Measuring the Ocean
- Coastal Oceanography -

Aida Alvera-Azcárate
a.alvera@ulg.ac.be
Contents

Introduction to the most common ocean sensors in physical/biological oceanography

- Temperature
- Salinity
- Ocean Currents
- Tides

Platforms

Ocean Observing systems

Mooring logistics

Ocean Remote Sensing
Temperature

How to measure it (most common methods used in physical oceanography):

- Expansion of a liquid or metal
- Change in electric resistance
- Infrared radiation from the ocean surface
A Letter from Dr. Benjamin Franklin, to Mr. Alphonsus le Roy, member of several academies, at Paris. Containing sundry Maritime Observations.

At Sea, on board the London Packet; Capt. Truxton, August 1785:

"... I annex hereto the observations made with the thermometer in two voyages, and possibly may add a third. It will appear from them,

that the thermometer may be an useful instrument to a navigator,

since currents coming from the northward into southern seas, will probably be found colder than the water of those seas, as the currents from southern seas into northern are found warmer...."
Reversing thermometer

Widely used during 1900 – 1970

Precision: ±0.1 °C

- constriction in the mercury capillary
- the thread of mercury breaks when thermometer is turned upside down
- usually deployed in pairs (protected/unprotected against pressure)
Bathythermograph

Measures changes in T and pressure
 Allows for profile records
 Thin copper tube (17m) filled with toluene + mechanical stylus

Limitations and sources of errors
 Depths up to ~300 m
 Ship must move slowly
 Permanent deformation of metal
 Records written by hand
 Theoretical precision ±0.06 °C
Expendable Bathythermograph (XBT)

- Change in **resistance of metals** provides T

- XBTs are thermistors (semiconductors)

- Depth is determined by elapsed time (free-falling probe)

- Data transfer wire

- Depths up to 800 m

- Ship does not need to slow down

- Sensor is lost

- Accuracy ±0.1°C

Widely used since 1960s

Easily deployed from Ships of Opportunity
**XBT bias problem**

Depth calculated with free-fall equation:

\[ z(t) = a t^2 + b t \]

With:

- \( t \): time
- \( z(t) \): depth
- \( a, b \): empirically-determined constants

Accuracy:
- ±2\% or 4.6m in depth
- ±0.2°C in temperature

However, XBTs fall faster than specified by manufacturer:
- Weight change with depth
- Denser waters at depth

Depth and temperature biases change with time, zone and manufacturer

Result: warm bias in upper ocean heat content estimates
**Example**

Evolution of depth errors for:

- low-resolution Sippican T4/T6 (1969–93; green dots)

- high-resolution Sippican T7/DB (1987–2011; black dots)

Data in 3-yr nonoverlapping bins

Dots are the depth errors for all of the results. Heavy black lines are the median for all results. Shaded red area is 2 standard errors.

From Cowley et al, 2013, JAOT.
XBT bias correction: some recent studies


See more at http://www.nodc.noaa.gov/OC5/XBT_BIAS/xbt_bibliography.html
**Thermistor chains**

- Similar sensor to XBTs
- For fixed-point moorings or strings
Deployment of 2 thermistor strings (200 m long each) in the Puerto Rico Trench, to measure internal waves.

Source: NIOZ
Conductivity-temperature-depth profiler (CTD)

Measures:
- Electrical resistance of platinum → Temperature
- Pressure → Depth
- Conductivity → Salinity

Can be attached to a variety of platforms
Lightweight
Can be lowered up to several thousand meters

The ship needs to stop to launch a CTD Calibration needed
**Response time of the CTD sensors**

Typically (for a fall rate of 1 m/s):

Platinum thermometer: 250 ms
Conductivity cell: 25 ms

Result: spikes in density estimated from T and S

Some CTDs include also a thermistor to provide accurate and fast measures by combining both
World Ocean Database: most used sensor types for temperature measurements

World Ocean Database

# of Temperature profiles ($10^4$)

- Bottle
- MBT
- XBT
- CTD
- PFL
- Other*

Year

- 1900
- 1910
- 1920
- 1930
- 1940
- 1950
- 1960
- 1970
- 1980
- 1990
- 2000
APB  Autonomous Pinniped Bathythermograph data
CTD  High resolution CTD data
DRB  Drifting buoy data
GLD  Glider data
MBT  Mechanical bathythermograph
MRB  Moored buoy data
OSD  Bottle, low resolution CTD
PFL  Profiling float data
UOR  Undulating Oceanographic Recorder data
XBT  Expendable bathythermograph data
Nansen and Niskin bottles
**Argo Profilers**

Autonomous profilers that measure in the first 2000m of the water column.

