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Baltic Earth
Earth System Science for the Baltic Sea Region

Climate state and global circulation patterns in the atmosphere

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The atmosphere

- Properties
- Processes
  - Radiation (SW and LW radiation)
  - Dynamics (mean meridional circ., eddies)
  - Turbulence
- Water and clouds

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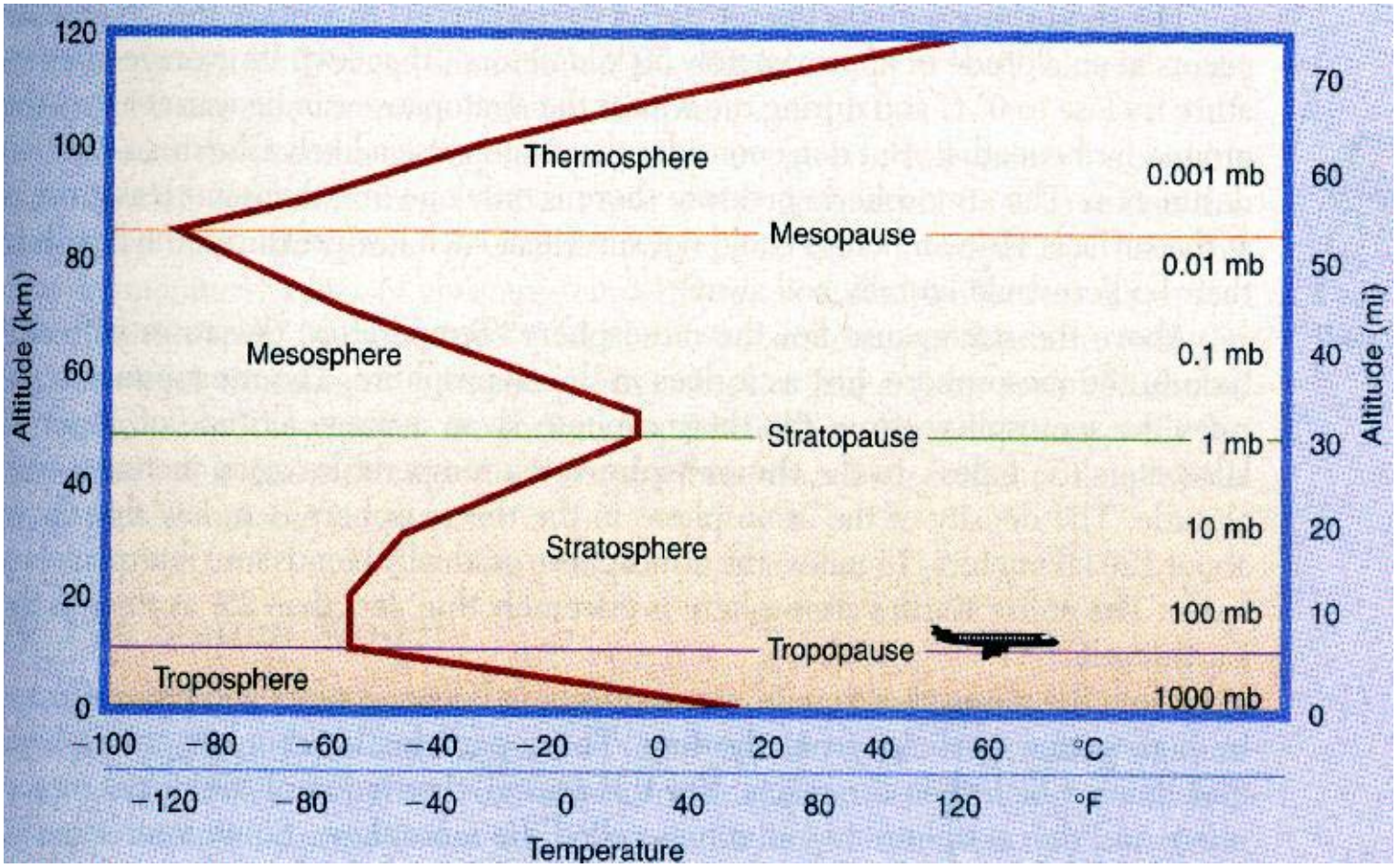
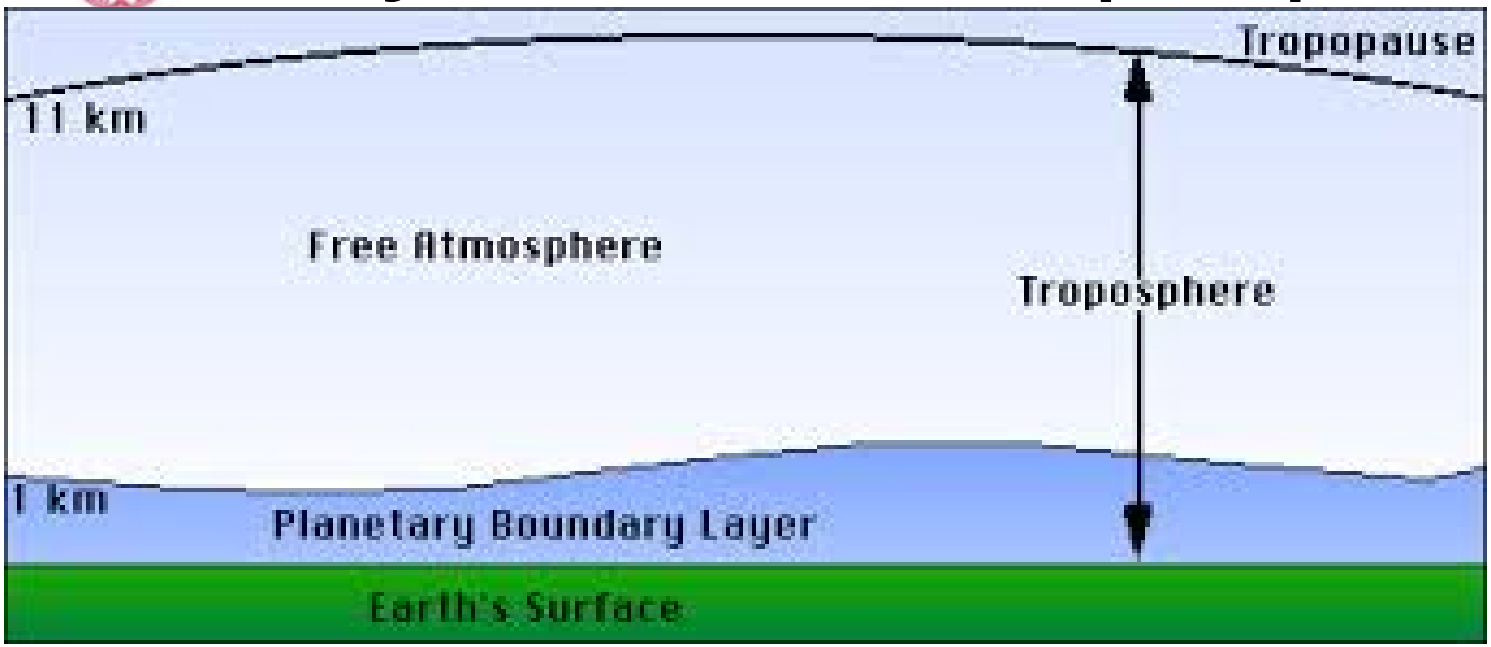
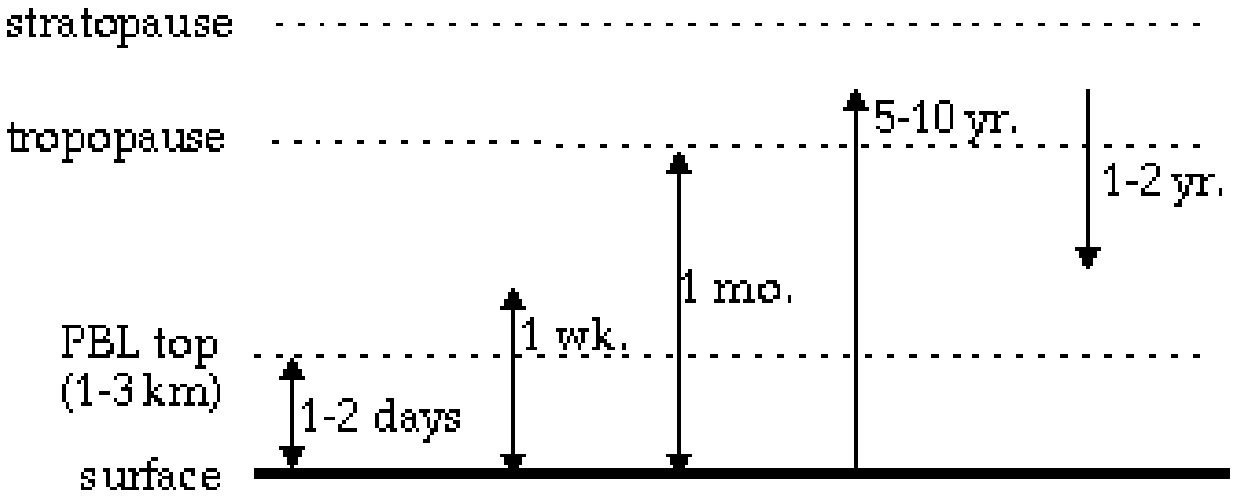
Temperature profile



