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 1: "big picture"

Outline

- canvas, Zoom and admin things

- approach of the course
  $\rightarrow$ focus on qualifying things (e.g. via drawing pictures)
  $\rightarrow$ little bit of quantification (no more than multiplying some numbers together)

- what is physical oceanography + why should you care?
  $\rightarrow$ climate, biogeochemistry, ecology, engineering, trade, law, policy etc. (maybe even just curiosity?)

Ocean physics is not easy, but you need enough of it!!!

Key terms: physical oceanography, dynamics

Practicalities

Instructors:

- I Julian Mak (`jclmak@ust.hk`)
- TA Han Seul Lee (`hsleeai@connect.ust.hk`)
- TA Huaiyu Wei (`huaiyu.wei@connect.ust.hk`)

Course grade breakdown:

method	%
attendance	10
assignments	$4 \times 10 = 40$
exams (mid term + finals)	$2 \times 25 = 50$

Practicalities

Method of delivery:

- Zoom (meeting ID on Canvas) until further notice
  → **Tue and Thurs, 1:30pm to 3pm** (open from 1:15pm)
  → possible transition to mixed mode when policy changes
  → join meeting through Canvas ideally (for taking attendance reasons)
  → lectures will be recorded on the cloud and made available ASAP after lecture

- "office" hours **Wed, 2-3pm** (Zoom ID: 915 4492 8604)
  → extra office hours dependent on availability of TA and/or Instructor
  → ask questions on the Canvas course forum (TA mostly, occasionally Instructor)

Approach of course

What this course is:

- a descriptive intro to topics in physical oceanography

  $\rightarrow$ bias from me on topics to do with **dynamics** and large-scale circulation

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  $\rightarrow$ make some plausible assumption, roll with it and see where it leads to

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- focus on getting you to be able to start digesting/using the facts from books

Approach of course

What this course certainly is <u>not</u>:

- a computation based course on physical oceanography

  $\rightarrow$ **basic/overall** understanding, but devil is of course always in the details (go to OCES 3203 for the beginnings of that)

- ✓ e.g. **why** you might want to use potential over in-situ temperature (i.e. θ and not T) (see Lec 6)
- × e.g. **recall the formula for and calculate** potential temperature θ

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  (suck it up, learn the useful language to save the pain later on)

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- a complete course on physical oceanography

  → further directions throughout the course notes

Lecture format

Lectures do not follow any particular book:

1. Pickard & Emery, "*Descriptive physical oceanography*" 5th edn

   → I actually hate this book but may suit some (IMO it makes oceanography seem much harder than it needs to be)
2. Talley, "*Descriptive physical oceanography*" 6th edn

   → IMO what the above book should have been, but wasn't...
3. Knauss, "Introduction to physical oceanography", 2nd edn
4. Wunsch, "Modern observational physical oceanography"
5. Williams & Follows, "Ocean dynamics and the carbon cycle"

   → "harder" but really worth it IMO

You shouldn't <u>need</u> anything outside the lecture slides

- course notes link on Canvas (**continually updated**)

Syllabus

Part 1: Basics

L01 Big picture

L02 Terminology + oceans

L03 Seas, shelves, estuaries etc.

L04 Forces and equations of motion

L05 Sea water properties: temperature and salinity

L06 Sea water properties: some thermodynamics + beyond *in situ* variables

L07 Forces: pressure and gravity

L08 Forces: Coriolis

L09 Forces: Wind

L10 Forces: Viscosity and friction

- calculus revision in Lec 4
- fundamentally revolve the concepts of **buoyancy**, **hydrostatic balance**, **geostrophic balance**, and theme and variations thereof

Syllabus

Part 2: Dynamics

L11 Wind driven gyres: geostrophy and Sverdrup balance

L12 Wind driven gyres: western boundary currents and vorticity balance

L13 MOC: Southern Ocean and ACC

L14 MOC: global MOC + boundary currents

L15 Dynamics: intro to waves

L16 Dynamics: types of waves

L17 Dynamics: instabilities

L18 Dynamics: tides

L19 Observations: in-situ

L20 Observations: remote

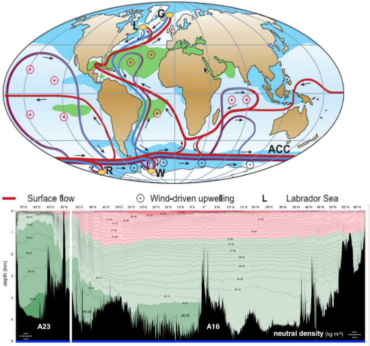
- wind drive gyres theory to demonstrate successes of “**make some assumptions, roll with it and see what you get**” principle

