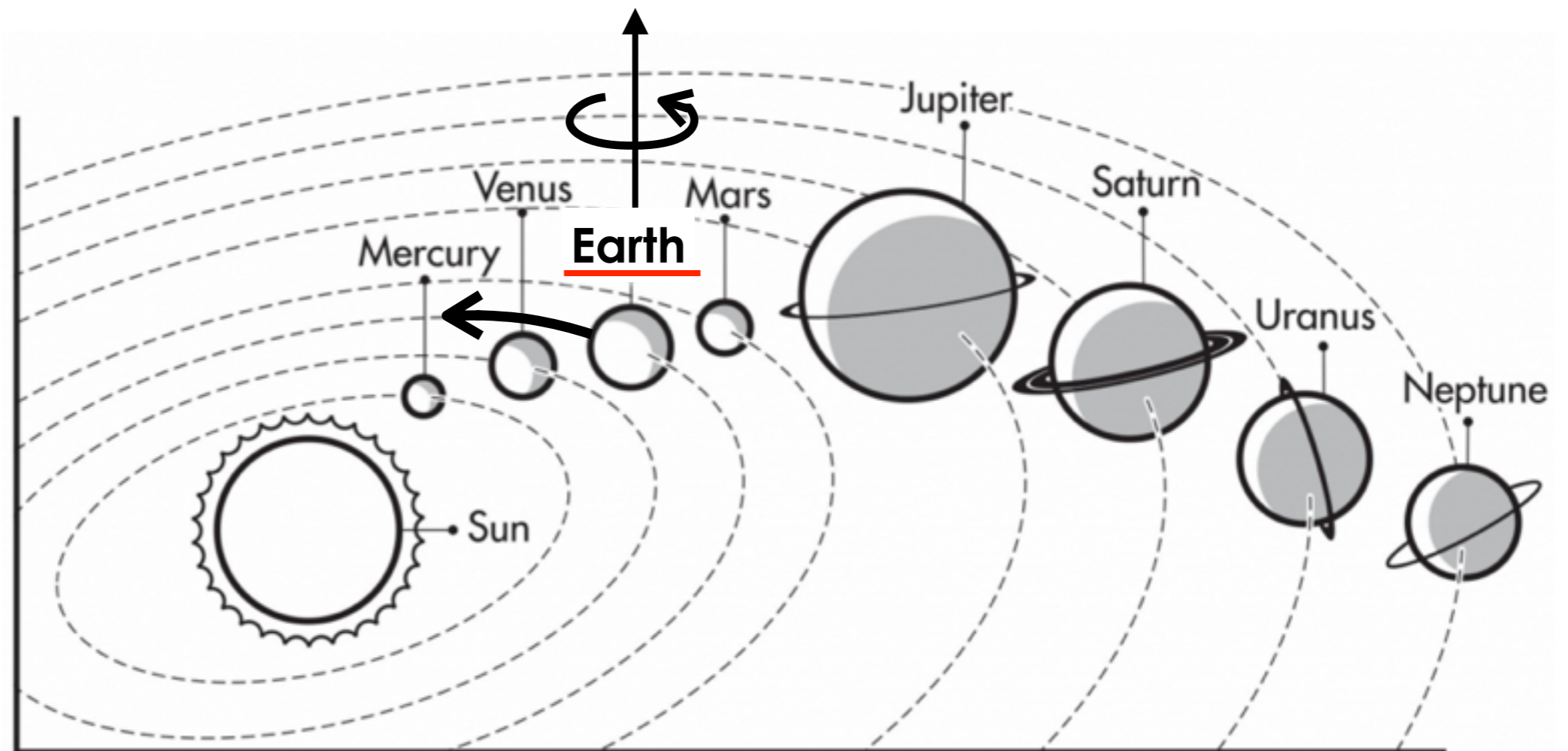


# Earth's atmosphere

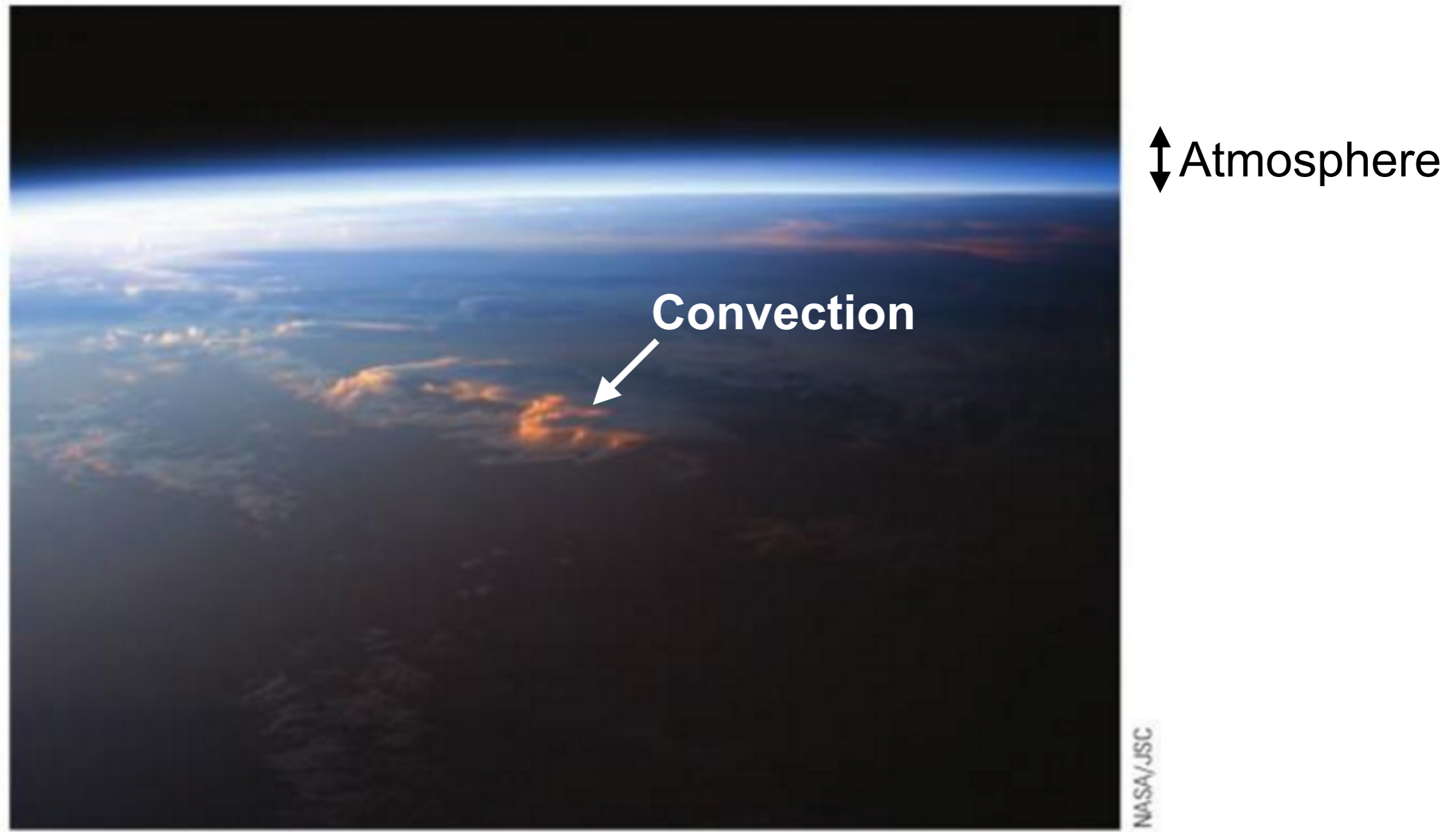
Things we understand, so far (we think...)

1. Composition
2. Structure
3. motions or phenomena



(from [www.timeforkids.com](http://www.timeforkids.com))

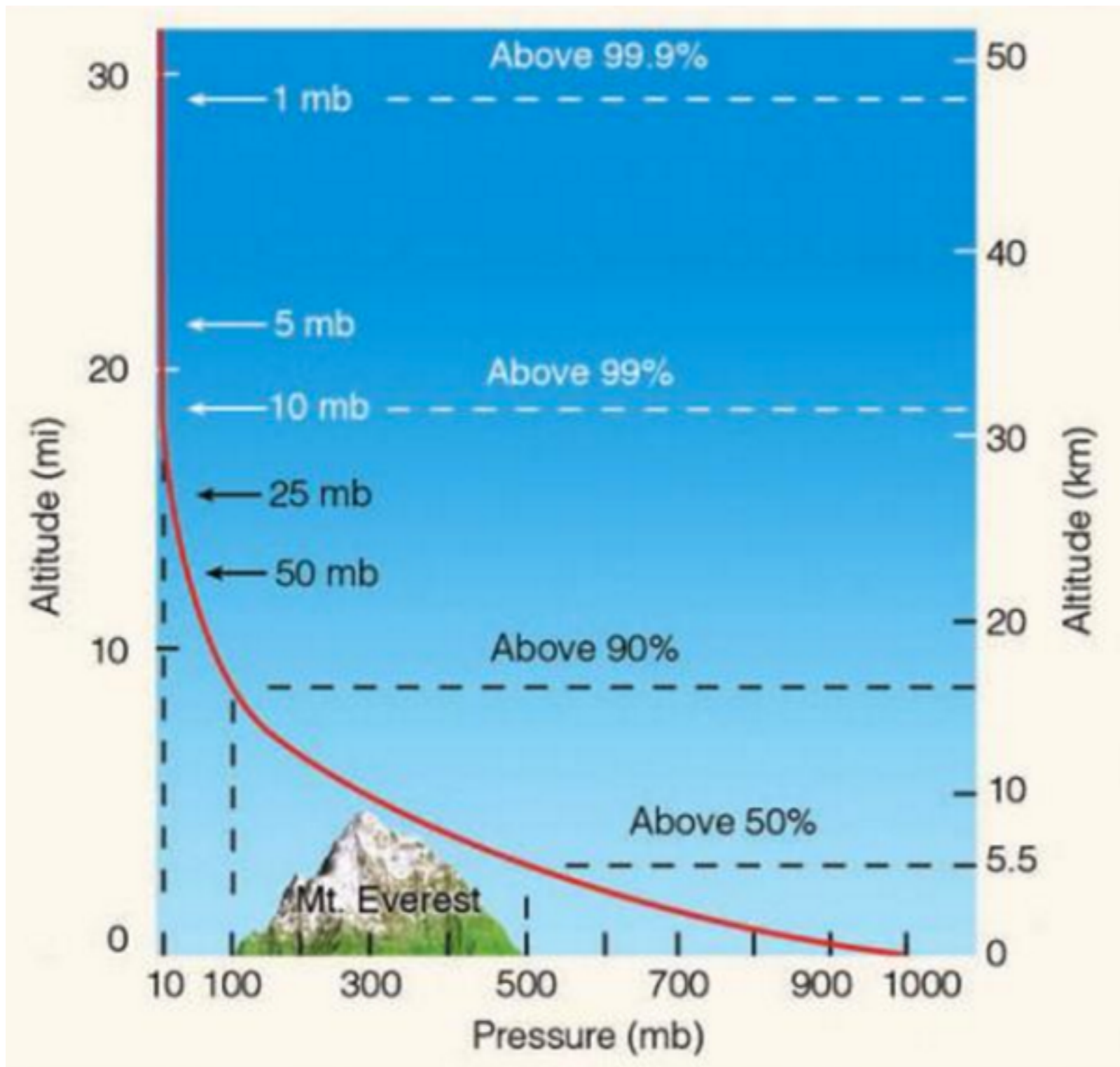
# The Atmosphere



*(from Meteorology today)*

- Very **thin layer** compared to the earth's radius ( $a = \sim 6400$  km)

# Pressure (as a function of altitude)



- Pressure decrease **exponentially** with increasing altitude

*(from Meteorology today)*

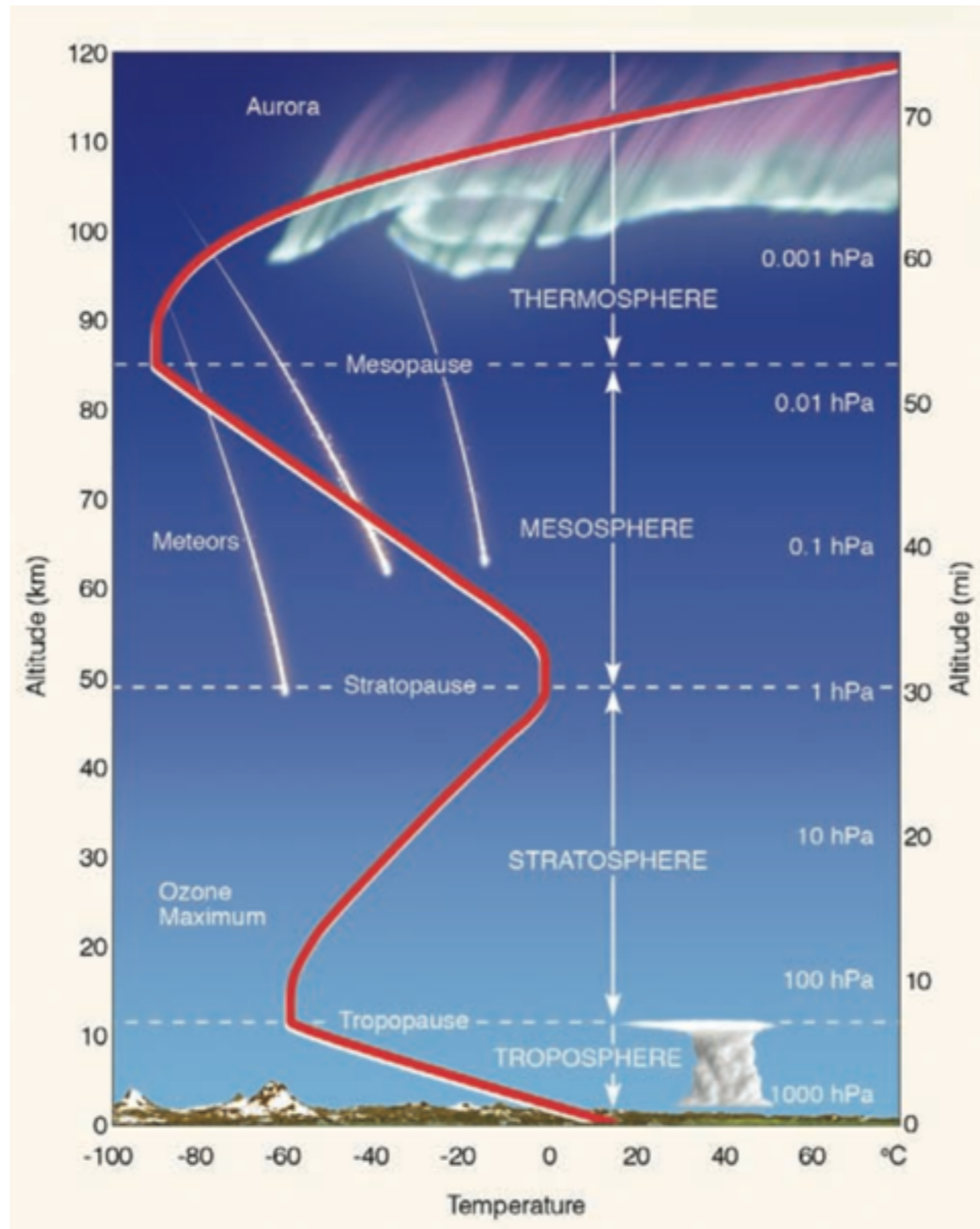
# Atmospheric composition (not a full list)

