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eciphering spectral features of extra-solar planets

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Weather on strange new worlds: A troposphere benchmark model for a tidally locked terrestrial planet

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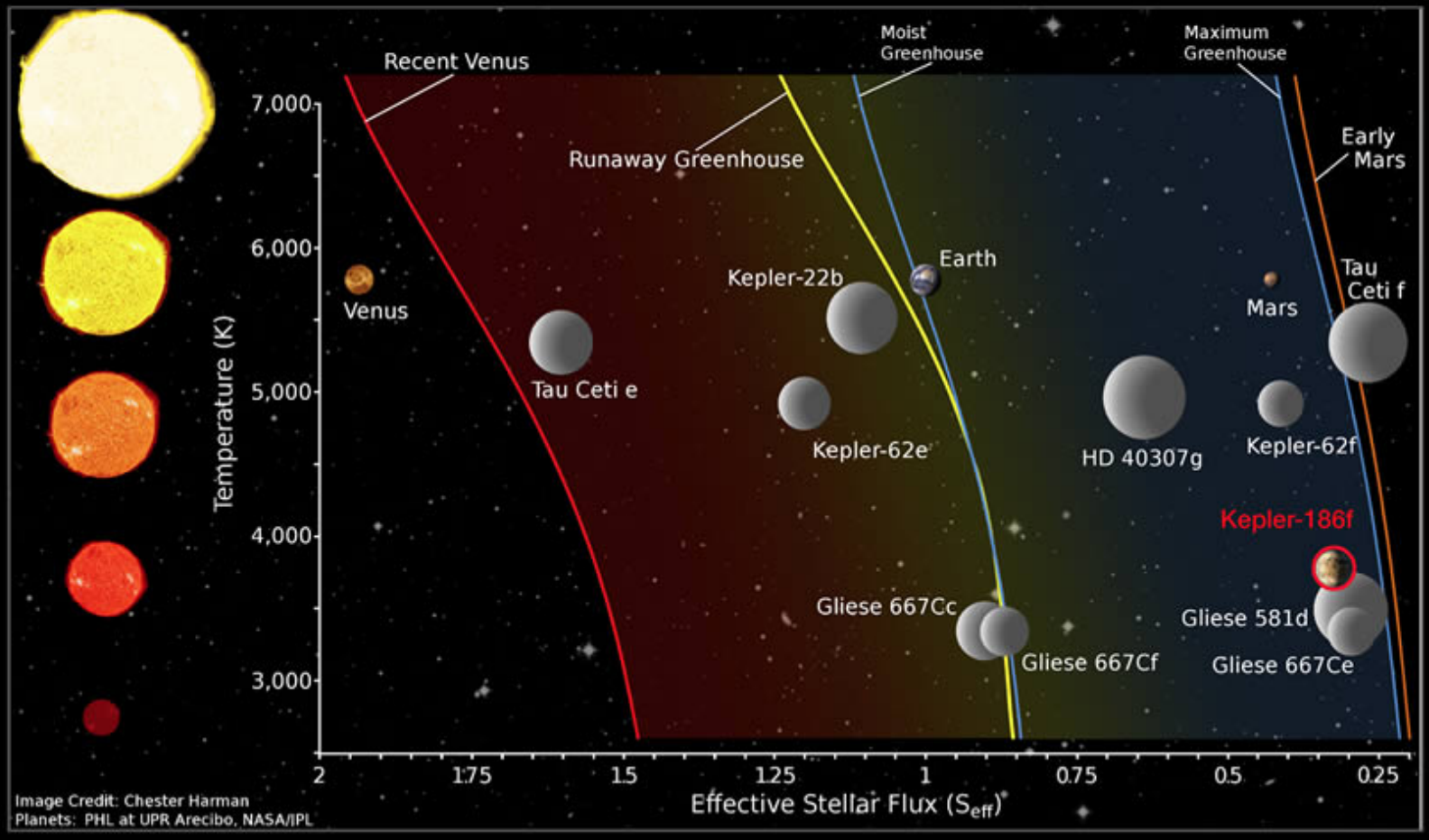
The Habitable Zone



Held &Suarez 1994: 'fruitfly' of climate research – Fluid Dynamics

- Navier-Stokes equation under hydrostatic equilibrium (HPE)

$$\frac{D\vec{v}_h}{Dt}+\left(2\vec{\Omega}\times\vec{v}\right)_h+\frac{1}{\rho}\nabla_h p=F_h$$ Horizontal momentum equation

$$\frac{\partial p}{\partial z}+\rho g=0$$ Hydrostatic equilibrium

$$\frac{1}{\rho}\frac{D\rho}{Dt}+\nabla_h\cdot\vec{v}_h+\frac{\partial w}{\partial z}=0$$ Continuity equation

$$\frac{D}{Dt}=\frac{\partial}{\partial t}+\vec{v}_h\cdot\nabla_h+w\frac{\partial}{\partial z}$$

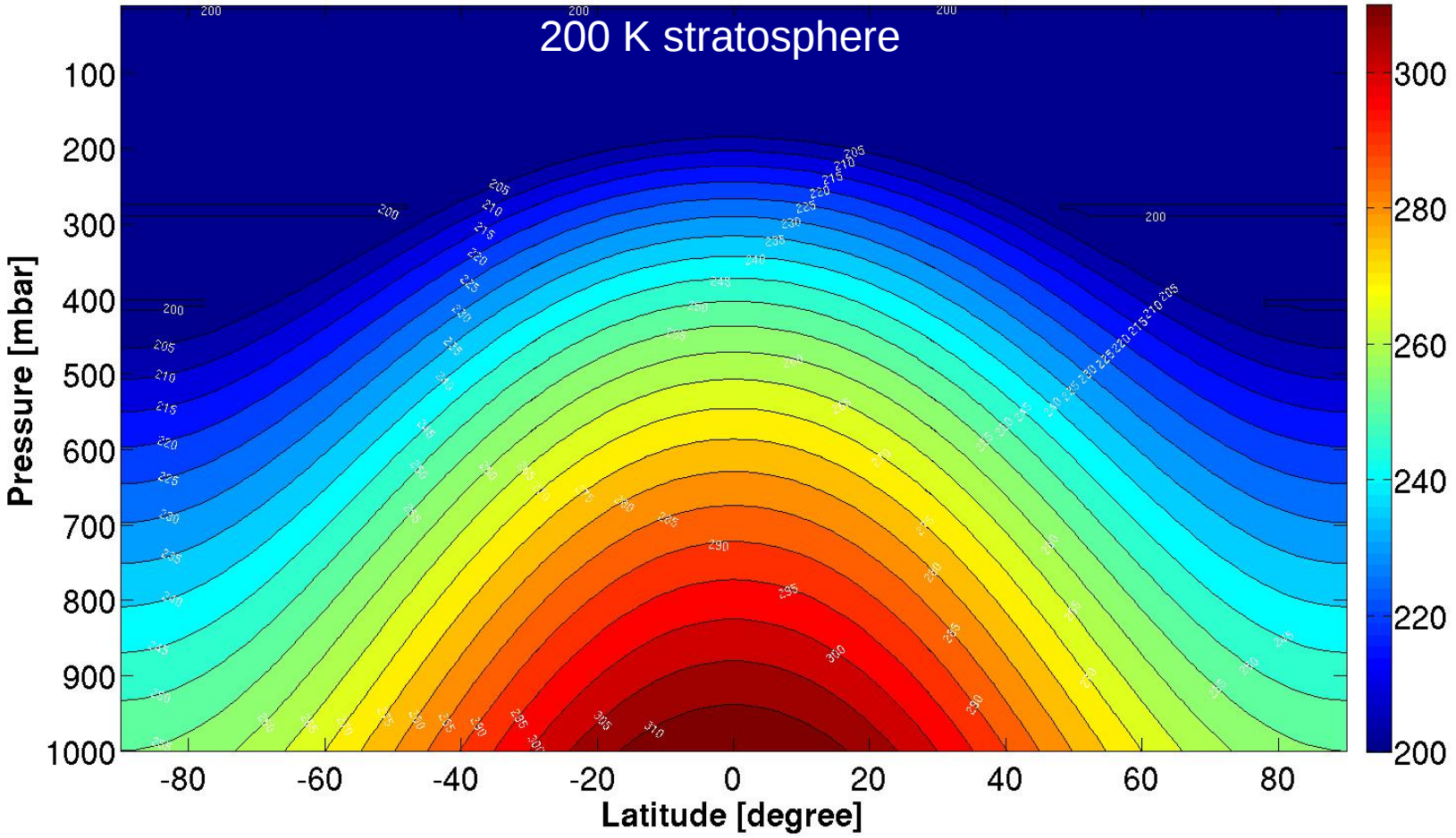
Held &Suarez 1994: 'fruitfly' of climate research – Thermal forcing

- Navier-Stokes equation (HPE)
- Newtonian relaxation towards equilibrium temperature

$$\frac{DT}{Dt} = \frac{-[T - T_{eq}]}{\tau_{rad}}$$

40 d for Earth

Temperature forcing for Earth



Held &Suarez 1994: 'fruitfly' of climate research – Surface <-> Atmosphere friction

