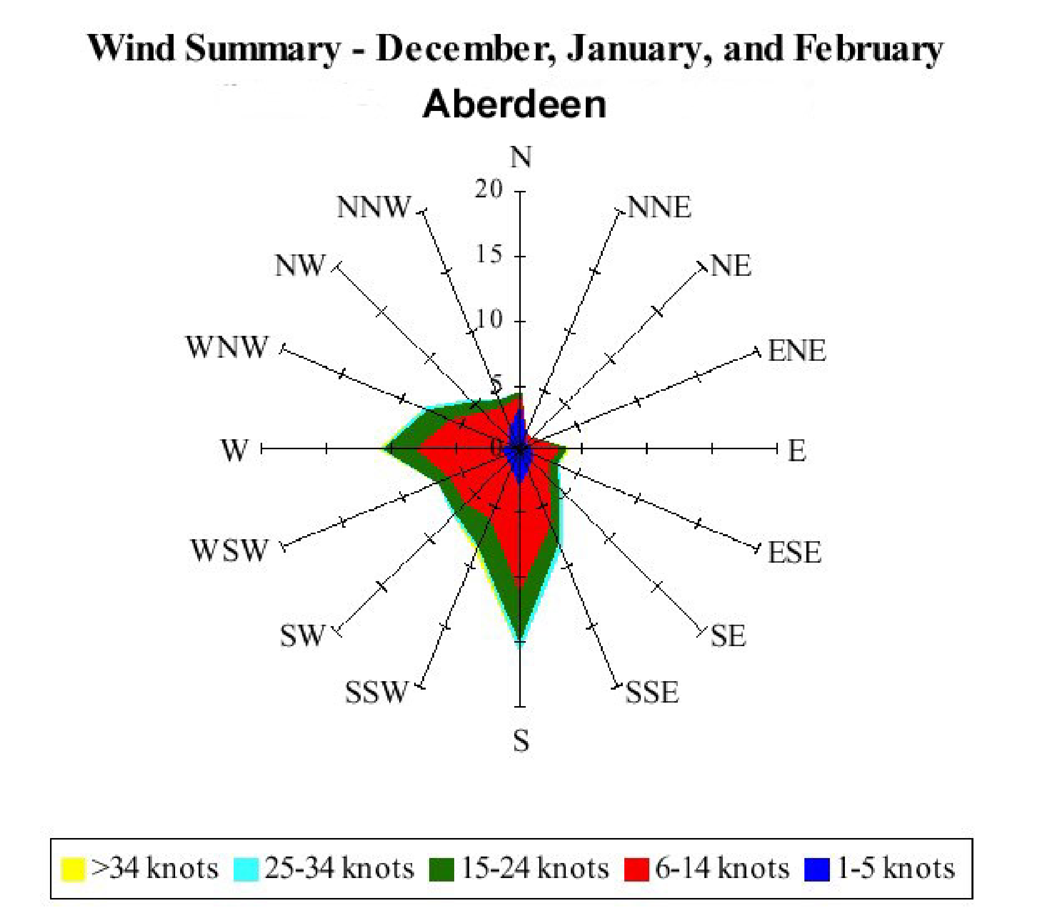
Global Circulation

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



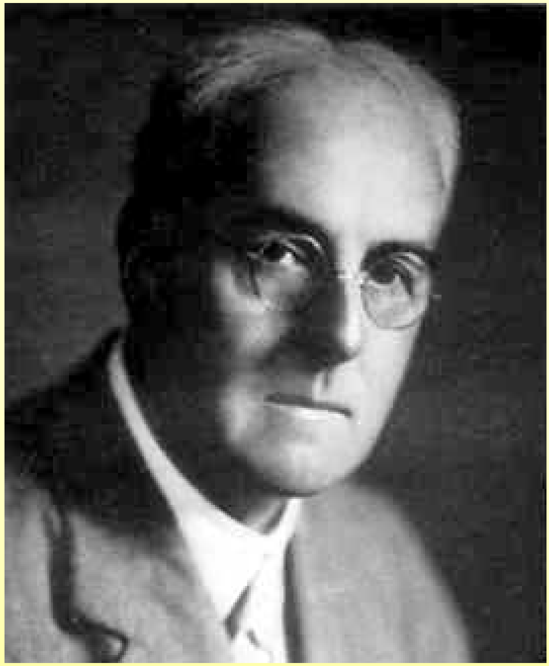
Wind rose shows % frequency of winds around the compass

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

Island of Eigg on Scottish W. coast: photo JSR

Digression: Lewis Fry Richardson (1881 – 1953)



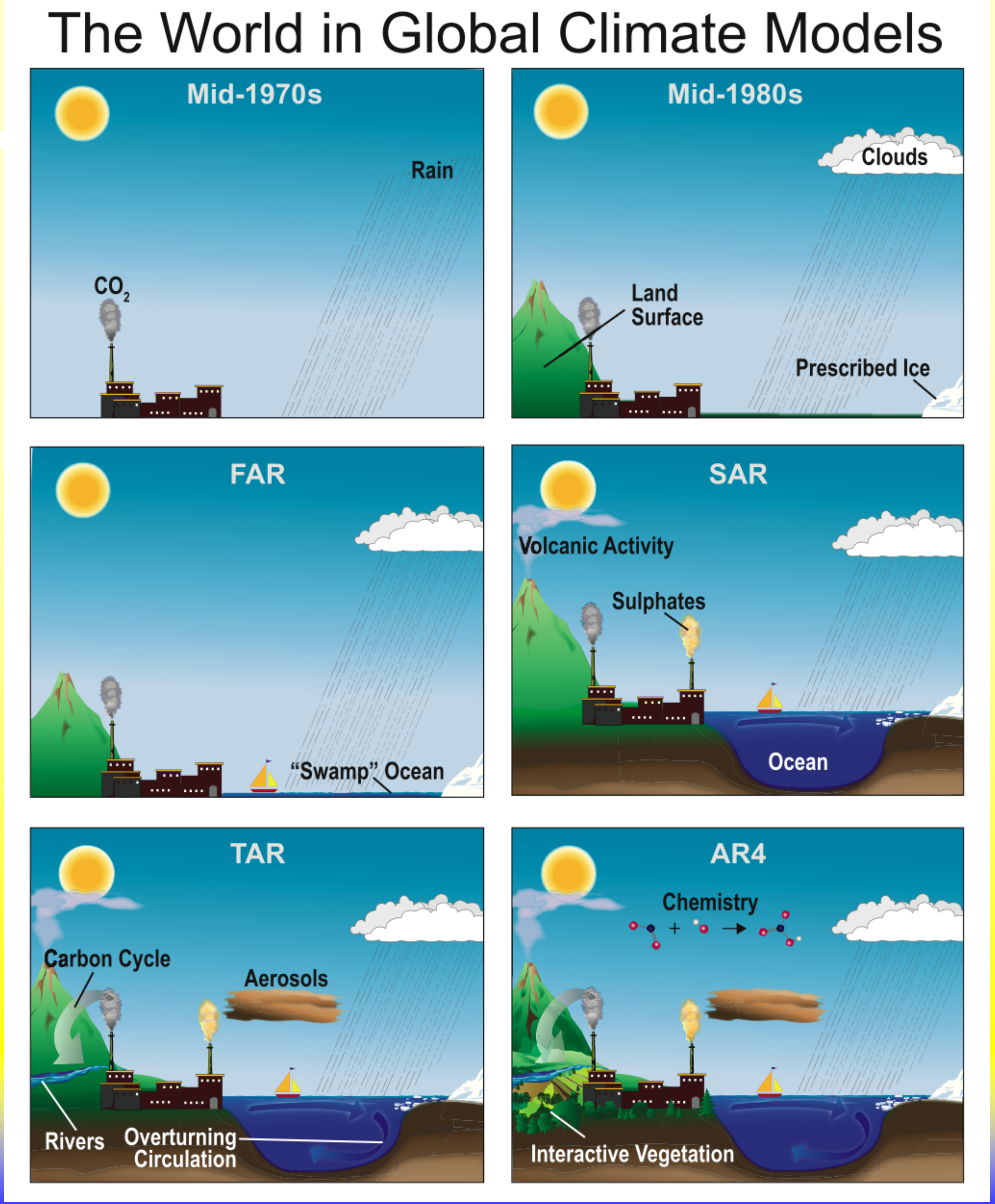
- Numerical forecasting using the laws of physics isn't a new idea
- L F Richardson outlined the method in his book *Weather Prediction by Numerical Process*, published in 1922
  - he realised that you need weather data from a grid of weather stations, not clumps near population centres
  - he realised 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