PERMANENT GASES						
Gas	Symbol	Percent Dry Air (by volume)	Parts per Million* ppm (by volume)	Atmospheric Sources	Atmospheric Sinks (removal mechanism)	Atmospheric Residence Time† (in years)
Nitrogen	N <sub>2</sub>	78.084	780,840	decaying plants and animals combustion	nitrogen-fixing bacteria in soil and oceans lightning	14,000,000
Oxygen	O <sub>2</sub>	20.946	209,460	photosynthesis water and nitrous oxide breakdown by ultraviolet radiation in the stratosphere	plant and animal respiration decaying plants and animals chemical rock weathering growth of shellfish	4,500
Argon	Ar	0.93	9,300	radioactive decay of potassium	no sinks	forever, gradually accumulating

VARIABLE GASES						
Gas and Particles	Symbol	Percent Dry Air (by volume)	Parts per Million* ppm (by volume)	Atmospheric Sources	Atmospheric Sinks (removal mechanism)	Atmospheric Residence Time† (in years)
Water vapour	H <sub>2</sub> O	0 to 4	0 to 40,000	evaporation transpiration	precipitation	0.026 or 9.5 days
Carbon dioxide	CO <sub>2</sub>	0.0389	389	respiration combustion, (especially fossil fuels) industrial activity volcanoes oceans	absorbed by oceans photosynthesis burying organic material (landfills)	5 to 200 plus, depending on source
Methane	CH <sub>4</sub>	0.00018	1.8	wetlands growing rice agriculture	atmospheric oxidation (breaks down when it reacts with OH (hydroxyl) radicals)	8.4

(from Meteorology today)

# Temperature profile



(from *Meteorology today*)

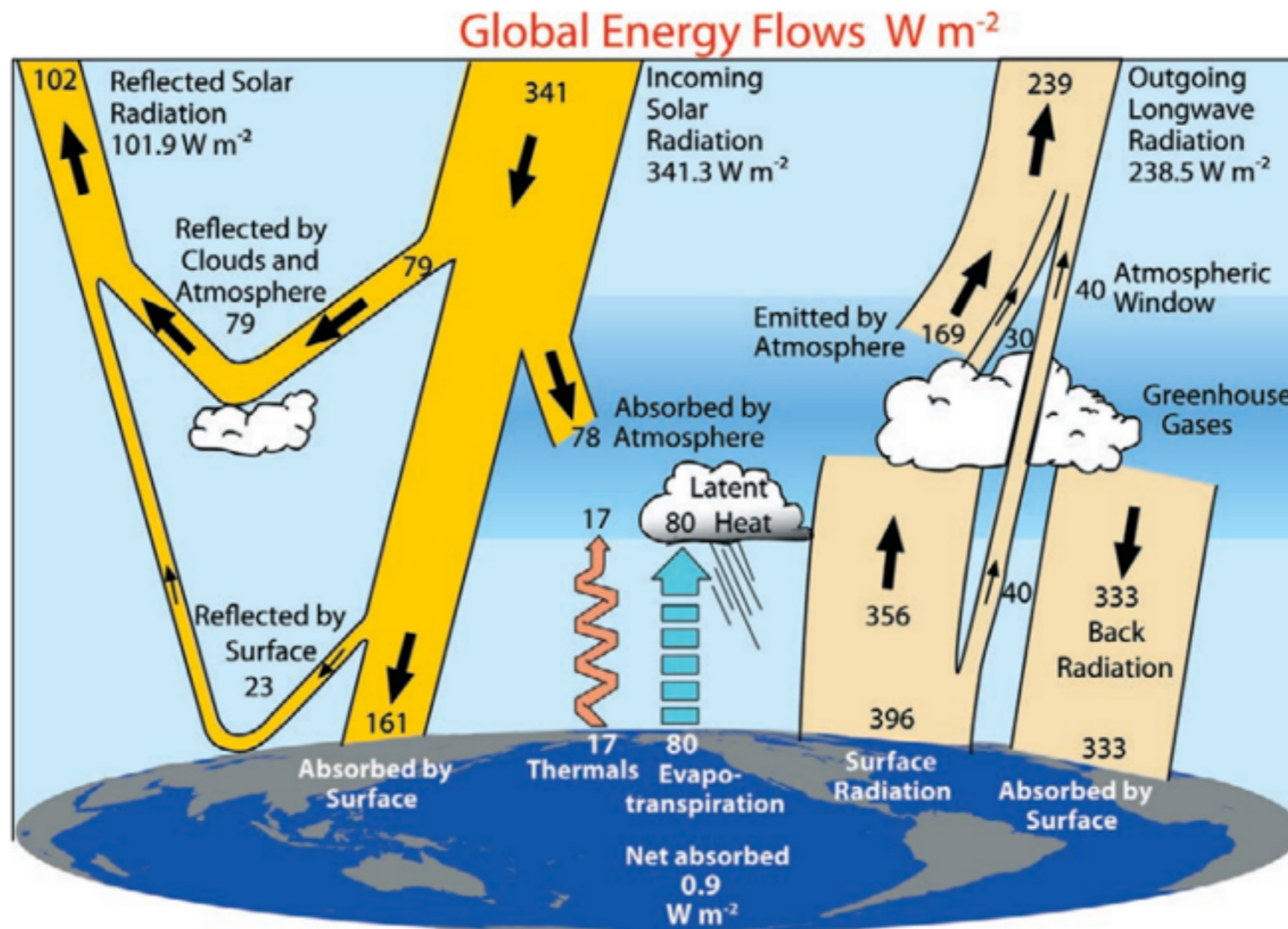
Rocketsonde  
(~20-100 km)



Radiosonde  
(~10-40 km)



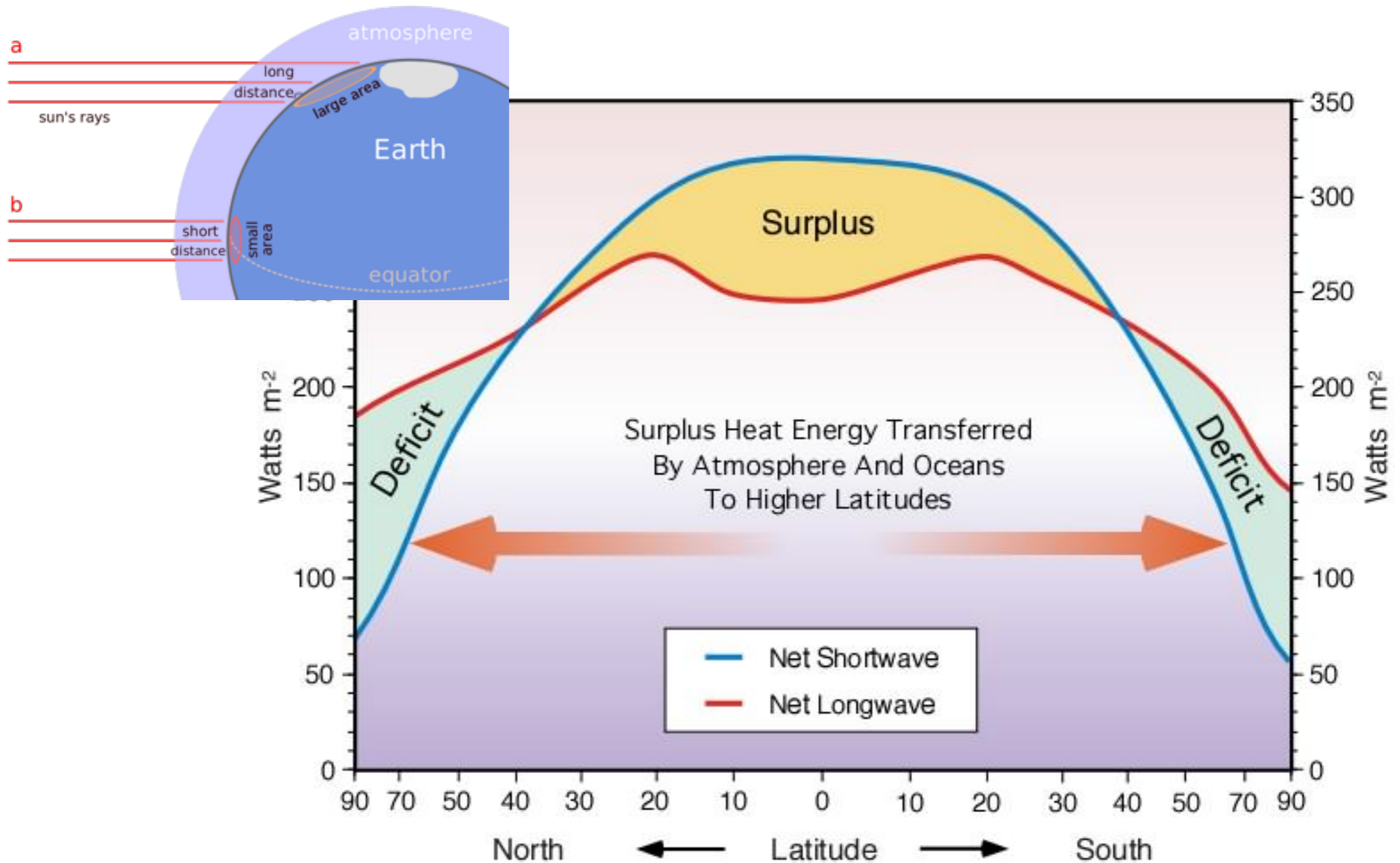
# Earth's energy budget



**FIG. 1. The global annual mean Earth's energy budget for the Mar 2000 to May 2004 period ( $W m^{-2}$ ). The broad arrows indicate the schematic flow of energy in proportion to their importance.**