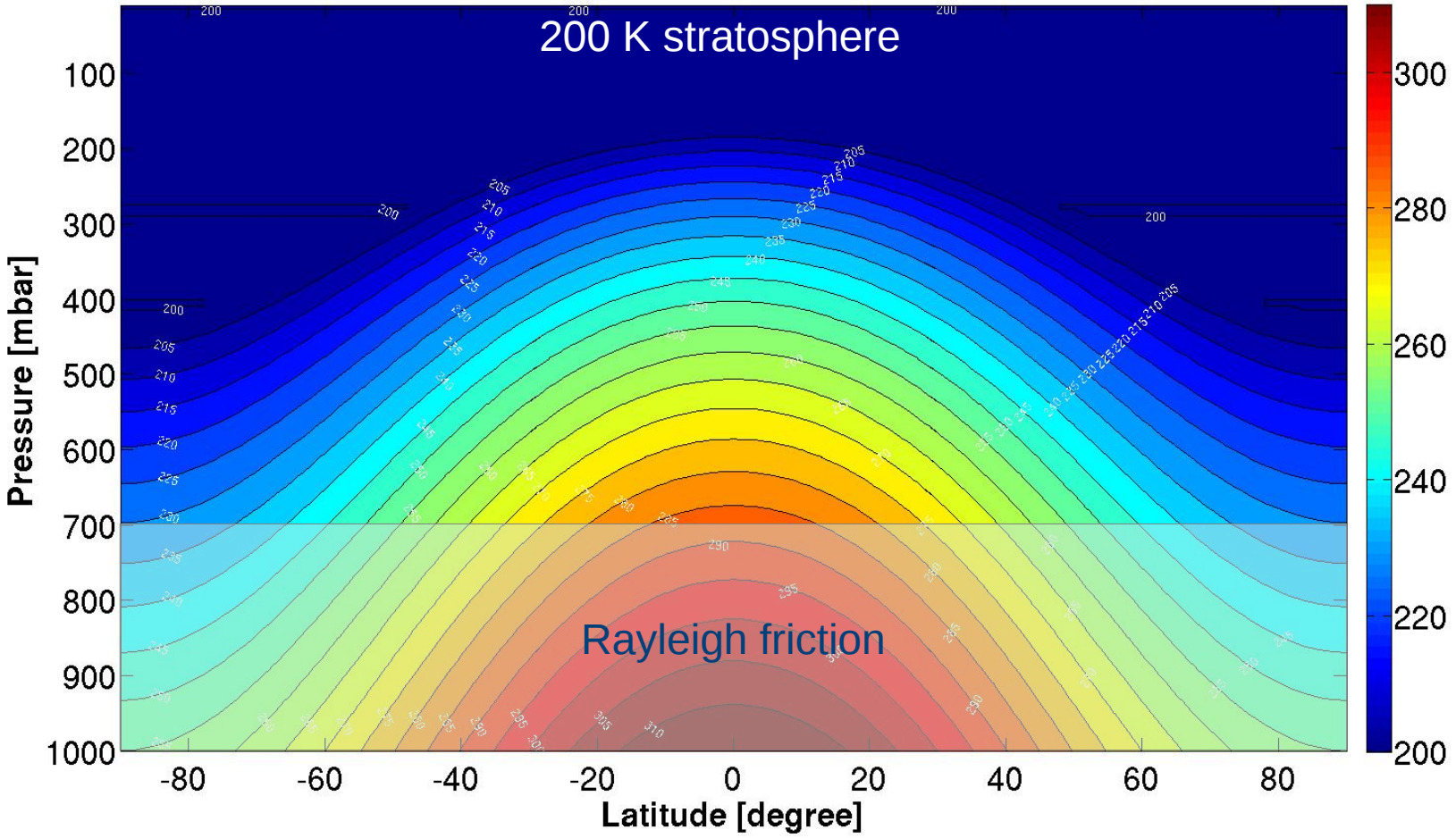
- Navier-Stokes equation (HPE)
- Newtonian relaxation towards equilibrium temperature
- Rayleigh friction between surface and atmosphere

