Boring but important disclaimers:

- If you are not getting this from the GitHub repository or the associated Canvas page (e.g. CourseHero, Chegg etc.), you are probably getting the substandard version of these slides Don't pay money for those, because you can get the most updated version for free at

  `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.
- As said on the repository, I have tried to honestly use content that is self made, open source or explicitly open for fair use, and citations should be there. If however you are the copyright holder and you want the material taken down, please flag up the issue accordingly and I will happily try and swap out the relevant material.

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?

  → 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.)

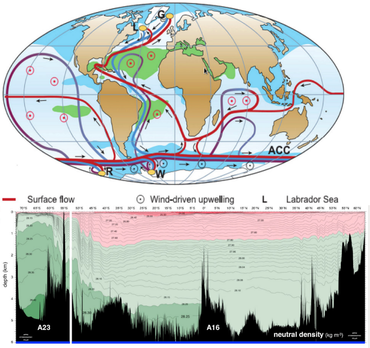
- sample programs: RAPID, O-SNAP, GO-SHIP, Argo

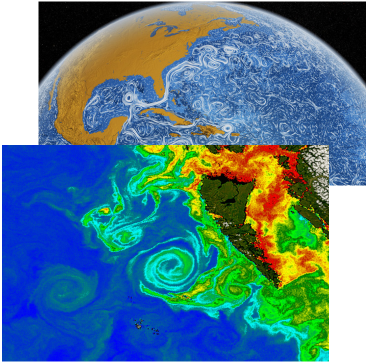
Key terms: in-situ measurements, CTDs, marine mammals, AUVs, Argo

Recap: physical oceanography (Lec. 1)

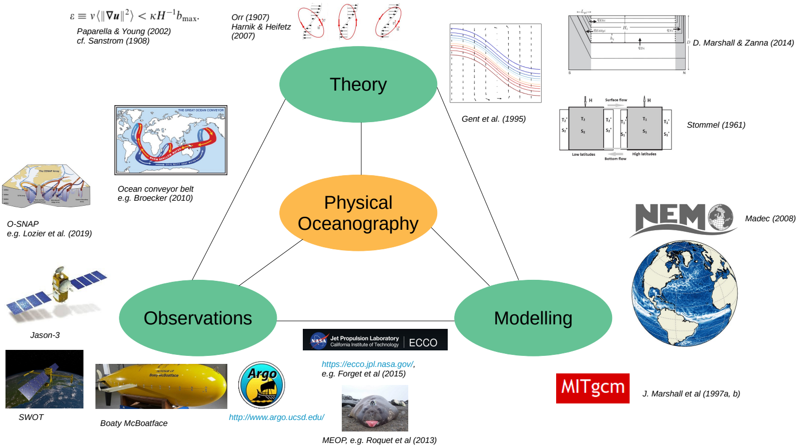
Study of physical features and processes of the ocean

- **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)

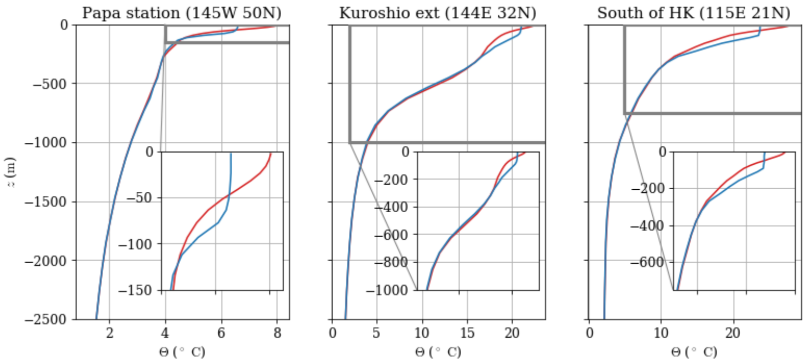


Figure: Vertical variation of Θ at some designated locations, based on WOA13 data. Red and blue line denote summer and winter climatology. See `plot_WOA13_sample.ipynb`

How did we get this...?

