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<https://github.com/julianmak/academic-notes>

The repository principally contains the compiled products rather than the source for size reasons.

- ▶ Associated Python code (as Jupyter notebooks mostly) will be held on the same repository. The source data however might be big, so I am going to be naughty and possibly just refer you to where you might get the data if that is the case (e.g. JRA-55 data). I know I should make properly reproducible binders etc., but I didn't...
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OCES 2003 : Descriptive Physical Oceanography

(a.k.a. physical oceanography by drawing pictures)

Lecture 19: Observation 1 (in-situ)

Thur 22th Apr

Outline

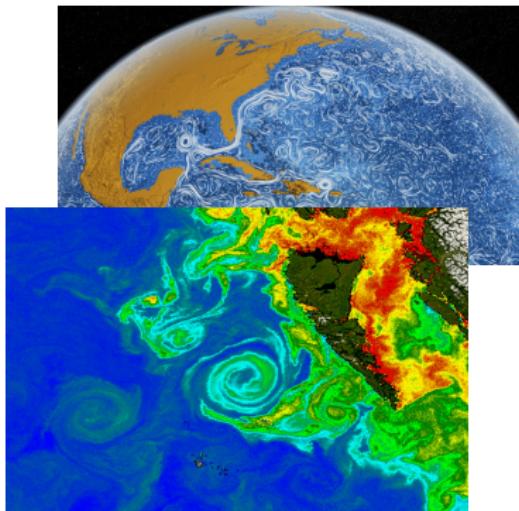
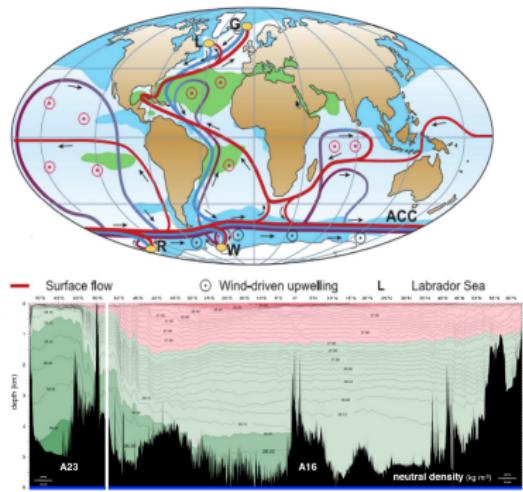
- ▶ what might we want to measure?
 - recall what we have studied so far
 - errors/**biases + uncertainties?**
- ▶ **in-situ** observations
 - instruments (e.g. **XBT, CTD, floats**, etc.)
 - ships, moorings, floats, marine mammals, **AUVs** (e.g. seagliders, drones, etc.)
- ▶ sample programs: RAPID, O-SNAP, GO-SHIP, Argo

Key terms: in-situ measurements, CTDs, marine mammals, AUVs, Argo

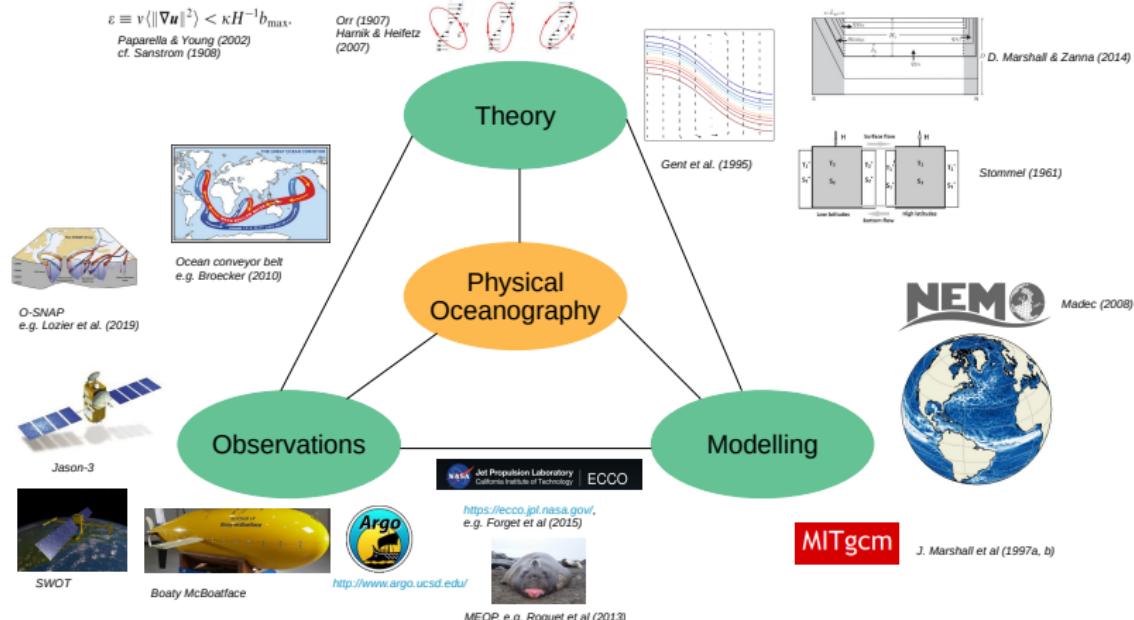
Recap: physical oceanography (Lec. 1)

Study of physical **features** and **processes** of the ocean

- ▶ **what** does it look like?
- ▶ **why** does it look like the way it does?



