Sensors

- Sensing vs. Sampling
  - Some samples are altered by changes in temperature and pressure
  - More efficient for exploration and mapping

- What is a sensor?
  - A device that converts a physical property or a change in a physical property into a more easily manipulated form (e.g., voltage, displacement, resistance)

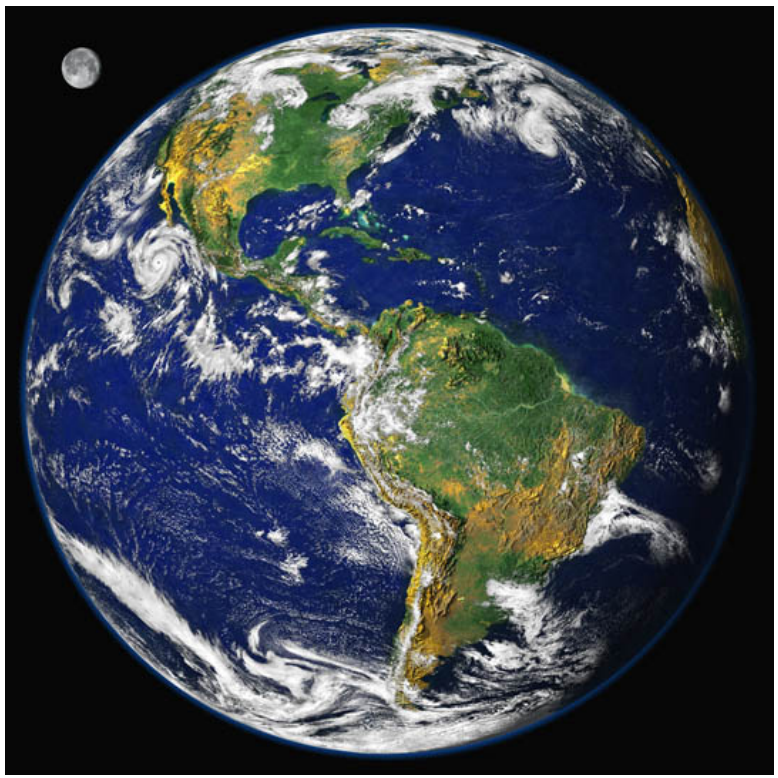
Key Definitions

- Accuracy
  - difference between a measured value and the true value
- Precision
  - difference between individual measurements of the same quantity
- Error
  - Systematic
    - results from a basic fault in the measurement (affects accuracy)
  - Random
    - results from basic limitations in the method (affects precision)
- Resolution
  - The smallest increment that can be measured

Key Issues

- Response time
- Calibration
- Drift
- Bio-fouling
- Small form factor
- Low power
- Low cost
- Ease of use

Properties of the ocean we want to measure



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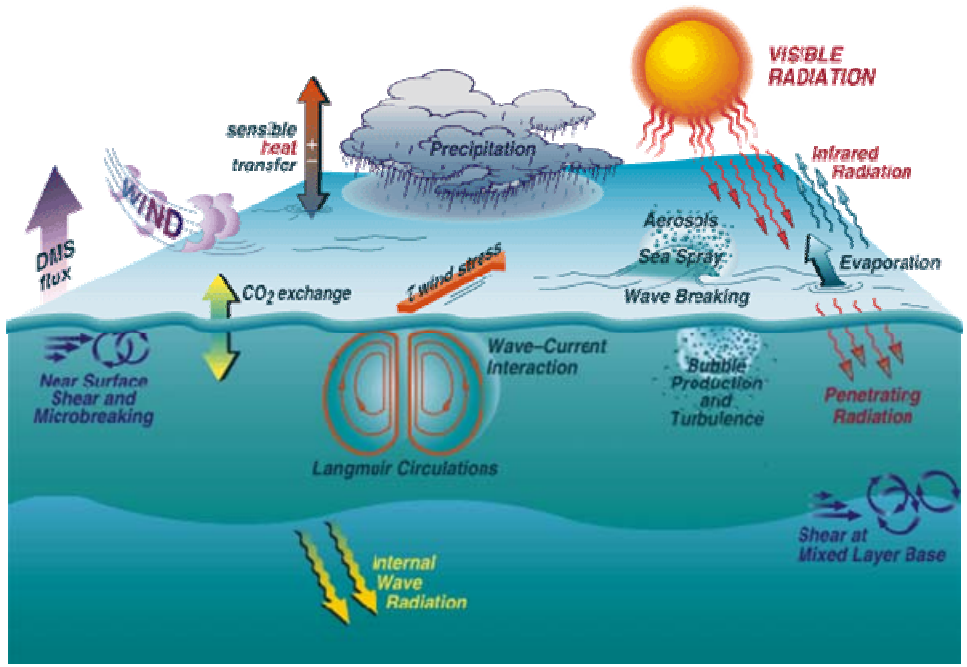

