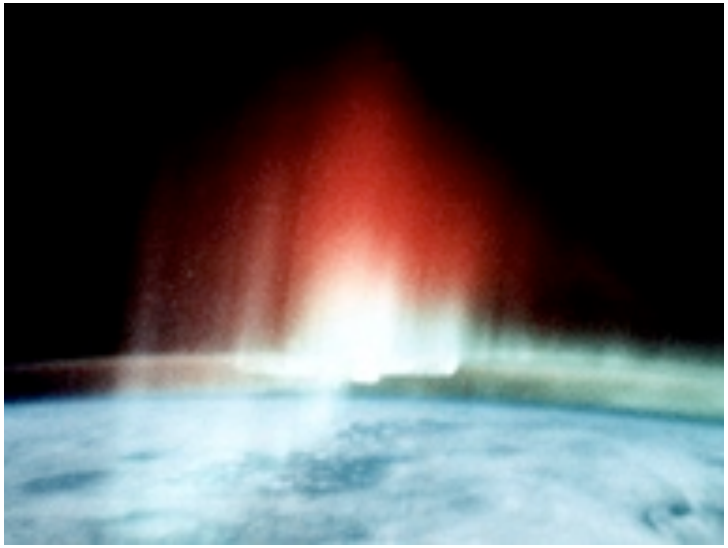
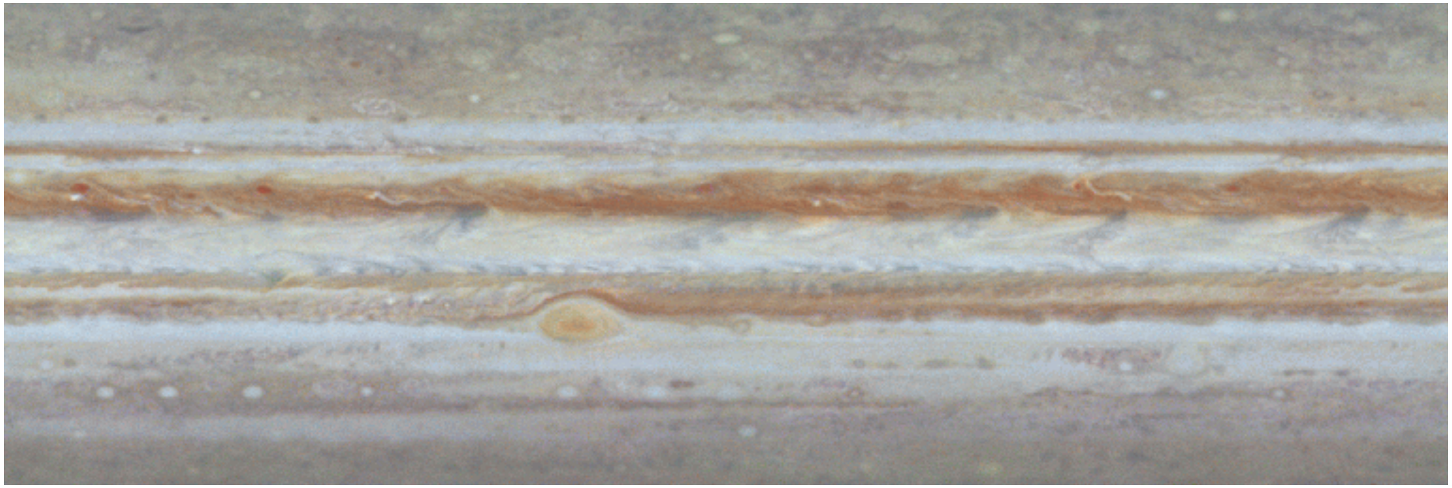
# Planetary Atmospheres

Structure
Composition
Clouds
Photochemistry
Meteorology
Atmospheric Escape

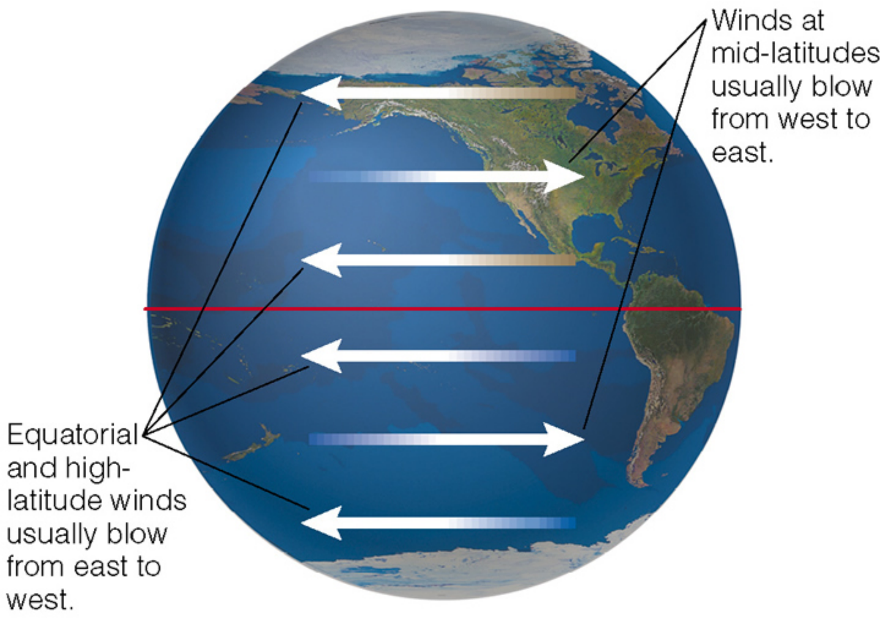




# What are Weather and Climate?

**weather** – short-term changes in wind, clouds, temperature, and pressure in an atmosphere at a given location

**climate** – long-term average of the weather at a given location






- These are Earth's **global wind patterns** or circulation
  - local weather systems move along with them
  - weather moves from W to E at mid-latitudes in N hemisphere
- Two factors cause these patterns
  - atmospheric heating
  - planetary rotation