Layers in the troposphere





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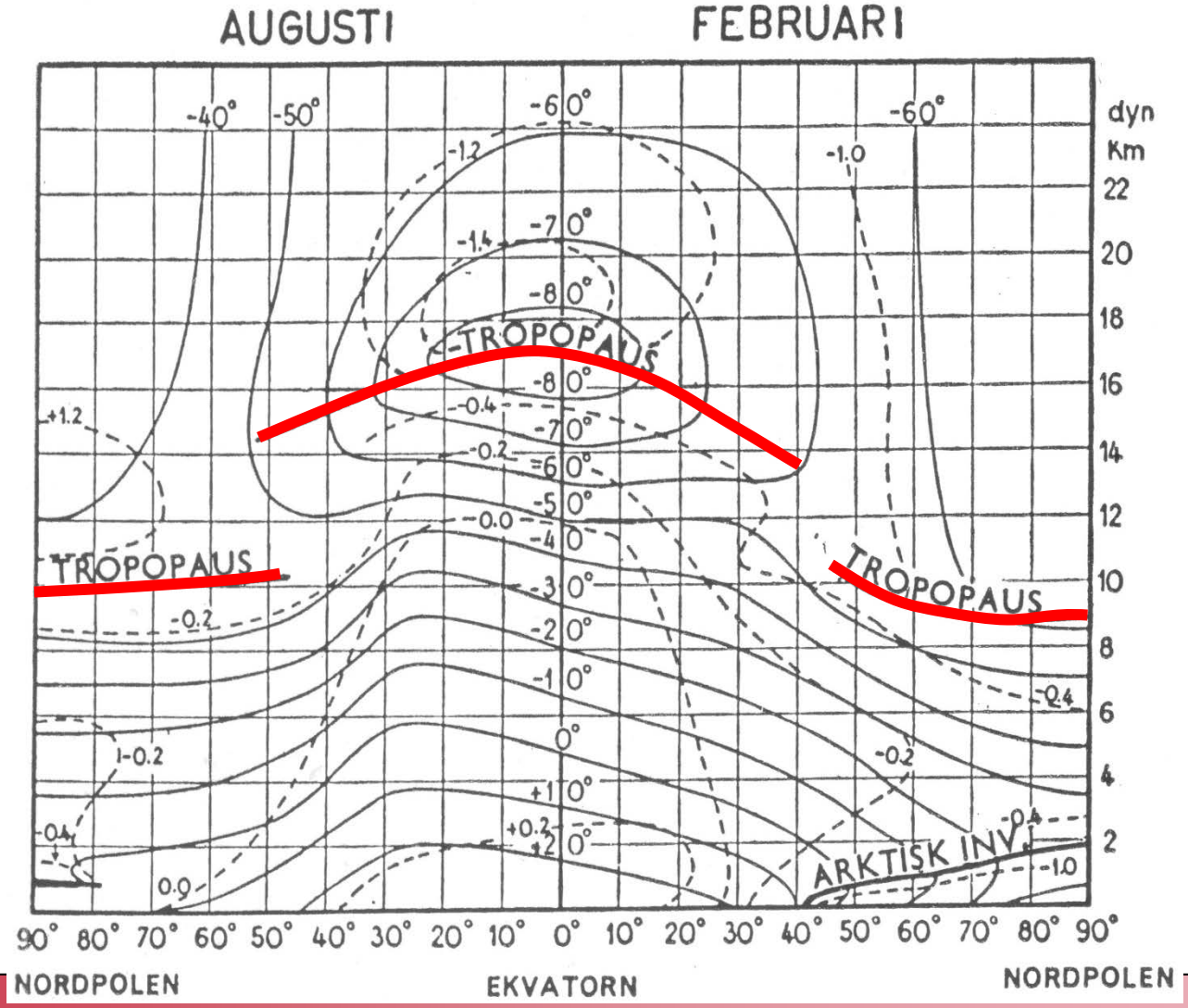
Variations in time and space



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Processes

- Radiation (short-wave , SW, and long-wave, LW)
  - Source of energy (SW).
  - Mainly heats the surface (SW).
  - Small fraction of SW is absorbed in gases and clouds, large fraction of LW.
- Dynamics
  - Heat is carried from the equator and pole-ward.
  - Rotation creates a meridional transport of energy.
- Turbulence
  - Flow close to the surface is always turbulent due to viscosity of the air.
  - Turbulent motions carry heat/matter to/from the surface.

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Radiation

- Radiation function of temperature of the radiating body, usually divide into:
  - short-wave (sun)
  - long-wave (colder bodies as earth and clouds)
- The sun (short-wave radation) is the external source driving the earth-atmosphere system.
- The atmospere is nearly transparent to short-wave radiation, about 20% is absorbed by gases (H_2O and O_3), particles (aerosols and cloud droplets).
- About 30% of the short-wave radiation is reflected by the surface or clouds.

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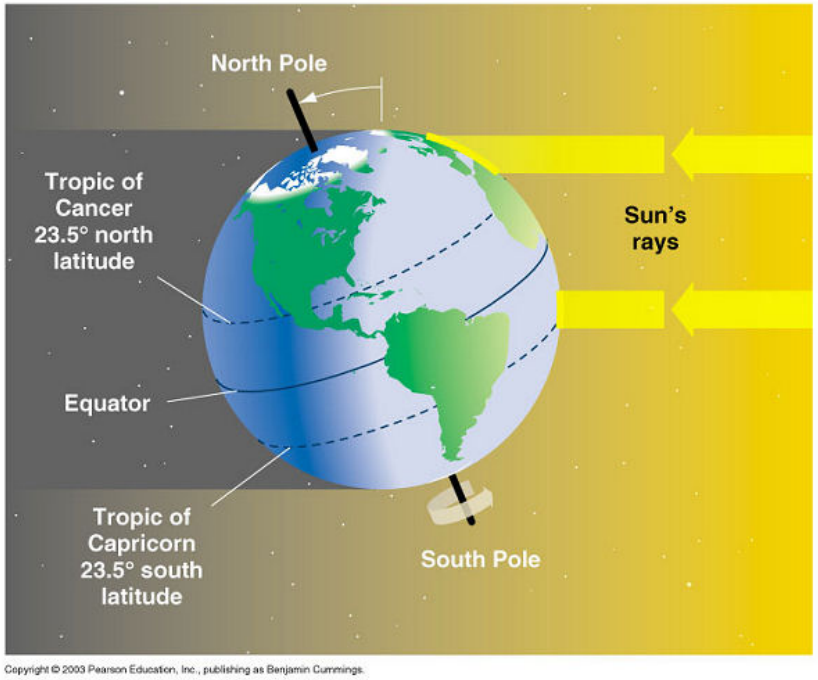
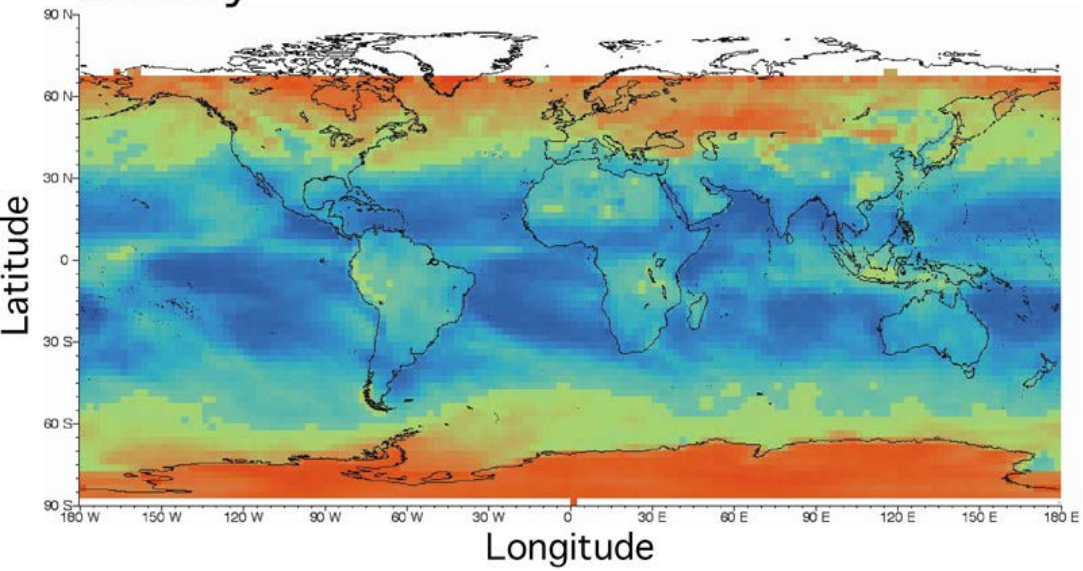
Climate

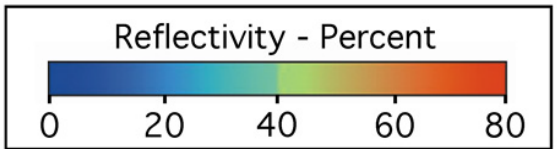
- Uneven heating equator/poles
- Heat transport toward the poles