Late 1980s

Mid 1990s

Late 1990s

Mod 2000s



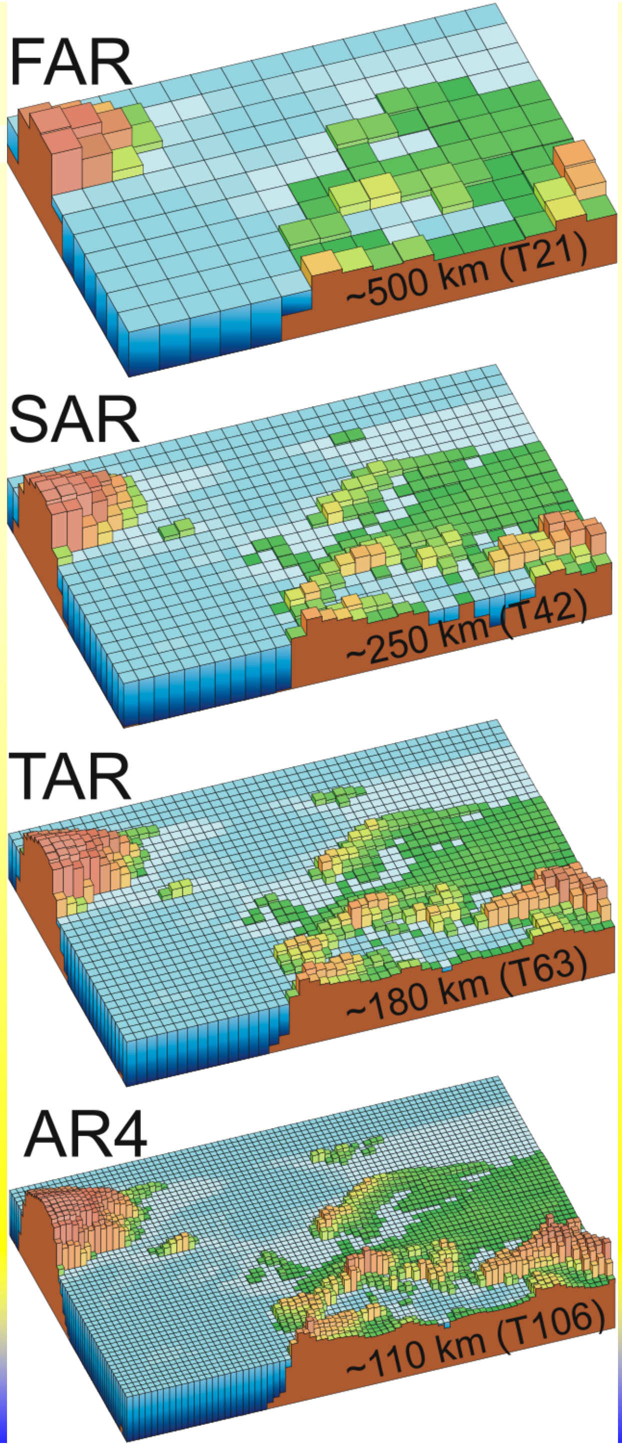
Courtesy: IPCC 2007

First Assessment Report 1990

Second Assessment Report 1996

Third Assessment Report 2001

Fourth Assessment Report 2007

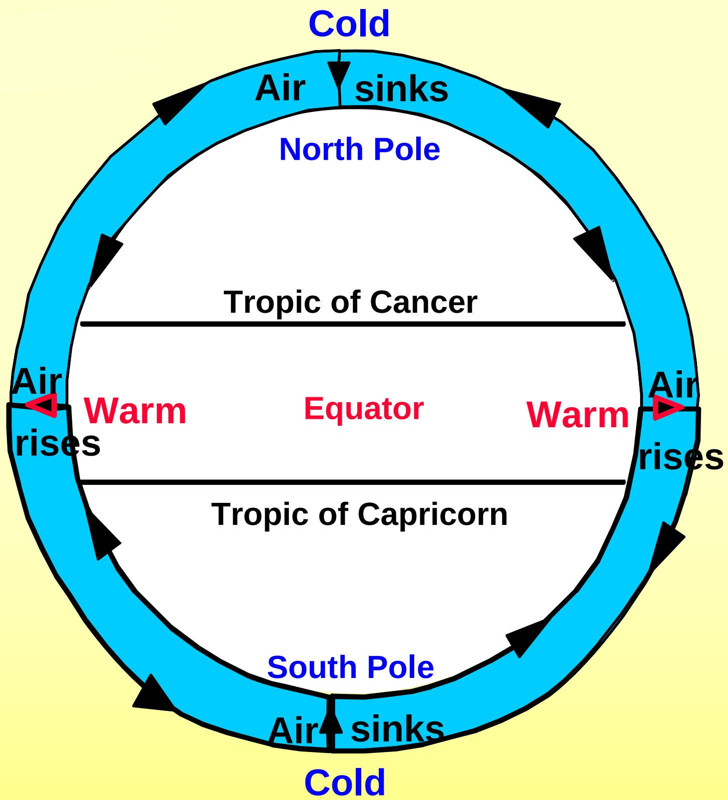


Geographic resolution of climate models

Courtesy: IPCC 2007

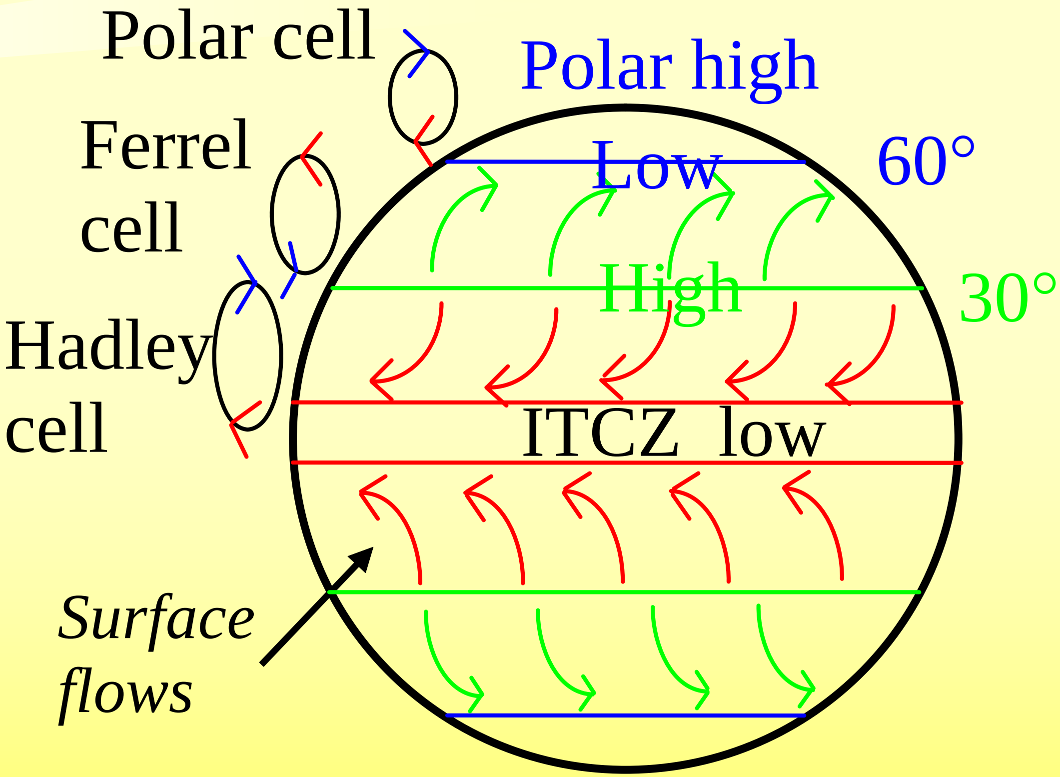
The Hadley Cell

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



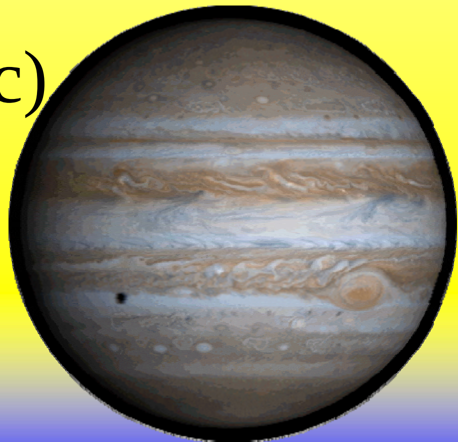
- Hot equator and cold poles create a pressure difference that drives surface air from pole to equator
- Winds aloft flow in the opposite direction, to complete the cell [fig. 11.1/10.1], as expected
- This model is too simple to predict the observed circulation

Six-cell Model



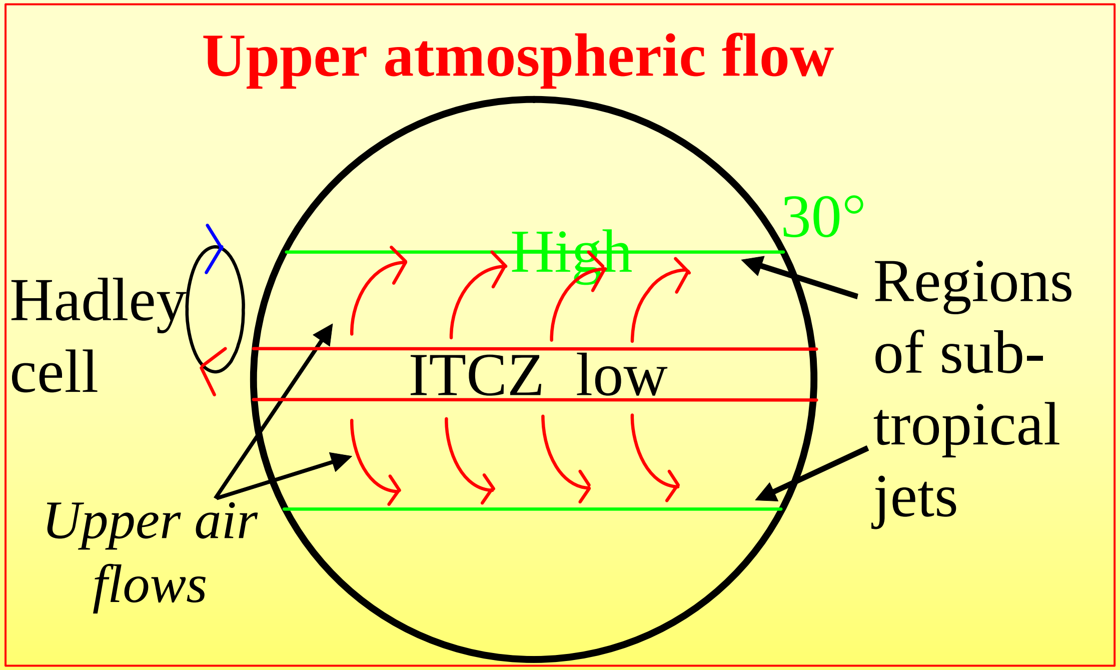
- Earth's rotation makes a big difference to the very simple model
  - equatorial low
  - subtropical high ('Azores' in Atlantic)
  - subpolar low
  - polar high
- [Fig. 11.2/10.2]

The greater number of cells in Jupiter's atmosphere shows conspicuously →



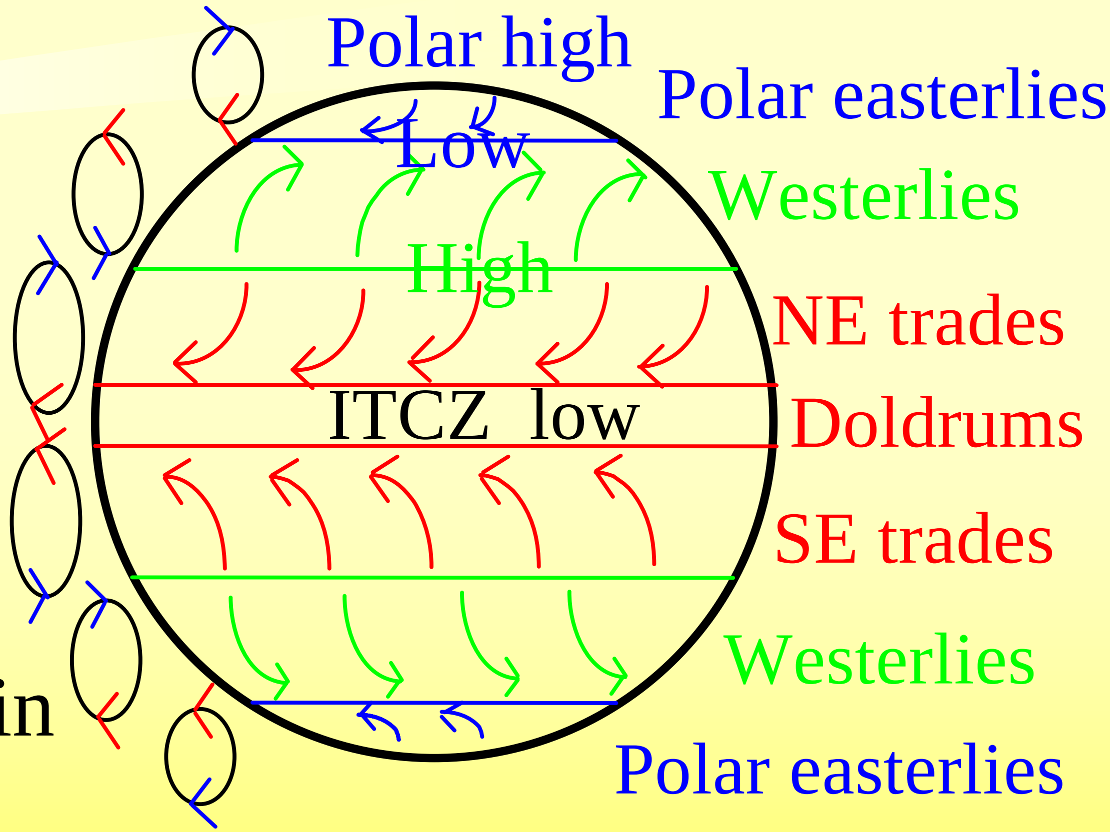
Influence of the Coriolis Force

- The **upper level circulation** from the warm equator is expected to be polewards
- Coriolis force bends the flow to the right

