

Temperature and General Circulation of Earth's atmosphere

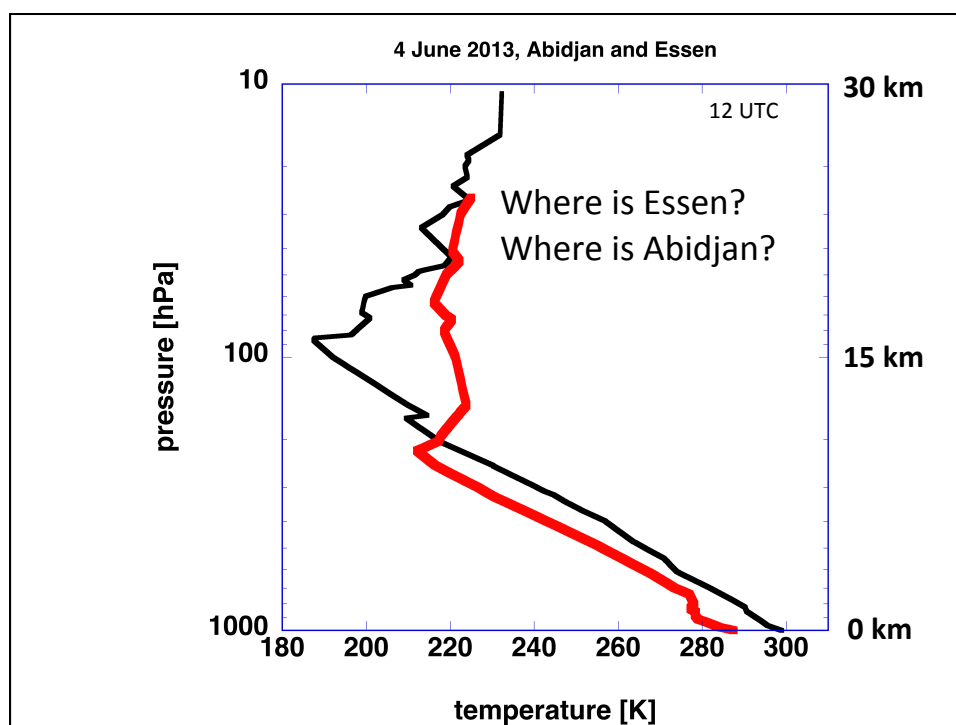
Aarnout van Delden

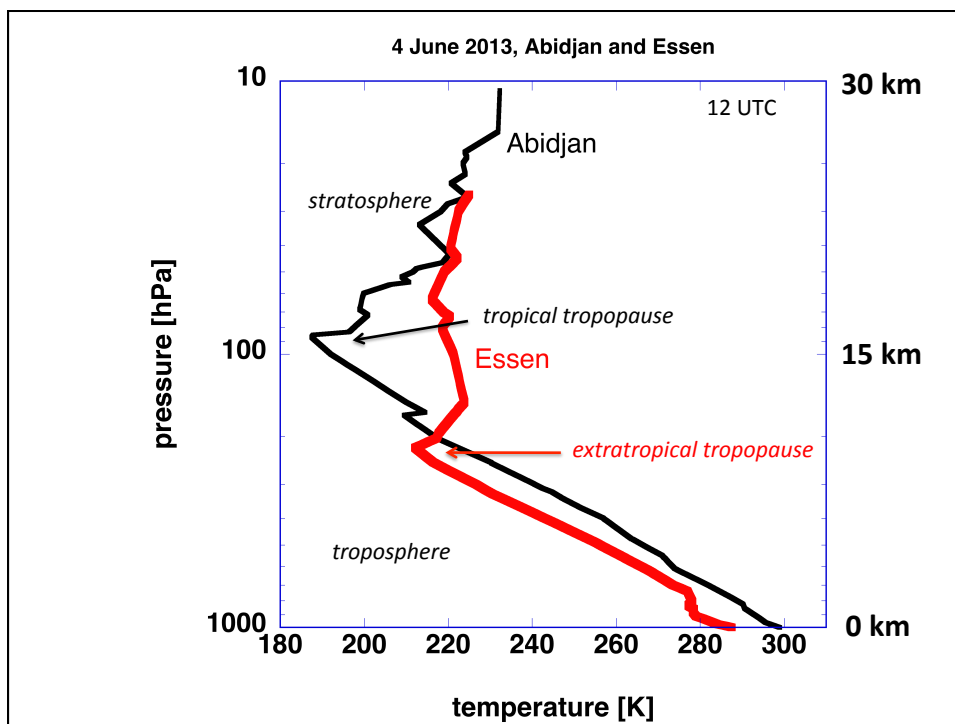
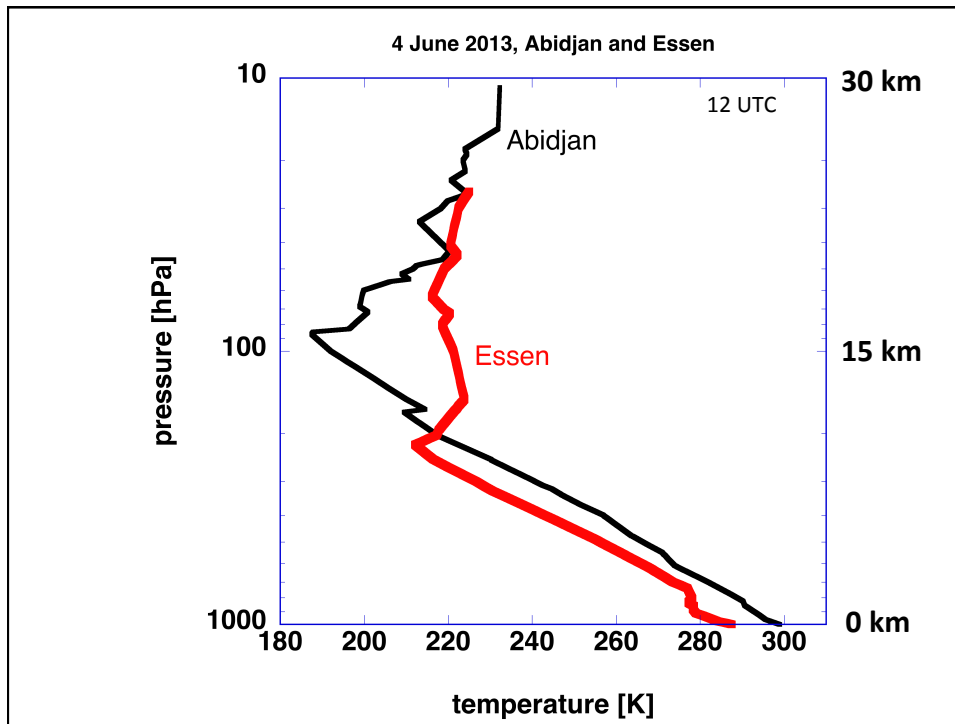
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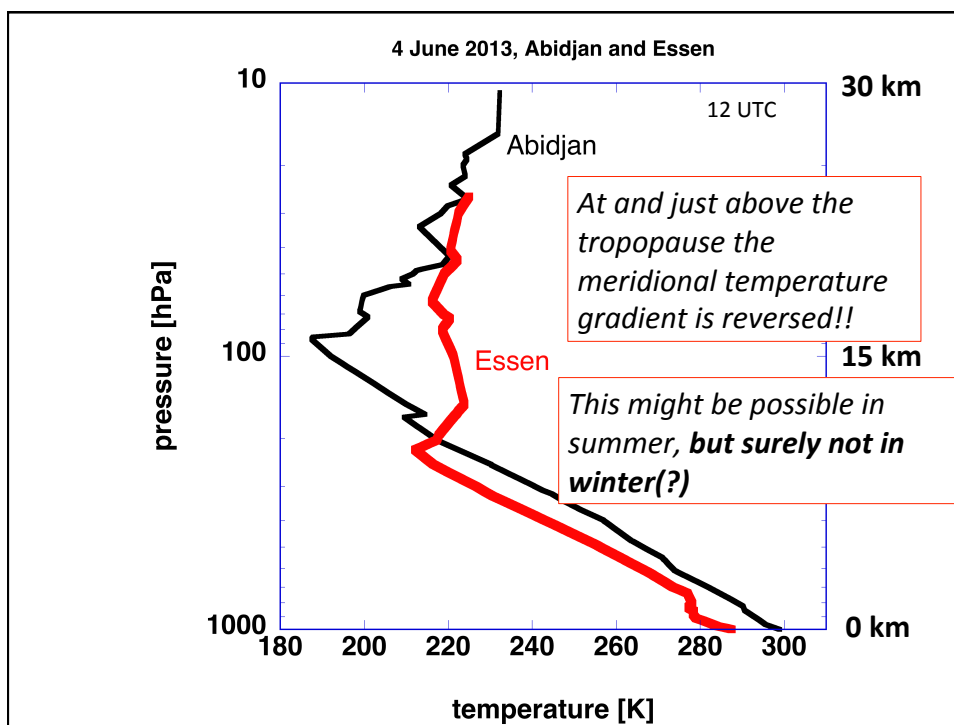
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"Diabatic-dynamical interaction in the general circulation":

