Exercise week 10 - Course atmospheric processes

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In this exercise, we will analyse a weather event over Switzerland on 05-06 January 2025. We will study this event going from the large to the local scale, linking what you learnt in large-scale dynamics with mountain meteorology.

1 Synoptic situation

Figure 1 shows the synoptic situation over Europe on 06 January 2025 at 00 UTC.

1. What is the main flow direction over the Alps at 500 hPa?
2. Localise the axis of the main trough over Europe and the corresponding low pressure system.
3. Where is the low-pressure system located with respect to the trough? How could this explain this very deep low pressure system?

2 Stability

We consider the radiosounding profile from Milano on 6 Oct at 00:00 UTC (below) as representative of the atmospheric conditions on the southern side of the Alps during the event.

The overall objective of this question is to evaluate the stability of the flow (in the lowest layer) impinging the Alps.

1. We will consider the layer between 1000 and 650 hPa. Estimate the altitude range between the two pressure levels (1000 and 650 hPa) using the hypsometric equation and assuming the virtual temperature is similar to the temperature.
2. Approximating the potential temperature gradient as the difference between the potential temperatures at 1000 and 650 hPa (using 1000 hPa as reference), estimate the Brunt-Vaisala frequency of this layer.
3. From the radiosounding data and considering that the Alps are about 3500 m high in this region, estimate the Froude number and the dimensionless mountain height of this layer.
4. From these values, what can you conclude about the flow in this layer when approaching the Alps?

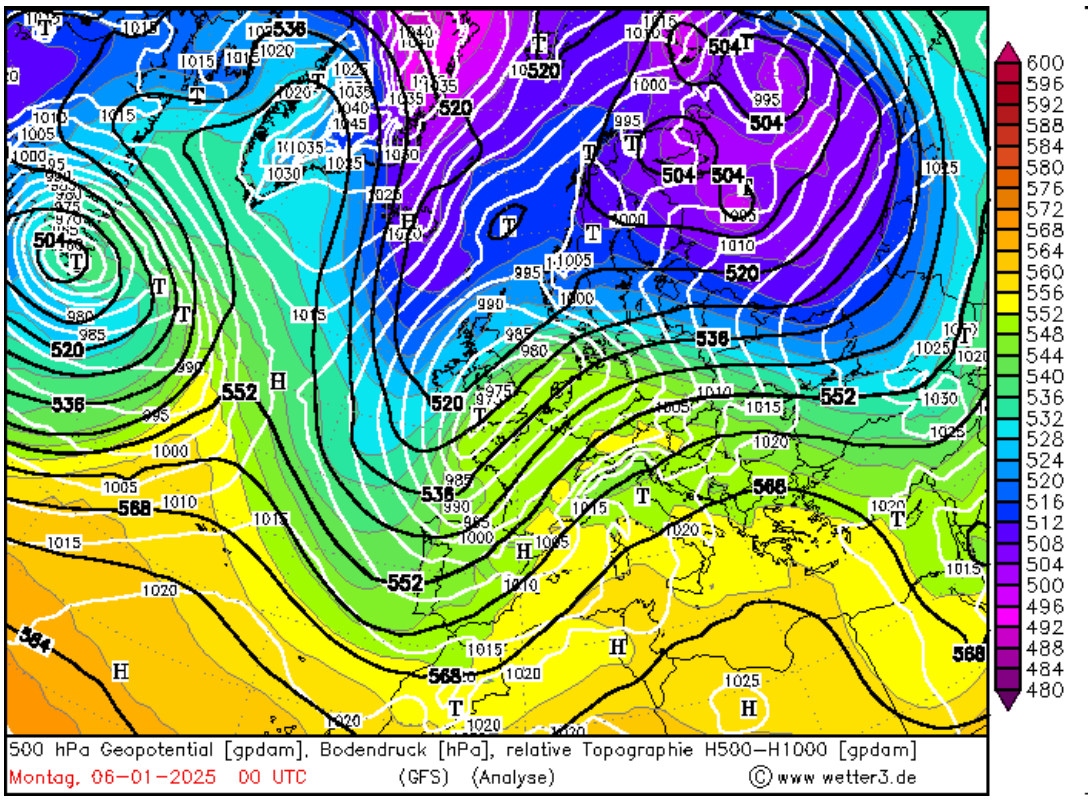

Figure 1: Synotic situation on 06 January 2025 at 00 UTC. White contours show mean sea level pressure in hPa, black contour geopotential height at 500 hPa in decametre, and colours the thickness between 500 and 1000 hPa in decametre. "T" represents centres of low pressures and "H" of high pressure.

