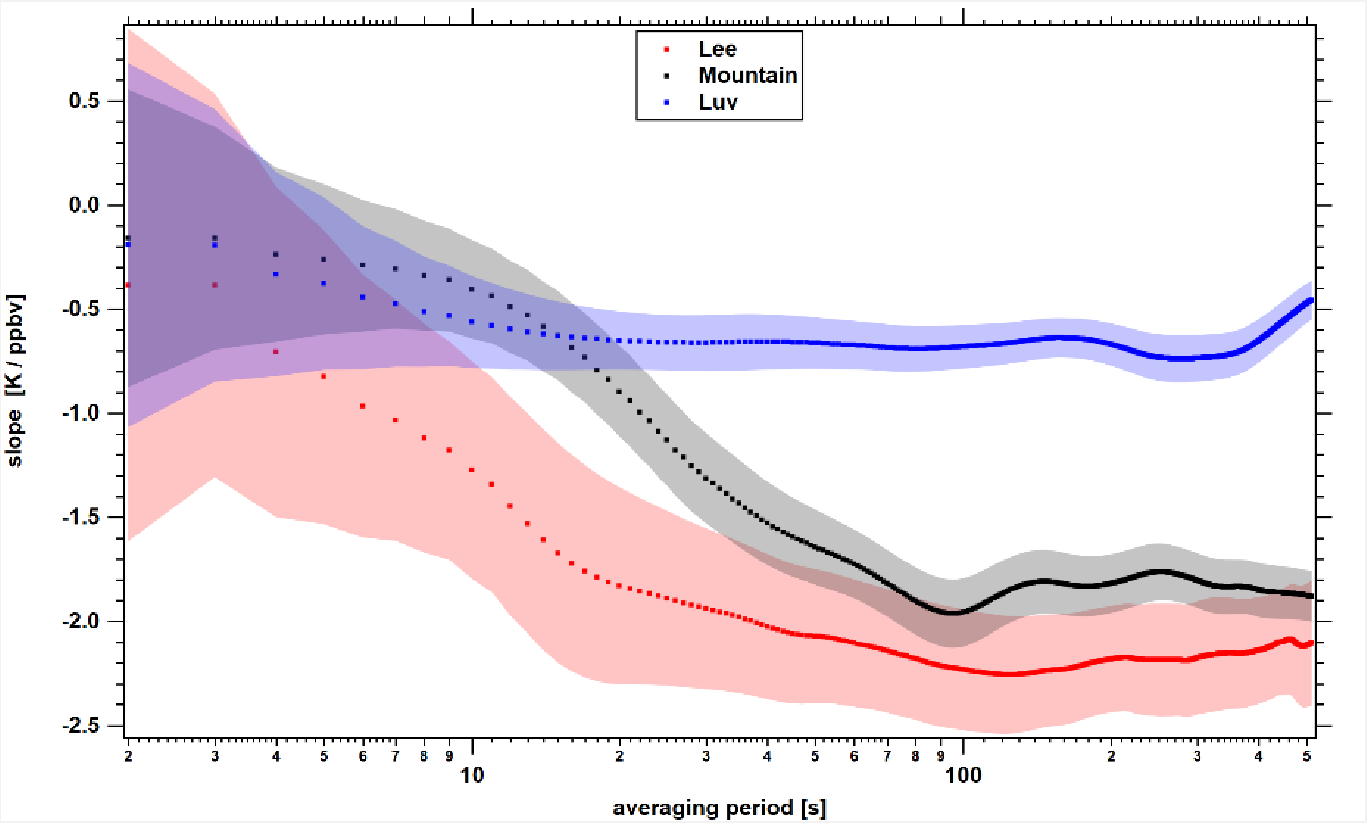
<=>

$$q'(t) = q(t) - \bar{q}$$

How do the slopes depend on the averaging time scale (and thus on the wavelength)?

