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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...
- I do not claim the compiled products and/or code are completely mistake free (e.g. I know I don't write Pythonic code). Use the material however you like, but use it at your own risk.
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OCES 2003 : Descriptive Physical Oceanography

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

Lecture 19: Observation 1 (in-situ)

Outline

- what might we want to measure?
  $\rightarrow$ recall what we have studied so far
  $\rightarrow$ errors/biases + uncertainties?

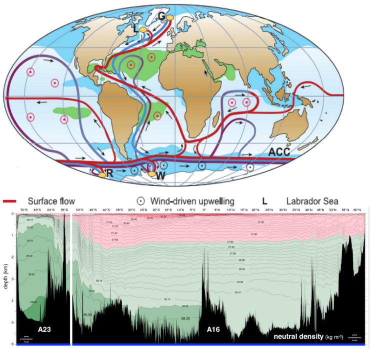
- in-situ observations
  $\rightarrow$ instruments (e.g. XBT, CTD, floats, etc.)
  $\rightarrow$ ships, moorings, floats, marine mammals, AUVs (e.g. seagliders, drones, etc.)
- sample programs: RAPID, O-SNAP, GO-SHIP, Argo

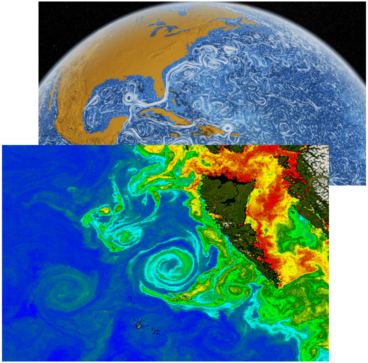
Key terms: in-situ measurements, CTDs, marine mammals, AUVs, Argo

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?



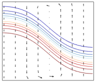


Recap: physical oceanography (Lec. 1)

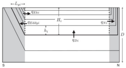
$\varepsilon \equiv \nu\langle\|\nabla \boldsymbol{u}\|^2\rangle < \kappa H^{-1} b_{\max}.$

Paparella & Young (2002)
cf. Sanstrom (1908)

Orr (1907)
Harnik & Heifetz (2007)

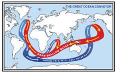


Gent et al. (1995)

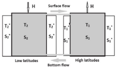


D. Marshall & Zanna (2014)

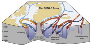
Theory



Ocean conveyor belt
e.g. Broecker (2010)



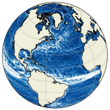
Stommel (1961)



O-SNAP
e.g. Lozier et al. (2019)

Physical Oceanography

Madec (2008)



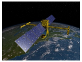
Jason-3

Observations

Modelling

ECCO

https://ecco.jpl.nasa.gov/,
e.g. Forget et al (2015)



SWOT

Boaty McBoatface

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

MEOP, e.g. Roquet et al (2013)

MITgcm

J. Marshall et al (1997a, b)

understanding the ocean require
interdisciplinary + complementary approaches

Recap: temperature profiles (Lec. 5)

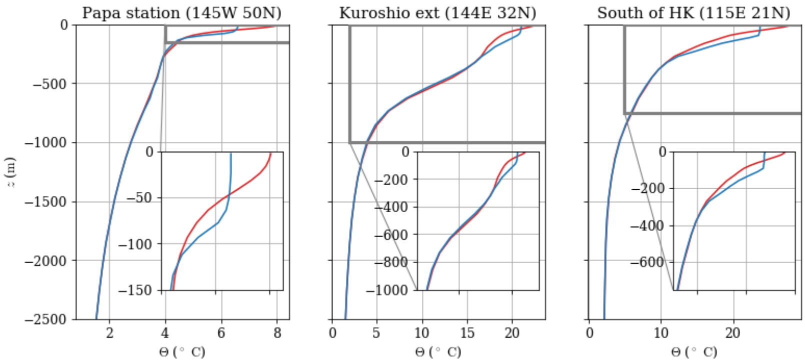


Figure: Vertical variation of Θ at some designated locations, based on WOA13 data. Red and blue line denote summer and winter climatology. See `plot_WOA13_sample.ipynb`

How did we get this...?

