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In-Situ Measuring Devices and Small Environmental Monitoring Systems

Because of their ability to gather data under natural conditions, *in situ* measuring devices, including automated monitoring systems, are useful tools for field observational scientists. They permit the determination of a variety of parameters under a broad range of conditions. They provide time-series data needed to elucidate natural processes that control the response of systems to perturbations. Automated *in situ* systems greatly expand the scope of manual field sampling and measurements, therefore represent more incisive tools. Unfortunately, several distinct disadvantages must be considered when using such systems.

Advantages of *in situ* measurements include:

1. Data are gathered under ambient conditions
2. *In situ* data acquisition is useful for exploratory or diagnostic studies
3. Allow you to decide if you wish to collect samples for laboratory work
4. Real time data acquisition allows altering research strategy, if necessary

Disadvantages if *in situ* measurements include:

1. Cannot verify or make additional measurements after leaving site
2. Requires additional sample collection if laboratory measurements and/or archiving are desired
3. Some important types of measurements cannot be made in the field

In observational studies, a combination of *in situ* spot measurements, automated time-series data acquisition and manual and automatic sampling for laboratory analyses is often undertaken. More recently, *in situ* samplers have been developed that allow the researcher to both make measurement as collect samples (for subsequent retrieval and analysis)

Real Time Devices:

These are instruments that produce continuous (or at least high frequency discrete) measurements. The “sampling” frequency varies from multiple hertz to every few minutes, depending on the device. Today we will discuss both research prototypes and some commercially available systems. The laboratory exercise this week will involve in field measurements with several of these devices.

The basis of operation of real-time sensors varies from those measuring a physical property that is manifested through an electrical signal to those which carry out reaction chemistry through the mixing of reagents and sample through complex systems of pumps, injection valves and detectors. The instruments whose data are based on measurement of a physical property or its manifestation through a response directly attributable to the amount of analyte tend to produce data of very high precision and accuracy. This is largely due to our ability to readily and very reproducibly measure electrical properties. Instruments whose signals depend on the generation of light, light absorption tend to produce results with slightly less precision. This is particularly true when the latter are combined with specific reaction chemistry, such as nutrient analyzers based on spectrophotometric analysis of colored complexes. A few of the instrument types currently available are presented below.

1. Conductivity-Temperature-Depth recorder (CTD): this basic instrument is the workhorse of physical oceanographers and is widely used by all oceanographers. It provides accurate measurement of the three titled parameters. It is also used extensively by biological and chemical oceanographers typically in conjunction with a sampling bottle rosette for collection of water samples as a function of depth in the water column. Figure 1 shows a sampling rosette from the R/V Roger R. Revelle, equipped with Niskin bottles and a CTD that is also shown in greater detail in Figure 2. The CTD system on this system is also equipped with an oxygen sensor and a fluorescence detector. Transmissometers are often also attached to CTD systems.

   The CTD systems are based on measurement of physical properties/parameters. The conductivity of a solution depends on its composition and ionic strength and can be measured to a high degree of accuracy and precision (0.0003 S/m and 0.00004 S/m, respectively for SBE 911 instrument, see below) and is converted to salinity through an algorithm. Measurement is based on the “Wheatsone Bridge” principle. Temperature is measured by a “thermistor”, basically a metal thermocouple whose electrical resistance depends on temperature. A precision of 0.0002 ^{o}C and an accuracy of 0.001 ^{o}C are achievable with the SBE 911. Depth is measured by a pressure sensor whose precision and accuracy are typically 0.1-0.15% of full scale.

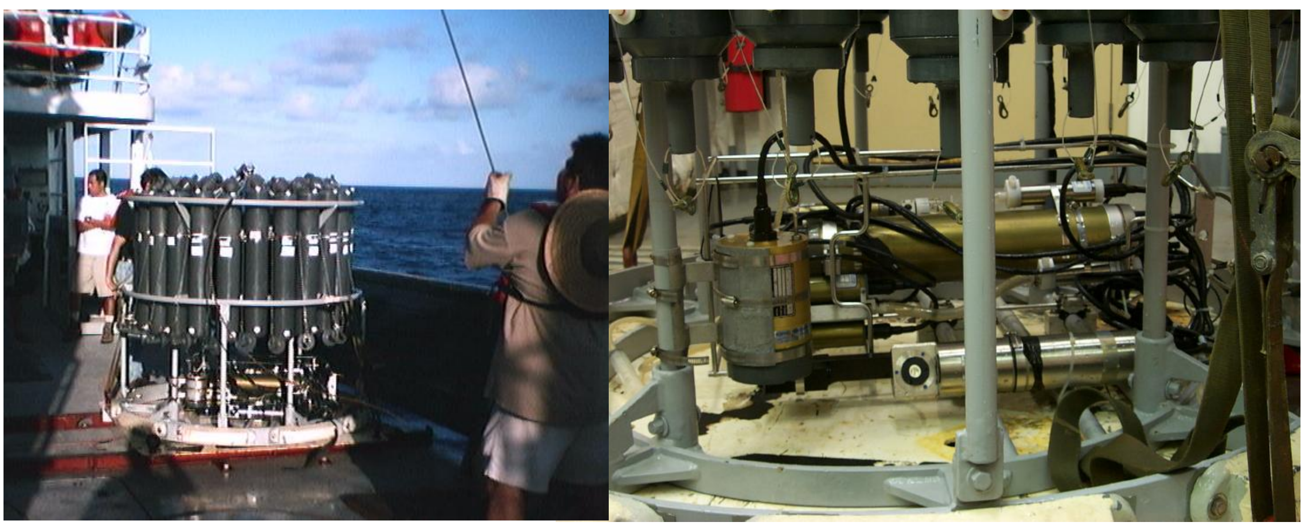


Figure 1. Top Left: Rosette with 24 Niskin (10 L capacity) bottles and CTD on deck of R/V Roger R. Revelle, EPREX 2000 Cruise (Honolulu to San Diego). Top Right: Close up of CTD unit below Niskin bottles.