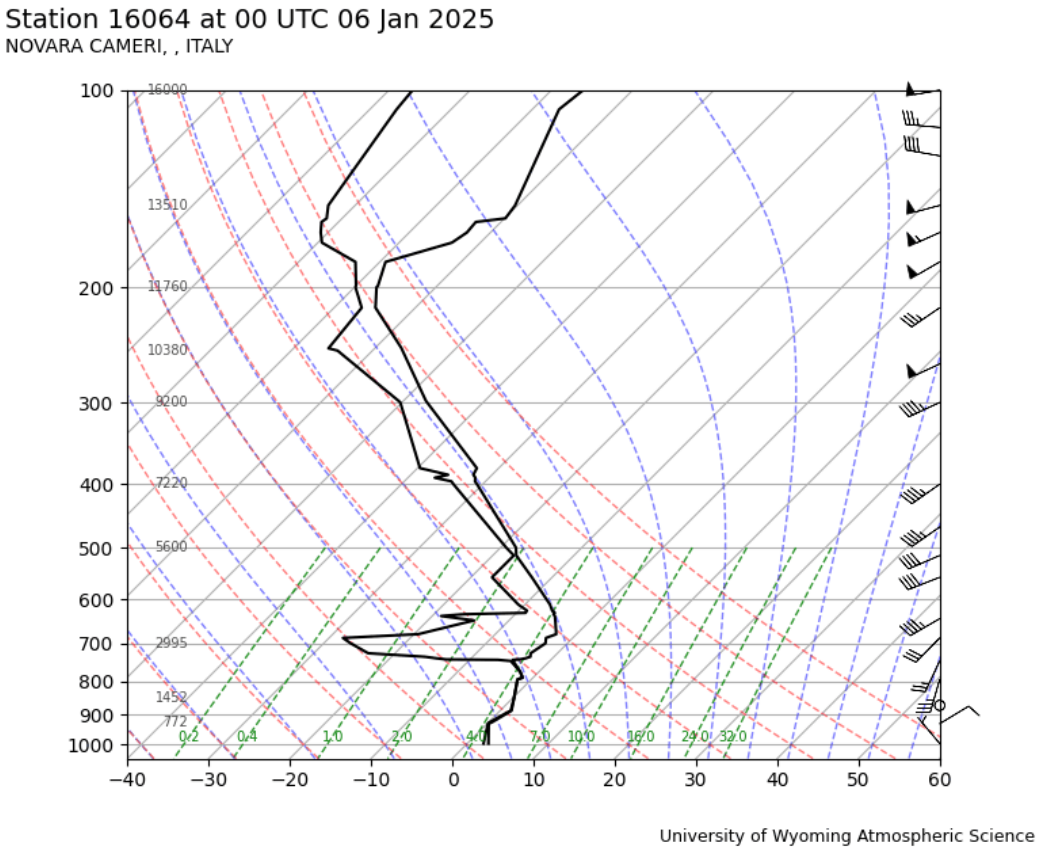

Figure 2: Radiosounding near Milano on 6 January 2025 at 00:00 UTC.

3 Surface wind

For this exercise, we will use automatic weather station measurements from MeteoSwiss at two locations: Altdorf (440 m a.s.l.) and Gütsch, near Andermatt (2288 m a.s.l.) both located in canton Uri. The locations of these stations are shown in Figure 5 and Figure 8. From Figure 3 and 4, analyse the evolution of the following variables:

1. Wind gust and wind direction. Identify in particular when there is a rapid increase of wind gust and change in wind direction.
2. Relative humidity, in particular when there is a rapid decrease and increase.
3. Potential temperature, in particular the difference between Altdorf and Gütsch.
4. What type of downslope wind does the period between 05 Jan at 20 UTC and 06 Oct at 18 UTC correspond to? What is the main direction of that wind? Explain your answer based on the evolution of the variables you just analysed.
5. Figure 4 shows the evolution of pressure at mean sea level for Altdorf and Lugano (located in the southernmost part of Switzerland). Analyse how the pressure difference between Altdorf and Lugano correlates with the wind gust of Figure 3. How could this pressure difference explain the strong wind gusts?
6. Try to locate the large pressure gradient between Altdorf and Lugano from Figure 1.