# Atmospheric Dynamics

Everything Starts with the Navier-Stokes Equation:

$$\frac{D\vec{v}}{Dt} \equiv \frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v} = -\frac{1}{\rho} \nabla P + \vec{g}_p + \frac{\mu}{\rho} \nabla^2 \vec{v} + f_c \vec{v} \times \hat{z}$$

Material Derivative

Inertial Term

Gravity

Coriolis

Local Derivative

Pressure Gradient

Viscous

$$\frac{\mu}{\rho} = \nu_v$$

$\mu$ is the dynamic viscosity

$\nu_v$ is the kinematic viscosity ($m^2/s$)

# Atmospheric dynamics: Rotation

- Coriolis effect – objects moving on a rotating planet get deflected (e.g. cyclones)
- Angular momentum – as an object moves farther away from the pole, *r* increases, so to conserve angular momentum $\omega$ decreases (it moves backwards relative to the rotation rate)
- Coriolis acceleration = $2\,\omega\, v \sin(\theta)$     $\theta$ is latitude
- How important is the Coriolis effect?

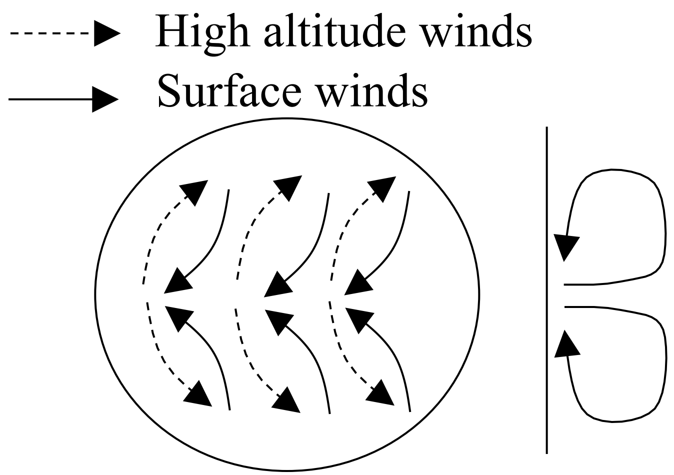
$$\frac{v}{2L\omega\sin\theta}$$

Rossby number = The ratio of inertial forces to Coriolis forces, a measure of relative importance.

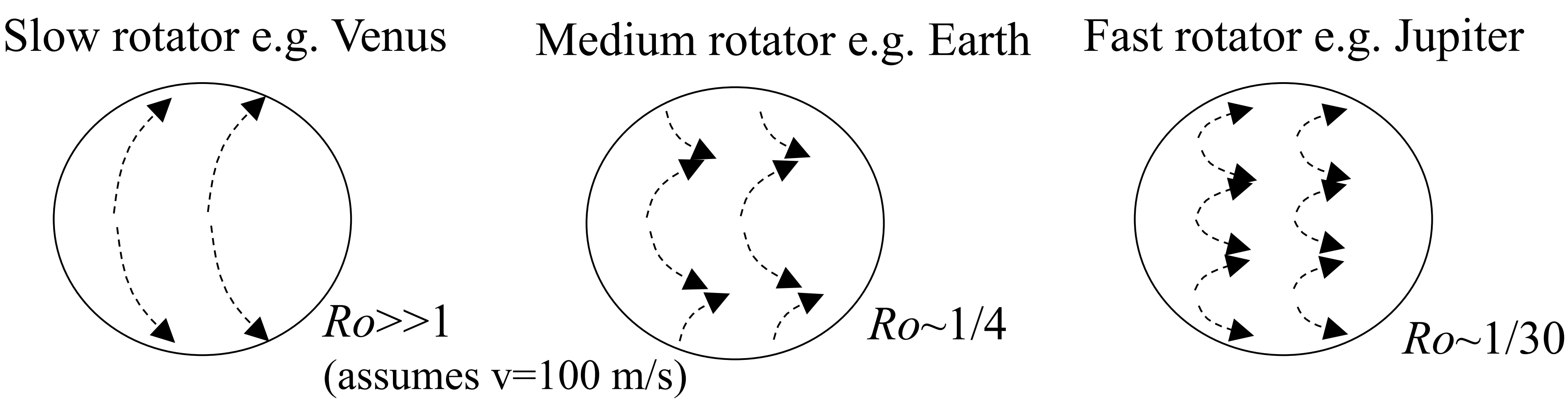
e.g. Jupiter v~100 m/s, L~10,000 km we get ~1/30 so important

# Coriolis Effect + Hadley Cells

Coriolis effect is complicated by fact that parcels of atmosphere rise and fall due to buoyancy creating Hadley cells (equator is hotter than the poles)

