Exercise - Atmospheric processes - Dynamics

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Exercise 1: Flight levels

Flight levels are assigned to aircrafts to allow for enough vertical distance between them. Aircraft altimeters actually measure the air pressure. To convert this pressure to an altitude they need (i) a reference pressure at sea level and (ii) a reference (virtual) temperature profile. For this and other reasons, the International Standard Atmosphere (ISA) was established. The ISA defines how pressure, temperature, density and viscosity varies with altitude. By using the ISA reference sea level pressure and temperature (1013.25 hPa and 15 °C, resp.), and a lapse rate of $-6.5\,°\mathrm{C\,km^{-1}}$, it is possible to determine the altitude of an aircraft above the 1013.25 hPa surface from its pressure measurement. Therefore, aircrafts fly along surfaces of constant pressure (i.e. isobars) and not constant altitude above sea level. This concept is illustrated in Fig 1. If an aircraft flies from a high pressure to a low pressure (from left to right on Fig. 1) its real altitude will decrease, despite the altimeter showing the same value.

With this freshly acquired knowledge and that of yesterday's lecture, you have just been hired by MeteoSwiss (congratulations!) as an aviation meteorologist. A typical flight level to cross the Alps is FL180. For a standard atmosphere (ISA), this corresponds to a pressure of 506 hPa or 18000 feet (5486.4 m) above the 1013.25 hPa surface. One of your duty is to provide the air traffic controller "Skyguide" with the real altitude of FL180. On your first day in operations on 15 October 2020, there is a low pressure to the south of the Alps (see Fig. 2). The radiosounding in Payerne gives you a column average virtual temperature of 268.5 K and the mean sea level pressure is 1012.6 hPa.

- What will be the real altitude above sea level at which the airplane will be flying above the Alps?
- Given that the altitude of the Mt-Blanc is 4808 m a.s.l., would you advise Skyguide to assign a higher flight level to aircrafts crossing the Alps in this situation?

Figure 2 shows the geopotential height at 500 hPa, the mean sea level pressure and the thickness of the layer 1000 hPa to 500 hPa on that day. An airplane is flying the route Reykjavik to Beirut on FL180 passing above the Mont Blanc massif.

- Draw the route on Fig. 2.
- Draw a vertical cross-section showing the (approximate) evolution of the real altitude of the airplane, assuming it is flying on FL180. Add an approximate terrain height showing the Alps on your cross-section.

Notes:

- The gas constant for dry air is 287 $J\,kg^{-1}\,K^{-1}$ and the average gravity at sea-level is 9.81 $m\,s^{-2}$.
- MeteoSwiss provides every 12 hours a measurement of the real altitude of the FL180, which allows Skyguide to decide which flight level to attribute to fly across the Alps. When the altitude of FL180 goes below its ISA value (i.e. 18000 feet or 5486.4 m a.s.l.), Skyguide gives higher flight levels to airplanes crossing the Alps.
- The 1950 Air India Flight 245 crash in the massif du Mont Blanc is an example of what could happen if the real altitude of flight levels is not monitored around major mountain ranges.

