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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.
- ▶ 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 20: Observation 2 (remote)

Outline

- ▶ remote sensing: acoustics and satellites
 - sonar, **doppler effect**, ADCPs
 - TOPEX/Poseidon, JASON, QuikSCAT, GRACE, Sentinel...
- ▶ example applications
 - geostrophic currents from SSH (recall Lec. 8, 9, 13)
 - data assimilation + **reanalyses**
 - **acoustic tomography**
- ▶ datasets and repositories

Key terms: remote sensing, satellites, reanalyses

Recap: geoid (Lec. 7, 18)

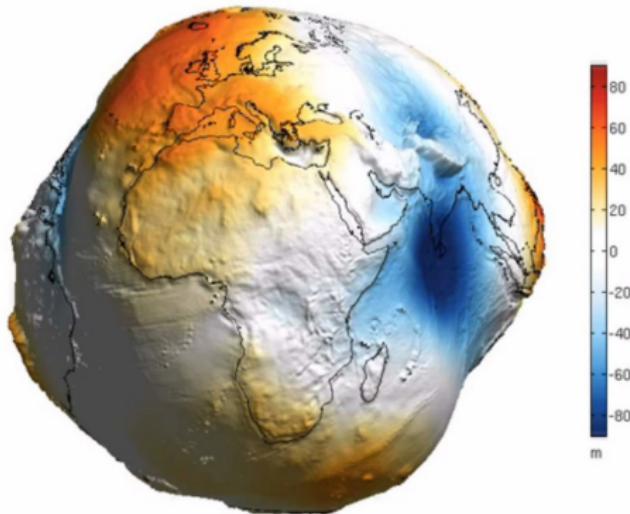


Figure: The “lumpy potato” Earth, variations in the geoid height magnified by several orders of magnitude to highlight difference. From Earth Gravitational Model 2008.

How do we get this...?

Recap: SSH (Lec. 7, 8)

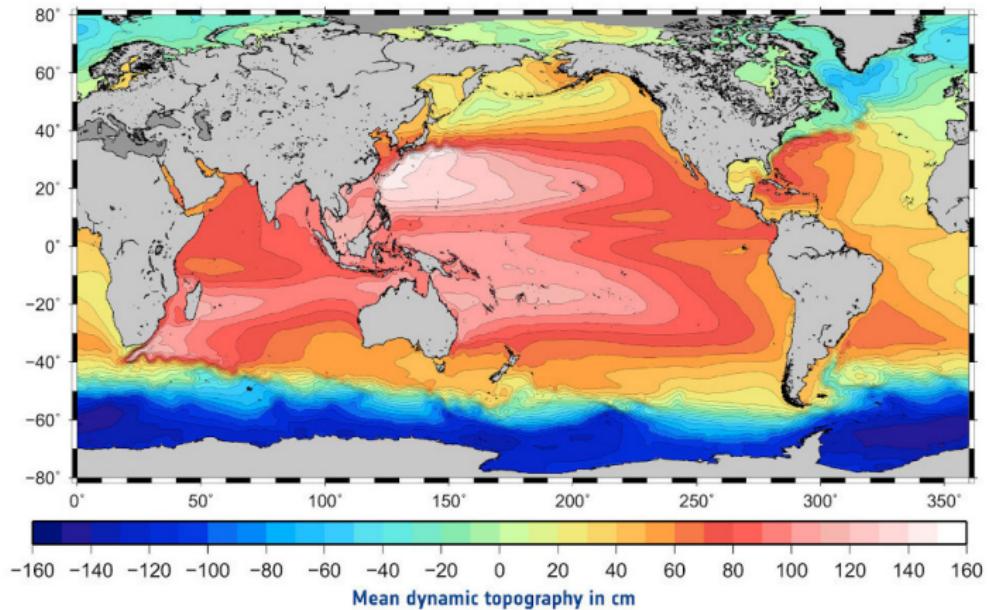


Figure: Time-mean global SSH (also called mean dynamic topography), with time-mean currents drawn on (notice the orientation around high/low SSH regions). Modified from Rio *et al.* (2011), J. Geophys. Res.: Oceans.

Or this...?

Remote sensing

- ▶ **in-situ** observation is sampling of location at the location
- ▶ **remote sensing** is observing from somewhere else
 - relies on reflected/emitted signals

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waves!!! (Lec 15)

- ▶ some sort of detector to 'sense' perturbations
→ sound (**acoustics**), electromagnetic (EM) radiation (cf. Lec. 5)

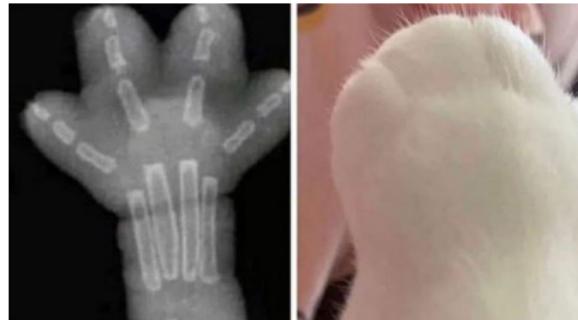


Figure: Probably a kitten paw X-ray? (Bones may appear detached in very young animals in X-rays; see veteriankey.com.) Image taken from cheezburger.com, source Twitter account appears suspended.

Recap: EM spectrum (see also Lec. 5)