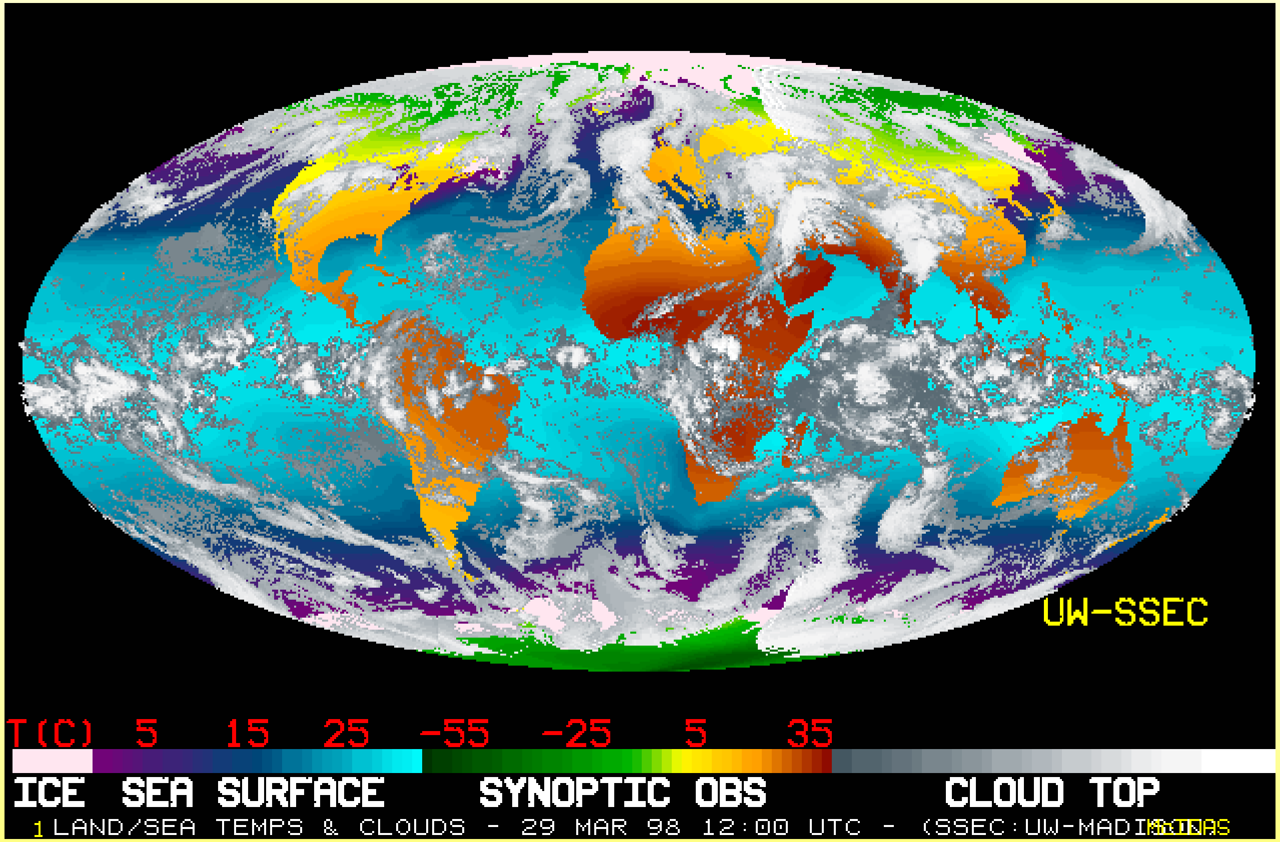


- A geostrophic balance occurs around latitudes 30°, limiting the Hadley cell
- If the Earth rotated faster, or the insolation was less, this limit would be nearer the equator

Global Winds



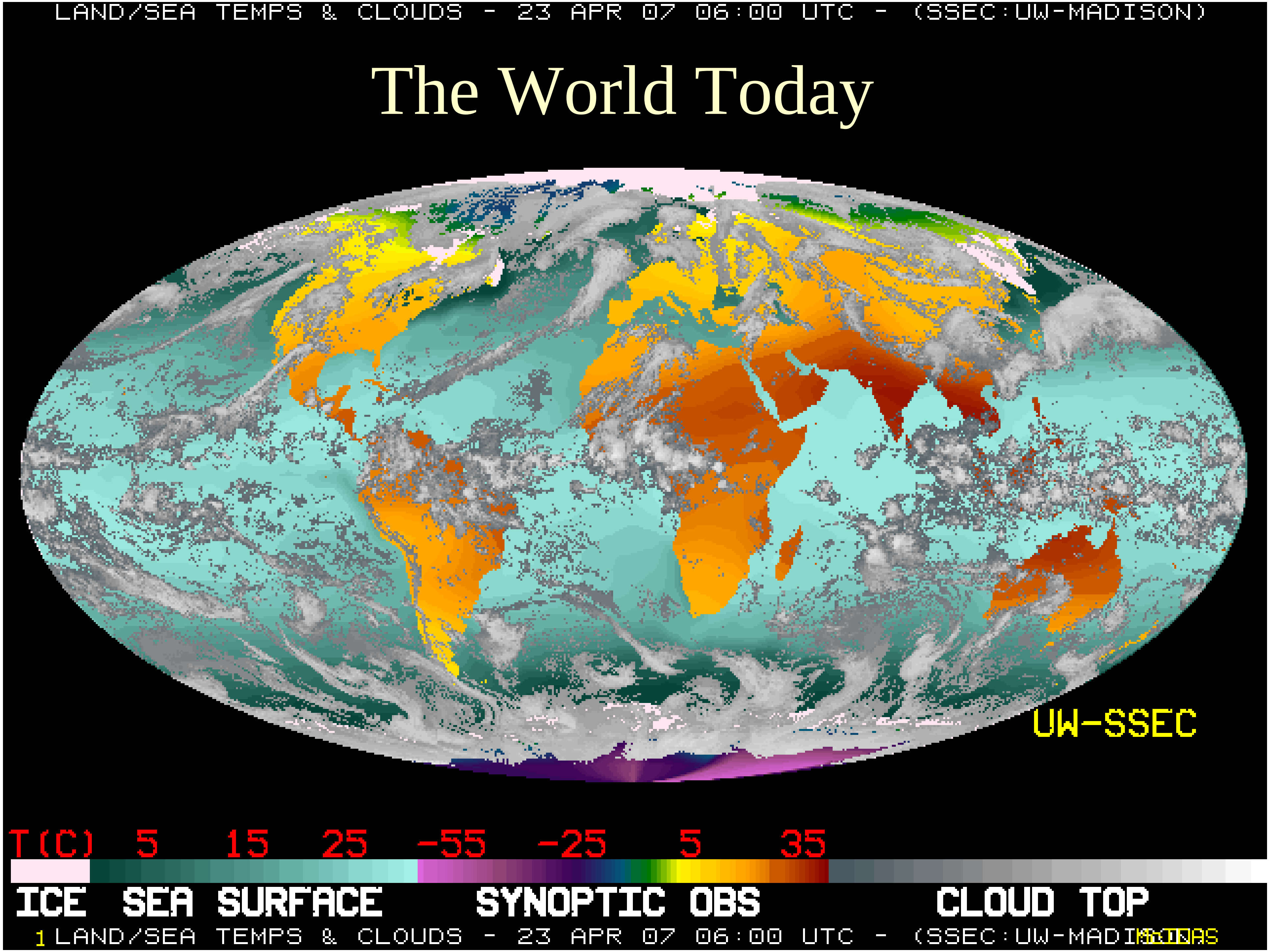
- 3 cells per hemisphere define a broad picture of **surface winds** in moderately good agreement with observed winds
- Notice the importance of the Coriolis force in determining the direction of the winds
- The **Intertropical Convergence Zone** (ITCZ) is where the trades run together into the doldrums