how the interaction between heat sources and sinks, due to diabatic effects, and adiabatic transport of heat by the circulation determines the temperature and associated circulation in the atmosphere



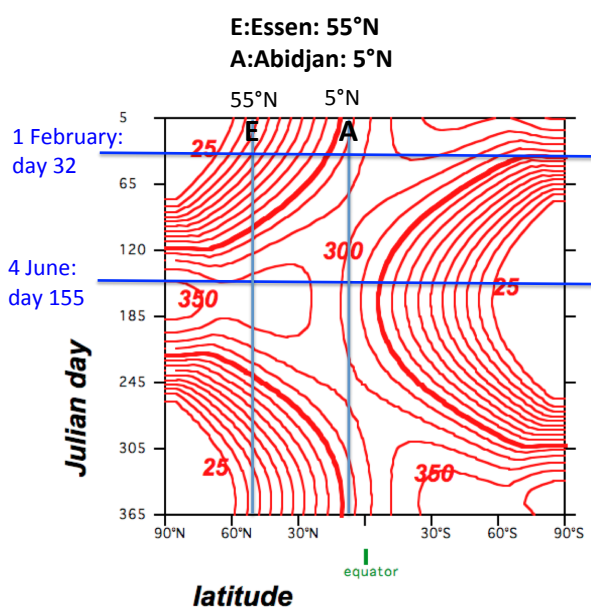


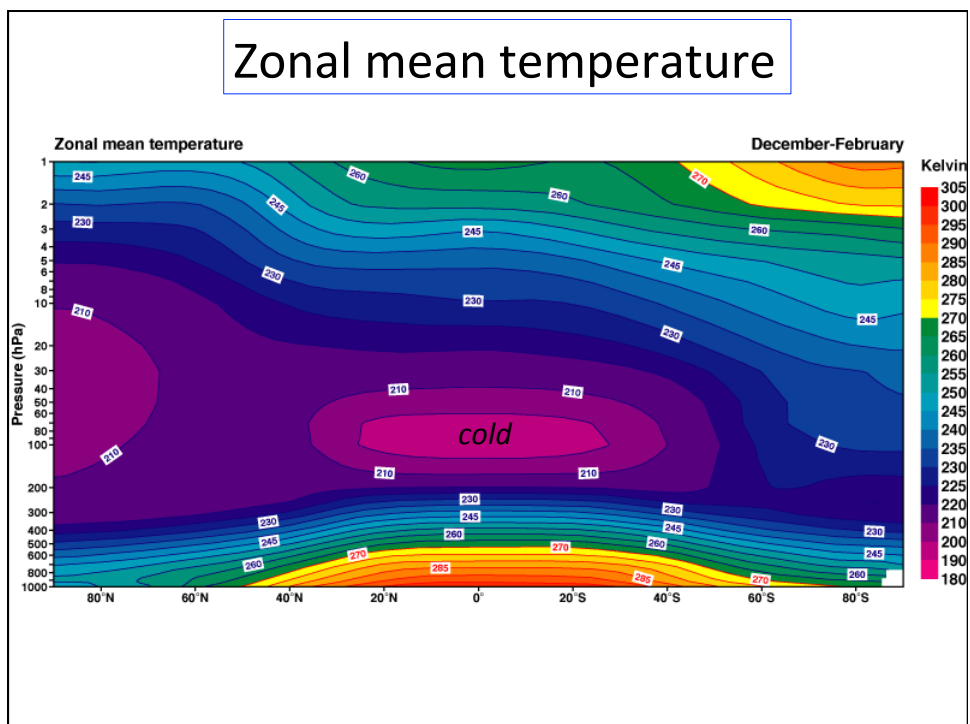
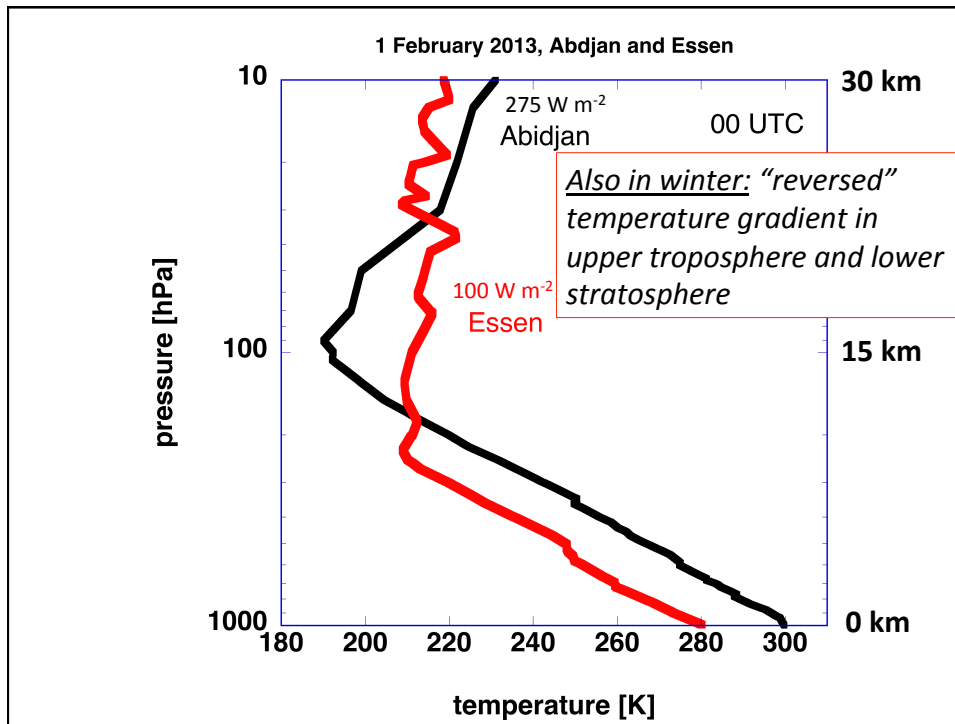