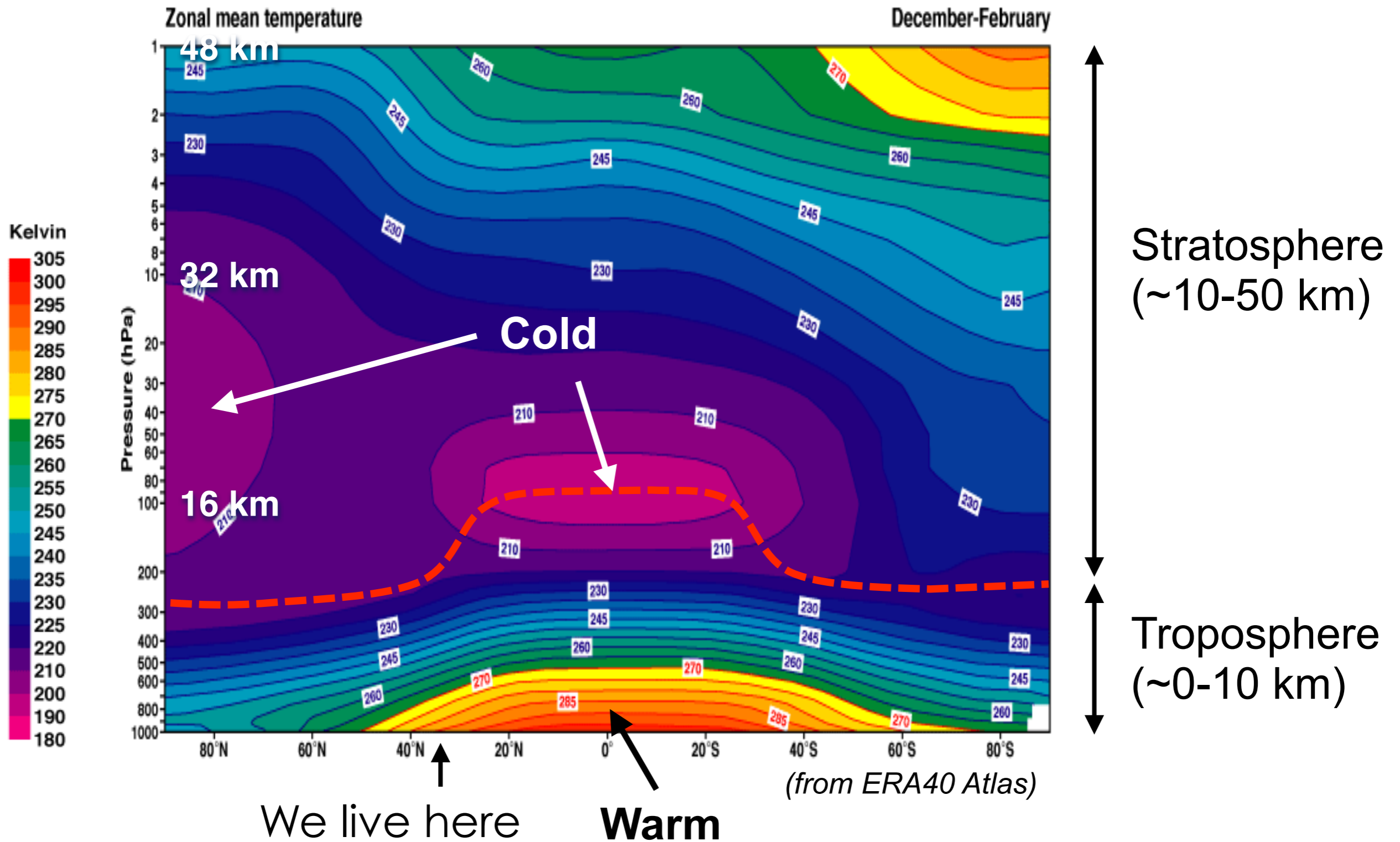
*(Trenberth 2009, BAMS)*

# Energy transport



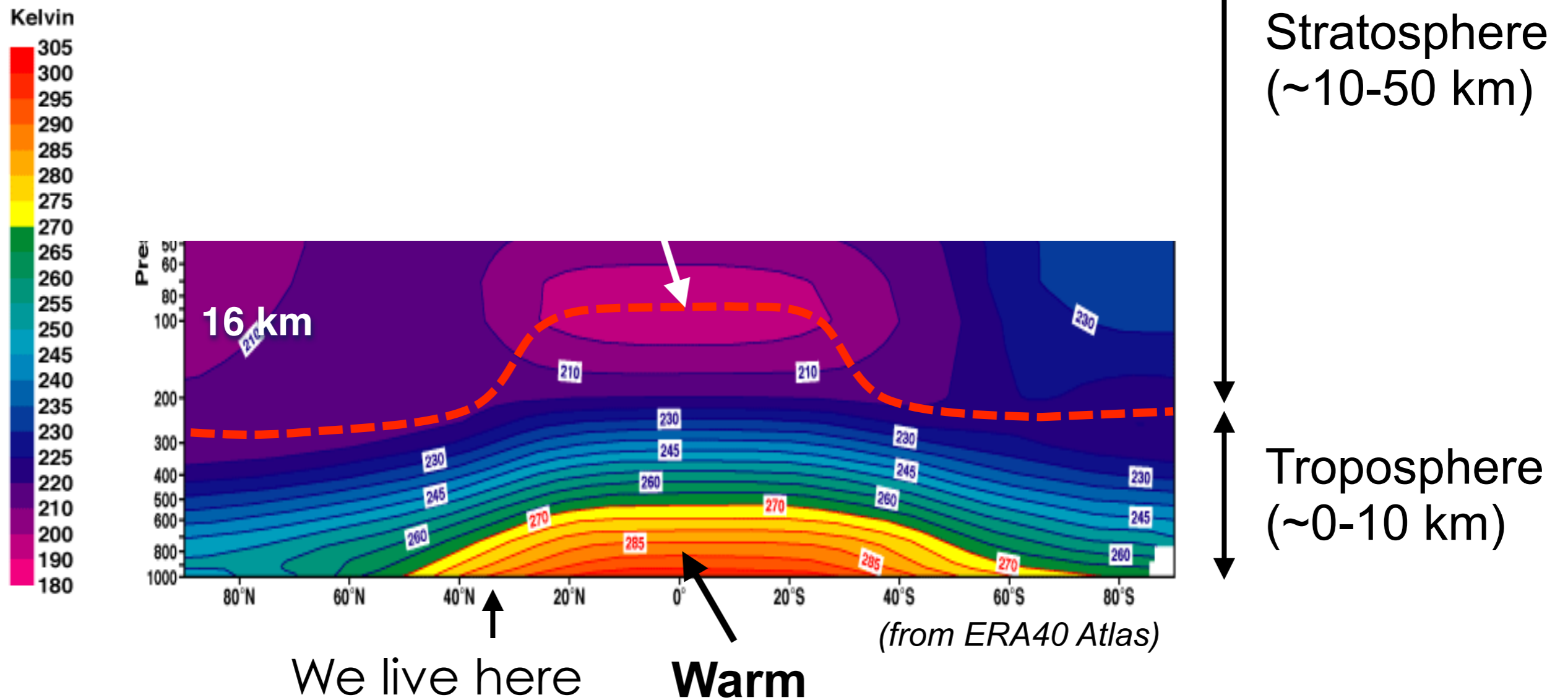
(from wikibooks and <http://www.physicalgeography.net>)

# Meridional structure (temperature)

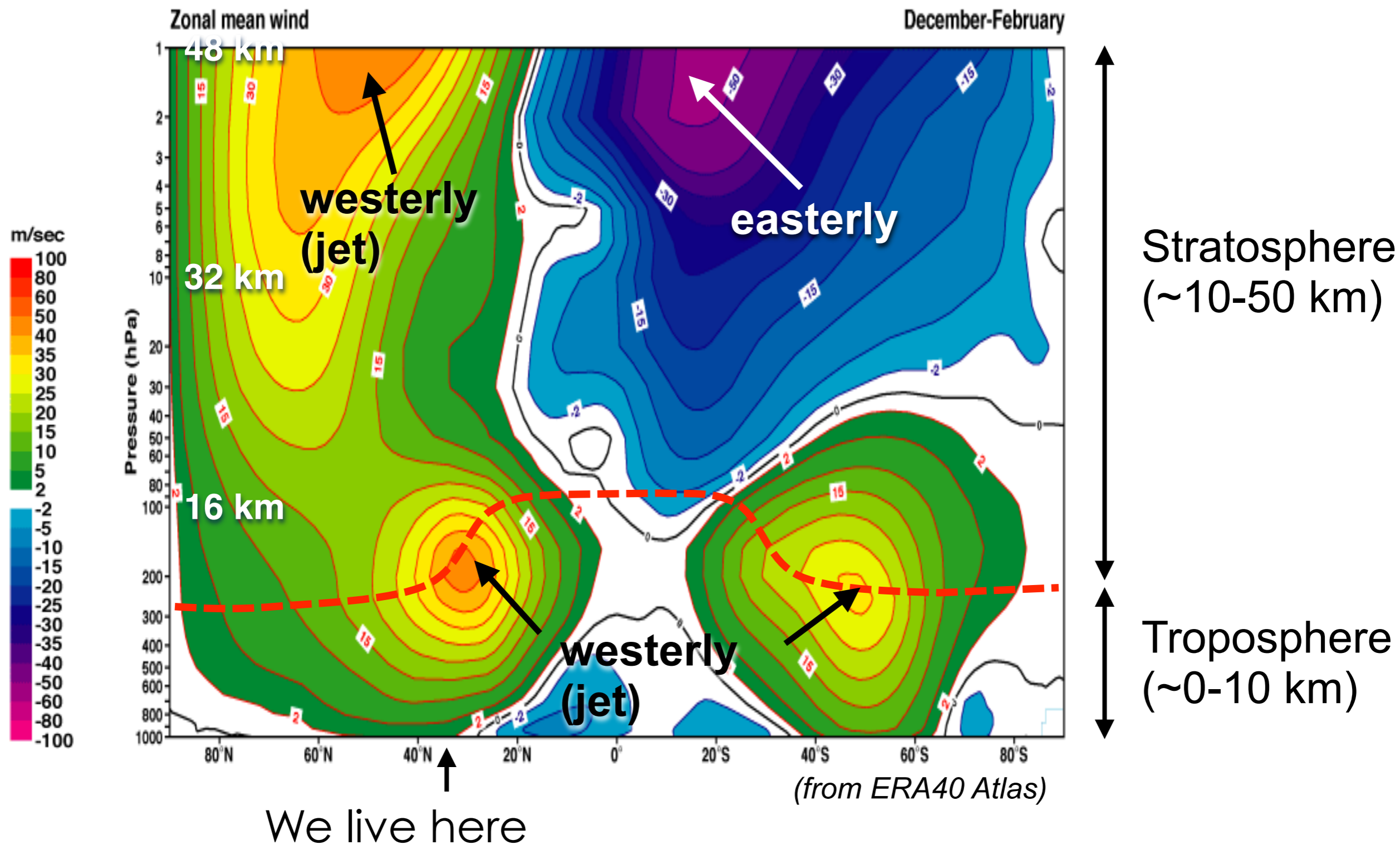


# Meridional structure (temperature)

Will be covered in another course

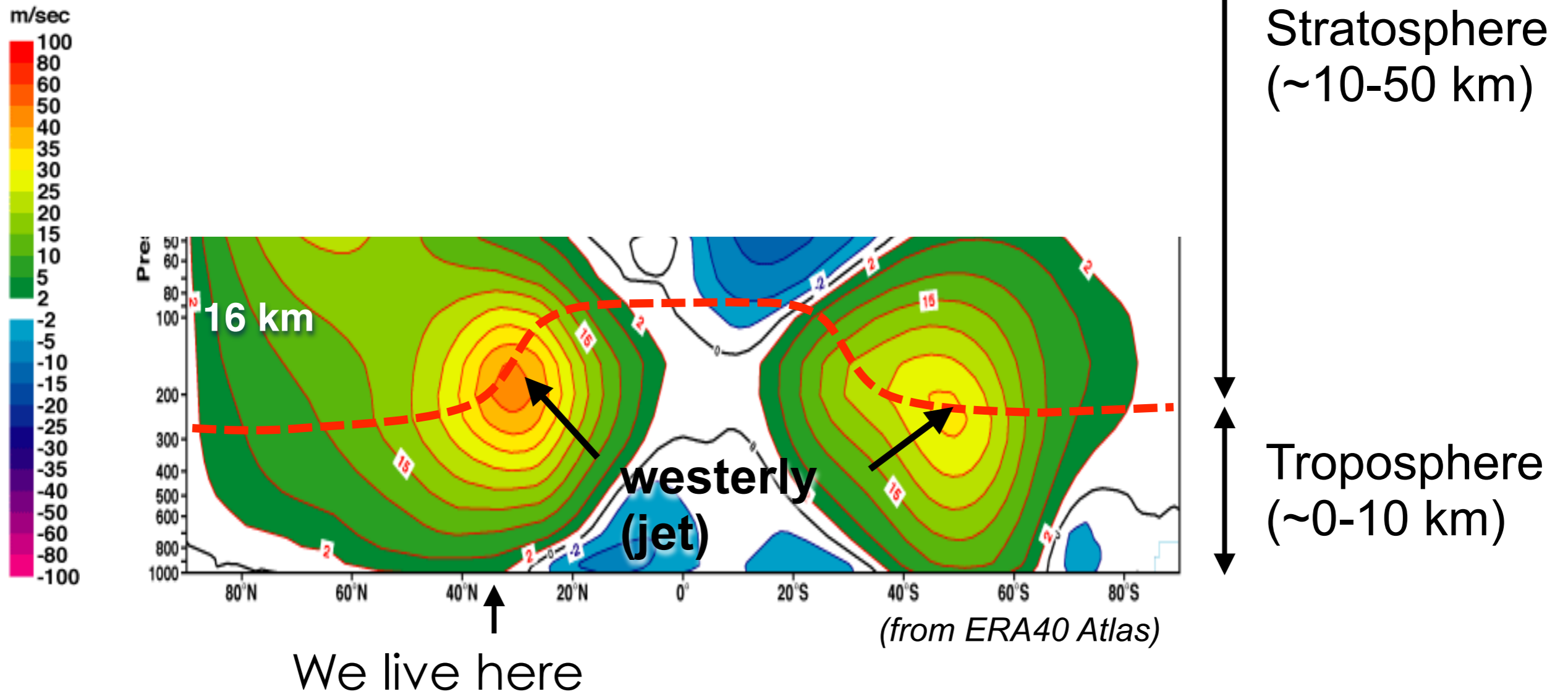


# Meridional structure (zonal wind)



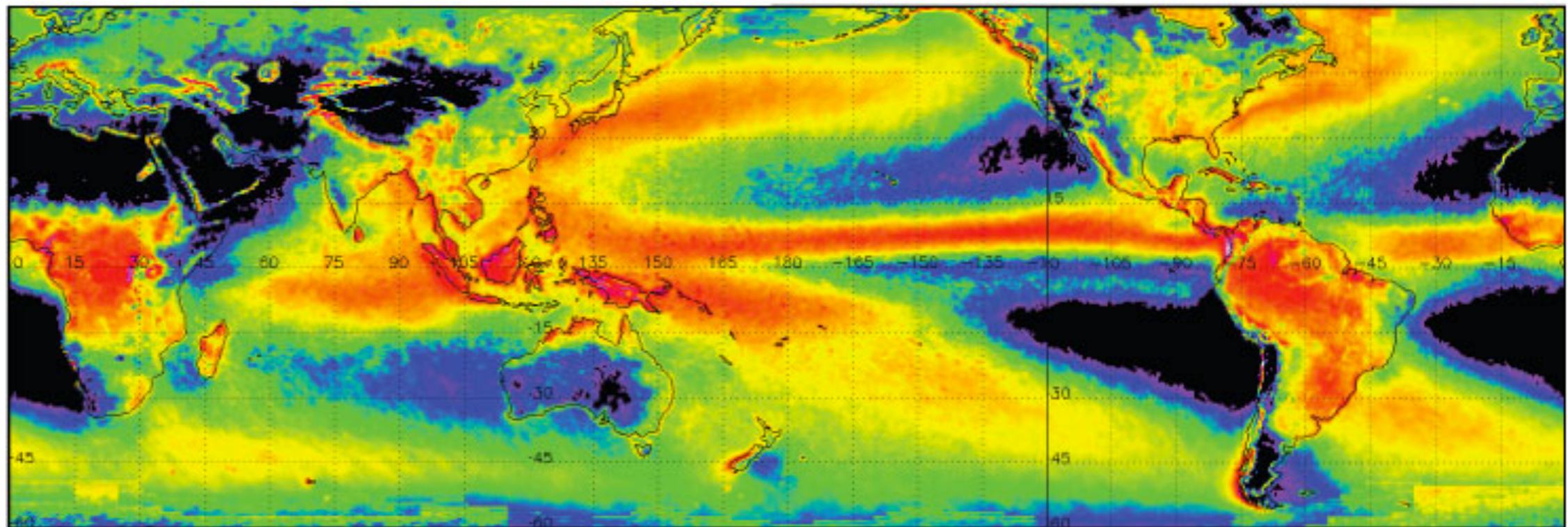
# Meridional structure (zonal wind)

Will be covered in another course

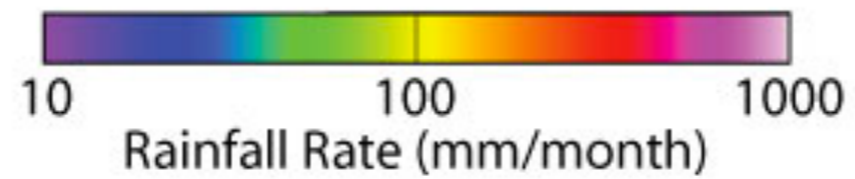


# Convection

Global Rainfall Rate

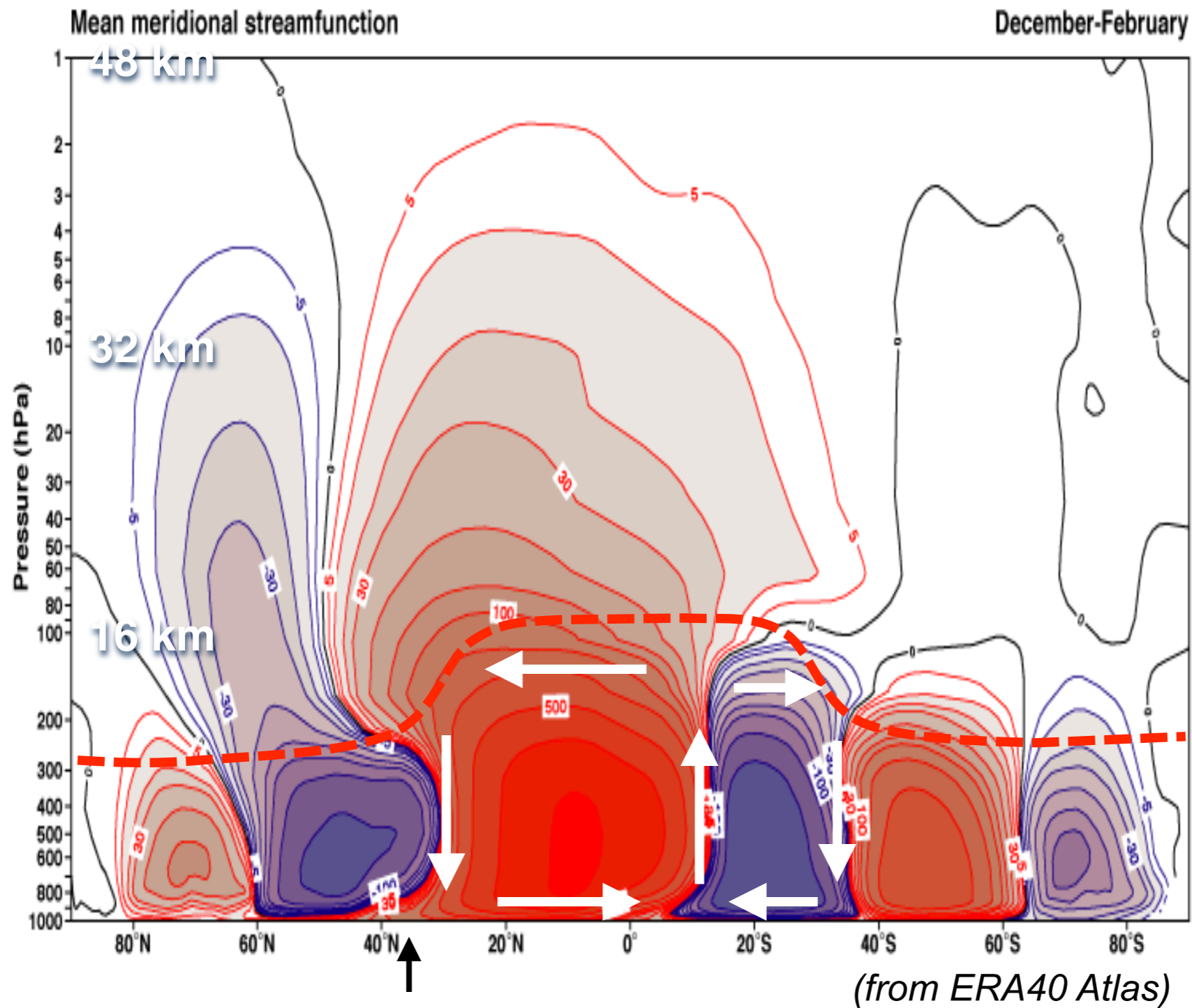


Negri (2004)