CTD systems are typically connected to the ship through a conducting co-axial cable. Data are transmitted to the ship in real time as the CTD is lowered (and raised) through the water column. Niskin or other bottles are often tripped (during the upcast) at depths chosen on the basis of data provided by the CTD during the downcast. The Sea Bird Electronics corporation (SBE, http://www.seabird.com/) makes CTD systems that are widely used throughout the oceanographic community. Their main product line is headed by the SBE 911*plus* (9*plus* & 11*plus*), 25, 19*plus*, 49, 52-MP, & 41/41CP instruments. The instruments are factory calibrated and must be returned to the manufacturer on an annual basis for calibration and recertification. SBE will custom design instrument packages and offers third party sensors compatible with their power and data transmission components and that are routinely incorporated into SBE systems. A list of third party sensor manufacturers and some of the sensors they offer is provided here for your information. These field sensors will not be discussed in detail in this course, although several that are associated with instrumentation available at UH will be illustrated.

Biospherical Instruments
PAR Sensors (Photosynthetically Active Radiation)
QSP-2300L, MCP-2300, QCP-2300L, QSP-2200 (PD), QCP-2200 (PD), QSR-2200, QCR-2200

D & A Instruments
Designers and manufacturers of turbidity monitor, sediment and water-quality instrumentation for the dredging industry, defense agencies, research organizations; OEM.

LI-COR
PAR Sensors, LI-192-SA, LI-193-SA

Ocean Test Equipment, Inc. (also see *SBE Improved* O.T.E. Model 110 Sample Bottle)
PVC Sample Bottles

Seapoint Sensors, Inc.
Seapoint Turbidity Meter (STM), Seapoint Chlorophyll Fluorometer (SCF)
Fluorometers for Rhodamine, Fluorescein, and CDOM

Teledyne Benthos, Inc.
Sonar Altimeters

Turner Designs
SCUFA II Chlorophyll and Turbidity sensors
SCUFA III Rhodamine and Turbidity sensors
Cyclops-7 Chlorophyll fluorometers

WET Labs, Inc.
Absorption/Attenuation Meters
Mini-Fluorometers
C-STAR Transmissometers
Flow-thru Chamber

2. The Yellow Springs Instruments (YSI) Corporation (http://www.ysi.com) manufactures a line of extended deployment systems (EDS) designed for water quality applications. These small systems are particularly useful for monitoring of pipe discharges, streams and rivers, lakes, estuaries, and to a more limited extent, the ocean. Most of the multiparameter probes do not measure depth and are designed for shallow water or pipe settings. Others, such as the YSI 6600, include a depth sonde, and are suitable for profiling deployments down to about 200 meters. Biofouling and settling is addressed by cleaning the probes with sponges and brushes.

Figure 2: Profile of the new 6600 EDS depicting probes for temperature-conductivity (small probe), chlorophyll, turbidity, ROX (optical) dissolved oxygen, and pH/ORP. Probes are maintained free of fouling by the Clean Sweep™ universal wiper assembly, as well as individual optical wipers. (Conductivity is not cleaned by the wiper).

The basis of operation of YSI sensors for pressure, conductivity and temperature is conceptually the same as that described above for the CTD.

The basis of operation for other sensors varies slightly but there is a strong reliance on measurements of light absorption, fluorescence or scattering. Turbidity is measured based on the scattering of a pulse of light emitted by the sensor. Chlorophyl-a is measured by fluorescence in the water column stimulated by a pulse of light emitted by the sensor. Dissolved oxygen, which was previously measured electrochemically at a Pt electrode on the basis of the reduction of O_2, is now also measured optically.

YSI sensors require a rigorous maintenance and calibration program. Our experience indicates that the performance of sensors begins to deteriorate after about two weeks of deployments in seawater, during which measurements are made every five to ten minutes. Calibration of sensors is performed by the user in his/her laboratory and must be carried out for each individual sensor except temperature. Calibration typically involves the immersion of probes in various solutions of known composition and development of a calibration curve. The calibration of sensors does not drift uniformly. All sensors are prone to biofouling, a significant problem in productive waters. A significant fraction of the maintenance of sensors is ensuring their cleanliness and minimization of biofouling (often accomplished with biocides).

The YSI multiparameter probes are battery operated and are deployable for days to months depending on sampling frequency and other environmental parameters. YSI multiparameter sondes operate in a pulsed mode to save battery power, only drawing full power during measurement cycles.

The YSI corporation recently bought out SONTEK, a manufacturer of current meters based on the Doppler principle. Hence, YSI instruments can now also be integrated with Sontek ADCP, ADV and other wave, current, and tide measuring systems. Telemetry is also available for remote downloading of data.

YSI also produce floating platforms that can be moored in shallow to intermediate depths. The line includes buoys with 250 to 1000 kg capacities. YSI floating platforms provide mounting for solar panels, battery packs, telemetry and data acquisition electronics, antenna, meteorological sensors, mooring assembly, and a collision lamp. The YSI EMM550 Environmental Monitoring Module provides 250 kg of buoyancy for monitoring in lakes, rivers and coastal areas. The height of the stainless steel tripod allows attachment of solar panels and optimizes the antenna placement high reliable telemetry. Three YSI models (550, 800 and 2000) are shown below:

The hull is made of non-sinkable proprietary foam, and the framework is stainless steel. Stainless watertight compartments are O-ring sealed and have waterproof connectors for the electronics and rechargeable batteries. The manufacturer claims that the densified foam outer skin can withstand significant impact yet the foam hull is resilient enough to avoid damages, to the buoy and to the deploying vessel.

