CSP SIO 210: Introduction to physical oceanography
Fall, 2016
Lynne Talley, Professor; Weijie Wang, TA

Course requirements (graded)

2 exams: mid-term and final

1 project (data project or tank experiment)

4 problem sets

Grade: Final (40%), Mid-term (20%), Project (12%), problem sets (7% each)

Course resources

Lectures: M/W 10:30-11:50

Coursework tutorial with TA, preferably Friday 10:30-11:50 (same time)

Math tutorial for basic concepts if desired (with PM TA Shantong Sun)

Electronic reserves, resources linked to website

Schedule changes

Wed. Sept. 28 class at 9:30-10:50

Wed. Oct. 5 and Nov. 16: move to Friday, Oct. 7 and Nov. 18 at 10:30-11:50

Course TAs

- Shantong Sun (shs041@ucsd.edu)
  - Course content tutorials for afternoon SIO 210
  - Math tutorials
- Weijie Wang (wew052@ucsd.edu)
  - Course content tutorials for morning (CSP) SIO 210
  - Rotating tank experiment leader

Website and Textbook

Website: http://pordlabs.ucsd.edu/ltalley/sio210/index_sio210csp.html

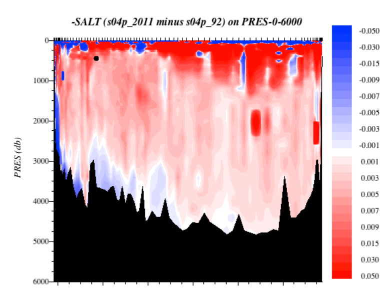
Primary text:

1. Descriptive Physical Oceanography (DPO) (6th edition) by Talley, Pickard, Emery, Swift (2011).

Online through course reserves or ScienceDirect (sciencedirect.com)
Go to the class url (listed below and in your email), and click to course reserves, or go directly to reserves.

CSP SIO 210 course project

- Choose between
  - Data analysis project
    - Climate related using http://giovanni.gsfc.nasa.gov/giovanni/
    - Oceanographic using Java Ocean Atlas with Jim Swift



  - Rotating tank experiment (groups of 2-3), using our MIT "Weather in a Tank", with Weijie Wang

Math tutorials

Math tutorials will be run by Shantong Sun.

- Derivative (Wolfram link)
- Partial derivative (Wolfram link)
- Integral (Wolfram link)
- Not necessary for this course, but for general math knowledge: Ordinary differential equations (simple ones for this tutorial)
- Scalar
- Vector
- Scalar ("dot") product
- Vector ("cross") product
- Gradient
- Divergence
- Curl
- Not necessary for this course, but general math knowledge: Partial differential equations (simple ones for this tutorial)

Tutorial and study groups

Math tutorial: 1 per week (Sun)

Basic refresher on vectors, derivatives, partial derivatives and short different equations

Review of equations that appear in lectures

Course tutorials: 1 per week (Sun for PM SIO 210; Wang for CSP SIO 210)

Study groups: I strongly advise forming them. I am happy to meet with you. TAs are happy to answer questions, meet with you.

STUDENTS to do:

1. Choose section and tutorials to attend (flexible!)
2. Start considering project (paper, data analysis, tank experiment)

Outline for today

Introduction: time and length scales for fluids on rotating Earth

1. Ocean basins (physical setting) (spatial scales)
2. Earth rotation and orbit (time scales)
3. Scales of motion; physical oceanographic phenomena from small to large scale.
4. Scale analysis as a way of simplifying fluid mechanics; non-dimensional parameters

Physical properties of seawater I

1. Pressure
2. Temperature
3. Salinity and possibly 4. Density

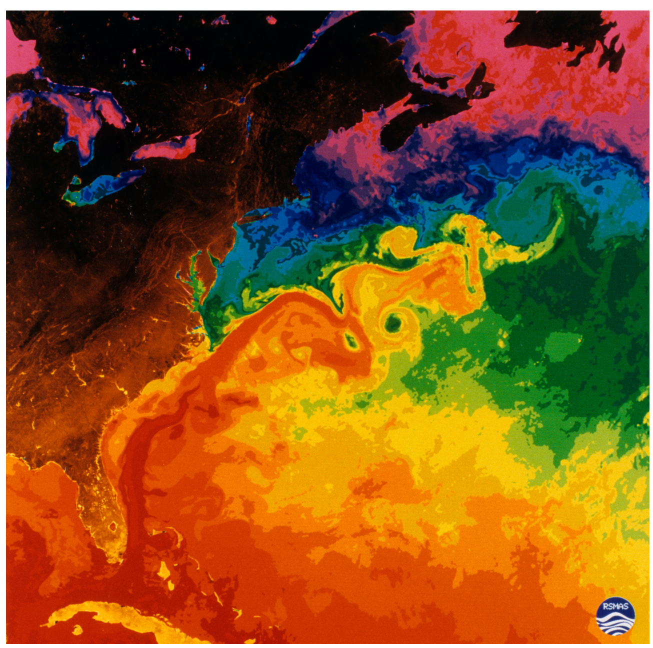
Reading and study for today's introductory lecture (SIO 210 PM):

- Course website, lecture 1
- DPO Section 1.2 (definitions)
- Extra background: Pedlosky, Geophysical Fluid Dynamics: Sections 1.1, 1.2, introducing non-dimensional scale analysis (linked to website)
- Study questions from lecture
- DPO Chapter 2 (just what is in lecture, not the rest of chapter)

Reading and study for today's introductory lecture (SIO 210 CSP):

- DPO Section 1.2 (definitions)
- DPO Section 2.1.
- You might enjoy reading more of Ch. 2 as well.
- Study questions from lecture

1. Overview: Ch. 1 DPO



1. Overview: Ch. 1 DPO

- Gulf Stream as an example
- Satellite color image (Figure 1.1a)