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Properties of the ocean we want to measure

- Temperature
  - measured in $^{\circ}$ C
- Salinity
  - total concentration of dissolved salts
  - measured in PSU (practical salinity units)
- Density
  - $\rho = \rho(T,S,p)$
  - measured in kg/m^3
- Depth
  - measured in m
- Currents
  - direction the current is moving from 0-360°
  - speed measured in m/s
- Chemical constituents
  - dissolved gases
  - nutrients
  - measured in ppm, ppt, mg/l, moles/kg
- Biological organisms
  - biomass
  - numbers of organisms
  - Types of organisms

Measuring Temperature

- Mercury thermometer
  - bucket measurements
  - reversing thermometers

- Platinum resistance thermometers
- Thermistor
- Thermocouple

- Bathythermograph (BT)

- Expendable BT (XBT)

image credits: USCG

Measuring Salinity

- About 85% of total dissolved solids are NaCl
- Silver nitrate ($AgNO_3$) titration
  - ship- or shore-based
  - S = 0.03+1.804*chlorinity

$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

(white)

$2Ag^+(aq) + CrO_4^{2-} \rightarrow Ag2CrO4(s)$

(red-brown)

- Electrical conductivity
  - Inductive cell
  - Electrode cell

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Please see: http://www.seabird.com/

  - is temperature dependent

$$S = 3.55 + 10.2 \cdot C - 0.73 \cdot T$$

Measuring Pressure/Depth

- Hydrostatic pressure

$$P = \rho g dz$$

$$P = \int_o^h \rho(z) g dz$$

  - 10 m of water = 1 atm

- Absolute pressure
- Gauge pressure
  - referenced to atmospheric pressure

- Strain gauge
  - measuring the electrical resistance of a metal
- Vibratron
  - measuring the natural frequency of a vibrating tungsten wire
- Quartz crystal
  - measuring the natural frequency of a quartz crystal

CTD – Conductivity/Temperature/Depth

- Primary tool for determining the physical properties of seawater
- Water samples can collected at different depths with a rosette of Niskin bottles

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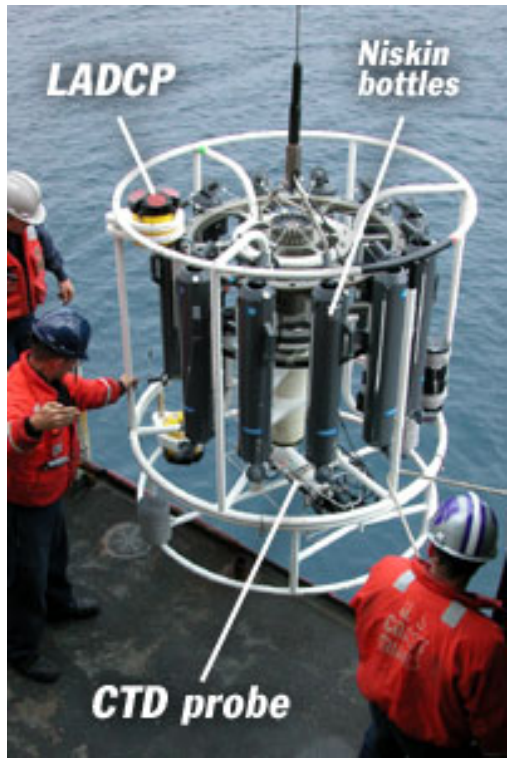