*(from Negri, 2004)*

# Meridional structure (meridional wind)

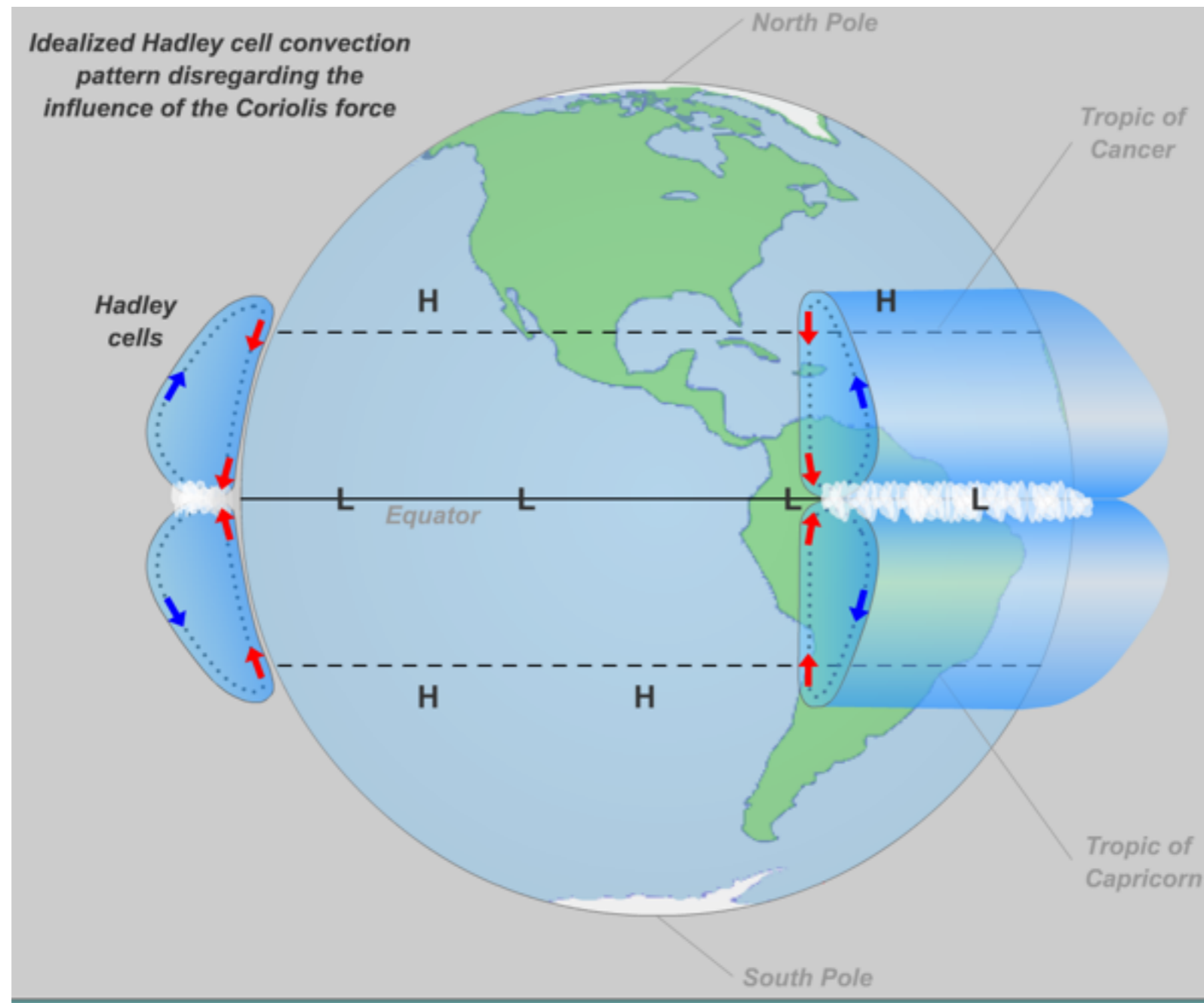


Stratosphere  
(~10-50 km)

Troposphere  
(~0-10 km)

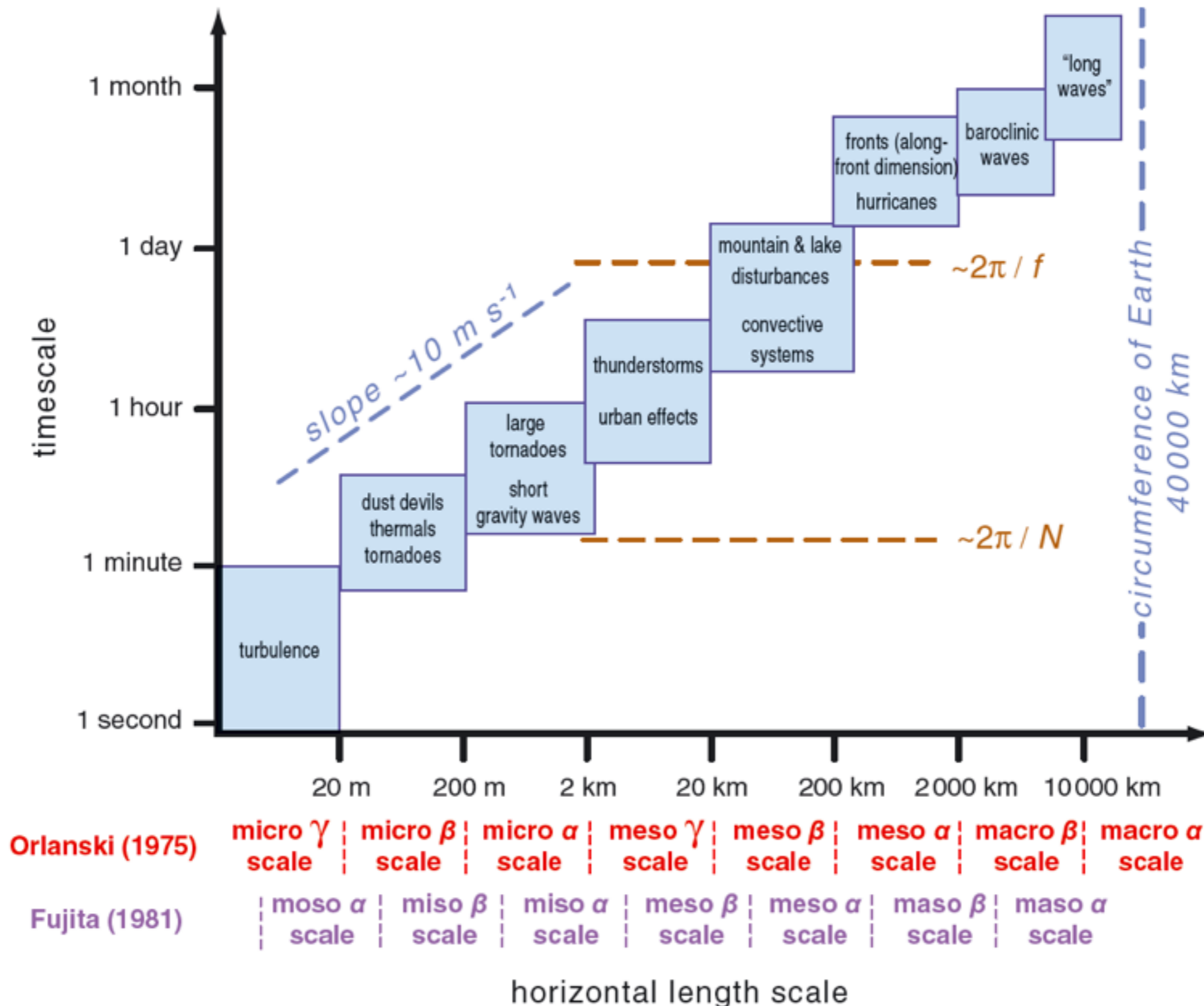
↑  
We live here

# Global circulation

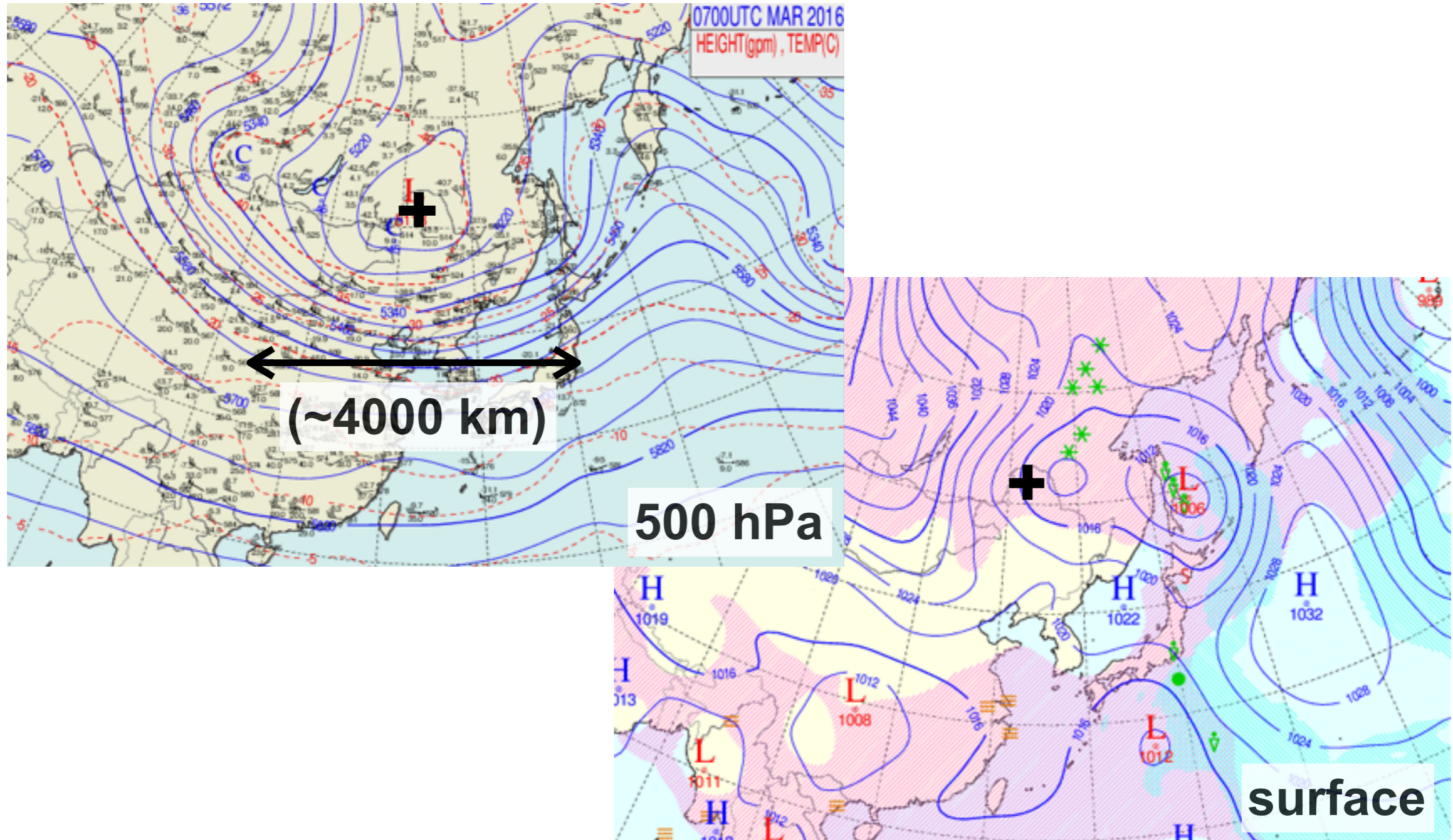


- <http://www.geography.hunter.cuny.edu/tbw/wc.notes/7.circ.atm/animations/GlobalWind.html>