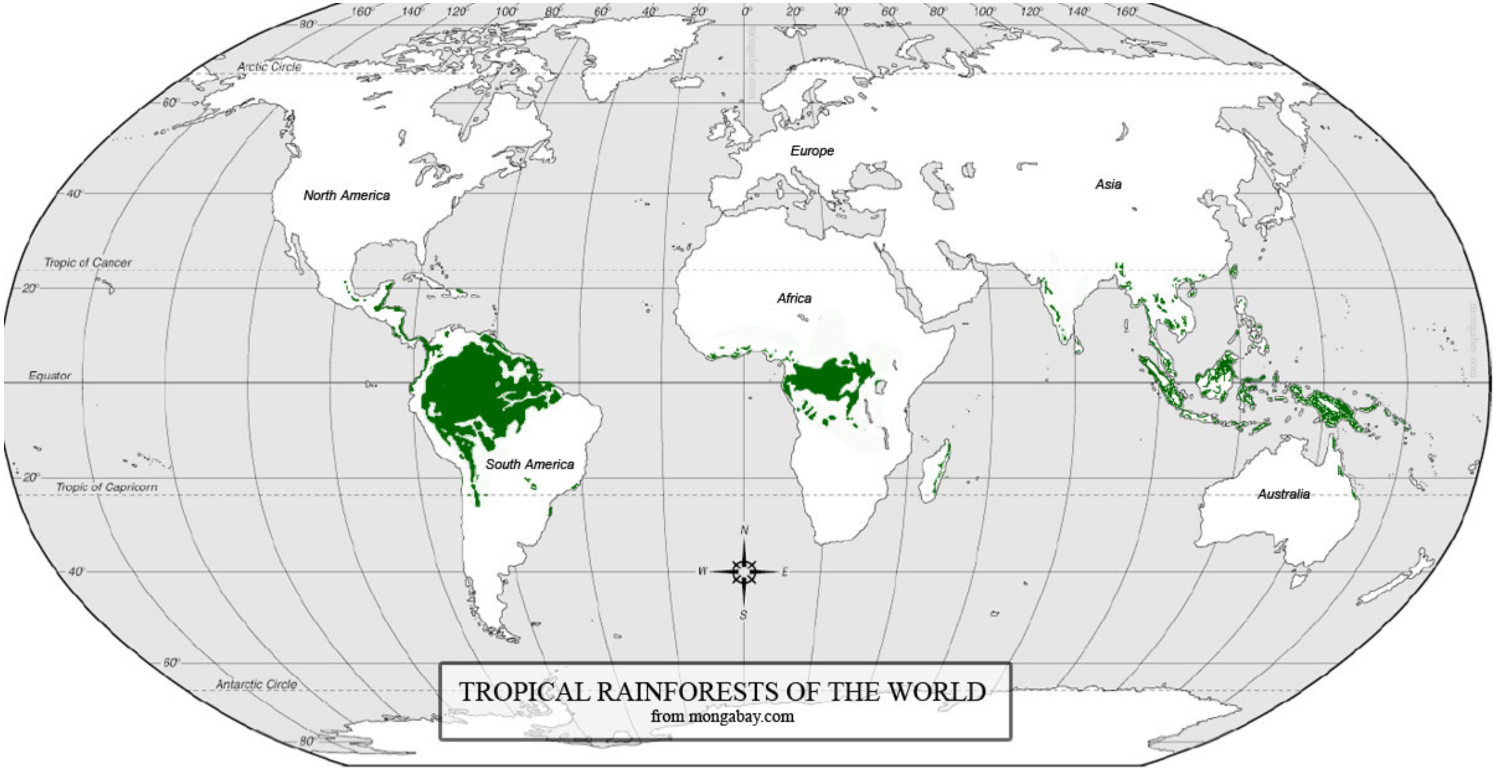



- The result is that the atmosphere is broken up into several Hadley cells (see diagram)
- How many cells depends on the Rossby number (size, rotation rate)



