

2.693 Oceanographic Instrumentation

Lecture 1: Introduction to Class

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Oceanography is an observational driven science. That is, nearly all our knowledge of the ocean and the processes that occur there comes from observations made in the ocean. Therefore, this class will provide some guidance on information that you will need to make quality observations in/of the ocean.

Objective of an Ocean Observing Program (experiment):

1. Describe the statistics of the ocean -
 - Mean temperature at a place,
 - Maximum and minimum temperature during a year,
 - Variance of currents at a location,
 - Covariance or correlation between temperature and atmospheric winds,
 - The average vertical density gradient in the North Atlantic,
 - The power spectral density of the internal wave elevation in the open ocean,
 - The tidal component of the sea surface elevation, etc.
2. Therefore, we need observations. To observe the ocean we need –
 - Platforms from which to make observations
 - Sensors to make measurements,
 - Data conditioning circuits,
 - Recorders with sampling programs in time or space and in quantity measured,
 - Power supplies (batteries, solar panels),
 - Storage media,
 - Analysis (processing) – such as calculating the density gradient and normalizing this to the Brunt Vaisala frequency, $N^2 = g/\rho \partial\rho/\partial z$, from measurements of temperature, conductivity as a function of pressure (depth) using the Practical Salinity Scale of 1978 and the Equation of State of Seawater 1980) to get the potential density and estimate the scaled gradient.
3. Need to know what results you want to be able to design an experiment, select sensors, plan sampling (in both time and space) to get the required statistics/description.
4. All of these processes can be thought of as “coloring” the data that you get – you are looking at the ocean through colored glasses, and you need to know what effects each of the steps has on the data, to assure that you are getting the statistics that truly represents the ocean. This is what this class is about.

To good information from an experiment you need to:

1. Place a sensor (transducer) in the ocean – Here you need a platform from which to make the measurement – on a surface buoy or ship, on a mooring line, on a cable lowered from a ship, mounted on a bottom tripod, on an ROV, AUV, neutral buoyant float, satellite, aircraft, etc.
2. A transducer which changes the environmental signal (e.g. temperature) into something we can measure (e.g. resistance in the case of a thermistor). Note this

is a critical point. If you mess up here or in the next couple of steps, you cannot recover lost information!

3. Signal conditioning – A sensor generally consists of a transducer and signal conditioning. A transducer's output needs further processing before it can be recorded. This may be a regulated voltage supply with a bridge with the thermistor in one leg, an operational amplifier that changes the resistance of the thermistor into a voltage for digitizing. At the same time the circuit can have a filter in it to remove unwanted high frequency signals (to prevent aliasing) so that only low frequency signals of interest remain, (and the sampling and storage requirements are simplified/reduced).
4. Sampling – this is making a measurement at discrete points in time for a finite record length. (This determines what frequencies you can obtain information about from your data). Also the sampling (e.g. an A/D converter) quantifies the signal into discrete intervals – e.g. temperature is digitized so that one count is equal to 1 millidegree C. The with a 16-bit digitizer, the A/D will be off scale with its maximum value at 16.383 °C. Therefore, you will need to make the resolution smaller or increase the number of bits in the A/D to cover the full oceanographic temperature range. Note that the size of the number from the A/D puts requirements on how many digits are recorded and therefore the size of storage needed. You should consider how many digits to digitize a measurement (you don't want too much resolution that is unused) and the range of the digitizer so you cover the range of variations in the ocean you are measuring.
5. Internal processing – this is possible with the large selection of low power, high capability microcontrollers available now. This could consist of data compression by taking Fourier transform, averaging in frequency space and saving the results (much smaller space required). Filtering the data to eliminate some frequency, or to pick out some frequency (such as a tsunami). Calculating statistics and saving these rather than the time series. Conditional sampling that will alter the sampling rate depending on environmental signals present, so that you only sample occasionally when nothing exciting is happening, and then more rapidly during a high energy event.
6. Data storage. This can be internal to the instrument or transmitted to another location for storage. Data can be stored in the instrument on RAM, compact flash cards, hard disks, or EEPROMS. It can be stored elsewhere by sending the data over a radio link to shore, or a over wire to a ship for storage. For example:
 - A CTD sends its data up the wire to the ship using FSK techniques where it is stored on a PC on hard disk.
 - An offshore buoys sends data to shore via:
 - a. GOES (Geostationary Operational Environmental Satellite) in GLOBEC on Georges Bank and currently by GoMOOS – The Gulf of Maine Ocean Observing System –www.gomoos.org in buoys far from the coast. The data capacity of GOES is limited to 1 m at 100 baud per hour.
 - b. ARGOS (Polar orbiting satellite which also provides platform position for finding a buoy should it break loose from its mooring). Argos is

also used for tracking drifters, but only returns about a dozen messages of 32 Bytes each per day.