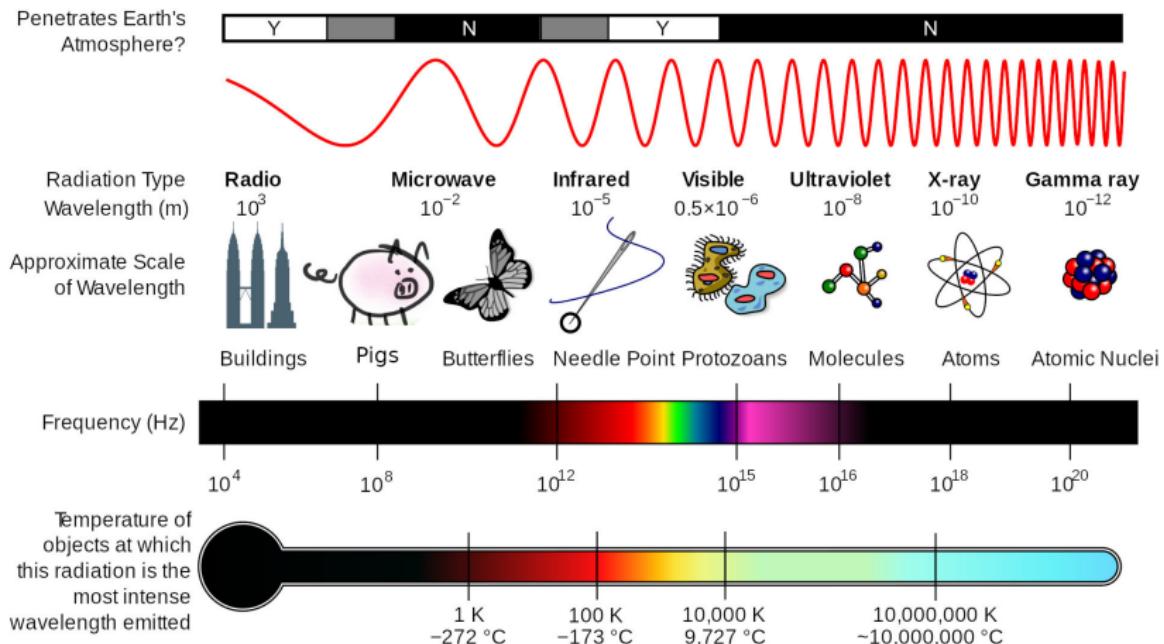


Figure: The electromagnetic spectrum by wavelength and frequency. Image from Wikipedia, adapted from an image from NASA.

Remote sensing

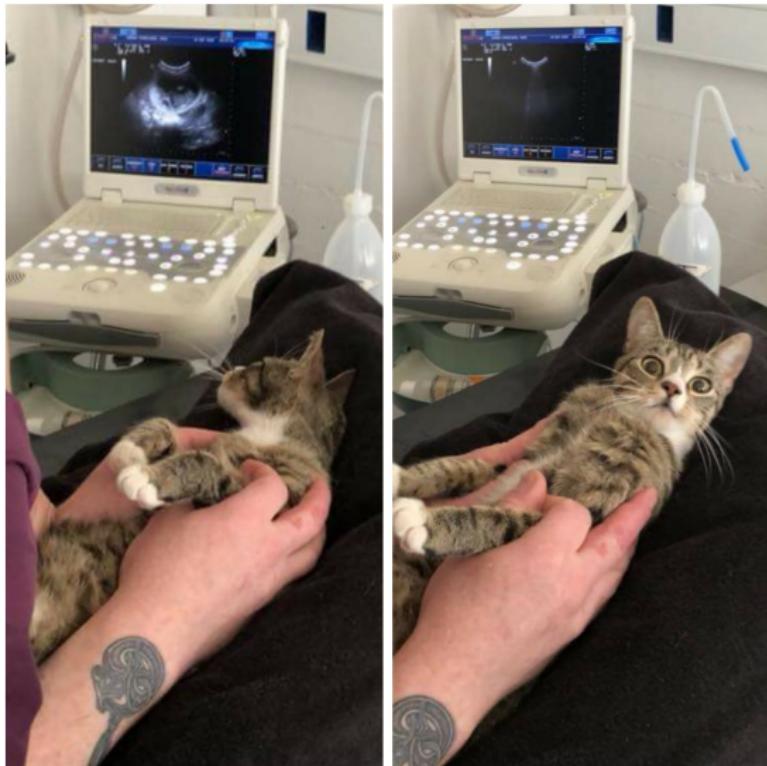


Figure: Ulla shocked (?) at finding out she is pregnant from the ultrasound. From Dyrenes Venner Greenland's facebook page.

Recall: wave propagation (Lec. 15)

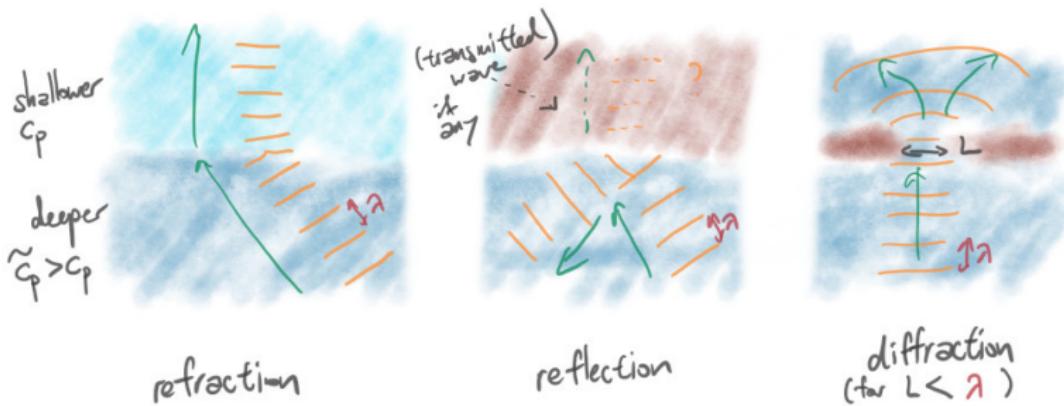


Figure: Schematic of **refraction**, **reflection** (and **transmission**), and **diffraction**, nominally using **monochromatic** (i.e. one choice of k) surface gravity wave as an example. The orange lines are phase lines (e.g. think wave crests).

- ▶ propagation properties depends on
→ medium + type of wave (e.g. sound vs. EM)

Acoustics

- ▶ recall that ocean is **opaque**
 - EM waves of limited use in ocean, but **sound waves** ok?
- ▶ e.g. **SOund NAVigation and Ranging**
 - bats + dolphins, ultrasound example above
 - navigation, mapping the sea floor, etc.
 - choice of receivers?
- ▶ essentially application of $U = L/T$
 - U determined by wave type and medium, T you measure, get L out of it (devil is in the details though...)

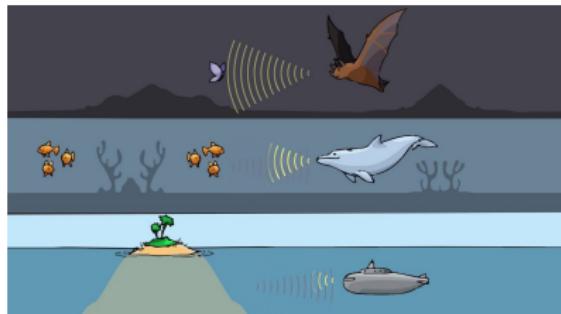


Figure: Schematic of Sonar. Image from the Smithsonian National Museum of Natural History.