Recap: geoid (Lec. 7, 18)

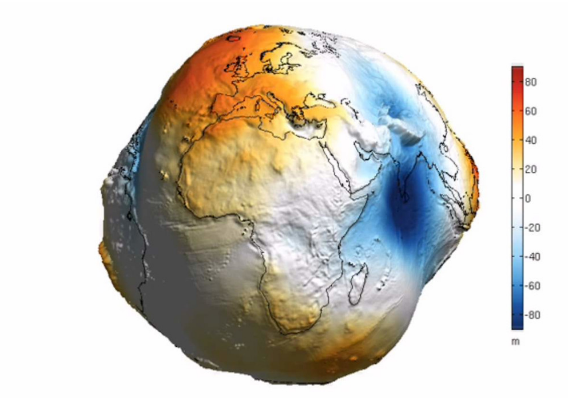


Figure: The "lumpy potato" Earth, variations in the geoid height magnified by several orders of magnitude to highlight difference. From Earth Gravitational Model 2008.

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

Recap: SSH (Lec. 7, 8)

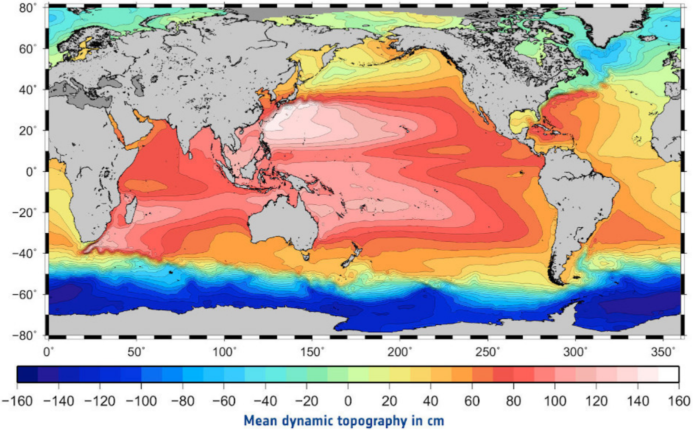


Figure: Time-mean global SSH (also called mean dynamic topography), with time-mean currents drawn on (notice the orientation around high/low SSH regions). Modified from Rio *et al.* (2011), J. Geophys. Res: Oceans.

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

Recap: something related to SSH (Lec. 18)

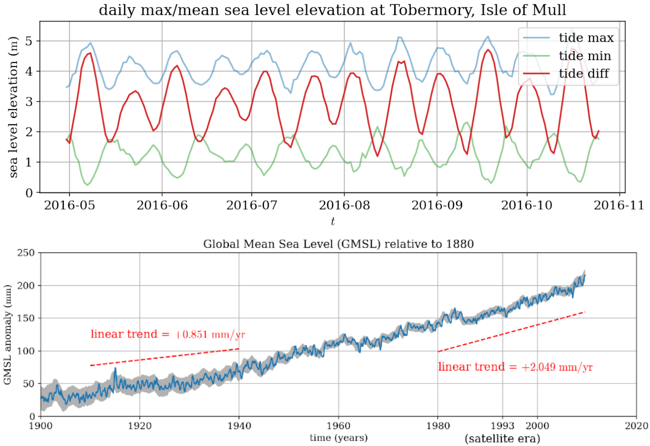


Figure: Daily maximum and minimum sea surface elevation (blue and green) and their difference (red) over a six month period (top), and global mean sea level over a hundred years or so (bottom). Data from BODC (top) and Church & White (2011) (bottom). See `tobermory_tides.ipynb` and `historical_sea_level_plot.ipynb`.

Or this...?

Data

1. direct data

   $\rightarrow$ systematic, targeted

   $\rightarrow$ generally (!) better control of quality + uncertainties

   $\rightarrow$ e.g. temperature, SSH, nutrient concentration...

2. proxy data

   $\rightarrow$ get at something by something else

   $\rightarrow$ generally (!) subject to errors and larger uncertainties

   $\rightarrow$ e.g. conductivity (to get salinity) [!?]

   $\rightarrow$ e.g. green-ness (to get chlorophyll-*a*)

   $\rightarrow$ 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

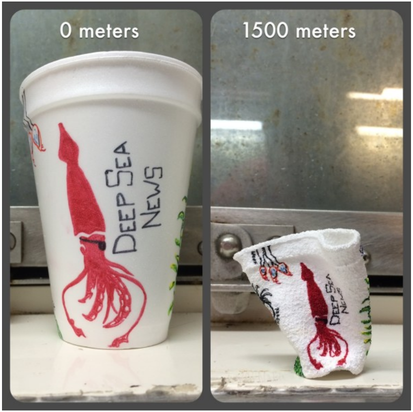


Figure: Styrofoam cup before and after being lowered to 1500 m depth in the ocean. Taken from `www.deepseanews.com`

- 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

  → 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**!