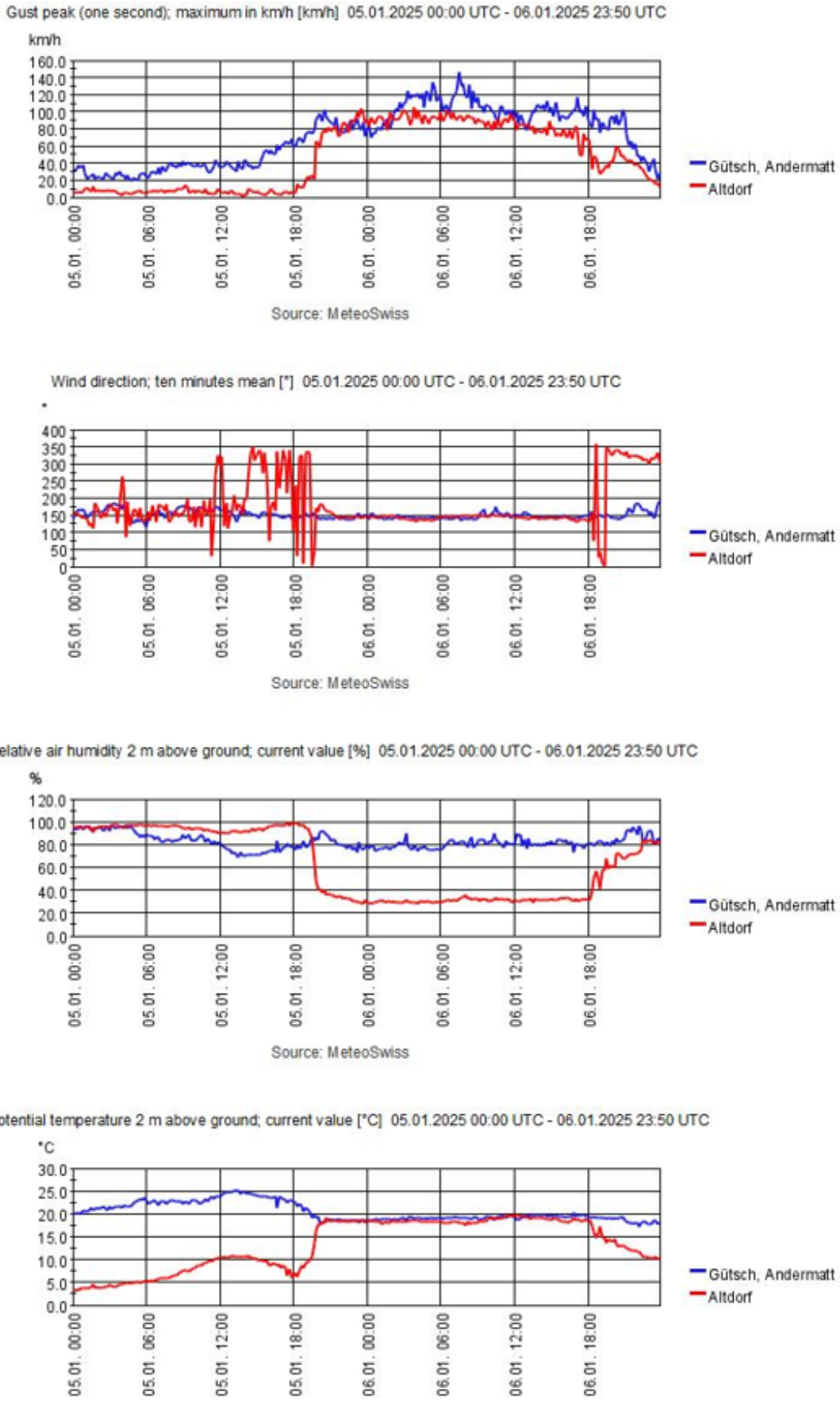

Figure 3: Time series of measured meteorological variables at ground level at Altdorf and Gütsch