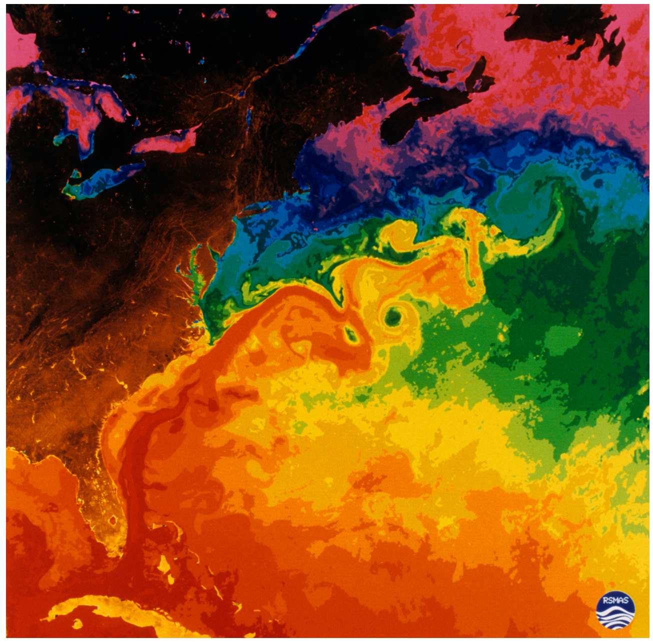
Phrases/words:

General circulation

Gyre

Western boundary current

Mesoscale variability



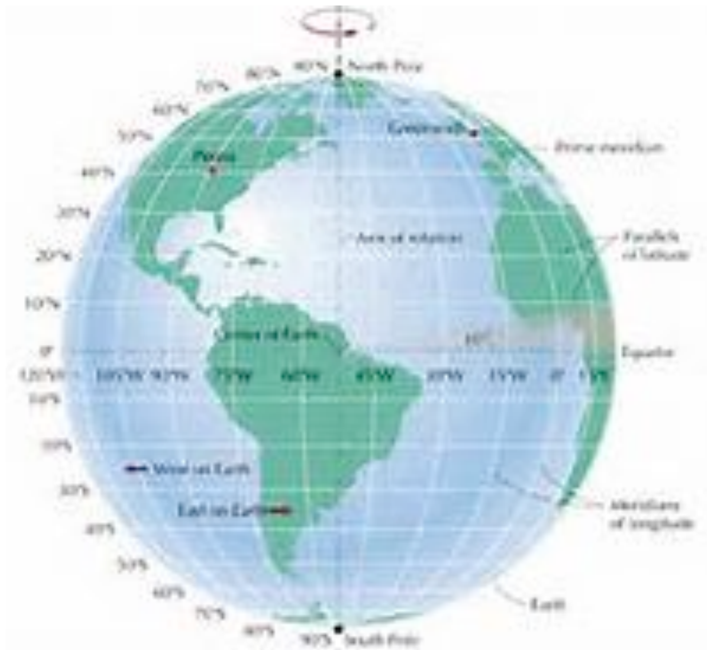
1. Overview: Ch. 1 DPO

- Gulf Stream as mapped in 1769 by Benjamin Franklin
- Note the accurate location, basically smoothed verson of previous image,without “mesoscale” (Figure 1.1b)

2. Physical setting: Ch. 2 DPO

Radius of the Earth ~ 6371 km.

(Personal assignment: what is its circumference?)



2. Physical setting: Ch. 2 DPO

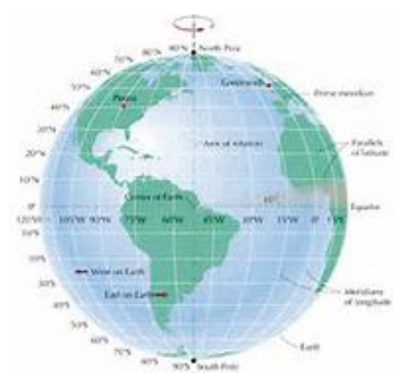
SPACE:

Latitude: from -90° at South Pole to 90° at North Pole

1 degree latitude
= 60 nautical miles (nm)
~ 111 km
1 minute latitude = 1 nm

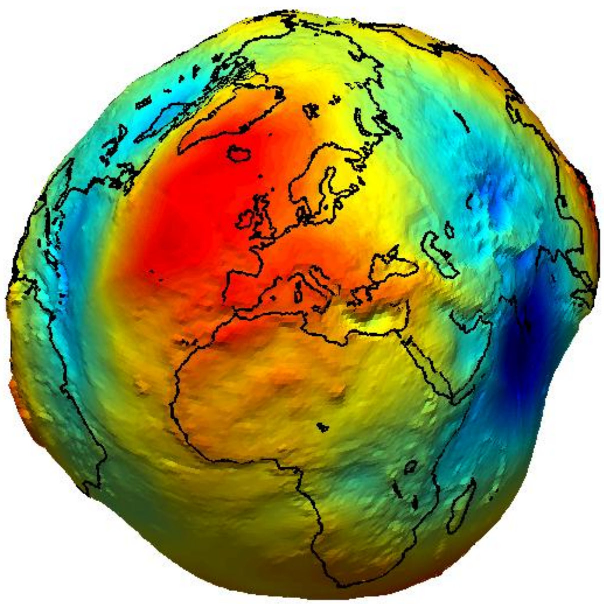
Longitude: from -180° at the Dateline to 0° at the Greenwich Meridian (England) to 180° at the Dateline

1 degree longitude
= (111 km) x cos(latitude)
(maximum at equator, 0 at poles)



*Earth is not exactly round ("oblate spheroid" with additional bumps) but we'll talk about that later. You might start mulling about why.