- c. Iridium satellite or the several LEOs (Low Earth Orbiting satellites) which provides two-way communications (at 4800 Baud) between a remote platform and the scientist (but is relatively expensive).
 - d. Spread spectrum radio (900 MHz or 2.4 GHz line of sight), which also provides two-way communications to shore or ship. This can be used to download control files or even new software to the remote system. However, you need to provide the shore based station
 - e. Cellular phone (as currently used by GoMOOS) when close to a cell system. Also two way link at lower cost than Iridium, and you don't need your own shorebased station.
- Storing the data (either as the primary or backup to remote storage) reduces the risk of losing data. Remember the important quantity is the data! If the instrument is lost but you had the data, you could still produce results. In the Gulf of Maine experiment in 1985, a buoy broke loose and drifted from Jordan Basin, out over Georges Bank and into the North Atlantic and drifted across the Atlantic with the Gulf Stream. A year later it was found on the French coast and the data system sent back. But because we had the data telemetered via satellite, we had a draft of a paper using that data before the data recorded in the buoy was recovered.
7. Calibration. This is the very important connection of a sensor's output with the quantity to be measured. This is the critical part of an observation that allows comparison of measurements between investigators, the use of historical data, etc. There is a need for standards, often provided by NIST – that National Institute of Standards and Technology (the new name for the Bureau of Standards). Regular calibrations (for example yearly), and maintaining a good calibration history allows you to study the stability and drift of a sensor. This will identify any sudden changes in behavior that may indicate premature failure. Also, it will allow you to identify a slow drift that will allow you to interpolate between calibrations for additional accuracy. For example temperature is measured relative to the International Temperature Scale of 1990, which is defined by the freezing and melting point of a series of materials. In the ocean we have the triple-point-of-water (0.01 °C) and the melting point of Gallium (29.7646 °C) which nicely span ocean temperatures. Also, to understand the “filtering” effects of a sensor, as a part of calibration you should determine the frequency response of a sensor, especially if you are measuring rapid fluctuations such as turbulence. We will discuss these the static and dynamic (frequency response) calibrations in more detail later.
 8. Programs often require Quality Assurance/Quality Control (QA/QC) statements to state how good a measurement is being made and how that data quality is being maintained. Often this is not carried out as well as it should be. Sensor outputs change with time (electronic or transducer ageing) and need regular calibration/checks. Because it is digital doesn't mean it is better! Consider a glass mercury thermometer versus an HP quartz thermometer with digital output for lab use. The zero offset of the quartz thermometer can shift with shock (same

with PRT transfer standards) providing lower quality data than could be obtained with a simple mercury thermometer.

9. Processing/Analysis. Data is not information! Information is what is needed to answer a question and this comes from processing the data e.g. calculating the correlation between the wind stress and an ocean current, calculating derived quantities such as density gradients, power density spectra, coherences, input to models, etc. The output of these calculations/models is the information required to answer a scientific question or provide resource managers with required information. A simple model/example is the need to close a beach because of high coliform bacteria. It was determined that when rain fall exceeded a certain amount in a certain length of time the sewage processing plants would overflow, releasing bacteria and the beach would need to be closed. As an example of the difference between data and information, SAIC did a study for the USGS in the New York Bight area and determined that the area was data rich but information poor. That is there were lots of observations that had been made in the Bight, there, but that the data was not adequate to allow many important questions to be answered. You need to know what question you are asking and what data you need to answer it before you collect data – don't just go out there and collect data. Erik Molo Christensen (former MIT faculty who moved to NASA) talked about NASA scientists “over averaging” the data and averaging out all the interesting information to obtain something “stable” – e.g. what is the average human gender – a mean less quantity. You need to process the data properly/optimally to obtain the most information from it! However, if you know there is random, high frequency noise in the data, then proper averaging will provide improved data quality – this is filtering the data and you need to know the effects of what you are doing to the data. Also, as part of this data processing, you need to know the statistical uncertainty of your results so that you can demonstrate that your answer is statistically significant.
10. Presentation of results (data product) – a plot, graph, model output that is readily understood. Your goal should be to provide information in an understandable form. This requires much simplification – e.g. many thousands of data points may be condensed into one number or several points on a plot. The human mind can only absorb so much information at once, and you don't want to overload your audience with too much data/information, but just enough information to prove your point/hypothesis.

Some measurements to consider:

1. **Time:** important to know when an observation was made
 - a. Pendulum & problem of time and longitude measurement at sea.
 - b. Quartz crystal oscillator – wristwatch made low cost and accurate.
 - c. \$ can provide the accuracy requirement for a project
 - d. WWV (Fort Collins, CO radio) and satellite controlled clocks
 - e. Naval Observatory for Official US Time – can get on Web
 - f. GPS clocks offer new, different approach to accuracy – used in surface mounted systems – e.g. GOES transmitter.

