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 Inertial Gravity Coriolis
Derivative Term Gravity Coriolis
$$\begin{array}{ccc}
\text{Local} & \text{Pressure} \\
\text{Derivative} & \text{Gradient} \\
\end{array}$$

$$\begin{array}{ccc}
\mu \\ is the dynamic viscosity \\
v_v is the kinematic viscosity \\
v_v is the kinematic viscosity \\
\end{array}$$

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 *w* decreases (it moves backwards relative to the rotation rate)
- Coriolis acceleration = $2 \omega v \sin(\theta)$ θ is latitude
- How important is the Coriolis effect?



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)

Slow rotator e.g. Venus Medium rotator e.g. Earth Fast rotator e.g. Jupiter Ro >>1(assumes v=100 m/s) $Ro \sim 1/4$

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 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)

Geostrophic balance

- In some situations/regions, the only significant forces acting are due to the Coriolis effect and due to pressure gradients
- The acceleration due to horizontal pressure $\frac{1}{\rho}\nabla P_h$ gradients is:
- The Coriolis acceleration is: $2 \omega v \sin \theta$
- In steady-state these balance, giving: $v = \frac{1}{2\rho\omega\sin\theta} \frac{\partial r}{\partial s}$



 The result is that winds flow along *isobars*, and will form *cyclones* or *anti-cyclones*

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