Recap: geoid (Lec. 7, 18)

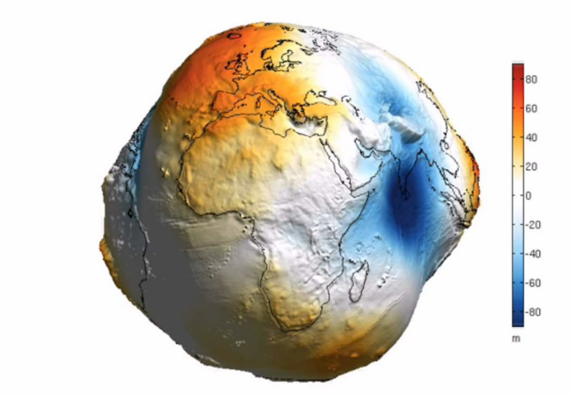


Figure: The "lumpy potato" Earth, variations in the geoid height magnified by several orders of magnitude to highlight difference. From Earth Gravitational Model 2008.

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

Recap: SSH (Lec. 7, 8)

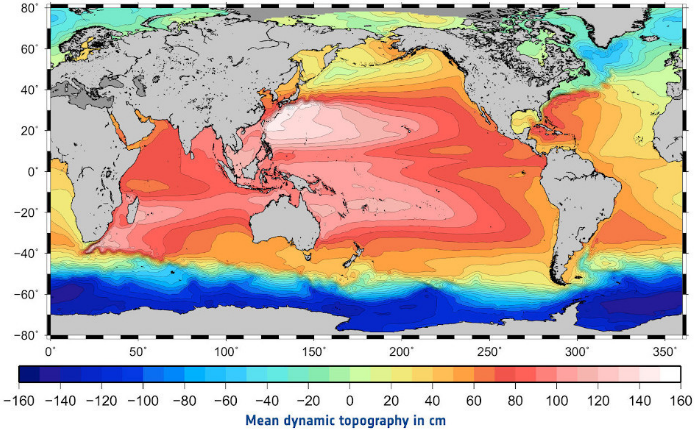


Figure: Time-mean global SSH (also called mean dynamic topography), with time-mean currents drawn on (notice the orientation around high/low SSH regions). Modified from Rio *et al.* (2011), J. Geophys. Res: Oceans.

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

Recap: something related to SSH (Lec. 18)

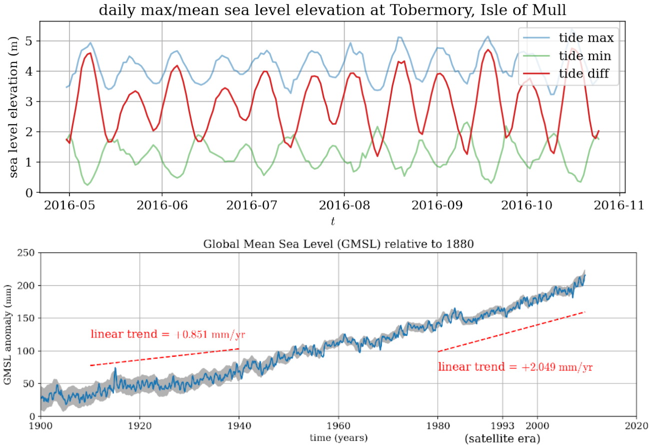


Figure: Daily maximum and minimum sea surface elevation (blue and green) and their difference (red) over a six month period (top), and global mean sea level over a hundred years or so (bottom). Data from BODC (top) and Church & White (2011) (bottom). See `tobermory_tides.ipynb` and `historical_sea_level_plot.ipynb`.

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. δ^{18}O (to get temperature) (see OCES 4001)

data analysing + uncertainty quantification important

(but not the focus here; see OCES 3301)

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

  $\rightarrow$ cf. atmosphere

- non-attached instruments need be at surface to communicate

  $\rightarrow$ passing data, navigation

  $\rightarrow$ exposure then to potentially harsh surface conditions...

Pressure

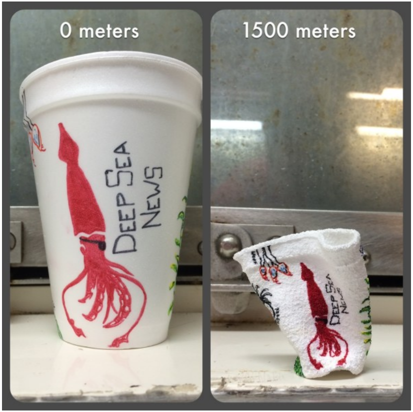


Figure: Styrofoam cup before and after being lowered to 1500 m depth in the ocean. Taken from `www.deepseanews.com`

- large pressures acting on objects

  $\rightarrow$ 10 m of seawater $\approx$ 1 atm

  $\rightarrow$ free diving is hard below 30 m (3 atm)

  $\rightarrow$ 1500 m $\approx$ 150 atm
- build things to resist the crushing?

  $\rightarrow$ cost?