Recap: physical oceanography (Lec. 1)



understanding the ocean require
interdisciplinary + complementary approaches

Recap: temperature profiles (Lec. 5)

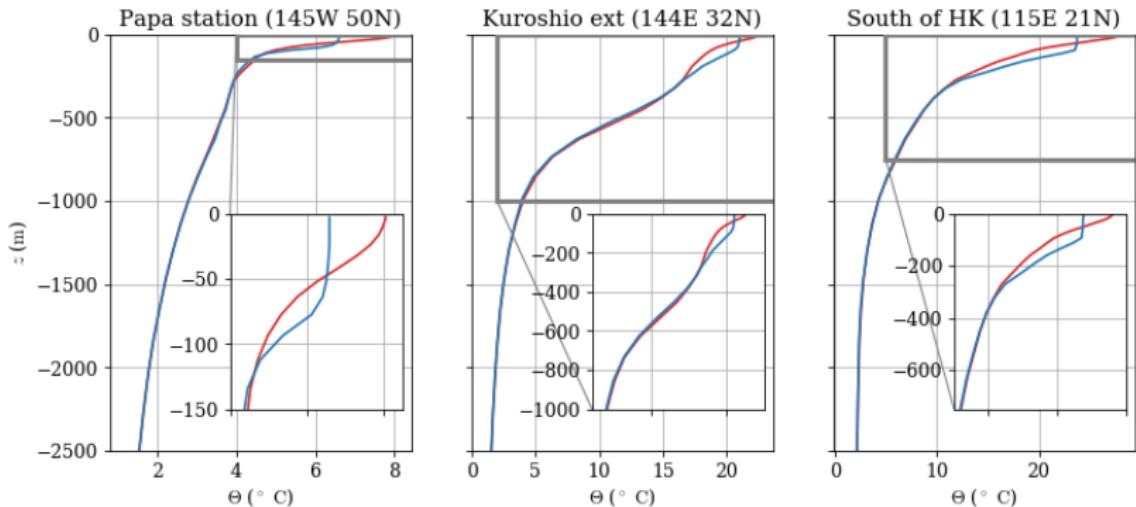


Figure: Vertical variation of Θ at some designated locations, based on WOA13 data. Red and blue line denote summer and winter climatology. See `plot_WOA13_sample.ipynb`

How did we get this...?

Recap: geoid (Lec. 7, 18)

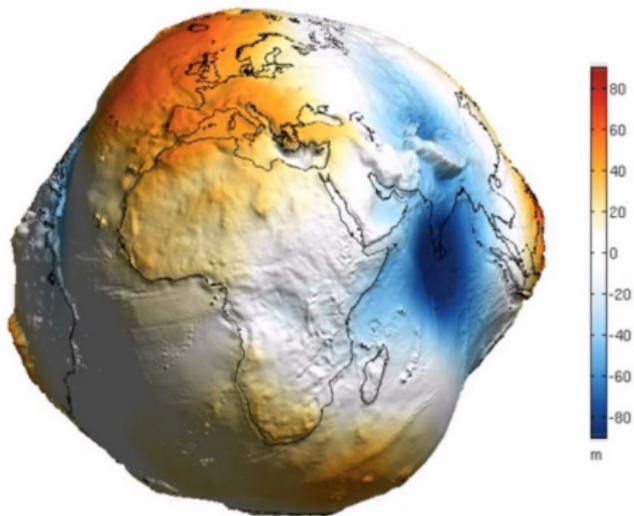


Figure: The “lumpy potato” Earth, variations in the geoid height magnified by several orders of magnitude to highlight difference. From Earth Gravitational Model 2008.

Or this...? (see next Lec.)

Recap: SSH (Lec. 7, 8)