2. Physical setting: geoid (greatly exaggerated)



http://www.esa.int/spaceinimages/Images/2011/03/New_GOCE_geoid

2. Physical setting: Seafloor topography

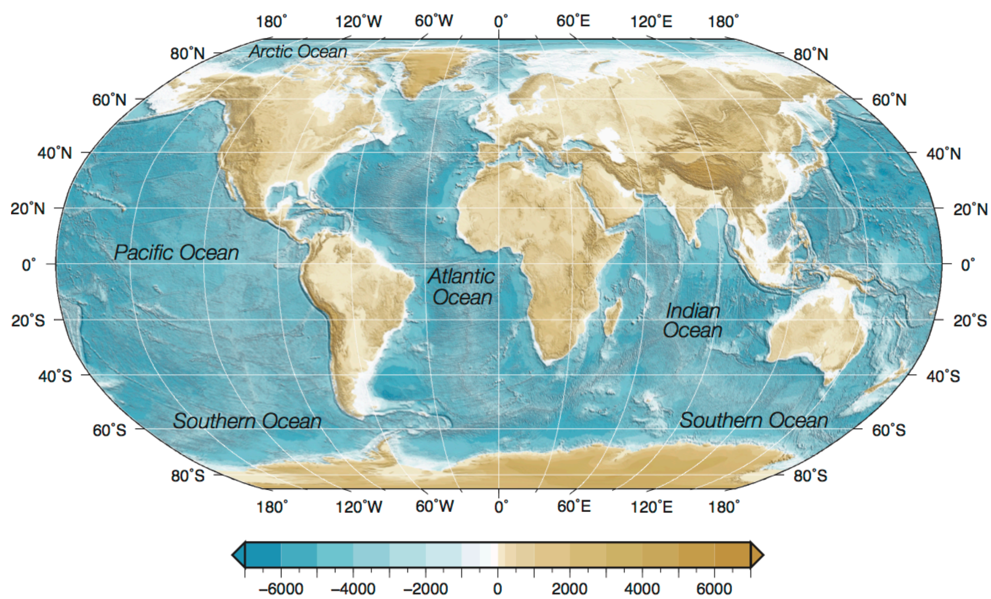
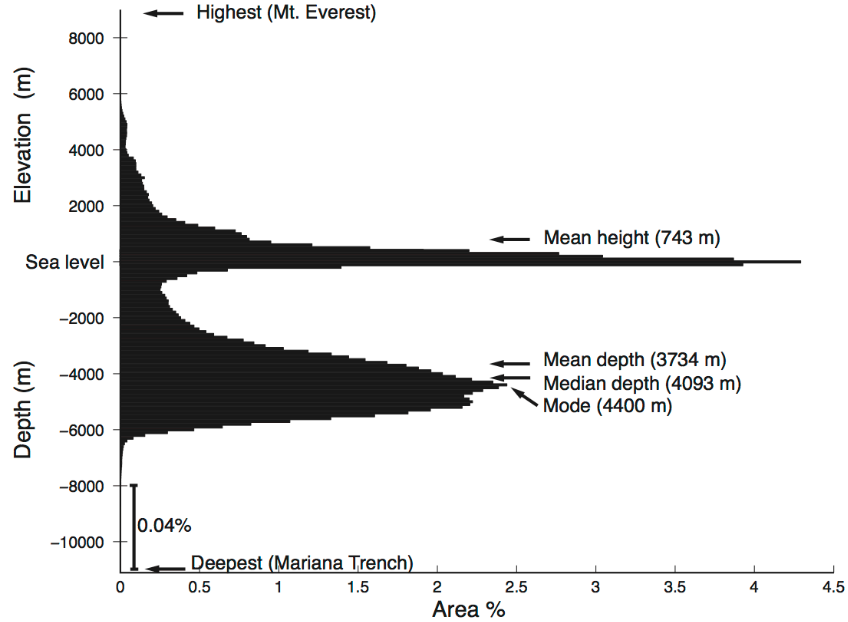


FIGURE 2.1

Map of the world based on ship soundings and satellite altimeter derived gravity at 30 arc-second resolution. Data from Smith & Sandwell (1997); Becker et al. (2009); and SIO (2008).

2. Physical setting: height/depth distribution



Areas of Earth's surface above and below sea level as a percentage of the total area of Earth (in 100m intervals). Data from Becker et al. (2009).

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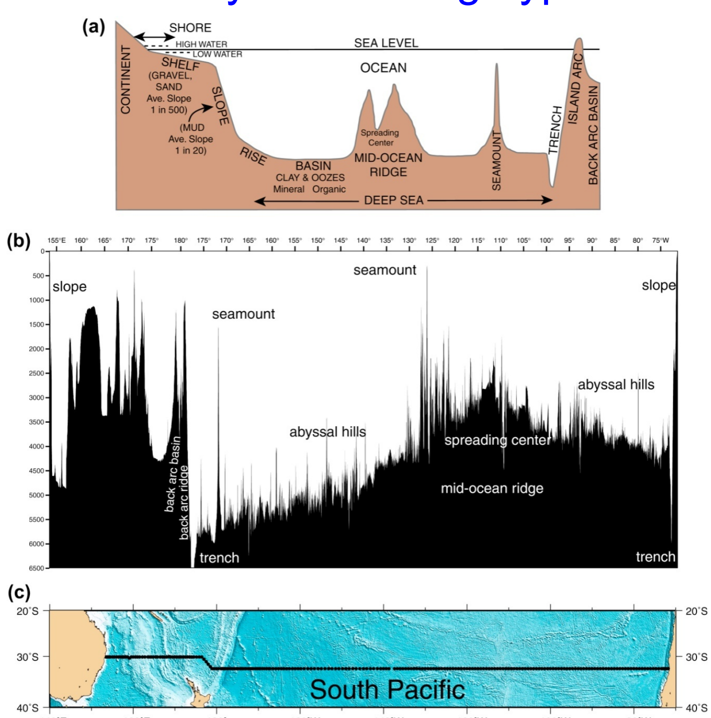
2. Physical setting: typical bottom features



a) Schematic section through ocean floor to show principal features. (b) Sample of bathymetry, measured along the South Pacific ship track shown in (c).

