THE CLIMATE SYSTEM

"The climate is a beautiful system, exceedingly rich in interconnections and complexities."
(A. H. Oort, 1986)

WEATHER:

• short lasting meteorological events.
• characteristic time scale: few days.

CLIMATE:

• Average state of the atmosphere (+ measures of variability) over a finite time for a certain number of years (e.g., climate of a day-night cycle, month, season, year, decade, or even longer).

• Statistics of weather averaged over a time period that contains many weather events, usually at least a month (e.g., the mean summer temperature, the mean February rainfall, the variance of the temperature).

• Interannual variation: the climatic statistics show significant variability from year to year, above the intrinsic random variability, associated with patterns that have characteristic properties in space and time. Ex.: ENSO.

(Fig. 5, from Lau, 1992, and Schneider, 1992)

Climate and weather prediction
COMPONENTS OF THE CLIMATE SYSTEM:

- Atmosphere
- Oceans
- Cryosphere
- Land/biosphere

Atmosphere and oceans

- Organized circulation, chaotic motions and random turbulence.
- React to perturbations on very different time scales.
- Interactions between them occur on many scales, close to their boundary.

Atmosphere

- Most rapidly reacting element of the system to forcing.
- Composition affect absorption and transmission of solar radiation

Oceans

- Major element in terms of long-term variability.
- Regulator of atmospheric temperature and gas concentrations.
- Storage and transport of heat and greenhouse gases.
Land/biosphere

- Extent, position, and orography of the continents (slowly changing)
- Characteristics of lakes, rivers, soil moisture, and vegetation (more rapid varying).
- Probably a vital climate control concerning the carbon uptake.
- Living organisms, particularly forests and plants, play a key role in atmospheric heat, moisture and energy budgets close to the surface.
- The two-way interactions between the biosphere and the atmosphere are still poorly known for their effects to be adequately included in climate modeling.

Cryosphere

- continental ice caps and floating sea ice - influences the surface energy balance by the high albedo and contributes to instabilities in the atmospheric general circulation as a result of temperature differences between the Poles and the Equator.
- It affects continental heating and upper ocean mixing and the energy exchange between the surface and atmosphere.
HEAT CAPACITY

• High heat capacity → low rate of temperature change in response to thermal change.

• heat capacity decreases with specific heat and density:
  → the oceans respond slowly to thermal changes, and act as stabilizers in the climate system.
  → the atmosphere, respond relatively quickly to changes in the forcing function.
  → The land surface falls in between.

• Thus, summer-winter temperature differences on land are much greater than in the oceans.

• Other reason for the different temperature response times of land and oceans:
  → the mobility of the oceans
  → the partial transparency of the oceans.

INTERACTIONS

• The climate system involves the interaction (over a wide range of differing time scales) of the air, sea, ice, land/biota, with solar radiation providing the energy that drives it.

• Variations of gaseous and particulate constituents of the atmosphere, along with changes in the Earth position relative to the sun, vary the amount and distribution of sunlight received.

• The temperature of the oceans has a marked influence on the heating and moisture content of the atmosphere.

• The sun radiant energy drives the atmospheric circulation, and by wind stress and heat transfer, it drives the circulation of the oceans. The atmosphere and oceans are both influenced by the extent and thickness of ice, as well as by the shape and composition of the land surface.

(Fig. 1, first part, from Harries, 1994)
RADIATION AND ENERGY BALANCE

• All physical things emit radiant energy in proportion to its absolute temperature, with wavelength inversely proportional to the temperature of the radiator:
  → Sun (6000 °C): shortwave radiation (centered in the visible interval).
  → Earth (15 °C): longwave radiation (infrared).

• Atmosphere: relatively transparent to the visible interval and a good absorber/emiter of longwave radiation.

• Upper atmosphere (O₃, O₂) absorbs almost all of the ultraviolet radiation.

Balance:

• Solar energy absorbed by E/A = escaping infrared radiation → effective radiation temperature of the planet: -18 °C.

• Greenhouse effect → average surface temperature = +15 °C → agents: H₂O, CO₂, CH₄, O₃ and particles.

• Heat source of the lower atmosphere: the Earth’s surface.

• Earth’s energy balance closure: sensible and latent heat fluxes.

• 2/3 of the thermal energy exchange with the atmosphere over the oceans are dominated by evaporation (latent heat) → importance of SST.

(Fig. 1, second part, and Fig. 2, from Schneider, 1993)

Convection with release of latent heating represents a major source of energy for the atmosphere → deep cumulus clouds are used as a proxy for atmospheric heating.
HYDROLOGICAL CYCLE

The energy cycle drives the water cycle, especially the movement of water vapor in the atmosphere (latent heat flux).

Evaporation $\rightarrow$ Condensation $\rightarrow$ Precipitation $\rightarrow$ Runoff.

Reservoirs:
- Oceans 95.96 %
- Ice caps and glaciers 2.97 %
- Groundwater 1.05 %
- Lakes 0.009 %
- Rivers 0.0001 %
- Soil Moisture 0.0045 %
- Atmosphere 0.001 %
  - Terrestrial 0.0003 %
  - Oceanic 0.0007 %
- Biosphere 0.0001 %

Over the oceans, evaporation exceeds precipitation: atmospheric water vapor is transported to the continents and is made up by input via runoff from the continents.

Precipitation and evaporation show much variability over the continents and oceans. For precipitation: 1) sufficient water vapor in the atmosphere and 2) rising air.

Net precipitation: highest near the equator (10S-10N) and in north and south middle latitudes (35-60), lowest in the subtropics north and south (15-30).

(Fig. 3, from Berner and Berner, 1996)
HEAT BALANCE OF THE EARTH:
ATMOSPHERIC/OCEANIC HEAT ENGINE.

- More solar radiation is received per unit area at lower than at higher latitudes because:
  - the earth is a sphere
  - the duration of daylight undergoes little seasonal change in the tropics.
- The long-wave radiation leaving the earth varies little with the latitude.

(Fig. 4, from Berner and Berner, 1996, and from Salby, 1993)

⇒ THERE IS AN IMBALANCE IN NET RADIATION

Why don't the poles become colder and the tropics become warmer?

Heat is transported from lower to higher latitudes by the circulation of the atmosphere and oceans by
(1) ocean currents carrying warm water,
(2) by atmospheric circulation (wind) carrying warm air, and
(3) by atmospheric circulation carrying latent heat in the form of water vapor.

The atmosphere and oceans act like a "heat engine" driven by latitudinal variations in solar radiation.