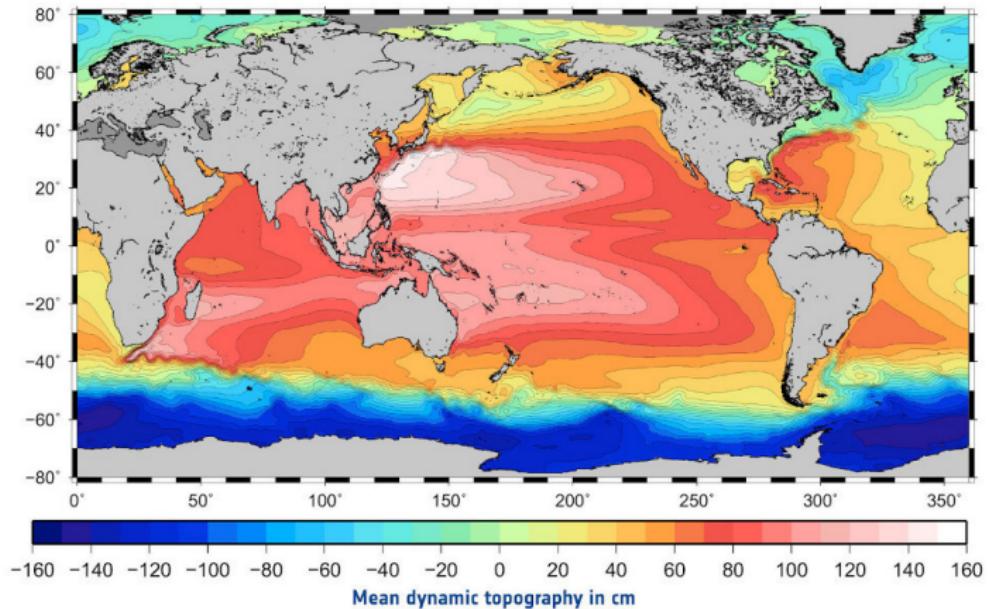


Figure: Time-mean global SSH (also called mean dynamic topography), with time-mean currents drawn on (notice the orientation around high/low SSH regions). Modified from Rio *et al.* (2011), J. Geophys. Res: Oceans.

Or this...? (see next Lec.)

Recap: something related to SSH (Lec. 18)

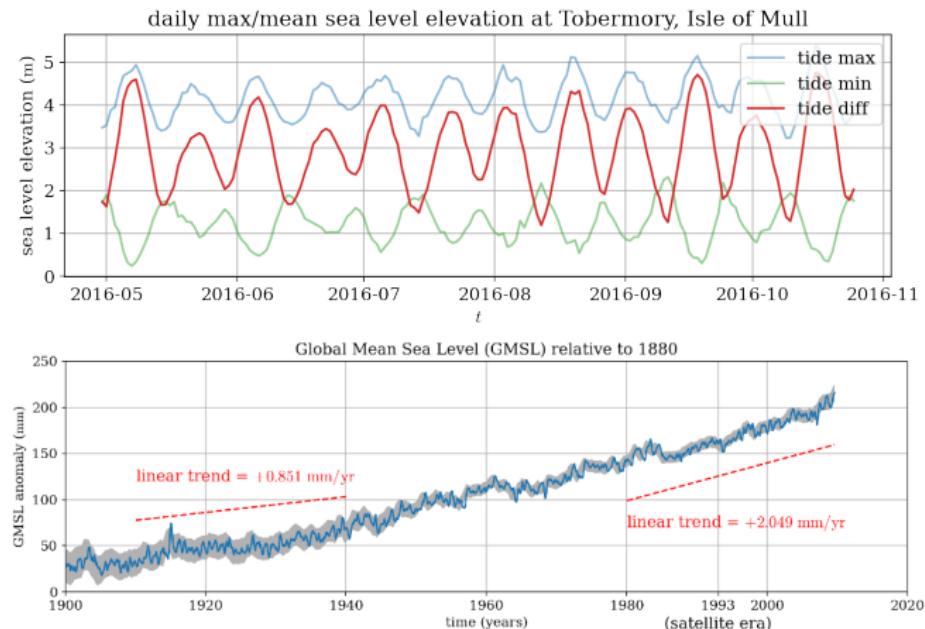


Figure: Daily maximum and minimum sea surface elevation (blue and green) and their difference (red) over a six month period (top), and global mean sea level over a hundred years or so (bottom). Data from BODC (top) and Church & White (2011) (bottom). See `tobermory_tides.ipynb` and `historical_sea_level_plot.ipynb`.

Or this...?

Data

1. direct data

- systematic, targeted
- generally (!) better control of quality + uncertainties
- e.g. temperature, SSH, nutrient concentration...

2. proxy data

- get at something by something else
- generally (!) subject to errors and larger uncertainties
- e.g. conductivity (to get salinity) [!?]
- e.g. green-ness (to get chlorophyll-*a*)
- e.g. $\delta^{18}\text{O}$ (to get temperature) (see OCES 4001)

data analysing + uncertainty quantification important

Observing the ocean is hard!

Opacity

- ▶ ocean is **opaque** (Lec. 5), electromagnetic radiation gets scattered quickly (Lec. 15)



Figure: Picture of the sea. CC0 Public Domain, taken from phys.org

- ▶ can't see into it well
- ▶ usual communication (e.g. microwave, infra-red) don't work well
→ cf. atmosphere

- ▶ non-attached instruments need be at surface to communicate
 - passing data, navigation
 - exposure then to potentially harsh surface conditions...