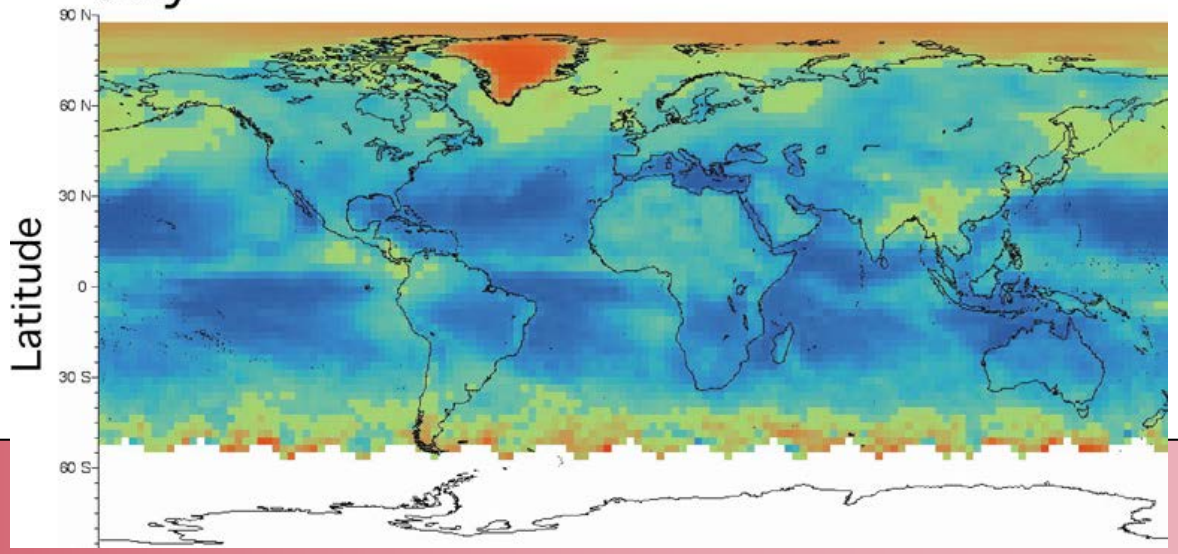
Planetary Albedo

January





July



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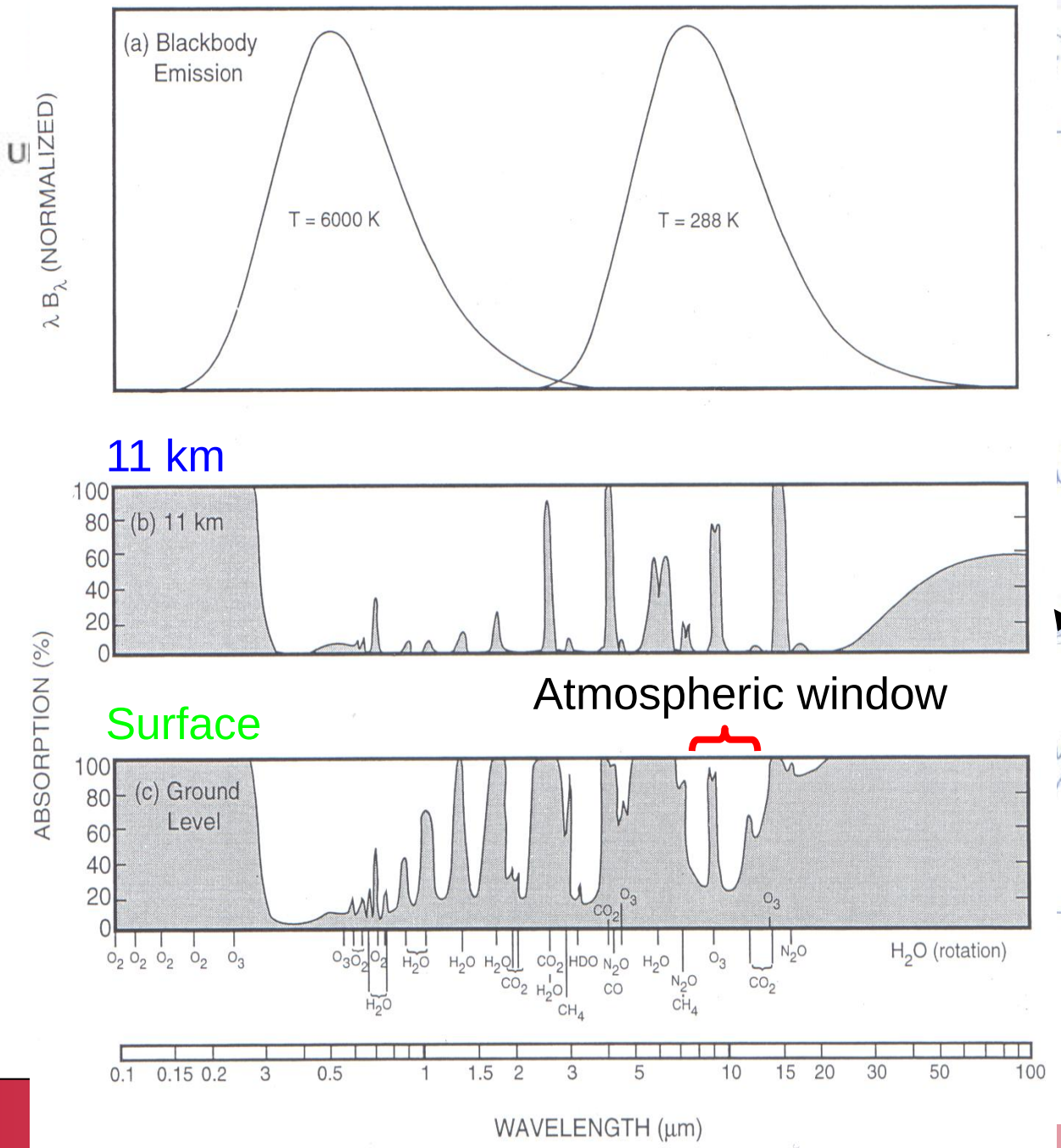
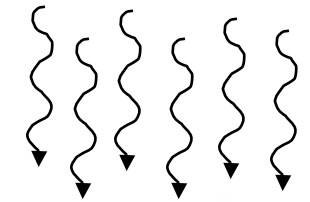
Long-wave radiation

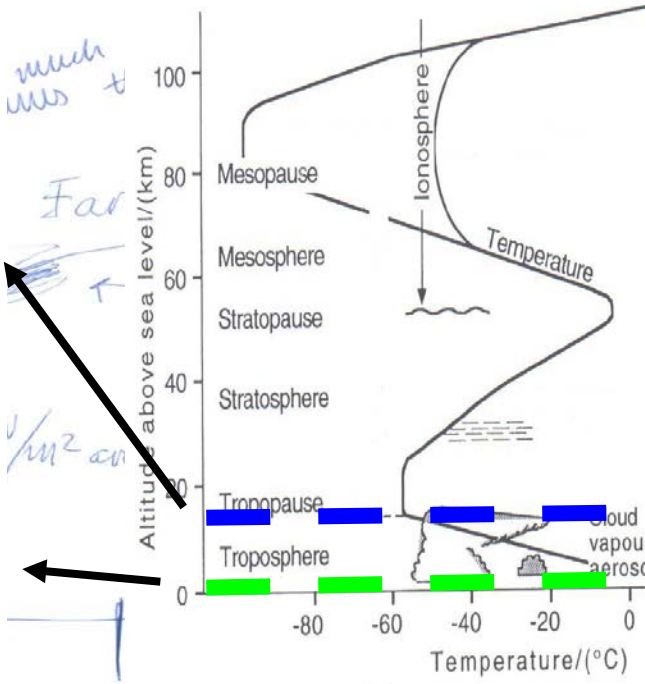
- Largest part of surface long-wave radiation is absorbed in atmospheric gases and aerosols (mainly H_2O and CO_2, but also CO, CH_4,N_2O and CFC's) but also in clouds.
- Long-wave radiation is also emitted back to the surface by gases and clouds (*Note: not reflected*).
- The absorption in gases and clouds of the long-wave radiaion is the GREEN-HOUSE EFFECT, without it the average surface temperature would be -19° C (instead of +14° C).
- There is also transport from (to) the surface by turbulent eddies (sensible and latent heat flux).



Short wave radiation

S=1370 W/m^2





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The Earth

- The earth is a sperical rotating body
  - different heating
  - rotating coordinate system
- Chemical components (N_2, O_2 also Ar, CO_2 etc)
  - absorption/emission in constituents
- Fysiography
  - distribution of land/ocean
  - montain ranges
- Water
  - water in different phases, phase changes
- Flow is never at rest, turbulence near the surface

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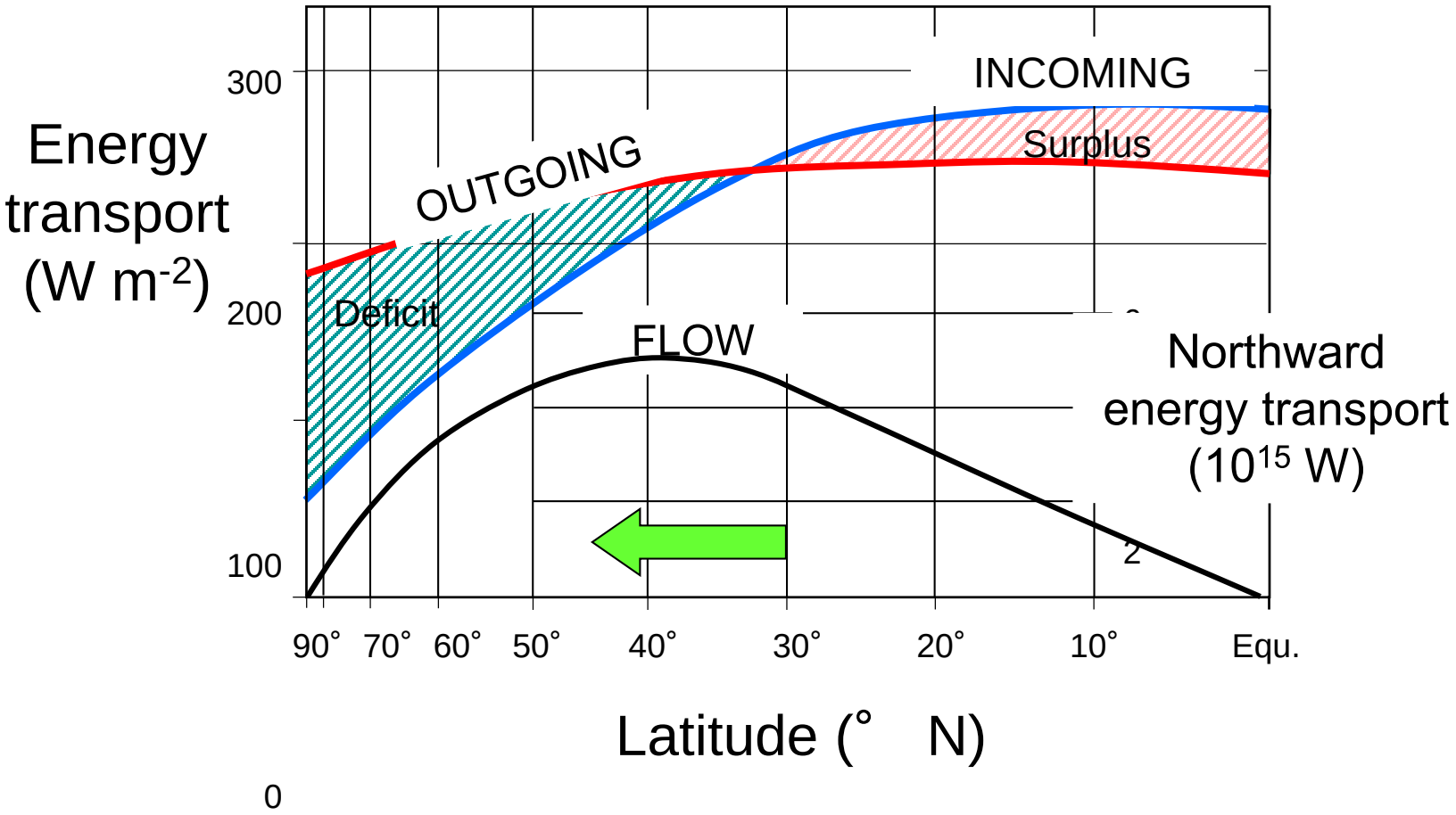
Radiation balance