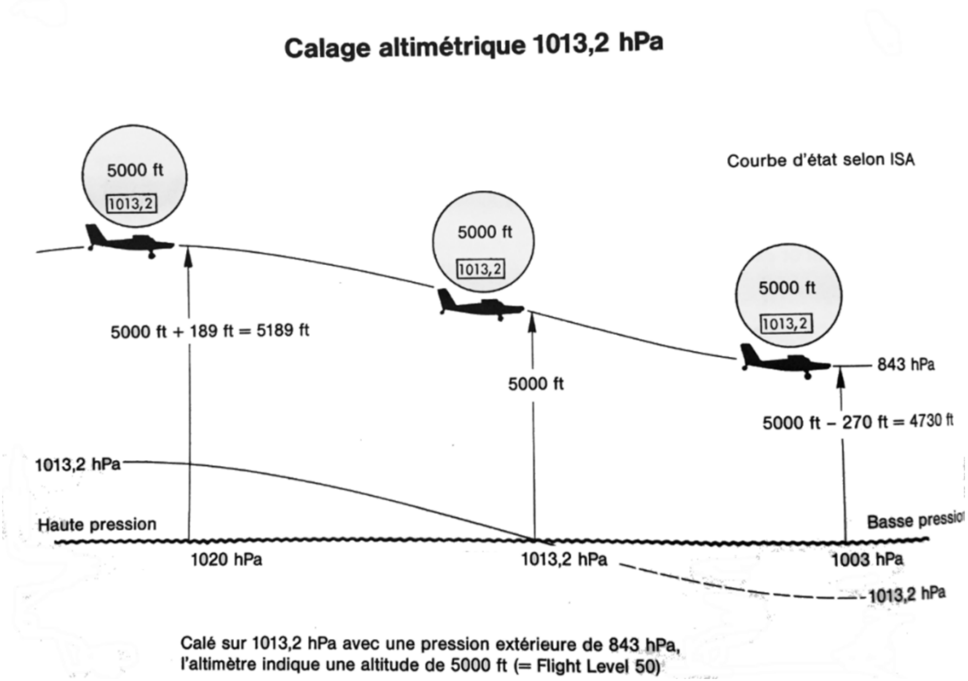

Figure 1: evolution of the cruising altitude of an aircraft flying on FL050 (5000 ft) going from a high pressure (left) to a low pressure (right). Source : K.H. Hack Météorologie pour aviateurs, éditeur Aéroclub de Suisse

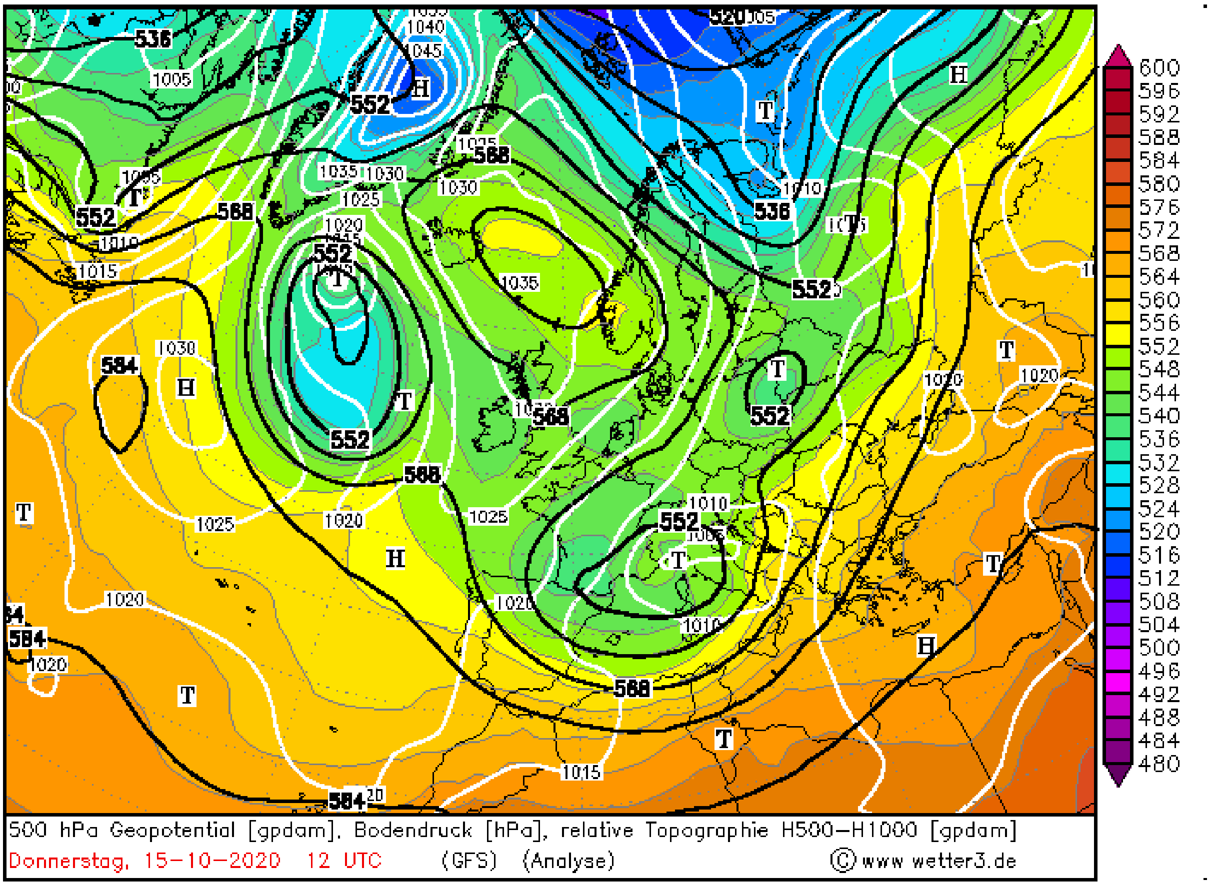

Figure 2: Geopotential height at 500 hPa (black contours, labels in decametre), mean sea level pressure (white contours, labels in hectopascal, "T" represents low pressure centres and ’H" high pressure centres), and 500 hPa to 1000 hPa thickness (colour filled in decametre) on 15 October 2022 at 12 UTC. Remember that the 500 hPa to 1000 hPa thickness is directly proportional to the average virtual temperature between these two levels. Source: GFS analysis.