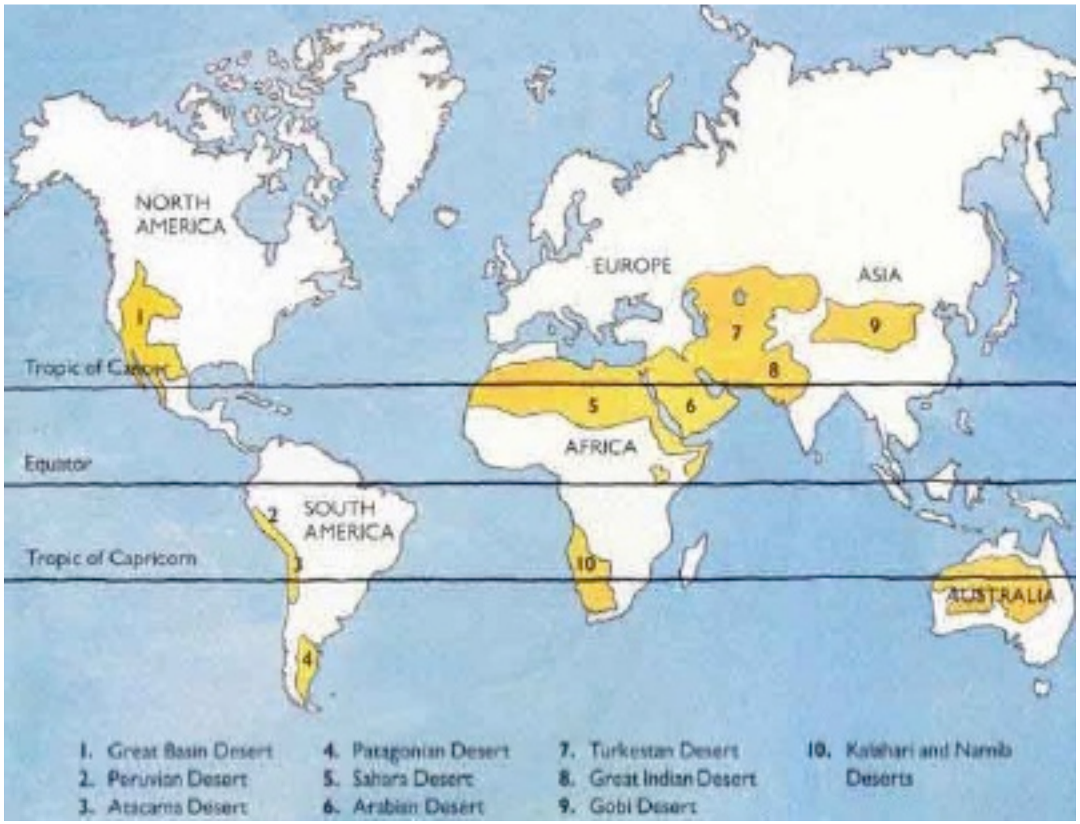
# Global Wind Patterns: Hadley Cells

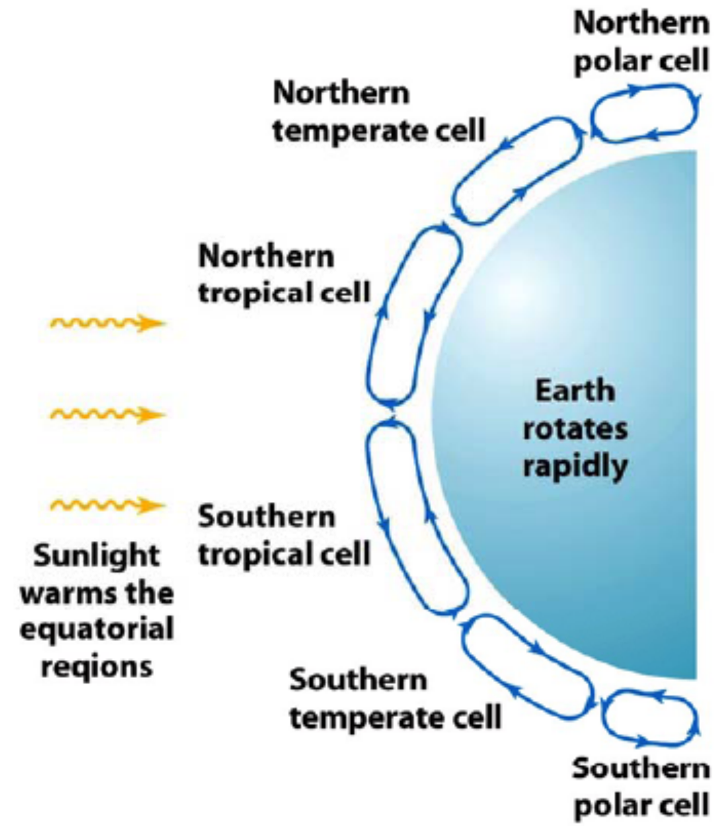
- Air is heated at the equator and rises
- As it rises it cools, clouds condense and generates rain



# Global Wind Patterns: Hadley Cells

- Air (now dry) is pushed away from equatorial upwelling and moved toward the tropics
- As it descends, it heats up - dry hotter air helps create deserts



# Global Wind Patterns: Hadley Cells

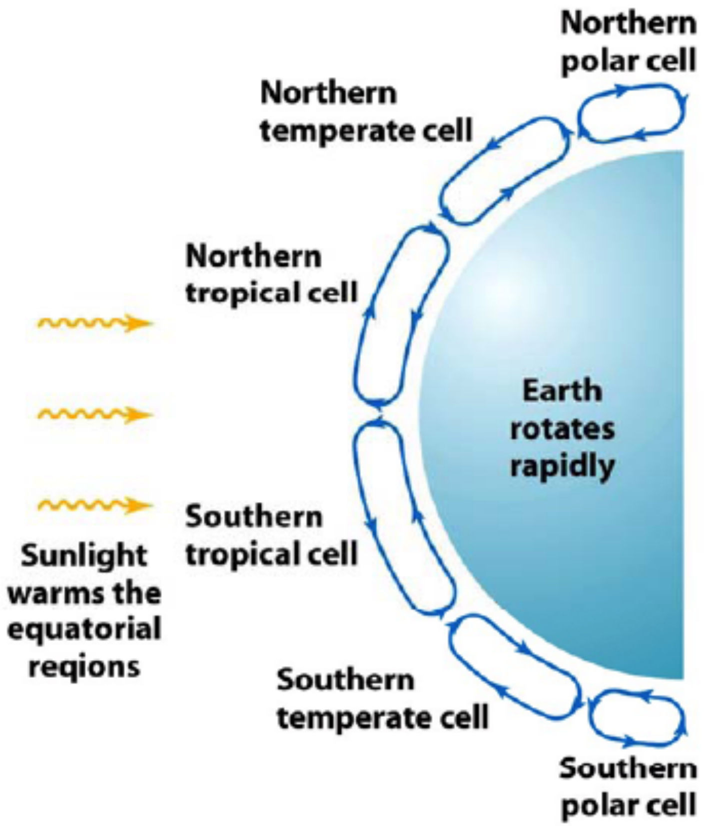
Polar cells work the same way

- Cold air descends over the poles
- Flows along the ground and eventually warms from being in contact with the surface
- Rises at ~60° N/S latitude

