Case studies on turbulence in different tropopause folds

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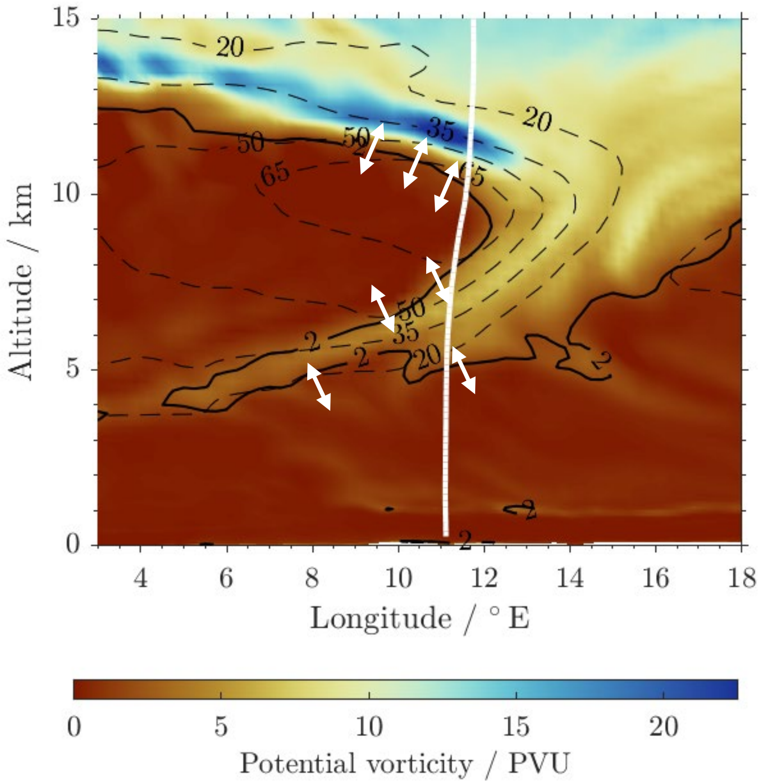
The phenomenon: Tropopause folds



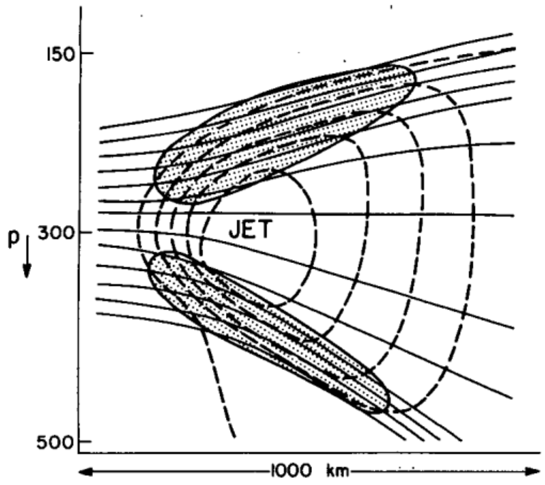
Adapted from: Söder et al. (2021), their Figure 3.

Left: tropopause fold shown in the ECMWF-IFS data by potential vorticity (PV) and isotaches (dashed)

- Location: above northern Germany on 19 Jan 2020, 15 UT
- Characterised by an intrusion of stratospheric (high PV) air in tropospheric altitudes, showing strong tropopause jet with wind speeds exceeding $75\,ms^{-1}$
- Tropopause folds known for strong stratosphere-troposphere exchange (e.g. Holton et al., 1995)
- Local PV maximum in shear layer above jet

Tropopause folds and turbulence

The original picture by M.A. Shapiro



Stippled areas denote turbulence. From Shapiro (1976)

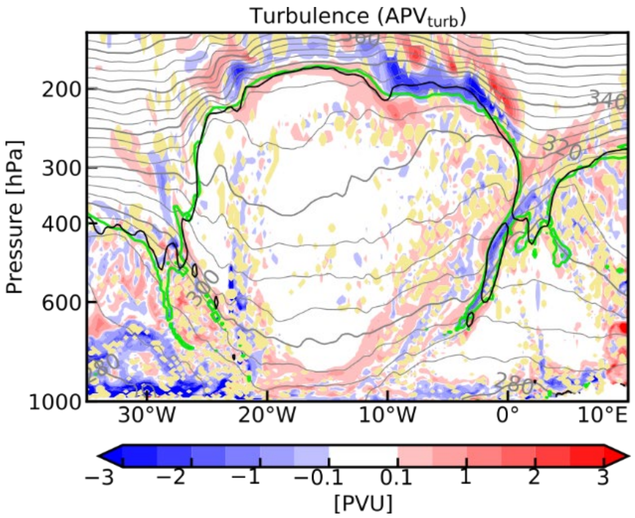
In tropopause folds, turbulence is both a consequence and a driver of the meso-scale flow:

- Upper-level jet-front systems are characterised by strong vertical wind gradients inducing low Richardson numbers and turbulence.
- Effect of turbulence on larger scales by non-conservative PV modification:

$$\frac{dPV}{dt} = g(\xi_\theta + f)\frac{\partial^2}{\partial p^2}\left(-\rho\overline{w'\theta'}\right)$$

- $\overline{w'\theta'}$: vertical eddy flux of potential temperature created by turbulence

Recent findings on tropopause folds



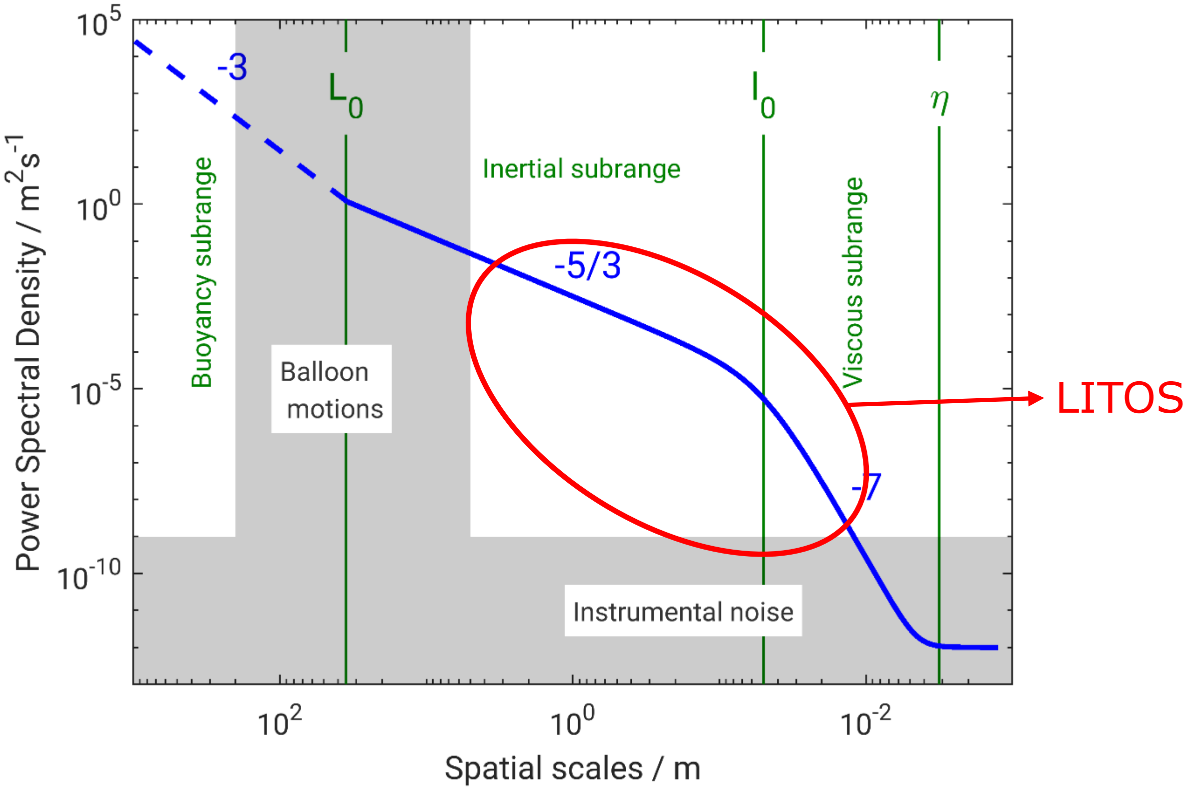
24 h accumulated PV by turbulent processes from an ECMWF-IFS study by Spreitzer et al. (2019). Inconsistent grid points marked in yellow.