Absorbed Solar radiation, Q

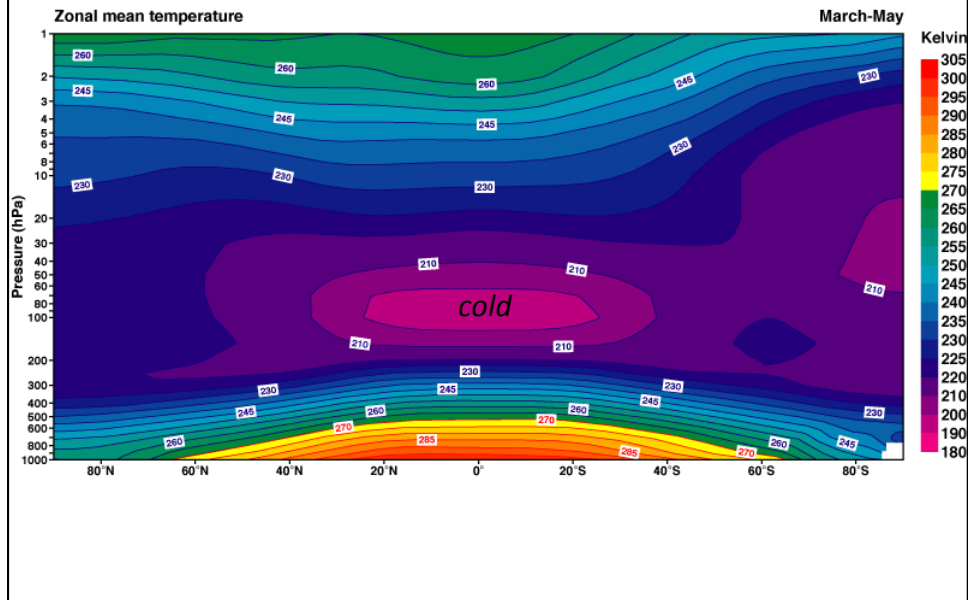
Figure: Absorbed Solar radiation (Q) (indicated in W m^{-2}) as a function of latitude and time for a planet with a uniform **albedo equal to 0.3**. Contour interval is 25 W m^{-2} . Thick contour corresponds to 250 W m^{-2} .

On 4 June Essen receives about as much Solar radiation as Abidjan, but not in winter...