What if the target moves?

- Doppler shifting, i.e. change in frequency + wavelength
→ e.g. ambulance pitch changing relative to pedestrian



Figure: Schematic of Doppler shifting. Red/blue shift (decrease/increase in frequency) if target is moving away/towards observer. Principles apply generically for waves (e.g. similar principles are used to detect universe expansion).

Acoustic Doppler Current Profiler (ADCP)

- ▶ (better) alternative to current meters
 - fewer moving parts = good thing usually!
 - still need to control biofouling
- ▶ dependent on things in water to rebound from
 - not as good if water quality is good (!)

- ▶ high freq = more precise
 - sample smaller scales
- ▶ low freq = travel further
 - less scattering etc.
- ▶ multibeams to sample velocity components



Figure: An ADCP mounted on a frame. Image from Wikipedia, user DopplerMusic.

Satellites

Satellite = object in space that orbits a bigger object

- ▶ the moon a **natural** satellite of the Earth
 - interested here in **artificial** satellites for observing
- ▶ principles similar: shoot some stuff out, see what reflects
 - use EM waves here (atmosphere is only a bit opaque)
 - much better horizontal coverage, limited somewhat to **surface**

the devil is in the details that we are going to skip here

Satellite orbits

- ▶ Low Earth Orbit (LEO)
 - altitude about 1/3 of the Earth's radius (≈ 2000 km)
 - orbital period of less than 128 minutes (how many orbits a day then?)
 - ✓ high bandwidth, less latency/lag
 - ✗ restricted 'vision', space debris?
- ▶ others above this (MEO, geostationary, HEO etc.)
 - e.g. Global Positioning System (GPS)
 - more latency, wider 'vision' etc.



Figure: To scale diagram of sample orbital ranges of Earth. Counting from the upper limit of the MEO, the moon is about ten lots of MEO away to the right of the diagram (not shown). Image taken from Wikipedia, user Rrakanishu.

Satellites: TOPEX/Poseidon

- ▶ one of the first **satellite altimeters**
→ from 1992 to 2006
- ▶ measure SSH (relative to ellipsoid)
→ want it relative to the **geoid?** (see GRACE later)

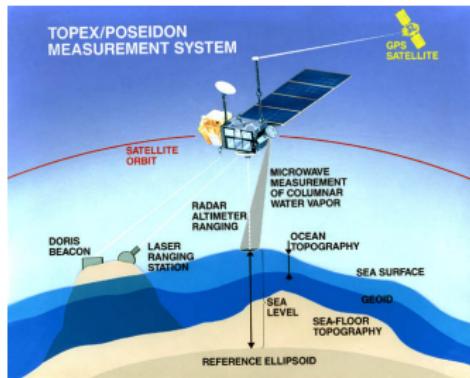


Figure: Brief schematic of TOPEX/Poseidon.

- ▶ measure ocean topography by rebounds
→ again, $U = L/T$ really, but need careful calibrating to get it accurate enough
- ▶ measure (on global scales) sea level, tides, large-scale waves, etc.

Satellites: Jason



Figure: The Jason series of satellite altimeters. Image from the European Space Agency.

- ▶ successor to TOPEX/Poseidon
→ three of them
- ▶ measures SSH
- ▶ from Jason and the Argonauts in Greek mythology

- ▶ uses multiple navigation systems to determine position
 - GPS, DORIS, LRA
 - needed for accuracy, $O(1 \text{ cm})$, but flying $O(1000 \text{ km})$ above Earth's surface!

Satellites: GRACE

- ▶ measure anomalies in g from changes in **mass**
 - e.g. ice loss
- ▶ two of them chasing the other in low-ish orbit
 - 'Tom' and 'Jerry'
 - about 220 km apart, 500 km above Earth in polar orbit
- ▶ measure mutual distance by Doppler shifts + geolocation (e.g. GPS, and others)
 - advertised accuracy of 10 **μm** (1/10 of width of human hair!)

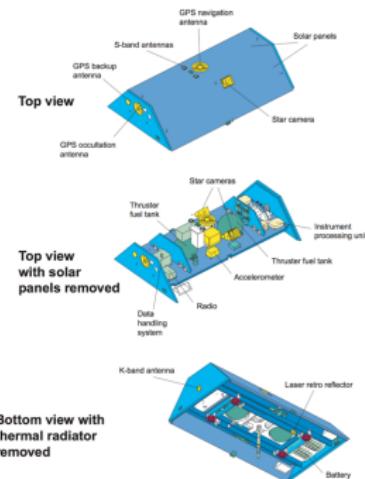


Figure: GRACE schematics. Modified image originally taken from NASA.

Satellites: GRACE brief rationale

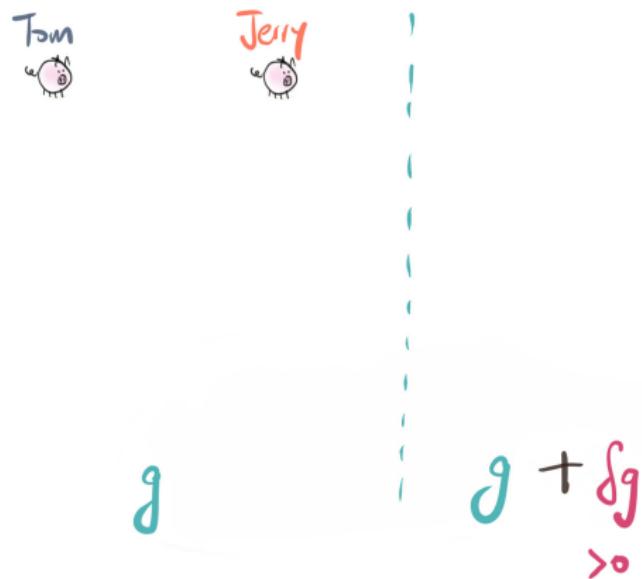


Figure: Rough schematic of idea behind GRACE. Satellites travelling through gravitational field anomalies accelerate and decelerate, and one can get the relative changes in the distances via Doppler shifts between the satellites. Together with pinpointing the location of the satellite relative to Earth, changes in the gravitational attraction can be inferred accordingly.