First proposed at OceanObs99 conference: development of an international ocean observing array

Goal: at least 3000 profilers actively measuring (one float per $3^\circ \times 3^\circ$ global grid) ($\sim 50\%$ US) → about 800 new profilers each year

Most common measures: T and S (and currents), also bio-profilers

For open ocean monitoring

More maps at:

http://www.argo.ucsd.edu/

http://w3.jcommops.org/cgi-bin/WebObjects/Argo.woa/wa/maps
How Argo profilers work

Argo floats rise and descend by changing its density

http://www.argo.ucsd.edu/
- Easy deployment
- Autonomy for ~200 cycles

- Can be washed ashore
- No near-surface measurements (5-10 m)
- Very few have biological sensors
Gliders

Autonomous underwater vehicle (AUV)
Changes in buoyancy + wings → vertical + horizontal motion
Pre-defined trajectories
Measures T, S, depth [currents, chlorophyll]

- Speeds of ~0.25 m/s
- Very cost efficient

www.whoi.edu
Example of glider data, from www.socib.es
A transatlantic challenge

April 2009

Scarlet Knight glider (Rutgers University)

Atlantic Ocean crossing with 1 battery charge

221 days at sea, 7400 km

22000 climbs and dives (~300m each)
Measure of salinity

First definition of salinity:

“The total amount of solid material in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, all the bromine and iodine replaced by chlorine and all the organic material oxidized” Forch et al, 1902.

Approach non practical for modern oceanography

In ~1950s: measurement of electrical conductivity (related to ion content of water, directly proportional to salt content) of seawater become standard

Conductivity measures also refer to an empirical definition of salinity, the practical salinity scale, which establishes the salinity with respect to a standard water of salinity 35.

Salinity does not have units.
Measuring ocean currents

1. Eulerian currents

Currents measured at a fixed point in the ocean

Direction and speed

Mechanical current meters like here →

Major problem: moving parts, subject to malfunction
Non-mechanical current meters → **Acoustic Doppler Current profiler**

Transmission of high frequency sound waves
+ determination of Doppler frequency shift of the return signal

Reflectors: “clouds” of planktonic organisms, changes in density...

ADCP provide measures of flow over several depth-averaged bins
HF-radar: measure of the ocean currents

High frequency (HF) radar systems measure the speed and direction of ocean surface currents in near real time.

Uses Doppler shift principle to calculate currents.

At least 2 antennas needed.

Measures up to 200 km offshore.
Maps of surface currents measured every few minutes.

Applications:
- Study ocean currents.
- Search and rescue operations.
- Marine navigation.
- Ocean energy production.
- Monitoring:
  - Oil spill.
  - Water quality.
  - Harmful Algal blooms.
  - Fisheries…
Measuring ocean currents

2. Lagrangian currents

Following a parcel of fluid as it moves

“Surface drifter”: satellite tracked, with specific size and subsurface drogue

Speed of drifter determined by 15-m surface currents, + wind currents

Problems: rogue can fall off

Surface Velocity Program "mini" drifter

In-situ observations of sea surface temperature, upper ocean currents, and other physical parameters

VOS Crew Deploy Next Generation SVP Drifter
Photo by: GDP
Measuring tides

Older tidal measuring stations
Mechanical floats and recorders →

New generation of monitoring stations:
advanced acoustics and electronics.

Audio signal sent down a 12 mm wide sounding tube
Time it takes for the reflected signal to travel back from the water's surface.

Data is directly transmitted to headquarters
Tsunami warning systems

Example: Deep-ocean Assessment and Reporting of Tsunami (DART), NOAA

To ensure early detection of tsunamis and to acquire data critical to real-time forecasts

Stations located in zones with potential for tsunami generation
How do they work?

- An anchored seafloor bottom pressure recorder (BPR)
- A companion moored surface buoy for real-time communications (acoustic link)
- Temperature and pressure at 15-second intervals → sea surface height
- Two way communication between buoy and tsunami warning center: buoys can be set up in “event” mode preventively
**Mooring logistics**

Mooring type depending of depth, instrument load

Battery life

Zone of deployment: mean currents, marine traffic, ice presence...