$$\vec{F}_h = k_v \vec{v}_h$$

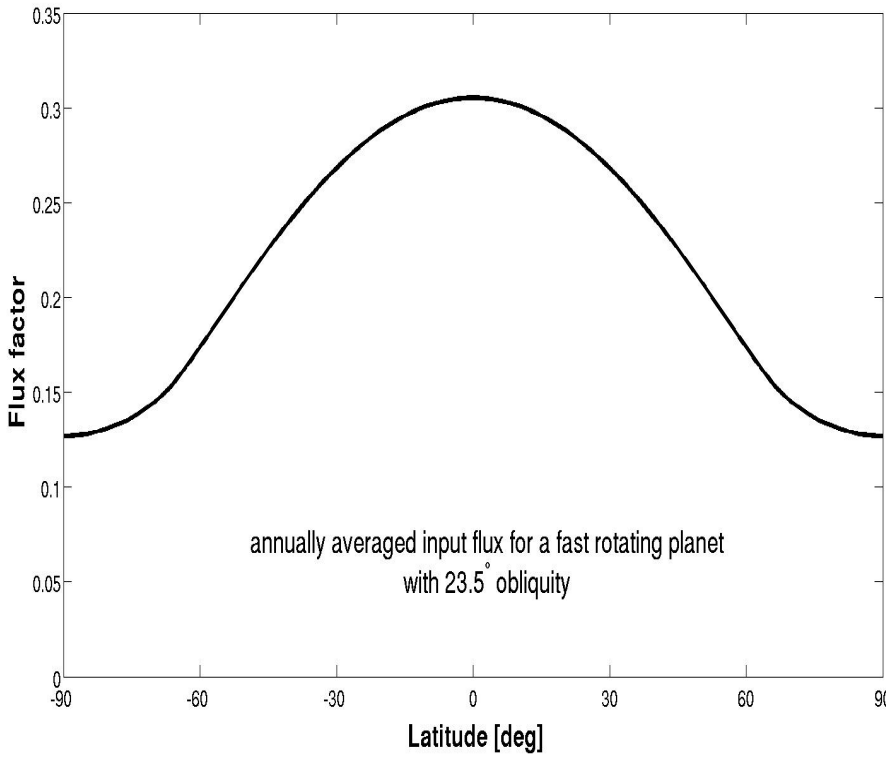
k_v=1 day^{-1}...0

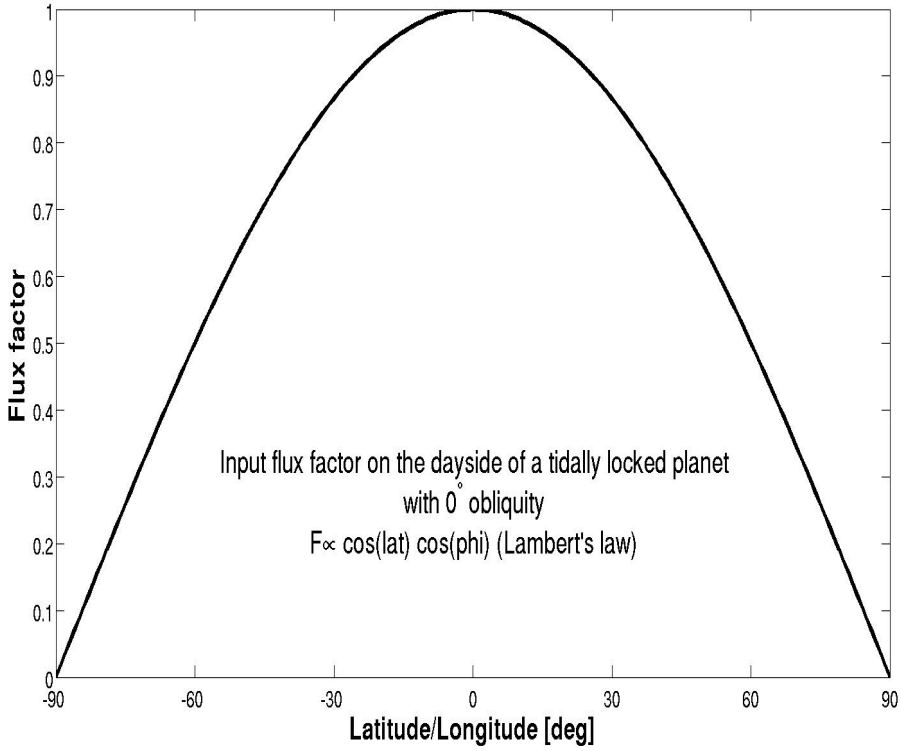
p=1000-700 mbar

Temperature forcing for Earth



Adaptation for tidally locked dayside

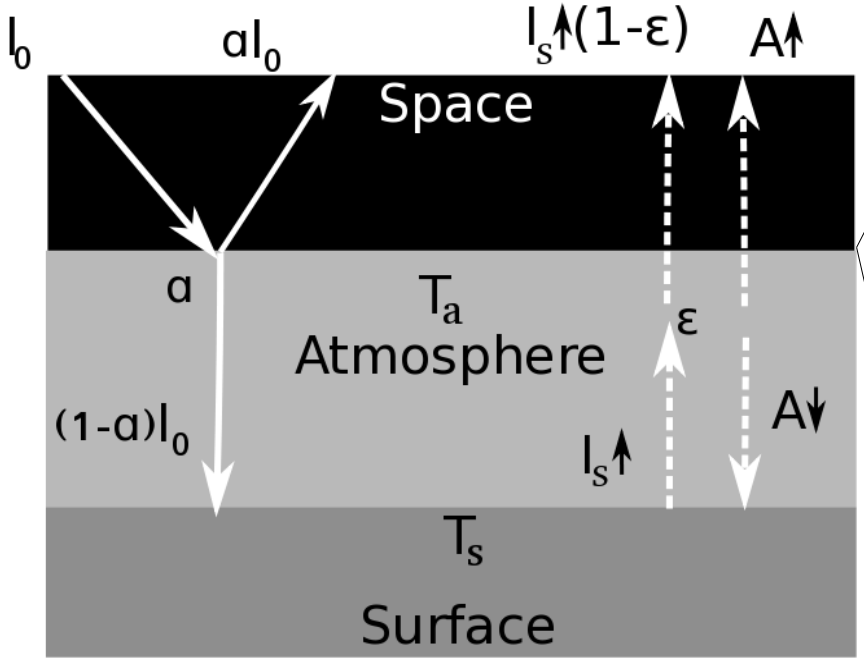




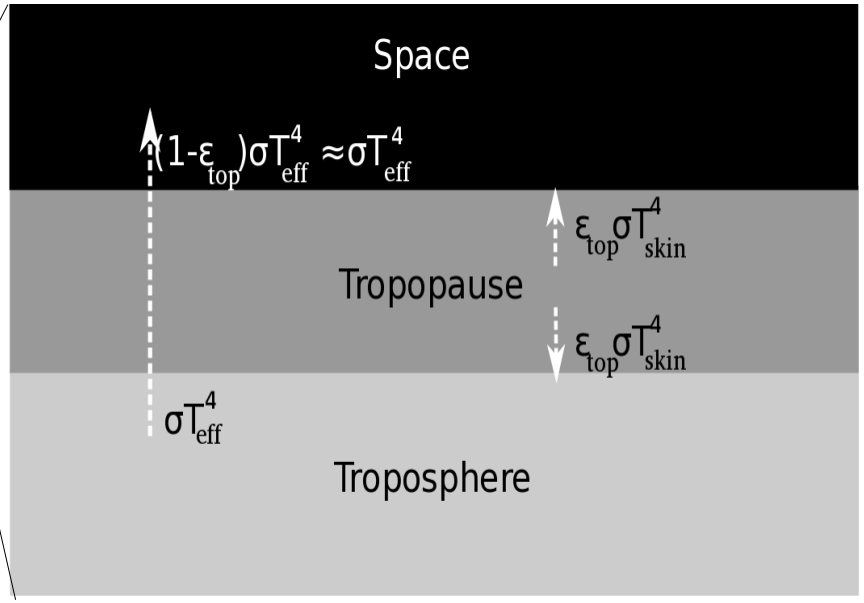
$x I_0 (1-\alpha)$ determines $T_{eff,P}$

Assuming leaky greenhouse model+ skin layer concept

e.g. J. Marshall 2008



e.g. Pierrehumbert 2010

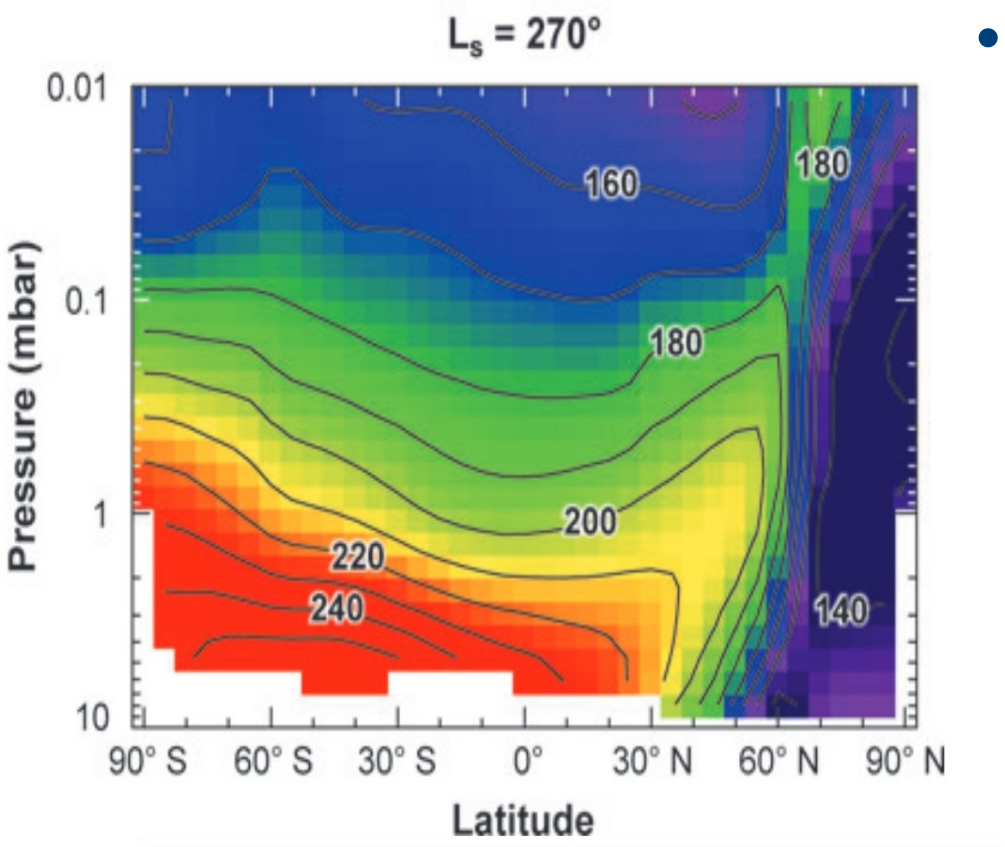


$$T_s = \left(\frac{2}{2-\epsilon}\right)^{1/4} T_{eff,P}$$

0.8 for Earth

$$T_{tropopause} = 0.5^{1/4} T_{eff,P}$$

At the nightside and terminator: Martian polar night scenario



- Equilibrium between condensation and IR-back radiation of atmosphere

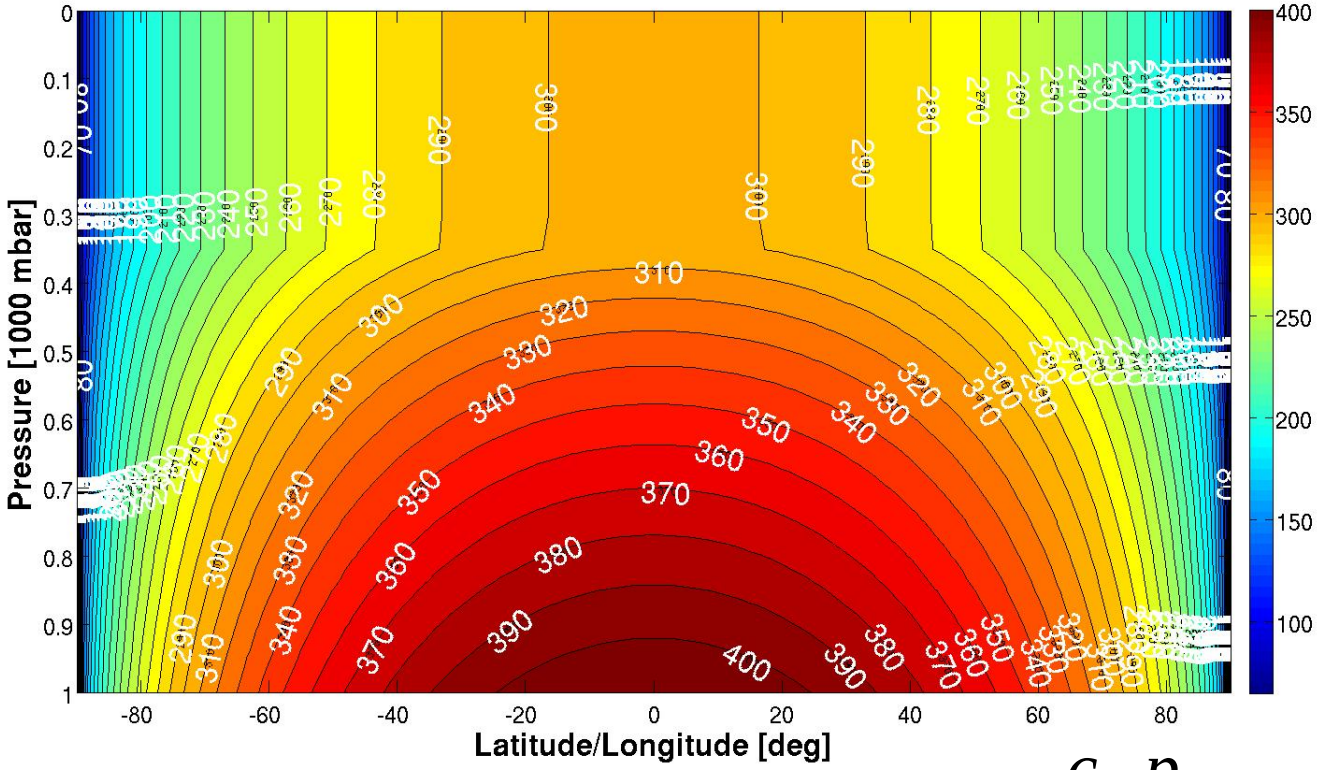
$$T_{cond} = \frac{T_{ref}}{1 - \frac{RT_{ref}}{L} \ln\left(\frac{p}{p_{ref}}\right)}$$

T_{ref}=77 K @ p_{ref}=1000 mbar for N_2

Smith, 2008, Spacecraft Observations of the Martian Atmosphere, Annu. Rev. Earth Planet. Sci. 2008. 36:191–219