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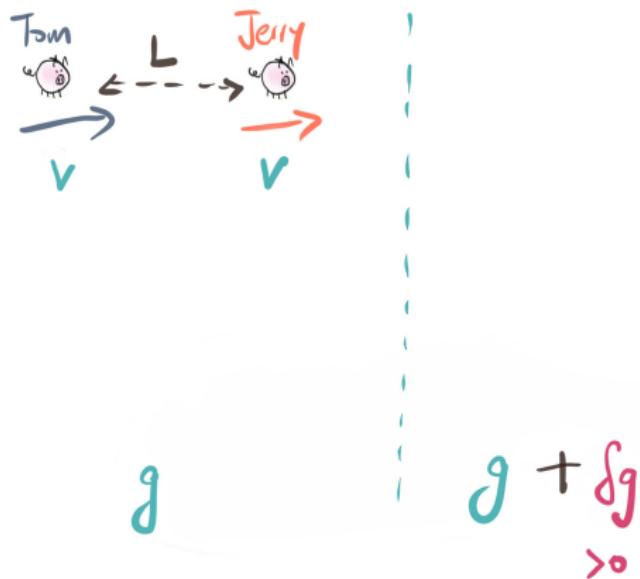


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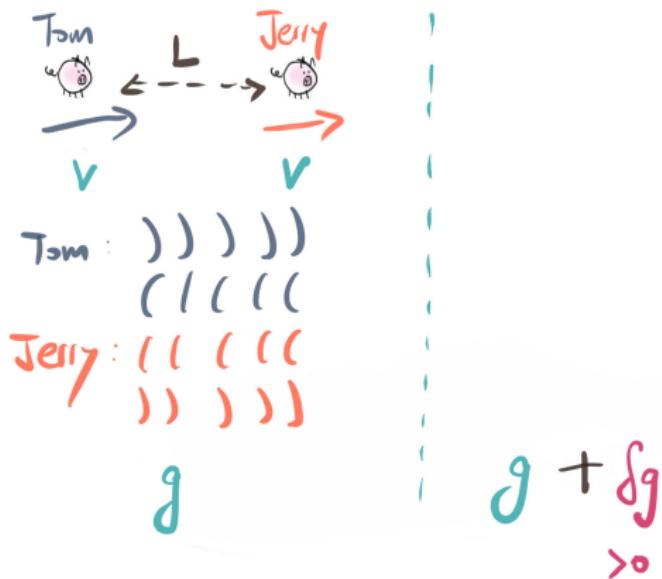


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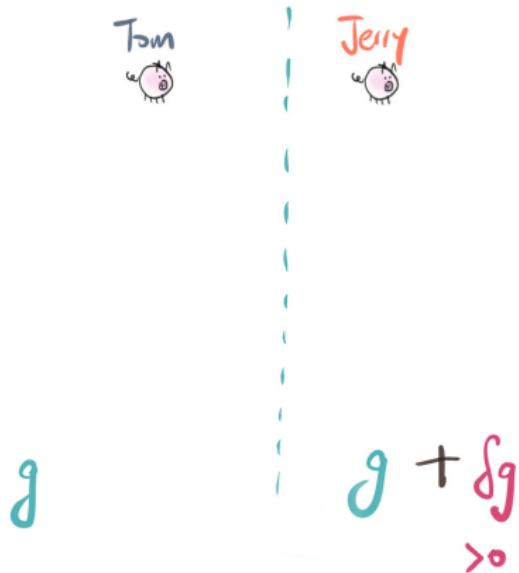


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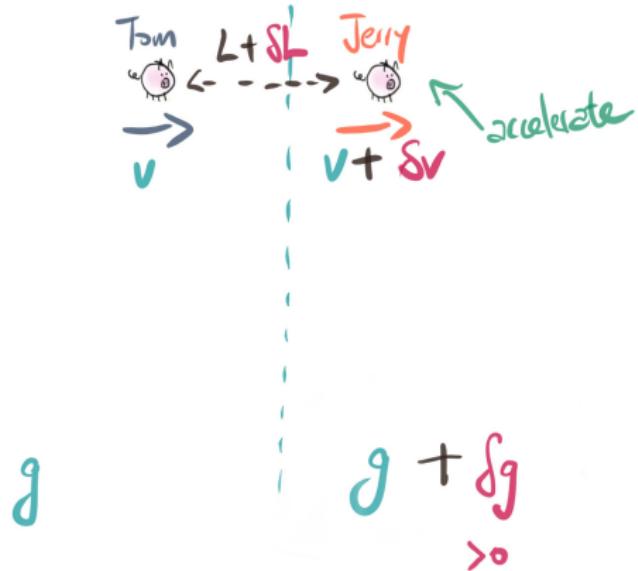


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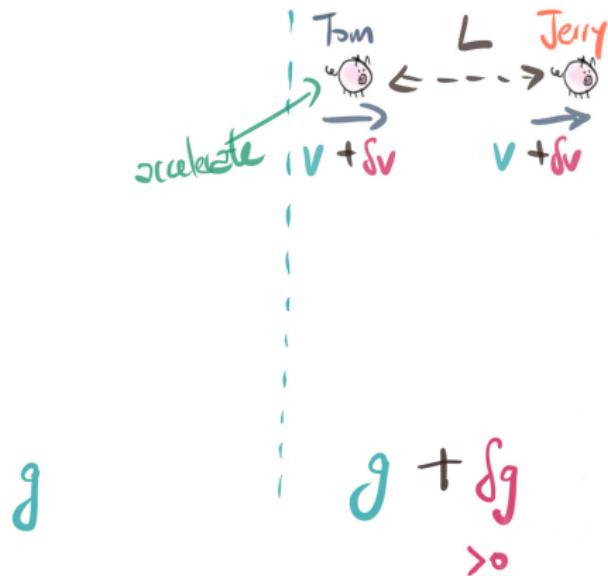


