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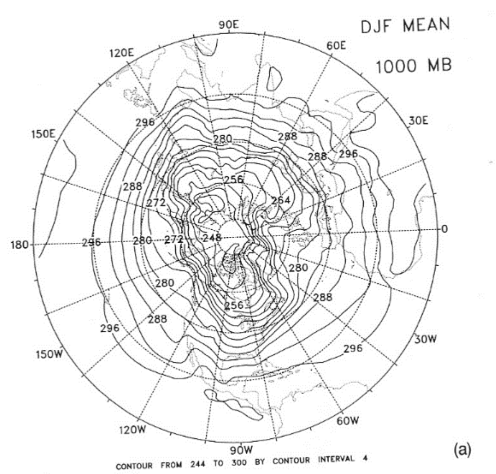
Chapter 6 Introduction to General Circulation of the Atmosphere

- **Major features on sea-level synoptic charts**

The major features include cyclones, fronts, and wave-like large-scale disturbances. The complicated patterns are mainly due to orography and land-sea contrasts.



(Bluestein 1993)

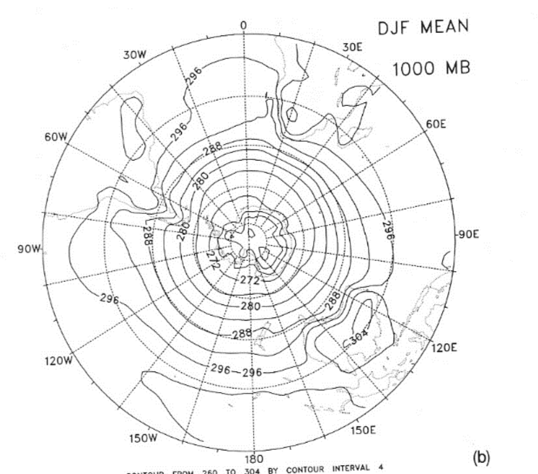


Figure 1.44 Average temperature (K) at 1000 mb in (a) the Northern Hemisph for the winter and (b) the Southern Hemisphere for the summer (Deceml January, and February) (from ECMWF data, 1979–1988; courtesy Kevin Trenb and Amy Solomon, NCAR).

Northern Hemisphere Southern Hemisphere

- **Major features on 500-mb charts**

The 500-mb charts are much smoother than sea-level synoptic charts. There are about 5 lows circling around the North Pole, which are associated with baroclinic waves (Fig. 3.1Hess).

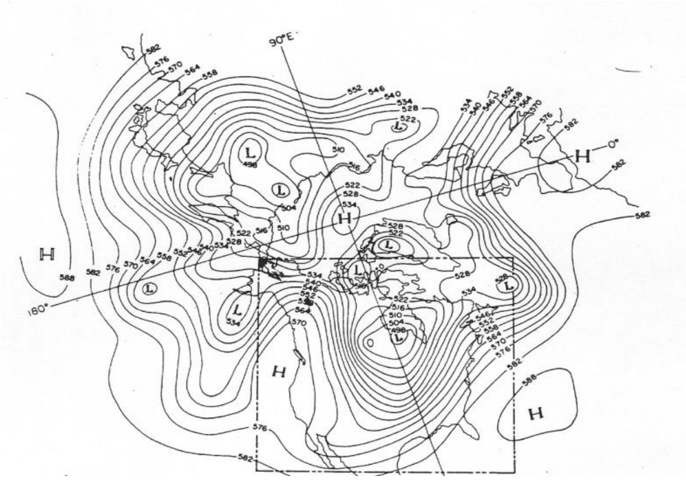


Fig. 3.1(Wallace & Hobbs): Distribution of geopotential height on the 500-mb surface at 00 UTC 20 November 1964. Labels on contours represent geopotential height (in m). The letters H and L denote centers of high and low geopotential height, respectively.

This type of baroclinic waves is often observed in the atmosphere, such as the 500-mb analysis chart shown below.