Scale analysis

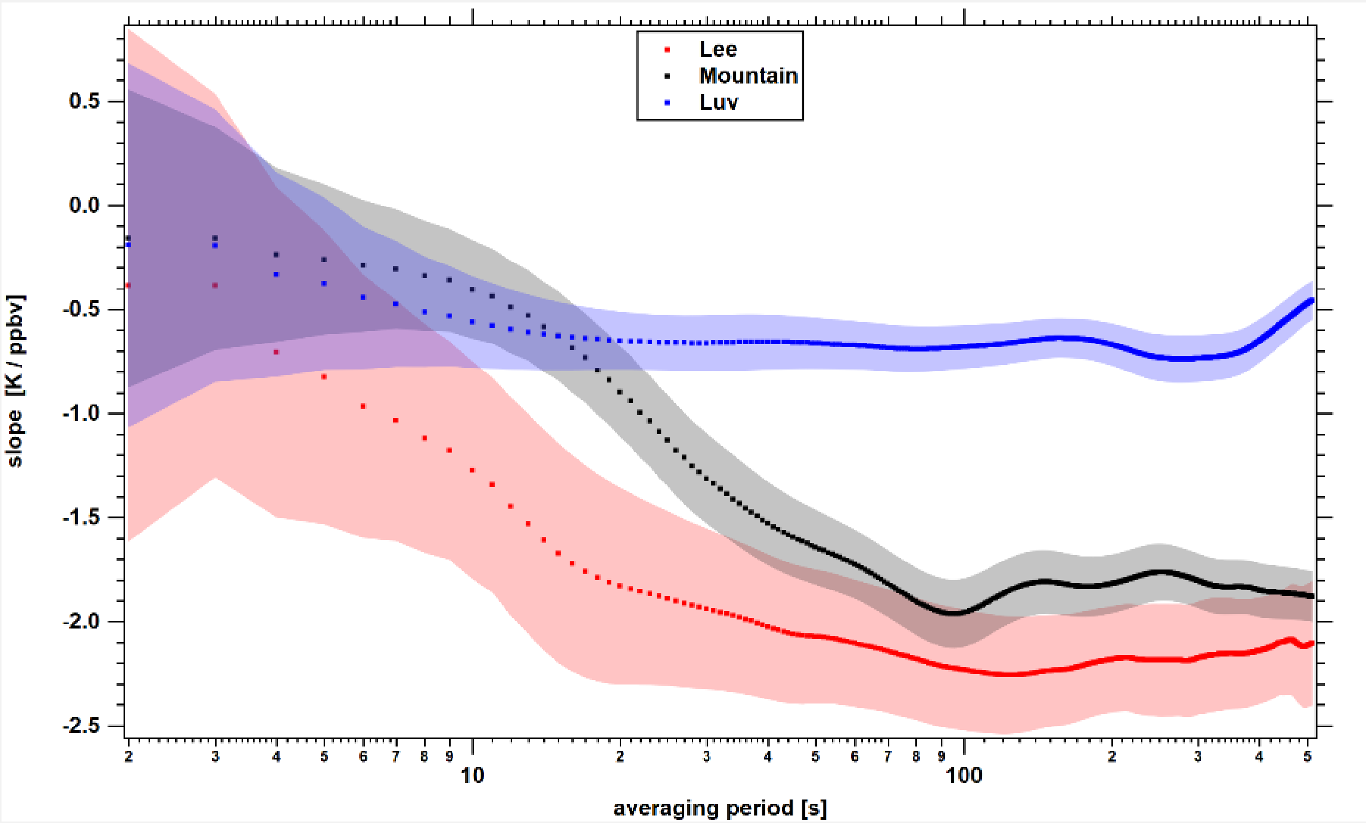
preliminary data



- slope values for the relation of Theta and N_2O as a function of averaging time separated into the regions upstream (blue), above mountains (black) and leeward of the mountains (red)
- long time scales (i.e. wavelengths): different slopes upwind and downwind