Pressure

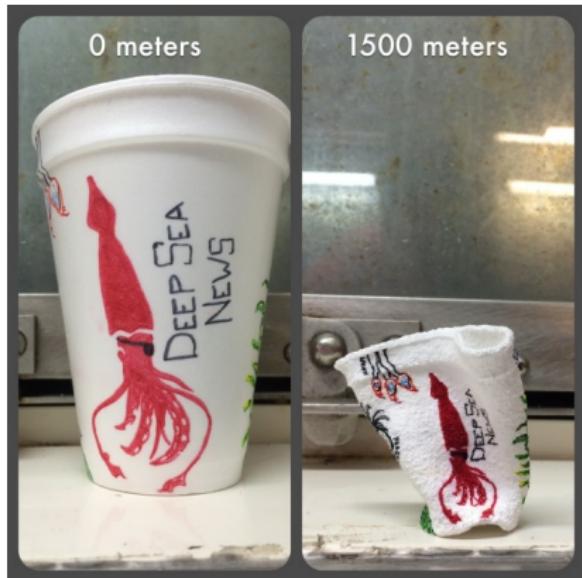


Figure: Styrofoam cup before and after being lowered to 1500 m depth in the ocean. Taken from www.deepseanews.com

- ▶ large pressures acting on objects
 - 10 m of seawater \approx 1 atm
 - free diving is hard below 30 m (3 atm)
 - 1500 m \approx 150 atm
- ▶ build things to resist the crushing?
 - cost?

Sea water corrosion

- ▶ salty water is chemically **corrosive**
 - disassociation of NaCl increases conductivity
 - allows easier flow of electrons
 - oxidation, forming iron oxide, which then forms rust
- ▶ in-situ instruments can lose integrity, sensitivity etc.
 - how to get extra **protection?**



Figure: Amorgos Shipwreck of Olympia. From taosailing.com

Biofouling



Figure: Zebra mussels on a current meter (left) and a moldy sea cucumber on a couch (right)? Image from NOAA (left) and personal collection.

- ▶ organisms attack/latch on to objects
 - e.g. mold in your house
- ▶ added weight
- ▶ chemical outputs from organisms
 - e.g. mold in your house

- ▶ protection + cost?

Cost

- ▶ Ocean observation is **expensive!**
 - instrument, people, maintenance, development etc.
 - ship time by itself
 - $\geq \$30,000 \text{ day}^{-1}$
- ▶ isolated efforts previously
 - von Hulmboldt, Nansen, Prince Albert of Monaco...
- ▶ need coverage, i.e. money
 - government backed civilian organisations
 - navies, military



Figure: From when Elon Musk was bigging up dogecoin. From Elon Musk's twitter account (@elonmusk).

Tide gauge

Some ‘traditional’ equipment first (in no particular order)

Tide gauge

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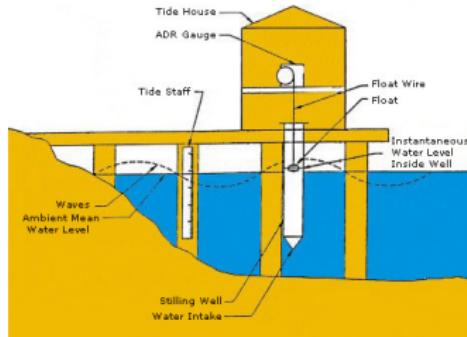


Figure: Old style tide gauge station schematic.
From NOAA.

- ▶ measures **sea surface height**
 - relative to the underlying land
 - contrast with what satellites measure (see next Lec.)
- ▶ marker floats up and down, mark on height
 - now done automatically by machine

Reverse thermometer

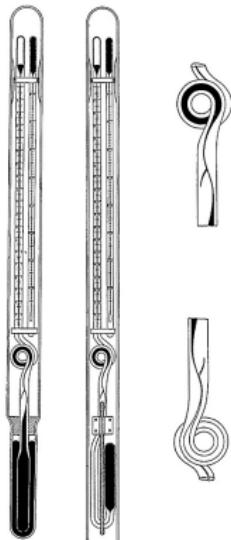


Figure: Schematic of unprotected and protected reversing thermometer. From *The Oceans Their Physics, Chemistry, and General Biology* by Sverdrup, Johnson & Fleming (1942).

- ▶ measures **temperature**
- ▶ when reversed, the mercury can no longer fill the thermometer
 - marks temperature at depth
- ▶ **unprotected** one to measure T
- ▶ **protected** one to measure θ
 - some pressurised casing
 - can use difference to get p and thus **depth** too

Nansen / Niskin bottles

- ▶ measures water tracers
- ▶ when reversed, water fills bottle but then gets sealed
 - to get water samples
 - use in conjunction with reverse thermometers to get T/θ and p
- ▶ chain a few of them up together with reverse thermometers
 - drop chain and let it settle
 - send **messenger** (a weight) down, trigger, reverse, send another weight, continue
 - pull chain up, repeat

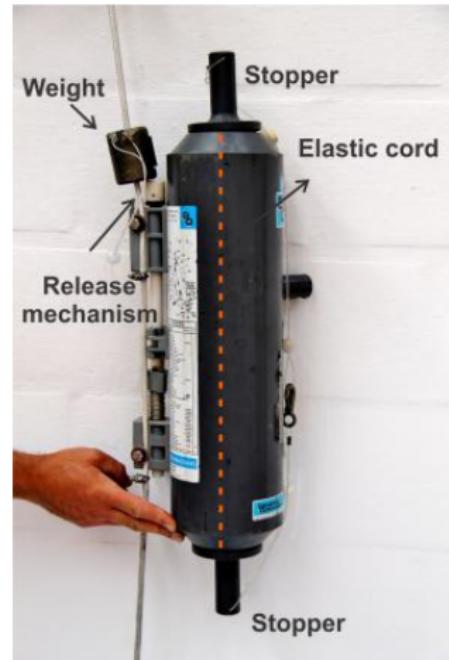


Figure: A picture of a Nansen/Niskin bottle. From Flanders Marine Institute (VLIZ).