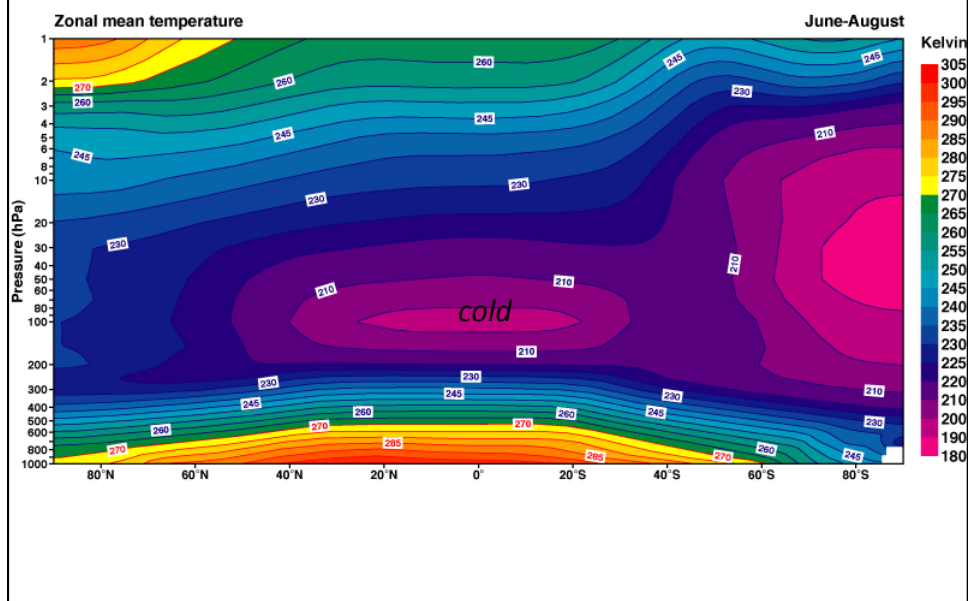




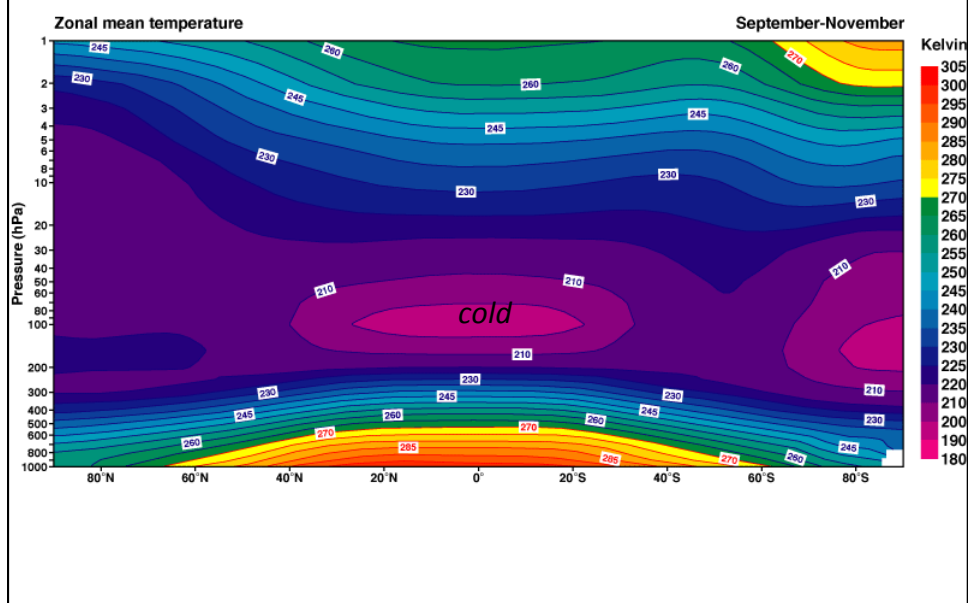
Zonal mean temperature



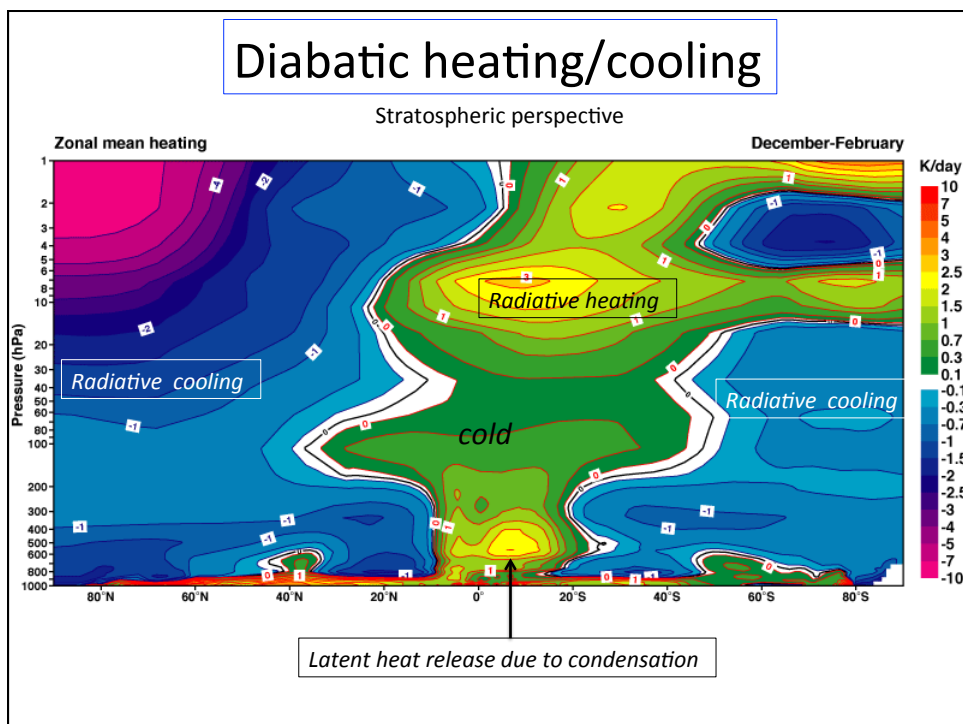
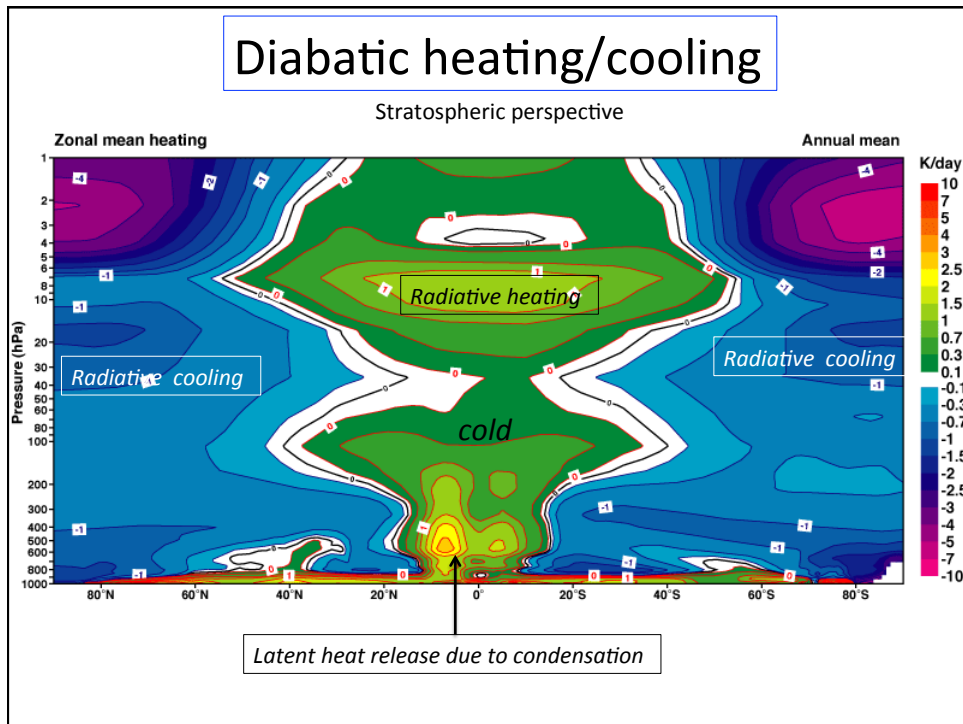
Zonal mean temperature

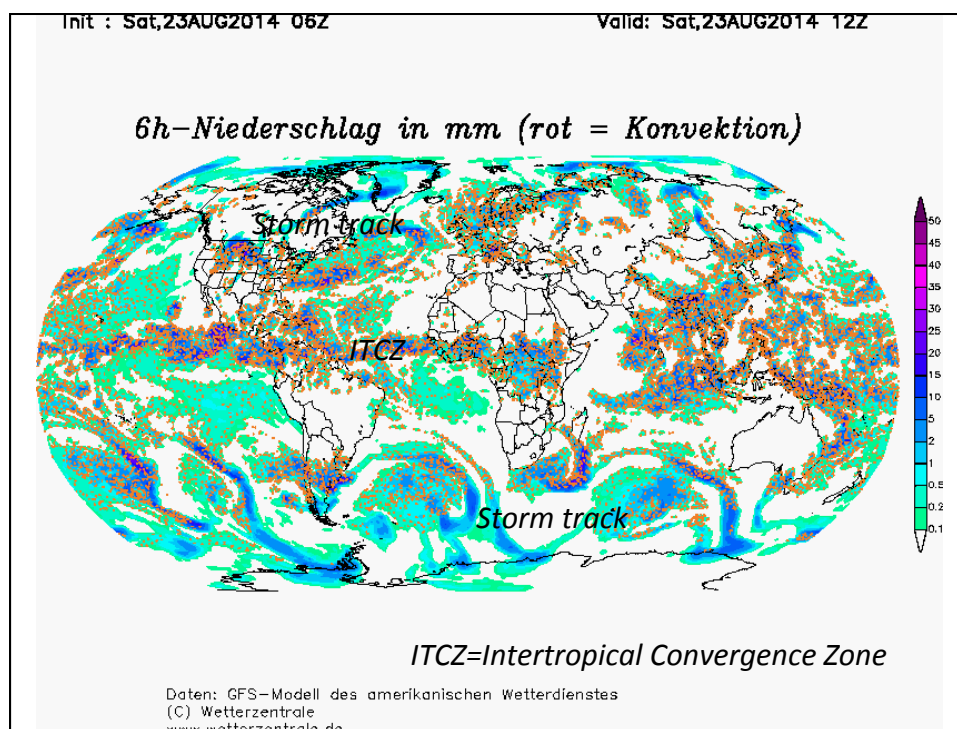
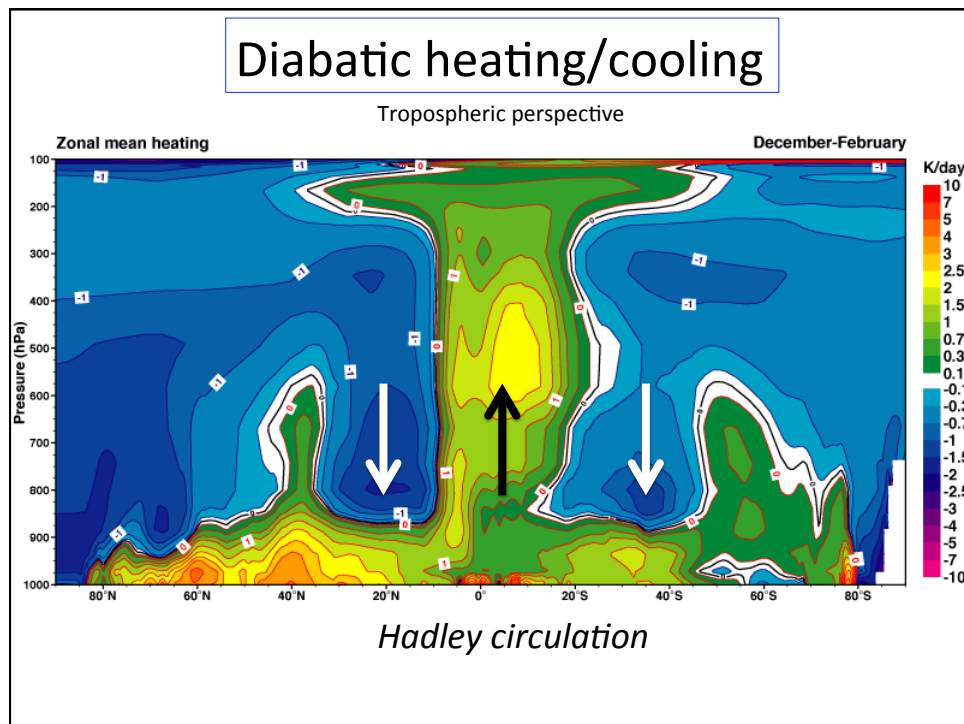