Recently, Spreitzer et al. (2019) published a study on non conservative processes around the tropopause.

- Their ECMWF-IFS analyses showed a strong contribution of turbulence in the generation of tropopause folds, as predicted by Shapiro (1976).
- They reveal a tripole shaped PV tendency in the shear layer above the tropopause jet due to turbulence (left).
- However, turbulence measurements in this region are extremely sparse.

➢ Let’s investigate turbulence in tropopause folds!

How to measure turbulence?



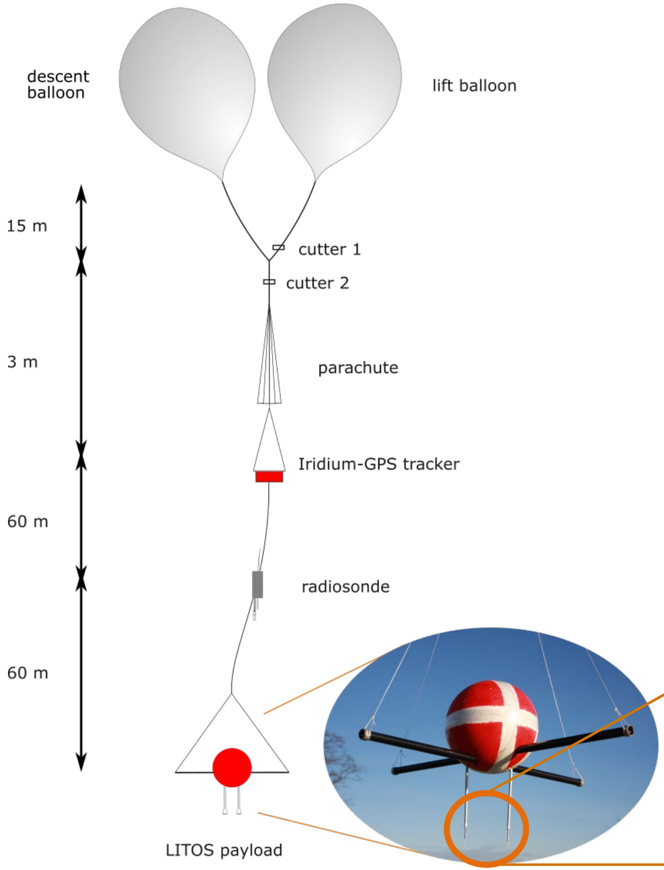
LITOS (Leibniz-Institute Turbulence Observations in the Stratosphere):

- Fit Heisenberg spectrum for turbulent velocity fluctuations
- Retrieve dissipation rate from Taylor microscale l_0:

$$\varepsilon = c_1 \frac{\nu^3}{l_0^4}$$

- How to measure velocity fluctuations down to centimetre scales?

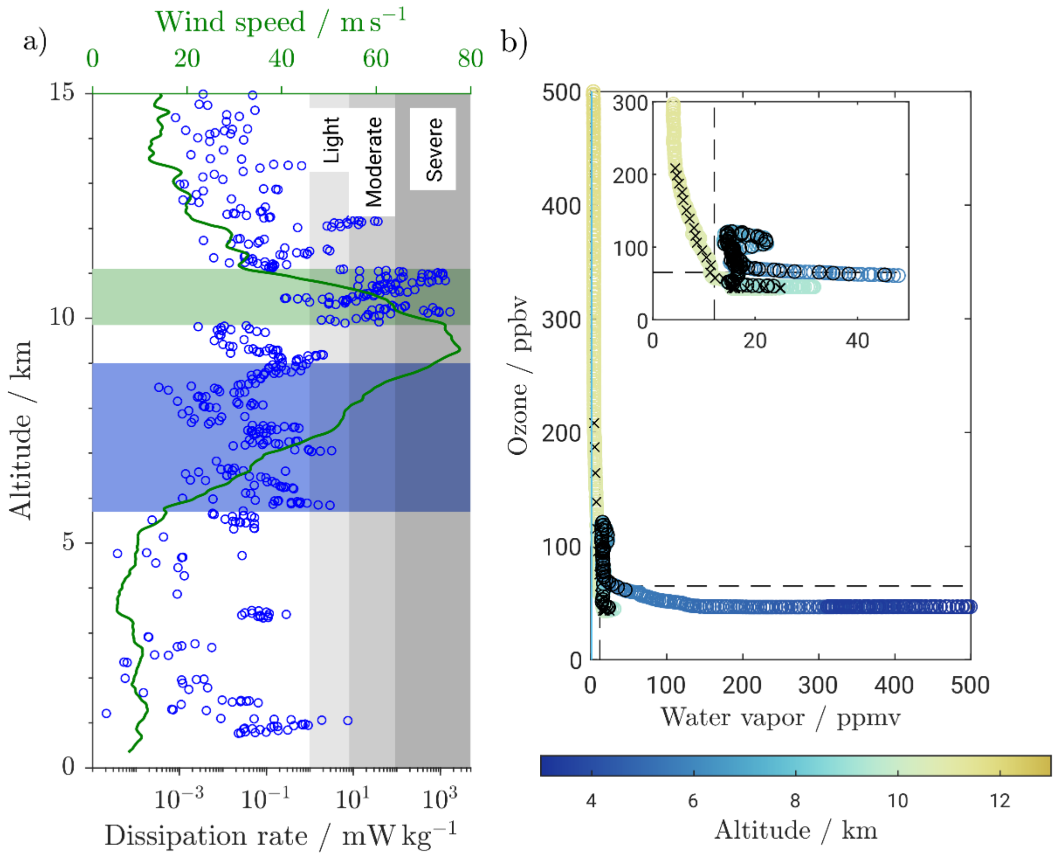
Why constant temperature anemometry?