3. RBR sensors **(**http://www.rbr-global.com/) Manufacturers of high precision instruments for oceanographic, freshwater, groundwater and cryospheric research. The company produces instruments calibrated to WOCE standards. They make conductivity, pressure, temperature, and multiparameter recorders that house up to 13 sensors such as turbidity, fluorescence, dissolved oxygen, pH/ORP, PAR, and other sensors, thermistor chains, tide gauges, and wave gauges.

Recent products include a versatile, and laboratory **salinometer**. Instruments are built on a modular platform to permit rapid custom configuration.

Calibration equipment at RBR permits traceable calibration for oceanographic instruments including temperature to +/- 0.002 degrees, conductivity to +/- 0.003 mS/cm and pressure to +/- 0.015%. In house calibration of DO, pH, ORP and turbidity complement those for the fundamental physical measurements.

The RBRconcerto CTD systems also measure the speed of sound (of importance to the naval forces and a parameter expected to change with OA). The systems have long deployment lifetimes (company claim up to five years with sampling frequency of 1 minute). Data stored on memory are retained even when batteries are removed.

Conductivity – Measured with an inductive sensor, suitable for deployment in marine, estuarine, or fresh water. There are no exposed contacts, which avoids susceptibility to corrosion, and the housing may be frozen into ice without damage. It is characterized for the mechanical effects of both temperature and pressure to allow for accurate correction in salinity derivation. These coefficients are provided for customers who prefer to calculate their own corrections. In addition, it is suitable for use outside the usual realms of PSS-78 practical salinity scale, in applications such as desalination brine monitoring.

Temperature - The sensor is built and calibrated in-house using an aged thermistor. The temperature channel is calibrated an accuracy of ± 0.002°C (ITS-90) over the range -5 to +35°C. Extended range calibrations are available.

Pressure - Measured with a piezo-resistive transducer with nickel based super alloy diaphragm to avoid corrosion. Accuracy is 0.05% of the full scale rating and achievable resolution is 0.001%. The pressure sensor is available in a range between 10dbar to 740dbar. See the data sheet for possible sensor ratings.

4. Profiling systems are made by several manufacturers. One such system is the SeaTramp manufactured by OceanOrigo (http://www.oceanorigo.com/). The system consists of a CTD in a frame, to which can be attached a variety of other systems (some of which are discussed below). Figure 3 shows the "box" whereas a diagram of the system is given in Figure 4. The SeaTramp can take up to 1000 unattended profiles from its maximum depth of 600 m up to the surface zone. The data are stored on RAM and a non-volatile hard disk.

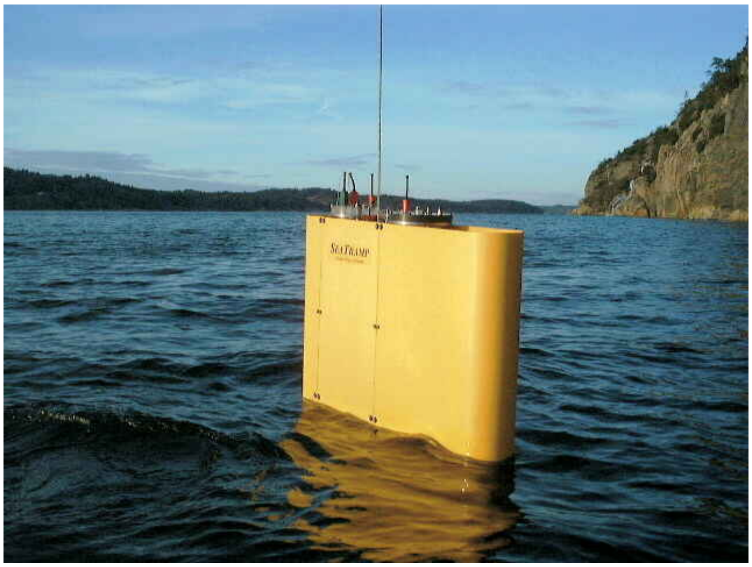


Figure 3: Sea Tramp autonomous, multicycling, data collecting platform designed for unattended marine monitoring and research. It profiles along a guiding wire and performs well also in stratified waters and when equipped with non stream-line payload. Sensors are selected by the operator and may be installed on site.