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Current Velocity

Franklin-Folger map of the Gulf Stream

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Current Velocity – Eulerian

- Measurements made at a fixed point

- Rotors/vanes
- ADCP
  - Acoustic Doppler Current Profiler

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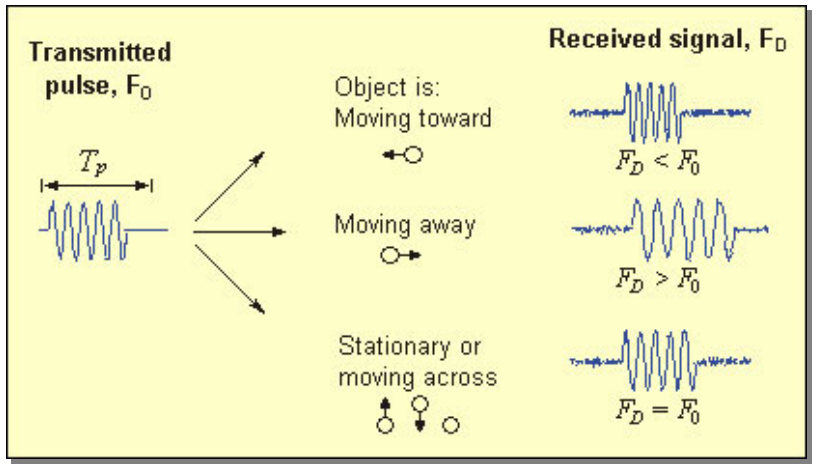
Pickard, George L., and W. J. Emery, eds. *Descriptive Physical Oceanography: An Introduction*. Woburn, MA: Butterworth-Heinemann, 1990. ISBN: 075062759X.

Current Velocity - ADCP



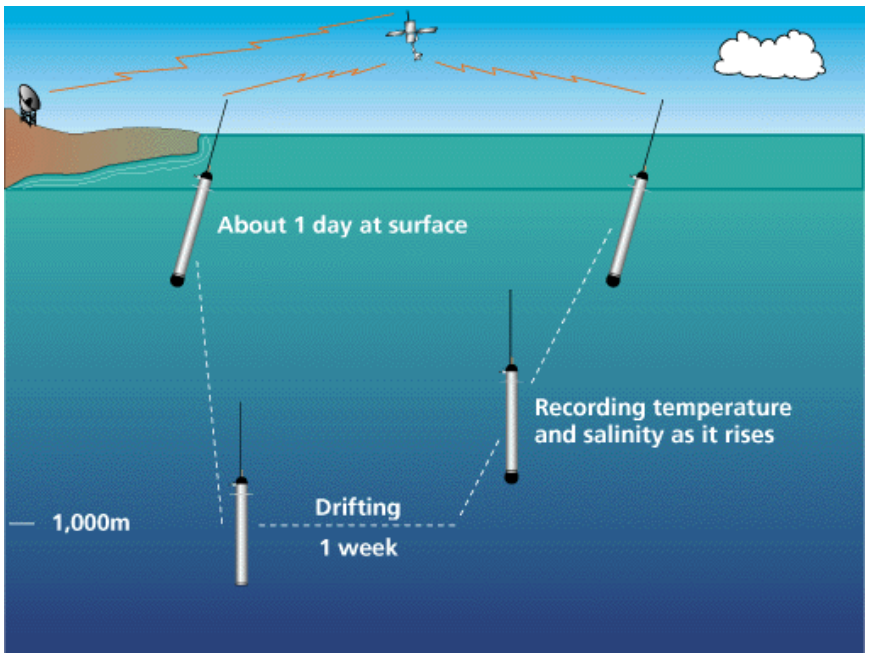
- Acoustic Doppler Current Profiler
  - Measures a current profile up to 1000 m long
  - Sends out “pings” at a certain velocity
    - Measures time of return and change in frequency

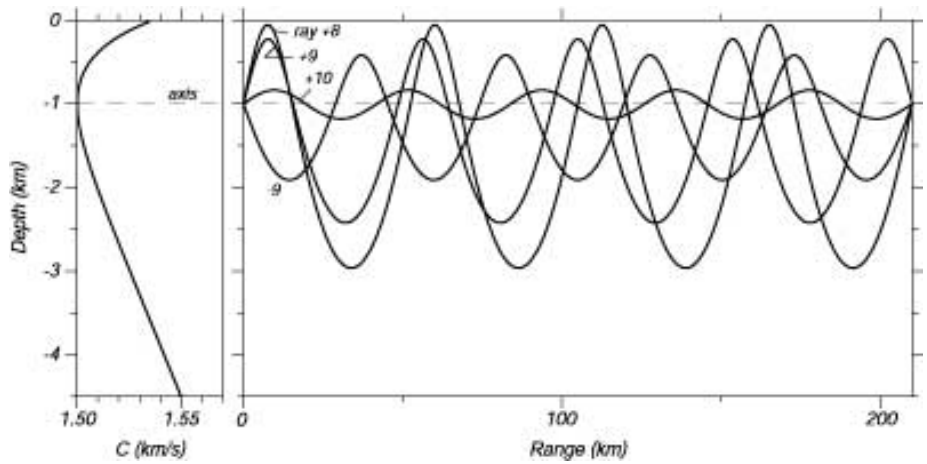
image credit: WHOI

Current Velocity – Lagrangian

- "Where does the water go?"
- Follow the water parcel
  - Measure current and other water properties