2. Temperature:

- a. Measure of the energy – relative to absolute zero, where all motion stops.
- b. Mercury or alcohol thermometer – thermal expansion of material in a column of known cross section marked off in readable values. Hard to get into a computer.
- c. Gas law thermometer – measure pressure to get temperature.
- d. Thermistor – Resistance $\sim \exp(-\alpha \text{Temperature})$
- e. Platinum Resistance Thermometer – Resistance $\sim \beta \text{Temperature}$
- f. Limit to many measurement systems is “Johnson Noise”

$$i^2 = KTB/R \text{ or } e^2 = 4KTBR \text{ where } e = i R$$

Where i^2 = mean square current noise (amperes)

e^2 = mean square voltage noise (volts)

K = Boltzmann's constant = 1.39×10^{-23} (J/K)

T = temperature ($^{\circ}\text{K}$)

B = bandwidth (Hz)

R = resistance (ohms)

Therefore, to reduce noise you can:

Lower the temperature, T

Reduce the Bandwidth, B

Raise the Resistance, R – generally can't control this

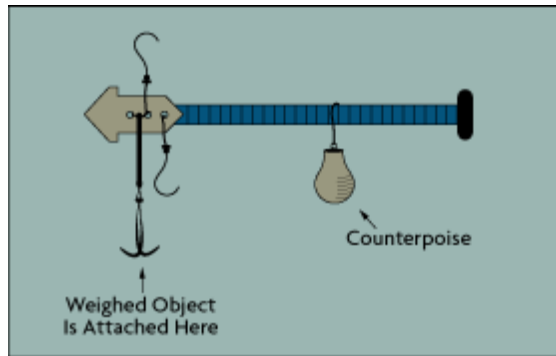
Use the signal to noise ratio as a measure of data quality. Signal is what you want, and noise is what you don't want and what gets in the way of your seeing the signal. A measure of data quality is the signal to noise ratio – the amount of signal relative to the amount of noise:

$$\text{SNR}(\text{db}) = 20 * \log_{10}(\text{voltage ratio}) = 10 \log_{10}(\text{power ratio})$$

The higher the signal to noise the better. Note that an unwanted signal is really noise. If you are trying to measure pressure and the pressure sensor is sensitive to temperature, than that introduces noise, but it is really signal. You can calibrate the sensor's temperature sensitivity and remove these effects provided you calibrate the pressure sensor properly. Same with voltage sensitivity – calibrate out or use constant voltage source such as Lithium batteries. So some signals which produce noise, can be corrected to reduce the noise in the signal, and hence improve the SNR.

3. Weight/Mass

- a. Spring balance – assumes linear spring constant
- b. Pan balance or equal arm balance – put object to be weighted in one pan, and known weights in the other.
- c. Steelyard – ratio arm balance – similar to platform balance used in Doctors offices, shipping platforms, etc. Different size weights gives extended dynamic range. Change in pivot gives different ranges.



- d. Strain gauges – load cells used in bathroom scales, platform weighting devices, etc. measures stress in beam of known material and size. Requires electronic signal conditioning and display.
- e. Metler balance – add length of chain of known mass to balance weight put in measurement pan.

4. Velocity:

- a. Pressure drop due to velocity – Bernoulli effect
Along streamline $p \sim B \text{ vel}^2$
- b. Acoustically
 - i. Travel time – MAVS – time difference for acoustic signal traveling one way as compared with signal traveling the other way. Requires the temperature (and salinity and pressure) to determine the sound velocity in water, then time difference is proportional to velocity.
 - ii. Doppler – ADCP - (the old change in whistle frequency of a train passing the observer) - measure the scattered energy off particles in the water column, and assuming that the particles are advected with the water, the shift in frequency is proportional to the water velocity along the path.
- c. Mechanically:
 - i. Savonius rotor – used in VACM and Aanderaa current meters, but is non-linear (can rectify oscillatory signals).
 - ii. Fan – linear device designed for VMCM to be used in wave environments to average out wave currents. Orthogonal fans can provide orthogonal components of velocity.
 - iii. Drag on a ball on a stick – strain gauges measures velocity
 - iv. Anemometer effect - measure the cooling in a heated element – hot film and hot wire devices for turbulence.
- d. Lagrangian and Eulerian referece – a drifter that moves with currents. Traces out water parcel trajectory rather than Eulerian measurement of the current at a location. Alice floats collect data then surface to give position and profile data. RAFOS are acoustically tracked drifters that remain at depth and surface to give position periodically. Midwater SOFAR floats are tracked by the acoustic listening system set up by the US to track

Russian submarines and by triangulation can locate a drifter. Same as the system used to located downed military aircraft that let a depth charge in the sound channel to allow system to locate the position to aid in the recovery of survivors.