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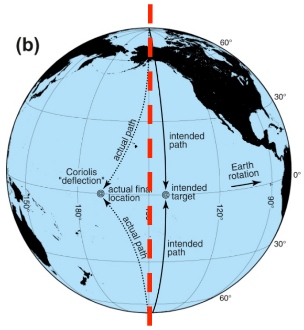
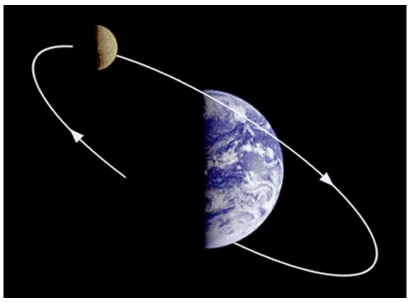
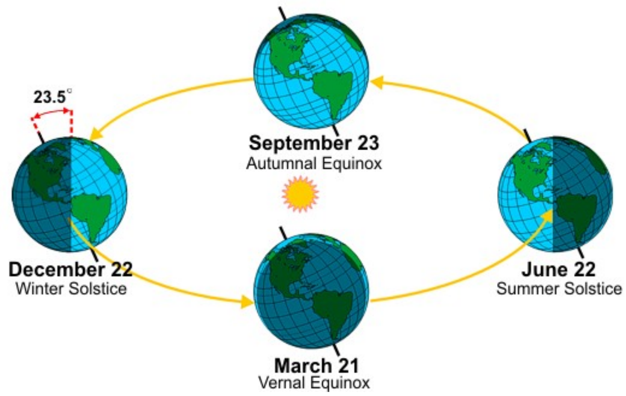


3. Time scales: Earth rotation and orbit

Earth rotates about its axis (right-hand rule), once per day. This has a fundamental effect on all fluid motions with time scales of about 1 day and longer (diurnal time scale).





Moon orbits around Earth, which is rotating (tides on diurnal time scale).

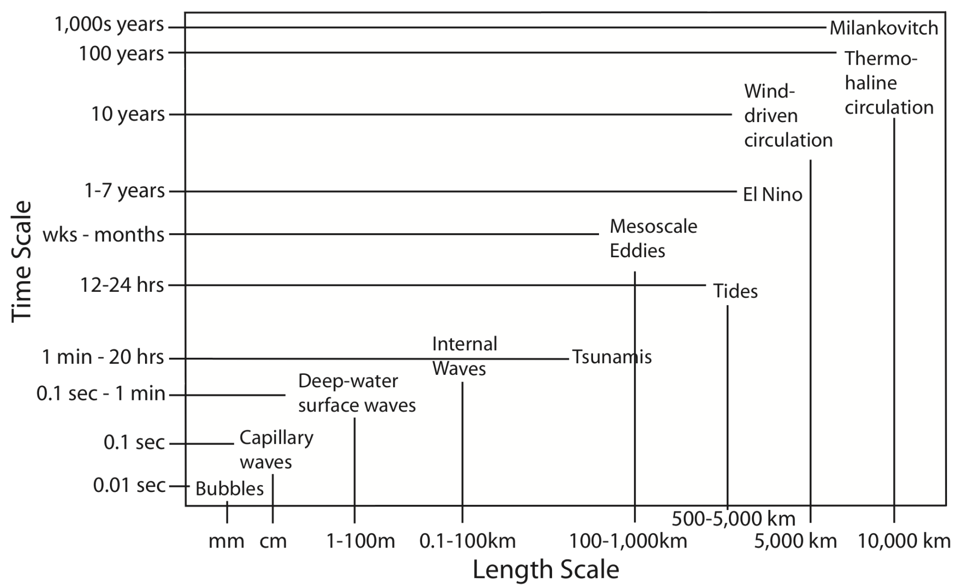
Earth orbits around the sun. Obliquity (tilt of axis) results in seasonal time scale, also called the annual time scale.

4. Scales of motion for various oceanographic phenomena

- Ranging from shortest length and time scales to the longest length and time scales
- Most examples taken from the DPO textbook
- Not necessary to remember the details in the captions: to get an idea of what we will be studying, and of their length and time scales

4. Scales of motion: Length and time scales

T



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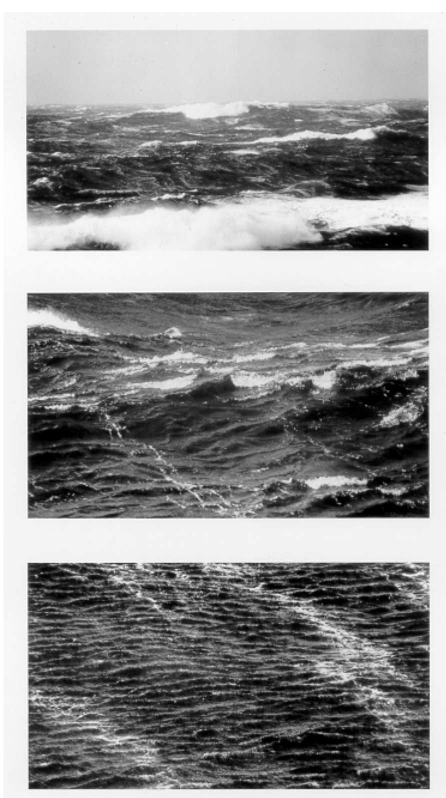
L

Time and space scales of physical oceanographic phenomena from bubbles and capillary waves to changes in ocean circulation associated with Earth's orbit variations.



Melville (1996)

4. Scales of motion: Smallest scales: Breaking surface waves and bubbles

Routes to Breaking I

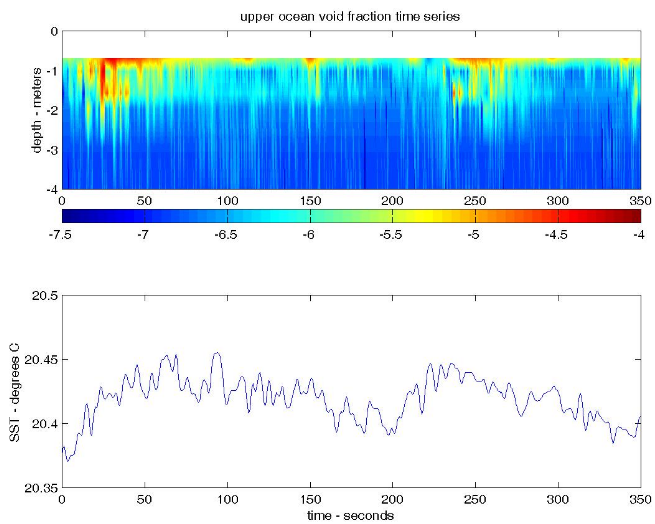
Breaking at larger scales may result from
dispersive focusing, geometric focusing, wave-wave and wave-current interactions without wind-forcing being directly involved: a,b.