- Surface Drifters
- Floats
  - PALACE
  - SOFAR
  - RAFOS





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Chemical Sensors

- Salinity
  - Electrode cell
- Dissolved gases
  - Electrochemical reactions
  - Fluorescence quenching
  - Gas tension device
    - Gas permeable membrane
    - Measure pressure in cell

Dalton's Law

$$P_T = \sum p_i$$

Henry's Law

$$c_i = s_i \cdot p_i$$

    - Slow response time
    - Subject to bio-fouling

- Concentrations are often calculated from other measurements

- Carbon in the ocean
  - Particulate organic carbon
  - Particulate inorganic carbon
  - Dissolved organic carbon
  - Dissolved inorganic carbon

  - CO_2 in the ocean

$$CO_2(aq) + H_2O \rightleftharpoons H_2CO_3$$

$$H^2CO^3 \rightleftharpoons H^+ + HCO_3^-$$

$$HCO_3^- \rightleftharpoons H^+ + CO_3^{2-}$$

Chemical Sensors

- Sensors now exist for
  - Nitrate
  - Nitrite
  - Total nitrogen
  - Total phosporous
  - Phosphate
  - Ammonia
  - Fe^{II}/Fe^{III}

- Most current *in situ* chemical sensors measure the dissolved state

- Gases and solids are also a part of the chemistry of the ocean

- New types of *in situ* spectroscopic instrumentation are now being developed

Biological Sensors

- Secchi disk
  - Measures attenuation and thus material in the water

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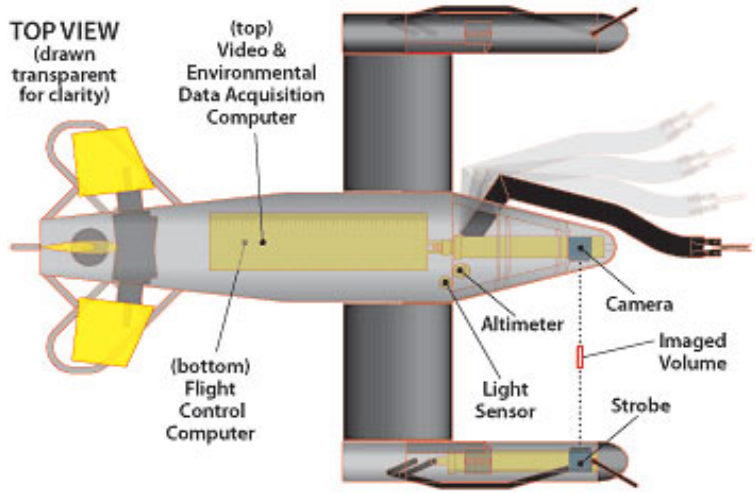
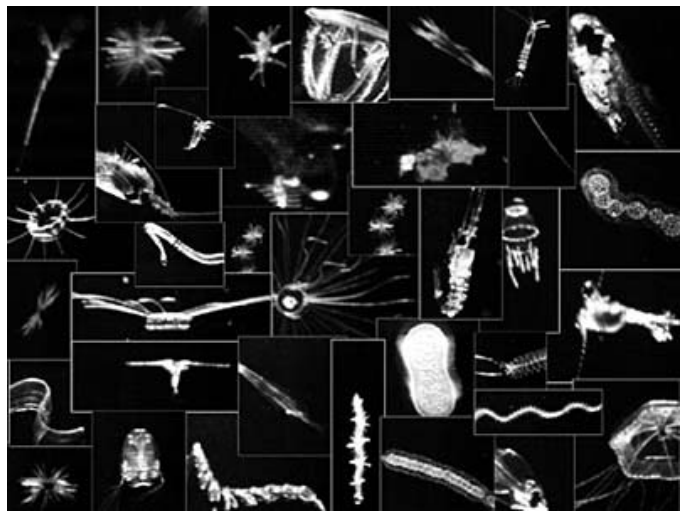
- Optical Backscatter Sensor (OBS)
  - Measures concentration of particles
- Laser In Situ Scattering and Transmissometry (LISST)
  - Determines size distribution of particles

- Fluorometer
  - Fluorescence can be used to determine amount of chlorophyll or distinguish chlorophyll from other material
- Flow Cytometer
  - Uses fluorescence to look at one cell at a time

Biological Sensors – Imaging Sensors

- Video Plankton Recorder (VPR)
  - Underwater video microscope
- FlowCytobot
  - Measures light scattering and fluorescence
- Environmental Sampling Processor (ESP)
  - Uses DNA probes and fluorescent tags





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