Global Circulation

- Local weather doesn’t come from all directions equally
- Everyone’s weather is part of the global circulation pattern

Wind rose shows % frequency of winds around the compass

Global Circulation Models

- The only way forward for understanding our climate is to set up computational **general circulation models**
  - global circulation represents the average winds around the world

Digression: Lewis Fry Richardson (1881 – 1953)

- Numerical forecasting using the laws of physics isn’t a new idea
  - he realised that you need weather data from a grid of weather stations, not clumps near population centres
  - he realised that you need upper atmosphere readings and he pioneered methods of balloon borne data collection
  - he tried putting the ideas into practice but hadn’t adequate computational technology

The Hadley Cell

- spherical Earth
- no difference between land and sea
- Sun over the equator
- no influence of Coriolis force

- Hot equator and cold poles create a pressure difference that drives surface air from pole to equator
- Winds aloft flow in the opposite direction, to complete the cell [fig. 11.1/10.1], as expected
- This model is too simple to predict the observed circulation

Geographic resolution of climate models

- First Assessment Report 1990
- Second Assessment Report 1996
- Third Assessment Report 2001
- Fourth Assessment Report 2007
Earth’s rotation makes a big difference to the very simple model:
- equatorial low
- subtropical high ('Azores' in Atlantic)
- subpolar low
- polar high

The greater number of cells in Jupiter’s atmosphere shows conspicuously.

The upper level circulation from the warm equator is expected to be polewards.
Coriolis force bends the flow to the right.
A geostrophic balance occurs around latitudes 30°, limiting the Hadley cell.
If the Earth rotated faster, or the insolation was less, this limit would be nearer the equator.

The Intertropical Convergence Zone (ITCZ) is where the trades run together into the doldrums.

The ITCZ is characterized by warm, rising air, plenty of clouds and rain.
The trade wind belts are comparatively cloud free.
The ITCZ is clearly seen on geostationary satellite images.

Winds at different heights can be derived from observing the speed at which features seen in different wavelength bands move.
Ocean Surface Winds

- Quikscat radar reflection remote sensing gives surface winds at 10 m height over the oceans

Real World Winds

- The interaction of land and sea introduces semi-permanent highs and lows around the world
  - January [next slide]: notice the lows in S. hemisphere over Australasia, S. America and Central Africa → our weather is dominated by the Icelandic low
  - July [second slide on]: weaker Icelandic low; central Asian low has replaced the Siberian high → our weather is influenced by the Azores high moving northward at irregular intervals. Long-term tendency is known as the North Atlantic Oscillation (NAO)

January Winds

July Winds

Global Precipitation

- Precipitation is associated with warm, rising air fed with ocean moisture [p. 279/262]. See also appendix G
- The general circulation features move about 10° to 15° in latitude following the Sun's movement

Wind Aloft

- A lot of weather tends to come down on us from above
  - when an anticyclone dominates, the air within it is sinking
  - when a depression comes over, we experience a sequence of clouds of decreasing height
- Winds aloft tend to determine the direction that storms move and how deeply they intensify [fig. 11.8/10.8]
Jet Streams

- The Polar front jet stream has an important influence on our weather
  - jet stream circles Earth in a huge wavy line a few hundred km wide, a few km thick, around height of tropopause, with central speeds typically 200 km hr$^{-1}$ in direction West to East
  - jet stream forms at the junction of cold, polar air to north and warm subtropical air to south [fig. 11.10/10.12]
  - there is also a subtropical jet stream where the Hadley and Ferrel cells meet. See the next slide

Polar cell

Polar jet

Hadley cell

Jet Stream Locations

- Air moving round the earth with speed $v$ and towards the pole must increase its speed to preserve its angular momentum, since its distance from the Earth's rotation axis is less [p. 287/268]

Origin of Jet Stream

- Polar jet stream occurs at the junction of warm and cold air, where there is a sharp pressure change and a strong pressure gradient [fig. 11.12/10.12]
  - the faster winds occur near the highest altitude in the troposphere

Role of Angular Momentum

Ocean Currents

- Ocean currents are driven by 3 effects
  - atmospheric winds
  - temperature and salinity gradients (‘thermo-haline’)
  - hydraulic heads (height differences)
- Gulf Stream is largely a wind driven current circulating water around the Sargasso sea
- North Atlantic drift drives current into the Arctic Sea with the help of a hydraulic head
- Salinity gradient drives cold water return south from Greenland

Ocean currents transport energy

- Ocean currents transport large amounts of energy to different latitudes
  - energy transport happens on a timescale measured in months
  - ocean currents extend to the ocean floor, producing long-term movement of water around the globe on a timescale measured in centuries
- Major feature of ocean currents are a sequence of loops called gyres [next slide]
Global Ocean Currents

Ekman Spiral
- Surface water moves at about 45° to the driving wind, due to the action of the Coriolis force
  - water below the surface moves at an angle to water on the surface that is driving it [Fig. 11.17/10.17]
  - water further down moves at an angle to subsurface water that is driving it, and so on …...
- The result is a spiral pattern of velocity, with an average movement about 90° to the wind

El Niño
- El Niño is an intermittent, warm surface ocean current from the West at equatorial latitudes that impinges on South and Central America, the result of a disturbed ocean-atmosphere system
- El Niño is accompanied by a reversal of normal atmospheric pressure systems over West and East Pacific

Normal and El Niño Circulation
- Normal: wet weather to the West, cool sea on East Pacific
- El Niño: wet weather in the East and warm sea

Monitoring the Atmosphere and Ocean
- TAO the Tropical Atmosphere Ocean project of NOAA monitors sea temperatures and winds from an array of Pacific buoys

The Atmospheric Connection
- The atmospheric pressure reversal is called the Southern Oscillation
  - combined with El Niño: ENSO

Diagrams courtesy Canadian Institute of Ocean Sciences
El Niño and La Niña

PDO → 20 – 30 year period


Sea Surface Temperatures Recorded

1997/98 was a strong El Niño year

PDO → 20 – 30 year period


El Niño occurs near the end of every year but usually lasts only a few weeks

A strong El Niño lasts for many months, chokes off the nutrient rich cold Peruvian current, with important knock-on economic effects

(animation: http://www.cdc.noaa.gov/map/clim/sst_olr/sst_anim.shtml

The Wider Effects of El Niño

El Niño isn't just about Peruvian fishermen loosing a living, or flooding of the coastal plains in Ecuador and California, or drought and bush fires in Australia

the extra, warm, tropical water injects large amounts of additional moisture and latent heat into the atmosphere, probably modifying subtropical jet streams

correlated climate anomalies in terms of modified rainfall and temperature patterns seem to occur in regions around the world [fig. 11.24/10.24 and next slide].

see the next slide

trying to understand these secondary effects is one of the goals of today's meteorological research.