Sea water corrosion

- salty water is chemically **corrosive**

  $\rightarrow$ disassociation of NaCl increases conductivity

  $\rightarrow$ allows easier flow of electrons

  $\rightarrow$ oxidation, forming iron oxide, which then forms rust

- in-situ instruments can lose integrity, sensitivity etc.

  $\rightarrow$ 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

  $\rightarrow$ e.g. mold in your house
- added weight
- chemical outputs from organisms

  $\rightarrow$ 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

Some 'traditional' equipment first (in no particular order)

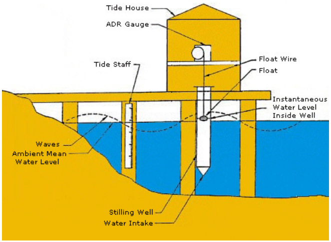


Figure: Old style tide gauge station schematic. From NOAA.

- 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

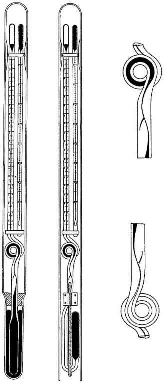


Figure: Schematic of unprotected and protected reversing thermometer. From *The Oceans Their Physics, Chemistry, and General Biology* by Sverdrup, Johnson & Fleming (1942).

- measures **temperature**
- when reversed, the mercury can no longer fill the thermometer

  $\rightarrow$ marks temperature at depth
- unprotected one to measure T
- protected one to measure θ

  $\rightarrow$ some pressurised casing

  $\rightarrow$ 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

  $\rightarrow$ to get water samples

  $\rightarrow$ use in conjuction with reverse thermometers to get T/θ and p
- chain a few of them up together with reverse thermometers

  $\rightarrow$ drop chain and let it settle

  $\rightarrow$ send messenger (a weight) down, trigger, reverse, send another weight, continue

  $\rightarrow$ pull chain up, repeat

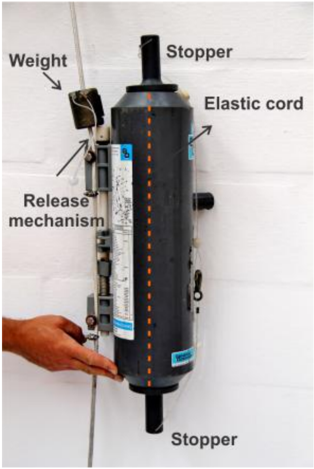


Figure: A picture of a Nansen/Niskin bottle. From Flanders Marine Institute (VLIZ).

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?

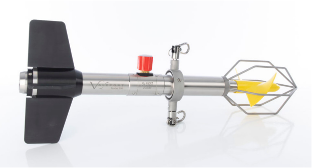


Figure: A mechanical ocean current meter (top) and a anemometer (bottom). From `www.valeport.co.uk` (top) and Wikipedia (bottom).

eXpendable BathyThermographs (XBTs)

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

- XBTs snap when wire runs out
  $\rightarrow$ conventional BTs are recovered (!)
- some on sides of ships for calibrating sonar
  $\rightarrow$ 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

  $\rightarrow$ conductivity to get S

  $\rightarrow$ temperature for T

  $\rightarrow$ it really measures p to get depth

- normally in a rosette

  $\rightarrow$ Nansen bottles to take water samples

  $\rightarrow$ 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
  $\rightarrow$ can do water sampling
  $\rightarrow$ 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

  $\rightarrow$ can control where it is

  $\rightarrow$ specialist equipment (e.g. winches, labs etc.)

  $\rightarrow$ important for some urgent water sampling etc.

- dedicated cruises expensive!

  $\rightarrow \geq \$30,000\ \text{day}^{-1}$ just on ship time!

  $\rightarrow$ salary, equipment, consumables...

Ships

- 'ships of opportunity'
  $\rightarrow$ volunteer merchant / fishing ships
  $\rightarrow$ cheaper but less control
  $\rightarrow$ limited things to do (e.g. XBTs)
  $\rightarrow$ 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 shipping ships" in. Image from Wikipedia, user Kees Torn.

Moorings

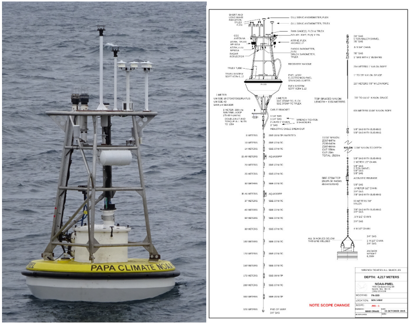


Figure: Station Papa (left) and schematic (right) in 2015; see also Lec. 5. From PMEL NOAA.