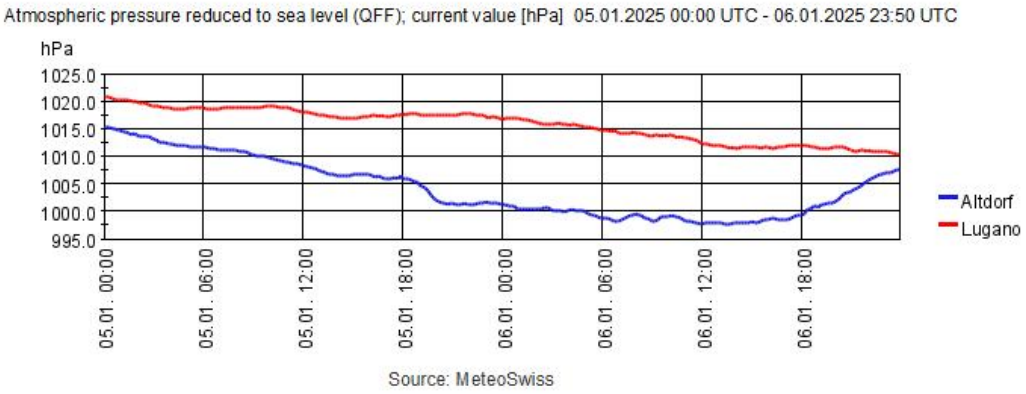

Figure 4: Time series of pressure reduced to mean sea level for Lugano and Altdorf

4 Surface wind from model

In this section, we focus on the atmospheric conditions simulated by the ICON model, which is operationally used by MeteoSwiss for weather forecast. We more precisely analyze the analysis runs (at 1 km resolution), i.e. the simulations after data assimilation.

The map in Figure 5 presents the topography and the location of the transect along which the vertical cross-sections have been extracted.

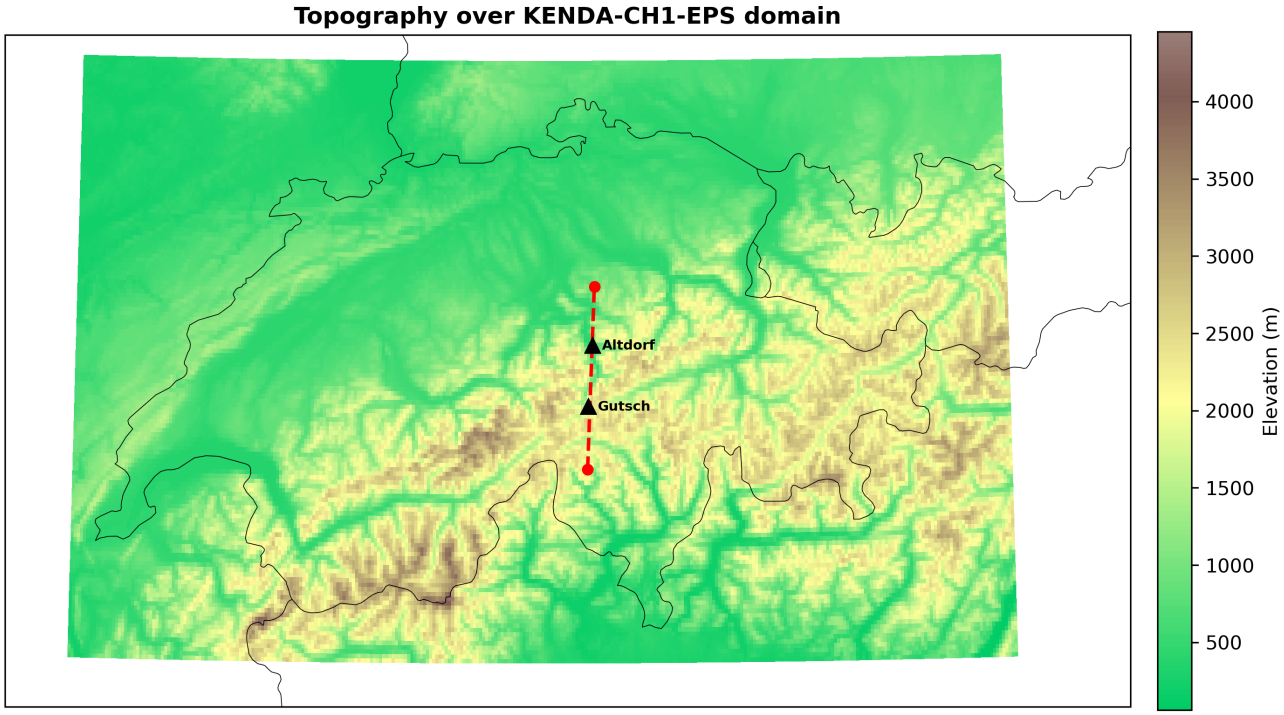

Figure 5: Topography in the ICON model at 1 km grid-spacing and location of the transect including Altdorf and Gütsch.