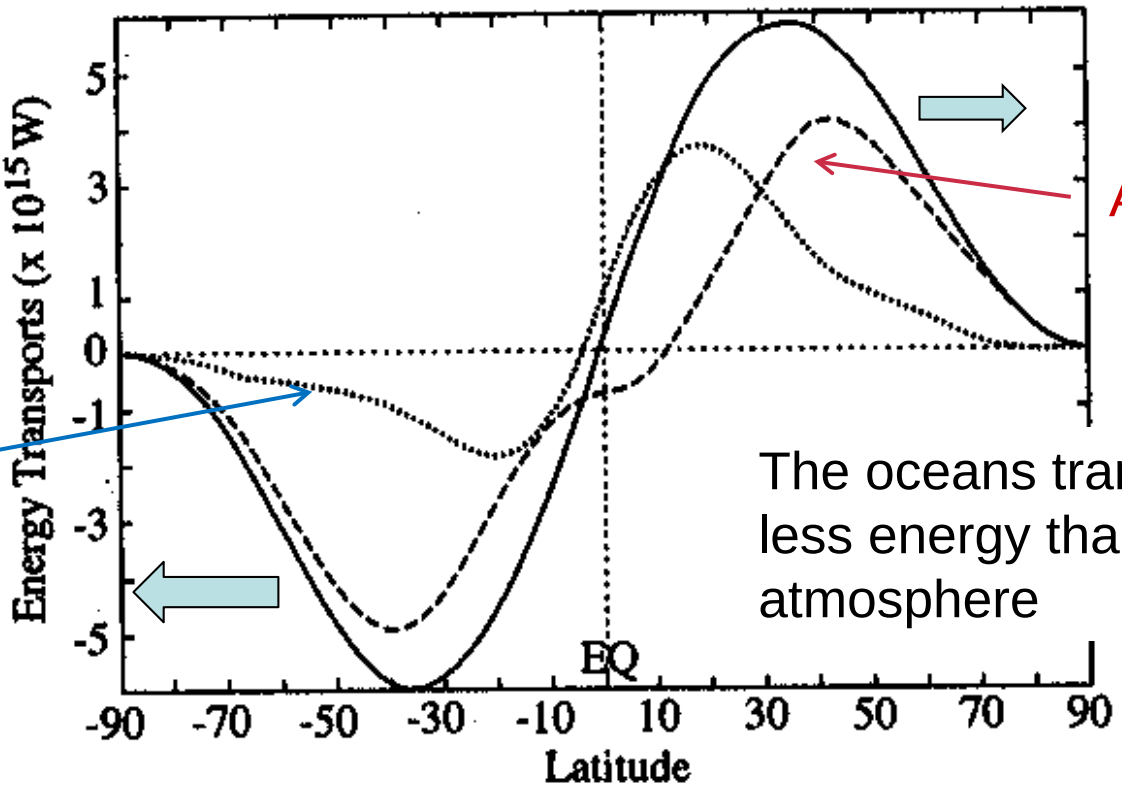


Figure 12.5 Annual mean northward energy transports required to equalize the pole–equator radiative imbalance. The solid line represents the top-of-the-atmosphere radiation budget, the dashed line represents the atmosphere, and the dotted line represents the ocean (From Zhang and Rossow, 1997).

Northward energy transport

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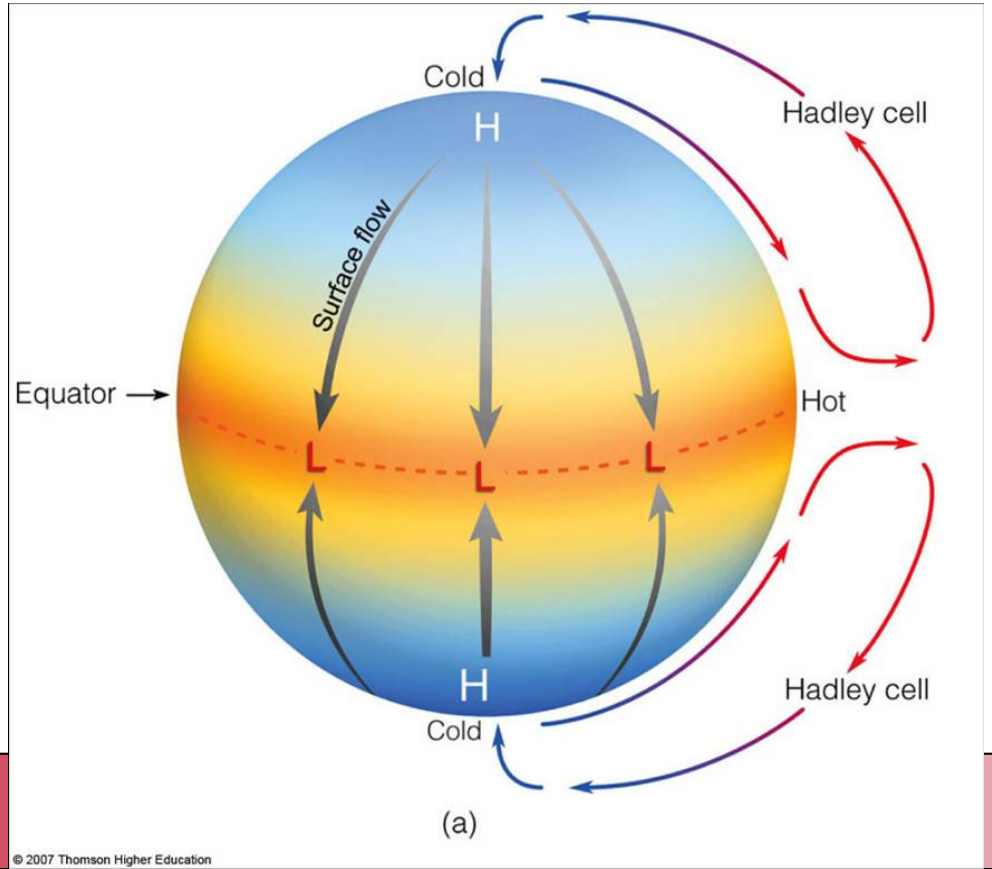
Poleward transport of energy (in the atmosphere) by:

1. Mean meridional circulation (Hadley cell).
2. Stationary eddies (monsoon circulations).
3. Transient eddies (low pressure systems).

Mean meridional circulation

- More solar heating at the equator, convection and rising air form a closed circulation – the ’Hadley cell’.
- Earth rotation (coriolis force) makes the Hadley cell break down at higher latitudes.



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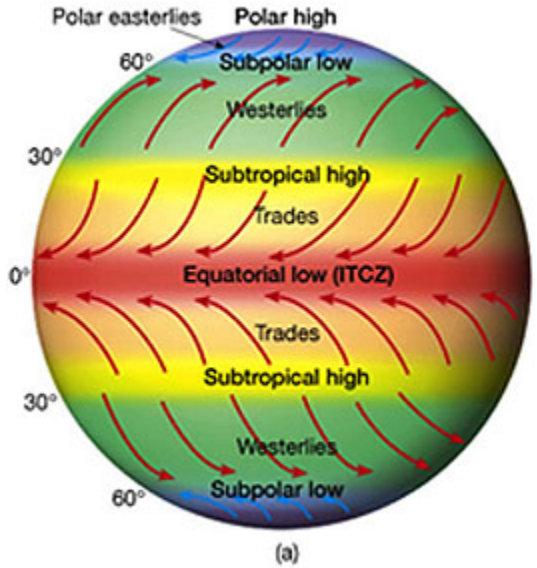
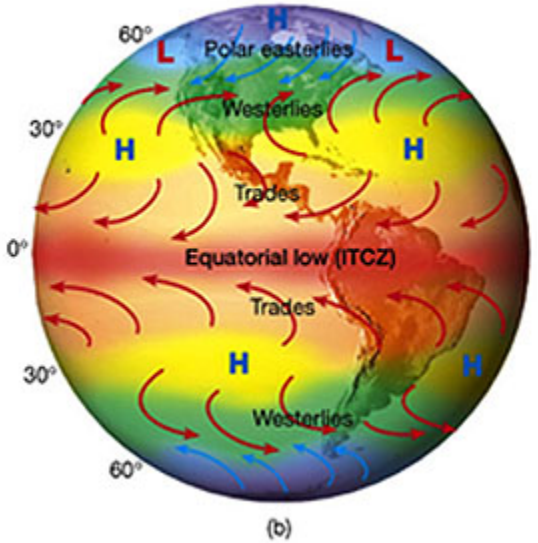
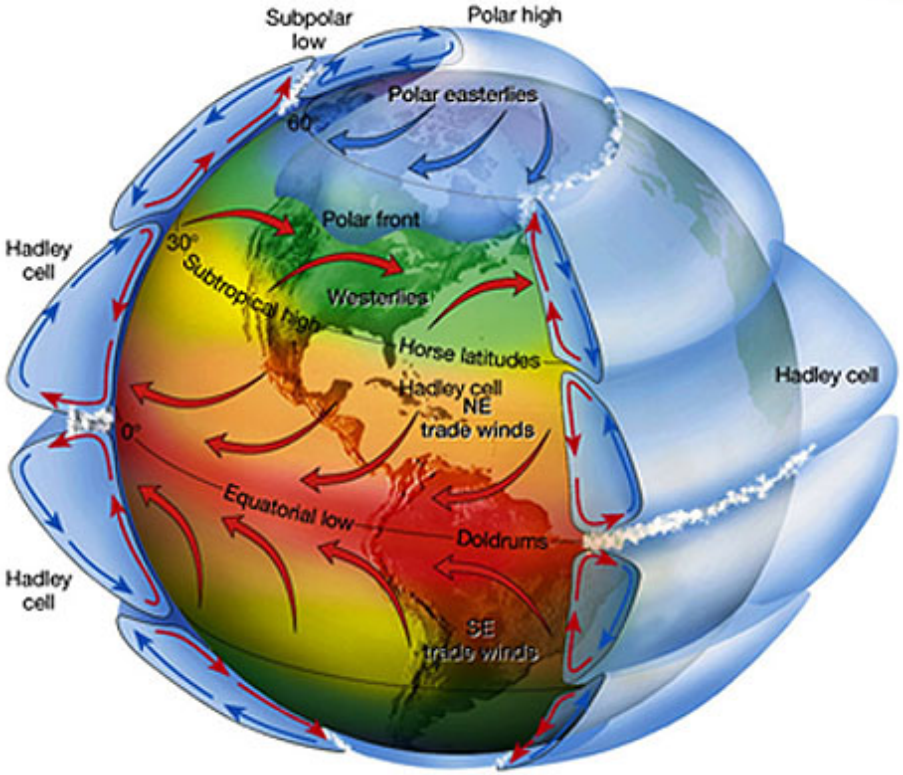
Three cell planet