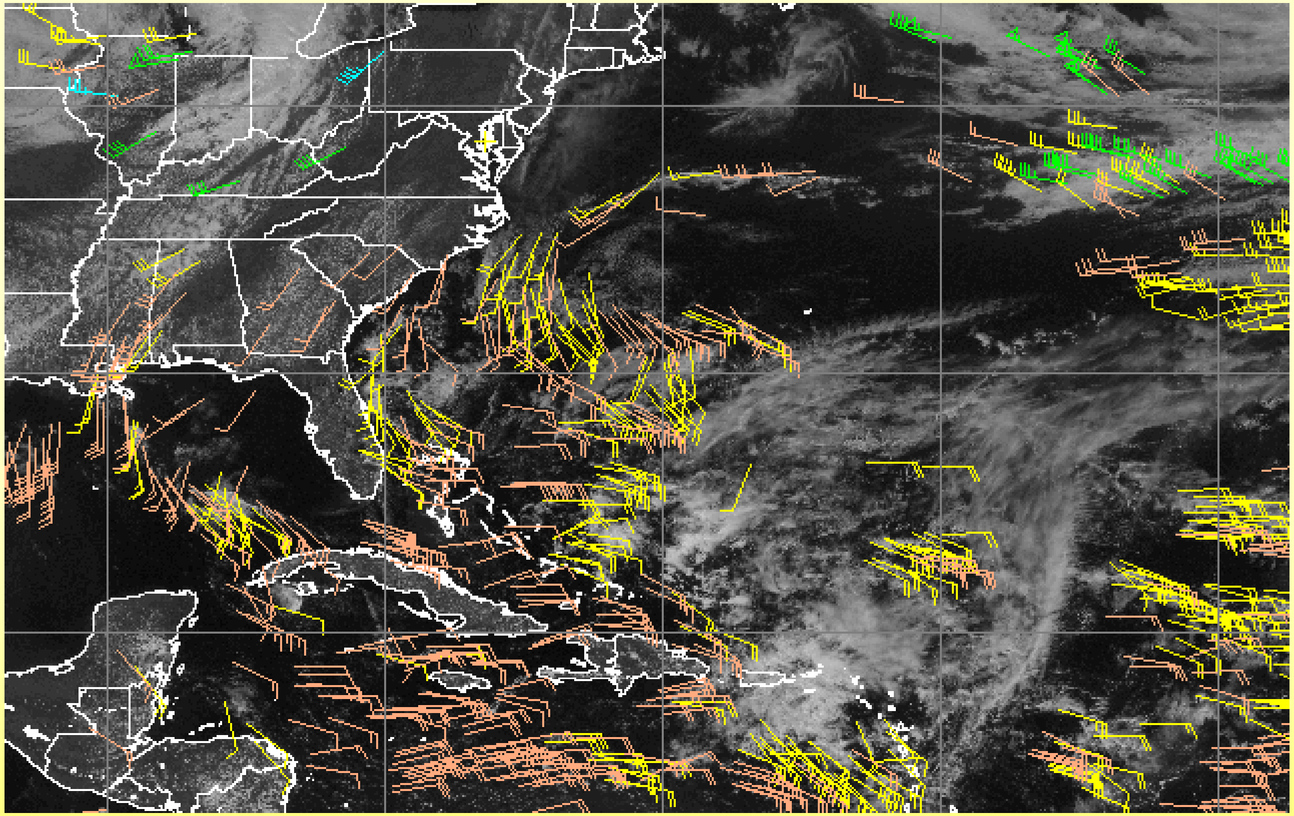


Global View

- 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

The World Today



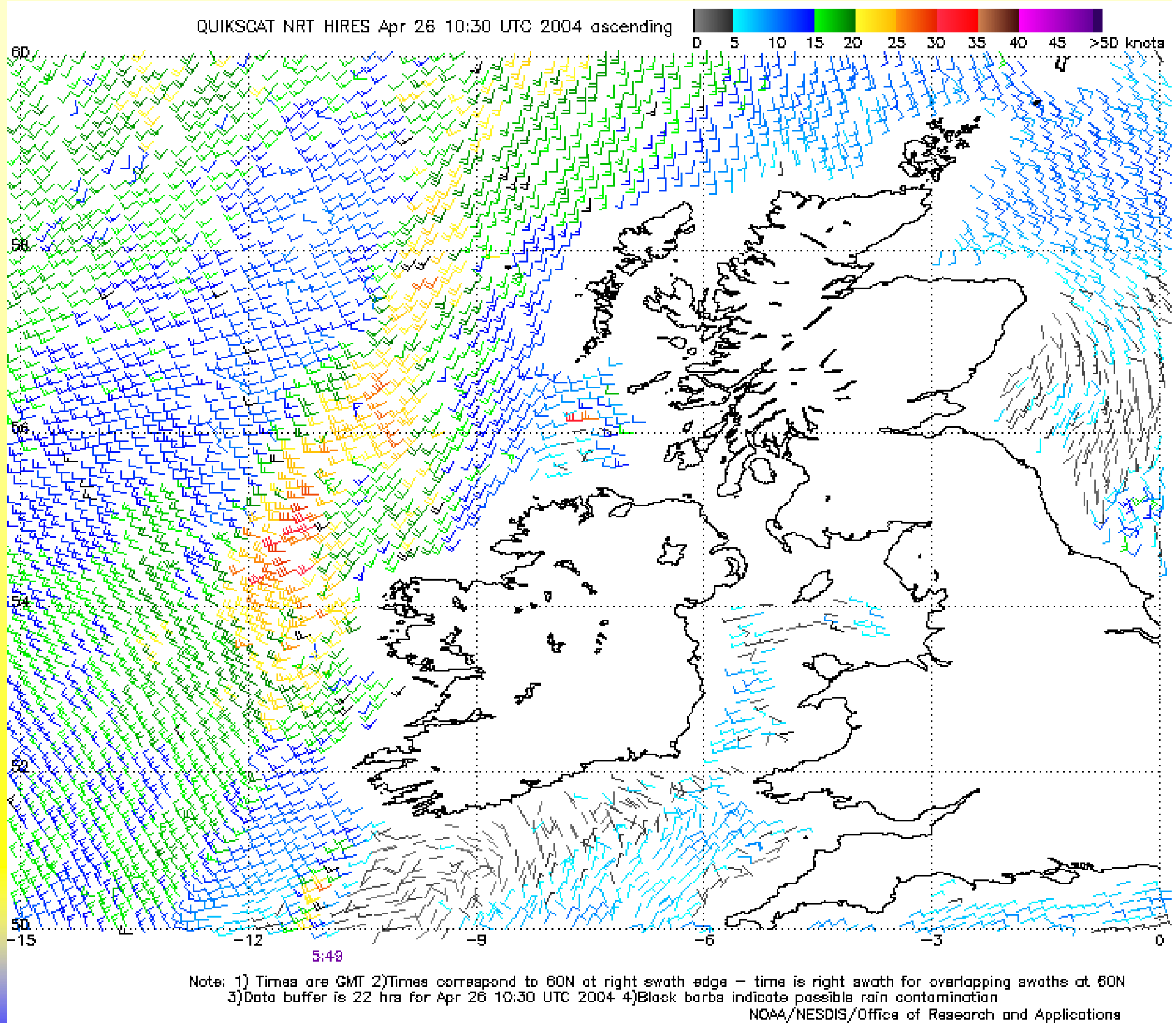


Winds from Satellite Measure-ments

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

Ocean Surface Winds

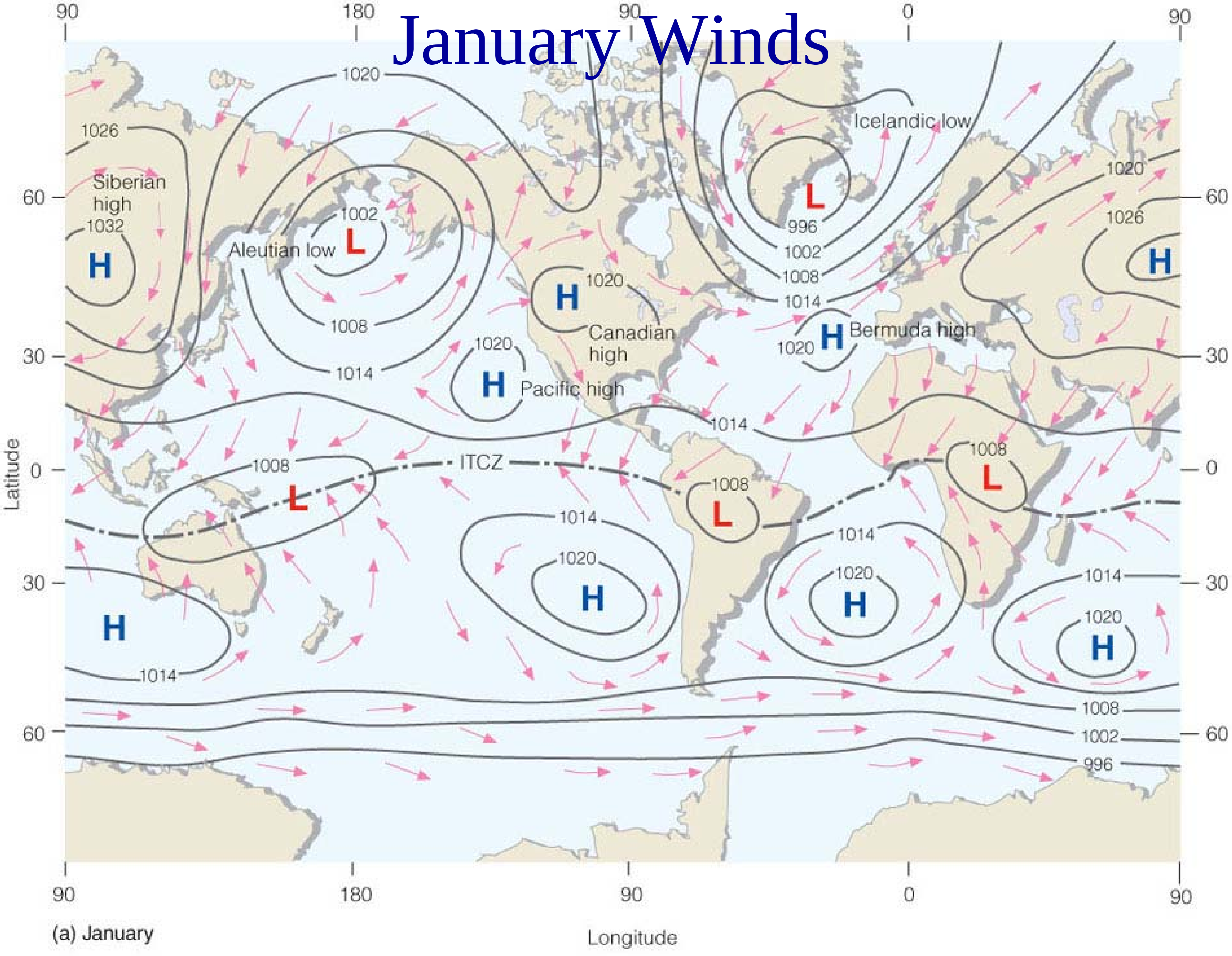
- Quikscat radar reflection remote sensing gives surface winds at 10 m height over the oceans



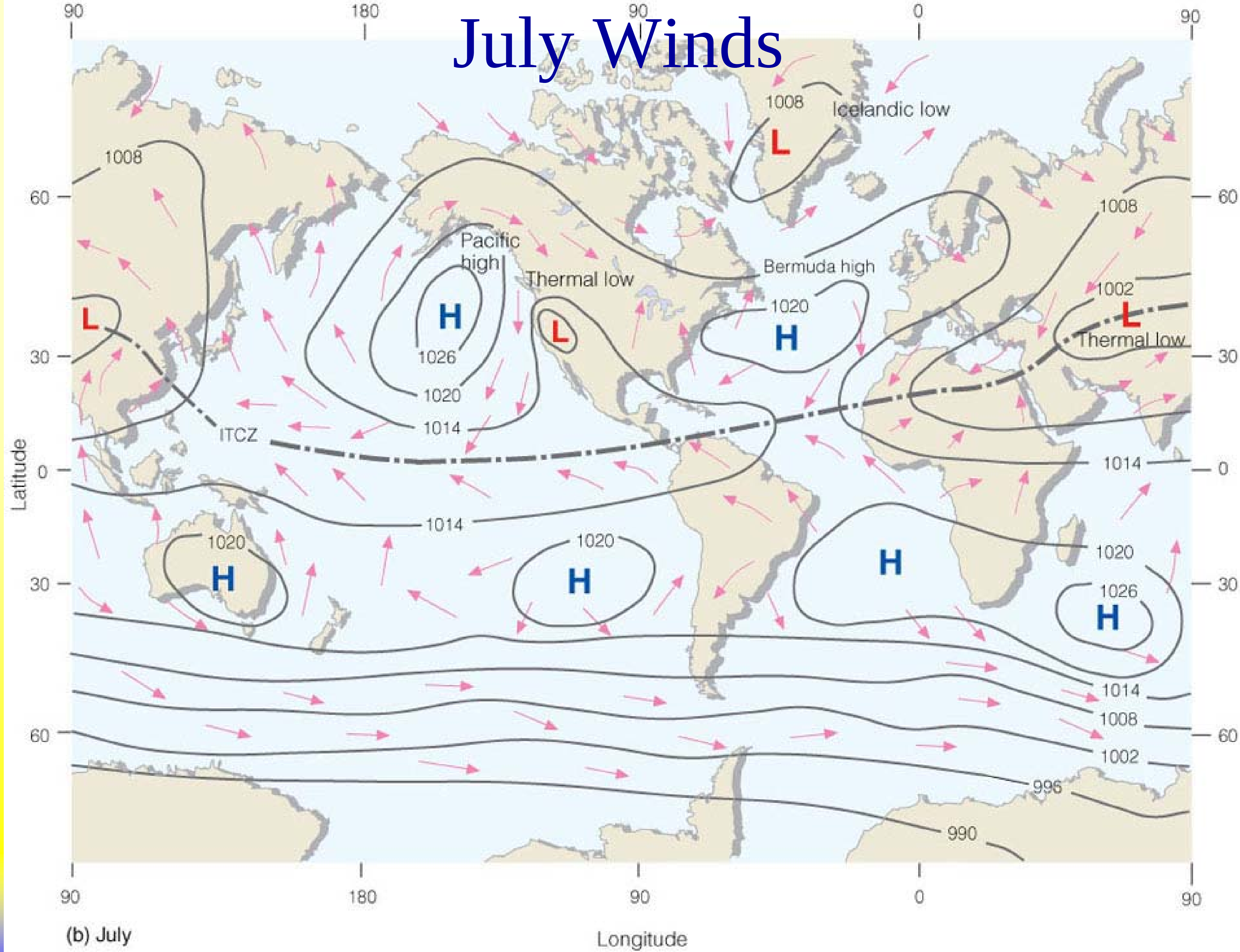
Real World Winds

- 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



90
180
90
0
90
60
30
0
30
60
Latitude
Longitude
1008
Icelandic low
L
Pacific high
H
Thermal low
Bermuda high
1020
1026
1014
ITCZ
1002
Thermal low
996
990
(b) July