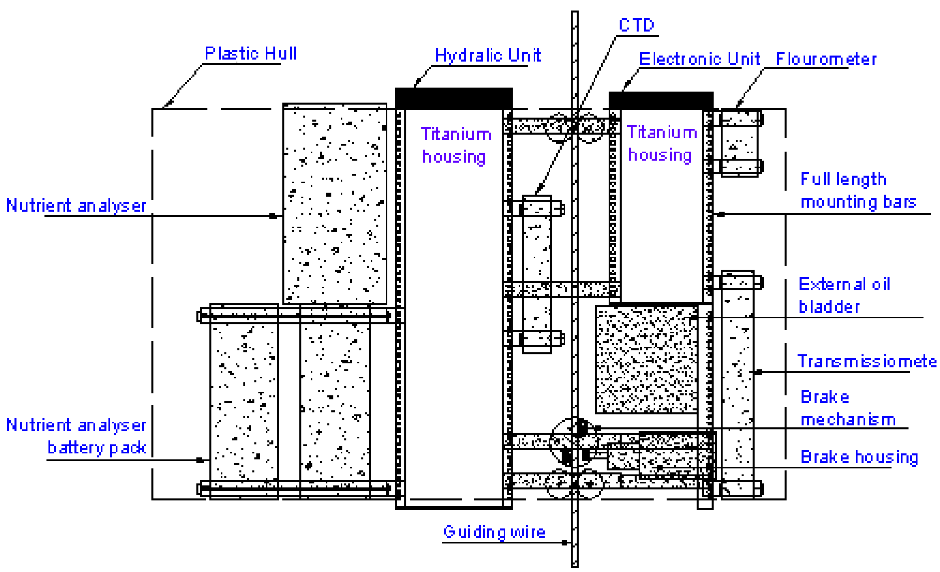


Figure 4: Diagrammatic representation of Sea Tramp Profiling system by Ocean Origo.

Another profiler system is the Sea Horse profiler. This system was developed by the Bedford Institute of Oceanography and commercially produced by Brooke Ocean Technology (http://www.brooke-ocean.com/s_horse1.html). SeaHorse utilizes surface wave energy to move a sensor platform up and down a mooring wire. The system permits a complete vertical profile to be obtained with a single sensor, eliminating the need for multiple sensors on the mooring line. The sensor platform can be pre-programmed to dwell at depth for set periods of time. SeaHorse can be configured to carry a variety of payloads including CTD, optical and acoustic sensors. Typically SBE (e.g., Sea-Bird 19*plus* CTD) systems are standard equipment on the SeaHorse. Most sensors capable of being piggybacked on the SBE19*plus* can also be employed on the SeaHorse.

The SeaHorse uses a ratchet system controlled by an onboard microprocessor to harness the natural energy of waves and transfer it into motion. This ratchet system can be set to glide freely or engaged to set the profiler in motion. The profiler can climb down to depth, wait for a pre-programmed length of time and then float along the mooring wire towards the surface by disengaging the gripper mechanism. During the profiling motion the onboard microcomputer logs sensor data in memory. The profiler will operate reliably, even in very calm conditions (as little as 15 cm wave height at 2 second period will cause the

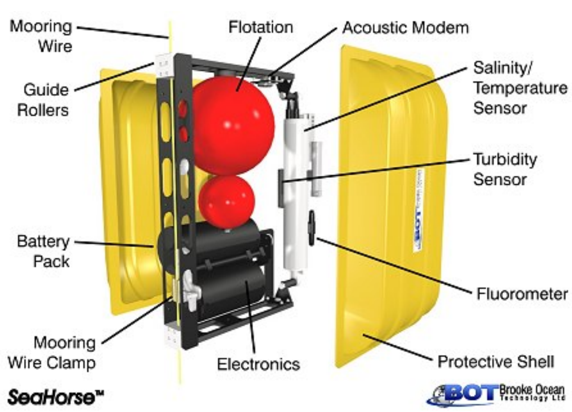


Figure 5: SeaHorse system cutaway (left) and photograph on deck of a ship (middle) and guideway (right) on which it rises/falls.

SeaHorse is adaptable to various mooring scenarios. The basic SeaHorse profiler can operate in water depths up to 200 m. Shallower deployments can be carried out with a minimum of handling equipment and manpower. The photo below shows the typical size of vessel required for shallow to medium-water deployments. All the gear required for the mooring can be laid out on the deck of the ship.

Programming the SeaHorse is accomplished with a laptop computer prior to deployment. Programming involves the input by the operator of parameters such as time between profiles and timeouts for data recording. The laptop must be equipped with either a serial 9-pin comm port or a USB-to-9-pin serial adapter. Data retrieval can also be accomplished with the laptop. This mobility allows the data to be downloaded on the spot or at a later time back in the shop.

5. Various oceanographic sensors built by Chelsea Instruments Ltd. can be viewed at the following url: http://www.chelsea.co.uk/. Propaganda and web links for several systems available through this manufacturer's web site are reproduced in the table below.

http://www.chelsea.co.uk/Instruments%20FASTtrackaII.htm	Award winning Fast Repetition Rate Fluorimeter designed to measure variable fluorescence of marine phytoplankton.
http://www.chelsea.co.uk/Instruments%20MINItracka.htm	Small, low cost fluorimeter available in chlorophyll, rhodamine, fluoroscein, phaeophytin, phycoerythrin and nephelometer versions.
http://www.chelsea.co.uk/Instruments%20AQUAtracka.htm	Compact, lightweight, submersible fluorimeter for the determination of Chlorophyll-a, dye tracing or turbidity.
http://www.chelsea.co.uk/Instruments%20UV%20AQUAtracka.htm	Submersible fluorimeter to monitor the concentration of hydrocarbons (360nm) and Gelbstoff (440nm) in a wide range of applications.
http://www.chelsea.co.uk/Instruments%20ALPHAtracka.htm	Compact, highly accurate, submersible transmissometer for suspended and dissolved solids. Blue, green, yellow or red light versions available.
http://www.chelsea.co.uk/Instruments%20MINIPACK.htm	Compact, SmartMediaTM based multi-parameter (CTD-F) monitoring system
http://www.chelsea.co.uk/Instruments%20Plankton%20Sampler.htm	A modern Plankton Sampler updating the Hardy design for automated towed, moored and ship-borne use.
http://www.chelsea.co.uk/Instruments%20GLOWtracka.htm	Submersible bioluminescence sensor which monitors the visible emissions from bioluminescent organisms in seawater.
http://www.chelsea.co.uk/Instruments%20PAR.htm	For the measurement of Photosynthetically Active Radiation.