Current meters

- ▶ measure velocity with turbines + compass
 - turbines to get speed
 - compass to get orientation
- ▶ cf. **anemometer**
- ▶ mechanical
 - **acoustic** version better (see next Lec)
- ▶ noisy signals
 - motions at all scales?



THE ROBINSON ANEMOMETER.

Figure: A mechanical ocean current meter (top) and an anemometer (bottom). From www.valeport.co.uk (top) and Wikipedia (bottom).

eXpendable BathyThermographs (XBTs)

- ▶ substantially less dangerous (!) version of the Mechanical BathyThermograph
- ▶ temperature sensor and **transducer**, connected by wire to ship
 - differences in electric signal from fluctuations in pressure
 - roughly get (limited) depth and temperature

- ▶ XBTs snap when wire runs out
 - conventional BTs are recovered (!)
- ▶ some on sides of ships for calibrating **sonar**
 - warfare uses



Figure: XBT being launched (left) and schematic of XBT (right). From NOAA (left) and NASA (right).

Conductivity Temperature Depth (CTD) profiler

- ▶ does what it says on the tin
 - conductivity to get S
 - temperature for T
 - it really measures p to get depth
- ▶ normally in a **rosette**
 - Nansen bottles to take water samples
 - can put other sensors on (e.g. pH, oxygen, etc.)



Figure: CTD profiler (in the center of rosette for this set up) and Nansen bottles surrounding it. Image from OCEAN-HK.

Fixed stations



Figure: Bornö 2018 workshop. Image from Team Ocean, University of Copenhagen.

- ▶ fixed location, long term measurements possible
 - can do water sampling
 - fixed to coastal (shallow) regions

Ships



Figure: The German RV Sonne when it was docked in Hong Kong. Image from personal collection.

- ▶ floating and moving stations
 - can control where it is
 - specialist equipment (e.g. winches, labs etc.)
 - important for some urgent water sampling etc.
- ▶ dedicated cruises
 - expensive!
 - $\geq \$30,000 \text{ day}^{-1}$ just on ship time!
 - salary, equipment, consumables...

Ships

- ▶ ‘ships of opportunity’
 - volunteer merchant / fishing ships
 - cheaper but less control
 - limited things to do (e.g. XBTs)
 - bias to certain regions (e.g. major shipping lanes)



Figure: The MV Black Marlin. Not really a ship of opportunity, but I just really wanted to put “a shipping ship shipping ships” in. Image from Wikipedia, user Kees Torn.

Moorings

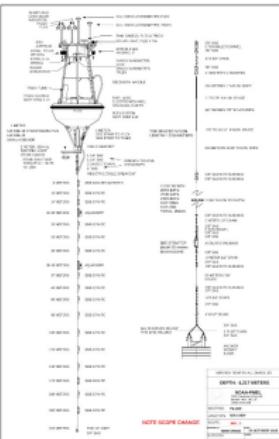


Figure: Station Papa (left) and schematic (right) in 2015;
see also Lec. 5. From PMEL NOAA.

- ▶ doesn't go anywhere, but longer term
- ▶ usually need exposure to atmosphere for communication
 - at mercy of harsh surface conditions
- ▶ limited/no water sampling
- ▶ maintenance
- ▶ blown around by wind, biases?

Floats

- ▶ goes with the flow
 - no control where it goes as such
 - get **Lagrangian** information?
- ▶ old school: bottles
- ▶ unintentional ones:
Friendly Floatees
- ▶ dedicated ones: Argo (see more later)
 - think CTDs but floating around



Figure: An Argo float being thrown off a ship (top) and some rubber ducks at the Ken-ducky derby (there is a caption mismatch). Image from NOAA (top) and Cassie Marshall (bottom).

