Exam Atmospheric Physics and Chemistry: Part Physics (1h)

The polar vortex is a feature that develops during the polar nights at both poles and is the simplified description of the fact that the polar air mass becomes partly separated from the rest of the atmosphere. It is a very nice example of the interaction between physical and chemical processes in the atmosphere. The stratospheric ozone depletion in the polar vortex is a result of reduced mixing of the air masses with air from lower latitudes. We have chosen the polar vortex as a theme for the exam and a few problems will be centered around the polar vortex.

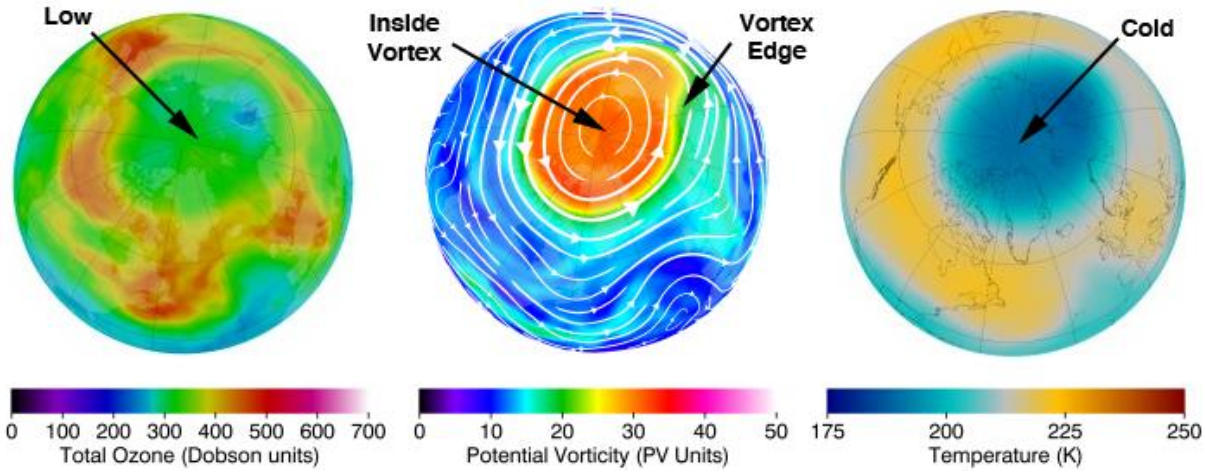
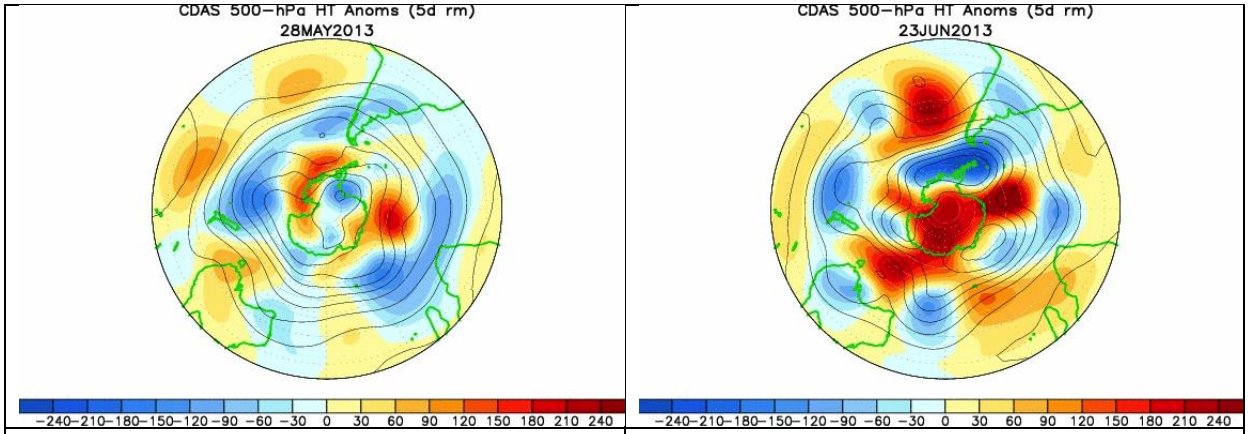


Figure 1: The polar vortex is characterized by low ozone, high potential vorticity and cold temperatures (http://ozonewatch.gsfc.nasa.gov/facts/vortex_NH.html).

Problem 1:
Qualitatively describe how the polar vortex forms using your knowledge about general circulation patterns. Discuss how vertical and horizontal movements interact. In particular describe how pressure differences lead to horizontal winds and why a vortex results. Hint: Figure 1a and 1b give valuable information.

Problem 2:



a) End of May 2013 | b) End of June 2013

Figure 2: Pressure anomalies for the Antarctic polar vortex at high tropospheric altitude (500 hPa). Source: http://www.cpc.ncep.noaa.gov/products/intraseasonal/z500_sh_30d_anim.gif.

In the Southern Hemisphere (Antarctica), the polar vortex gets particularly strong. Right now, two members of our CRYOS lab are close to Antarctica on the German Polarstern research vessel to make "snow on sea ice" measurements. As they approach the southern tip of South America, the question is whether they have experienced stronger or weaker winds over the past weeks.

2a)

Please discuss why the polar vortex is stronger in Antarctica then over the North Pole and (based on Figure 2), what trend in the geostrophic wind speeds occurred over the past weeks close to the Antarctic Peninsula.

2b)

Then, based on Eq. (7.15c) in the textbook, estimate the strength of the geostrophic wind speed in the area, using the information that the distance between the northern tip of the Antarctic Peninsula and Cap Hoorn (Tierra di Fuego) is approximately 2000 km. Assume that the contours in Figure 2 denote geopotential (Eq. 3.20) with a spacing between contours of 5000 $m^2\ s^{-2}$. Assume the coriolis parameter to be 0.00013 s^{-1} and document your estimation of the other parameters.

Problem 3:

3a)

The geostrophic wind is not the wind that is experienced on a research vessel or by a sailor. Assuming a roughness length of 20 cm for a rough sea or sea-ice surface, please calculate the wind at the ship's bridge, if the wind at the upper height of the boundary layer (700 m) is 17 m s^{-1}.

3b)

Given the boundary layer parameterization for the drag coefficient $C = \left[\frac{k}{\ln(z/z_0)}\right]^2$, please calculate by what percentage the surface exchange becomes less efficient if the ship gets into an area of smooth ice, which has only a roughness length of 0.5 cm.

Problem 4:

Finally, the Polarstern gets out of the messy sea ice and heavy winds and approaches the harbor of Punta Arenas. The local winds come from the west (Pacific Ocean) and cross the mountains before they reach the harbor of Punta Arenas. Discuss qualitatively what happens to the air masses as they cross the mountains, in particular with respect to changes in moisture and temperature.