# Atmospheric phenomena (and their scale)

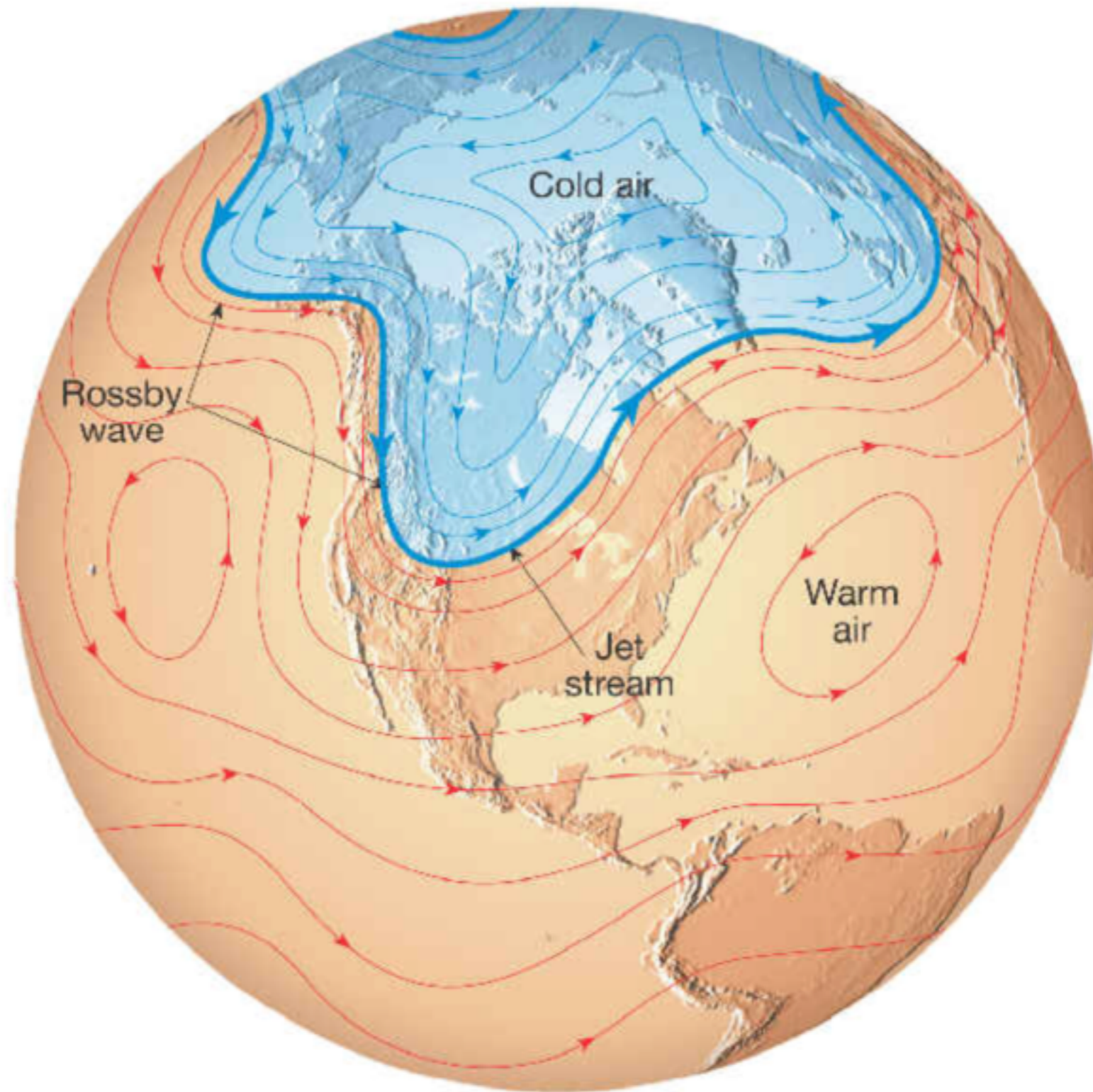


# Baroclinic waves (mid-latitudes)



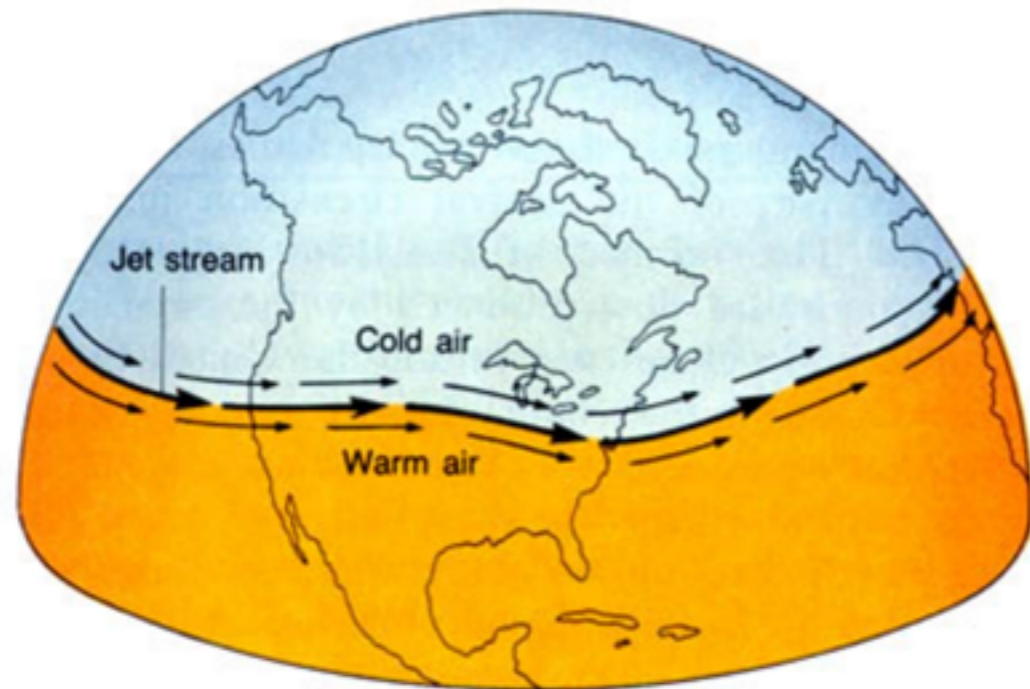
(from web.kma.go.kr)

# Rossby wave

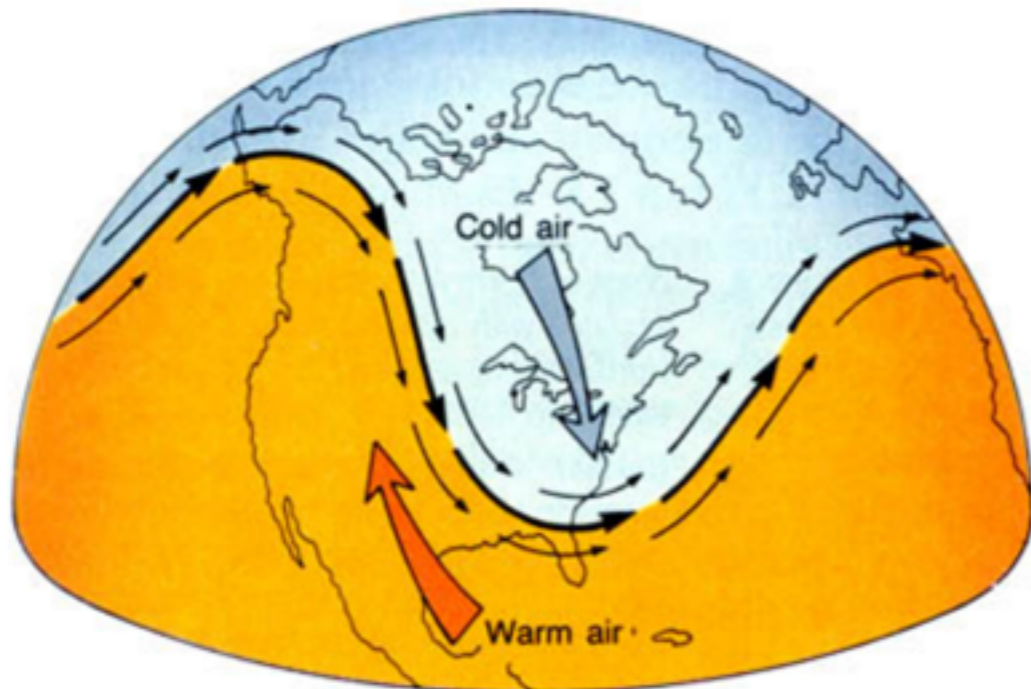


*(from [www.geography.hunter.cuny.edu](http://www.geography.hunter.cuny.edu))*

# Rossby wave



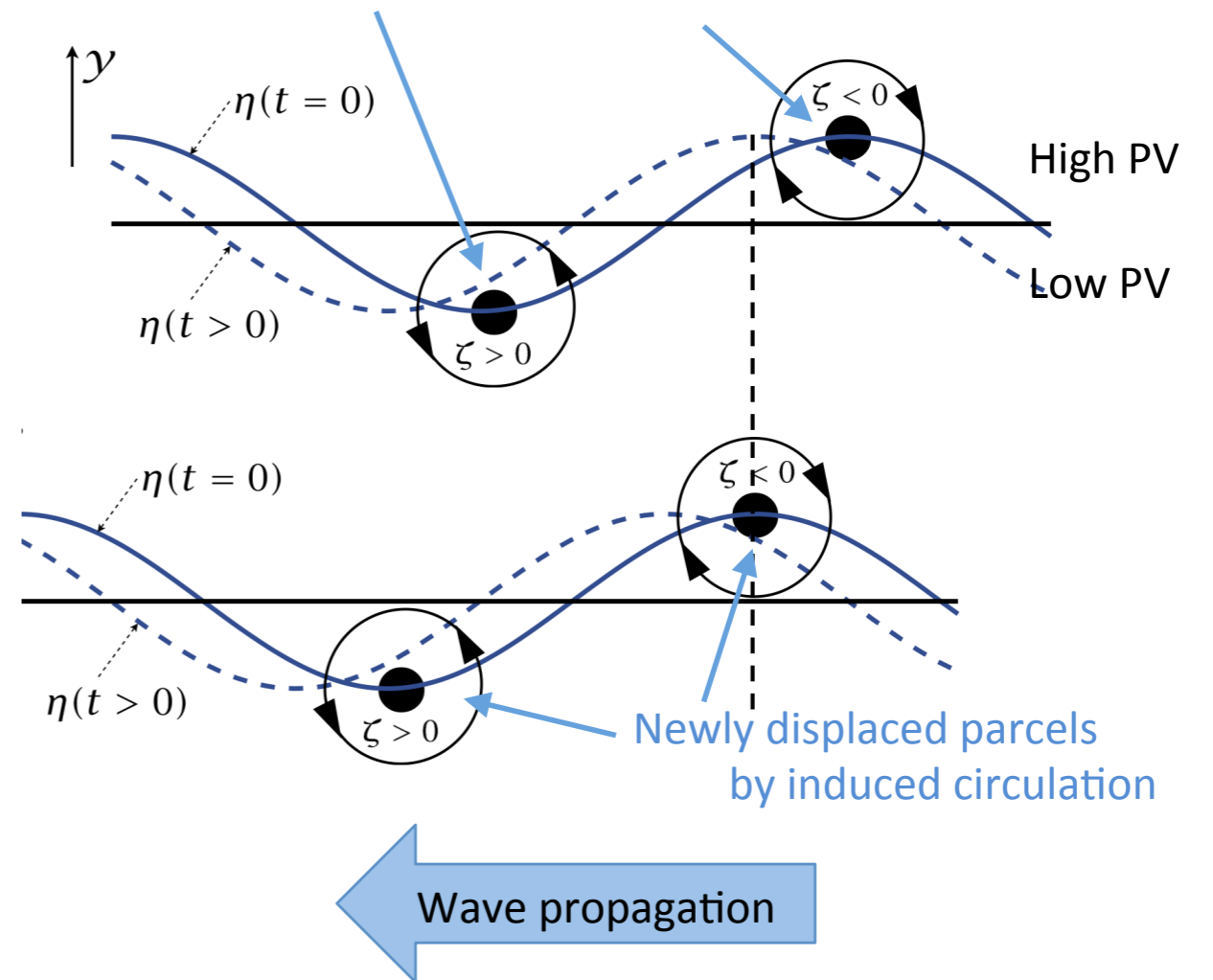
(a)



(c)

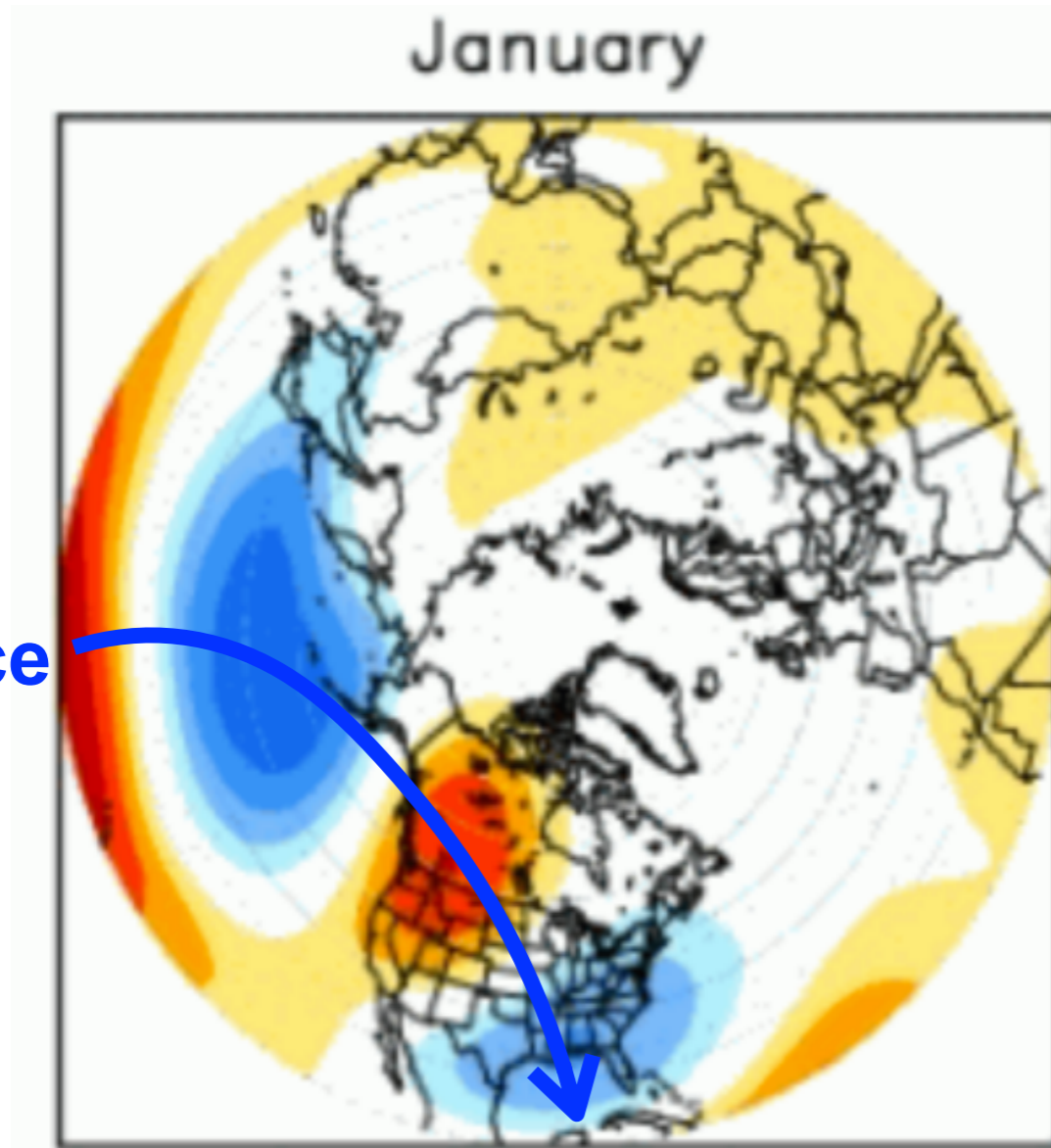
(+) tive PV anomaly  
=> cyclonic circ.

(-) tive PV anomaly  
=> anticyclonic circ.