  $\rightarrow$ instrument, people, maintenance, development etc.

  $\rightarrow$ ship time by itself $\geq \$30,000\ \mathrm{day}^{-1}$
- isolated efforts previously

  $\rightarrow$ von Hulmboldt, Nansen, Prince Albert of Monaco...
- need coverage, i.e. money

  $\rightarrow$ government backed civilian organisations

  $\rightarrow$ 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)

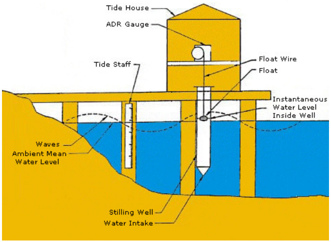


Figure: Old style tide gauge station schematic. From NOAA.

- 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

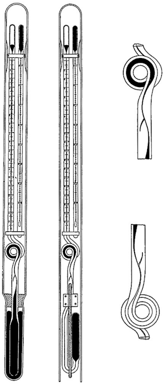


Figure: Schematic of unprotected and protected reversing thermometer. From *The Oceans Their Physics, Chemistry, and General Biology* by Sverdrup, Johnson & Fleming (1942).

- 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

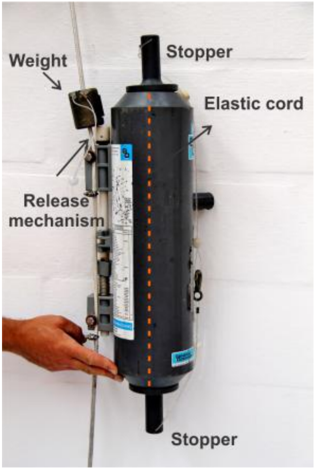


Figure: A picture of a Nansen/Niskin bottle. From Flanders Marine Institute (VLIZ).

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?

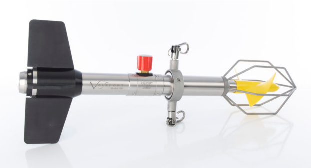


Figure: A mechanical ocean current meter (top) and a anemometer (bottom). From www.valeport.co.uk (top) and Wikipedia (bottom).

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

  → can control where it is

  → specialist equipment (e.g. winches, labs etc.)

  → important for some urgent water sampling etc.

- dedicated cruises expensive!

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

  → 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

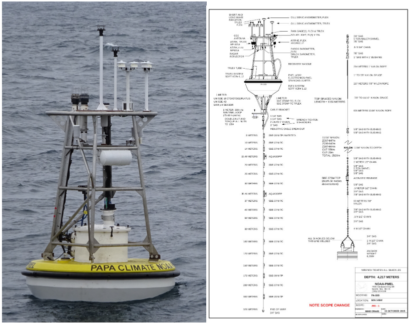


Figure: Station Papa (left) and schematic (right) in 2015; see also Lec. 5. From PMEL NOAA.

- 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

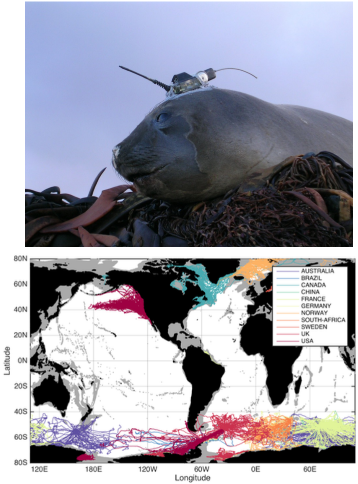


Figure: Seal with tag (top) and map of tracks (bottom). From Fabien Rouqet (top) and MEOP website `http://www.meop.net/` (bottom)

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

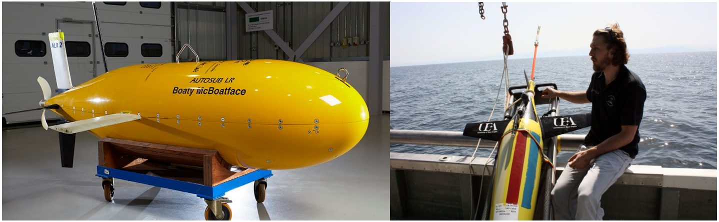


Figure: Boaty McBoatface, a Autosub LR (left) and a Kongsberg sea glider with Bastien Queste (now at Gothenburg) for scale (right). From UK National Oceanography Center (left) and Sergey Piontkovksi (right).

