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: $\text{N}_2\text{O}$ and CO

- $\text{N}_2\text{O}$ 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

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

- upper flight legs close to the dynamical tropopause
Time series of flight 9

- strongest wave signals within the south-western leg
N$_2$O - CO correlation

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

Flight 9

Troposphere

Stratosphere
N$_2$O - CO correlation

- 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 $\text{N}_2\text{O}$ profile
  - mixing and turbulence induced by mountain waves change the gradient of $\text{N}_2\text{O}$ and potential temperature
  - leeward side: new modified $\text{N}_2\text{O}$ profile
N$_2$O profile

- different slopes on windward and leeward side

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

- 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

- slope values for the relation of Theta and N\textsubscript{2}O 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
• 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

- 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

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

- $\text{N}_2\text{O}$ over the mountains follow the $-5/3$ slope
- this is an indication for turbulence
Graphical Turbulence Guidance
Mountain wave turbulence

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

- CO-N$_2$O 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.