Ferrell Cells (Temperate Cells)

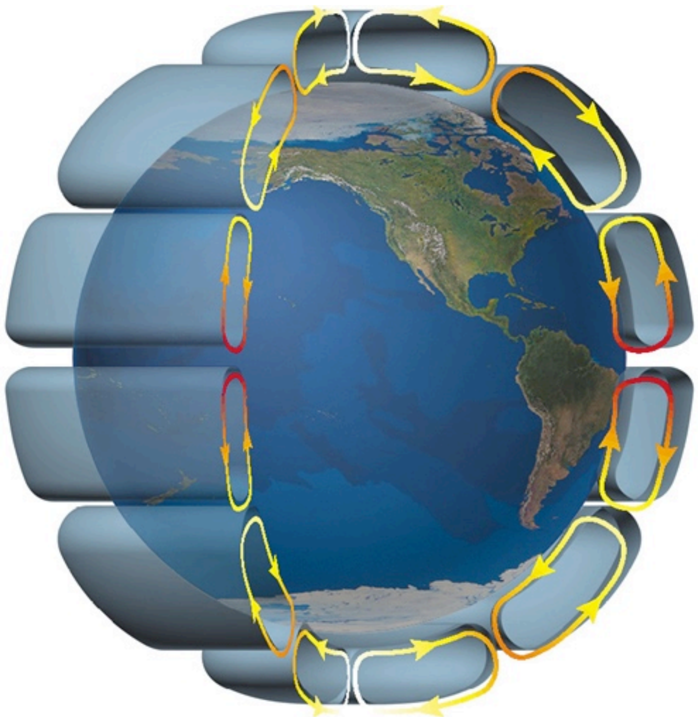
- Sandwiched between the polar and tropical Hadley cells
- Driven by their motion

The simple equator-to-poles convective motion is complicated by the Coriolis force due to the rotation of the Earth



# Global Wind Patterns

- On Earth, the Coriolis effect breaks each circulation cell into three separate cells
  - winds move either W to E or E to W