At sufficiently high winds and small wave scales, each wave may be breaking (c). Note also in (c) the foam streaks aligned with the wind.

T seconds to minutes.

H and L cm to m

4. Scales of motion: Air Entrainment, Gas Transfer, Acoustics & Mixing



Terrill, 1998

Breaking waves entrain air as the surface water is rapidly mixed down to depths comparable to the wave height.

Subsequently, slower processes mix the air-water mixture down to greater depths.

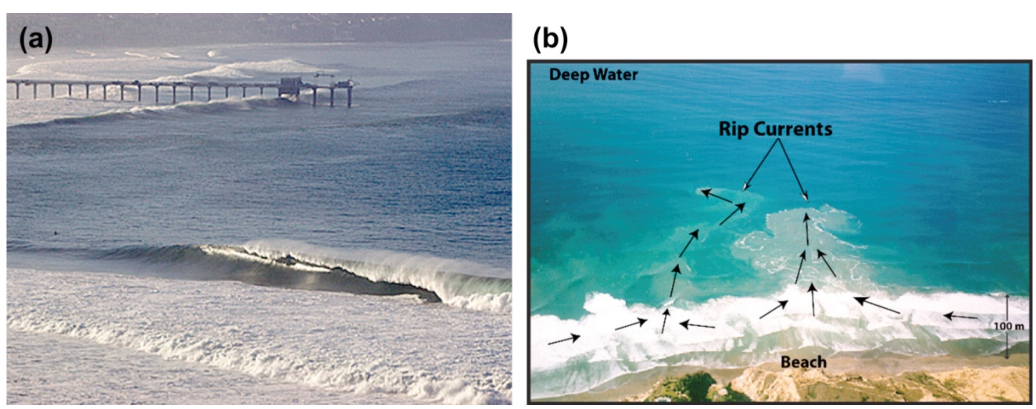
The smallest bubbles are a tracer for fluid that was originally at the surface.

Mixing can lead to fluctuations in the temperature field at the scales of the wave modulation - wave groups.

T seconds

H and L mm to m

4. Scales of motion: Surface waves

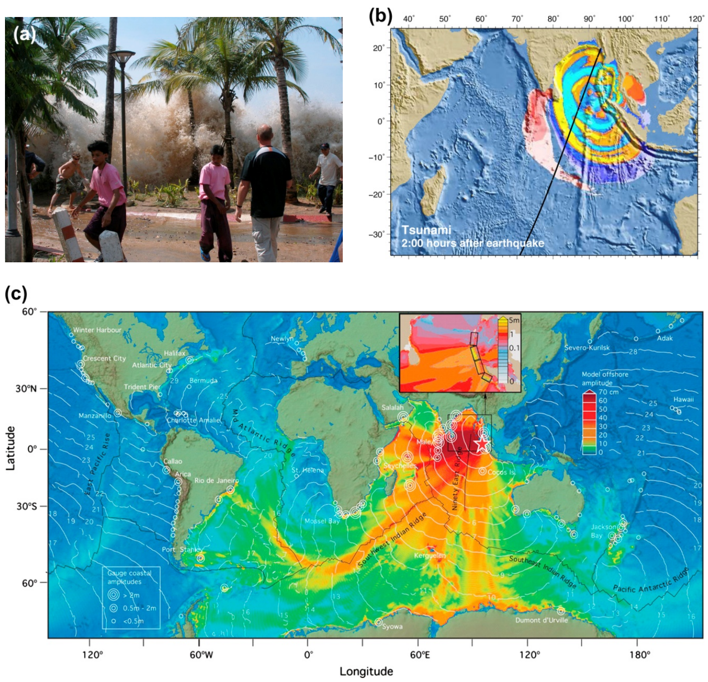


(a) Surf zone, looking toward the south at the Scripps Pier, La Jolla, CA. *Source: From CDIP (2009). (b) Rip currents, complex pattern of swell, and alongshore flow near the head of a submarine canyon near La Jolla, CA, Photo courtesy of Steve Elgar (2009).*

T minutes to hours

H and L 1 to 10s of meters

4. Scales of motion: Tsunamis: surface waves with very long wavelengths



Sumatra Tsunami (December 26, 2004). (a) Tsunami wave approaching the beach in Thailand. *Source: From Rydevik (2004)*. (b) Simulated surface height two hours after earthquake. *Source: From Smith et al. (2005)*. (c) Global reach: simulated maximum sea-surface height and arrival time (hours after earthquake) of wave front. Figure 8.7c can also be found in the color insert. *Source: From Titov et al. (2005)*.

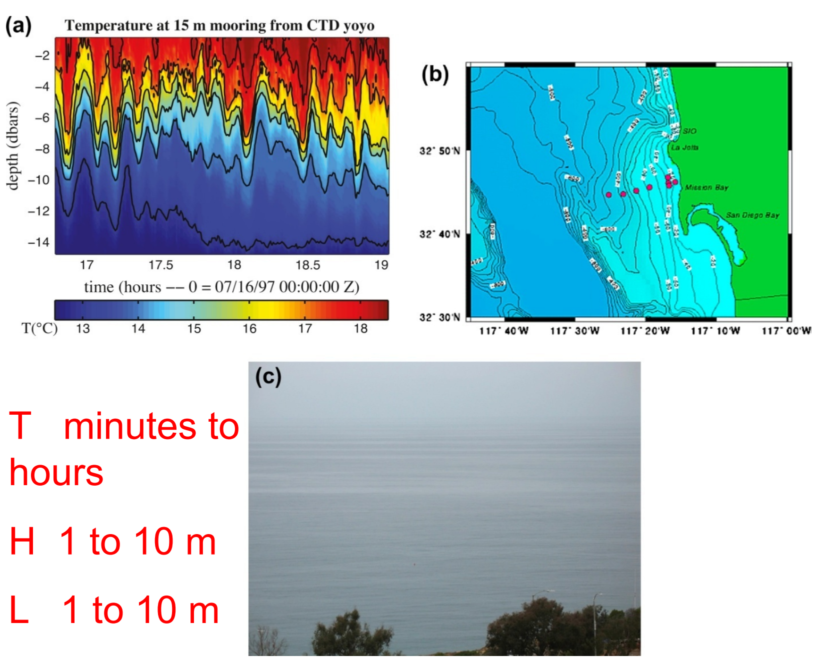
FIGURE 8.7

T minutes to hours

H 1 km

L 100-1000 km

4. Scales of motion: Internal waves



Internal wave observations. (a) Temperature as a function of time and depth on June 16, 1997 at location shown in (b) (Lerczak, personal communication, 2010). (b) Map of mooring location in water of 15 m depth west of Mission Bay, California. *Source: From Lerczak (2000)*. (c) Ocean surface west of Scripps Institution of Oceanography (map in b) on a calm day; the bands are the surface expression of internal waves propagating toward shore. (Shaun Johnston, personal communication, 2010).