- Measure on descent to avoid balloon’s wake (Söder et al., 2019)
- CTAs measure by means of convective cooling
- Provide unprecedented spatial resolution (< 1 mm)
- Require extremely thin sensor to counteract thermal inertia

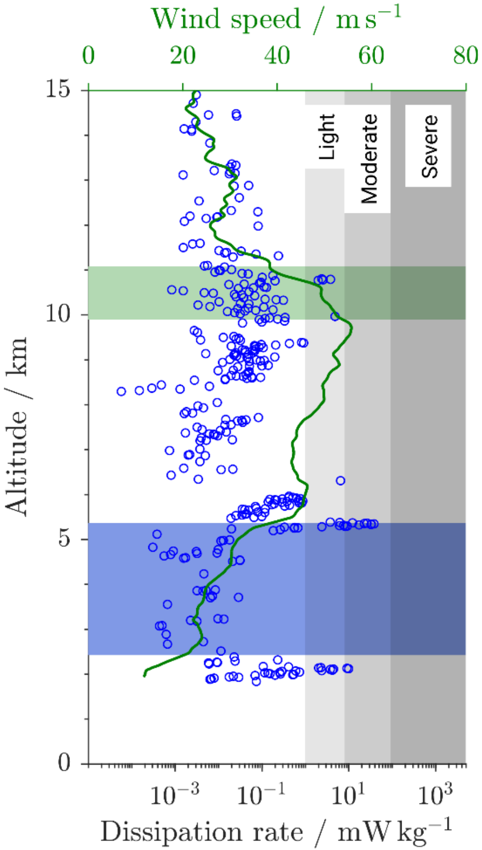
$d_{\mathrm{wire}} = 5\ \mu\mathrm{m}$

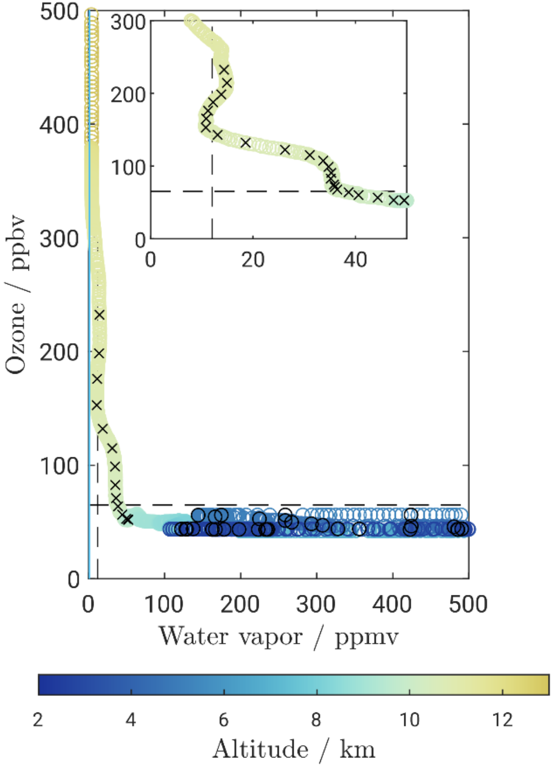
19 Jan 2020 Case



- Severe turbulence up to 1000 mW/kg in lower stratospheric shear layer (green shading).
- Findings similar to Shapiro (1976), despite different altitude distribution