Scale analysis

preliminary data

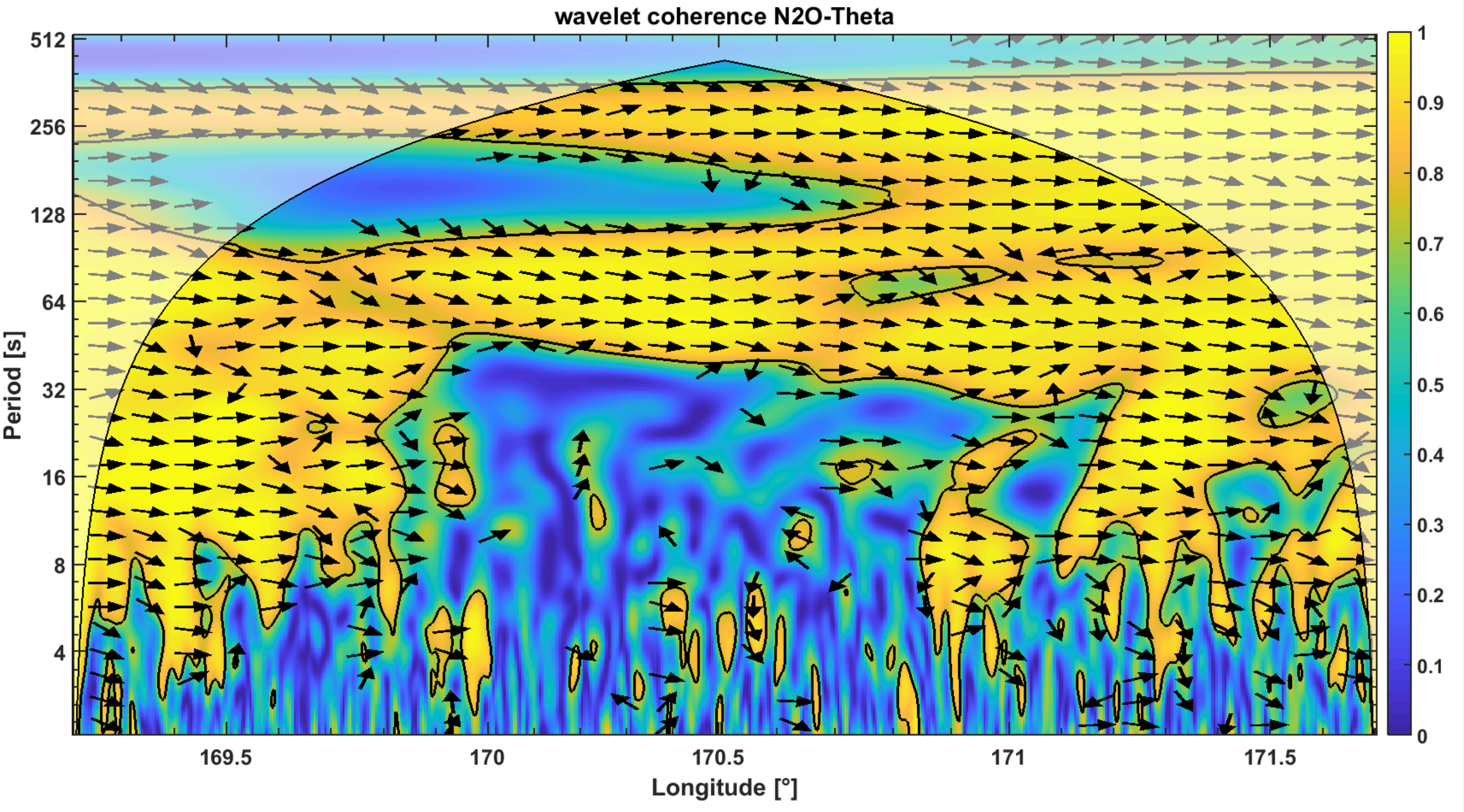


- short time scales slope change occurs for the transition from short to long time scales indicating the effect of small scale turbulent mixing on the tracer slope
- slope changes at small scales ⇒ waves may induce cross-isentropic mixing