Mammals

- ▶ floats but alive?
 - can't really control where it goes
- ▶ tag the mammals with sensors
 - geolocation
 - (simplified) CTD
 - sensor falls off when seals moult
- ▶ can get to places that are traditionally inaccessible
 - e.g. under ice

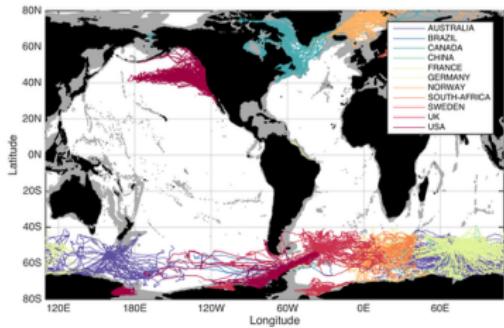


Figure: Seal with tag (top) and map of tracks (bottom).
From Fabien Rouget (top) and MEOP website
<http://www.meop.net/> (bottom)

Autonomous Underwater Vehicles (AUVs)

- ▶ basically drones, normally bright coloured (why?)
 - program a route or ‘flight’ settings in advance
 - comes up occasionally to pass data and/or receive new flight plans
 - battery powered, operation life varies
- ▶ below shows deep ocean focused equipment, but coastal models available



Figure: Boaty McBoatface, a Autosub LR (left) and a Kongsberg sea glider with Bastien Queste (now at Gothenburg) for scale (right). From UK National Oceanography Center (left) and Sergey Piontkovksi (right).

e.g. seaglider schematic

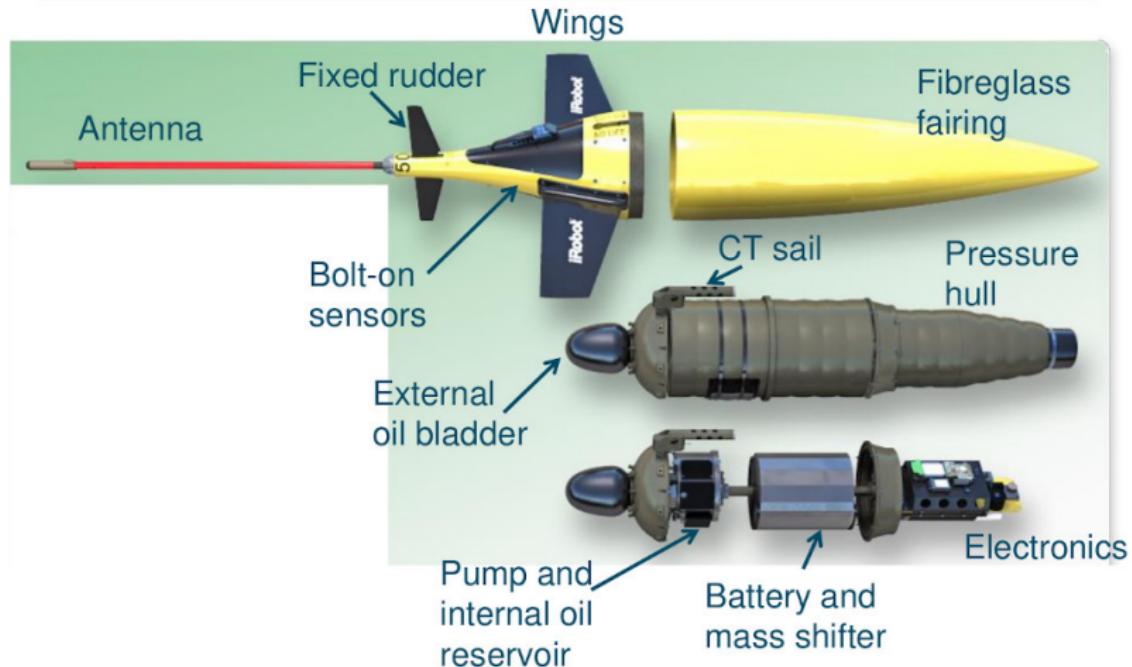


Figure: Components of a seaglider. Slide from 2018 ATSC winter school on gliders at University of East Anglia, UK. The mass remains constant but the volume (and thus density) is controlled by pumping oil into/out of the external bladder.

RAPID (AMOC)