Zonal mean temperature

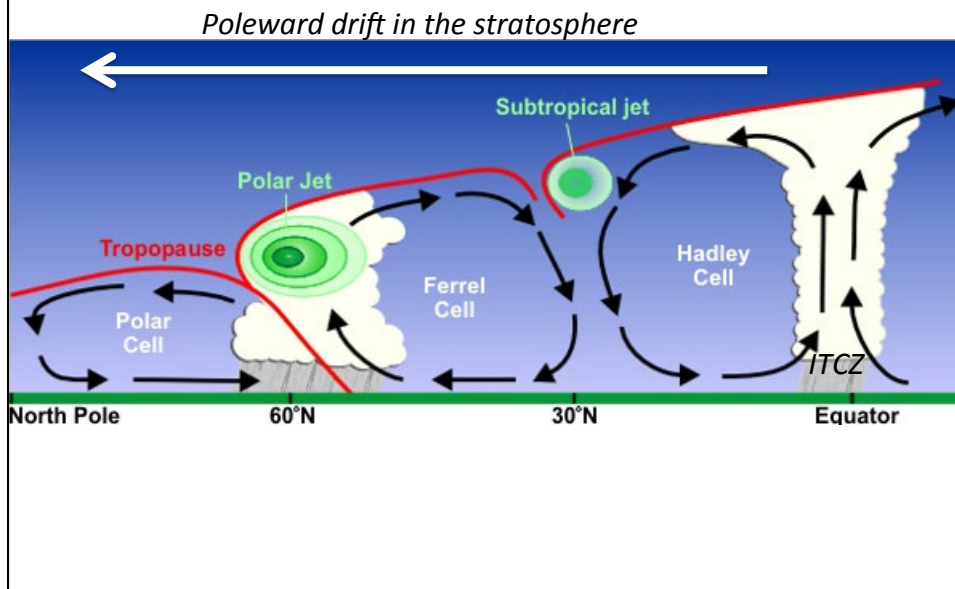


Temperature is determined by radiation, latent heat and heat-transport by circulation

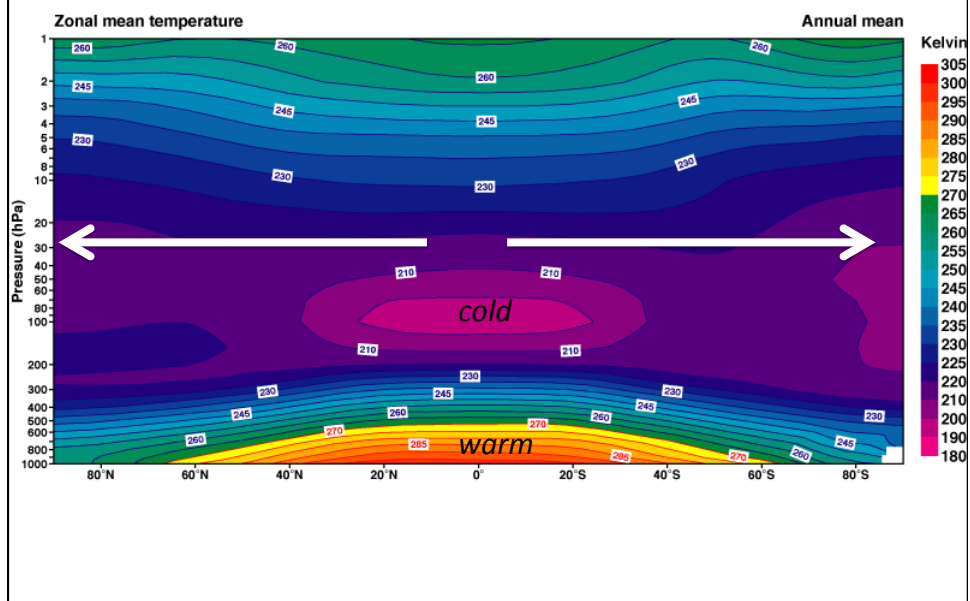


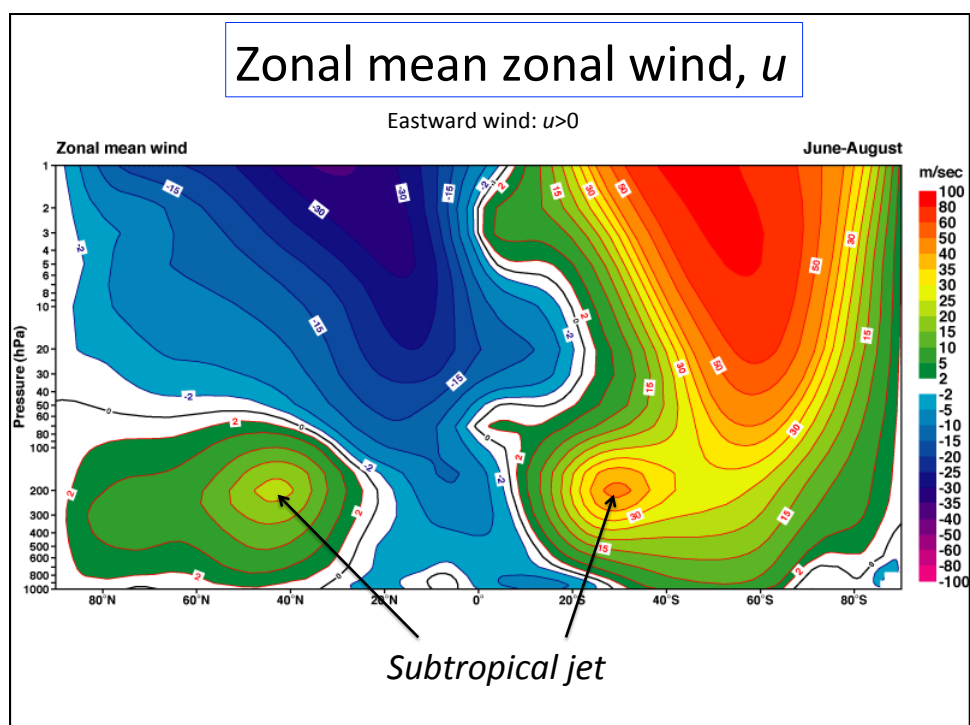
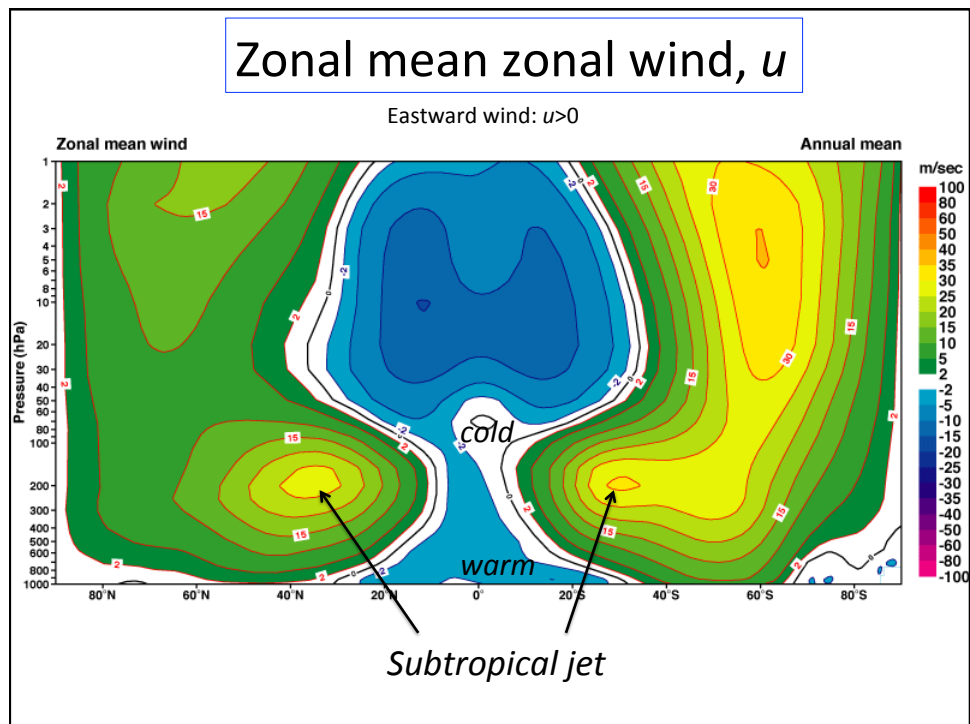


