OCEANOGRAPHY:

- Physical (Currents, waves, ocean basins)
- Biological (Marine Biology)
- Chemical (Ocean waters, marine pollution)
- Marine Geology (Ocean basins, marine geology processes)

Significance of the Oceans

1. Abundant Life
2. Sediments/Ores (iron, salt, gypsum, limestone)
3. Coastline (sea level changes, coastal processes)
4. Ocean – Atmosphere Interaction (weather)
5. Ocean – Climate effects (CO_2 storage)

Waters of the Oceans:

1. Oceans are ≈ 3 billion years old (de-gassing of Earth)
2. Salty because of dissolved elements from continents (today, ≈ in equilibrium)
3. Composition of seawater:

   H_2O + 3.5% (35‰; parts per thousand) salts (Na, Cl, SO_4, Ca, K, Mg)

4. Properties of water, H_2O

-- Dipolar molecule

-- Good solvent
-- Expands on freezing
-- High surface tension
-- Exists in solid, liquid and gas form on Earth

The reason for the 105 degree angle in the water molecule

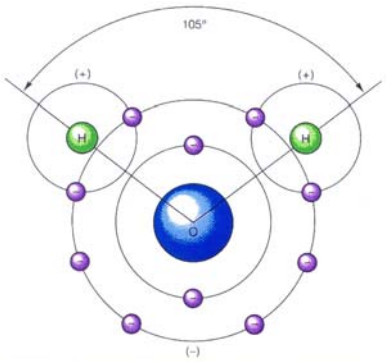
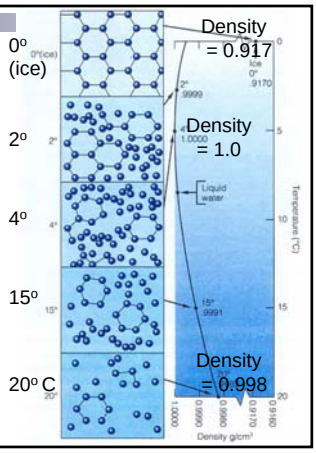
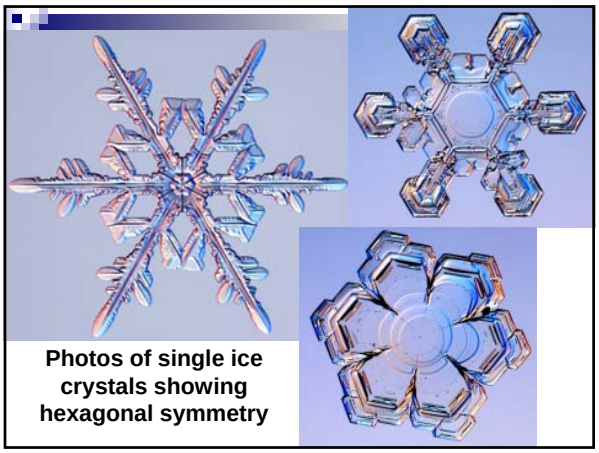


Figure 11.2 Arrangement of H and O ions in a covalent bond to form the water (H_2O) molecule. The molecule has a net positive charge on the H end and a negative charge on the O end because of its asymmetry.

As water freezes, the dipolar water molecules begin to arrange themselves into hexagonal patterns because of the electrical bonds formed by the positive and negative sides of the molecules.

This explains the hexagonal symmetry of snowflakes and ice crystals and the unusual property that ice is less dense than water.