Global Precipitation

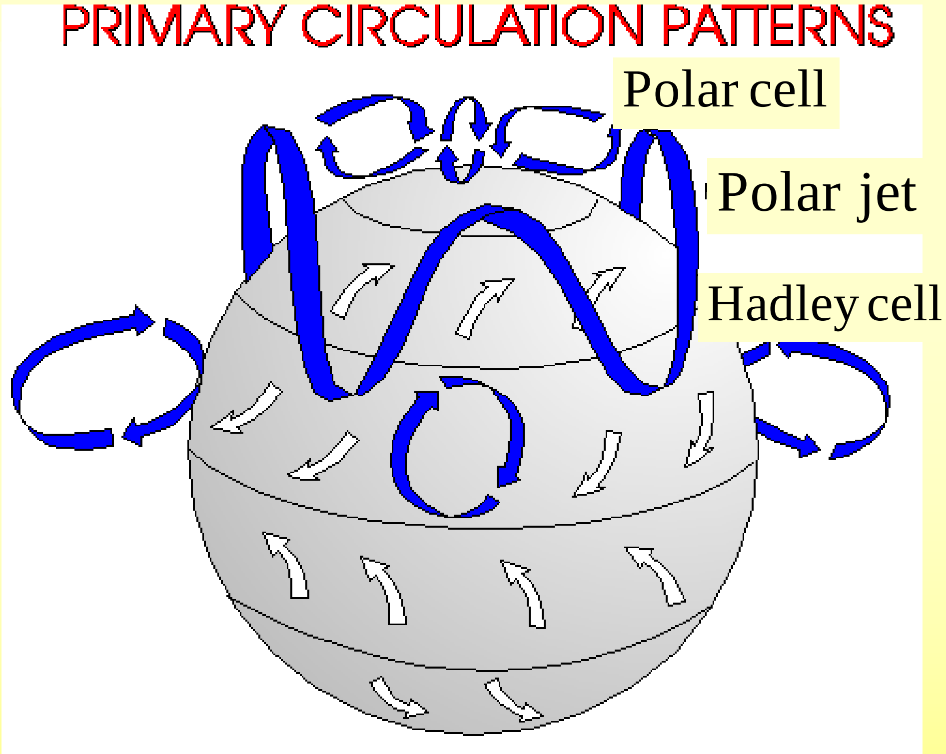
Incipient rain at Portmahomack: photo JSR

- 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

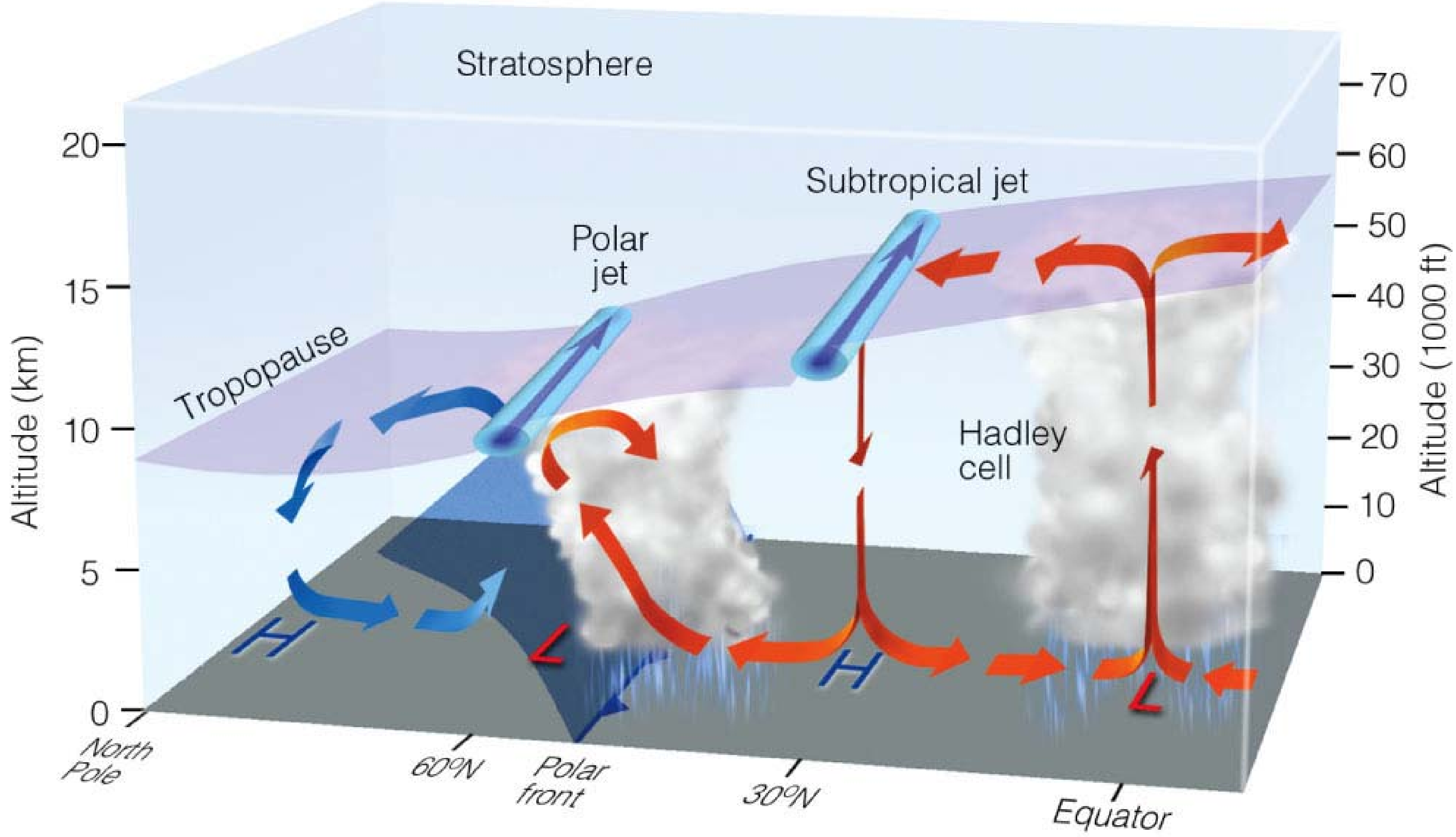
- A lot of weather tends to come down on us from above
  - when an anticyclone dominates, the air within it is sinking
  - when a depression comes over, we experience a sequence of clouds of decreasing height
- Winds aloft tend to determine the direction that storms move and how deeply they intensify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

Jet Streams

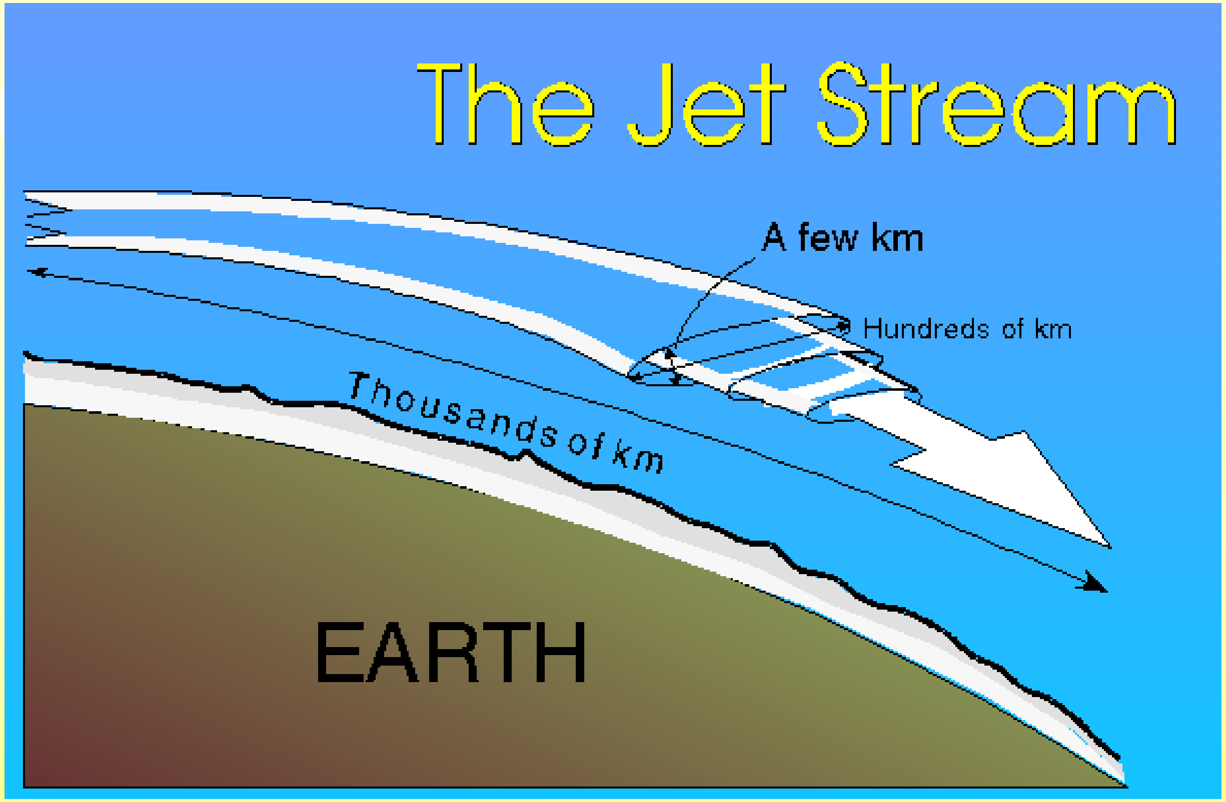


- The **Polar front jet stream** has an important influence on our weather
  - jet stream circles Earth in a huge wavy line a few hundred km wide, a few km thick, around height of tropopause, with central speeds typically 200 km hr^{-1} in direction West to East
  - jet stream forms at the junction of 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

Jet Stream Locations

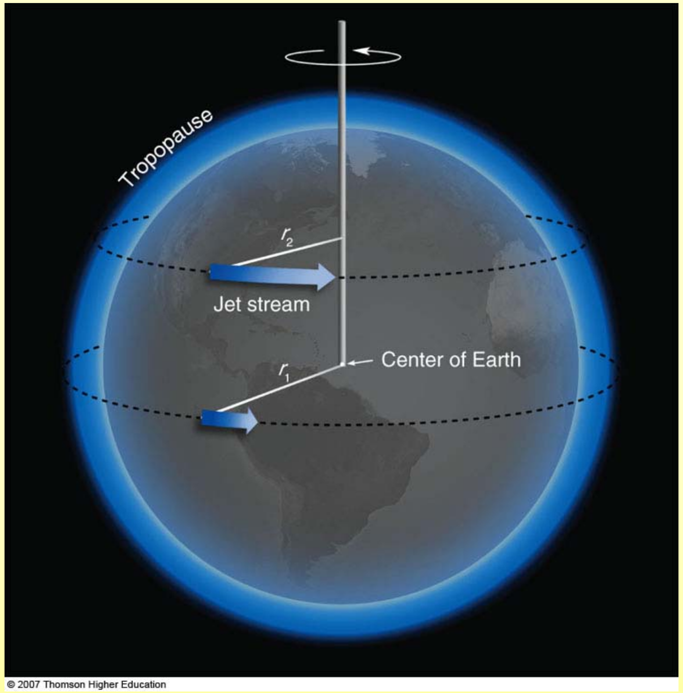


Origin of Jet Stream

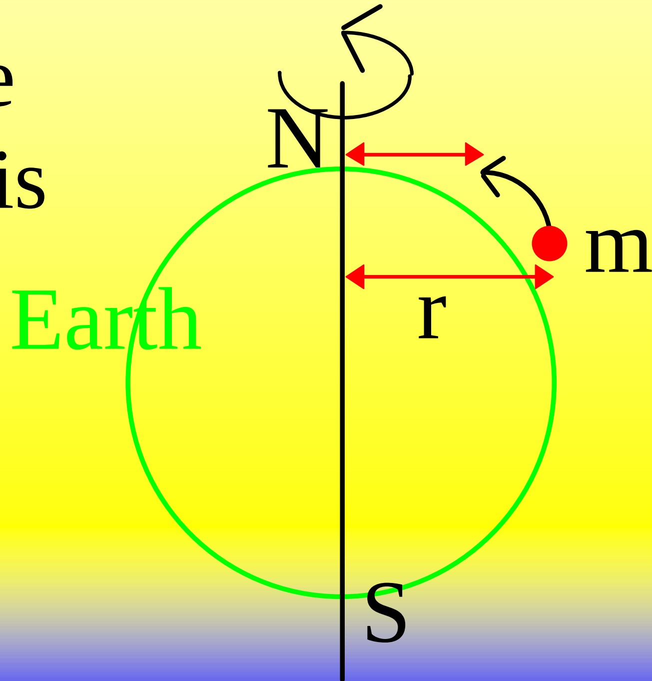


- Polar jet stream occurs at the junction of warm and cold air, where there is a sharp pressure change and a strong pressure gradient [fig. 11.12/10.12]
  - the faster winds occur near the highest altitude in the troposphere

