**Vertical structure of the atmosphere**. Troposphere: vertically mixed region of the atmosphere…storms penetrate to the top of the troposphere. Atmospheric scientists like to use pressure as a vertical coordinate rather than altitude. Meaning of omega = Dp/Dt, ~ - w since dp/dz < 0. 3 levels commonly examined:

| | |
|---|---|
| 250 mb | Top of troposphere |
| 500 mb | Middle of troposphere |
| 1000 mb | Near surface |

**Observations: *Temperature***

- Warm at equator, cool at pole
- Seasonal cycle
- Warmest places are subtropics over land in summer
- Tibetan Plateau always cool, region of strong horizontal gradients
- Warmer in western oceans, cooler in eastern oceans

**Observations: *Sea-level Pressure***

- Subtropical Highs
- Low Pressure centers
  - Equator
  - Western subpolar North Atlantic (Icelandic Low) and Pacific (Aleutian Low) in winter
  - Southern Ocean
- Tibetan Plateau
  - High pressure in January
  - Low pressure in August
- Lows over oceans intensify in winter (when warmer than land)
- Highs over oceans intensify in summer (when colder than land)

**Observations: *Surface winds***

- Winds converge on Equator
- Deep low around Antarctica
- Why aren't the winds as strong there as at lower latitude? Veloc ~ Pressure gradient / f
- Each ocean has its own wind gyre flowing anticyclonically around the subtropical highs. Winds near coast tend to parallel coast. In eastern oceans, winds are towards the equator along the coast.
- Easterlies on equator (trade winds), westerlies in subtropics, weak easterlies in polar regions
- Western Pacific and Indian Ocean seasonal reversal : Asian Monsoon.

**Observations: *Omega***

- Rising air in subpolar latitudes
- Rising air on equator, particularly over western Atlantic and Pacific
- Sinking air (subsidence) in mid-latitudes particularly in eastern Pacific, Atlantic and over desert regions on land.
- Indian Ocean tends to run the other way, with rising in east and subsidence over Africa and the Arabian peninsula.
- Rising centers migrate seasonally north-south (W Pac)
- Rising centers migrate over land in summer when warmer than ocean (lower pressure) and over sea in winter when land colder than ocean (higher pressure)

**DISCUSSION TOPICS:**

**Principles relating pressure and winds near the surface**

- Heating from below tends to produce rising air and low pressure at the ground.
- The rising air tends to be warm and moist and thus flux heat and moisture upwards.
- At the surface, air converges into low pressure zones to replace the rising air.
- The coriolis force turns inflow to the right (NH) or left (SH) to produce a "cyclonic" swirl flow around the low pressure center.
- Where cold dry air descends ("subsidence"), there tends to be high pressure at the ground.
- At the surface, air diverges from high pressure zones.
- Coriolis deflects air into an "anticyclonic" swirl around high pressure regions.

**Winds at 500 mb level**.

500 mb (geopotential) height. In the troposphere, almost identical to physical height above the sea surface. Interpret this as similar to a map of pressure at a constant height. Where geopotential height is higher, pressure is higher and vice versa.

Here, height and pressure are generally speaking higher at the equator and lower at the poles. Westerly winds dominate pattern in more or less geostrophic balance with this pressure field. Can also relate wind speed to the gradient in this field. Can also view this as two planetary scale circulations about the north poles…each one is called a *Circumpolar Vortex.*

Winter northern hemisphere not quite symmetric. Lower pressure over east coasts of North America and Asia. Winds loop southward following the "*troughs*" in the pressure field and northward around the "*ridges*". Southern hemisphere more symmetric, not as much seasonal variation.

**Three meridional circulation cells**

*Hadley Cell*

Tropical cell in latitude-depth plane. Rising near equator, sinking at midlatitudes (30° or so). Southward flow near the ground is deflected towards the west (forming the *Trade Winds*). At the ground, winds converge to a zone near the equator from both hemispheres, called the *Intertropical Convergence Zone (ITCZ)*. Where the tropical Hadley Cell descends the deflection of the Coriolis Force produces very strong westerlies in the upper troposphere. This region of strong winds is known as the sub-tropical jet-stream.

*Ferrell Cell Circulation*

A "reverse" cell from 30° to about 65°. This cell evolves because an equator to pole Hadley cell is unstable. In numerical models or lab experiments, if the heating differential is turned on at some time, the first stage is an equator to pole Hadley cell. The temperature distribution starts to intensify in midlatitudes and the winds intensify there as well. At some point the flow in midlatitudes becomes unstable ("baroclinic instability") and waves develop. The Hadley cell contracts to the tropics and a weak reverse cell becomes established in midlatitudes. This is the zone of the midlatitude *Westerlies*. The winds are not steady like the trade winds, but highly episodic…our winter storms are examples, though they average out to westward motion.

*Polar Cell*

North of about 65° there is a polar cell with rising air in subpolar latitudes and sinking over the poles. At the surface, the southward flow is deflected to the west creating the *Polar Easterlies.*

**Zonal tropical circulation cell: *Walker Cell***

One more important atmospheric circulation feature that is not in this schematic diagram. Over the ocean, water tends to rise where sea surface temperature is warmest and sink where it is coldest. The warmest waters are in the western Pacific. Cooler temperatures are found in the eastern Pacific. Air tends to rise in the west and sink in the east forming the *Walker Cell*.