Fishing activity

Vandalism, theft (subsurface mooring less prone to it)

Bio-fouling

Acoustic release of moorings: remotely-controlled linkage connecting the anchor (weight) to the recoverable parts (instruments/sensors)
Observing systems

Concerted efforts to perform a multivariate, multi-platform observation of the ocean

Examples:

http://www.cencoos.org/data
http://hfradar.ndbc.noaa.gov/
http://www.socib.eu/
http://www.argo.ucsd.edu/
Satellites allow to measure the surface of the Earth with an unprecedented frequency and resolution. Many oceanic variables are measured from satellites: temperature, colour-related variables (chlorophyll-a, turbidity, total suspended matter...), sea level height, sea ice, winds, salinity... Since ~1980 (temperature)

Gulf Stream viewed by MODIS
Satellite measures

1) Sea Surface Temperature, SST

Passive measure of the thermal radiation form the ocean surface: the ocean and most other objects emit radiation in the infrared and the microwave wavelengths.

The amplitude of these wavelengths vary with the temperature of the ocean and therefore can be used to measure it.

Measure of the ocean surface SST (skin temperature):

Infrared radiation of the ocean comes from the top 10 microns of the surface.

Microwave radiation results from the topmost 1-millimeter layer.

(attention must be given when comparing SST from satellite and in situ sources!)

Several satellite missions measure SST:

AQUA
AVHRR-Pathfinder
MODIS
TERRA
AATSR
MERIS
...

- **geostationary** (36 000 km)
  - METEOSAT, GOES, ...
  - Always the same area
- **near-polar** (600 - 800 km)
  - NOAA, ENVISAT, Aqua/Terra, Landsat, Sentinel 1A, Radarsat, ...
  - Period~100 min
IR – thermal
- AVHRR, Advanced Very High Resolution Radiometer,
- 1km resolution
- 2 passes per day
- Polar orbit
- Doesn't measure through clouds

Micro waves
- TMI Tropical Rainfall Measuring Mission (TRMM) Microwave Imager
- AMSR-E (Advanced Microwave Scanning Radiometer)
- ~10 km resolution
- 2 passes per day
- Measures through clouds but not through rain
Ascending pass (daytime)

TMI Sea Surface Temperature: December 06, 2007

Descending pass (nighttime)

TMI Sea Surface Temperature: December 06, 2007

TMI latitudinal limit

40° N-S
<table>
<thead>
<tr>
<th>TMI</th>
<th>vs.</th>
<th>AMSR-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>semi-equatorial orbit</td>
<td>near-polar orbit</td>
<td></td>
</tr>
<tr>
<td>Angle 35°: 40°N-S</td>
<td>Angle 55°</td>
<td></td>
</tr>
<tr>
<td>Min Temperature: 15 °C</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Non sun synchronous</td>
<td>Sun-synchronous (measures taken at the same time of the day every day)</td>
<td></td>
</tr>
</tbody>
</table>

All TMI/AMSR-E figures from http://www.remss.com
Salinity

Two recent missions (since ~2010)

Salinity is derived through the relationship between brightness temperature (BT) and sea surface temperature (SST)

SMOS (ESA) and Aquarius (NASA)
- Sea ice (concentration, extent)

Images from http://nsidc.org/data/seaice_index/
September Sea Ice Concentrations (1979-2007)

Movie from http://nsidc.org/sotc/sea_ice_animation.html
2) Chlorophylle, Total Suspended Matter, k-490, CDOM...

- Mesure dans le visible et proche-IR
- Mesure des premières mètres de la surface de l’océan
- Plusieurs variables sont dérivées des mesures su visible-proche IR
3) Mesures par radar (senseurs actives par micro-ondes)

Pictures from Robinson (2004)
• **Vents** (direction et vitesse)
  • Scattometer (diffusomètre)

• Senseur actif

• Multiples vues pour calculer le vents, à partir de la rugosité de la surface de la mer

**AMSR-E wind in polar regions (movie)**
• **Altimetrie**

• Mesure de point du nadir

• Indépendante des nuages

• On dérive le courant géostrophique de la surface

• Pour calculer l’hauteur absolu il faut connaître le géoïde (approximations)

• Géoïde: surface géopotentielle du champ gravitationnel, correspondant à la surface moyenne de la mer en équilibre stationnaire
• **Synthetic Aperture Radar (SAR)**

  • Mésure de la rugosité de la surface de la mer à petite échelle (i.e. quelques dizaines de mètres)

---

Wilkins Ice Shelf hanging by its last thread ([lien](Envisat’s Advanced Synthetic Aperture Radar, ASAR))

---

Ondes internes

---

[Lien Envisat](Lien images ESA)
Red Sea between Egypt and Saudi Arabia (lien)
True-color Terra MODIS image acquired on July 26, 2003.
NASA Earth Science Missions
In Operation, Development, and Formulation

SLI Satellites to be defined
Formulation in 2015