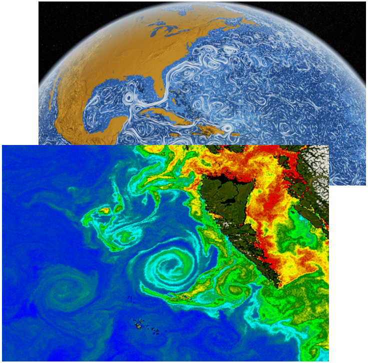
  → you learn from what it tells you AND what it doesn’t!
- gyres + MOC highlight controls by small-scale dynamic processes
- concepts in smaller-scale dynamics (pictures based)

What is physical oceanography?

Study of physical features and processes of the ocean

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



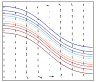


What is physical oceanography

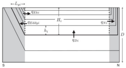
$$\varepsilon \equiv \nu \langle \|\nabla \boldsymbol{u}\|^2 \rangle < \kappa H^{-1} b_{\max}.$$

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

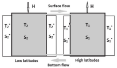
Orr (1907)
Harnik & Heifetz (2007)



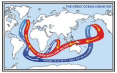
Gent et al. (1995)



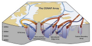
D. Marshall & Zanna (2014)



Stommel (1961)



Ocean conveyor belt
e.g. Broecker (2010)



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

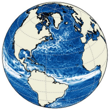
Theory

Physical Oceanography

Observations

Modelling

Madec (2008)



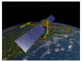
Jason-3

Jet Propulsion Laboratory
California Institute of Technology
ECCO

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

MITgcm

J. Marshall et al (1997a, b)



SWOT

Boaty McBoatface

Argo

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

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

understanding the ocean require
interdisciplinary + complementary approaches

Earth overview

from https://sites.google.com/site/climatetypes/

Ocean

The ocean covers $> 70\%$ of the Earth's surface:

- holds about **50** times more carbon than the atmosphere
- upper **2.5m** holds as much heat as the atmosphere

water moves $\Rightarrow$ **lots/large amounts** of things being moved

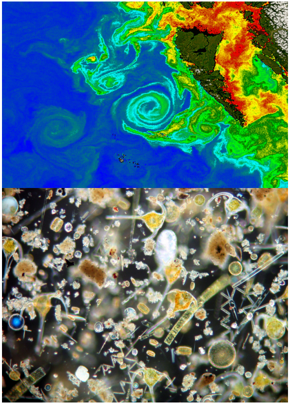
Oceans and weather/climate

"holds about 50 times more carbon than the atmosphere"

- some inorganic (e.g. carbonates) but largely organic
- role in carbon cycle + global warming
- ocean largely seen as a sink for atmospheric carbon

  → physical (e.g. turbulence, circulation)

  → biogeochemical (e.g. biological pump)

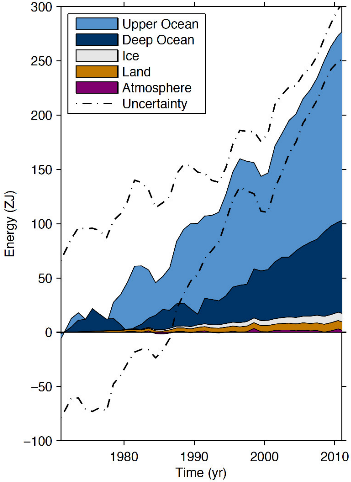


top: false colouring of chlorophyll concentration
bot: from Annegret Stuhr/GEOMAR

see more in e.g. Williams & Follows (2011), *Ocean Dynamics and Carbon Cycle Principles*, CUP

Oceans and weather/climate

"upper 2.5m holds as much heat as the atmosphere"



- high heat capacity (see Lec 5)

  → stores excess energy (measured as Ocean Heat Content) (more in OCES 4001)