e.g. seaglider schematic

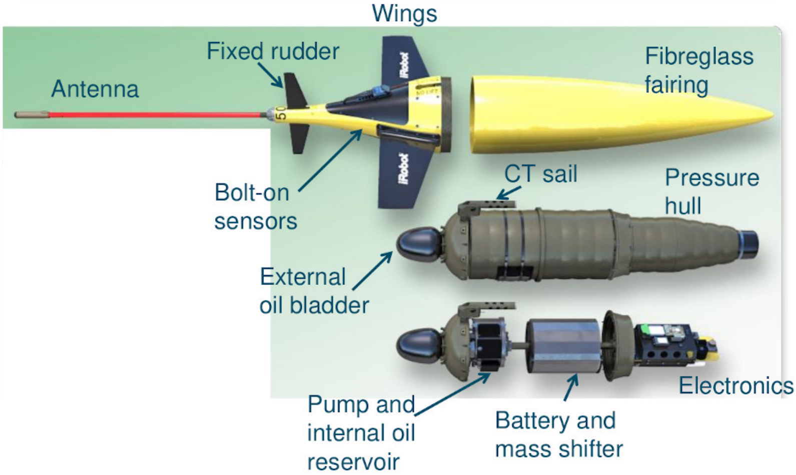


Figure: Components of a seaglider. Slide from 2018 ATSC winter school on gliders at University of East Anglia, UK. The mass remains constant but the volume (and thus density) is controlled by pumping oil into/out of the external bladder.

RAPID (AMOC)

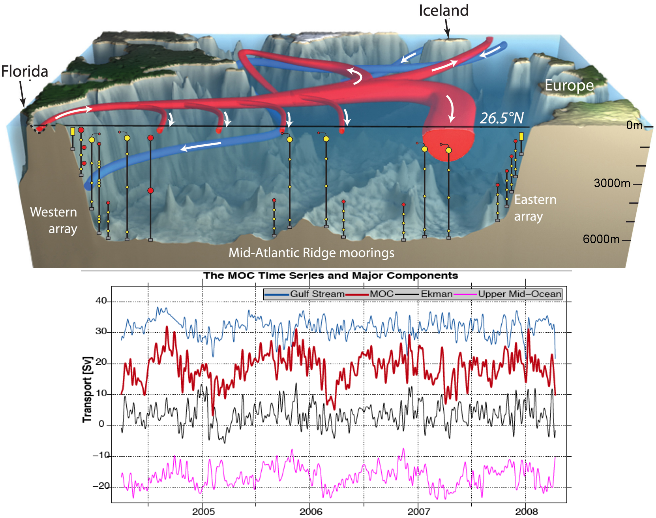


Figure: Schematic of the RAPID array at 26.5°N (top) and time series from the observed data (bottom). From `rapid.ac.uk`

O-SNAP (AMOC and watermass transformation)

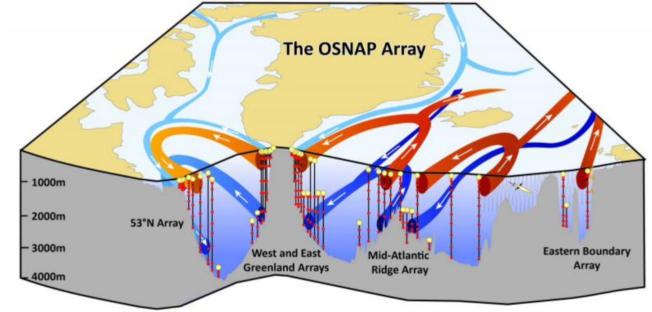


Figure: Schematic of the O-SNAP array in the North Atlantic subpolar gyre. From `www.ukosnap.org`

GO-SHIP ('gold standard' global)