(from *Atmosphere, Weather and Climate*)

# Rossby wave (energy propagation)



*Pacific/North American Pattern (PNA)  
(from CPC, NOAA)*

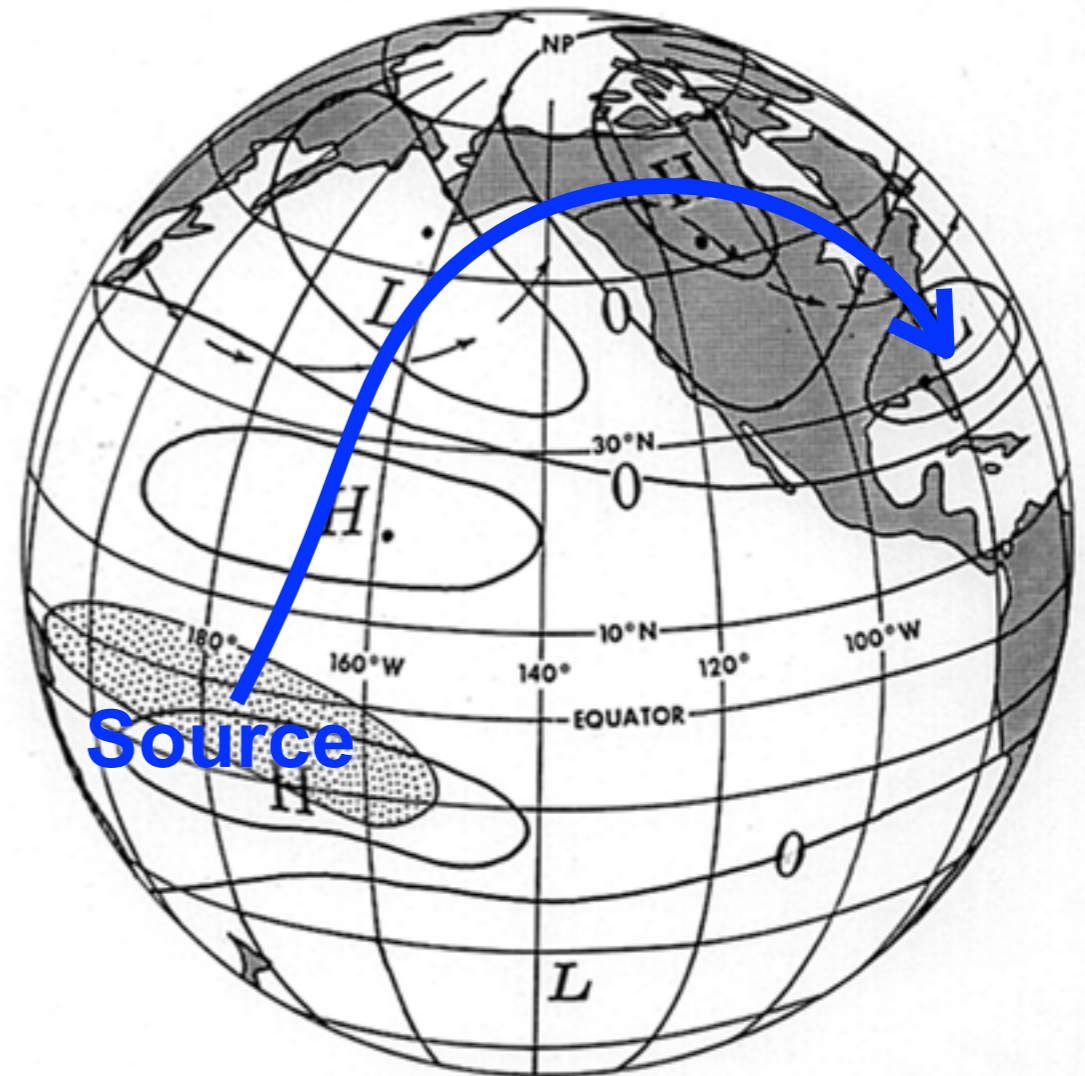
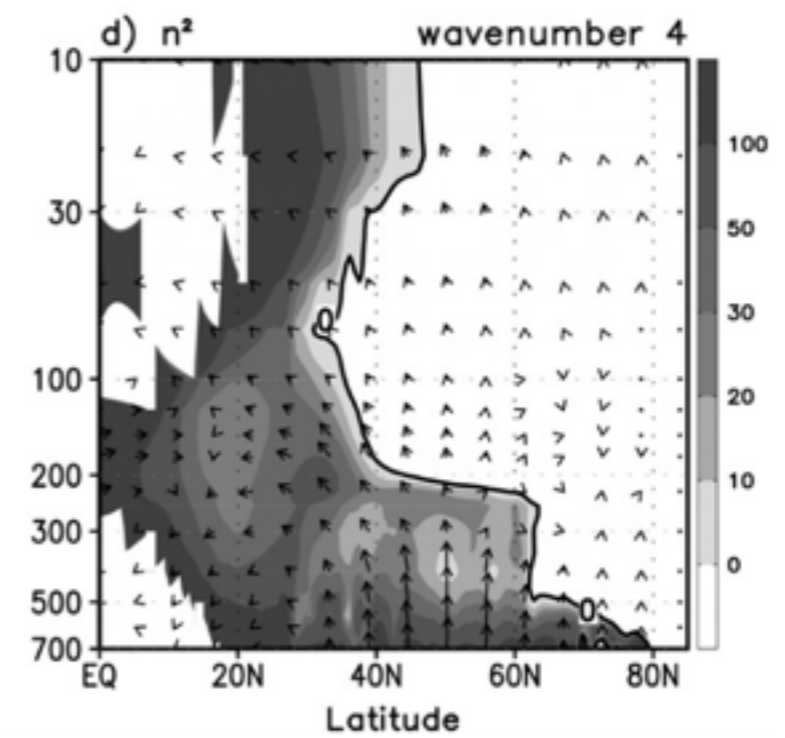
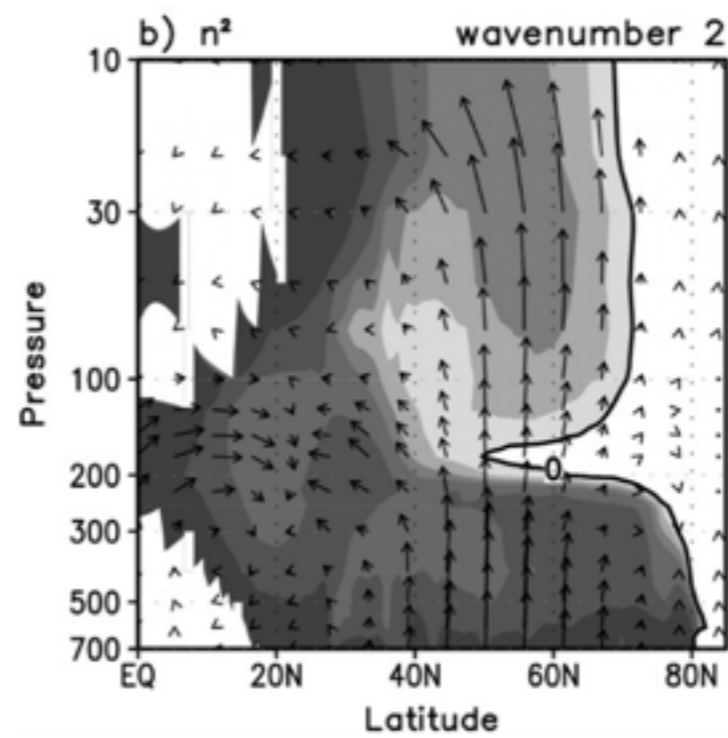
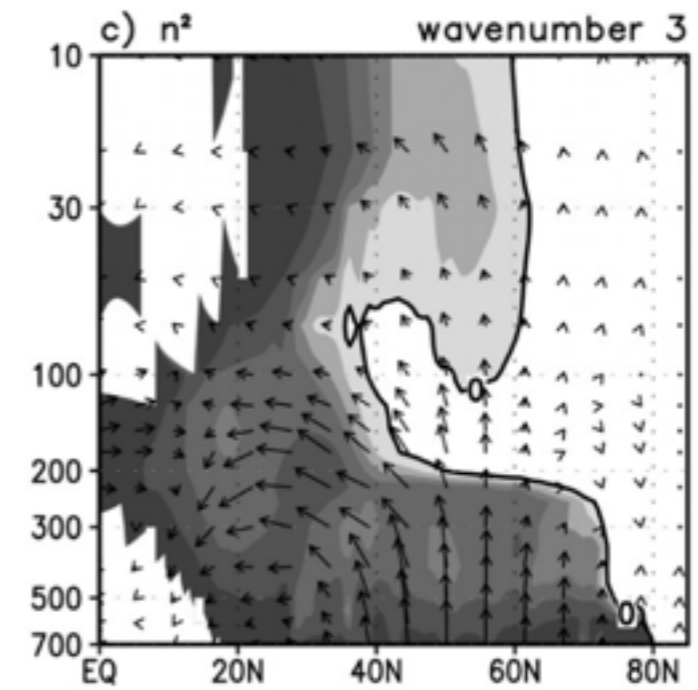
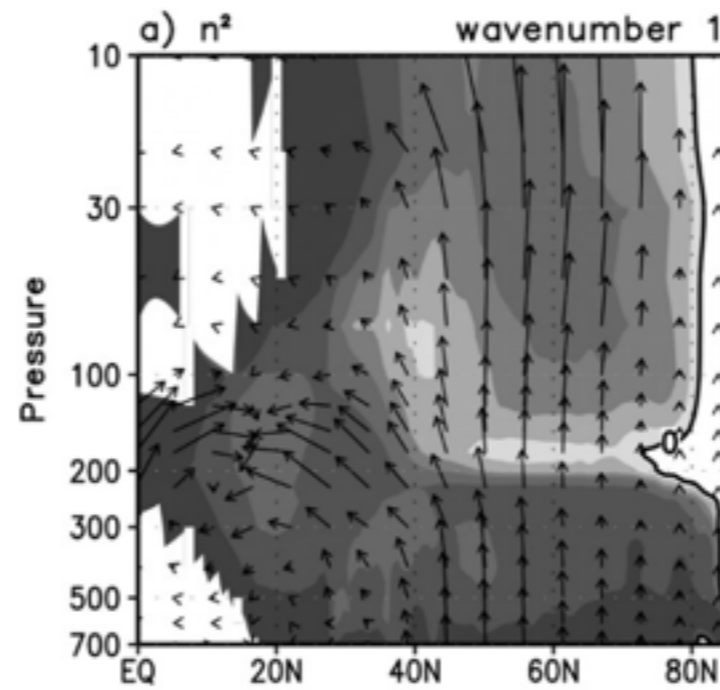
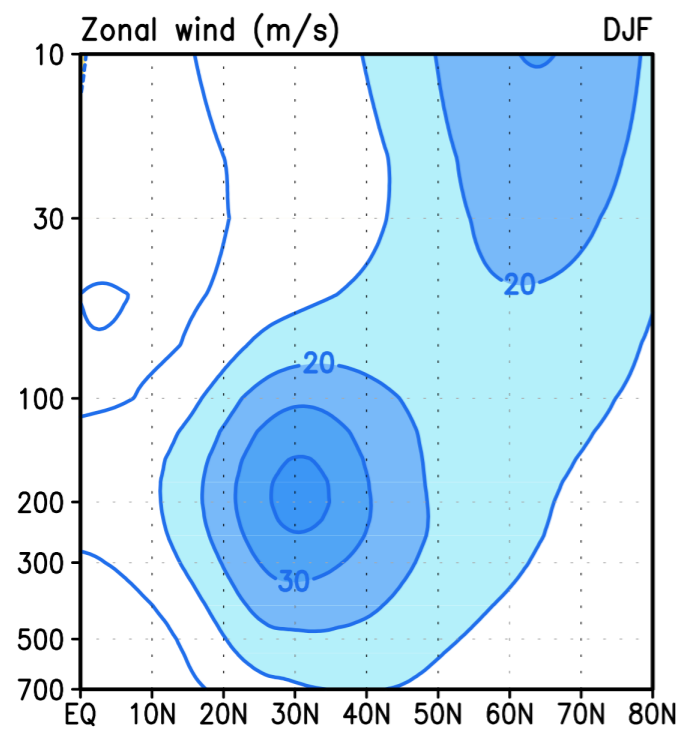


Figure 1.26. A schematic diagram of the Pacific North American (PNA) pattern of middle- and upper-tropospheric geopotential height anomalies during a Northern Hemisphere winter that coincides with El Niño conditions in the tropical Pacific. The arrows depict a mid-tropospheric streamline as distorted by the anomaly pattern, with pronounced "troughing" over the central Pacific and "ridging" over western Canada. Cloudiness and rainfall are enhanced over the shaded area. The dots indicate the stations used in the time series mentioned in Table 1.1. [From Horel and Wallace (1981).]

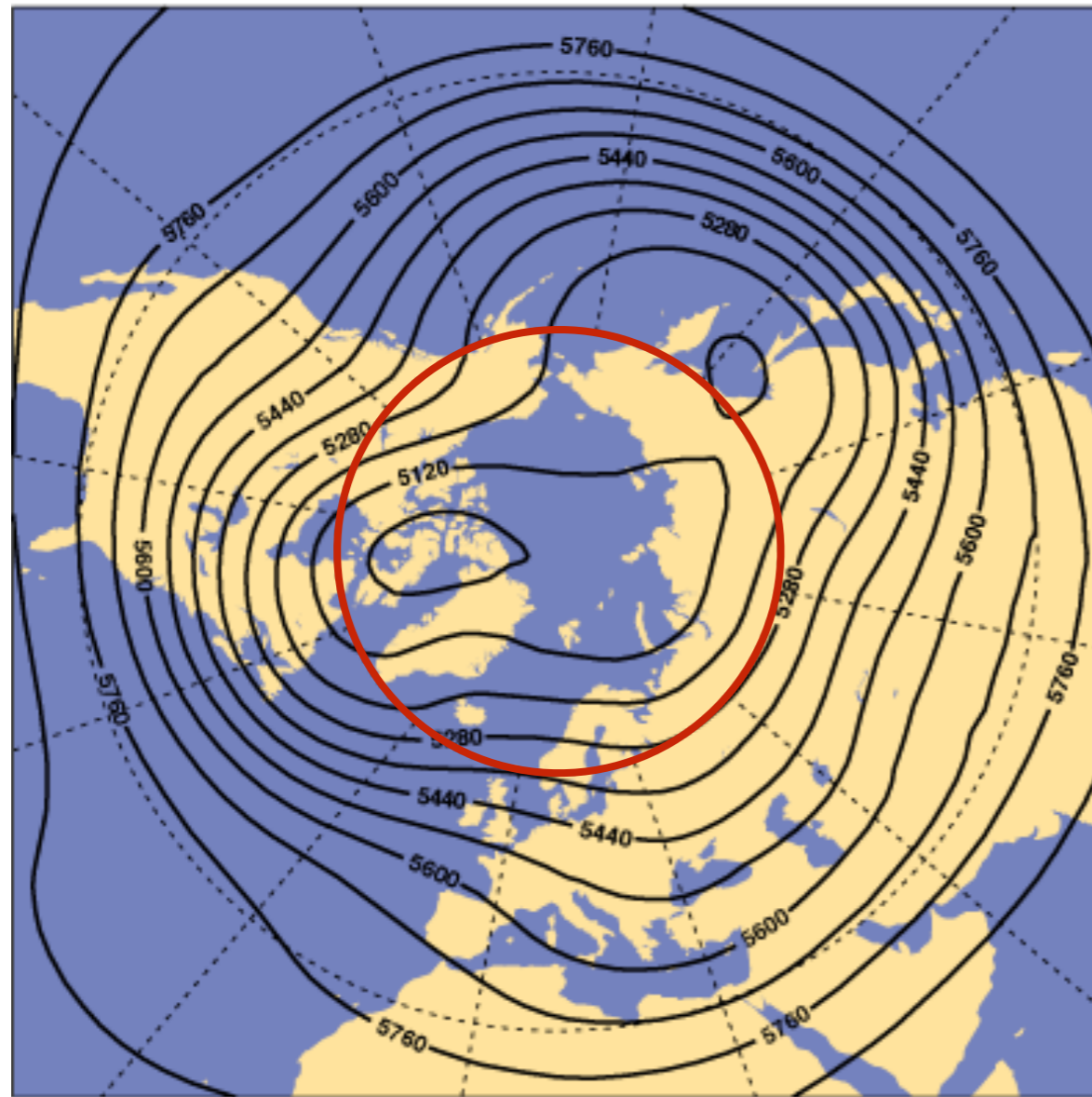
# Rossby wave (energy propagation)



