• Nearly ¾ of Earth’s surface is covered by liquid water
• More covered by solid water
• Where is it from?

Formation of Water on Planet Earth
• Combination of volcanic activity and strong enough gravity field
• Water vapor, H gas, HCl, CO, CO₂, and N escaped from the chemically active interior of Earth and were trapped in the atmosphere by gravity – steady state
• Water vapor condensed on cooling Earth to form water
World Ocean Characteristics

- Area: 361,100,000 km² – 71% of Earth’s surface
- Volume: 1,370,000,000 km³ – 97% of Earth’s surface water
- Average Depth: 3,800 m
- Average Temperature: 3.9°C
- Average Salinity: 35‰
Three Conventional Oceans...

- Pacific – bigger than all continents together
- Atlantic – 26% of area covered by oceans
- Indian – slightly smaller than the Atlantic, almost entirely in southern hemisphere

...And 2 Other Oceans

- Arctic Ocean – least studied because it is covered by ice
- Southern Ocean – mixing zone for all oceans

Large Seas

- Mediterranean Sea
  - Surrounded by Europe and Africa with a small open ocean connection – "middle of land" sea
- Caribbean Sea
  - Bounded by Antilles Islands (Lesser and Greater) and the Americas – named after Carib Indians
- Other seas
  - Bay of Bengal
  - Persian Gulf
  - Arabian Sea
  - Gulf of Mexico
The Pacific Ocean

- Average Depth: 3940 m
- Volume: 679.6 x 10^6 km^3
- Area: 155.6 x 10^6 km^2

The Atlantic Ocean

- Average Depth: 3844 m
- Volume: 313.4 x 10^6 km^3
- Area: 76.8 x 10^6 km^2

The Indian Ocean

- Average Depth: 3840 m
- Volume: 269.3 x 10^6 km^3
- Area: 68.5 x 10^6 km^2
The Arctic Ocean

- Average Depth: 1117 m
- Volume: $17 \times 10^6$ km$^3$
- Area: $14.1 \times 10^6$ km$^2$

The Southern Ocean

- Average Depth: 4500 m
- Volume: $91.5 \times 10^6$ km$^3$
- Area: $20.3 \times 10^6$ km$^2$

Mediterranean Sea

- Average Depth: 1500 m
- Volume: $3.75 \times 10^6$ km$^3$
- Area: $2.5 \times 10^6$ km$^2$
Caribbean Sea

- Average Depth
  - 2200 m
- Volume
  - 6.05 x 10^6 km³
- Area
  - 2.75 x 10^6 km²

The “Water” Hemisphere

Least studied areas of the world

Profound impacts on climate and carbon cycling

The “Land” Hemisphere

Many more records and measurements

Continental climate dominates
Water in Perspective

The Global Water Cycle

Residence Time

- Ocean Water
  - 4060 y (1.3x10^9/3.2x10^5)

- Atmosphere
  - 0.04 y (1.5x10^4/3.96x10^5)
  - Atmospheric water is completely exchanged ~26 times per year!
Salt Water

- Emitted from primordial volcanoes
- Dissolved from continents
- Unreactive, stay in solution
- Non-steady state accumulation in oceans (and some lakes)

Distillation across Isthmus of Panama

Evaporation in N. Atlantic basin is carried over the isthmus of Panama. Salt is left behind.

N. Atlantic is the saltiest open ocean.
**Hypsographic Curve**

- Elevation and Depth of Earth's Surface

- **Marine Provinces**
  - Continental Shelf (0-150m)
  - Continental Slope (150m-3500m)
  - Trench (as deep as 11,022 m (Marianas Trench))
  - Seamount and Mid-ocean ridge (2500m, islands)
Water, Planetary Tilt and Seasonality

- 23.5° tilt causes seasons

Seasonality in the Hemispheres

- Oceans have different heat capacity than land
- Seasonal effects of Earth’s tilt are different in each hemisphere

Seasonality in the Oceans

Austral Summer
Seasonality in the Oceans

Boreal Summer

Seasonality through Time

Eccentricity

• Change in Earth's elliptical orbit, varies on a 100,000y period
Precession

• Varies on 26,000 y period

Ice Ages

• Change in "steady state" of Earth’s hydrologic cycle
  – Flux of seawater to ice becomes greater ($F_{sw-ice}^+$)
  – Flux of ice to seawater becomes smaller ($F_{ice-sw}^-$)

Obliquity

• Tilt of the axis – varies on 41,000 y period
Scientific Exploration of Planet Water

- Research Vessels
  - R/V Seward Johnson – deploying a submersible
  - R/V Flip – a stable measurement platform
  - R/V JOIDES Resolution – a drilling ship

Measuring the Oceans

- CTD
  - Conductivity (salinity)
  - Temperature
  - Depth

- Rosette sampler
  - Niskin (Nansen) bottles

Measuring the Oceans

- Adjustable depth tow nets – sample plankton (microscopic organisms)
Measuring the Oceans
- Seismic reflection

Measuring in the Oceans
- Scuba
- Submersible
- AUV