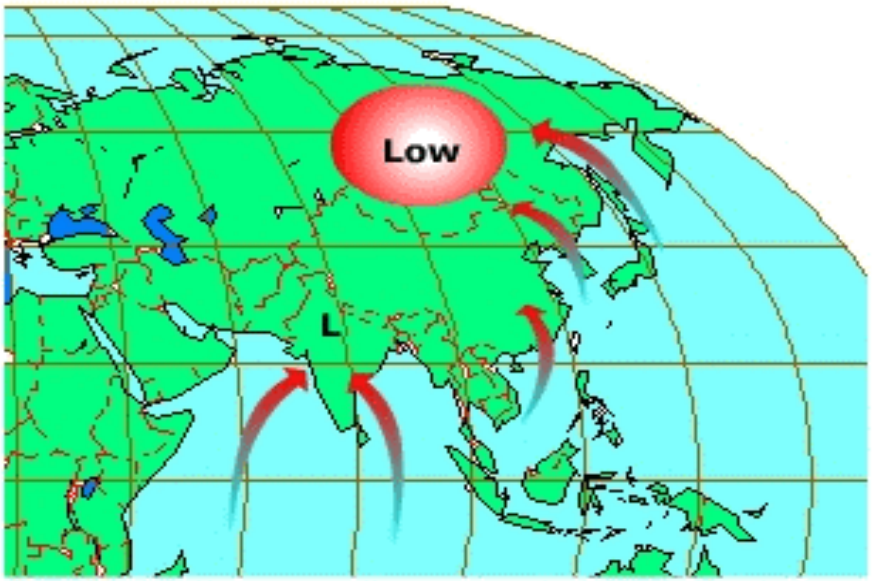




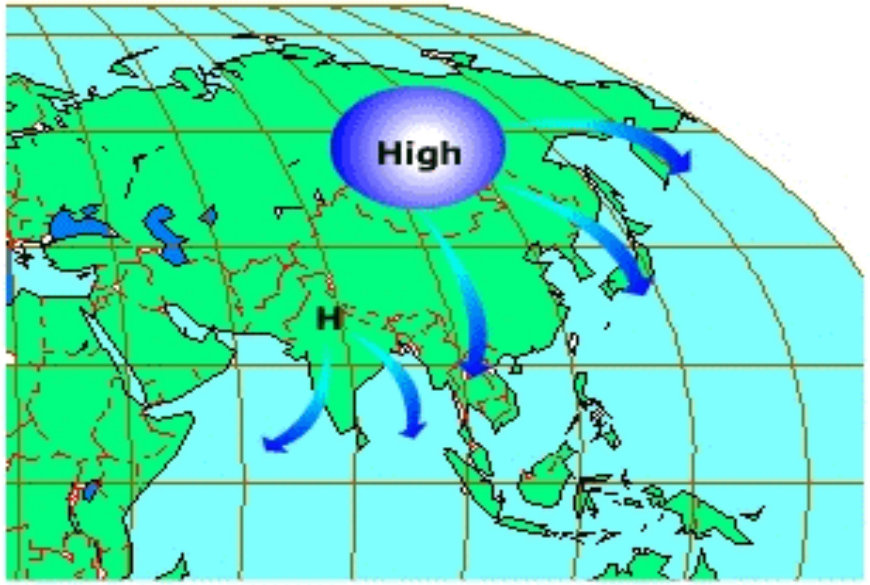
Stationary eddies

Stationary circulation systems (fixed by lans/sea contrast) – transporting energy poleward

Summer



Winter



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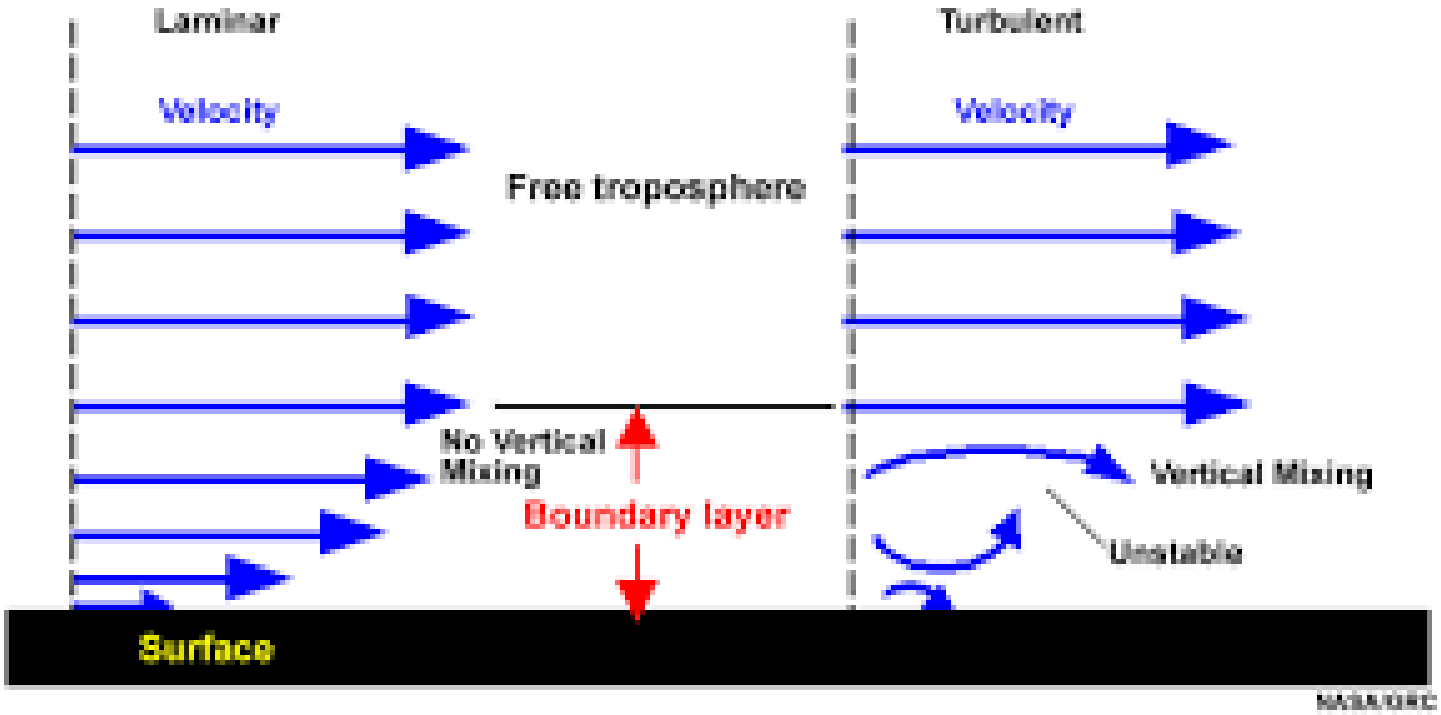
Turbulence



Surface friction and surface convection give:

- Turbulence (not laminar flow)
- Changes in vertical wind (speed and direction)
- Latent and sensible surface heat fluxes

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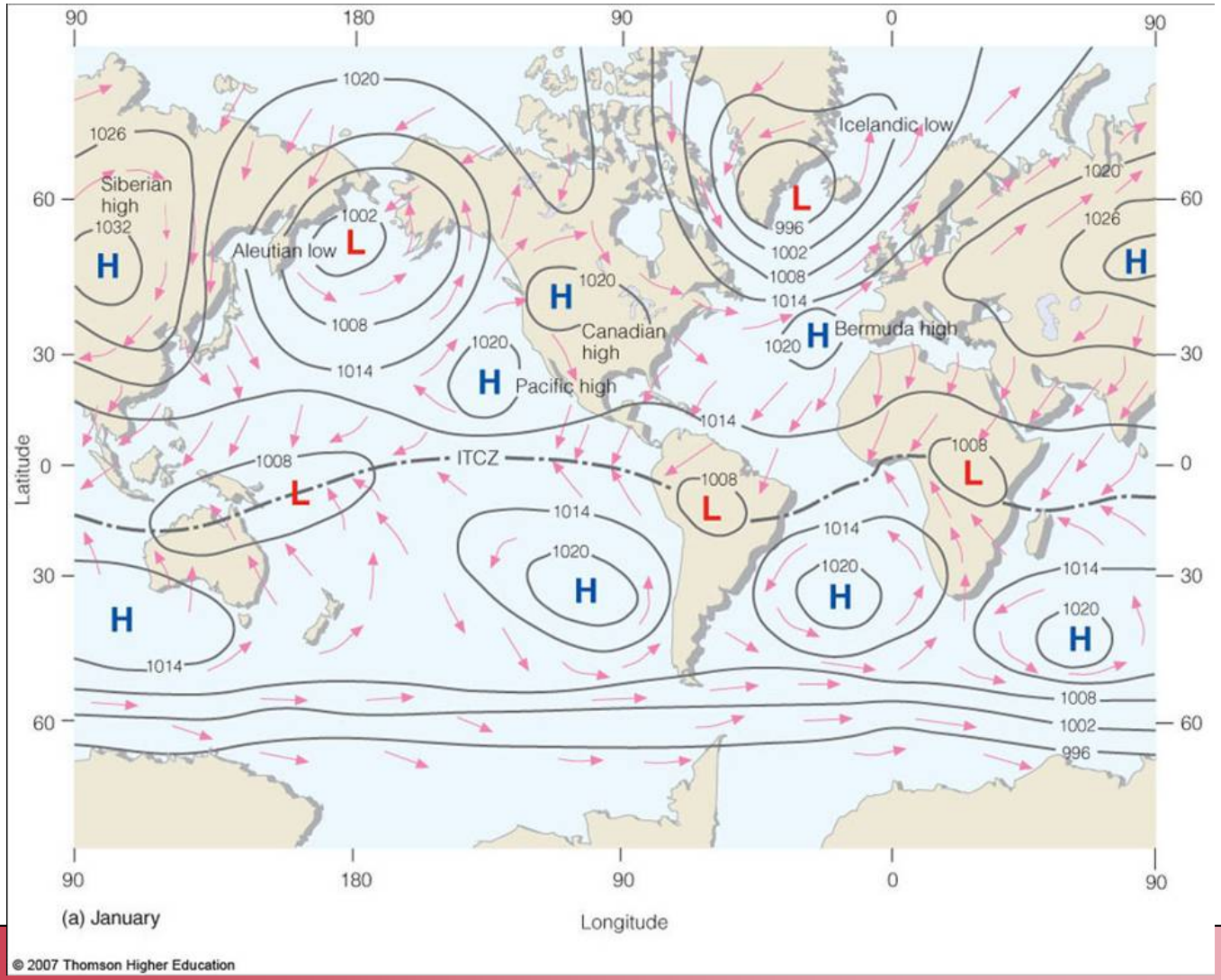
Observed average surface pressure and winds during January



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Transient eddies

- Rotation of the earth makes the Hadley cell break down at 30º. The flow then goes west-east instead of north-south.
- Instabilities in this easterly flow generates transient eddies (cyclones).
- These eddies transport heat and water towards the poles along frontal surfaces.
- The cyclones move along the quasi-stationary ’Rossby waves’ in the region 30º- 60º.
- On average they form the ’Ferrel cell’.