6. "Chemistry in a Box" systems. Instruments in this category are basically *in situ* laboratories. Typically a water sample is drawn from the environment into the system where it is mixed with reagents. Sample introduction and reagent mixing and the subsequent reaction chemistry are controlled by a system of micro-pumps, injection valves, and small reactor cells combined with (absorption or fluorescence) detectors. The basis of operation is miniaturization of bench scale colorimetric or fluorometric methods and leads to sensitive *in situ* measurement of any dissolved chemical species that can form a color complex. These systems, however, are "high maintenance" requiring frequent calibration of fluid delivery devices (pumps) and replenishment of multiple reagent and standard solutions, some of which are not particularly stable unless kept at low temperature and shielded from light. Data output from such devices typically requires extensive post-processing to produce useable data.

   One manufacturer of such systems is Sub-Chem Systems (http://www.subchem.com/) who specialize in nutrient analyzers. One instrument offered by Sub Chem is the SubChemPak Analyzer (Figures 6-7, http://www.subchem.com/prod01.htm), a rapid response, submersible chemical analyzer designed for high-resolution, real-time measurements of selected nutrients and other environmentally important chemicals. The four-channel, continuous-flow spectrophotometric analyzer is comprised of two modular components: 1) the SubChemPak reagent delivery module and 2) ChemStar, a four-six channel absorption detector manufactured by wet labs (manufacturer whose sensors are also use by SBE, described above).

SubChem Systems also specialize in customized applications and research projects. An ocean observation project at the Kilo Nalu Nearshore Reef Observatory (http://www.soest.hawaii.edu/OE/KiloNalu/research.htm) currently utilizes a customized SubChem Systems APNA (automated profiling nutrient analyzer). This instrument, was customized for cabled applications as part of a UH/SubChem Systems collaboration and is based on a prior profiling instrument developed by SubChem and combined with a CTD for proprietary research applications (Figure 7). The UH APNA is equipped with five channels (Figure 8) to determine various forms of nitrogen, silica and phosphorus. One channel can also be utilized for the determination of dissolved Fe simply by changing the reaction chemistry. The instrument has detection limits in the low nanomolar range for nutrients. Maximum sampling frequency in discrete mode is approximately once every 20 minutes.

Figure 6: (left) SubChem Pak Analyzer and battery.

Figure 7: (right) SubChem Systems profiling nutrient analyzer package.

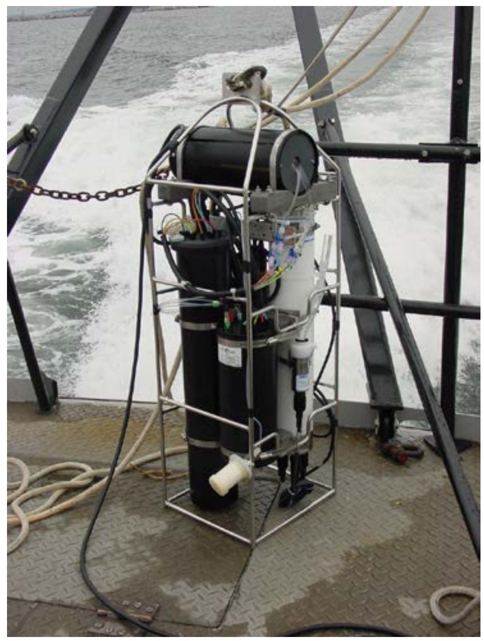


Figure 8: SubChem Systems APNA system for shipboard profiling applications. Components are shown below: Left: exposed analyzer, right: Analyzer and battery pack

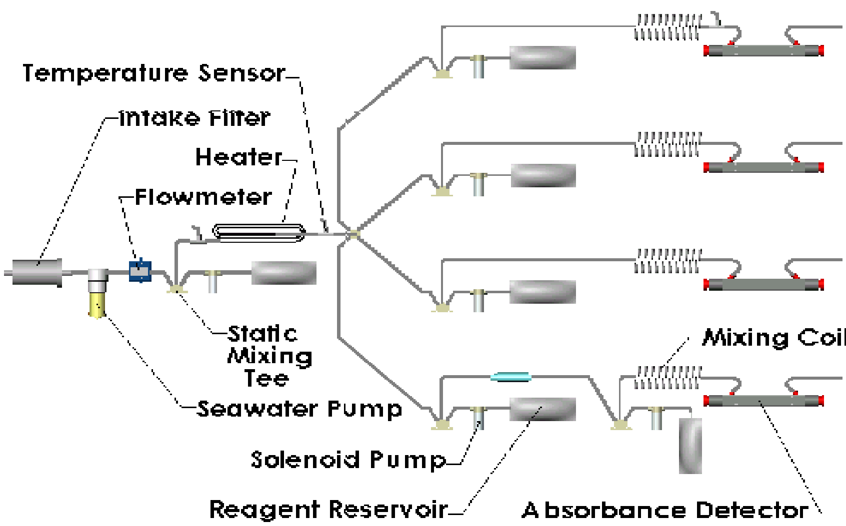


Figure 9: Diagram of plumbing of four-channel APNA system by SubChem Systems

7. Other flow through analyzer systems. Systems such as the NAS-2E (Figure 10) series manufactured by EnviroTech (http://www.n-virotech.com/products/nas.htm) use an "analytical chemistry in a box" approach to determine nutrient concentrations. These instruments are similar in concept to the APNA, in which a wet chemical method is applied *in situ* through a series of pumps and valves. Samples are drawn into a cell, mixed with reagents, and analyzed at predetermined (programmed) sampling

intervals. As stated above, the methods are nearly identical to those used in shore-based spectrophotometric auto-analyzer methods (e.g., Cd-reductase method for nitrate-nitrite). Data are transferred to a data logger and downloaded when the device is retrieved. The duration of deployments depends on battery power (i.e., is a function of the frequency of sampling) and a variety of other issues (e.g., biofouling). These systems, at least the earlier generation of instruments, are "high maintenance"…