Photos of single ice crystals showing hexagonal symmetry

Ocean Waters – Relative proportions of water and dissolved salts in seawater

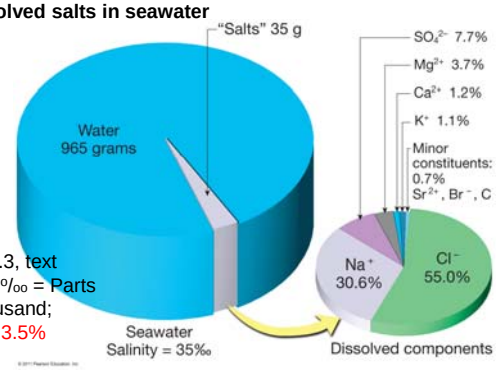
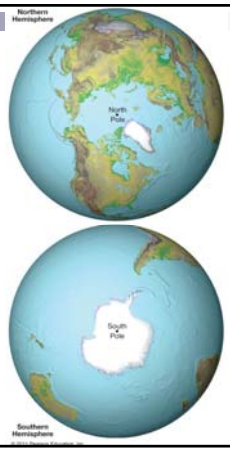


Figure 9.3, text
Salinity: ‰ = Parts per Thousand;
35 ‰ = 3.5%

Polar views contrasting areas covered by oceans

Figure 9.1, text



Distribution of Land and Water, Graph and Map

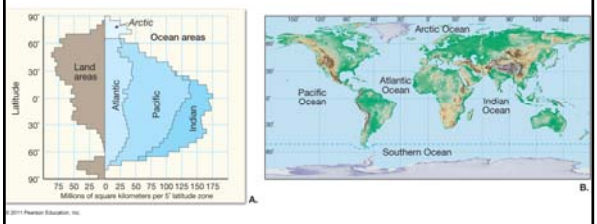
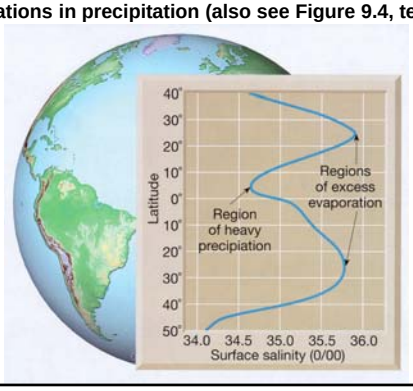


Figure 9.2, text

Differences in surface salinities partially caused by variations in precipitation (also see Figure 9.4, text)



Fluctuating location of shoreline due to glacier formation or melting (also see Figure 4.19, text, 2014)

Estuaries (were river valleys during ice age) along East Coast

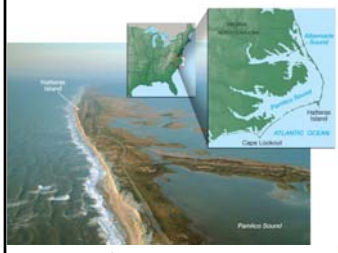


Figure 10.20, text

Figure 10.22, text

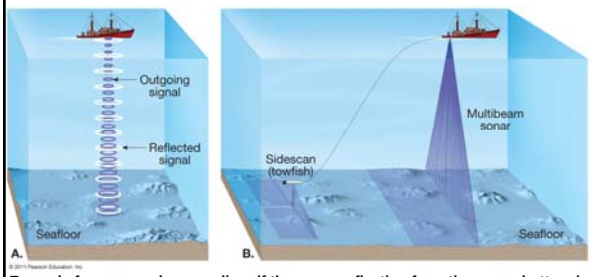
Ocean Basin Morphology

1. Shape of Earth – Ellipsoid (within ≈ 50 m)
2. If no continents, ≈ 2500 m water depth all over Earth
3. Shape of ocean basins due to continental geography (plate tectonics)

4. Main features of Ocean Bathymetry:
   - -- Shelf
   - -- Slope
   - -- Abyssal Plain
   - -- Mid-ocean ridge

Text p. 303-311

Echo Sounding measures the depth (bathymetry) and shape of the ocean floor, Figure 9.12 and 9.13, text



Example for sonar echo sounding: if the sonar reflection from the ocean bottom is 6 seconds (two-way time), the depth is 4500 meters (6 s x 1500 m/s = 9000 m; dividing by two to yield the one way depth = 4500 meters); the velocity of sound in water is ~1500 m/s.

Continental Margin and ocean bathymetry -- continental shelf (part of continental crust), Continental slope (transition to oceanic crust), abyssal plain. (Mid-ocean ridge not seen here).