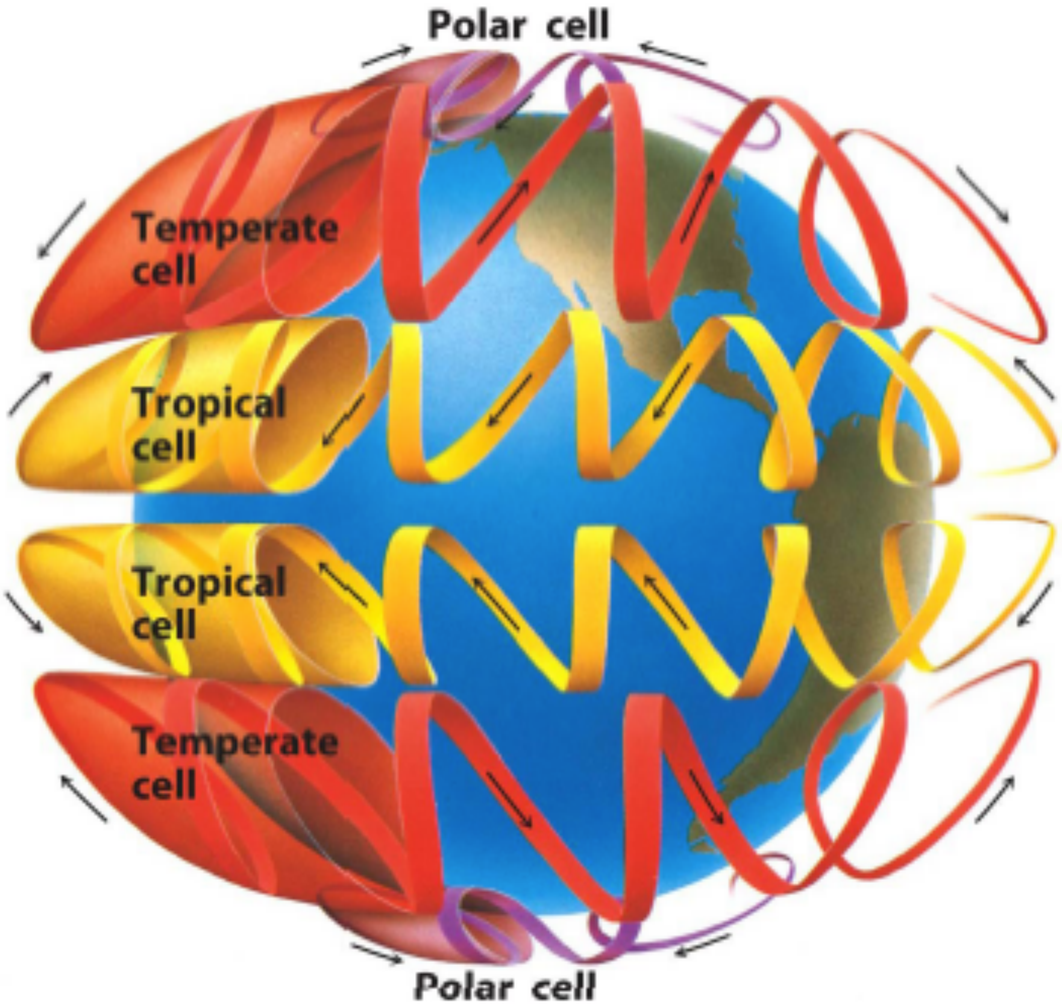


Coriolis effect not strong on Mars & Venus

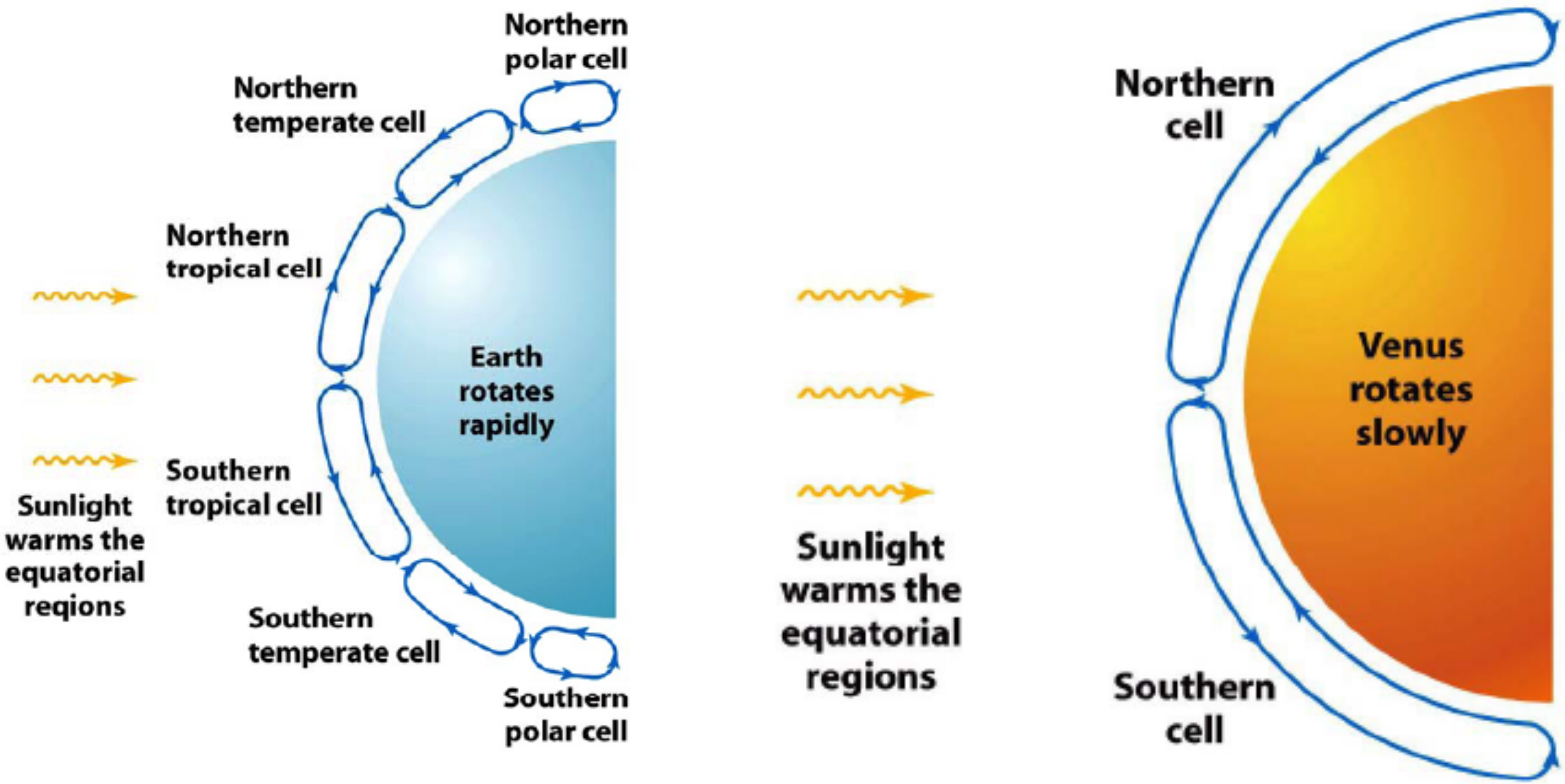
- Mars is too small
- Venus rotates too slowly

Rapid rotators such as the giant planets are significantly affected by the Coriolis force.