The simulated data will be analysed through vertical cross-sections in the 3D model domain over Switzerland, on the 6th of January 2025 at midnight. Figure 6 shows the vertical cross-section of relative humidity along the transect. Figure 7 shows the vertical cross-section of horizontal wind speed along the transect.

Questions:

1. What are the main features you see in the vertical cross-section showing the relative humidity along the transect (see Fig.6)?
2. What are the main features you see in the vertical cross-section showing the horizontal wind speed along the transect (see Fig.7)?

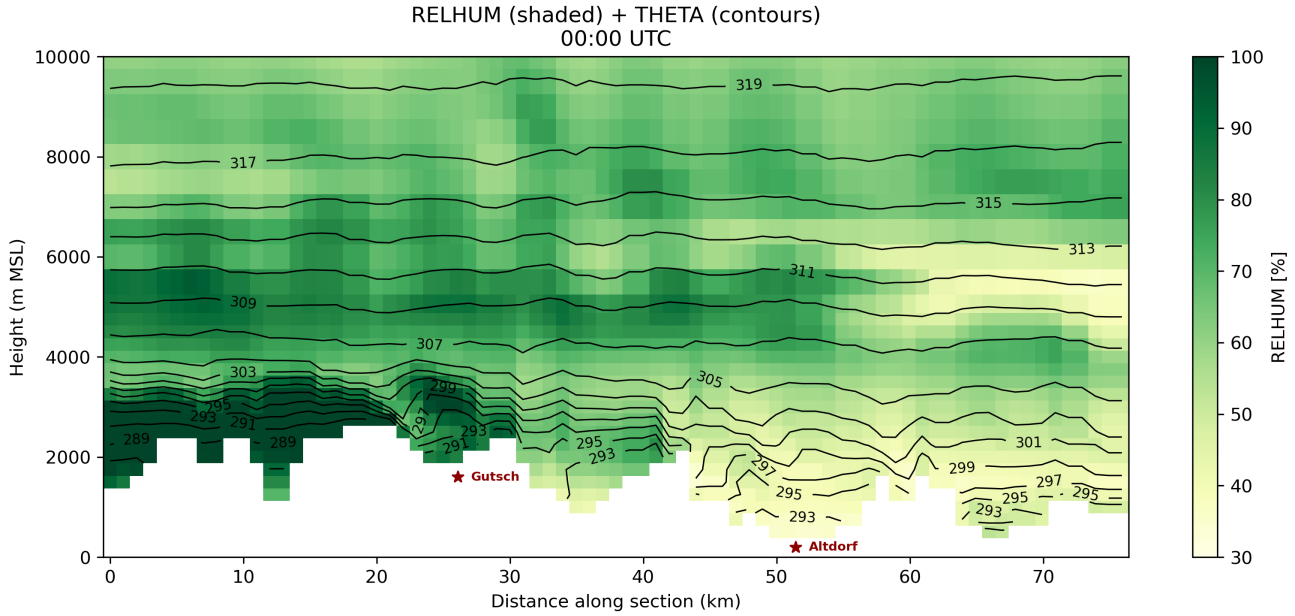

Figure 6: Vertical cross section of relative humidity over the transect.