- Ozone data from IFS and water vapour from radiosonde show hardly any mixing *yet* contrary to other studies (e.g. Woiwode et al., 2018).
- Despite other examples (e.g. Koch et al., 2005) no gravity waves are present

28 Jan 2021 Case

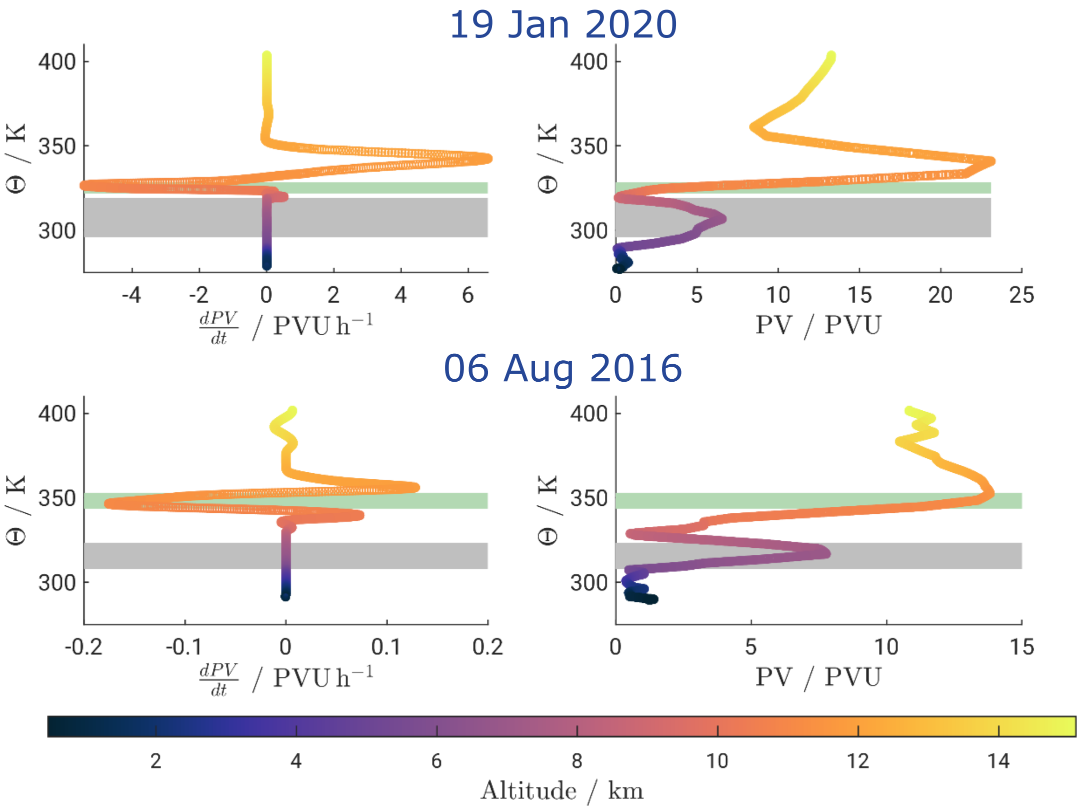




- Moderate turbulence detected around stratospheric intrusion (blue)
- Only light dissipation rates in the upper shear layer (green)
- As for the previous case, ozone data from IFS and water vapour from radiosonde show hardly any mixing, confined to upper shear layer

➢ Add ozone sonde to LITOS payload for better trace gas measurements.