Figure 10: NAS-2E system deployed on a mooring. Note the main (yellow) instrument control box and the two (black) cylindrical analyzers for N and P analysis. The NAS systems are capable of determining nitrate (and/or nitrite) phosphate, silicate, and ammonia.

8. Satlantic corporation (http://www.satlantic.com/) are now part of the SBE family of companies. They develop a wide range of sensors and systems for the study of aquatic environments. They offer active and passive optical sensors, and instrumentation for real-time *in situ* nitrate measurements and advanced systems for variable chlorophyll fluorescence analysis. The company also offer to carry out instrument integration, develop large scale ocean observatory solutions and data extraction tools that enable real-time operational decision making for their customers. Of specific importance to this course are the ISUS and SUNA nitrate sensors (Figure 11) and the SeaFET (pH) sensor.

   The ISUS is an UV absorption detector originally developed by Ken Johnson (MBARI, Moss Landing Laboratories) that, unlike the APNA, does not depend on reaction chemistry to measure this important nutrient. The sensor, however, is only applicable to nitrate and has a much poorer detection limit than the APNA. It is unable to detect nitrate in oligotrophic surface seawater. Their newer sensor, the SUNA, is a smaller profile instrument designed for autonomous monitoring and has some advantages in estuarine (high turbidity) environments. Detection limit constraints still limit the application of these instruments in oligotrophic waters such as those around the Hawaiian Islands.

Figure 11: The ISUS V3 nitrate sensor is a real time, chemical free system designed to overcome the traditional challenges associated with reagent-based nitrate analysis. The ISUS technology uses advanced UV absorption technology to provide accurate nitrate concentration measurements.

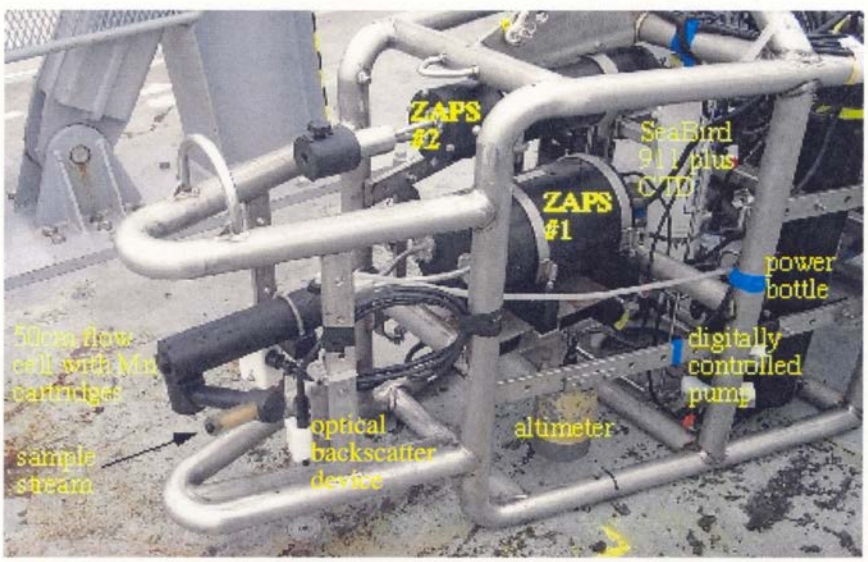
The SeaFET pH sensor was originally designed by Todd Martz (originally at MBARI now at SIO). The sensing element of the SeaFET is an ion sensitive field effect transistor (ISFET). This class of device has been used for pH sensing in industrial processes, food processing, clinical analysis and environmental monitoring. The advantages of the ISFET include robustness, stability and precision that make it suitable for ocean pH measurement at low pressure.

The SeaFET reports pH determined potentiometrically in two different ways. The ISFET potential is measured against a reference electrode bearing a liquid junction (internal reference) and against a solid state reference electrode without a liquid junction (external reference). This approach provides the user with the ability to quality assess instrument performance and ultimately achieve a greater understanding of the state of acid/base equilibria in seawater.

Figure 12: The SeaFET pH sensor from Satlantic.

9. The **ZAPS System** is a fiber-optic spectrometer that has been developed at Oregon State University over the last decade through funding from the Office of Naval Research. This is a customized (not commercially available) stowed system that can be used in coastal or open ocean waters. ZAPS includes a CTD and a flow-through chemical analyzer designed (by Prof. Gary Klinkhammer) to measure dissolved Mn in near real time. Samples are pumped across a filter membrane and the water analyzed for its dissolved Mn. The package has a robust (2" stainless steel) open system architecture frame, which allows modification of the system to add other instrumentation. The system is ideally suited to search for "plumes" in estuaries, near suspected hydrothermal vents, etc. The basis of the (chemical) method is a variable length flow cell and two chemical cartridges in tandem to the threaded end of a bifurcated fiber assembly. For Mn analysis, the first cartridge is filled with periodate embedded in soft acrylic beads. The second cartridge holds diethylaniline (DEA) immobilized in a microporous fluorocarbon substrate. A magnetically coupled pump pulls sample through the cartridges and flow cell. The pump is digitally controlled from the ship to deliver between 1 and 80 ml/min.