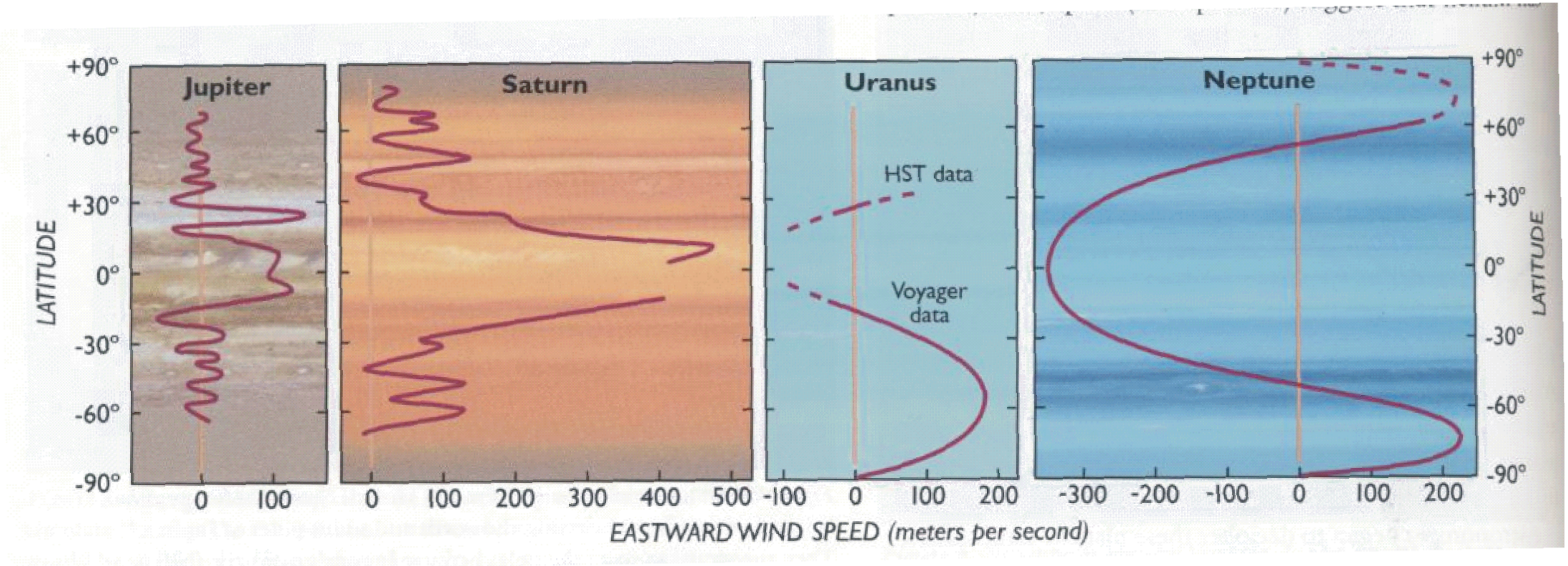
# Global Wind Patterns



# Comparisons



# Zonal Winds




- The reason Jupiter, Saturn, Uranus and Neptune have bands is because of rapid rotations (periods ~ 10 hrs)
- The winds in each band can be measured by following individual objects (e.g. clouds)
- Winds alternate between prograde (eastwards) and retrograde (westwards)

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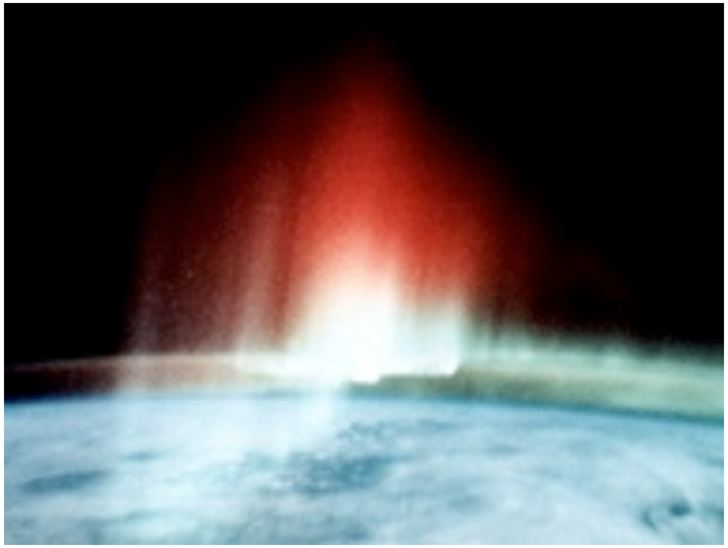
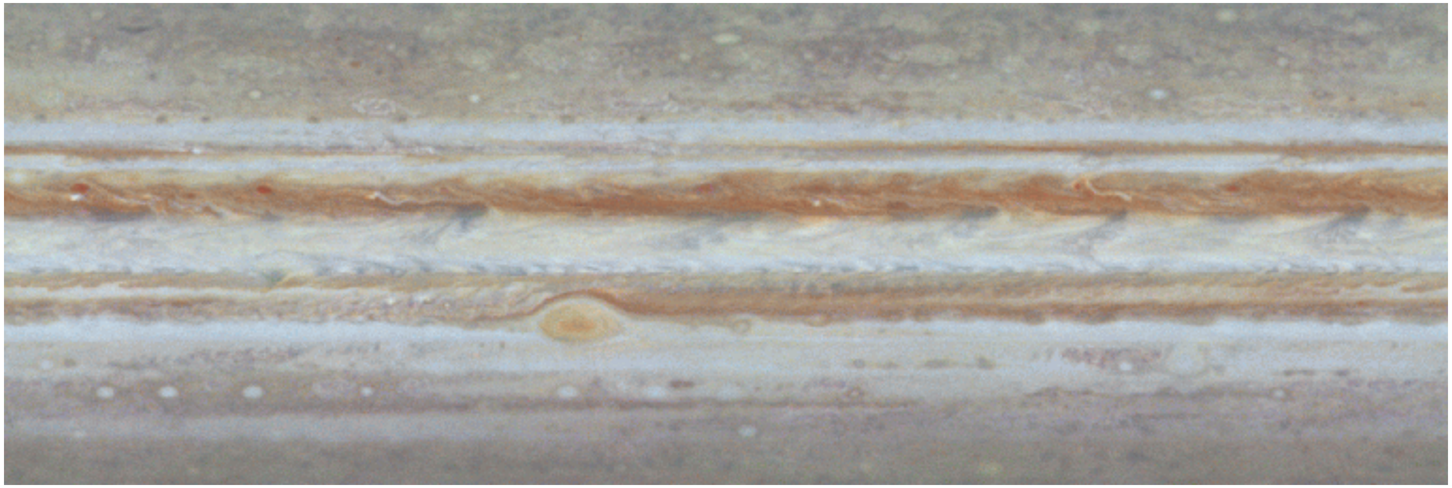
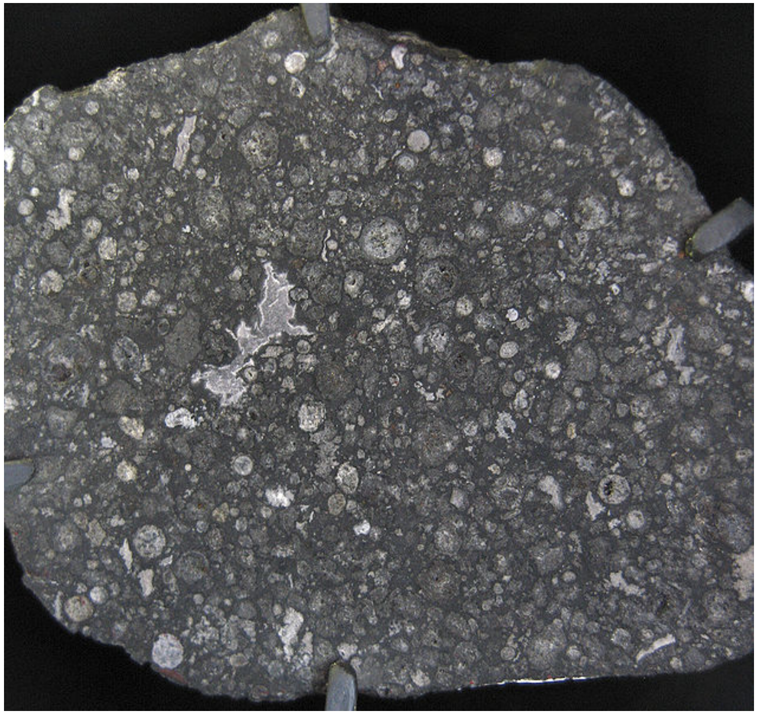