- doesn't go anywhere, but longer term
- usually need exposure to atmosphere for communication

  $\rightarrow$ 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

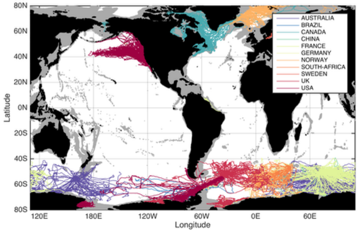


Figure: Seal with tag (top) and map of tracks (bottom). From Fabien Rouqet (top) and MEOP website `http://www.meop.net/` (bottom)

Autonomous Underwater Vehicles (AUVs)

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

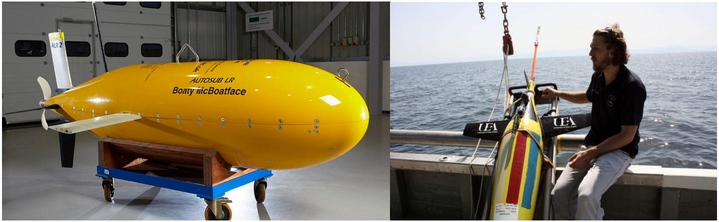


Figure: Boaty McBoatface, a Autosub LR (left) and a Kongsberg sea glider with Bastien Queste (now at Gothenburg) for scale (right). From UK National Oceanography Center (left) and Sergey Piontkovksi (right).

e.g. seaglider schematic

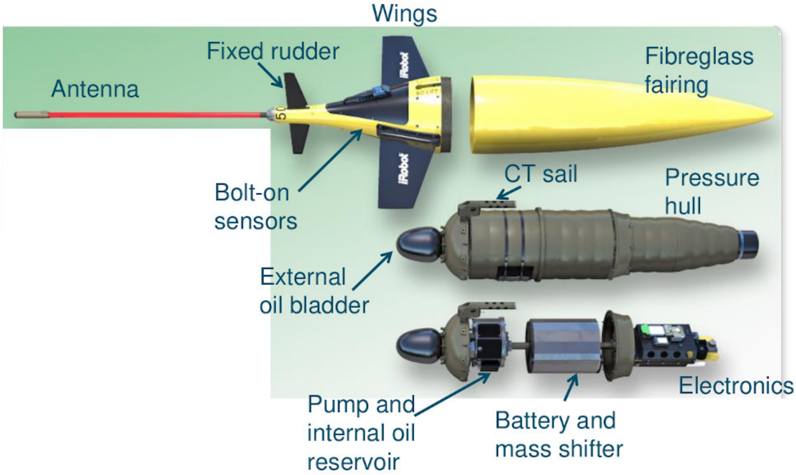


Figure: Components of a seaglider. Slide from 2018 ATSC winter school on gliders at University of East Anglia, UK. The mass remains constant but the volume (and thus density) is controlled by pumping oil into/out of the external bladder.

RAPID (AMOC)

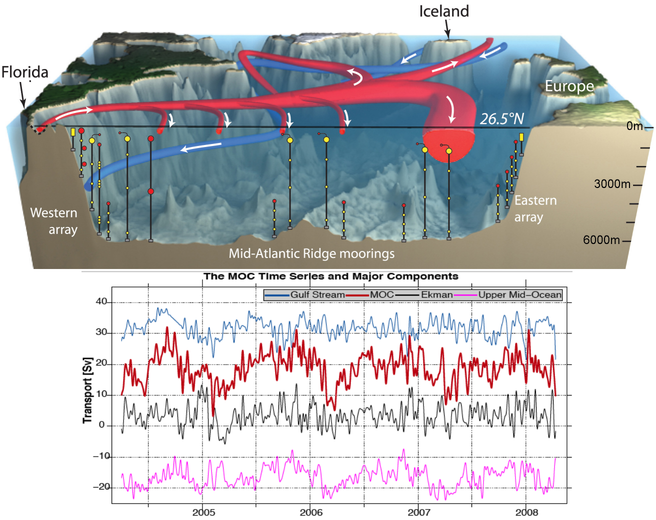


Figure: Schematic of the RAPID array at 26.5° N (top) and time series from the observed data (bottom). From `rapid.ac.uk`

O-SNAP (AMOC and watermass transformation)