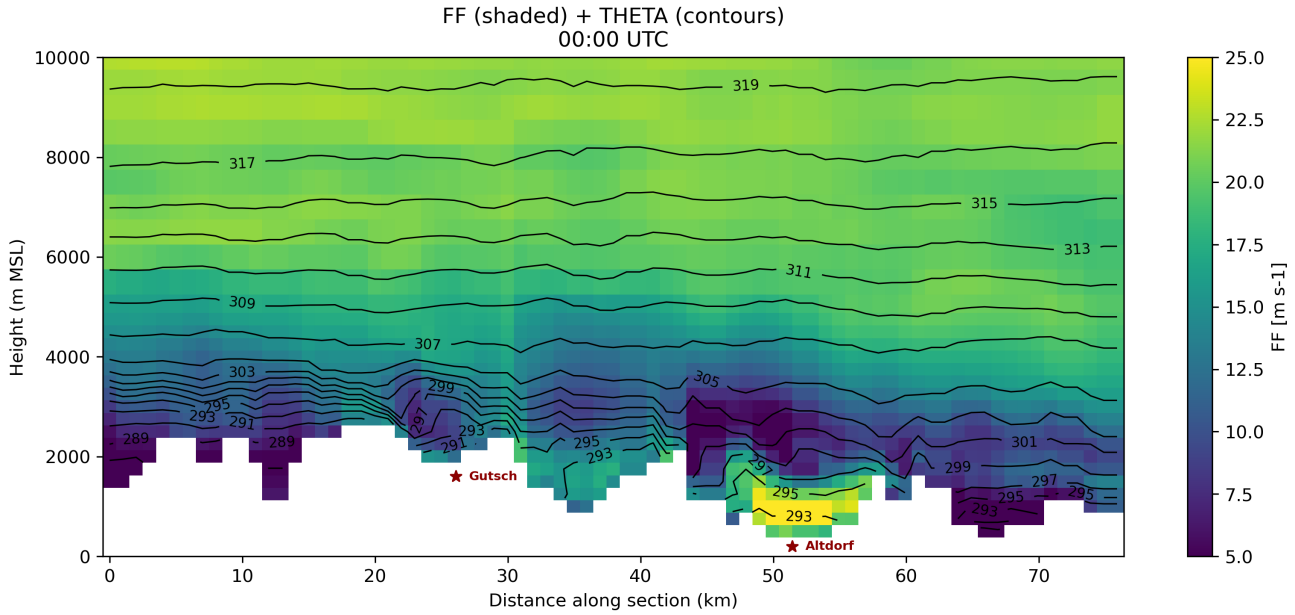

Figure 7: Vertical cross section of horizontal wind speed over the transect.

5 Mid-upper level stability

In this section, we will also use simulated fields from ICON, focusing this time on the stability at mid and upper level of the atmosphere. Figure 8 shows the horizontal cross section of vertical wind velocity at 5000 m of altitude, while Figure 9 shows the vertical cross-section of vertical wind velocity along the transect.