Role of Angular Momentum



- 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]



Angular momentum = mvr

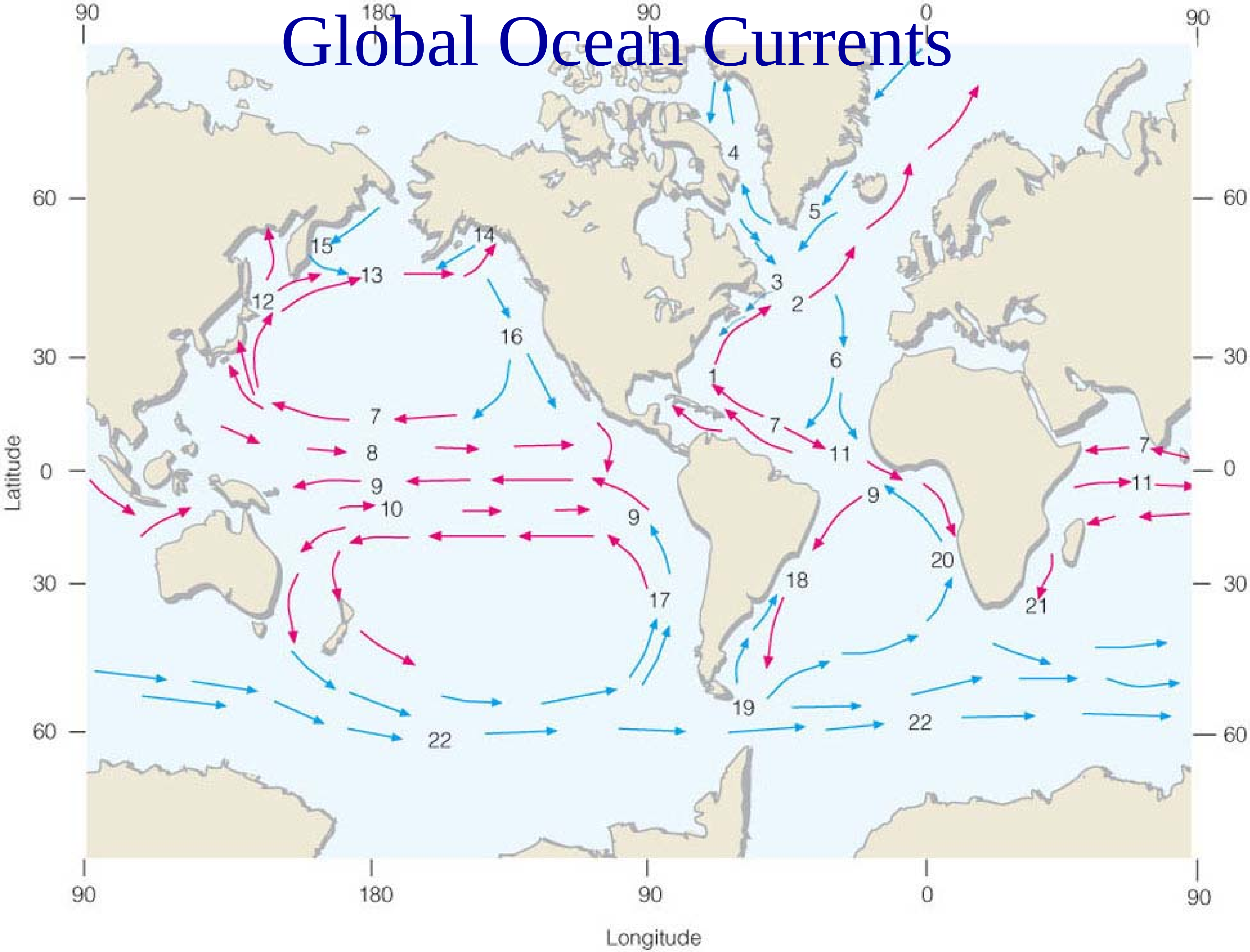
Ocean Currents

- 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

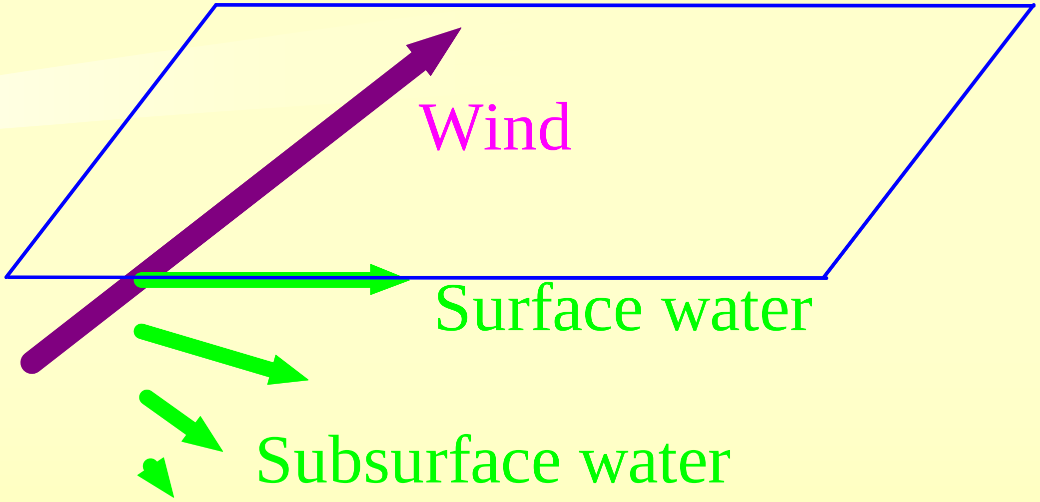
Ocean currents transport energy

- 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

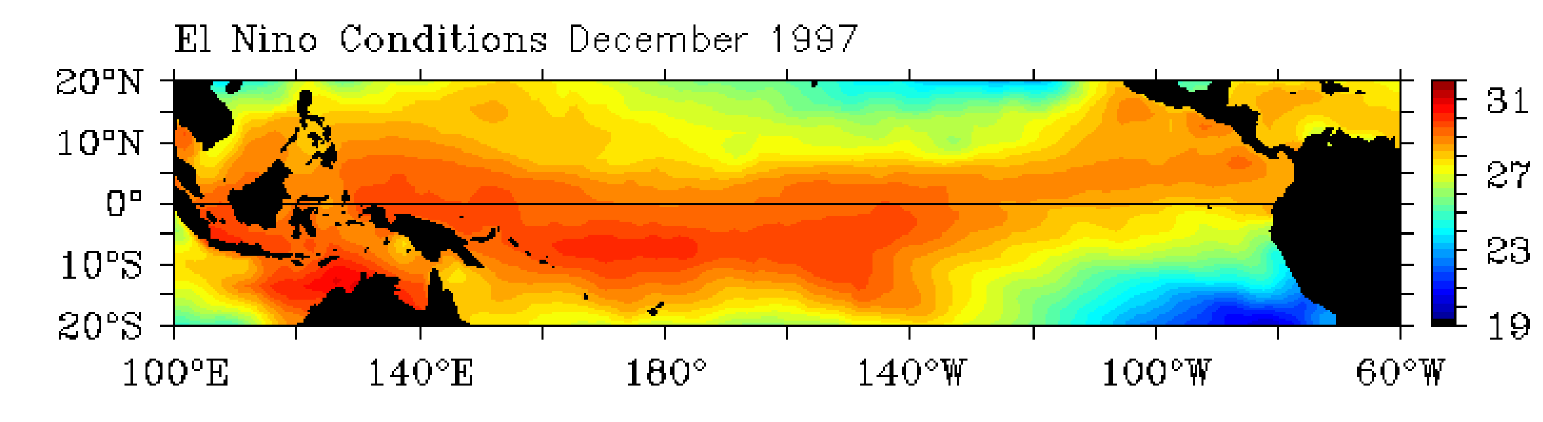


Ekman Spiral

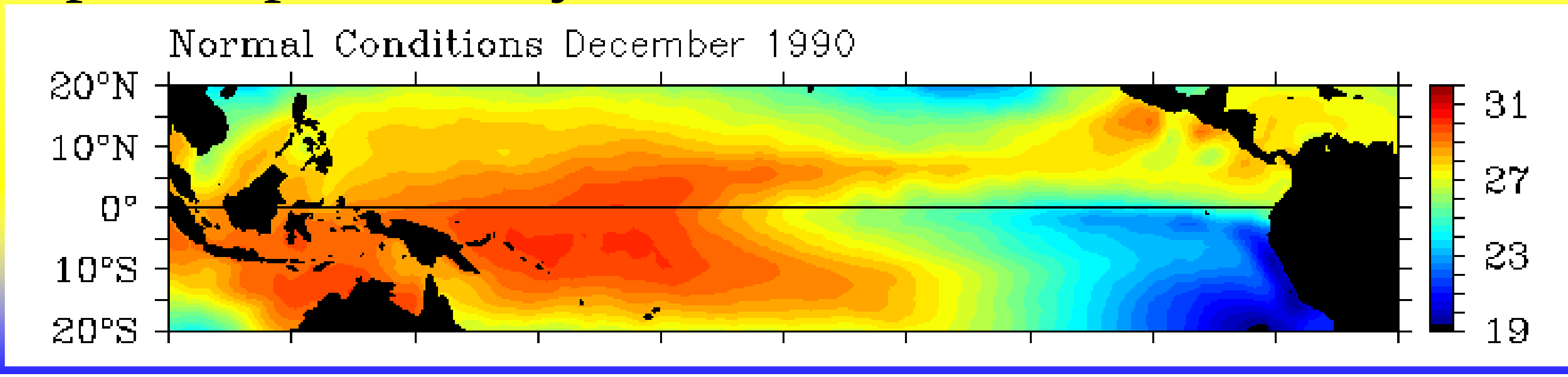


- Surface water moves at about 45° to the driving wind, due to the action of the Coriolis force
  - water below the surface moves at an angle to water on the surface that is driving it [fig. 11.17/10.17]
    - water further down moves at an angle to subsurface water that is driving it, and so on …...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