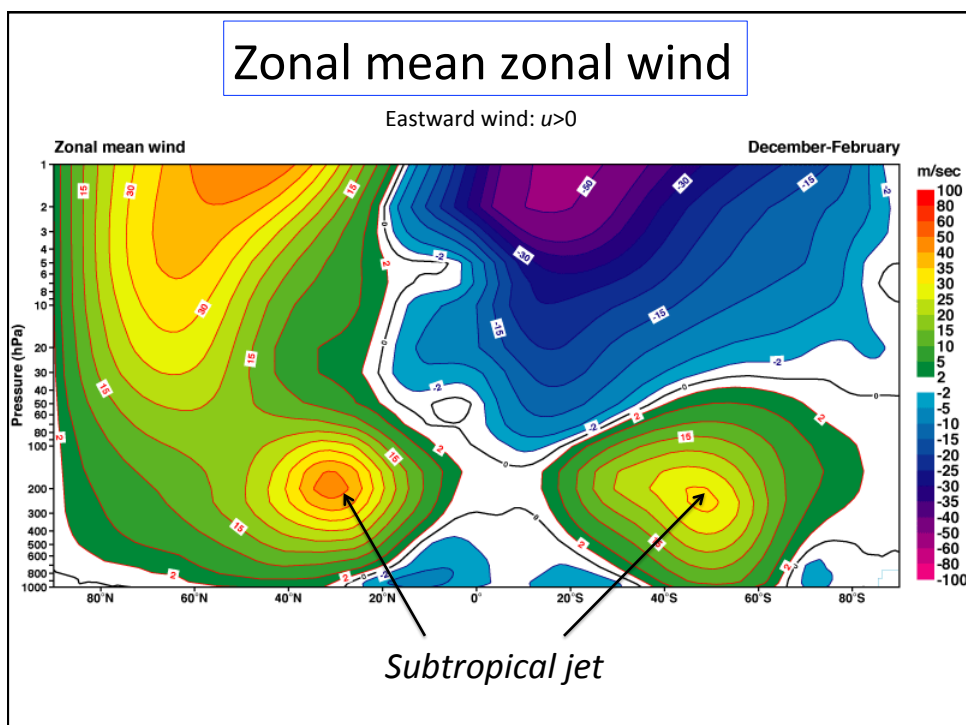
Zonal mean meridional circulation



Zonal mean temperature

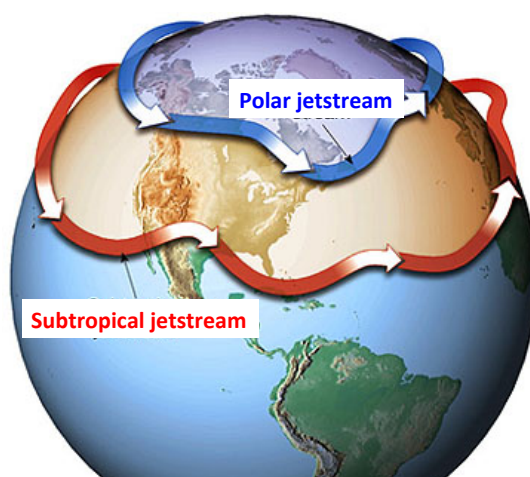






Where is the polar jet in the troposphere?

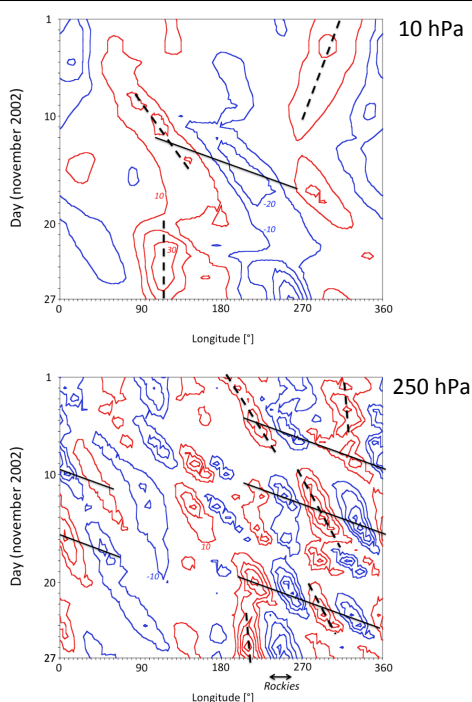
Polar jet is invisible in the long term mean because this jet meanders much more strongly than the **subtropical jet**. These meanders are a manifestation of planetary waves, but polar jet meanders more than the subtropical jet and even vanishes sometimes...



<https://www.youtube.com/watch?v=DHrapzHPCSA>

Planetary waves

Time evolution of the meridional component of the velocity, averaged between 40°N and 60°N, as a function of longitude at 10 hPa (upper panel) and at 250 hPa (lower panel) for the period 1-27 November 2002, based on daily mean NCEP-2 reanalysis. The contour interval is 10 m s^{-1} . Red (blue) contours correspond to poleward (equatorward) motion. Slanted solid straight lines indicate a succession of maximum development of meridional flow, characterizing a group of waves. Dashed lines are lines of constant phase.

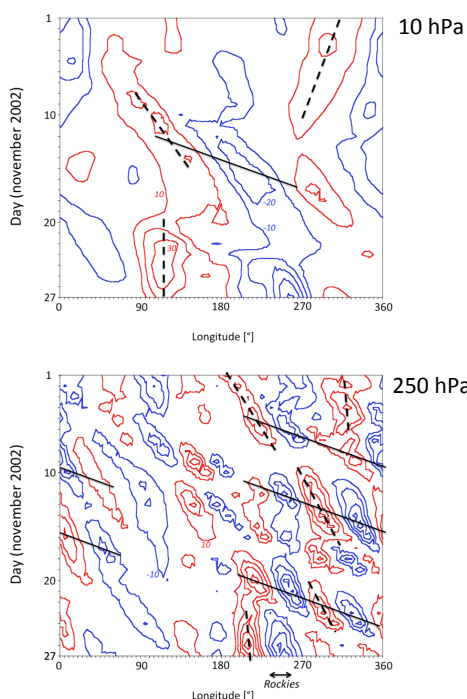


Planetary waves

Stratosphere:
only large scale waves

Short waves are not able
to penetrate upward into
the stratosphere. They
“break”

This leads to a kind of
“radiation stress” in the
lower stratosphere.