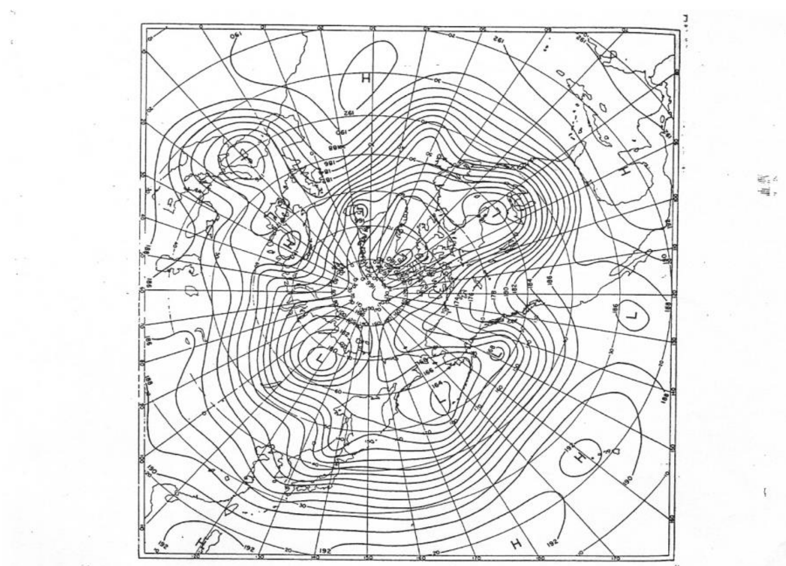


Fig. 6.1 (Holton): Meridional cross sections of longitudinally and time averaged zonal wind indicate strong seasonal variation.