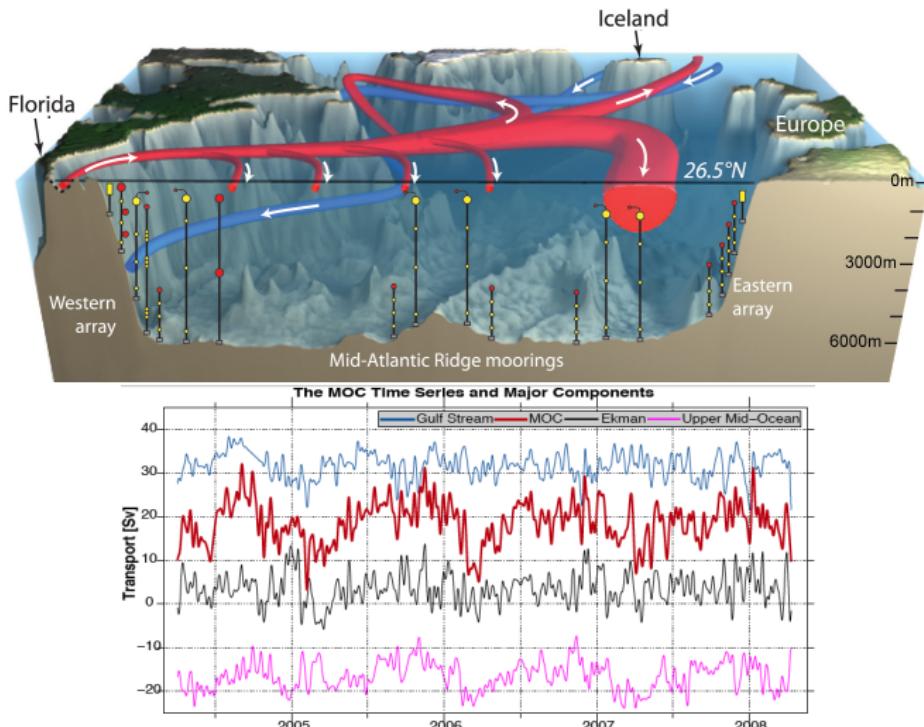


Figure: Schematic of the RAPID array at 26.5° N (top) and time series from the observed data (bottom). From rapid.ac.uk

O-SNAP (AMOC and watermass transformation)

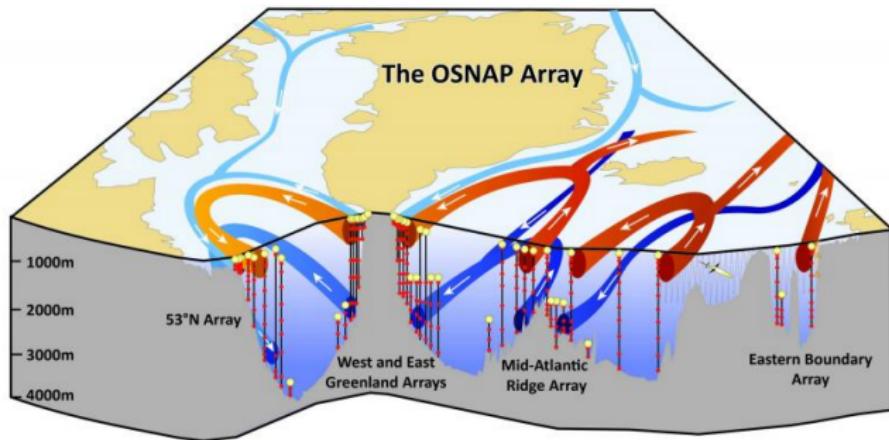


Figure: Schematic of the O-SNAP array in the North Atlantic subpolar gyre. From www.ukosnap.org

GO-SHIP ('gold standard' global)

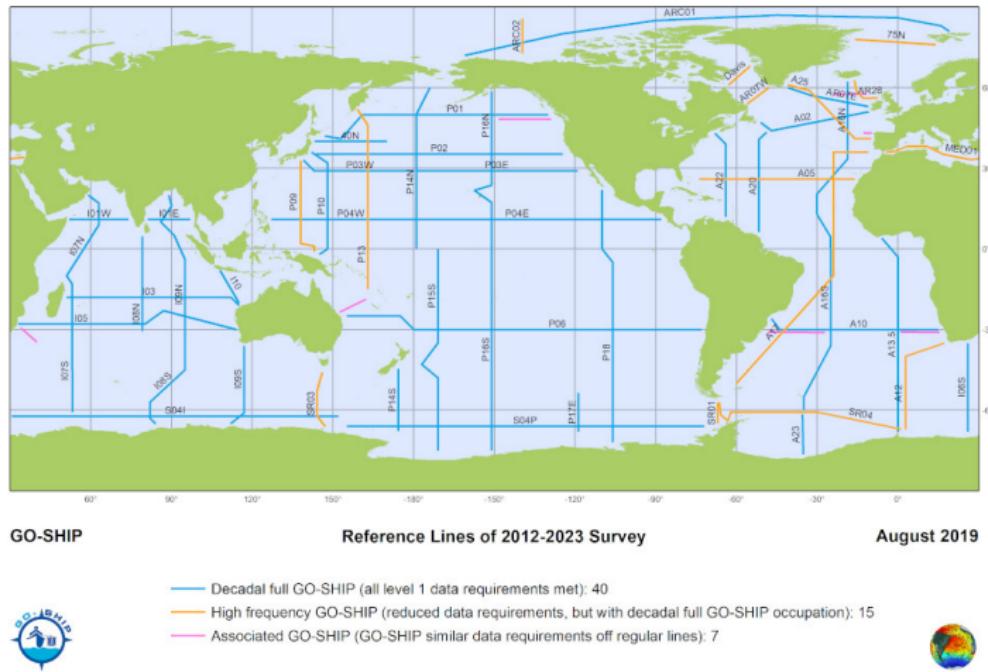


Figure: Reference sections as of 2019. From www.go-ship.org

Argo (global)