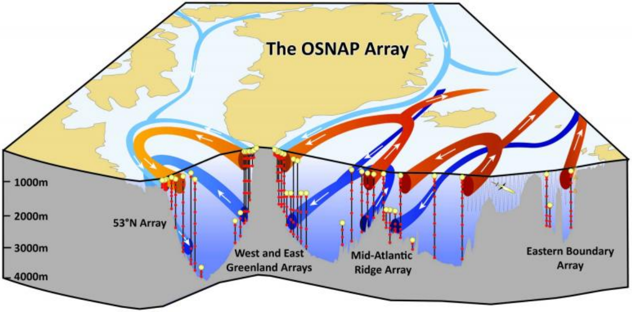


Figure: Schematic of the O-SNAP array in the North Atlantic subpolar gyre. From `www.ukosnap.org`

GO-SHIP ('gold standard' global)

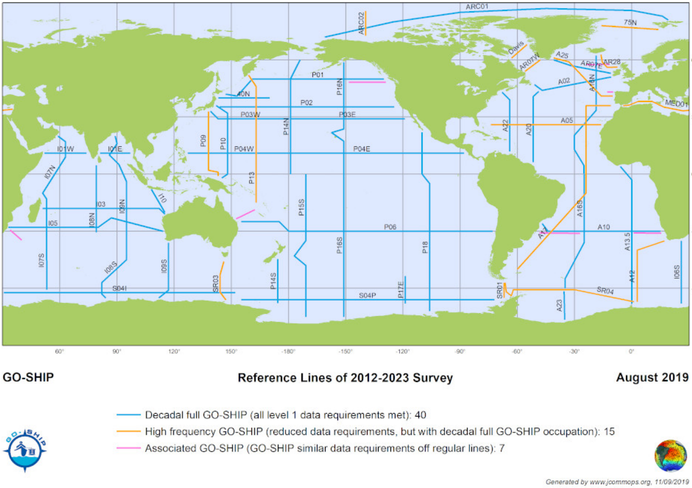


Figure: Reference sections as of 2019. From `www.go-ship.org`

Argo (global)

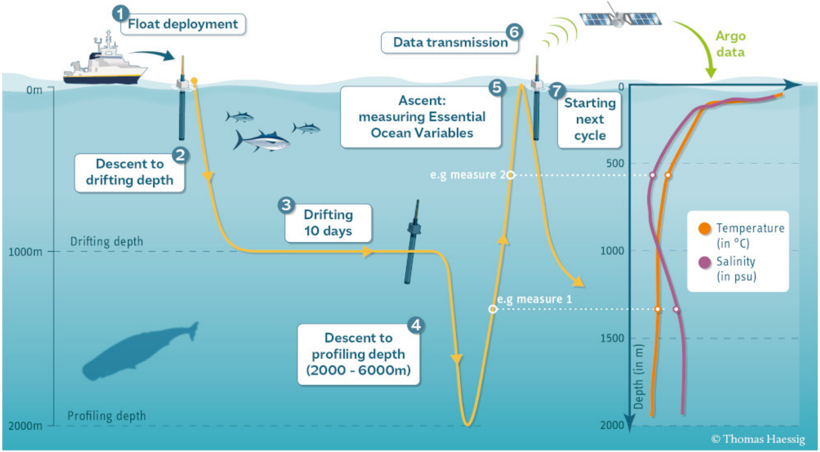


Figure: Argo float cycle schematic. From `argo.ucsd.edu`

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

Argo (global)

Figure: Argo worldwide locations over time. From `argo.ucsd.edu`.

Argo (global)

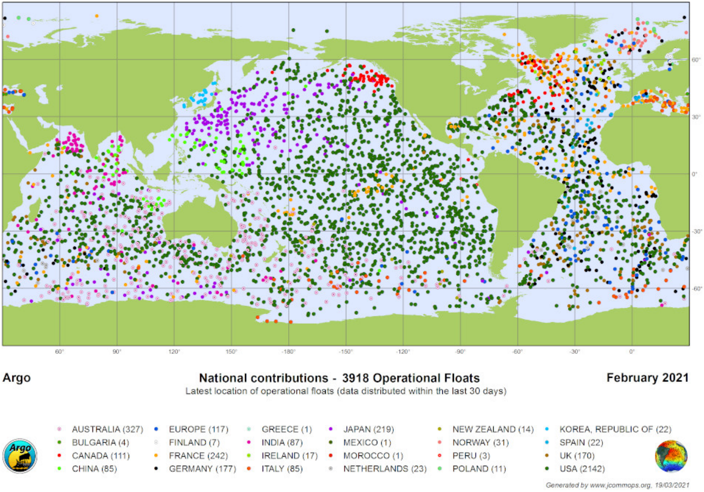


Figure: Argo locations as of Feb 2021. Note the dots are enhanced in size, so coverage is not as dense as it seems. From `argo.ucsd.edu`

Summary

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

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(but not the focus here; see OCES 3301)