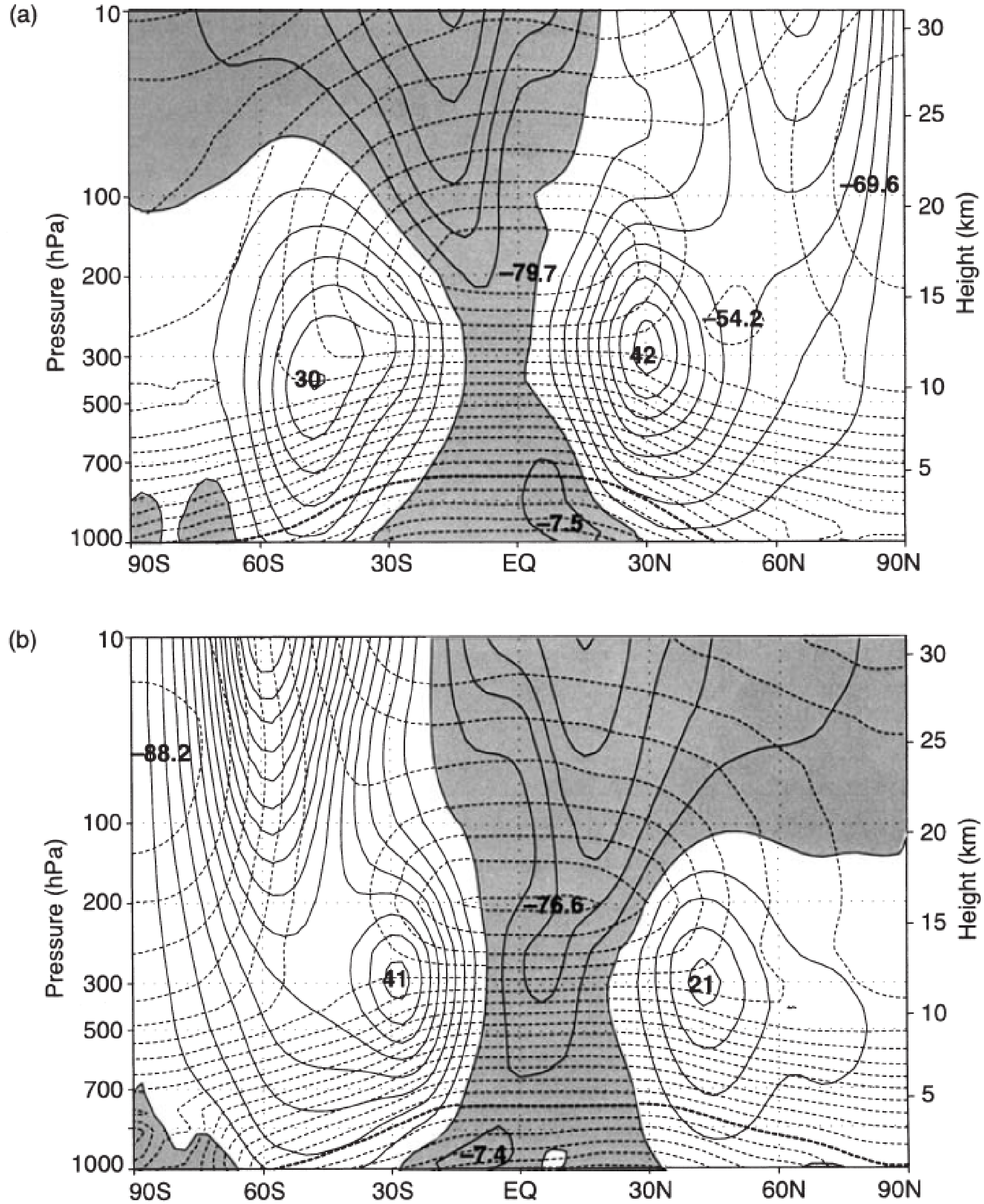


Fig. 6.1 Meridional cross sections of longitudinally and time-averaged zonal wind (solid contours, interval of m s^{-1}) and temperature (dashed contours, interval of 5 K) for December–February (a) and June–August (b). Easterly winds are shaded and 0° C isotherm is darkened. Wind maxima shown in m s^{-1}, temperature minima shown in °C. (Based on NCEP/NCAR reanalyses; after Wallace, 2003.)

- Fig. 6.2 (Holton): Mean zonal wind (heavy contour, 20 m/s) at the 200-mb level for Dec-Feb averaged for 1958-1997 (Wallace 2003). Jet streams in midlatitudes; jet streams are not continuous longitudinally.

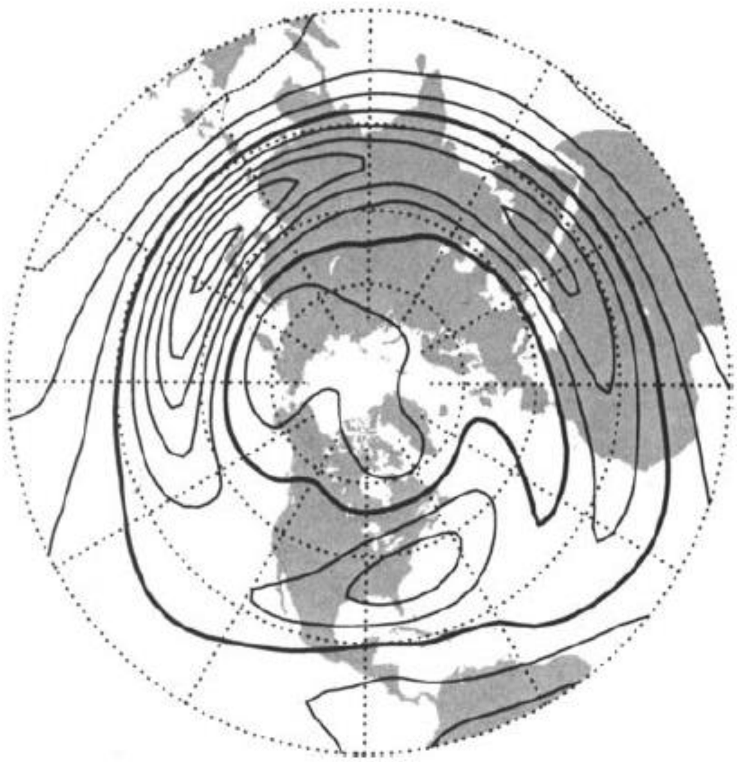
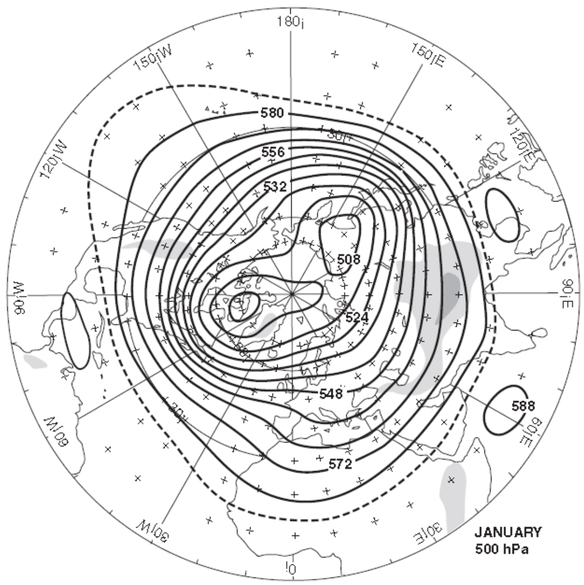
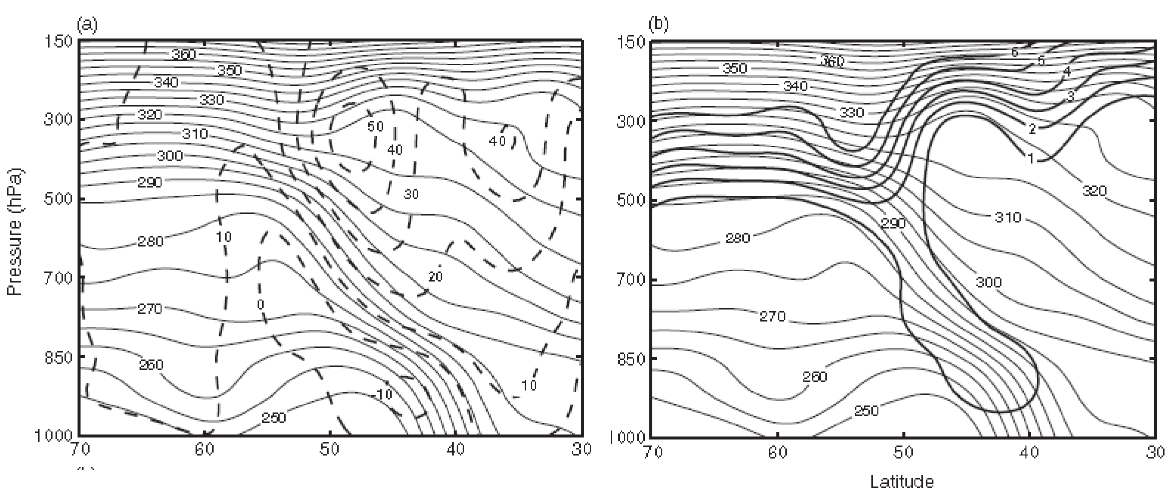