Turbulence induced PV changes

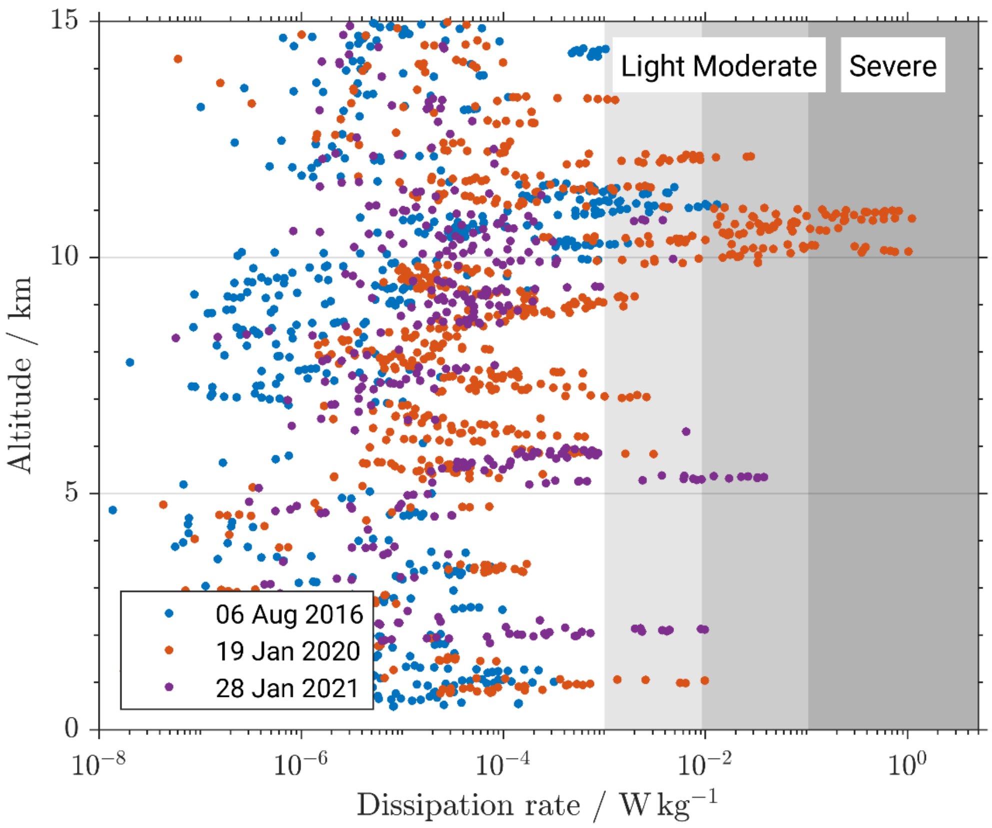


Taken from Söder et al. (2021), Fig. 7

- Turbulence induced PV tendencies depicted on the left show tripole (06 Aug 2016) and degenerate tripole structure (19 Jan 2020).
- These structures are in accordance with Spreitzer et al. (2019), but differ from Shapiro (1976).

➢ PV structures in the IFS shown on the right exhibit similar patterns. This hints the importance of turbulence in tropopause fold generation. Differences remain though.

Comparing all soundings

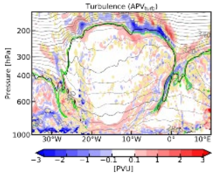


- Two soundings show dissipation rates in the upper shear layer exceeding those in the lower shear layer by three orders of magnitude, one shows turbulence around the intrusion

- ➢ Differs from previous measurements (e.g. Kennedy & Shapiro, 1980)

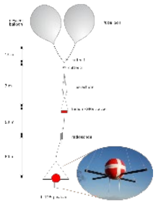
- ➢ Find reasons by performing further measurement campaigns in combination with analytical modelling.

Key points



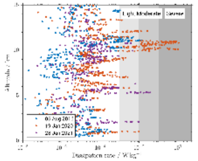
- Results from analytical and numerical modelling show turbulence induced mixing and non-conservative PV modification in shear zones above and below the tropopause jet.

Why?



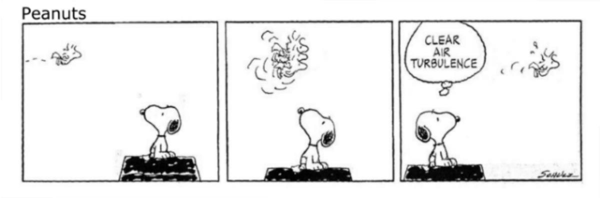
- Use balloon-borne LITOS turbulence measuring instrument to investigate both shear layers within a single sounding.

How?



- Generally, turbulence found in both shear layers. However, in two out of three soundings, dissipation rates in the upper shear layer three orders of magnitude larger than in the lower one.

Results



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