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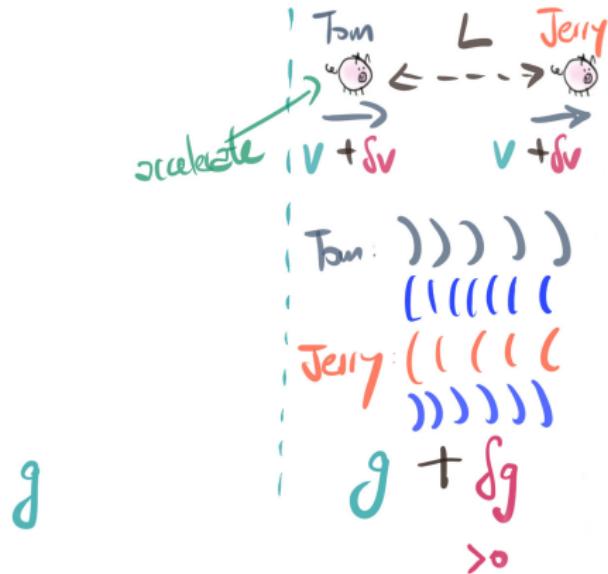


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Satellites: QuikSCAT

- ▶ measure scattering of emitted microwaves to get **wind speed** and **direction**
 - scattering depends on surface roughness
 - roughness depends on **surface waves** (cf. Lec 16)
 - waves depends on wind profile
- ▶ important for atmosphere forecasting (initialise state) + ocean forcing

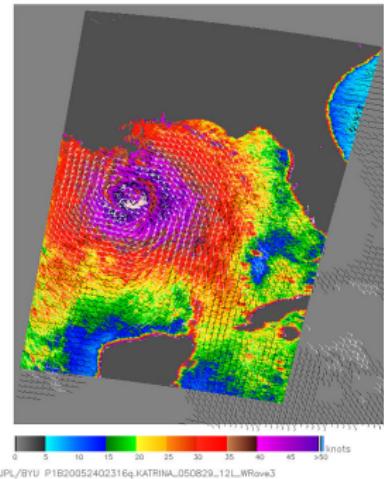


Figure: QuikSCAT image of Hurricane Katrina in 2005. Image from NASA / JPL.

Satellites: Sentinel

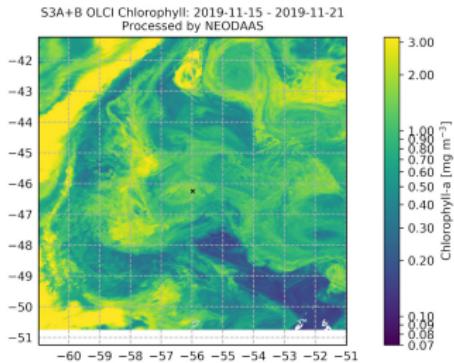


Figure: Inferred Chlorophyll-*a* from Sentinel 3a and 3b OLCI data. Image from UK NERC NEODAAS.

- ▶ run by the EU Copernicus programme
- ▶ various bands in the visible to infra-red spectrum
 - e.g. infra-red to infer for **SST**
 - e.g. green to infer for **chlorophyll-*a***
- ▶ various resolutions
- ▶ whole load of these, each of them do 'look' at different things

Sample usage: geostrophic currents from SSH

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- ▶ thermal wind ($\nabla \rho \sim \partial \mathbf{u}_g / \partial z$) to get some sort of depth profile
 - **in-situ measurements** to get T , S and p
 - feed into EOS to get a relevant density
 - need to assume a value of \mathbf{u}_g at some z

Sample usage: geostrophic currents from SSH

- e.g. eddy kinetic energy (EKE) (cf. $KE = 0.5mv^2$)

$$\frac{1}{2}\rho \overline{\mathbf{u}'_g \mathbf{u}'_g}, \quad \mathbf{u}_g = \overline{\mathbf{u}_g} + \mathbf{u}'_g$$

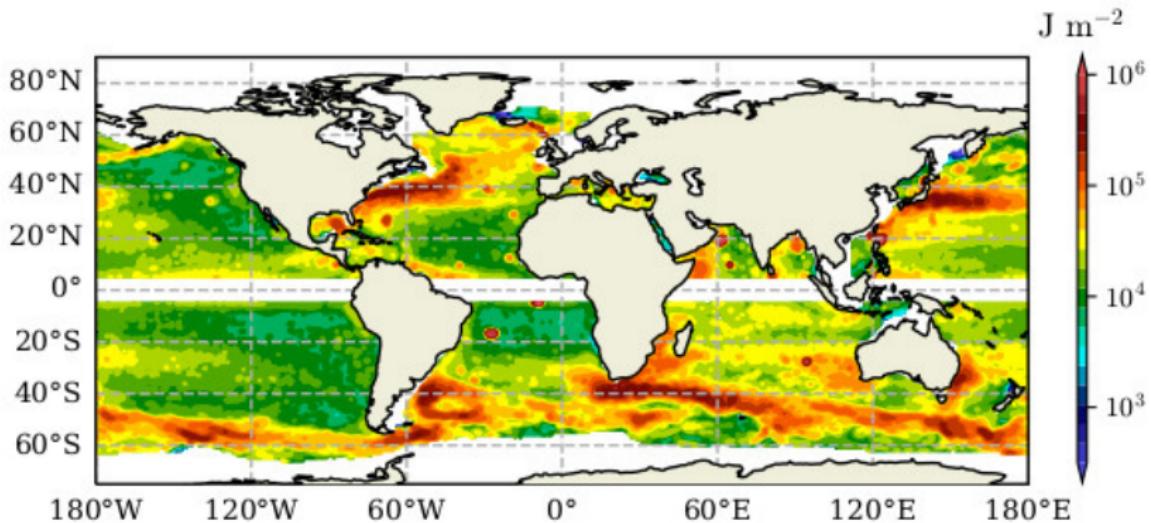


Figure: Depth-integrated eddy kinetic energy of geostrophic flow from satellite altimetry, extended down in depth using the first baroclinic mode. Data product provided by Xiaoming Zhai (University of East Anglia).