Fig. 6.2 Mean zonal wind at the 200-hPa level for December–February averaged for years 1958–1997. Contour interval 10 m s^{-1} (heavy contour, 20 m s^{-1}). (Based on NCEP/NCAR reanalyses; after Wallace, 2003.)

- Fig. 6.3 (Holton): Mean 500-mb height contours (in 10m) in January in the Northern Atmosphere (Palmen and Newton 1969).



- Fig. 6.4 (Holton): Latitude-height cross sections through a cold front: (1) strong baroclinicity near the front, (2) jet stream is collocated with the cold front due to thermal wind effect.



- General Circulation – The Hadley Cell Model (1735)

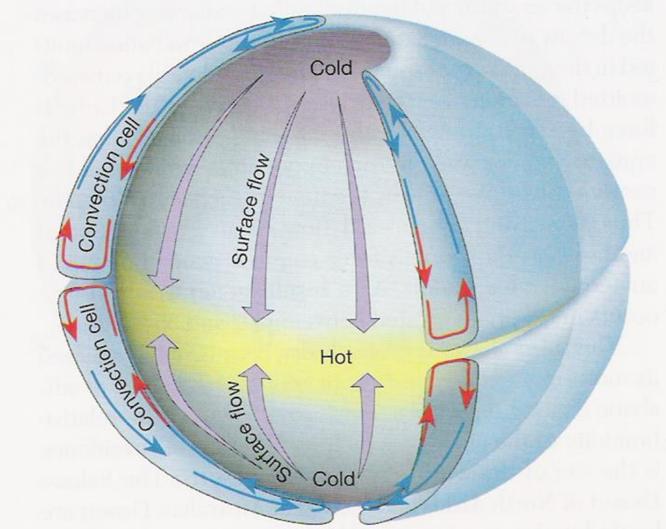


FIGURE 7-6 Global circulation on a nonrotating Earth. A simple convection system is produced by unequal heating of the atmosphere on a nonrotating Earth.

(Lutgens and Tarbuck 2004)

The major problem with the Hadley Model!!!

There is net radiative loss of heat by the atmosphere associated with the upper-level flow toward poles. This cold air must subside and spread poleward and equatorward.

Thus the radiative consideration forces a breakdown of the single Hadley cell!