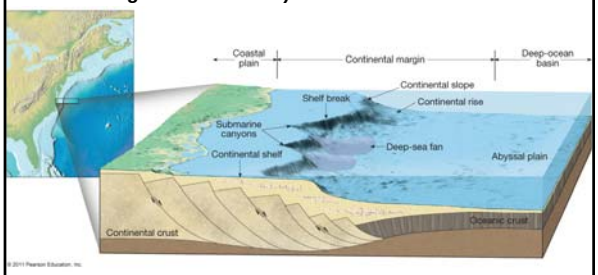
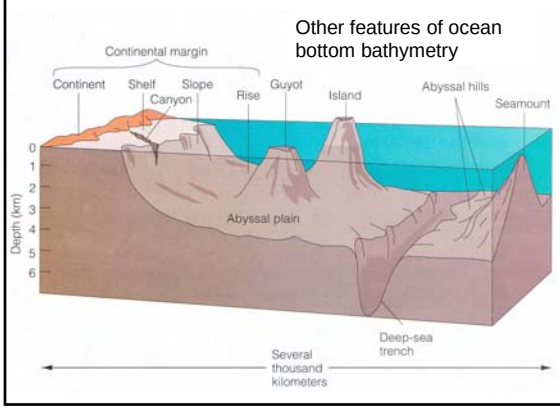


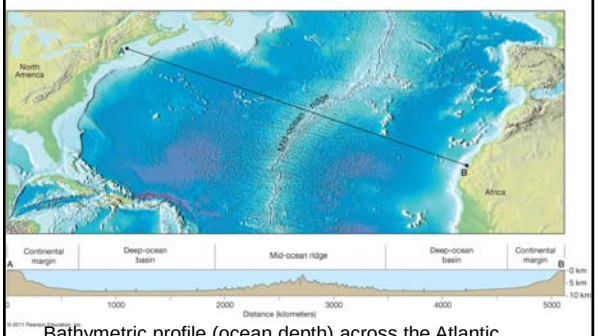
Figure 9.18, text

Ocean Basin Morphology (continued)

5. Other features of ocean bottom morphology (atolls, seamounts, trenches, fracture zones, etc.)
6. Movement of ocean waters (currents) controlled by:
   - -- Rotating Earth (tides)
   - -- Shape of ocean basins (3 dimensional)
   - -- Solar heating (temperature and salinity of water)
   - -- Wind directions

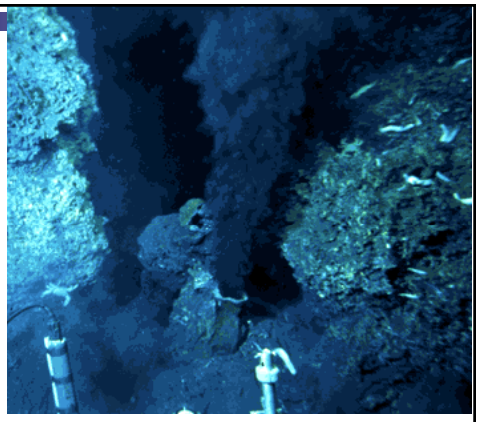
Other features of ocean bottom bathymetry



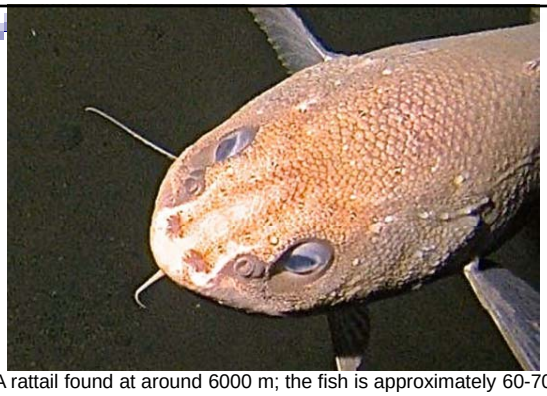


Bathymetric profile (ocean depth) across the Atlantic Ocean, Figure 9.16, text.