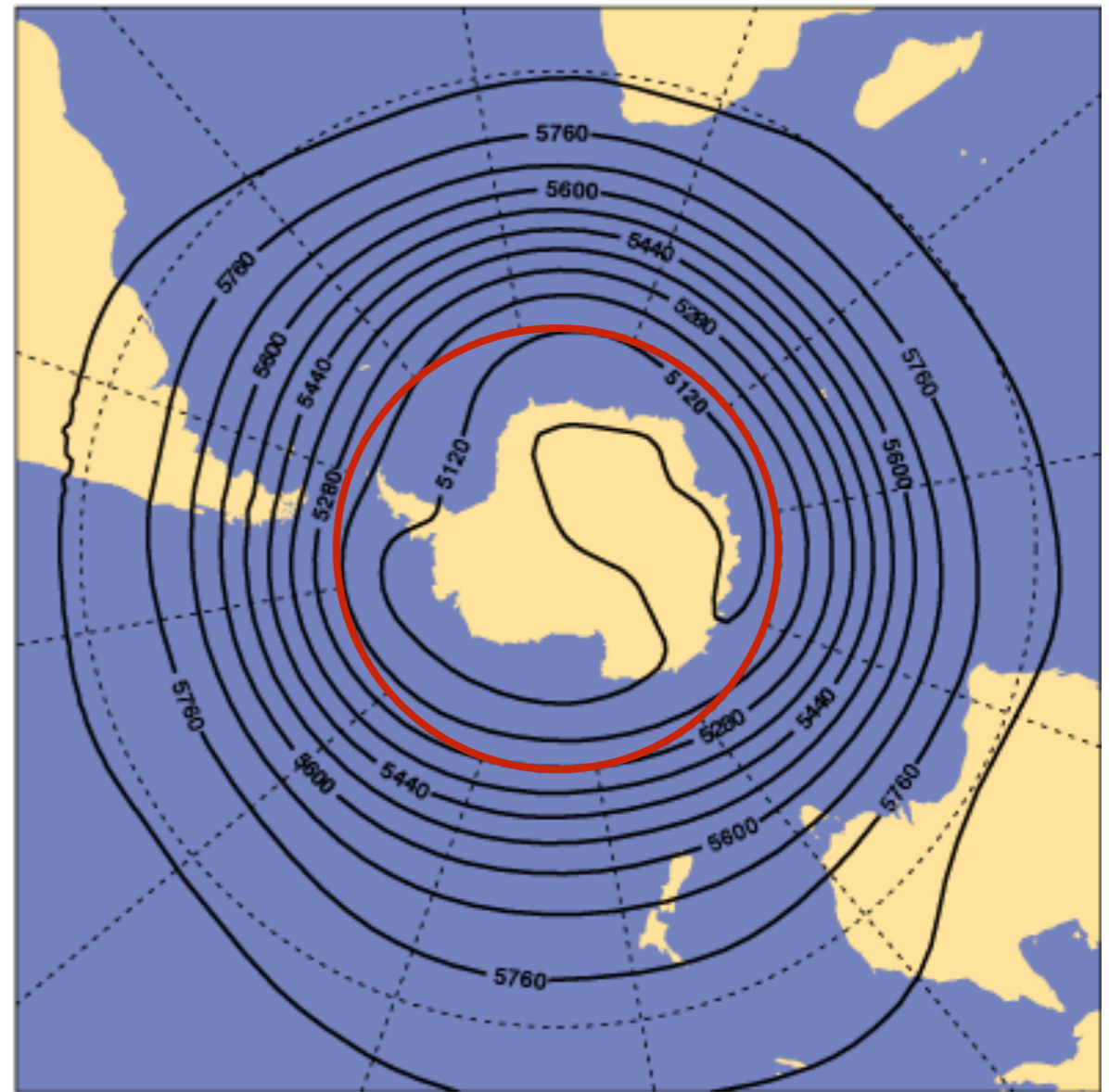
(Kim et al. 2016)

# Stationary waves (mid-latitudes)

Geopotential height at 500 hPa



December-February

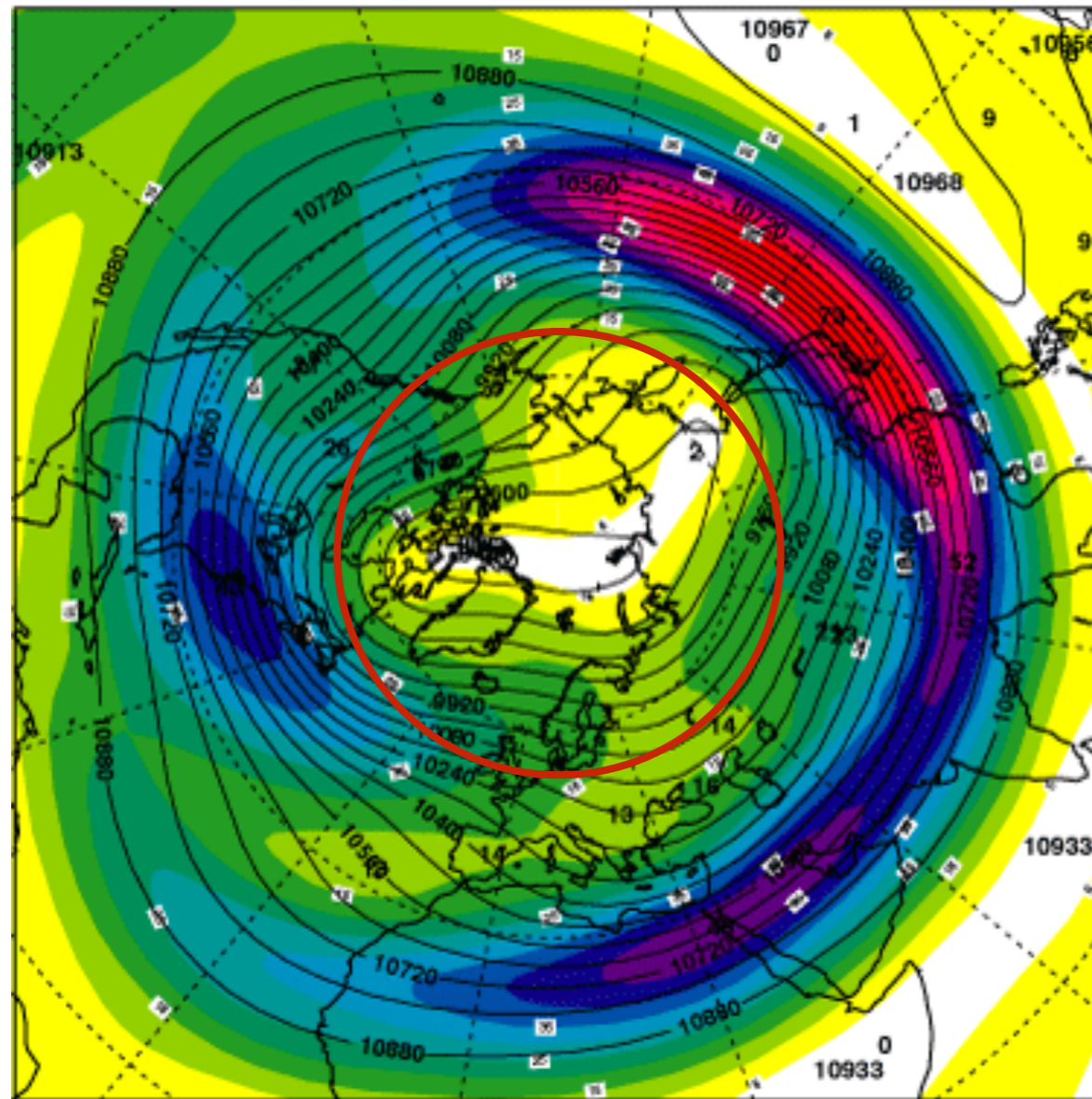


(from ERA40 Atlas)

- Effects of topography and land-sea contrast (N. Hemisphere)

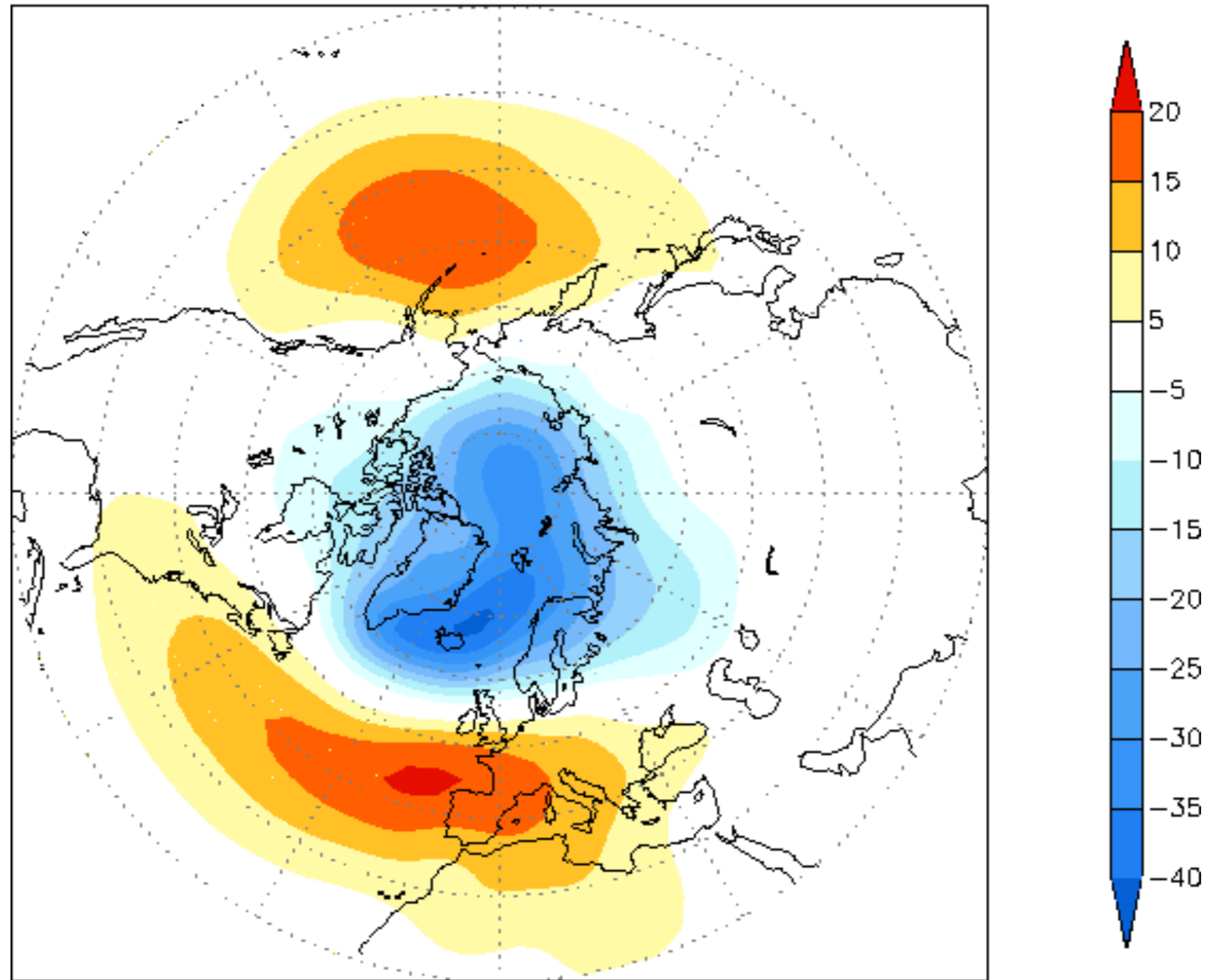
# Stationary waves (mid-latitudes)