- Three-Cell Circulation Model (Ferrel 1859)

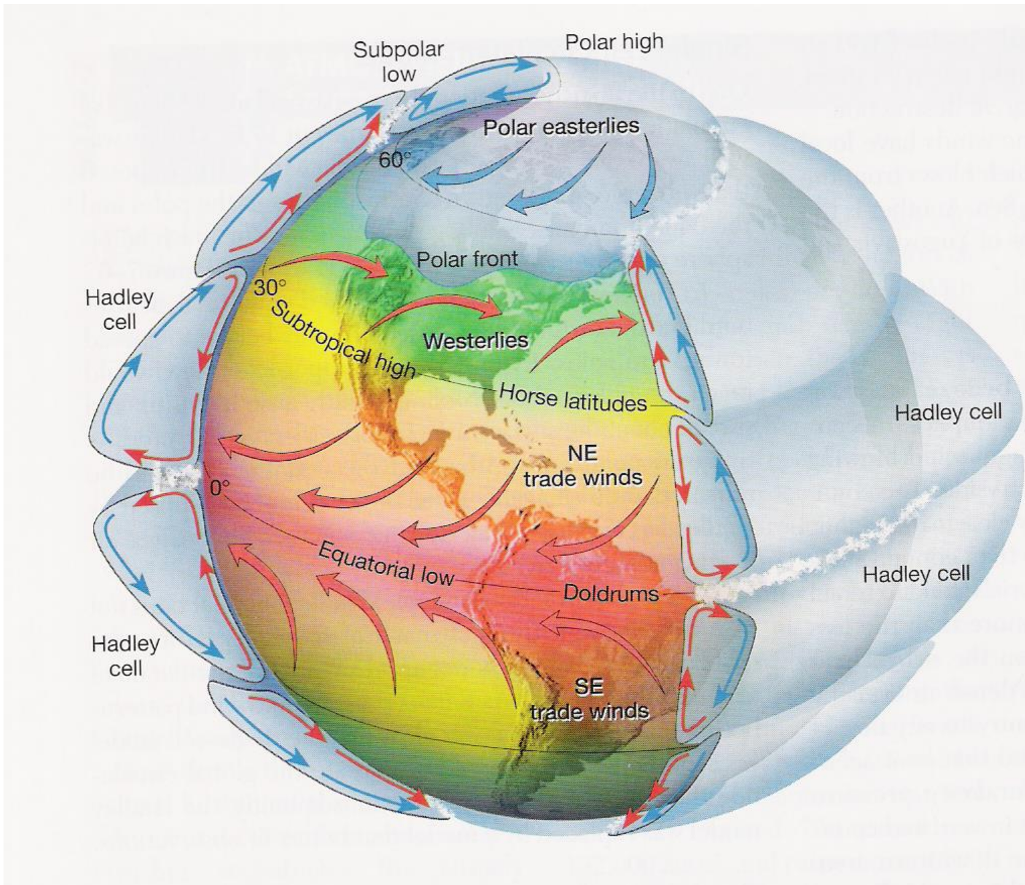


Figure 7.7 (Lutgens and Tarbuck 2004): Idealized global circulation proposed for the three-cell (Ferrel cell) circulation model of a rotating Earth.

- The 3-cell circulation was mainly driven by Earth's rotation and radiation on the upper branch of the Hadley cell.

- The problem with the three-cell model is that the theory fails to account for the fact that the westerlies of middle latitudes increase with height!

- Rossby has suggested that *large-scale turbulence* might link the upper westerlies of the Hadley cell and the polar cells to the upper troposphere of middle latitudes.