Tidally locked dayside rad.-conv.-T_{eq}

Earth-like atmosphere and insolation

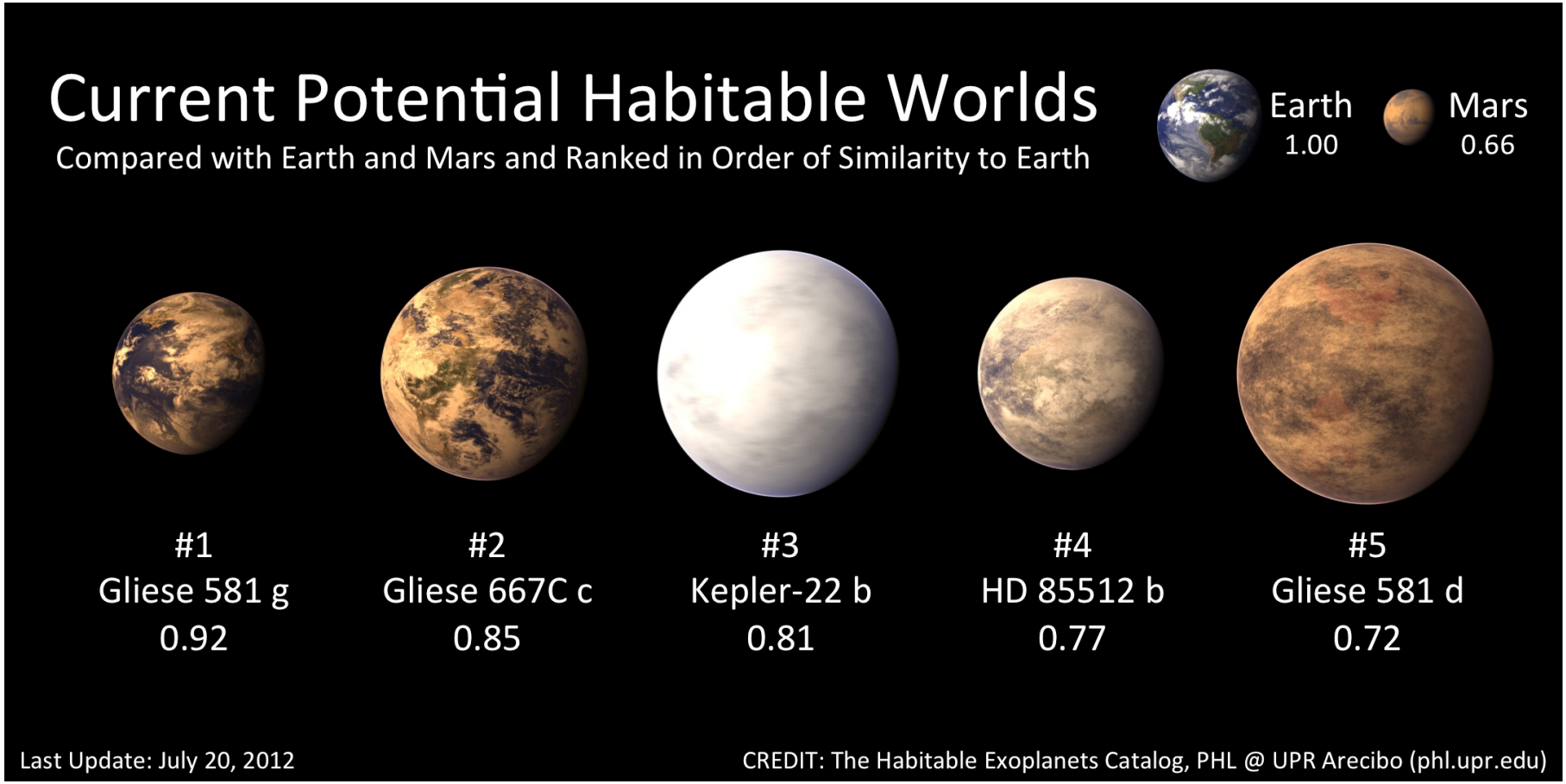


$$I_0 = 1368\, W/m^2 \quad \alpha = 0.3$$

$$\tau_{rad} = \frac{c_P p_s}{g\, 4\sigma T^3} = 4\mathrm{d} - 813\mathrm{d}$$

$$T(p) = max\left(T_s \left(\frac{p}{p_s}\right)^{R/c_p}, T_{tropopause}\right)$$

Put it on a Super-Earth



$$M_{Gl581g} = 3.1\,M_{Earth} \rightarrow R_{pl} = 1.45\,R_{Earth};\ g = 14.3\,m/s^2$$

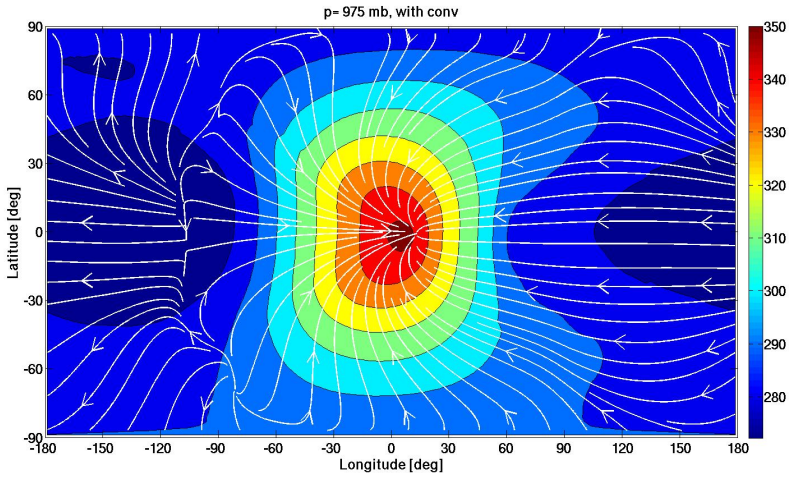
$P_{rot} = P_{orb}$ =36.5, 10d,... days,