Black smokers at mid-ocean ridges



Black smokers at mid-ocean ridges

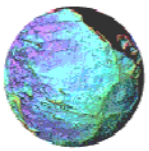


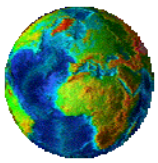
A rattail found at around 6000 m; the fish is approximately 60-70 cm. Photo taken by the Hadal Lander. Read more at: http://phys.org/news/2014-12-species-mariana-trench.html#jCp

URLs for some ocean bathymetry images:

http://www.ngdc.noaa.gov/mgg/global/global.html
http://www.ngdc.noaa.gov/mgg/image/2minrelief.html
http://www.ngdc.noaa.gov/mgg/fliers/97mgg03.html

http://www.ngdc.noaa.gov/mgg/image/global_topo_large.gif





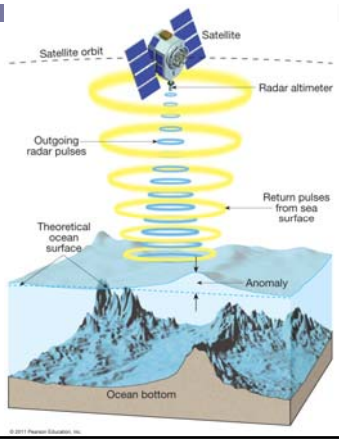
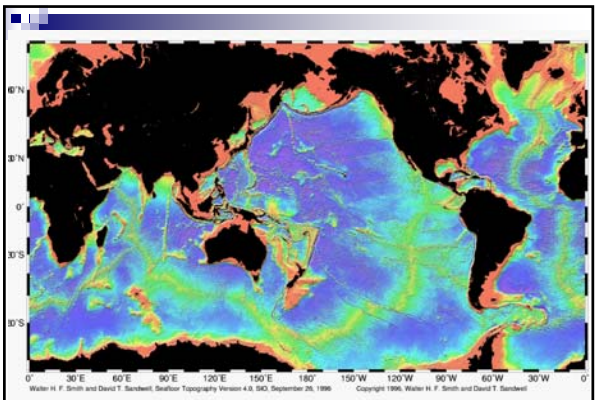
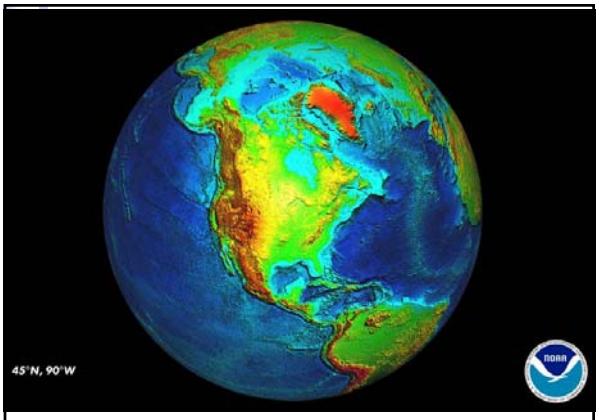


Figure 9.15, text



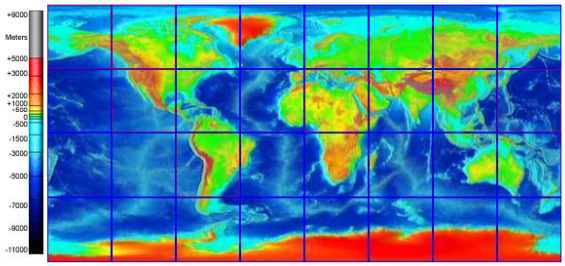
http://www.ngdc.noaa.gov/mgg/image/global_topo_large.gif



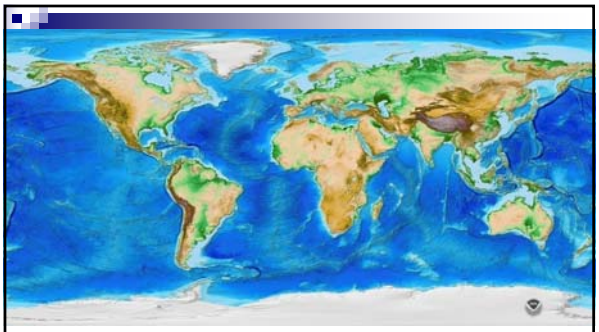
http://www.ngdc.noaa.gov/mgg/image/relief_slides2.html

