# *Global circulation of the atmosphere*

Rossby waves in the westerlies, and frontal cyclones are the atmospheric responses to excess heating at low latitudes and excess cooling at high latitudes. The atmosphere is redistributing its heat content such as to transfer heat poleward. The motions of the atmosphere that accomplish this transfer are largely horizontal, and can be seen quite readily on a surface weather map with highs and lows carrying warm air northward and cool air southward.

Such cyclones are mid-latitude phenomena and are not responsible for heat transfer in the tropics and low latitudes. We need to step back and view the system as a whole. Let us start by imagining an enclosure in which the fluid contained is forced into a circulation pattern by cooling at one side and heating at the opposite side as in the diagram. Because heating and cooling create density differences, motion is initiated as shown. This motion transfers heats from the warm to the cold side.
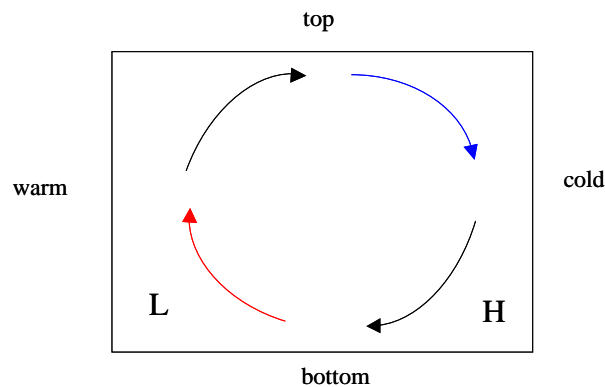

The buoyant rise of the fluid along the heated side creates a decreased pressure (L) at the lower left corner, while the negative buoyancy at the cold side produces a higher pressure (H). This pressure difference drives the fluid across the lower surface of the container. Based on such a thermally driven circulation, one can image a similar pattern of air motion within the atmosphere as a consequence of differential heating.
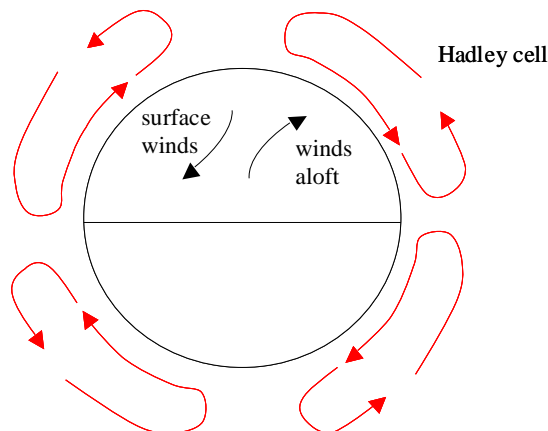
This single cell model, called the Hadley model, breaks
down for two reasons:

1) air moving poleward from the equator would gain very
   large speeds towards the east, according to the law
   of conservation of angular momentum. In fact, unless
   the air had very large speed as it left the equator
   heading north, it would not make it very far before
   the Coriolis force turned it around and forced it to
   return south again (recall the homework problem you
   walk north from Davis and complete a circle back to
   your starting point).

2) there can be no net east-west motion at the surface
   because there is no east-west force to drive the
   atmosphere either east or west. We are considering
   have the globally averaged surface wind field.
   Clearly at any one location or latitude there can be
   a large east or west component.

As a second level of sophistication, we can introduce
the possibility of a three-cell model (it is easy to
see why there must be an odd number of cells to ensure
continuity of vertical motions at cell boundaries).