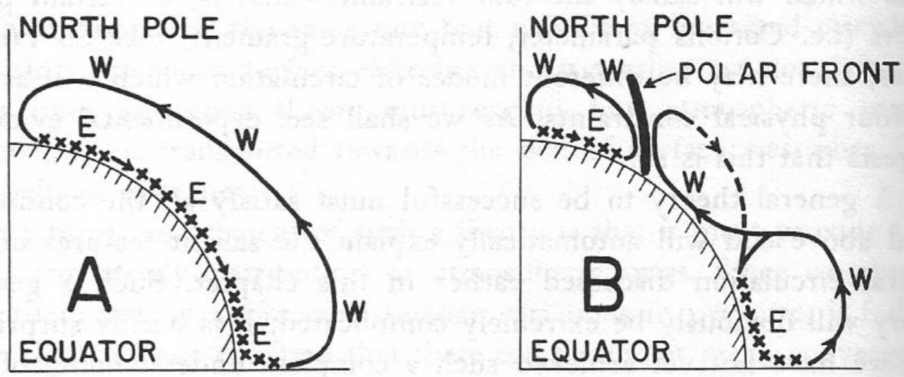
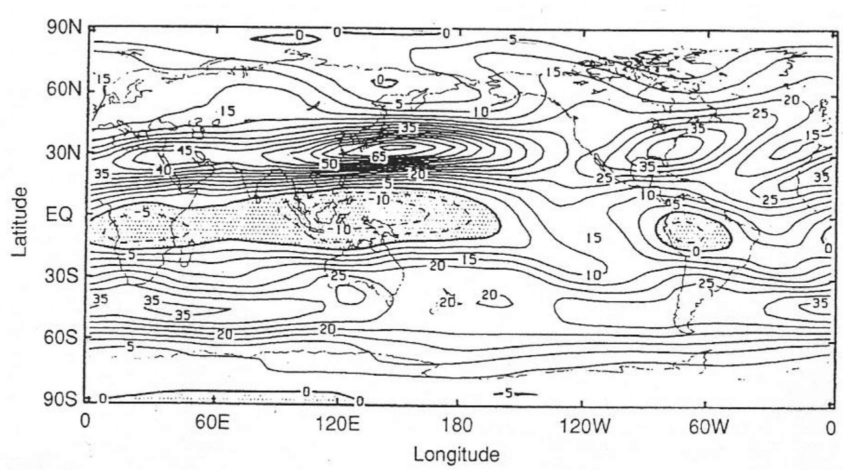


FIG. 21.4. Evolution of three cells in the general circulation according to a Hadley-meridional circulation theory

- The fact is that there exists a longitudinal variation of the flow, thus the jet stream is not continuous around the globe.



Latitude-longitude cross section of time-averaged zonal wind speed at 200 mb for DJF averaged for years 1980–1987. (After Schubert *et al.*, 1990.)

- Observed General Circulation of the Atmosphere

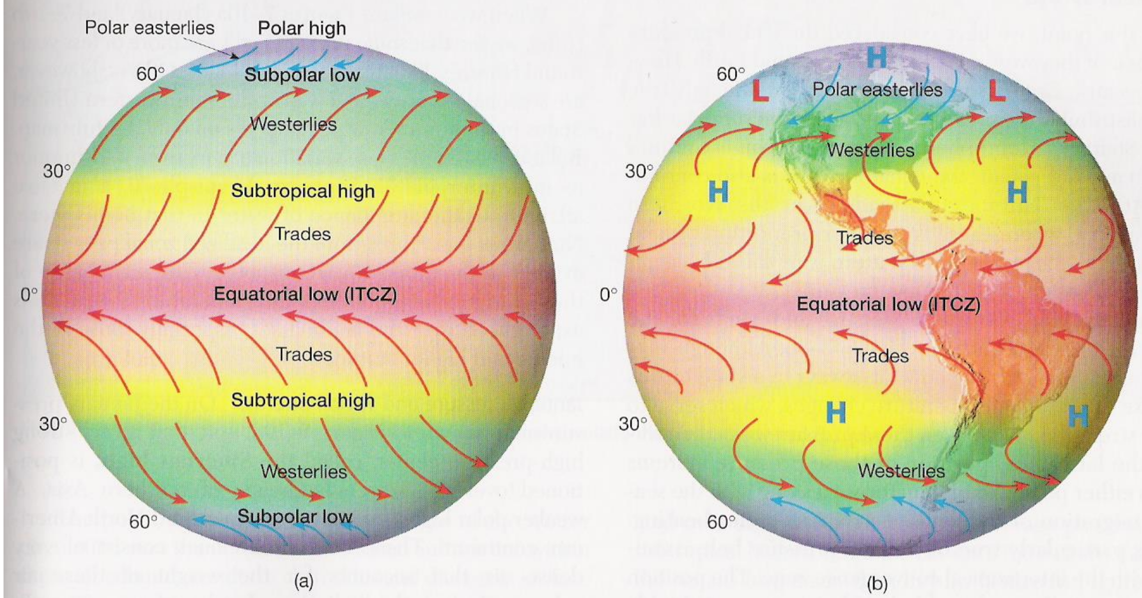
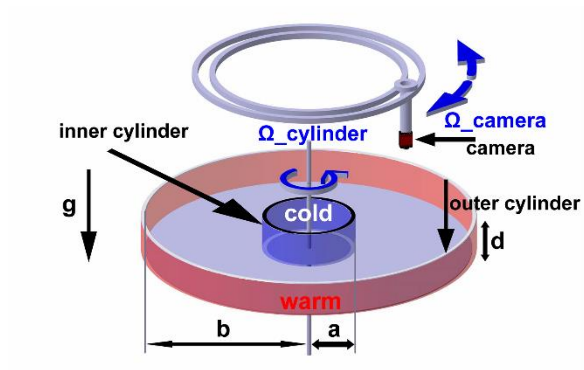