Wavelet coherence

Wavelet coherence

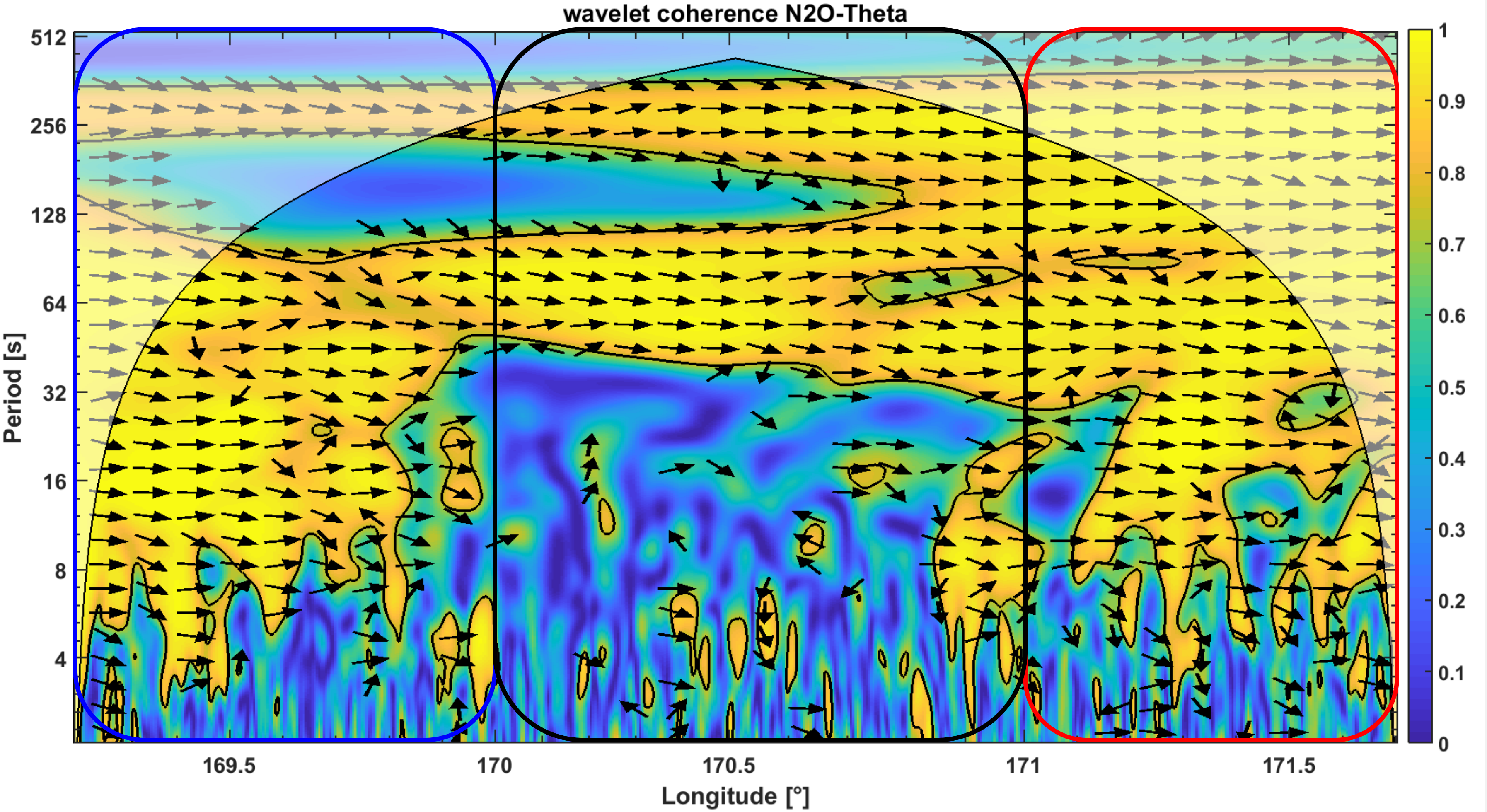
preliminary data



- wavelet coherence (color) is a measure of the intensity of the covariance of the two time series
- the arrows show relative phasing of two time series (right: anti-phase)