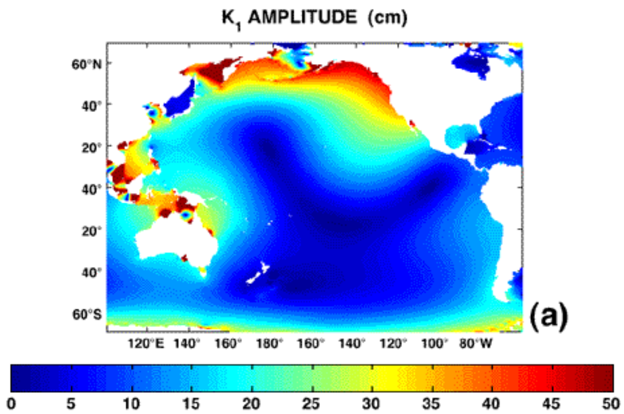
T minutes to hours

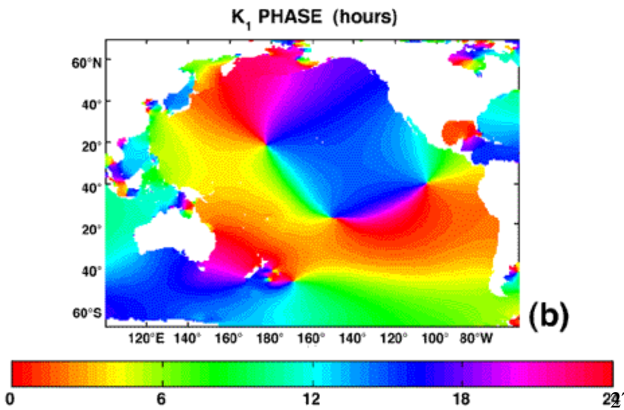
H 1 to 10 m

L 1 to 10 m

4. Scales of motion: Tides

Tides (the main diurnal or daily component): amplitude and phase, rotating around the amphidromes.





T 1 day

H 1 km

L 1000 km

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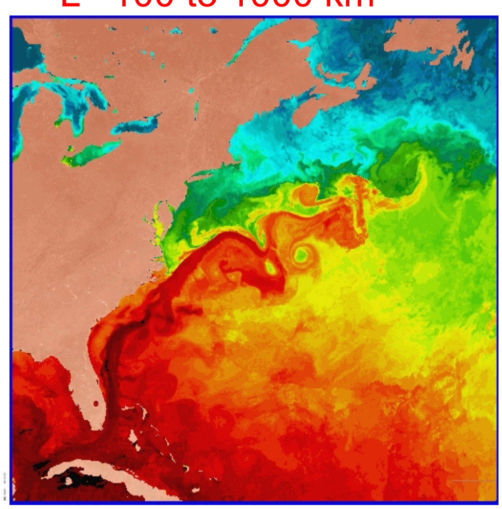
4. Scales of motion: Boundary currents and mesocale motions (eddies)

T weeks to 1000s years

H 5 km

L 100 to 1000 km

Franklin/Folger map of the Gulf Stream: mean flow



Satellite SST (AVHRR) image of Gulf Stream - O. Brown, R. Evans and M. Carle, University of Miami RSMAS, Miami, FL - mesoscale (meanders and eddies) - time dependent, O(100 km) scale, O(2 weeks - 1 month), from instabilities of mean

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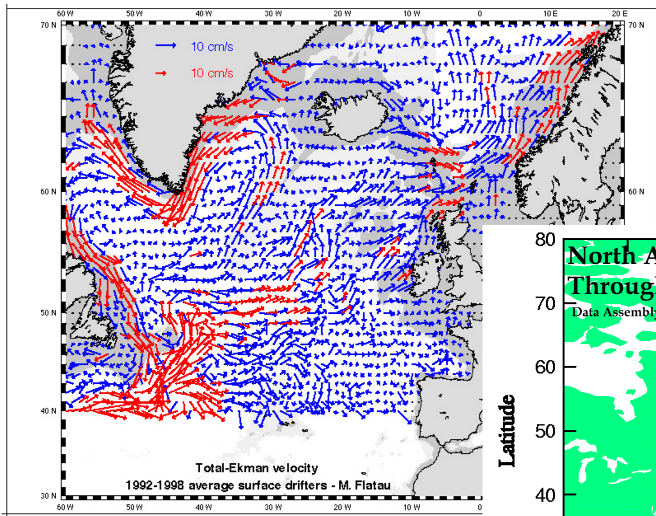
4. Scales of motion: Mean surface flow and original observations

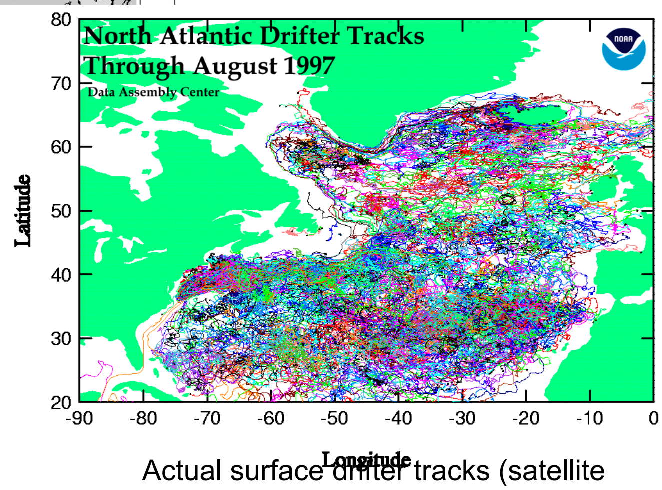


Mean surface flow from surface drifters (Flatau, Talley, Niiler, 2003).