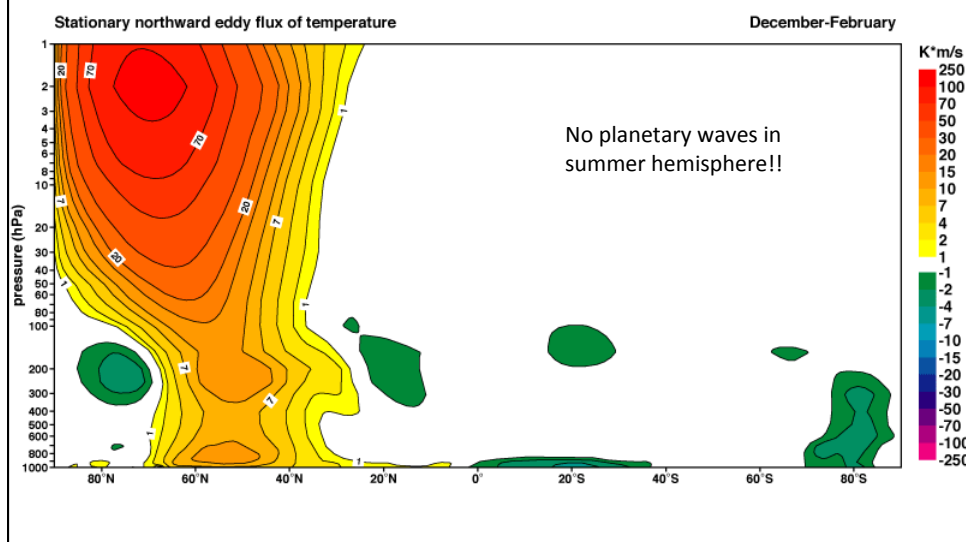
Radiation stress or wave drag

A well known example: breaking waves on beaches
induce a radiation stress, which drives a long shore



http://en.wikipedia.org/wiki/Radiation_stress

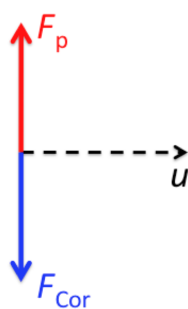
Manifestation of presence of planetary waves: eddy meridional heat flux, $[v^*T^*]$



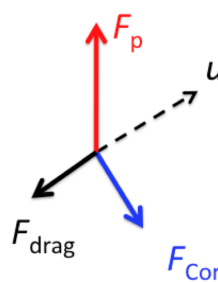
Influence of wave drag

F_{drag}

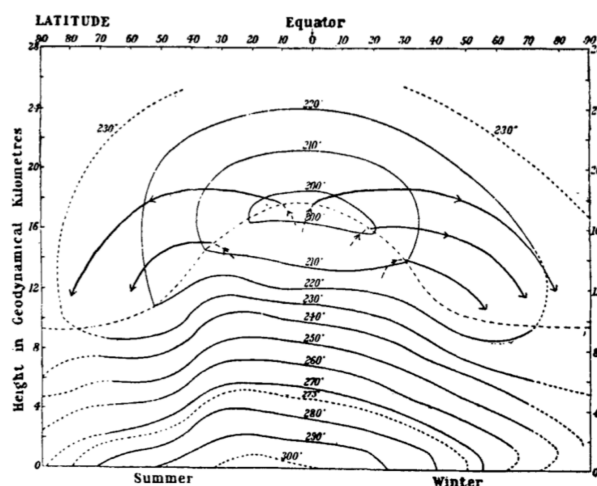
(a) Geostrophic equilibrium



(b) Balanced flow with drag

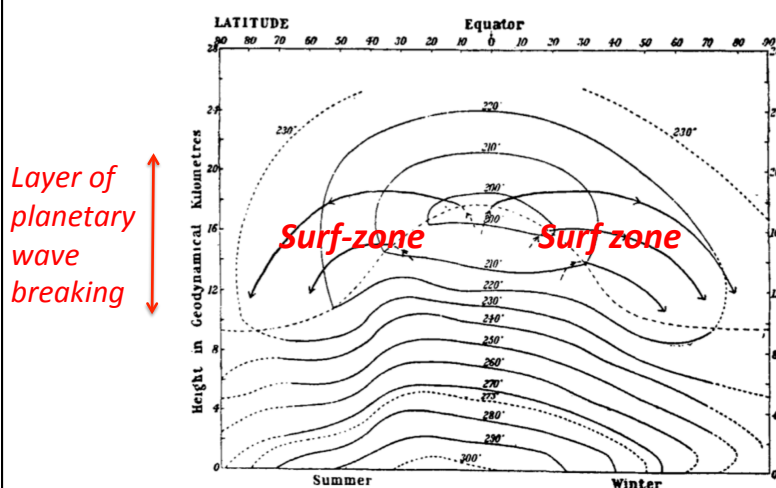


Poleward flow in the stratospheric surf zone



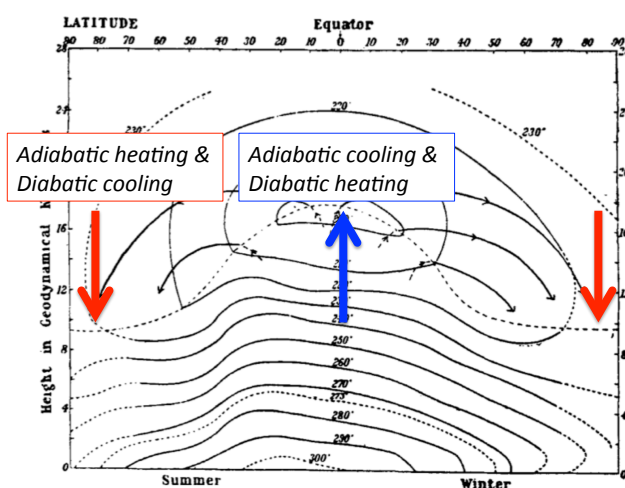
Brewer's (1949) original figure, illustrating what came to be known as the Brewer-Dobson circulation. "A supply of dry air is maintained by a slow mean circulation from the equatorial tropopause". The contours represent isotherms, labeled in units of K.

Poleward flow in the stratospheric surf zone



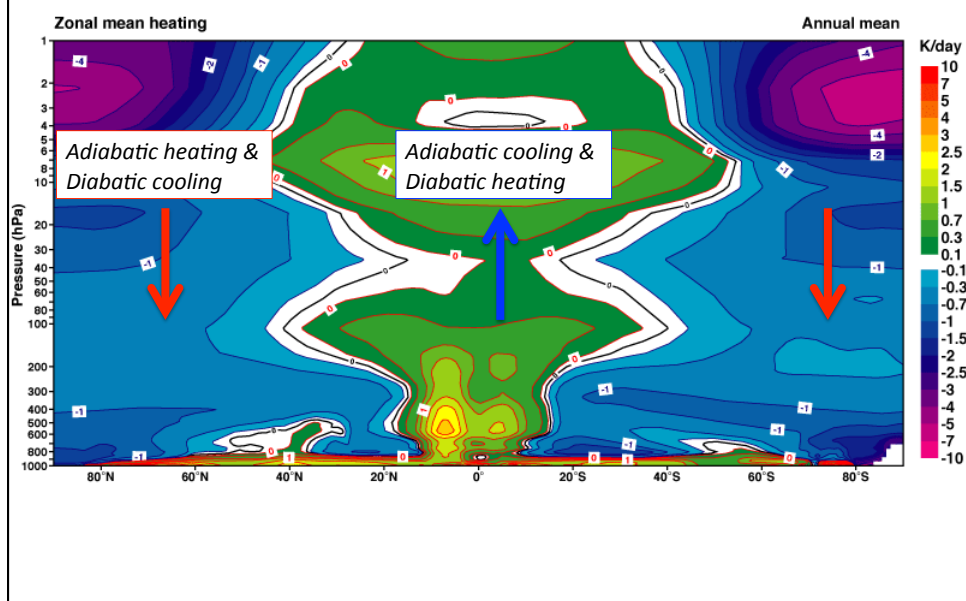
McIntyre and Palmer (1984) introduced the term "surf zone" to designate the layer in the stratosphere where planetary waves "break" and thus exert a stress on the zonal mean flow.