   A microprocessor in the ZAPS instrument signal board sends data to a specially designed "power bottle" on the package that contains the power supply, data packaging circuits, and other sensors. The modem transmits the data packets to the ship through a conducting cable to a deck unit that disseminates data to three locations (real time display, primary storage, and backup archiving). The deck unit also supplies 500W of power to the instrument package and encodes digital commands to the ZAPS instrument. The ZAPS system is depicted in Figures13.



The ZAPS instrument package showing some of the tools available for sensor verification. Not shown is the rosette mounted in the aft section. Note the chemical cartridges screwed onto the 50cm flow-cell of ZAPS 1. These cartridges filter the water and activate the sample stream for dissolved Mn. The elbows keep the reagents from mixing when the system is sitting on deck or not being pumped.

Figure 13: ZAPS instrument package being towed in the Columbia River Estuary. Photo courtesy G. Klinkhammer, COAS, Oregon State University.

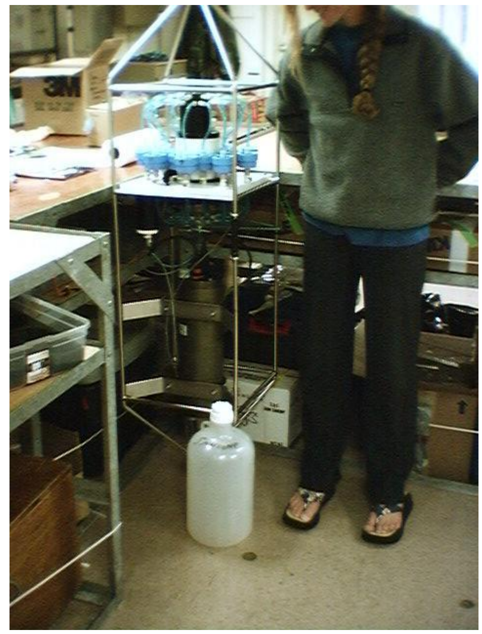
Typical probes on the ZAPS package include a SeaTech 25 cm Transmissometer, a SeaBird 911*plus* CTD, a photosynthetically available radiation (PAR) sensor (Biospherical Instrument Inc., Model QSP-200L), two optical backscatter devices, and a Simrad altimeter. Other probes that have been used on the ZAPS include the METS methane sensor (ASD Sensortechnik, Germany), an Eh probe (Koichi Nakamura, Geological Survey of Japan), and a Challenger large volume pump (deployed from the aft frame).

10. Sample collection pumping systems are designed to collect or process multiple water samples remotely. For example, EnviroTech produces the AquaLAB (Fig. 14) a 50-port water sampler developed in collaboration with a major research institutes and universities in the United States and Europe. Applications include trace gas analysis, extended deep ocean time-series sampling (with deployments up to and exceeding one year), precise time-series salinity determination, analysis of other parameter such as nutrients, tracers, and plankton, and high integrity short-term sampling via profiling system and remote vehicles. New gas-tight sample bags ensure high integrity sample acquisition and storage over long periods. Manufacturer claims are as follows:
    - Specifically designed to facilitate gas-tight water sampling
    - Utilises titanium foil sample bags
    - Titanium external construction
    - Rated to full ocean depth (6000m)
    - high precision sample volume

A custom built programmable and remote water filtering system is shown in Figures 15-16. The system allows pumping of small or large volumes of water across researcher chosen membranes housed in individual filtration capsules (blue capsules at top of system in Figure 13) The battery operated pumping system is triggered from the ship through a conducting cable, thereby allowing collection of samples from any desired depth (usually chosen on basis of CTD data.

Figure 14 (left): Aqualab by EnviroTech

Figure 15 (right): Mc Lane Particle collector system used aboard R/V Roger R. Revelle during EPREX 2000 cruise.



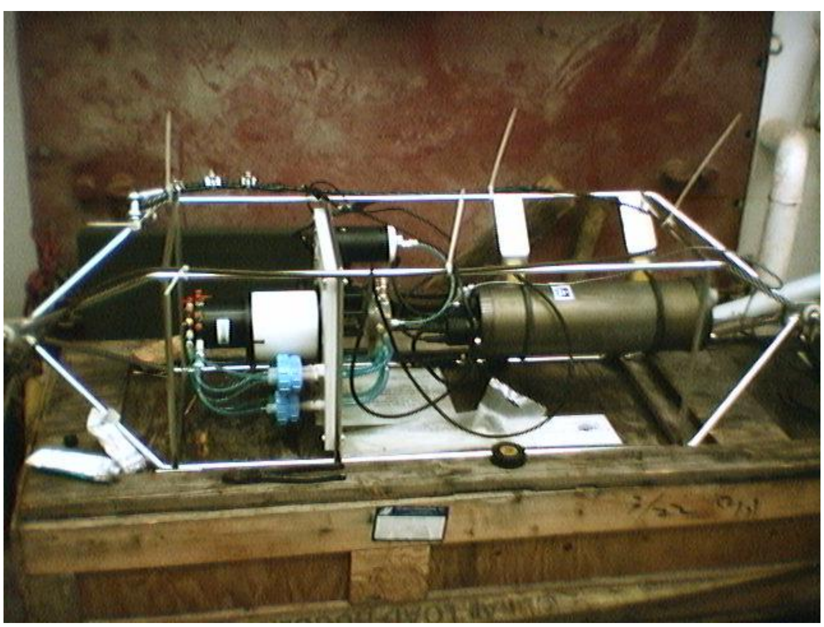


Figure 16: This particle collection system filters water for selected periods of time, thereby allowing *in situ* collection of particles from large volumes of seawater. An electric pump passes water through membrane cartridges that can be recovered once the system is brought back to the surface.