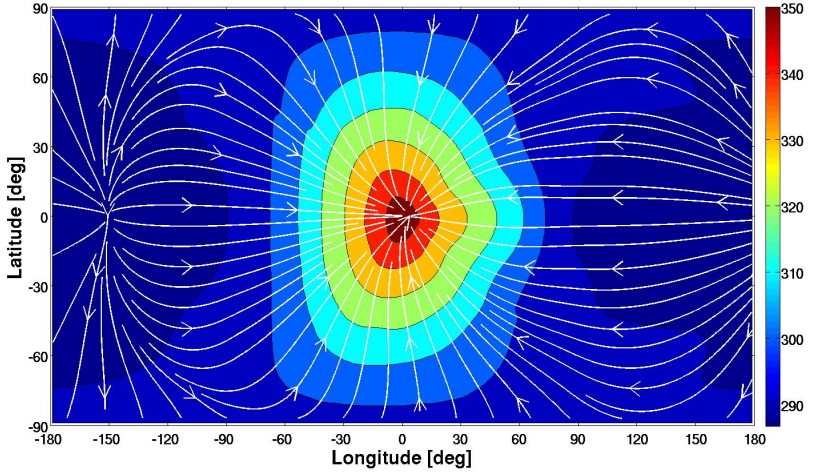
Dynamics on terrestrial Super-Earths

Prot=10 d

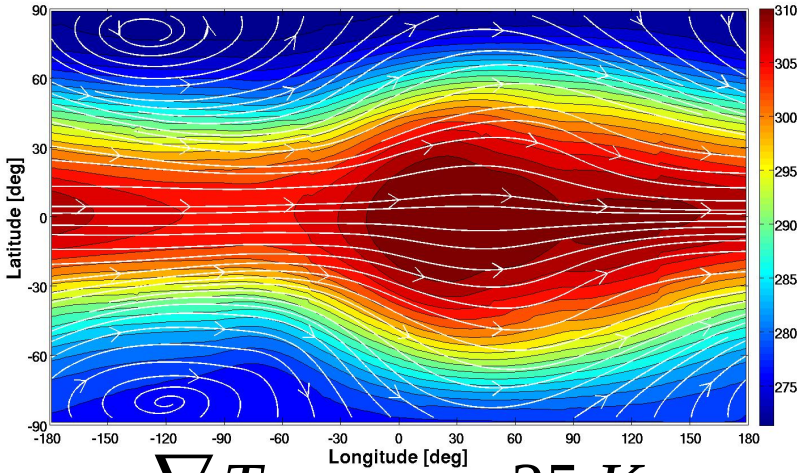
Prot=36 d

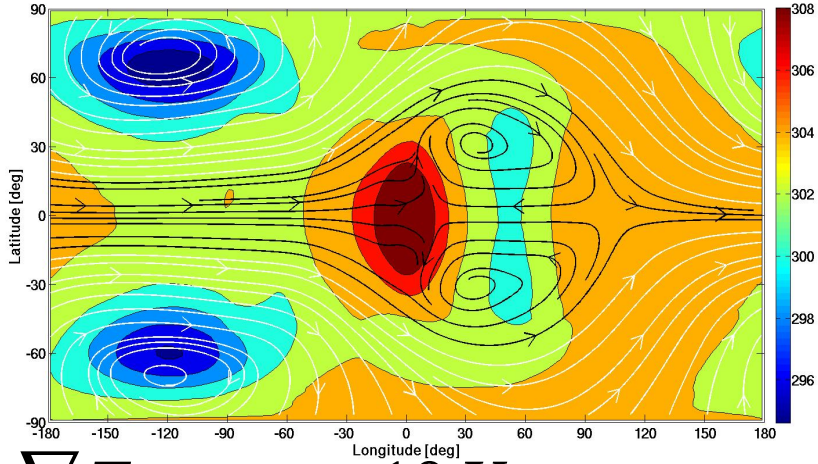
p=1000 mbar





p=525 mbar





$$\nabla T_{p=525\,mb} \approx 25\ K$$

$$\nabla T_{p=525\,mb} \approx 10\ K$$

1000 d time average

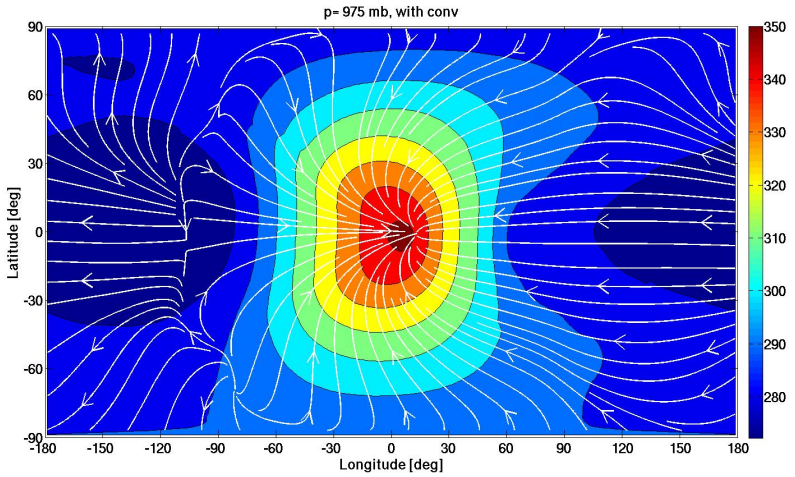
Dynamics on terrestrial Super-Earths

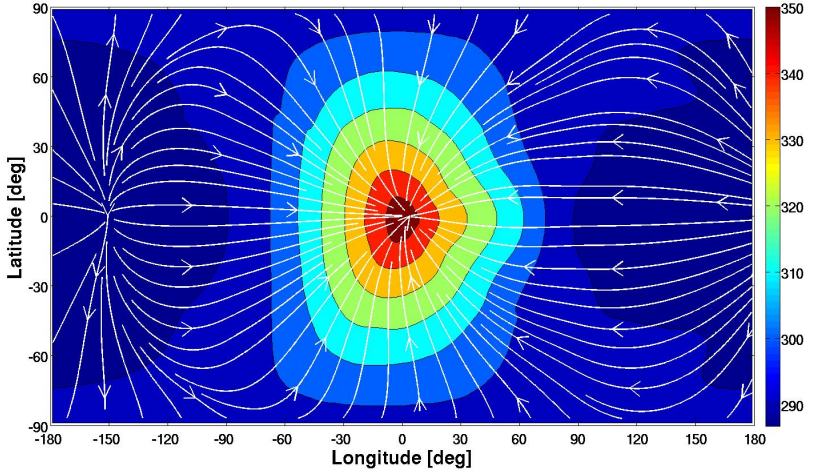
Prot=10 d

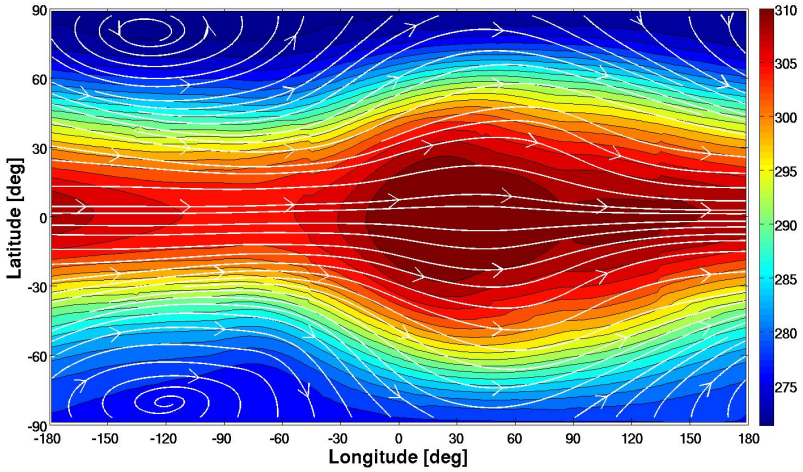
Prot=36 d

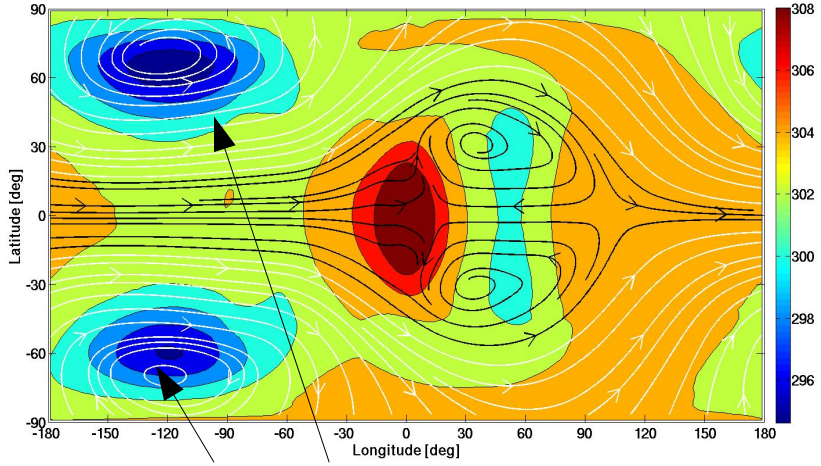
p=1000 mbar

p=525 mbar



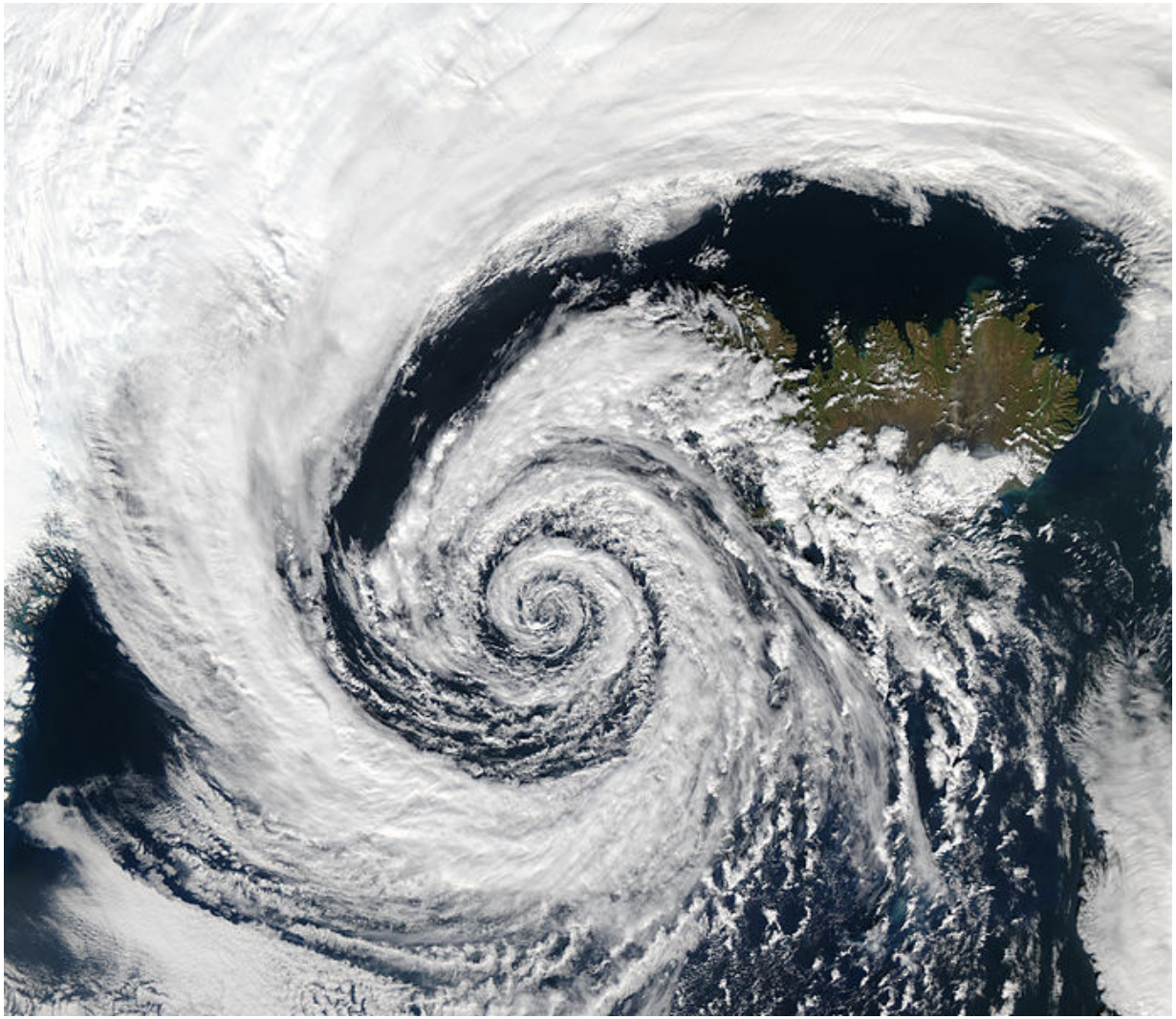






1000 d time average cyclones

Cyclones are cloud/ precipitation generators



Cyclone near Iceland

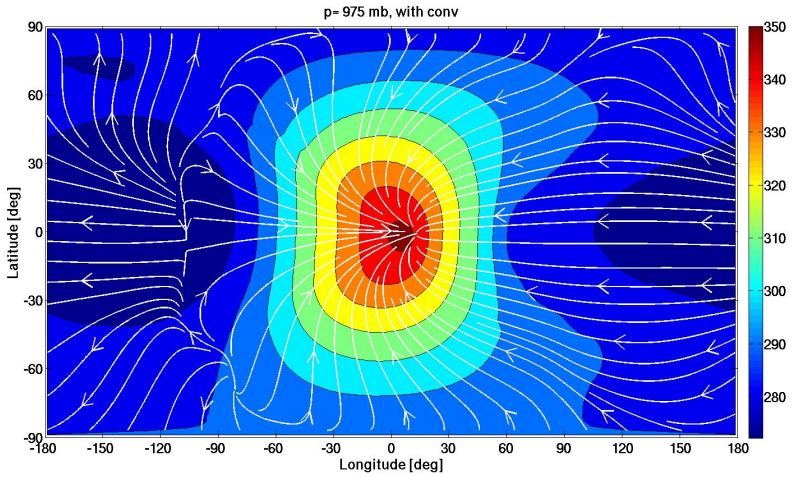
Wiki commons

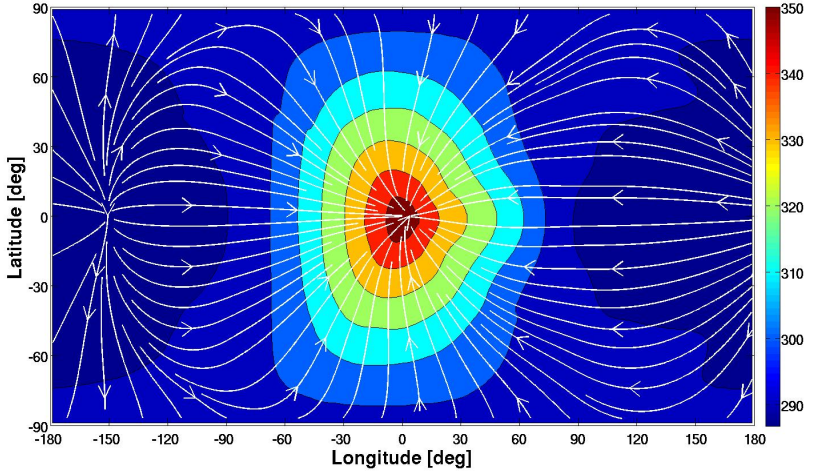
Dynamics on terrestrial Super-Earths

Prot=10 d