T weeks to 1000s years

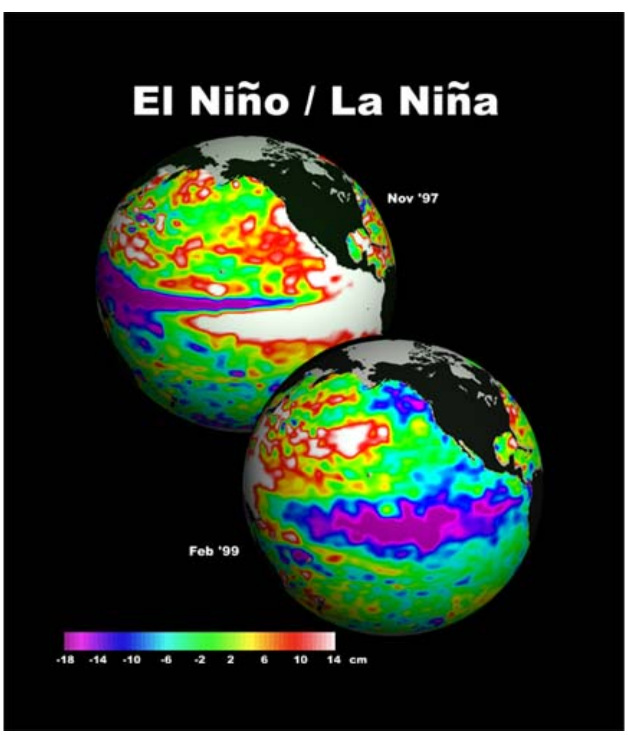
H 1 km

L 100 to 1000 km



Actual surface drifter tracks (satellite tracking) - note vigorous mesoscale

4. Scales of motion: El Nino/La Nina



Sea surface height anomaly during 1997 El Nino and 1999 La Nina, from Topex/Poseidon altimetry.

Sea surface is anomalously high in eastern equatorial region during El Nino and opposite in La Nina

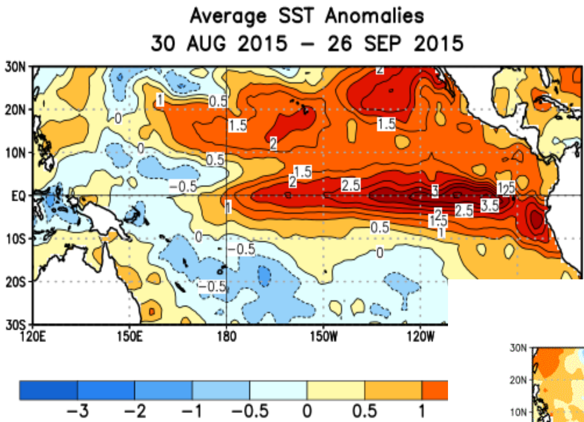
T 5 to 10 years

H 1 km

L 1000s km

NASA webpage: http://topex-www.jpl.nasa.gov/science/images/el-nino-la-nina.jpg

4. Scales of motion: El Nino/La Nina



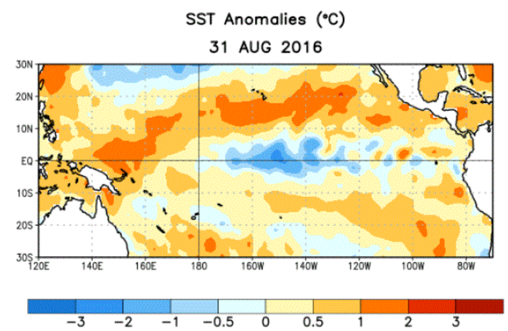
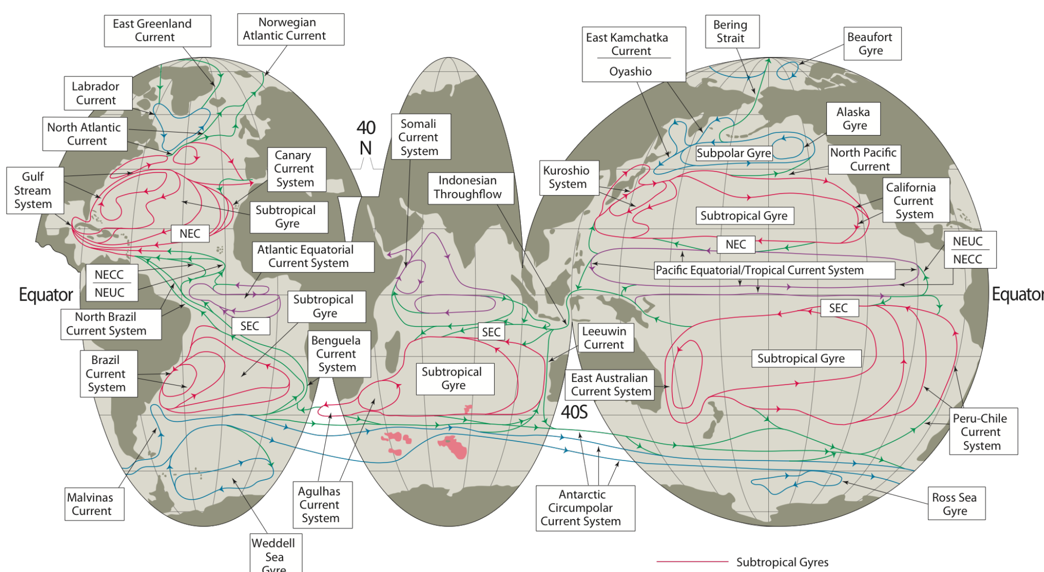


Figure 1. Average sea surface temperature (SST) anomalies (°C) for the week centered on 31 August 2016. Anomalies are computed with respect to the 1981-2010 base period weekly means.