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constrain the numerical model with observational data

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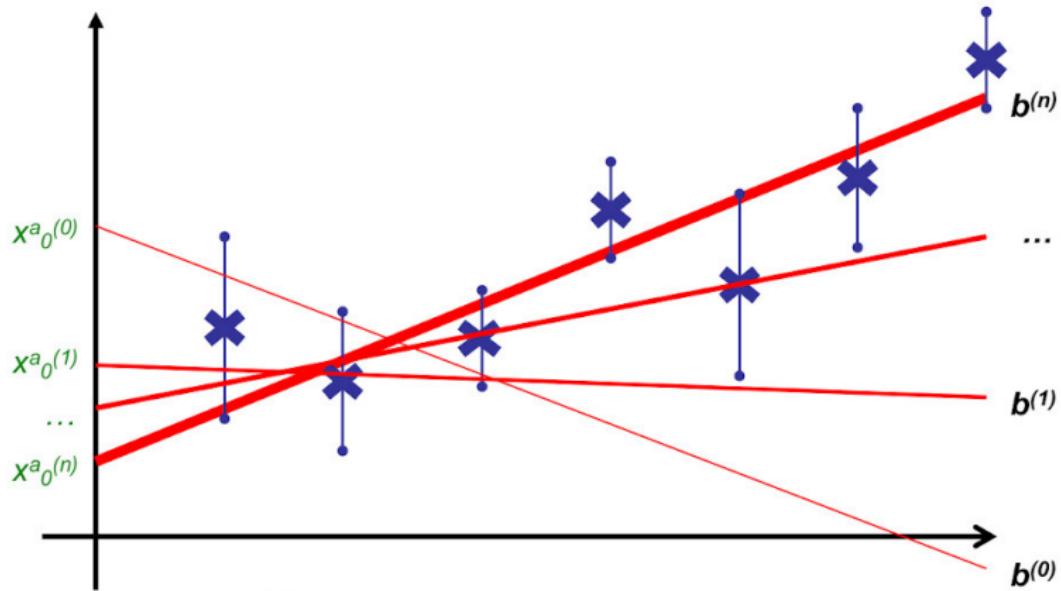


Figure: Illustration of an adjoint model adjustment, for a linear model $y = ax + b$. Adjust the parameter a and the starting value $y(x = 0) = b$ until the line is “close” to the data points (whatever “close” means). You may know this better as [linear regression](#). Figure from Patrick Heimbach (University of Texas).

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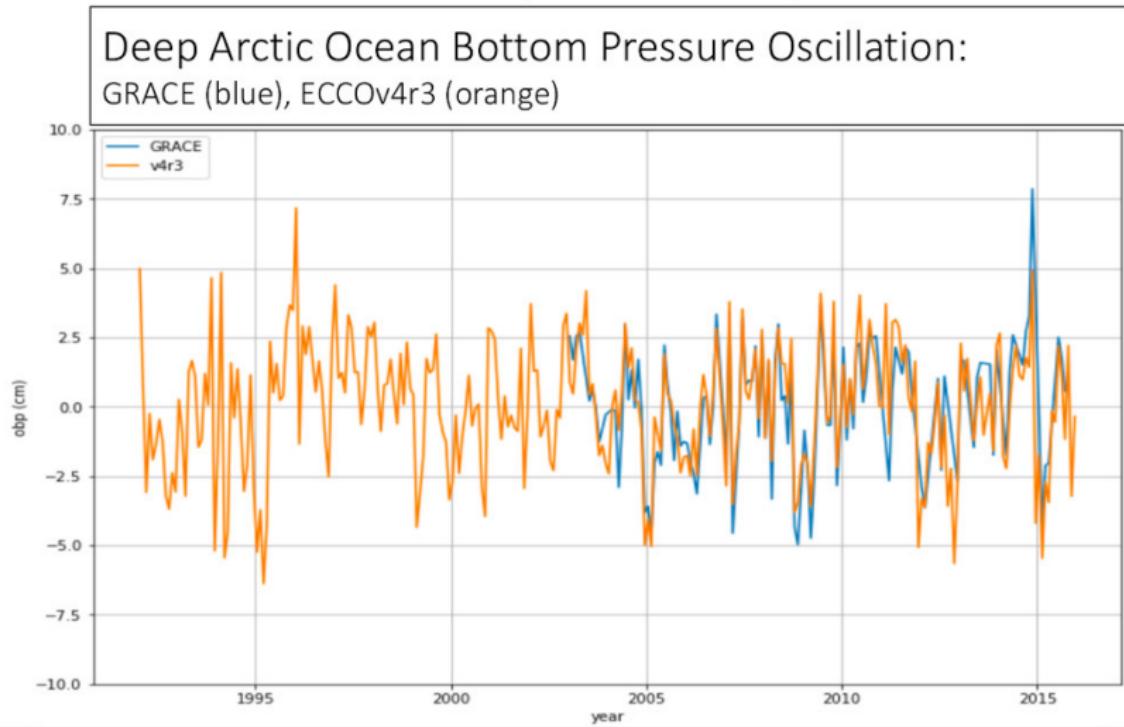


Figure: Bottom pressure in the Arctic Ocean as measured by GRACE (blue) and from the ECCO v4r3 state estimate. Figure from Ian Fenty (NASA JPL).

Sample usage: sea level reanalysis (Lec. 18)

eye candy

Sample usage: sea level reanalysis (Lec. 18)

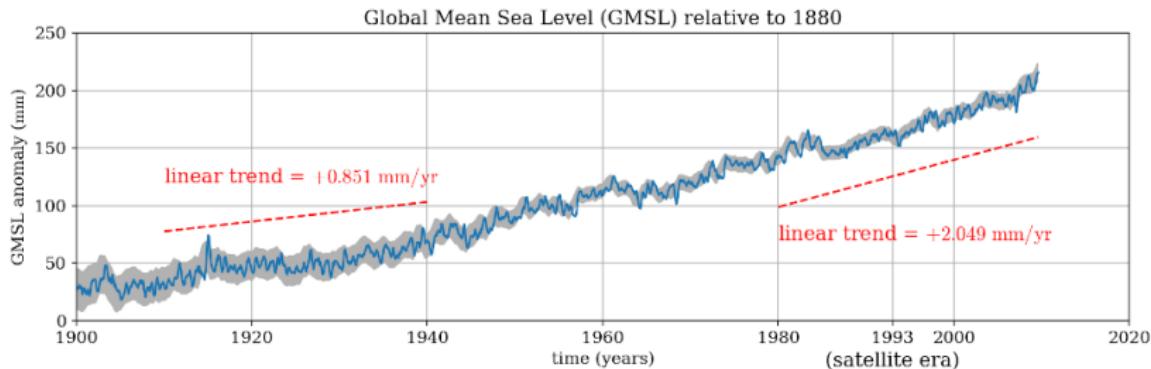


Figure: Global mean sea level over a hundred years or so. Data from Church & White (2011). See `tobermory_tides.ipynb` and `historical_sea_level.plot.ipynb`.