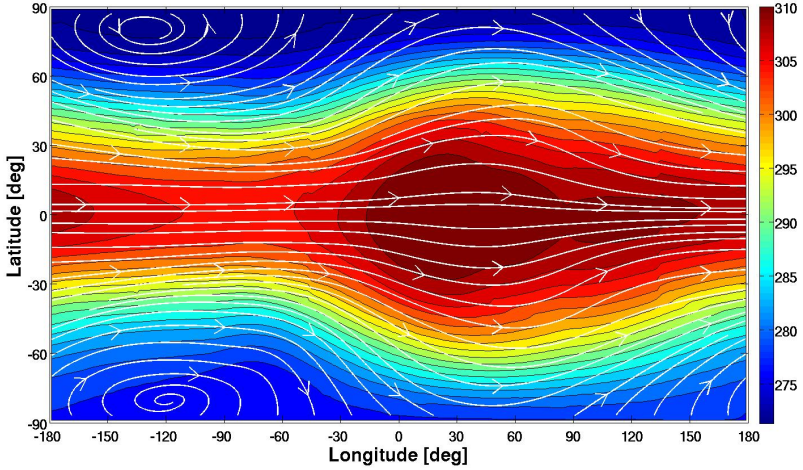
Prot=36 d

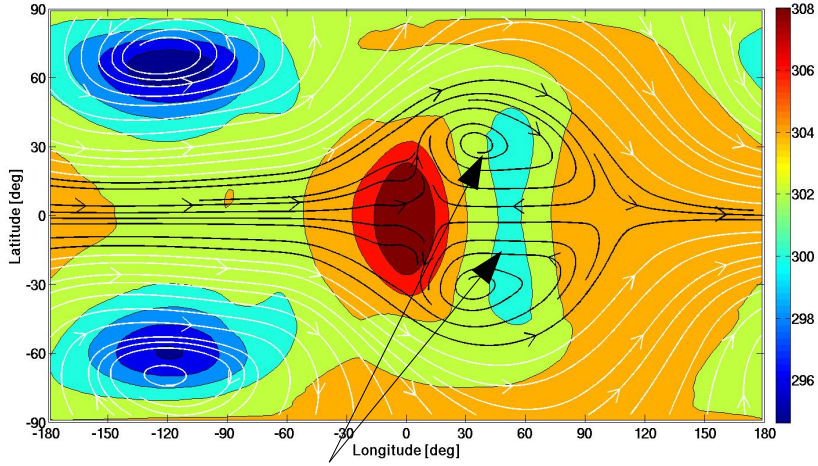
p=1000 mbar





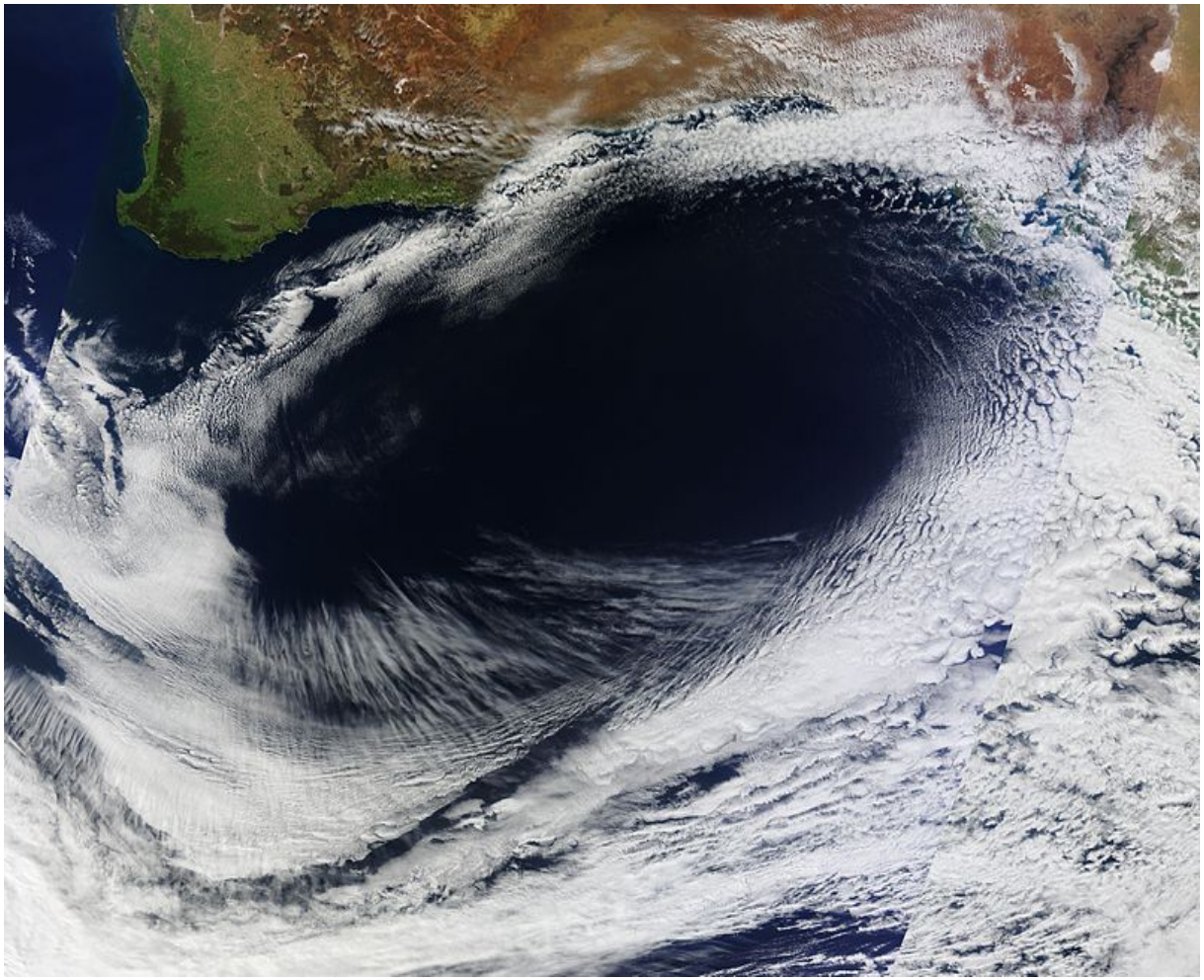
p=525 mbar





1000 d time average anticyclones

Anti-cyclones are cloud/precipitation dispersers

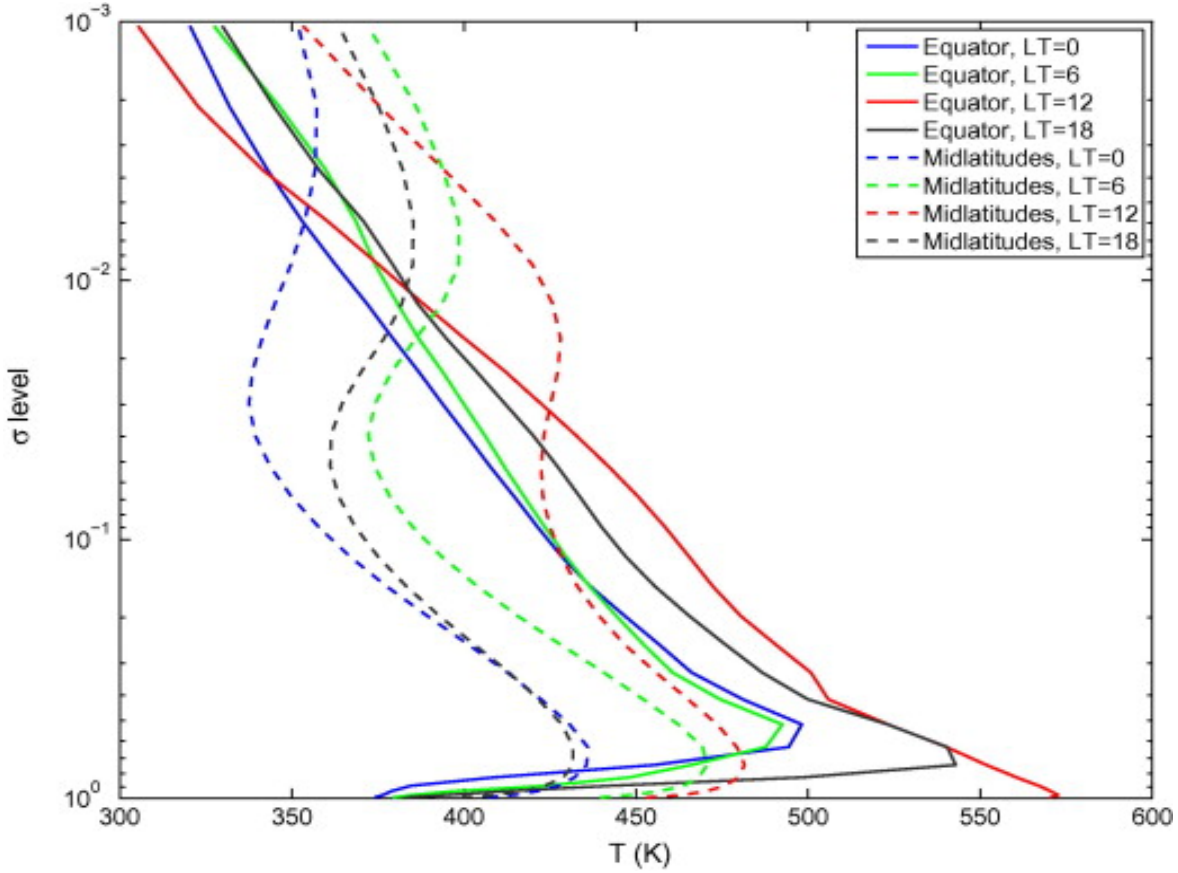


Anti-cyclone near South-Australia

Wiki-commons

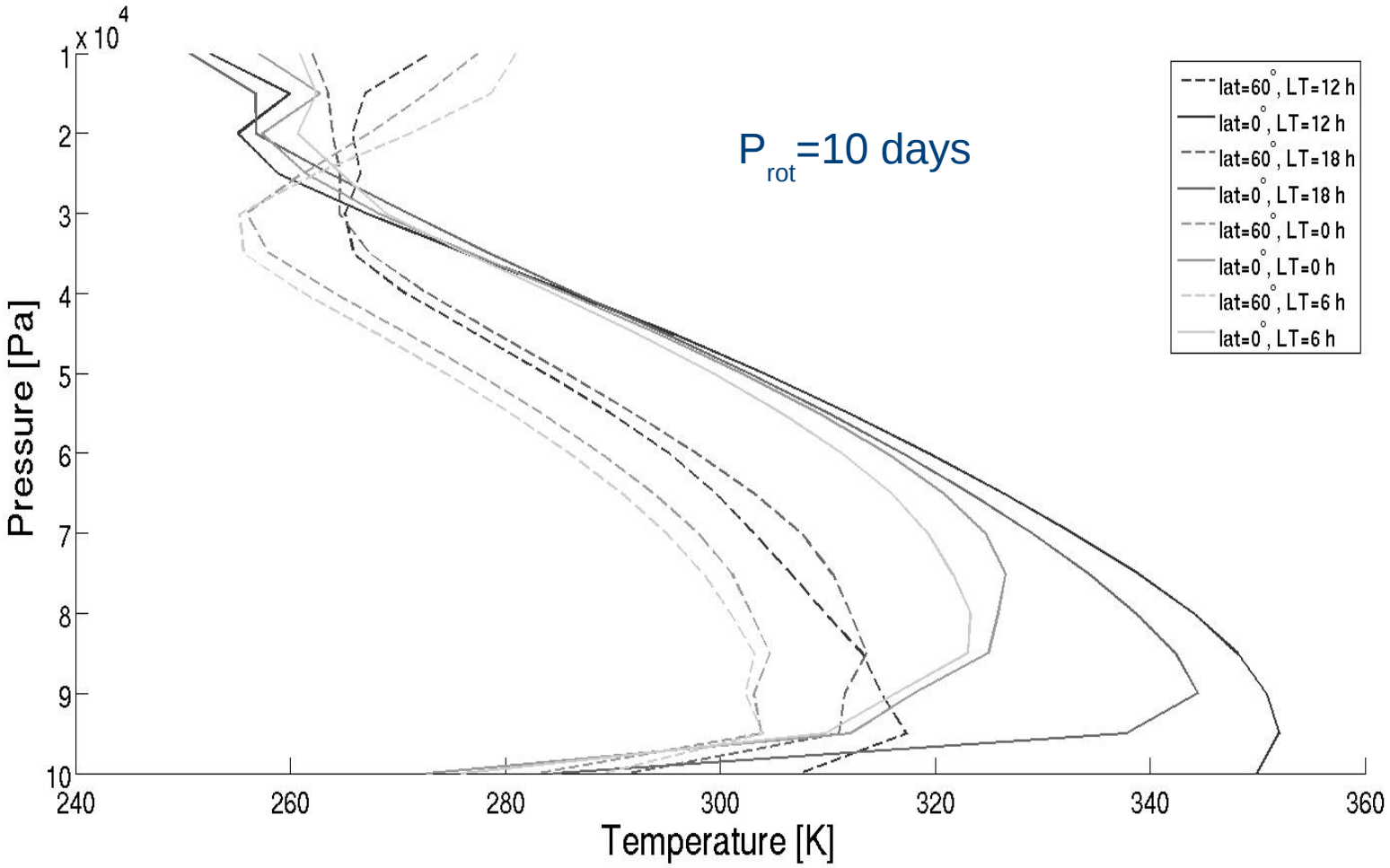
Zalucha 2013

- H_2O atmosphere, P_{rot}=1.5 d, Hot regime, ps=1000 mbar



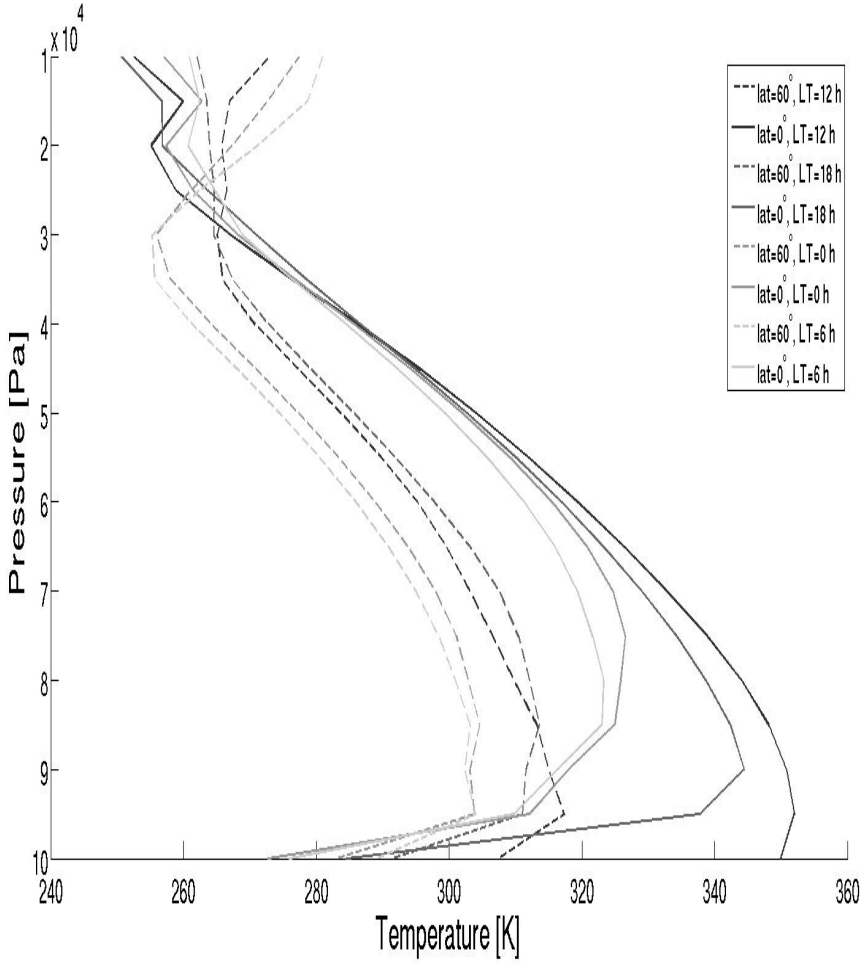
KU Leuven Benchmark

Prot=10 d

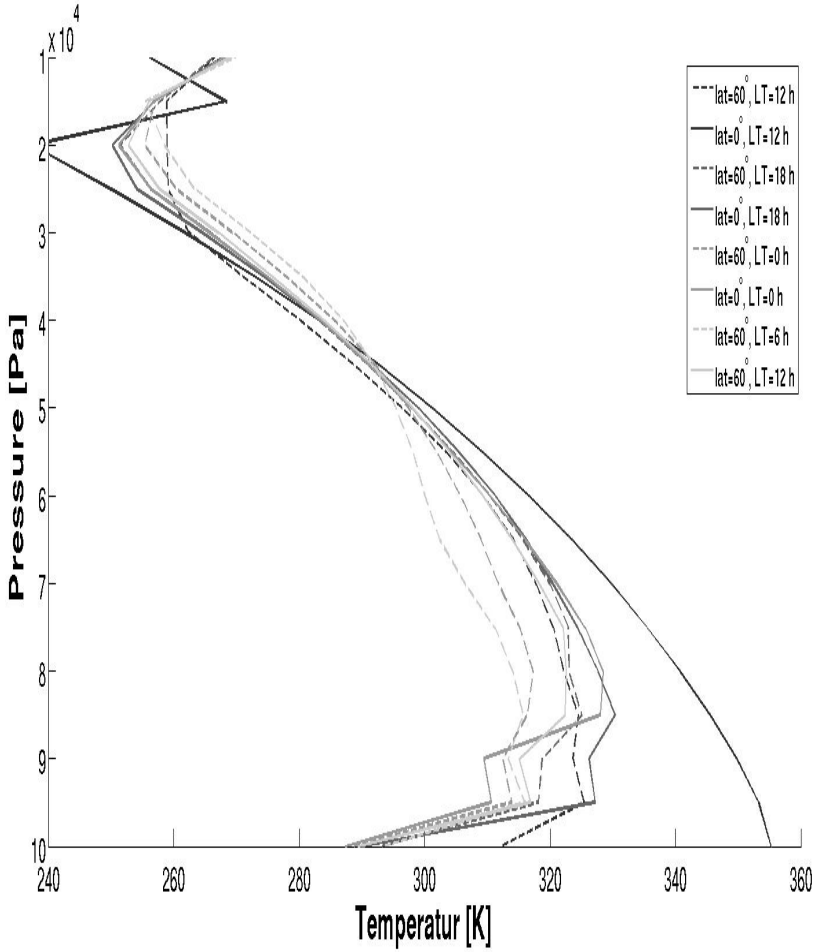


Our benchmark

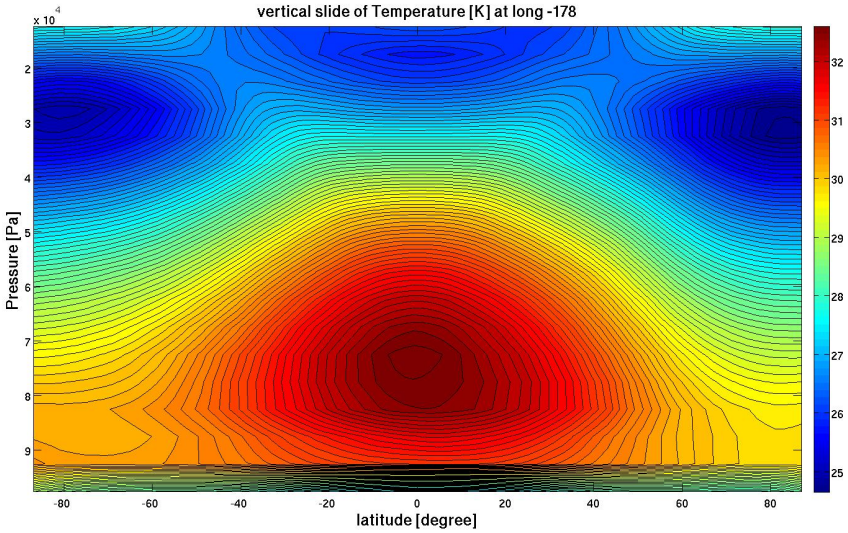
P_{rot}=10 days



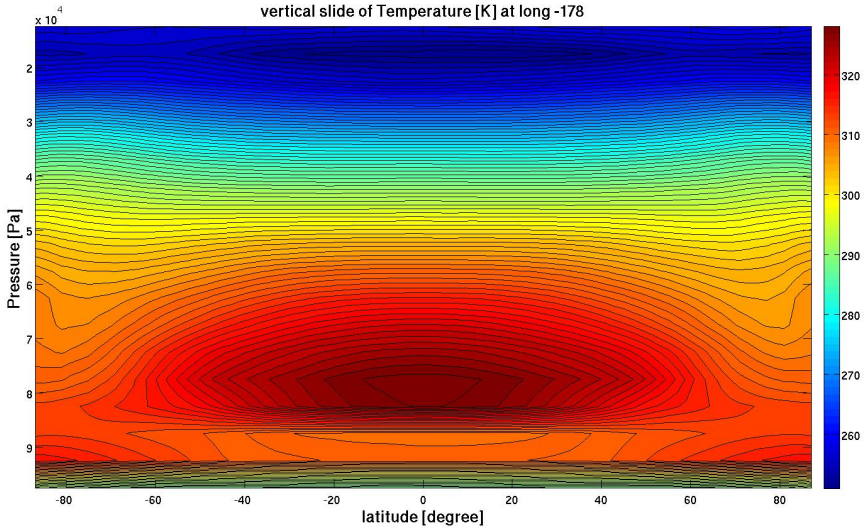
P_{rot}=36.5 days



Vertical temperature at anti-stellar point

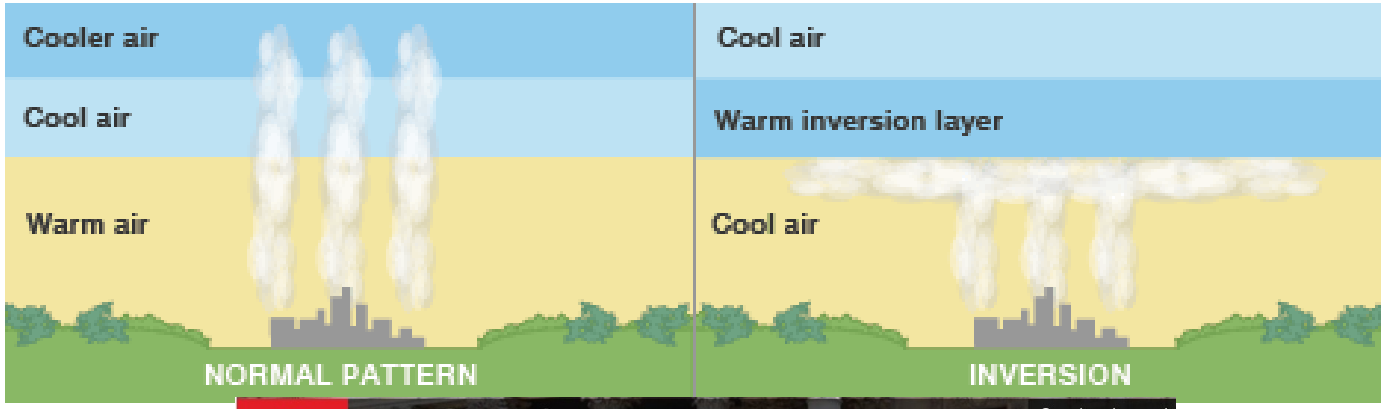


10d



36d

Thermal inversion-> Smog formation



BBC Weather

City of Brussels