El Niño

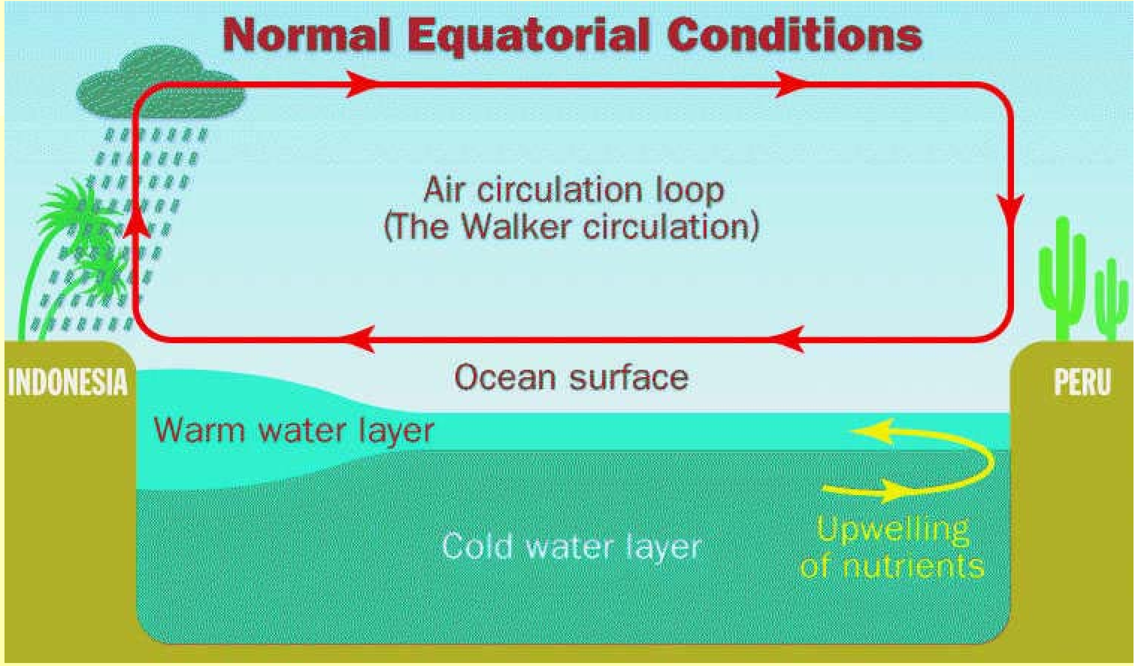


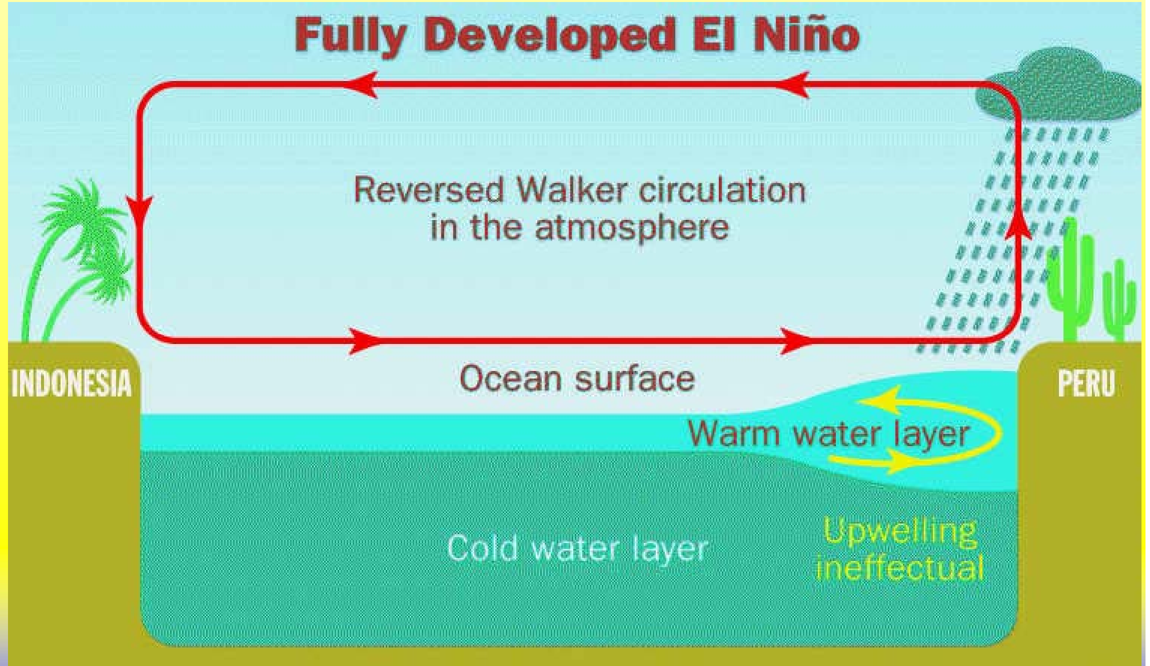
- El Niño is an intermittent, warm surface ocean current from the West at equatorial latitudes that impinges on South and Central America, the result of a disturbed ocean-atmosphere system
- El Niño is accompanied by a reversal of normal atmospheric pressure systems over West and East Pacific