NOAA webpage: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/enso_advisory/

4. Scales of motion: Surface circulation features



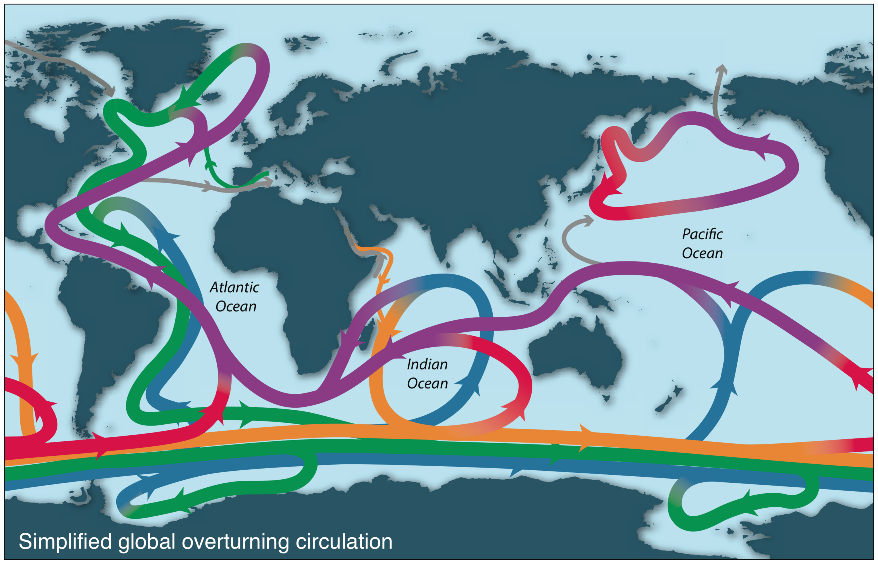
T 100s to 1000s years

H 1 km

L 1000s km

Surface circulation schematic. Modified from Schmitz (1996b).

4. Scales of motion: Global overturning circulation



Global overturning circulation schematic.

T 1000 years

H 5 km

L 10000 km

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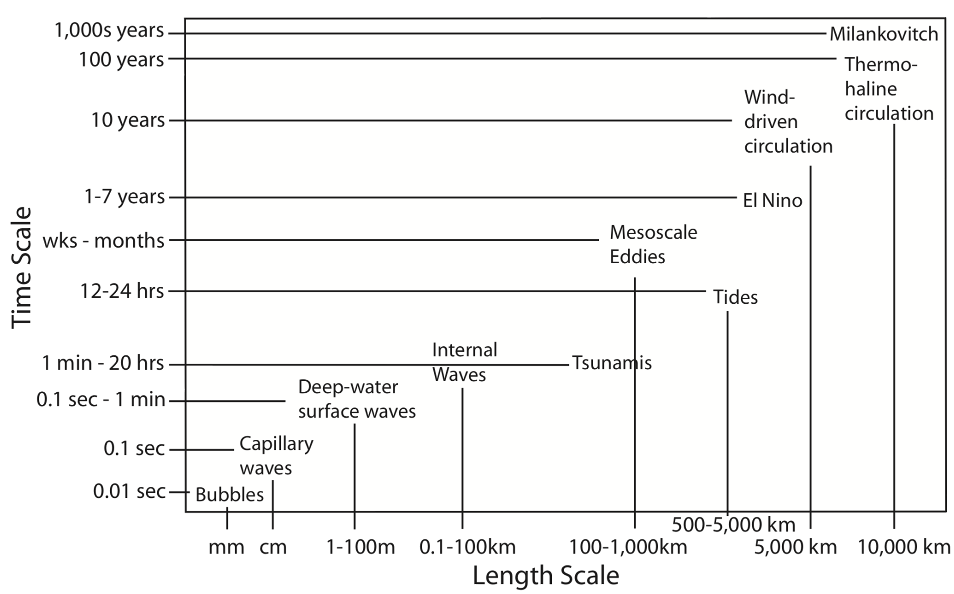
4. Scales of motion: Length and time scales

T



Talley SIO 210 (2016)

L

Time and space scales of physical oceanographic phenomena from bubbles and capillary waves to changes in ocean circulation associated with Earth's orbit variations.

5. Scale analysis in fluid mechanics

- Fluid equations cover vast range of space and time scales. Can't solve them exactly for every phenomenon.
- Therefore we approximate to decide which terms are important and which to ignore.
- Formal method:

  1. Choose length, time, mass scales appropriate for the phenomenon you are studying – *as in the examples we've just seen*

  2. Perform a "scale analysis" of the governing equations: assign approximate time, space scales

  3. Non-dimensional parameters (ratios of length scales or ratios of time scales, for instance)

  4. Solve the equations using only the most important terms; ignore the smaller terms (based on the non-dim. parameters – whether they are large or small – for instance, if length scale of fluid motion is much smaller than length scale of the ocean basin or the forcing scale)

5. Scale analysis: **non-dimensional** parameters

- 2 important parameters based on the approximate length (L), height (H) and time (T) scales of the motion
  - Aspect ratio = Height/Length
    - $\delta = H/L$
  - Rossby number = earth rotation time/time scale
    - $Ro = T_{rot}/T$ or $1/fT$ where f is the Coriolis parameter - defined later on in course
  - (Reynolds number and Ekman number will be introduced later in course, relevant to importance of viscosity)

Personal assignment: go back through the #4 slides and estimate the Aspect ratio and Rossby number for each phenomenon

Introduction: summary

Earth setting (radius, definitions)

Spatial scales set by geography and fluid motions

Time scales set by geophysical motions (orbit, rotation) and fluid motions

Examples for small to large phenomena

Scale analysis for simplification: non-dimensional parameters (aspect ratio and Rossby number introduced)

Summary: definitions

- Gyre
- Mesoscale
- Earth's radius
- Geoid
- Latitude
- Longitude
- Nautical mile
- Diurnal time scale
- Seasonal time scale
- Non-dimensional parameter
- Aspect ratio
- Rossby number