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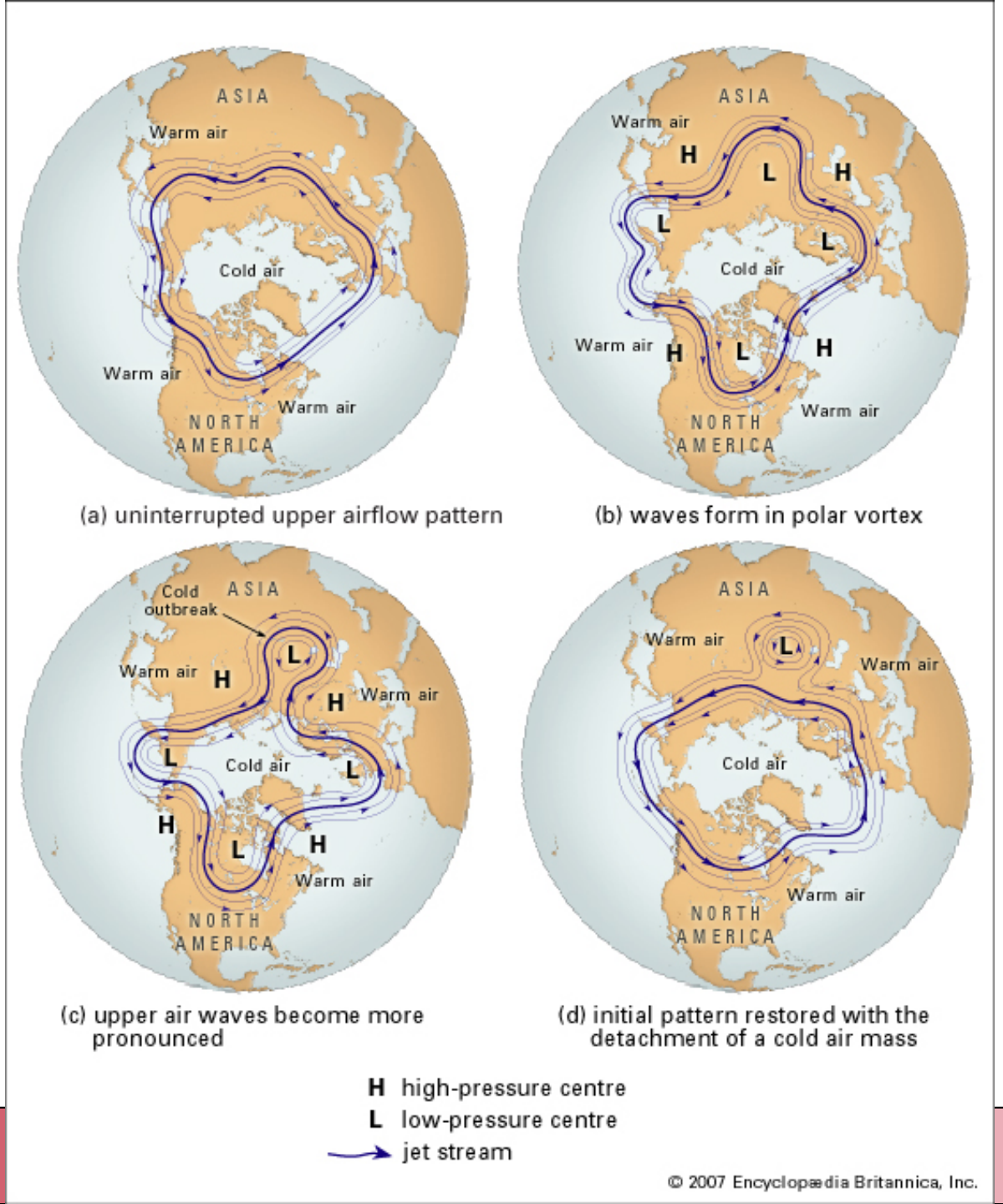
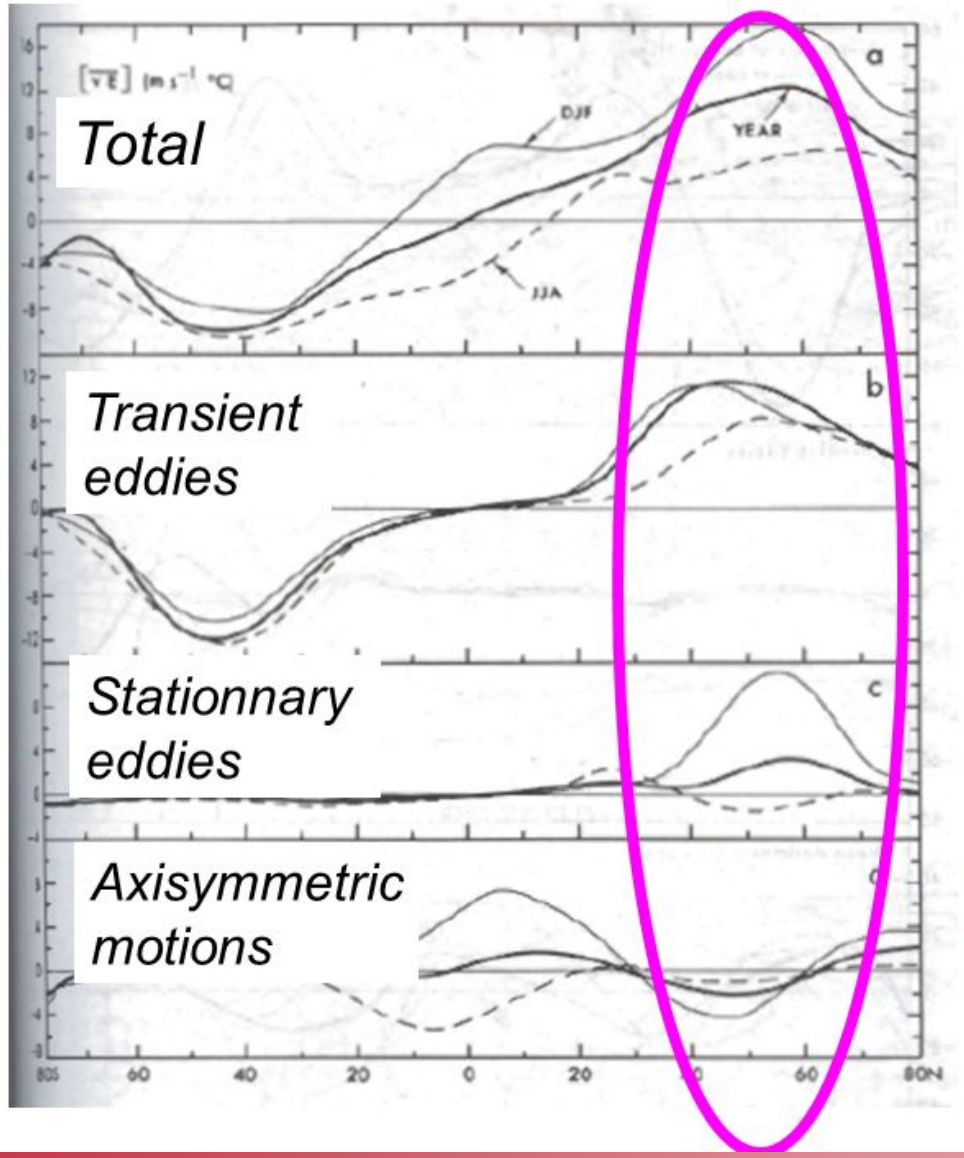
Rossby waves