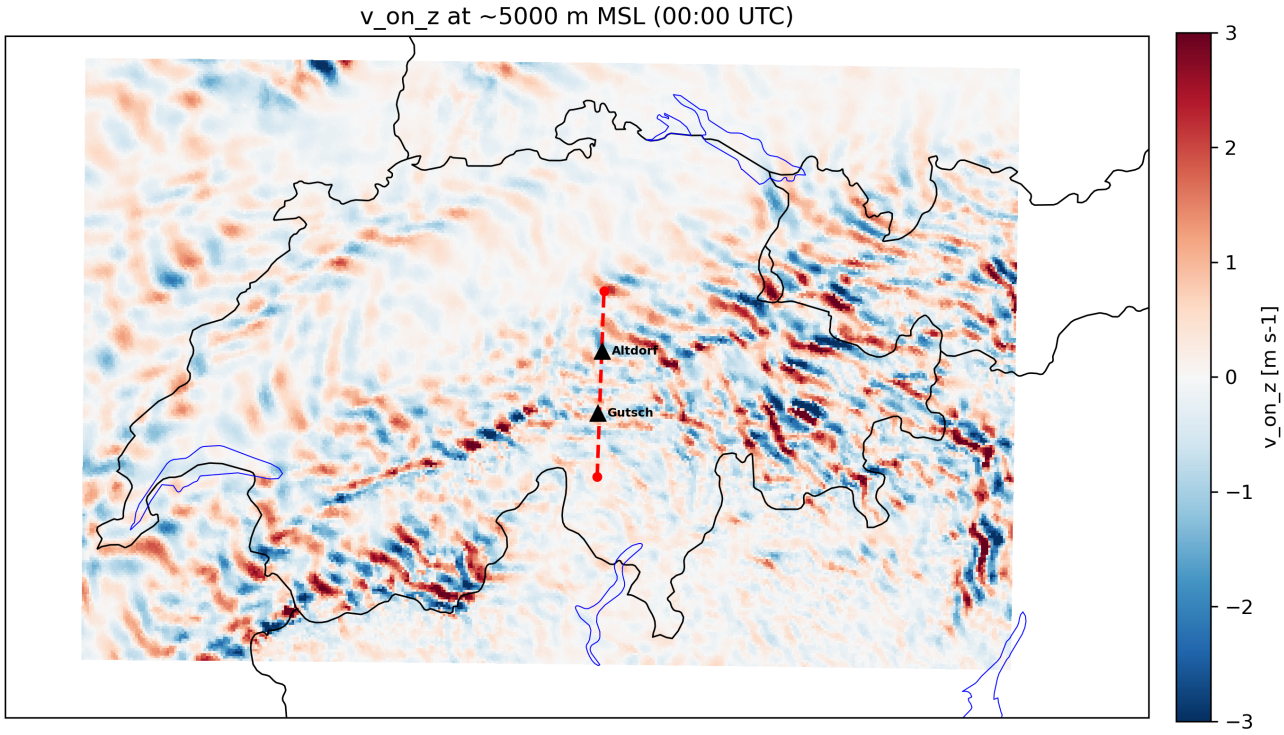

Figure 8: Horizontal cross section of vertical wind speed at 5000 m of altitude.

Questions:

1. From Figure 8, what phenomenon is happening over the second half of the transect?
2. From Figure 9, what is the vertical extent of this phenomenon?

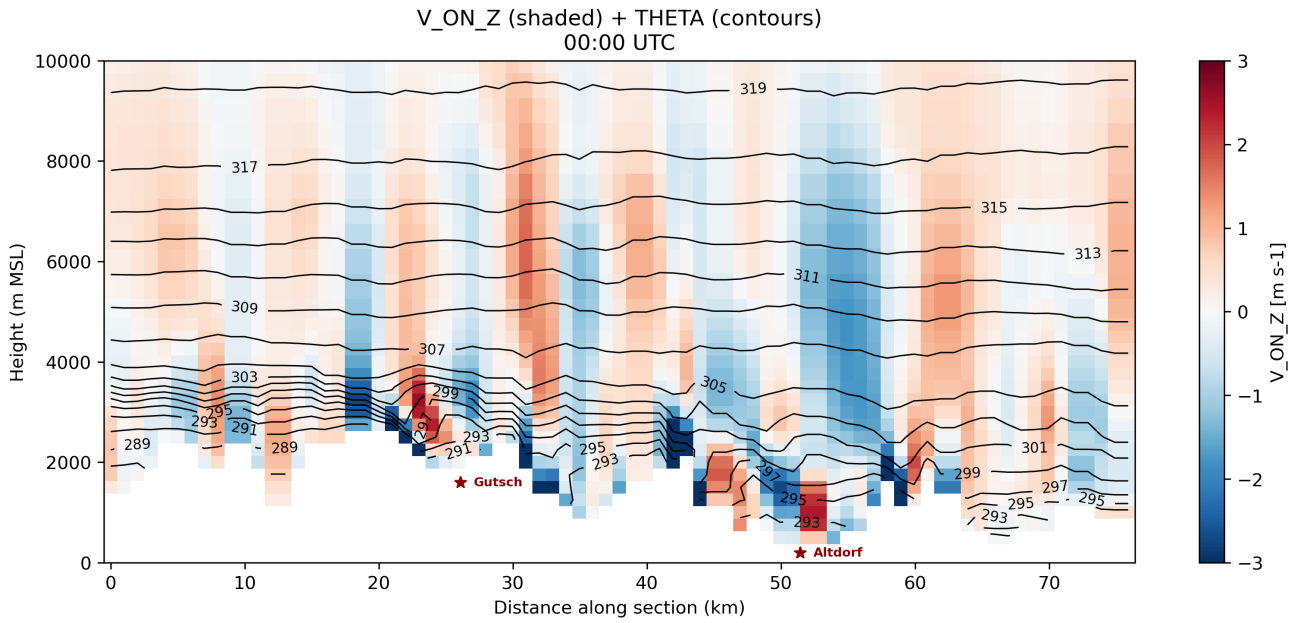

Figure 9: Vertical cross section of vertical wind speed over the transect.