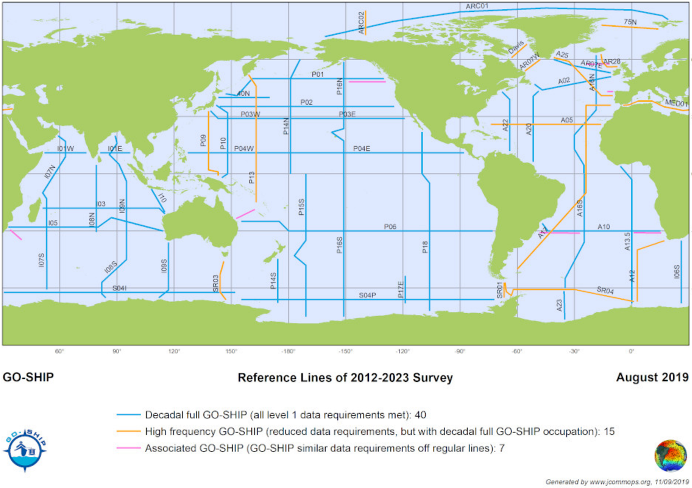


Figure: Reference sections as of 2019. From `www.go-ship.org`

Argo (global)

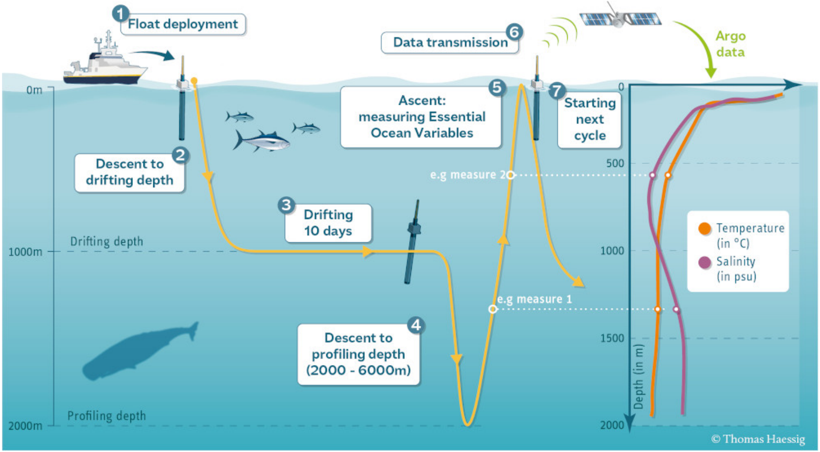


Figure: Argo float cycle schematic. From `argo.ucsd.edu`

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

Argo (global)

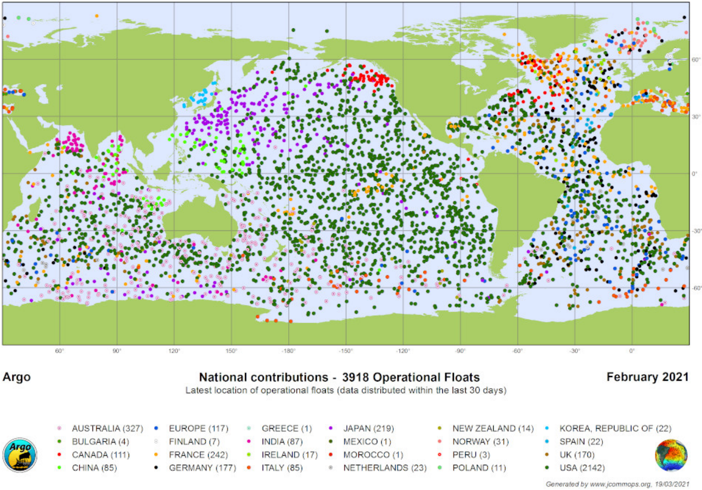


Figure: Argo locations as of Feb 2021. Note the dots are enhanced in size, so coverage is not as dense as it seems. From `argo.ucsd.edu`

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.

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.

- next lecture: remote sensing, applications and getting data

  $\rightarrow$ acoustics, satellites

  $\rightarrow$ some science applications (e.g. inference of geostrophic flow, data assimilation)

  $\rightarrow$ (raw and/or processed) data acquisition

Summary

- overview of physical oceanography + data

  → need for observations
- focusing on equipment to do in-situ measurements

  → tide gauges, CTDs, ships, floats etc.

- next lecture: remote sensing, applications and getting data

  → acoustics, satellites

  → some science applications (e.g. inference of geostrophic flow, data assimilation)

  → (raw and/or processed) data acquisition

data analysing + uncertainty quantification important

(but not the focus here; see OCES 3301)