Exercise 2: geostrophic and thermal wind balance

1. From the geopotential height field of Fig. 3, estimate the geostrophic wind at 500 hPa above Madrid (note that the distance between Madrid and the north of Portugal is about 400 km).
2. From the thickness field of Fig. 3, draw qualitatively the geostrophic wind at 1000 and 500 hPa above Madrid.
3. Is there a significant temperature advection (in the 1000 to 500 hPa column) over Madrid? If not, try to identify a region on the map where you expect warm air advection. Draw again qualitatively the geostrophic wind at 1000 and 500 hPa over that region.

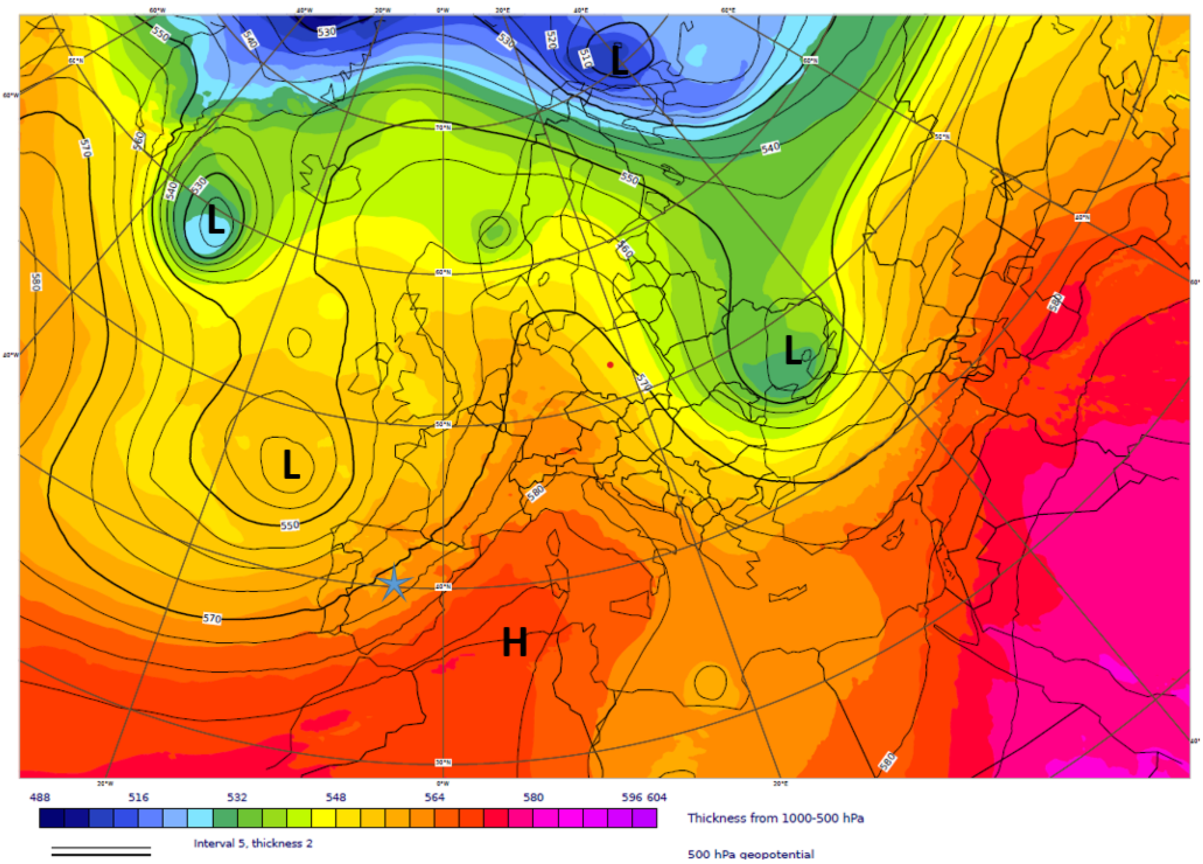

Figure 3: Geopotential height at 500 hPa (black contours, labels in decametre) and thickness between 500 and 1000 hPa (colour filled) on 20 October 2022 at 12 UTC. The approximate location of Madrid is shown with the blue star. The centres of low and high geopotential heights are shown with a "L" and "H", respectively. Source: analysis of the Integrated Forecast System (IFS) model