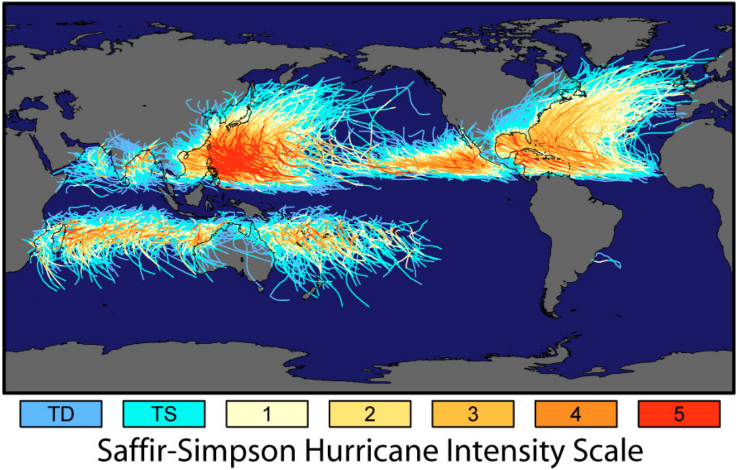
- ocean important part of energy balance

  → Earth tilt, uneven Solar heating (see Lec 5)

  → circulation affects and affected by excess energy redistribution (see Lec 13 + 14)

left: IPCC AR5 (2014)

Oceans and weather/climate



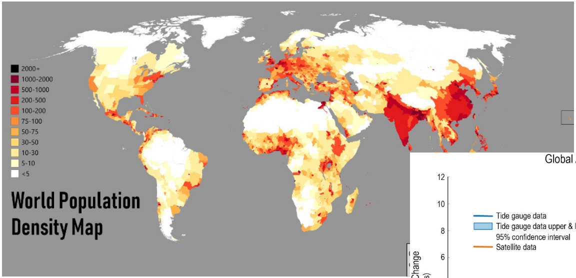
- ocean affects and is affected by the atmosphere (see Lec 9 + OCES 4001)

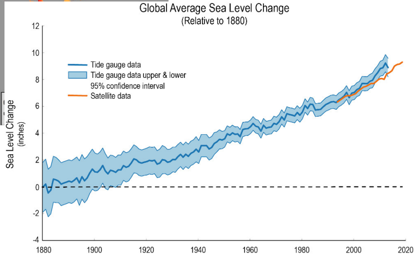
(from NASA)

Oceans and weather/climate

video: `https://www.youtube.com/watch?v=ASJSrVBPazw`

Oceans and weather/climate

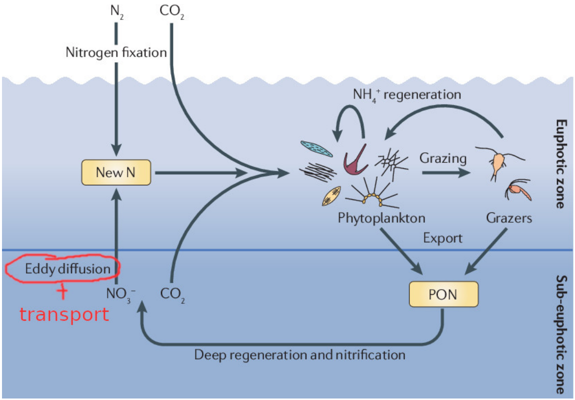




- global warming ⇒ sea level rise
  → thermosteric vs. halosteric (see Lec 5 + OCES 4001)
  → which sea level (eustatic, dynamic, relative...)? (see OCES 4001 and a bit in Lec 18)

left: reddit user `some_dawid_guy`; right: from USGCRP

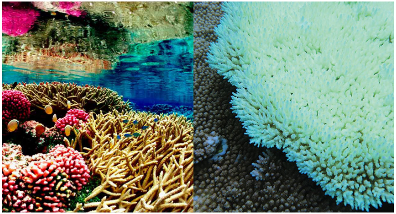
Oceans and ecology

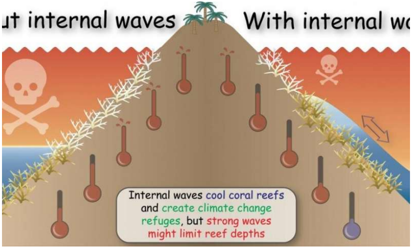


- nitrogen cycle as an example
- nutrient supply particularly through physical upwelling
  $\rightarrow$ wind and/or eddy driven?