The Aquamonitor (also by EnviroTech, Figure 17) is also a water sampler for use in a wide variety of deployment scenarios. Aqua Monitor can be integrated within traditional mooring arrangements, towed-vehicle systems, or ROV/AUV platforms. The device collects up to fifty discrete water samples for post recovery laboratory analysis. The instrument may be programmed for autonomous time series sampling or for operation in "slave" mode within an integrated system. Applications are as diverse as the range of possible deployment platforms and include sampling for nutrients, phytoplankton, salinity, suspended-load, tracers and contaminants.

Figure 17: Aquamonitor by EnviroTech. Features of the system, as specified by the manufacturer are:

- Fifty samples of up to 1 litre each
- Multiple preservatives per deployment
- Fully programmable sampling
- Deployable to 2500 m
- Ease of operation

11. Sequoia Scientific Instruments Inc. (http://www.sequoiasci.com), produce a series of instruments whose focus is on particles analysis. The LISST (Laser In Situ Scattering and Transmissometry) operate on the basis of Mie scattering theory and are used for the determinations of particle concentration, mean particle size, and particle size distributions. Accurate *in situ* particle size analysis is important for a variety of reasons, but many methods are plagued with difficulties (particularly calibration of the instrument with respect to what is actually measured in the field).

    The main advantage of the LISST-25 instrument over other instruments (e.g., transmissometers) capable of determining particle concentrations is an ability to maintain calibration over a range of several order of magnitude particle sizes. The Manufacturer presents a comparison of data derived from the LISST-25 with those from a transmissometer (see Application Note L10 at web site). Evaluation of the system with particles of a broad range of sizes and of several types (i.e., manmade spheres, terrigenous or marine sediments from different locations) the LISST-25 held calibration to within a factor of two, whereas transmissometer calibration changed by two orders of magnitude. The LISST-25 employs a patented optical system including a collimated laser beam to illuminate particles, and specially shaped focal plane detectors behind the receiving lens. A comet shaped detector senses volume concentration of particles, holding calibration over a 200:1 size range. A second detector measures the area concentration. A Sauter Mean Size of sediments is provided from the ratio of these two outputs also. Two models of LISST-25 are available from the manufacturer (This is a small company owned and operated by the two individuals responsible for the development of the technology. For example, see: Agrawal, Y.C., and H.C. Pottsmith, 1994: Laser Diffraction Particle Sizing in STRESS, Continental Shelf Res.14, 1101-1121.)

LISST-25A: The **LISST-25A** accepts external power, and delivers 2 analog voltages corresponding to optical transmission and sediment concentration. This device is meant to be used on CTD packages, replacing older technology transmissometers or backscatterance sensors.

LISST-25X: The **-25X** is battery powered, fully recording instrument, with the added features that the concentration and SMD are partitioned in 2 size classes - coarse, and fine. Pressure is also recorded for depth.

Figure 18: LISST 25 made by Sequoia Scientific Instruments Inc.

The **LISST-100** instrument (Figure 19, available at UH) is a multi-parameter system for *in-situ* observations of particle size distribution. It also records the optical transmission, pressure and temperature. The instrument is self-contained with a battery and data-logger. It can be used with manufacturer-supplied programs, or in specially designed modes, e.g. event triggered based on storms (pressure variance) or fronts (temperature front). Two instruments are available for different size ranges: 1.25-250 microns (Type-B) and 2.5-500 microns (Type-C). Standard memory size is 512KB, suitable for storing approximately 6,000 size distributions, with option to expand to 2MB, or 26,000 size distributions. Special versions are available for deep-ocean, high-concentration, or low-concentration environments. The difference between the latter two is in the size of the optical path over which measurement is made. At the heart of the instrument are a collimated laser diode and a specially constructed annular ring detector (see Application Note L001 at manufacturer web site). Scattering at 32 angles is the primary information that is recorded. This primary measurement is mathematically inverted to get the size distribution, and also scaled to obtain the volume scattering function (VSF), see

Application Note L002. The size distribution is presented as concentration (micro-l/l) in each of 32 log-spaced size bins. Optical transmission, water depth and temperature are recorded as supporting measurements. In order to convert volume concentrations to mass concentrations, however, prior knowledge of the particle density (and its distribution as a function of size) is necessary. It is theoretically possible to empirically determine the relationship between particle volume concentration and particle mass concentration by manual collection of enough samples to characterize the range of particle concentrations (and compositions) and simultaneous measurement of the LISST–100 parameters. A regression equation can then be applied to subsequently determine particle mass concentrations from LISST-100 data.

An optional auxiliary salinity sensor is available on the LISST-100 to obtain full CTD capability. Designed for extended field application, the LISST-100 is a self-contained battery-powered instrument that can be deployed on a tripod, used in a profiling mode, towed, or moored. Custom versions of the instruments have been built including for deep-sea applications (e.g., J. P. Cowen, UH Manoa has a low particle concentration system used exclusively for research on hydrothermal plumes). An optional Small Volume Mixing Chamber for the LISST-100 also allows use of this field instrument in the laboratory with small samples.

Figure 19: LISST 100 instrument undergoing programming by graduate student, C.W. Young, prior to deployment in Waiakeakua Stream, Oahu, Hawaii.