FIGURE 7-8 (a) An imaginary uniform Earth with idealized zonal (continuous) pressure belts. (b) The real Earth with disruptions of the zonal pattern caused by large landmasses. These disruptions break up pressure zones into semipermanent high- and low-pressure cells.

Annulus Experiments



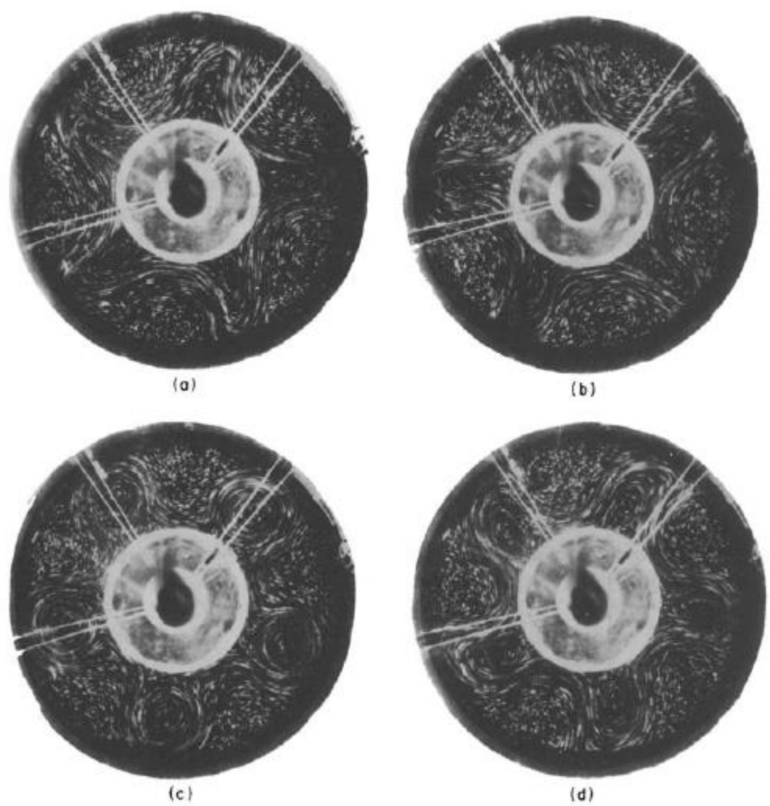


Fig. 10.20 (Holton): Time exposures showing the motion of surface tracer particles in a rotating annulus with heating at the rim and cooling at the core.

Flow regimes found from annulus experiment:

(1) Large Rossby number (low rotation rate) -- Hadley Regime

- Hadley cell circulation develops.
- The circulation is steady and symmetric.

(2) Moderately large Rossby number (medium rotation rate)

- Meridional flow breaks down.
- Jet streams can be found near the upper surface.
- Very steady pattern of Rossby waves exists in westerlies.
- Number of waves evolves from 3, 4, to 5 as rotation rate increases.
- Motions are quasi-geostrophic.

(3) Moderately small Rossby number (large rotation rate) -- Rossby Regime

- Flow is similar to regime 2
- Jets are shorter in length, not continuous
- Flow is markedly unsteady
- Five to six Rossby waves form
- Low-level cyclones and fronts appear
- Observed atmosphere features, such as cold anticyclones, are reproduced
- Troughs in the wave patterns tilted from NE to SW instead of lying along a meridian.

(4) Small Rossby number (very high rotation rate)

- Physical circulation entities become smaller, which mimic convective Elements or Bernard cells.
- Cells are quite unsteady and short-lived.
- Narrow jets are winding in and out among the cells.