Wavelet coherence

preliminary data

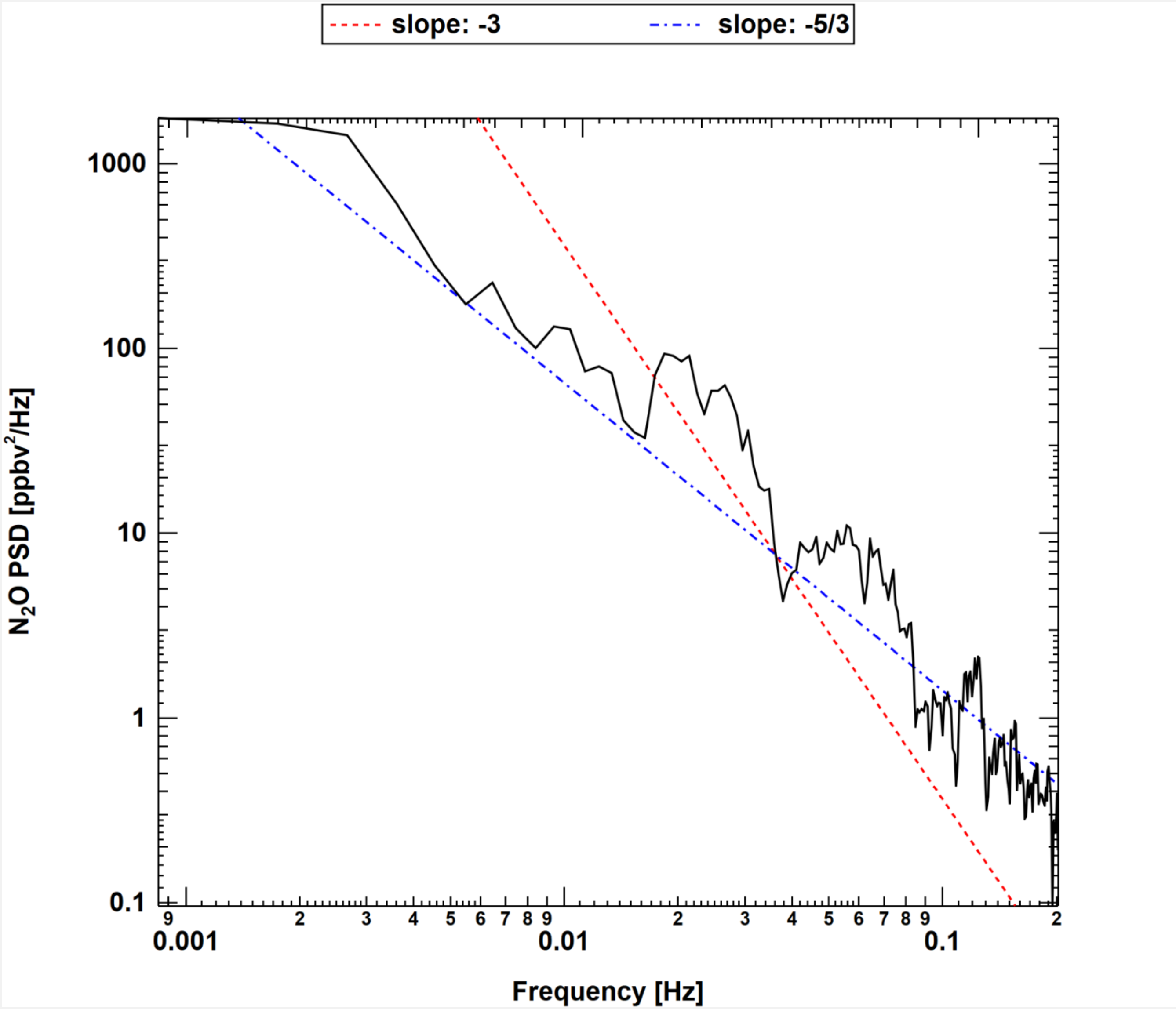


- areas of low coherence at small scales matches with the slope changes

Power spectral density

Power spectral density

preliminary data

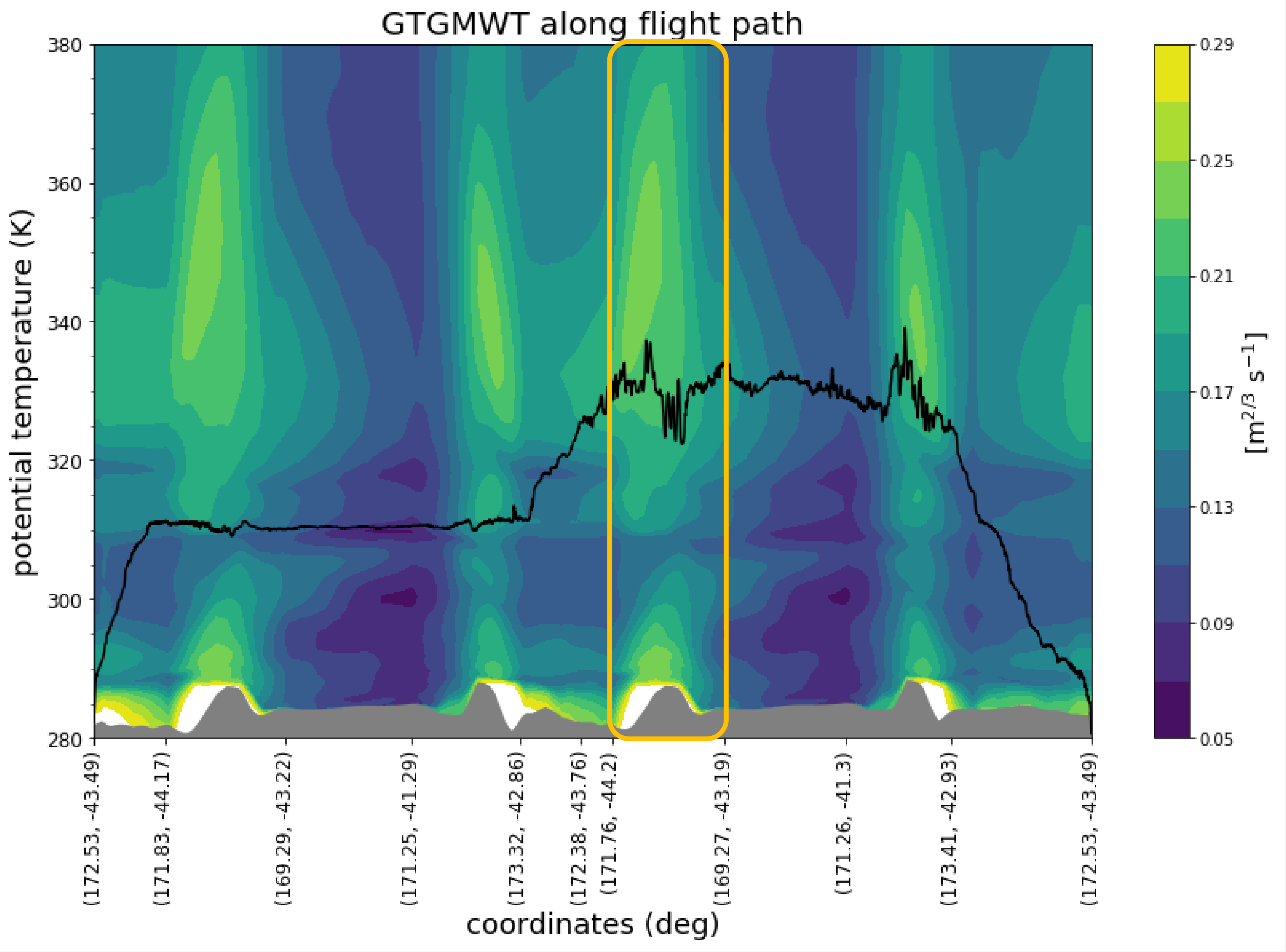


- N_2O over the mountains follow the -5/3 slope
- this is an indication for turbulence

Graphical Turbulence Guidance

Mountain wave turbulence

preliminary data



- Graphical turbulence guidance analysis (Bramberger et al., 2019) confirms the occurrence of turbulence in the region of analysis

Summary

Summary

- CO-N_2O correlation of high resolution airborne measurements of gravity wave induced mixing above New Zealand during DEEPWAVE 2014 shows signatures of mixing
- the slope changes could be a hint for cross-isentropic mixing
- Wavelet coherence supports the results of the slope analysis
- -5/3 slope and GTG calculations indicate the existence of turbulence
- mountain waves could lead to cross-isentropic mixing