Poleward flow in the stratosphere



Brewer's (1949) original figure, illustrating what came to be known as the **Brewer-Dobson circulation**. "A supply of dry air is maintained by a slow mean circulation from the equatorial tropopause". The contours represent isotherms, labeled in units of K.

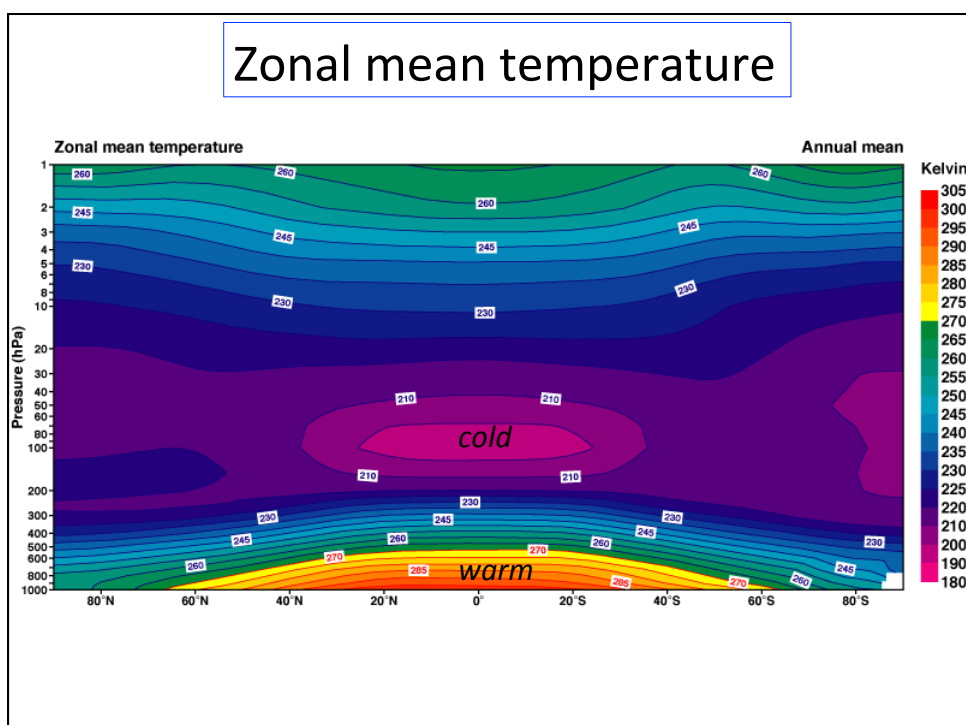
Diabatic heating/cooling

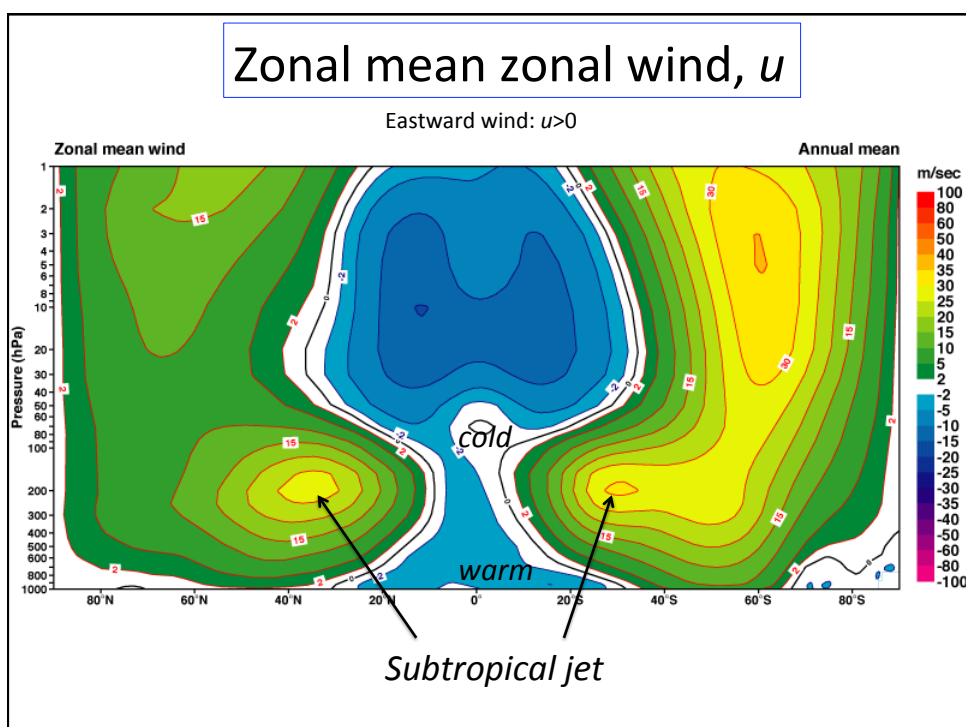


Brewer (1949):

“The observed distributions of ozone and water vapour can be explained by the existence of a circulation in which air enters the stratosphere at the equator, where it is dried by condensation, travels in the stratosphere to temperate and polar regions, and sinks into the troposphere. The sinking, however, will warm the air unless it is being cooled by radiation and the idea of a stratosphere in radiative equilibrium must be abandoned. The cooling rate must lie between about 0.1 and 1.1 °C per day but a value near 0.5°C per day seems most probable. At the equator the ascending air must be subject to heating by radiation.

The circulation is quite reasonable on energy considerations. It is consistent with the existence of lower temperatures in the equatorial stratosphere than in the polar and temperate regions, and if the flow can carry ozone from the equator to the poles then it gives a reasonable explanation of the high ozone values observed at high latitudes. The dynamical consequences of the circulation are not considered. It should be noted that there is considerable difficulty to account for the smallness of the westerly winds in the stratosphere, as the rotation of the earth should convert the slow poleward movement into strong westerly winds”.





Conclusion

The low temperature at the tropical tropopause is a manifestation of a complex interaction between temperature changes due to absorption of emission of radiation (a diabatic process) and temperature changes due to adiabatic heat transport and expansion/compression of air when it moves vertically. The horizontal wind adjusts to the associated pressure distribution such that atmosphere remains close to thermal wind balance. This explains the existence of jets. The “smallness of the westerly winds”, not understood by Brewer in 1949, is now thought to be the result of wave drag.

References

Brewer, A.W., 1949: Evidence for a world circulation provided by the measurements of helium and water vapour distribution in the stratosphere. **Q.J.R.Meteorol.Soc.**, **75**, 351-363.

McIntyre, M.E., and T.N. Palmer, 1982: Breaking planetary waves in the stratosphere. **Nature**, **305**, 593-600.

<https://www.youtube.com/watch?v=WXuGYSM2D8k>