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Pollution peak. Speed limit at 50 km/h in Brussels

This page has been automatically translated from French into English by a translation software. Automatic translations are not as accurate as translations made by professional human translators. Nevertheless these pages can help you understand information published by the City of Brussels.

The pollution peak (level 1) or smog alert has been announced for Thursday 13 and Friday 14 March 2014. In the Brussels Capital Region the speed limit is at 50 km/h. There are also extra speed controls.

Smog is mainly characterized by elevated concentrations of fine particles in the air. These substances, like ozone in summer, can cause health problems.

Extra speed controls

The Brussels Capital Region has a speed limit of 50 kilometers per hour during the alert. The police checks if the speed limit is strictly observed with extra controls. The rule has to improve the air quality. Around 50 km/h, a vehicle emits the least polluting substances.

Conclusion

- A tidally locked terrestrial planet benchmark with the same conceptional simplicity than the Held&Suarez benchmark
  - Fast, versatile, good for parameter study
- On average, nightside temperature does not drop very low (280-290 K)
- Dayside temperatures allow for liquid water (350-300 K)
- Substellar point is upwelling region (cloud formation)
- For slow rotation (>30 d), Cyclones at mid-latitude in mid-troposphere (cloud formation, reduced horiz. diffusion)
- Thermal inversion at the surface (hinders vertical diffusion)

In preparation:

Carone et al., Connecting the dots: A versatile terrestrial planet benchmark for tidally locked Super-Earths with Earth-like atmospheres, MNRAS