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- ▶ got heavily lobbied by animal rights group (see Wikipedia article),
but recent renewed interest (e.g. Wu *et al.*, 2020, *Science*)

Data acquisition + analysis

(more in OCES 3301)

- ▶ most commonly accessible are slightly processed data
 - time series, gridded data
 - e.g. SST, winds, g
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- ▶ skipping here completely on techniques in data analysis...

Data acquisition

NCEP: atmospheric data

 Physical Sciences Laboratory

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[Home](#) > [Gridded Climate Data](#) > NCEP-NCAR Reanalysis

On this page: [Temporal Coverage](#) | [Spatial Coverage](#) | [Levels](#) | [Update Schedule](#) | [Download/Plot Data](#) | [Analysis Tools](#)
[Restrictions](#) | [Details](#) | [Caveats](#) | [File Naming](#) | [Citation](#) | [References](#) | [Original Source](#) | [Contact](#)

NCEP/NCAR Reanalysis 1: Summary

We have transitioned the data files from netCDF 3 to netCDF-4-classic format on Monday Oct 20th, 2014.

Brief Description:

- NCEP/NCAR Reanalysis 1

Temporal Coverage:

- 4-times daily, daily and monthly values for 1948/01/01 to present
- Long term monthly means, derived from data for years 1981 - 2010

Spatial Coverage:

- Global Grids

Levels:

- 17 Pressure level and 28 sigma levels. N/A

Update Schedule:

- Daily

We have separated the data documentation into seven sections:

- Pressure level
- Surface
- Surface Fluxes
- Other Fluxes

Climate Datasets: By Category

- All
- Sub-daily
- Daily
- Monthly
- Surface
- Temperature
- SST
- Precipitation
- Land
- Ocean
- Multi-level
- Radiation
- Arctic
- Reanalysis
- Climate Indices
- Search Datasets 
- 20th Century Reanalysis
- Popular Datasets 

<https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html>

Data acquisition

NASA PO.DAAC: physical oceanography data

The screenshot shows the homepage of the NASA Physical Oceanography Distributed Active Archive Center (PO.DAAC). The top navigation bar includes links for HOME, FIND DATA, ACCESS DATA, RESOURCES, ABOUT, and HELP, along with a search bar and social media links. The main content area features four circular maps of the Earth showing various oceanographic data sets, such as sea surface temperature or salinity. Below these maps is a section titled "Data in Action: The 2020 Atlantic Hurricane Season: A Record Breaker", which includes a brief description of the record-breaking season. At the bottom, there is a "Science Disciplines" section and a "top" button.

NASA Jet Propulsion Laboratory California Institute of Technology

podaac
Physical Oceanography Distributed Active Archive Center

Follow Us

HOME FIND DATA ACCESS DATA RESOURCES ABOUT HELP Data Search

Data in Action: The 2020 Atlantic Hurricane Season: A Record Breaker

The 2020 Atlantic hurricane season set records, as the most active season as well as the most expensive in terms of property damage.

scroll for more

Science Disciplines

top

<https://podaac.jpl.nasa.gov/>

Data acquisition

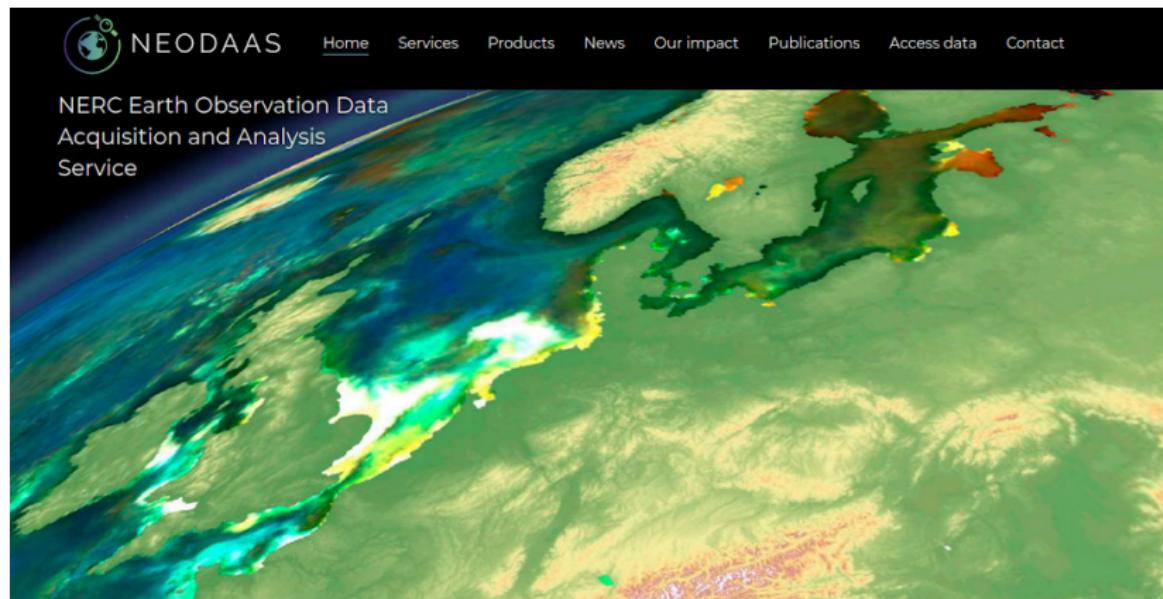
BODC: marine related data

The screenshot shows the homepage of the BODC website. At the top left is the BODC logo, which is a globe icon with blue and white patterns. To its right, the text reads "National Oceanography Centre" and "British Oceanographic Data Centre BODC". On the far right of the header are links for "Contact us", "Register", "Log in", and "Service status". Below the header is a navigation bar with links for "HOME", "SEARCH THE DATA", "SUBMIT YOUR DATA", "PROJECTS", "RESOURCES", "ABOUT", and a search icon. The main content area features a large, bold, white text overlay on a background image of turbulent blue ocean waves crashing against a rocky coastline. The text reads: "Marine data sharing and preservation, managed & operated by the National Oceanography Centre". At the bottom left of this area is a teal button with white text that says "Search our marine data" followed by a white arrow pointing right.