Energy transport



Eddy motions are the key energy carriers in midlatitudes

Northward transport of moisture

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Total

Transient eddies

Stationery eddies

Mean meridional circulation

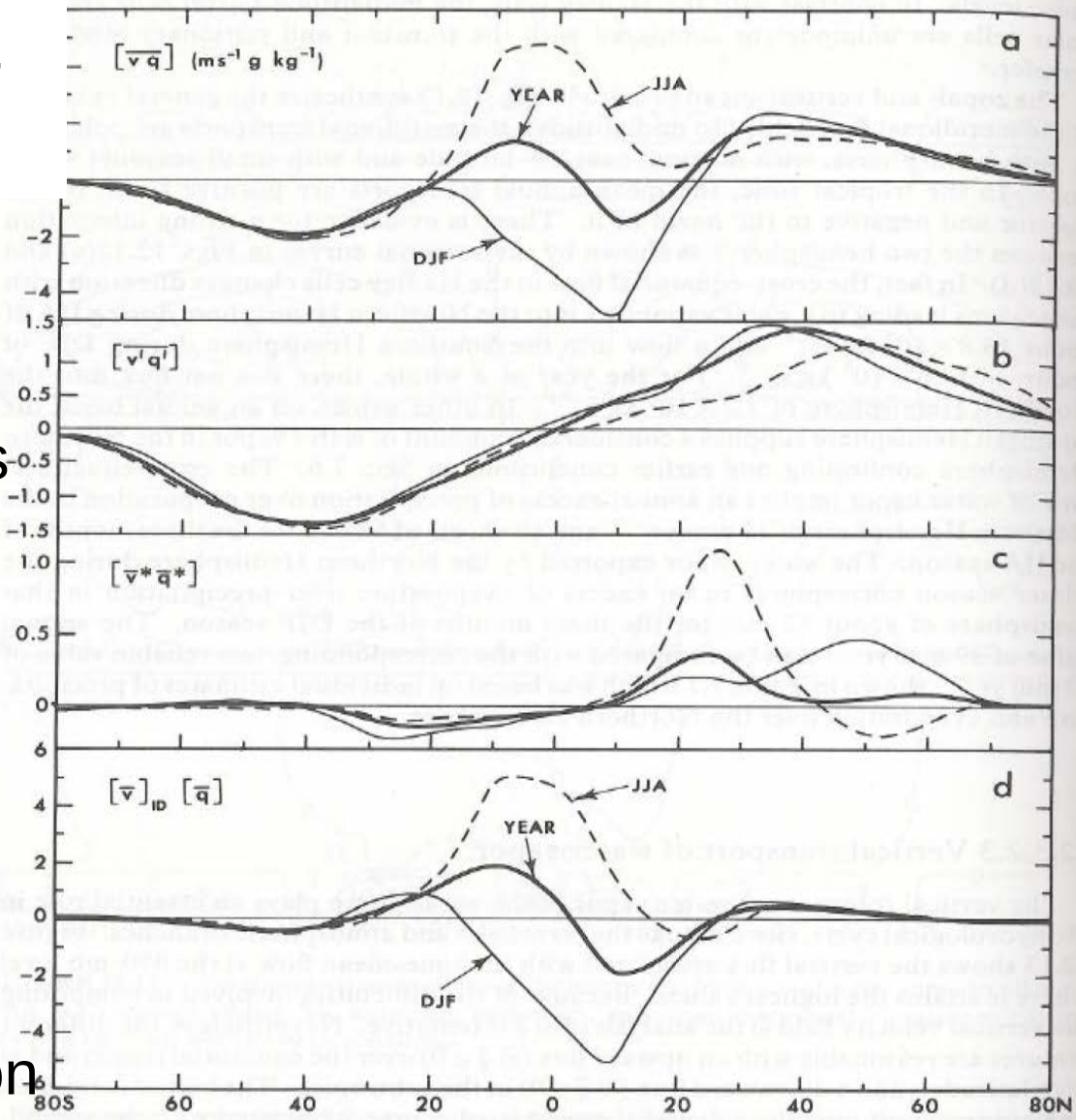


FIGURE 12.12. Meridional profiles of the vertical- and zonal-mean values of the northward transport of water vapor by all motions (a), transient eddies (b), stationary eddies (c), and mean meridional circulations (d) in m s^{-1} g kg^{-1} for annual, DJF, and JJA mean conditions. [To convert to total transport estimates multiply values by $10^{-3} 2\pi R \cos\phi \, p_0/g = 4 \cos\phi$ to find values in units of 10^8 kg s^{-1} or by 12.6 $\cos\phi$ to find units in 10^{15} kg yr^{-1}, where $2\pi R \cos\phi$ = length of latitude circle and $p_0/g = 10^4$ kg m^{-2} the total atmospheric mass per unit area.] (After Peixoto and Oort, 1983).

Mid-latitudinal hydrological cycle (North Atlantic – European sector)

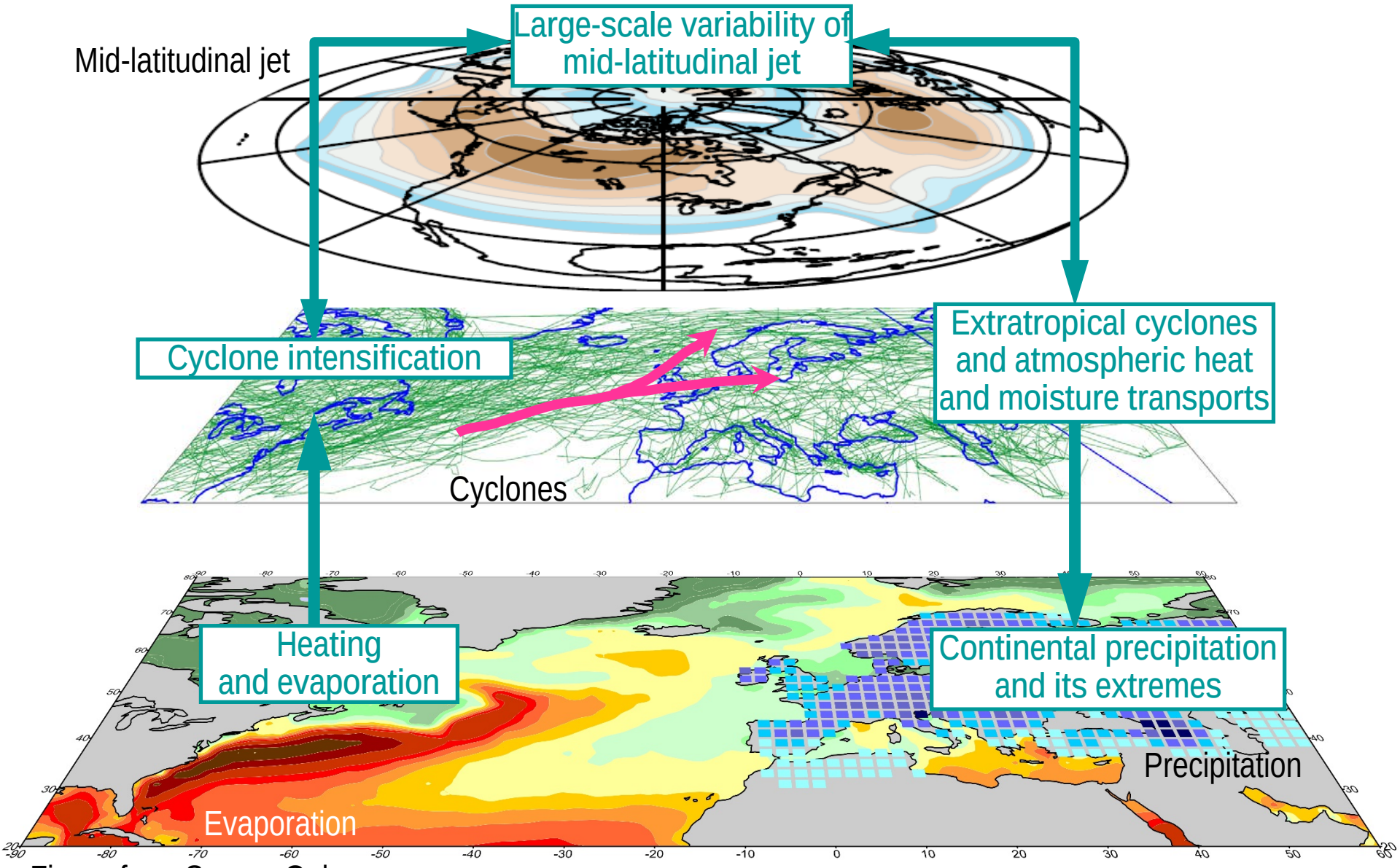
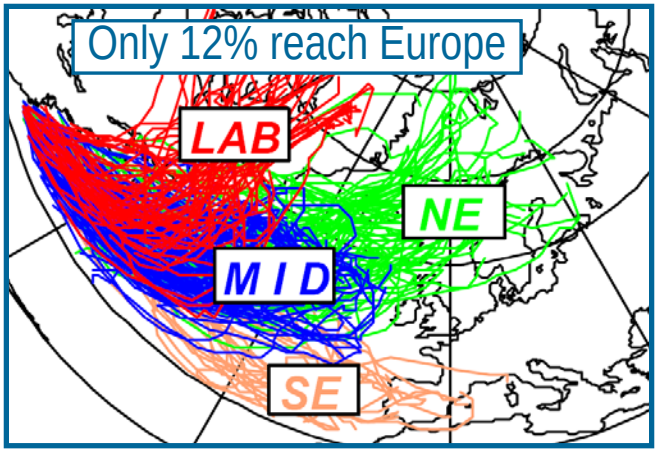
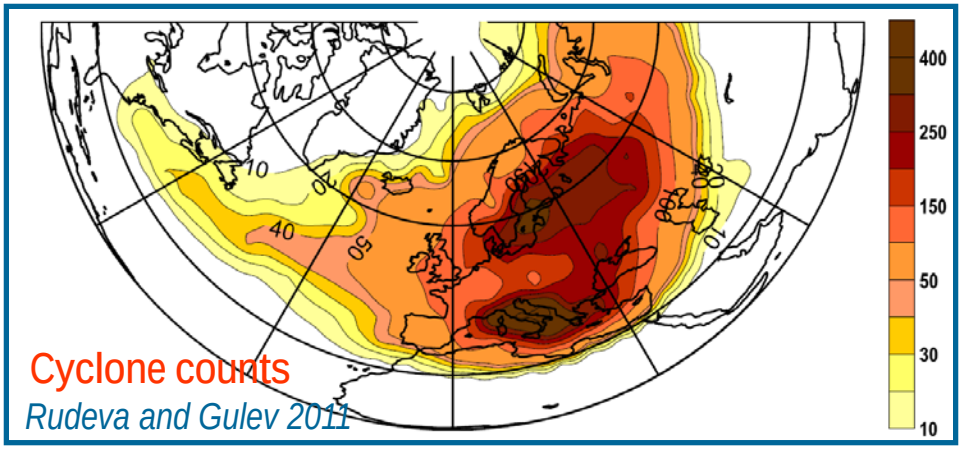


Figure from Sergey Gulev

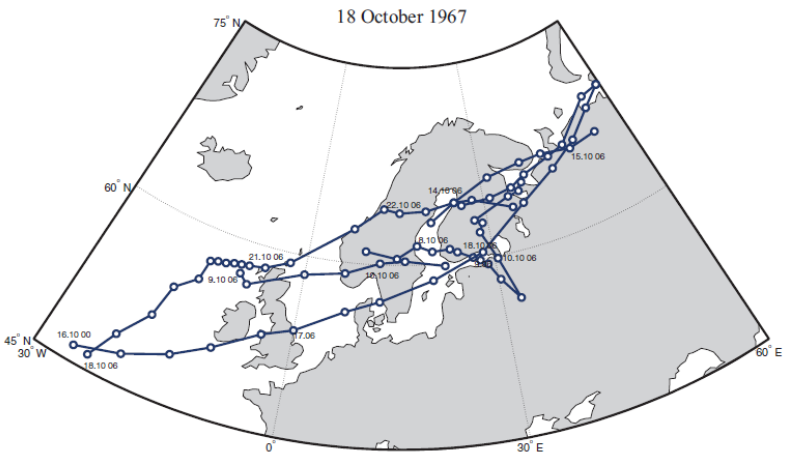
Which cyclones are bringing moisture and heat to Europe?