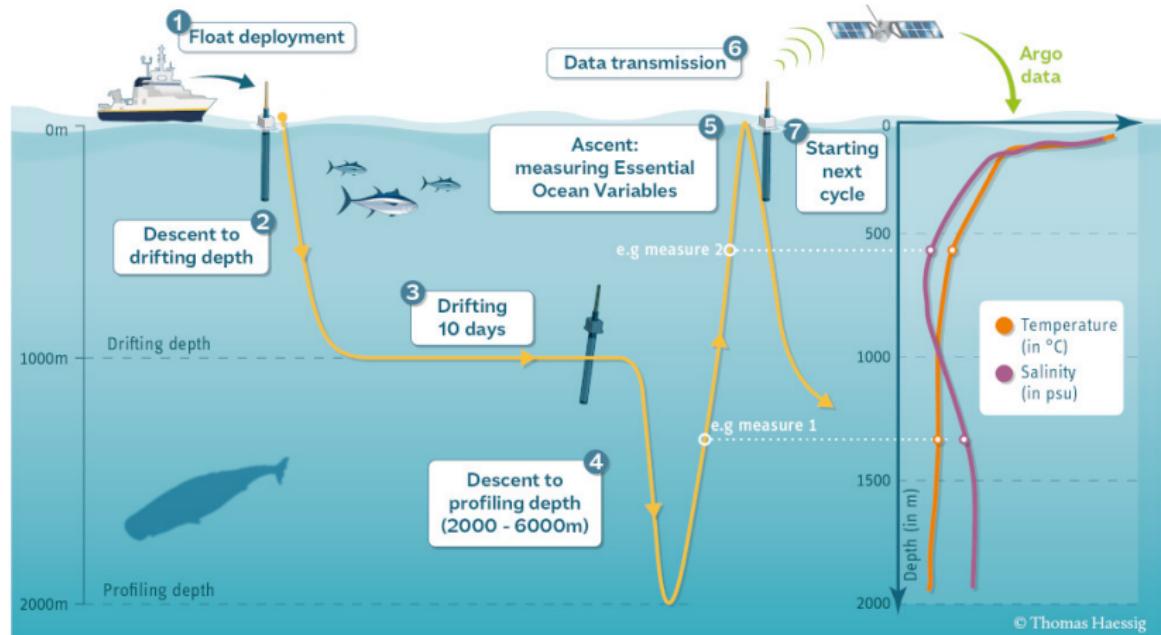


Figure: Argo float cycle schematic. From argo.ucsd.edu

- reason for 'Argo'? (look up some Greek mythology, or next Lec.)

Argo (global)

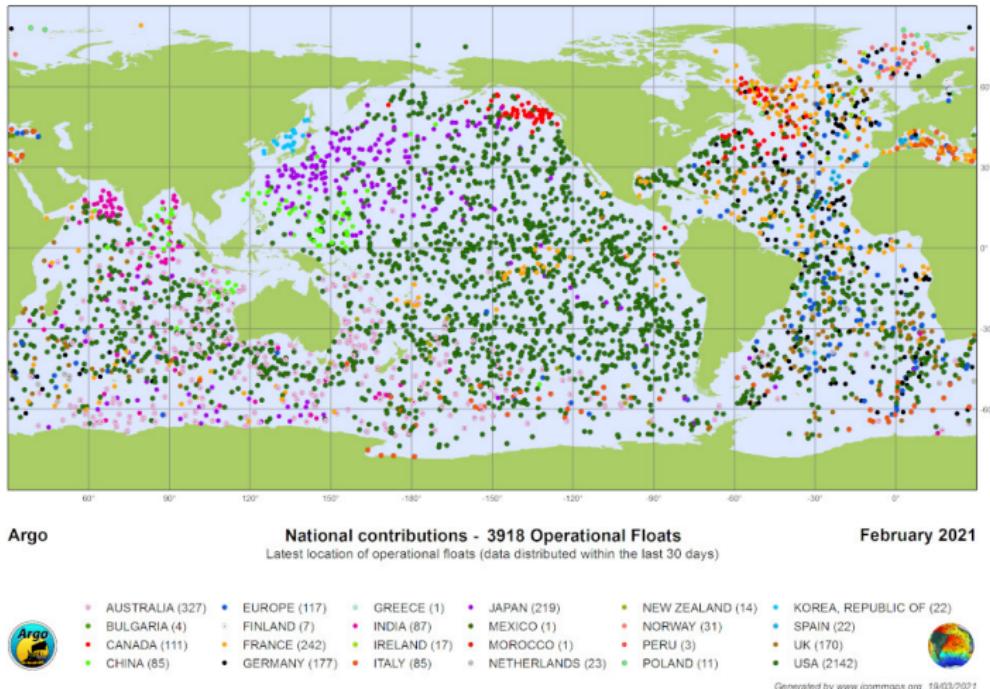


Figure: Argo locations as of Feb 2021. Note the dots are enhanced in size, so coverage is not as dense as it seems.
From argo.ucsd.edu

Summary

- ▶ overview of physical oceanography + data
 - need for observations
- ▶ focusing on equipment to do **in-situ** measurements
 - tide gauges, CTDs, ships, floats etc.

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 - (raw and/or processed) data acquisition

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(but not the focus here; see OCES 3301)