Geopotential height (m) (contours) and isotachs at 250 hPa



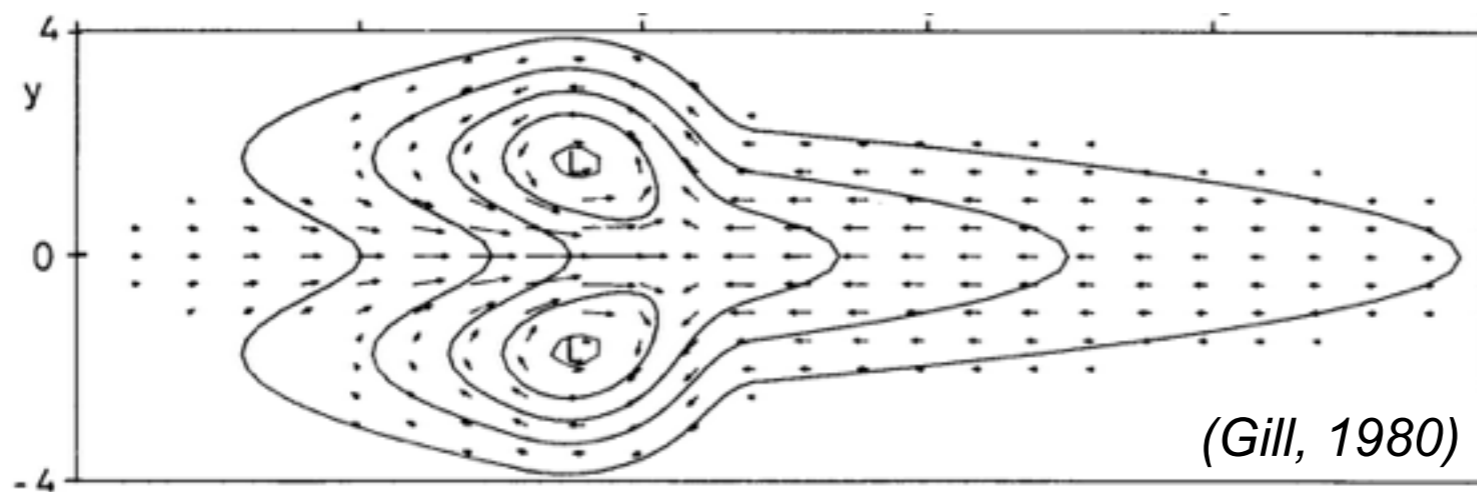
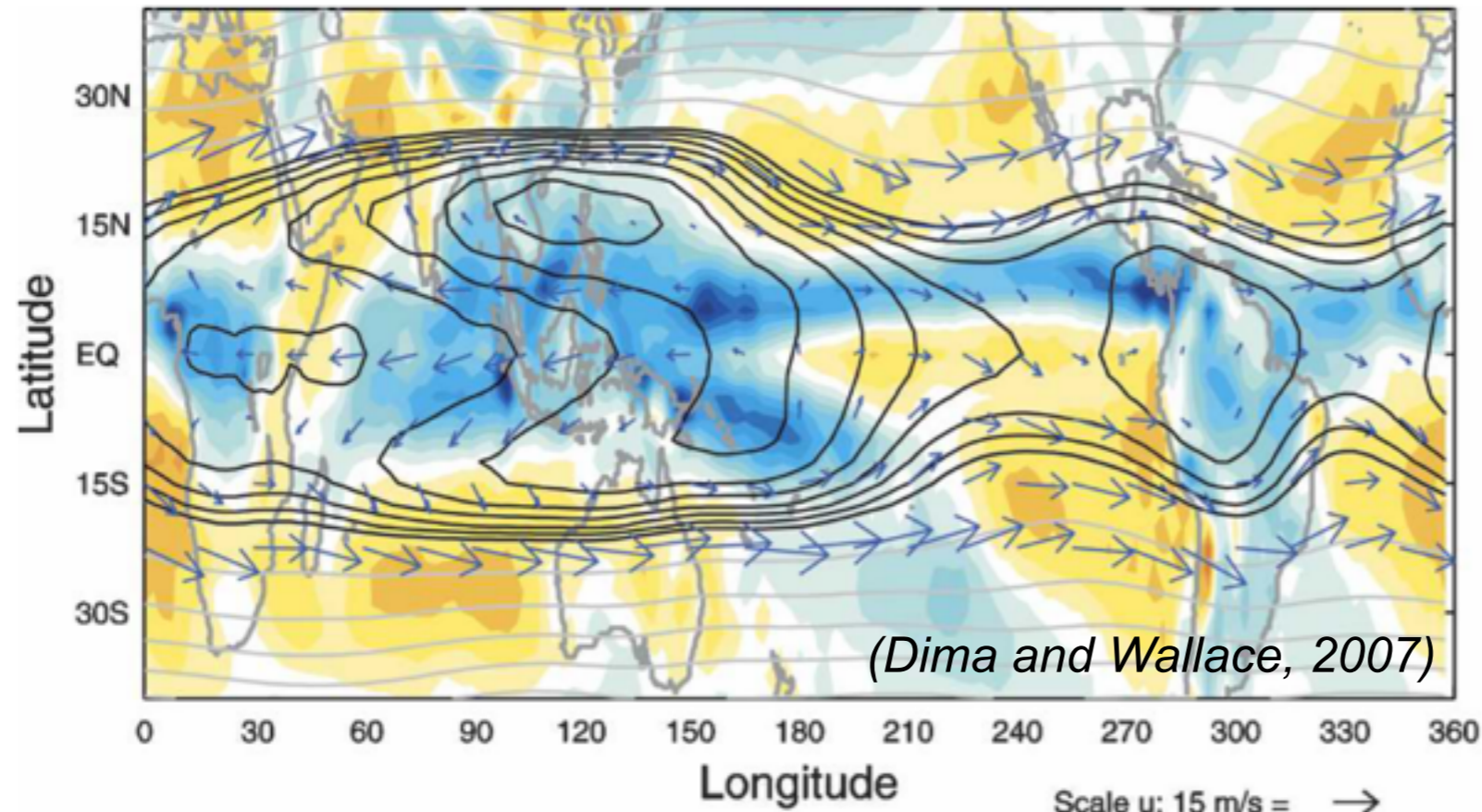
# Arctic Oscillation (AO; high latitude)

Leading EOF (19%) shown as regression map of 1000mb height (m)



(from CPC, NOAA)

# Gill-type response (tropics)



From basic equations set

$$\frac{\partial u}{\partial t} - \frac{1}{2} y v = -\frac{\partial p}{\partial x},$$

$$\frac{\partial v}{\partial t} + \frac{1}{2} y u = -\frac{\partial p}{\partial y},$$

$$\frac{\partial p}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = -Q.$$

Simplify and solve

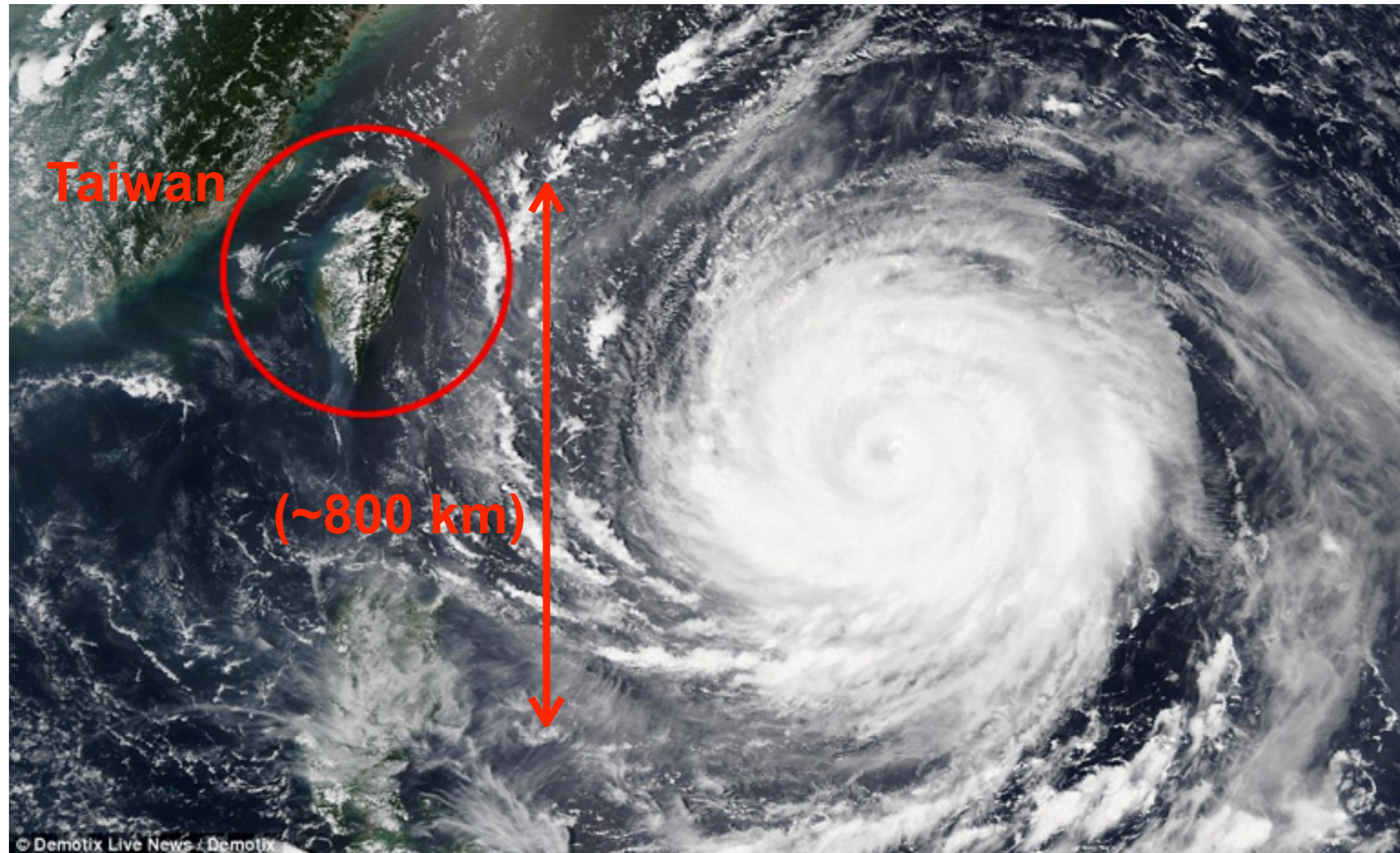
$$\varepsilon u - \frac{1}{2} y v = -\frac{\partial p}{\partial x},$$

$$\varepsilon v + \frac{1}{2} y u = -\frac{\partial p}{\partial y},$$

$$\varepsilon p + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = -Q,$$

$$w = \varepsilon p + Q.$$

# Tropical cyclone (typhoon, hurricane)

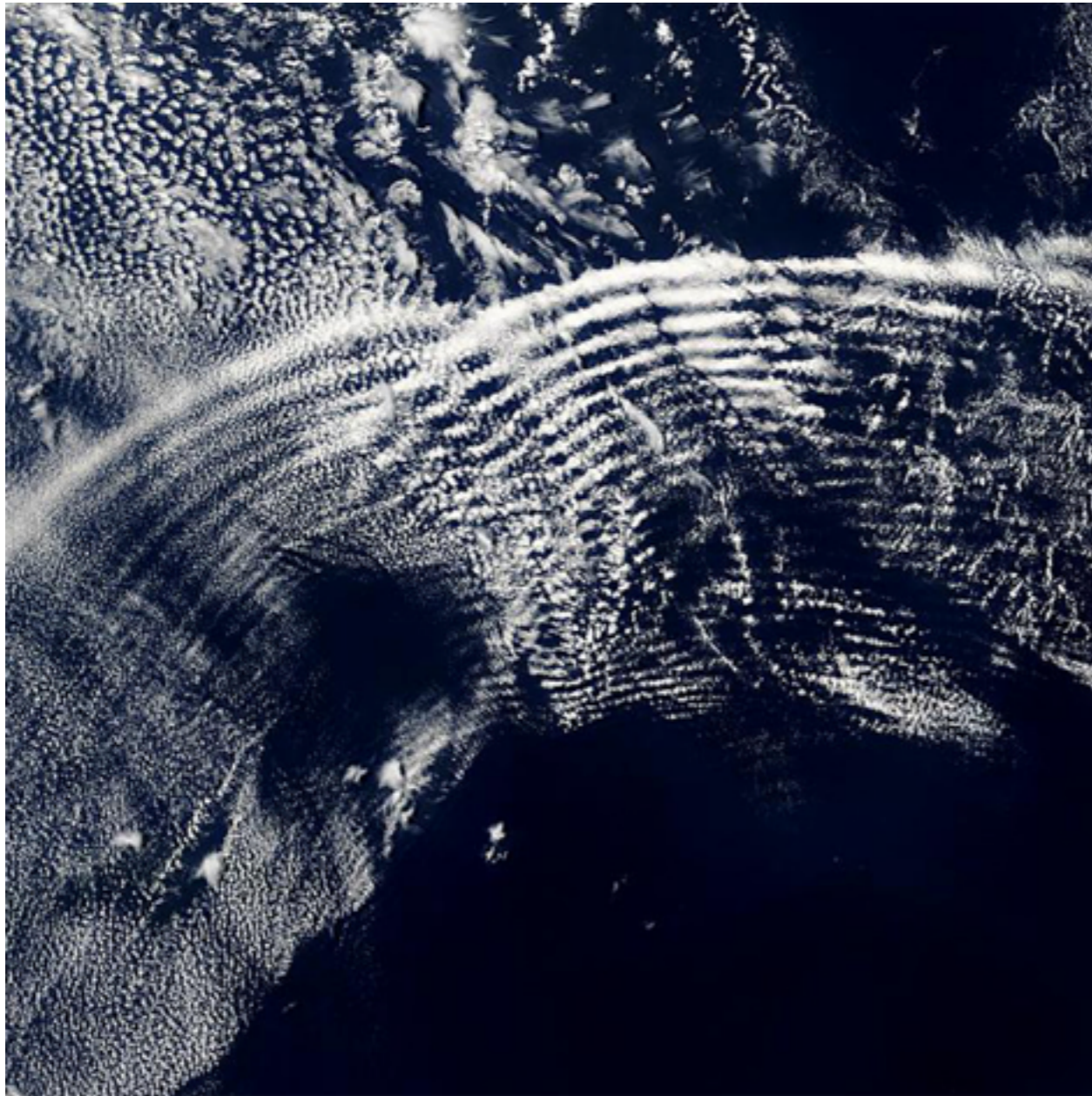


*(Typhoon Soudelor, NASA)*

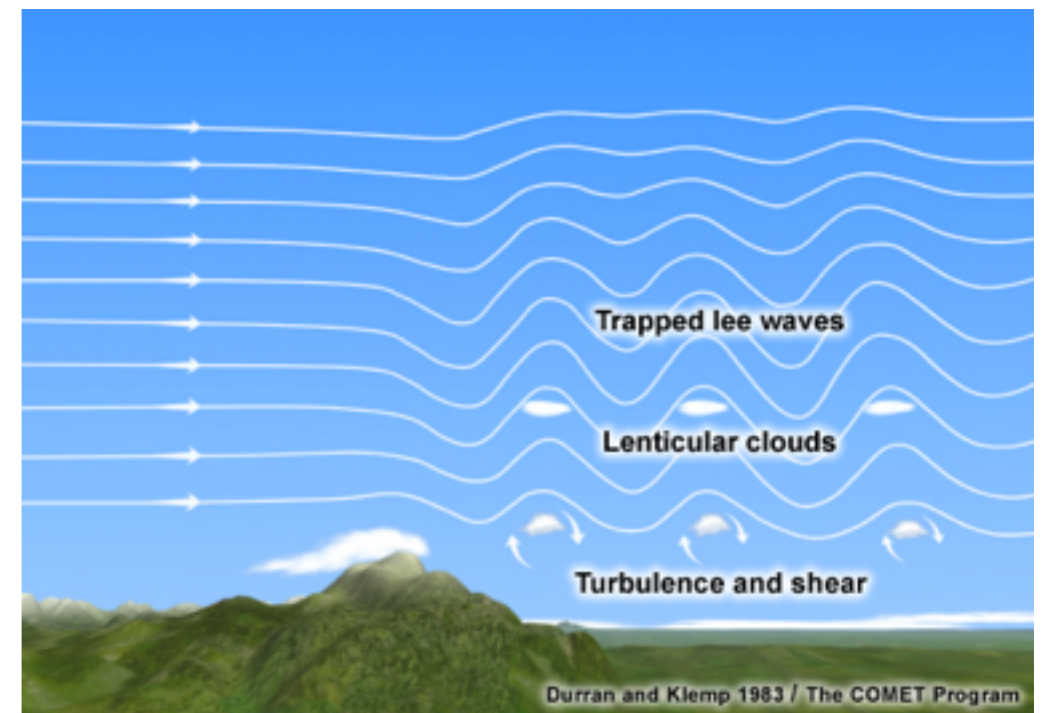
# Tornado



# Gravity waves



*(Gravity waves near Australia, NASA)*



*(from MetEd)*