<https://www.bodc.ac.uk/>

Data acquisition

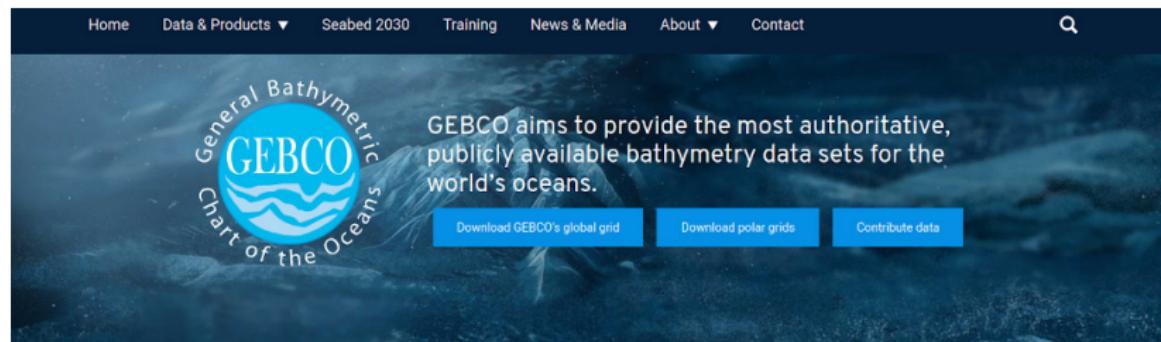
NERC NEODAAS: Earth observation data



<https://www.neodaas.ac.uk/Home>

Data acquisition

GEBCO: bathymetry and topography



The banner features the GEBCO logo on the left, which consists of a circular emblem with the text "General Bathymetric Chart of the Oceans" around the top and three wavy lines representing water inside. To the right of the logo, a text block reads: "GEBCO aims to provide the most authoritative, publicly available bathymetry data sets for the world's oceans." Below this text are three blue buttons with white text: "Download GEBCO's global grid", "Download polar grids", and "Contribute data".

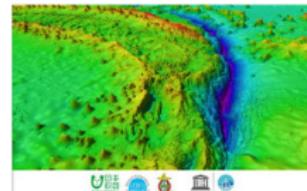
Gridded Bathymetry Data



Data & Products



Seabed 2030



<https://www.gebco.net/>

Summary

- ▶ highlighted a few (!) ideas, equipment and applications
 - Doppler shifts
 - how to use acoustic + EM waves to do remote sensing
 - applications, e.g. altimetry to get u_g

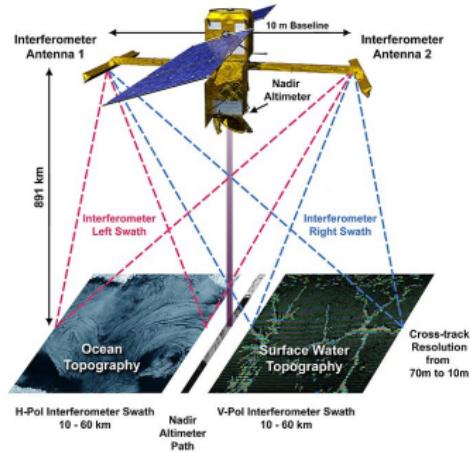


Figure: Schematic of SWOT. Image from NASA JPL.

quantitative principles in examples class (altimetry and u_g) + assignment 4 (GRACE)

The devil is in the details...

- ▶ how to do the data analysis? (OCES 3301)
 - methods, soft/hardware, presentation, management etc.
- ▶ uncertainty quantification
 - error bars
- ▶ attribution
 - data gives you correlation, how to get causation?

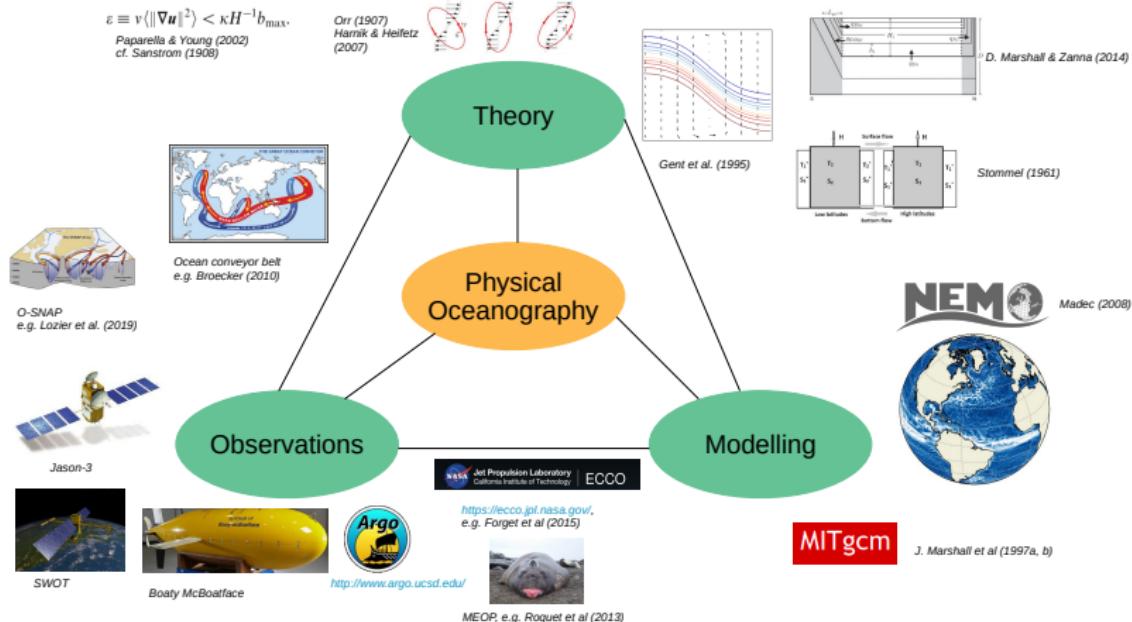
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- ▶ more quantitative theories? (OCES 3203)
 - OCES 2003 is descriptive + ideas + some terminology
 - scientific statements need quantification

What is physical oceanography (recall Lec 1)



understanding the ocean require
interdisciplinary + complementary approaches