adapted from Sohm *et al.* (2011), *Nature reviews*

Oceans and ecology





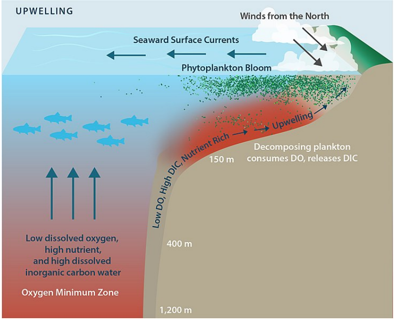
- environmental stresses on coral reef ecosystems

  $\rightarrow$ internal waves (see Lec 16)

  and associated heat relief?

left: Jim Maragos / U.S. Fish and Wildlife Service; right: The Pokémon Company; bot: courtesy of Alex Wyatt

Oceans and ecology



- hypoxia (i.e. low oxygen conditions in water)
  $\rightarrow$ some naturally occurring (e.g. Black sea see Lec 3)
  $\rightarrow$ human activity stresses?
  $\rightarrow$ influences by physical upwelling? (e.g. global warming
  $\Rightarrow$ increased outgassing?)

left: Gerwin (2010), *Nature*; right: Mobile bay jubilee event + dead stuff, photo from NOAA

Oceans and economy

Blue economy

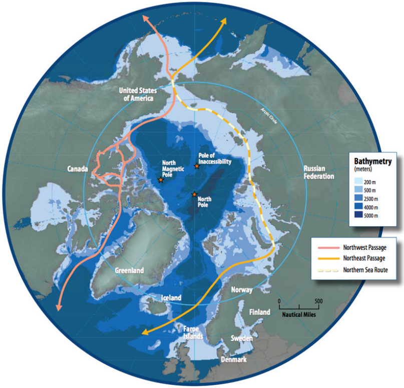
- *"sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem"* – The World Bank

e.g. fisheries + food security

- physics $\rightarrow$ biogeochemistry $\rightleftharpoons$ marine ecology $\rightleftharpoons$ fishing + fishery management

picture from HK AFCD

Oceans and economy



e.g. shipping

- **weather** influences on shipping?

  → e.g. route planning in South China Sea, one of the busiest regions in the world
- **climate** influences on shipping?

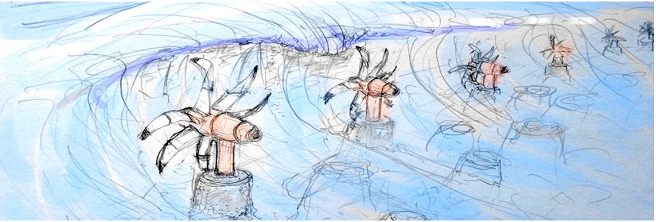
  → opening up of new routes if ice melts?

- policy, politics, sustainability etc.

  → physics has implicit influences (not immediate obvious influences maybe!)

image from Wikipedia (Susie Harder - Arctic Council - Arctic marine shipping assessment)

Oceans and economy



Sketch from Tsumoru Shintake (Okinawa Institute of Science and Technology Graduate University)

e.g. energy security

- harness ocean's vast energy for consumption

  $\rightarrow$ waves, tidal, geothermal etc.?

  $\rightarrow$ design/build equipment

  $\rightarrow$ how to optimise power generation

  $\rightarrow$ feedbacks and impacts on environment (physical and/or ecological)?

Summary

- physical oceanography is
  $\rightarrow$ study of **what** the ocean looks like
  $\rightarrow$ **why** does it look like the way it does

- ocean physics drives
  $\rightarrow$ weather and climate
  $\rightarrow$ ocean biogeochemistry
  $\rightarrow$ ocean ecology
  $\rightarrow$ economy, policy, etc...

Ocean physics is not easy, but you need <u>enough</u> of it!!!

Course structure + approach

Approach:

- descriptive in nature + focus on dynamics

  → focus on geometric interpretations

  → use a bit of calculus but **not examined**

Content structure:

- ocean features we want to explain (Lec 2 - 6)
- attempt at explaining (Lec 4 - 18)

  → bias on "clean" things
- how did we get those features anyway (Lec 19 - 20)