Polar front

Ferrel cell
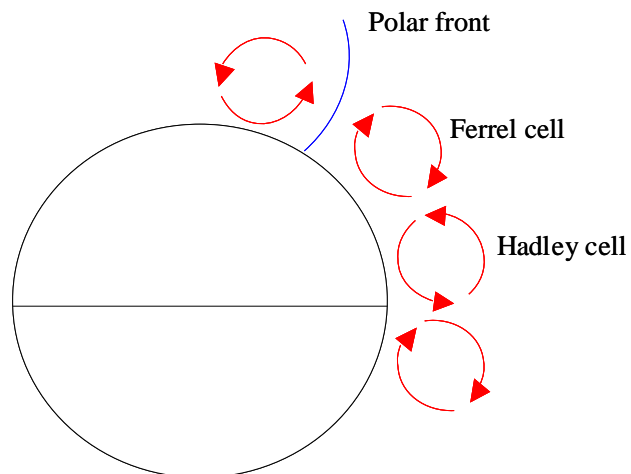
Hadley cell

The reverse cell in mid latitudes is called the Ferrel cell. A third cell at high latitudes contains sinking motion, as required at the cold polar regions. In this model, the Hadlley cell is restricted to low latitudes (0 to 20° N & S say) solving the conservation of angular momentum problem. The two cells in mid and high latitudes have one feature in their support, that is that surface convergence bringing warm air form the south and cool air from the north would create frontal boundaries which match our observations. However, the same problem with Coriolis deviations would prevent the formation of well-defined cellular patterns such as those shown in the diagram above.

The Hadley cell is realistic, though and observed features of tropical and subtropical climates support its existence.
These features are:

    1) an intertropical convergence zone (ITCZ)
    2) subtropical high pressures
    3) the trade winds.
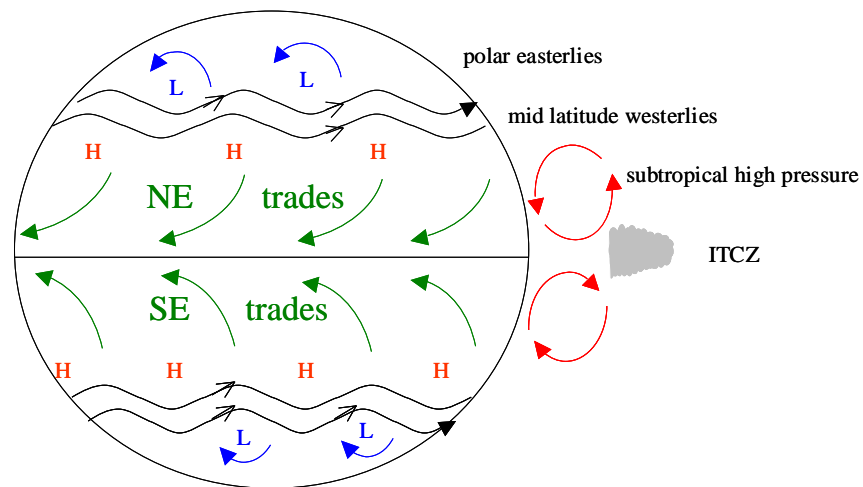
Where the N-hemisphere and S-hemisphere Hadley cells come together, there is convergence in the low level winds. The predominant rising motion results in a band of extensive convective clouds and high rainfall. This band is often shown by satellite photographs to be continuous for many thousands of kilometers but the influence of continents and large ocean bodies perturb the pattern shifting the convergence zone north or south, and making it discontinuous.

About 20° of latitude away from the ITCZ (the climatic equator) the air subsides forming areas of predominantly high pressure. These are called subtropical highs. Subsidence causes warming and drying and these zones have dry climates and are where the great deserts of the world are found.

As surface air returns towards the equator, the Coriolis force turns it to the right (to the left in the S-hemisphere) producing the NE and SE trade winds. Such winds were well known to early manners who found them to be a consistent system taking sailing ships from east to west.

A major influence on the general circulation system described so far is the presence of continents and oceans. Land masses warm up in the summer and cool in the winter much more than ocean bodies, which store large amounts of heat and mix such heat to large depths. Temperature changes at the ocean surface are much less between seasons than over land.

The following diagrams illustrate the northern hemisphere summer and winter mean surface pressure patterns. In summer, the Pacific and Atlantic are relatively cool and overlying cool dense air creates the Pacific and Atlantic (Azores or Bermuda) highs. Meanwhile, the land masses exhibit lower pressure, especially over the extensive Euro?-Asian continent.

The reverse is true in wintertime. The oceanic highs reduce in strength and are pushed southward and the northern oceans assume predominantly low pressure (Aleutian and Icelandic lows). Higher pressure builds over the continents at this time.

The predominance of such pressure patterns has a pronounced influence on the climate of certain regions of the globe. For example, the monsoons of southern Asia are a major perturbation on the simple view of a global circulation. Law pressure over the continent

during the summer months moves the convergence zone northward onto the land mass and produces heavy rainfalls at that time of year (see the following diagram). The dry summers of California are another example, and result from the dominant high pressure over the Pacific.