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

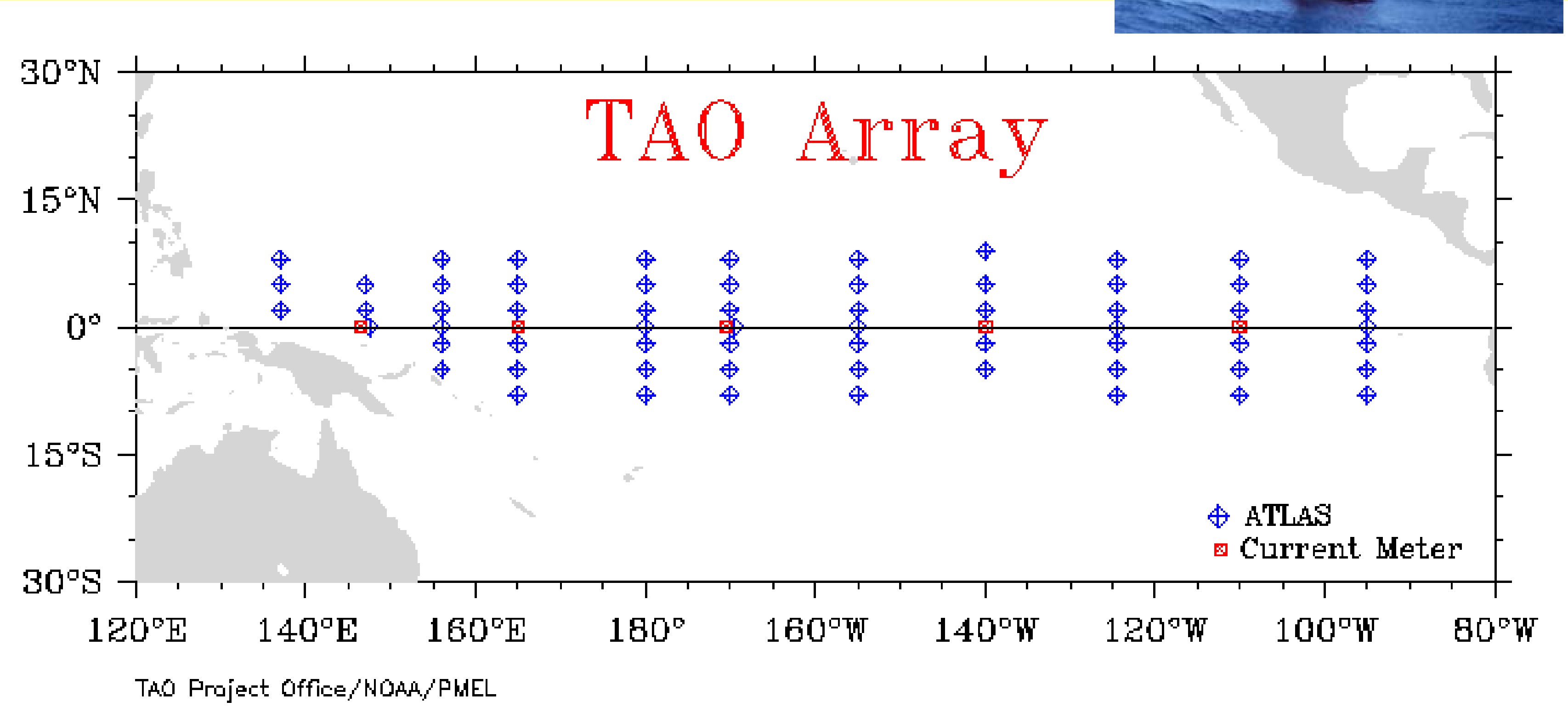




Diagrams courtesy Canadian Institute of Ocean Sciences

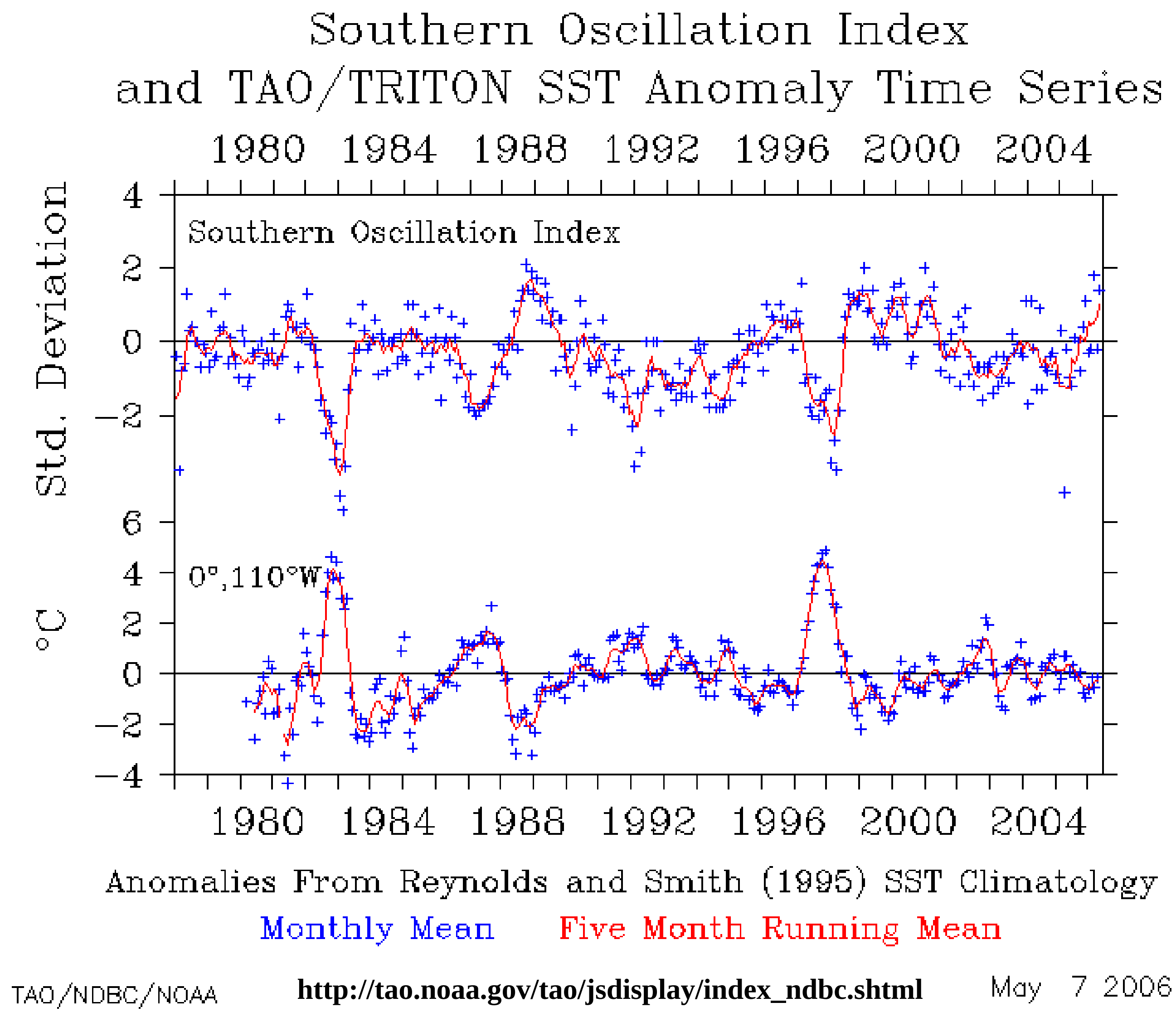
Monitoring the Atmosphere and Ocean

- 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**



http://tao.noaa.gov/tao/jsdisplay/index_ndbc.shtml

El Niño and La Niña

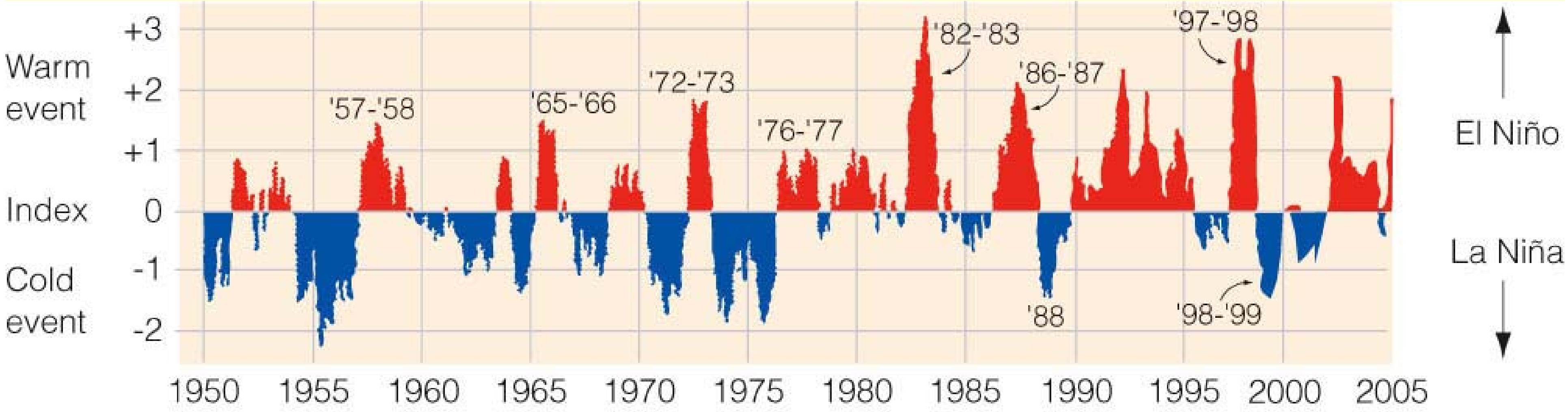
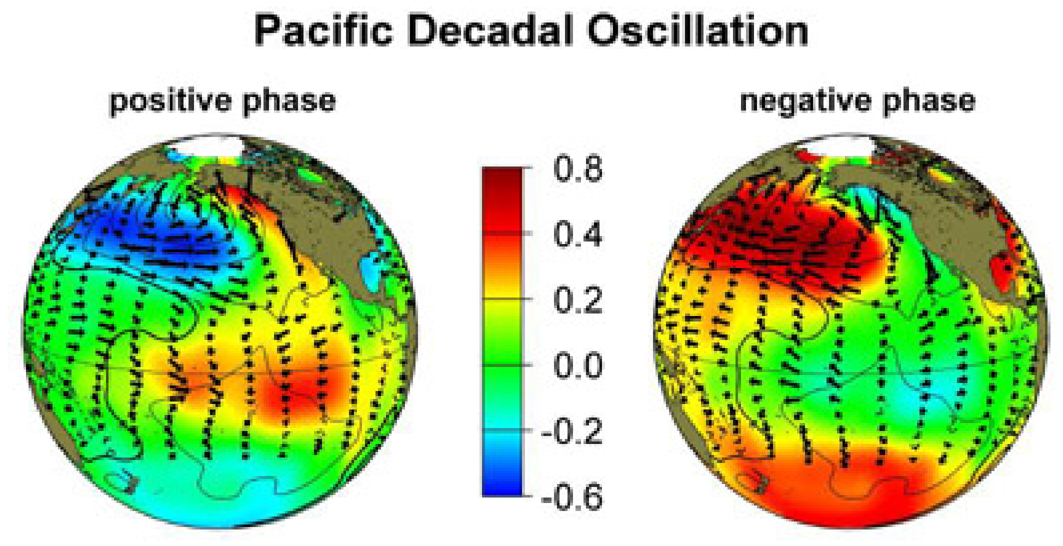


Fig. 10.22 ↑

PDO →

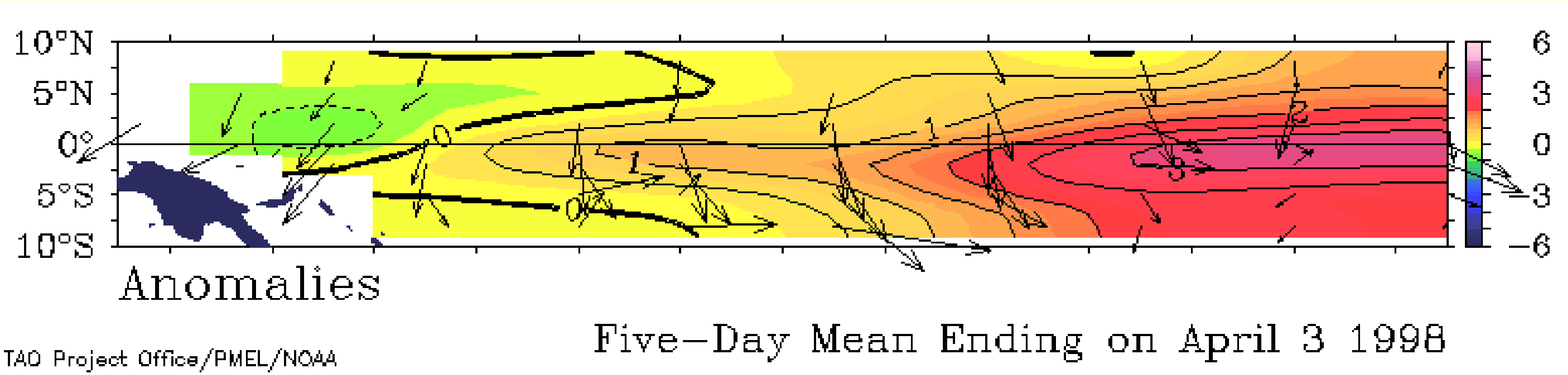
20 – 30 year period



http://topex-www.jpl.nasa.gov/science/pdo.html

Sea Surface Temperatures Recorded

- 1997/98 was a strong El Niño year

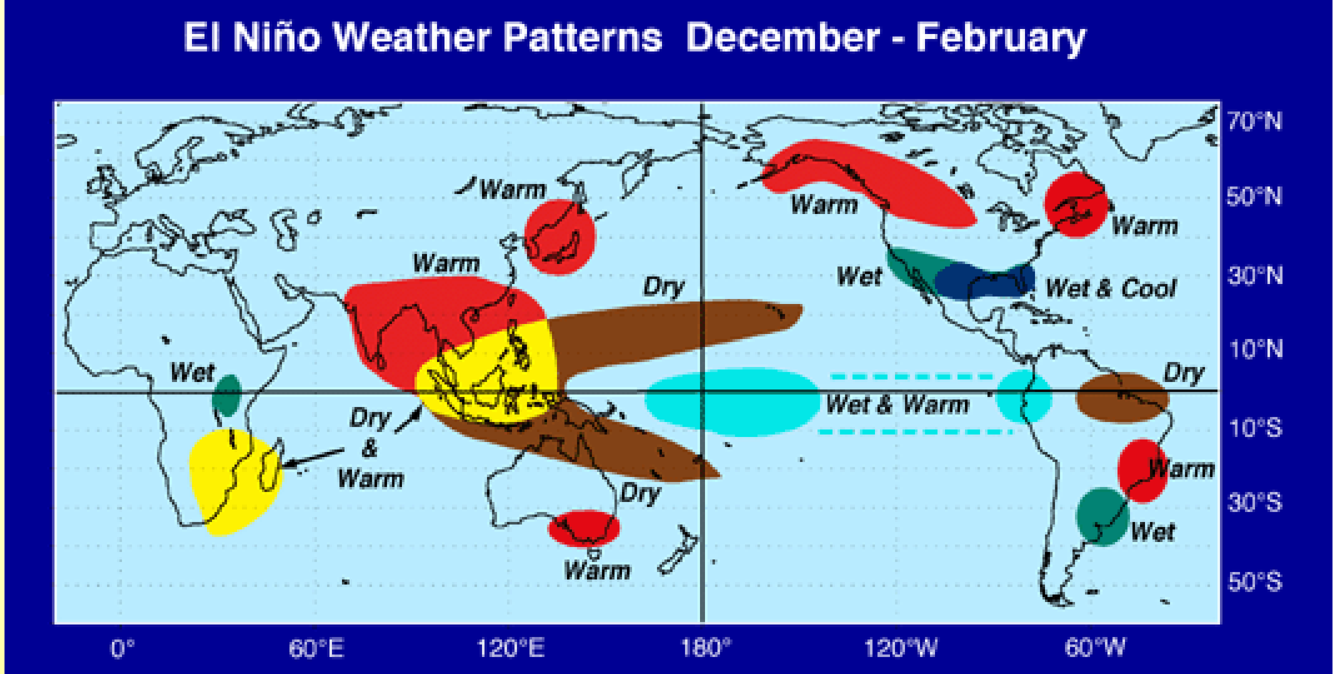


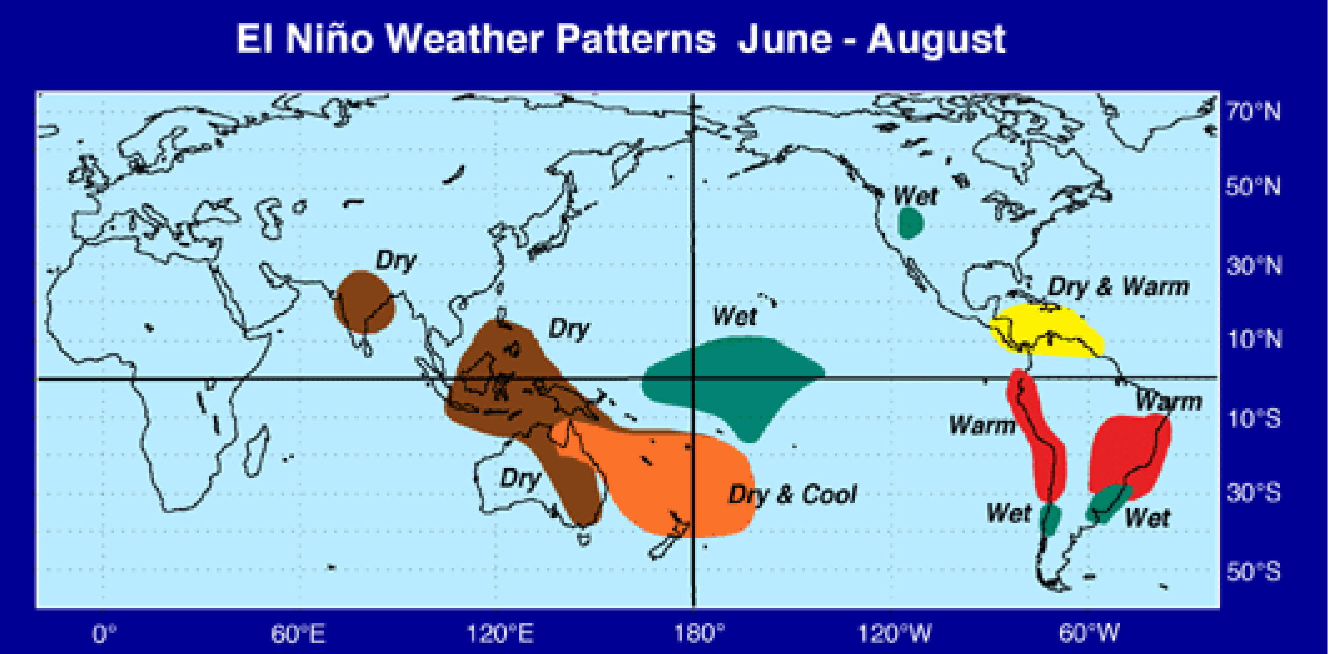
- El Niño occurs near the end of every year but usually lasts only a few weeks
- A strong El Niño lasts for many months, chokes off the nutrient rich cold Peruvian current, with important knock-on economic effects
- (animation: http://www.cdc.noaa.gov/map/clim/sst_olr/sst_anim.shtml

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 addition 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

Graphical summary of impacts





Courtesy: http://www.pmel.noaa.gov/tao/proj_over/diagrams/gif/weatherpat.gif