European weather is to a lesser extent dependent on cyclones generated over GS, but is rather determined by the transients generated in the NE Atlantic

Cyclones causing extreme sea levels in the Baltic Sea – also primarily EA cyclones



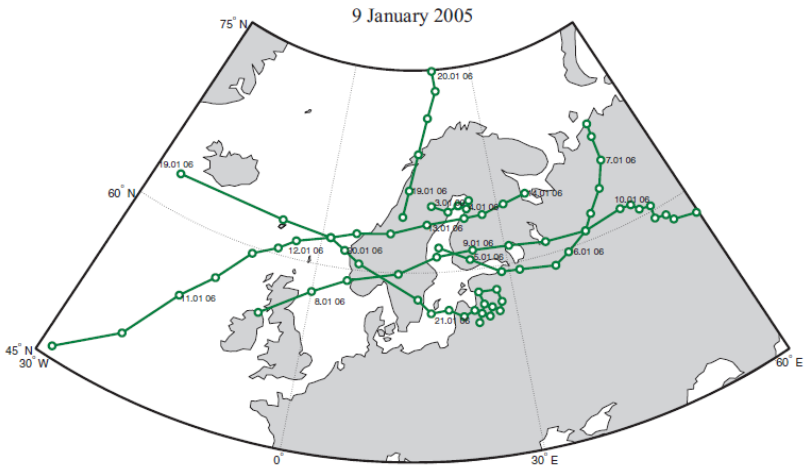
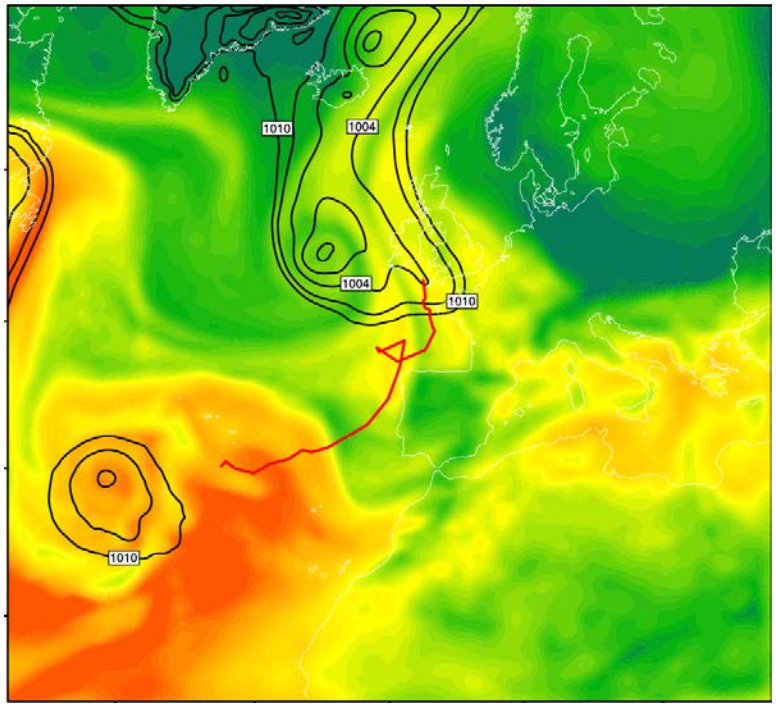


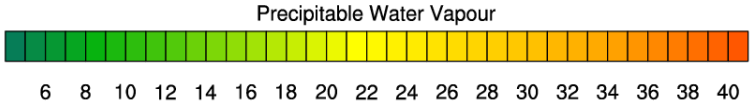
Figure from Sergey Gulev

Post and Kouts 2014

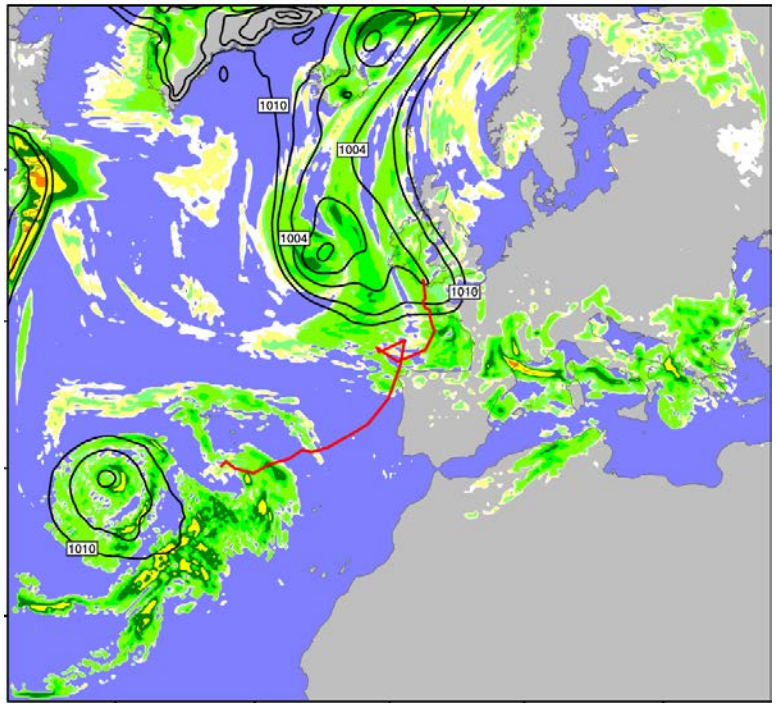
The role of cyclones in moisture and energy transports

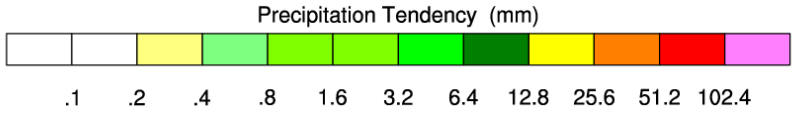
Precipitable water content





Precipitation





WRF, 12-km resolution, 27.11.2004 – 03.12.2004

Figure from Sergey Gulev

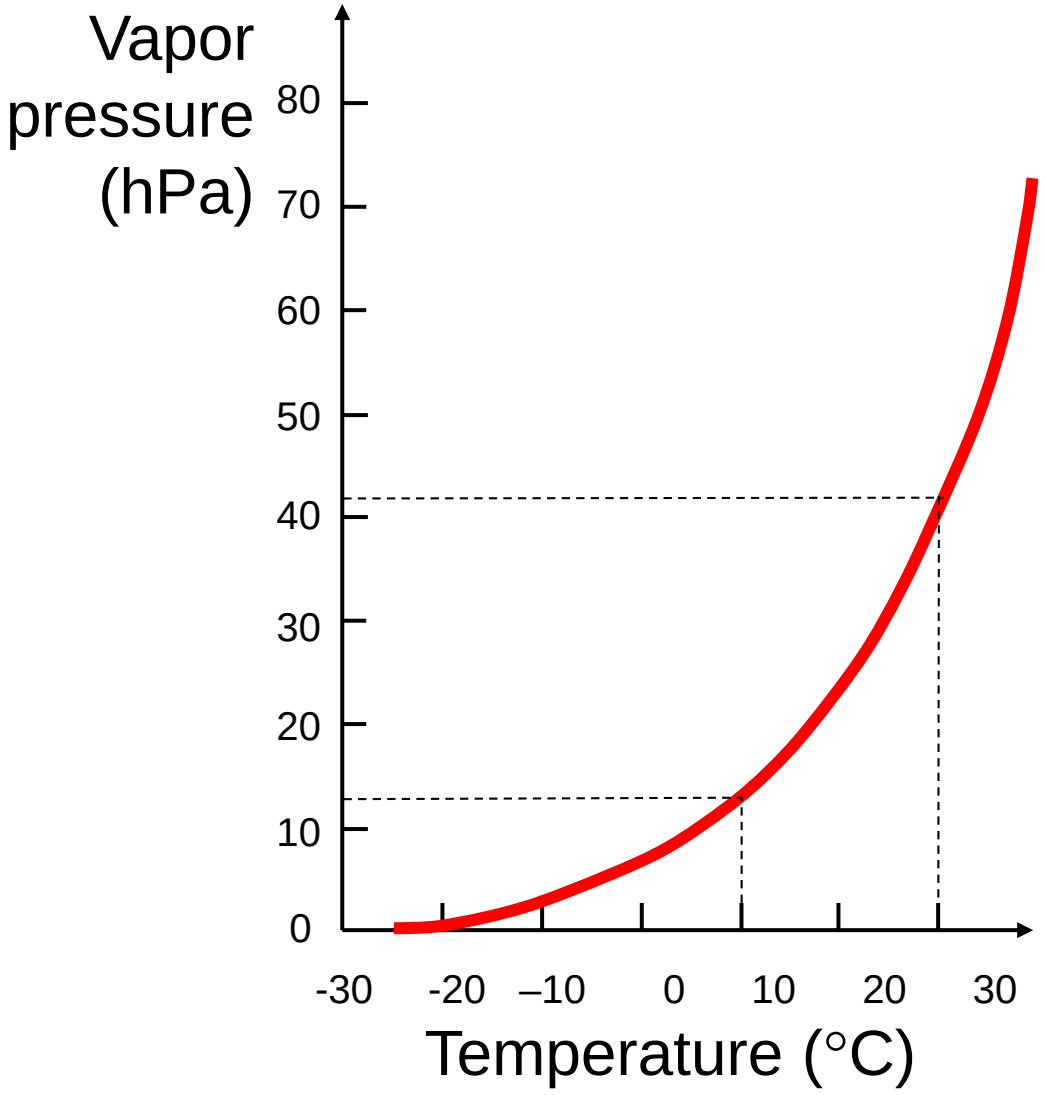
Gavrikov and Gulev 2014

Water

- Water appears in three phases in the atmospheric system (vapor, liquid and solid).
- The interchange between phases is an important energy transfer mechanism.

- Water vapor is the main'green-house gas'.
- The amount of water vapor in the atmosphere is determined by the temperature.
- For a higher temperature, the atmosphere can hold more water. A positive feed-back mechanism.

pressure


Vapor pressure (hPa)
80
70
60
50
40
30
20
10
0
-30
-20
–10
0
10
20
30
Temperature (°C)

Water

- Liquid water in the oceans, transport heat between different locations.
- Ice and snow changes the albedo of the surface.
- Ice changes the turbulent exchange (compared to open ocean).

- Surface loses energy when water evaporates. When the water vapor condenses into clouds the air is heated. When the water is precipitated the heat remains in the air.
- Evaporation is determined by water temperature or surface characteristics.

Clouds

- Water can be in liquid or solid forms. This affects the albedo of the system.
- Clouds absorb/reflects short-wave radiation and emits long-wave radiation.
- Cloud formation depends on condensation/freezing nuclei.
- Clouds either have a heating or a cooling effect in the atmosphere (positive or negative feedback…)

Mean annual cloud cover