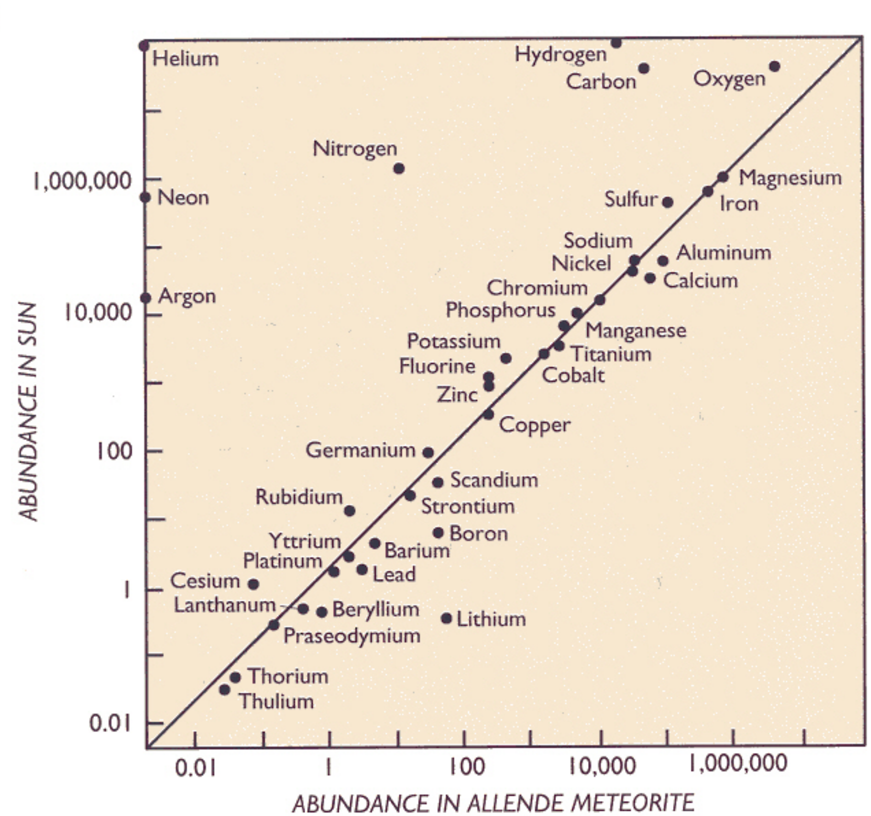
# Where do planetary atmospheres come from?

- Three primary sources
  - Primordial (solar nebula)
  - Outgassing (trapped gases)
  - Later delivery (comets/asteroids)
- How can we distinguish these?
  - Solar nebula composition well known (see next slide)
  - Noble gases are useful because they don't react
  - Isotopic ratios are useful because they may indicate gas loss or source regions (e.g. D/H)
  - $^{40}Ar$ ($^{40}K$ decay product) is a tracer of outgassing

# Carbonaceous chondrites



Compositions from Allende meteorite ⇒




Ref.: J. K. Beatty et al., *The New Solar System*, Ch. 26

Carbonaceous chondrites are considered to be the most similar in composition to the solar nebula