Surface of the Earth, 2 minute color relief images

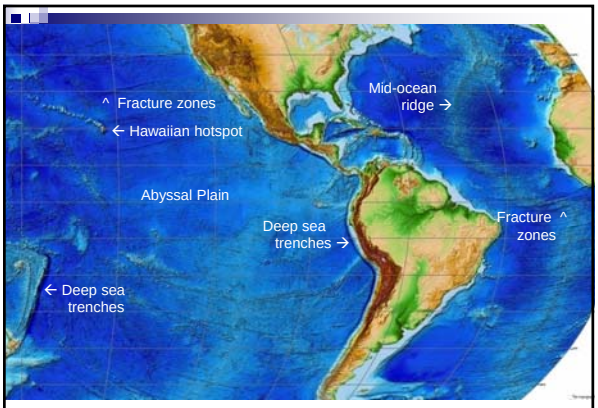
Click on a 45 degree by 45 degree square below to zoom in, then click on the image that comes up to see a full-resolution image



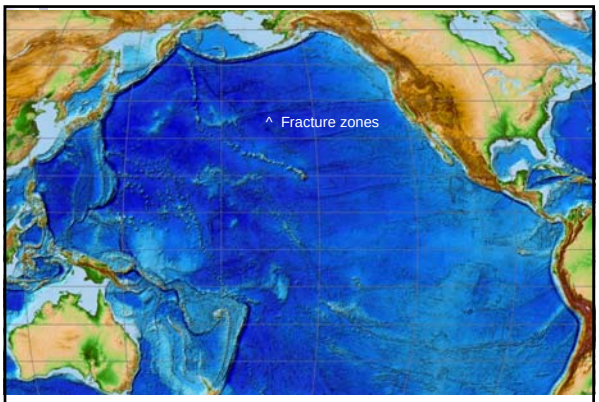
http://www.ngdc.noaa.gov/mgg/image/2minrelief.html



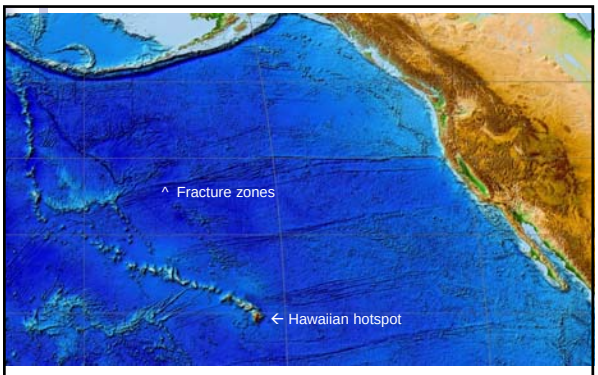
Global topography (etopo1 – 1 arc-minute [1/60th of a degree] grid) http://www.ngdc.noaa.gov/mgg/global/global.html



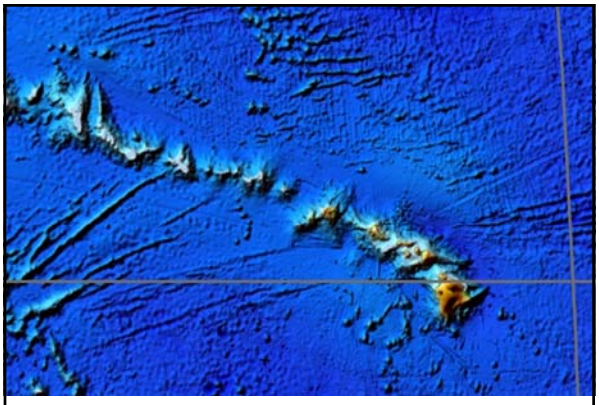
Bathymetry in Pacific and Atlantic Oceans area



Bathymetry in Pacific Ocean area

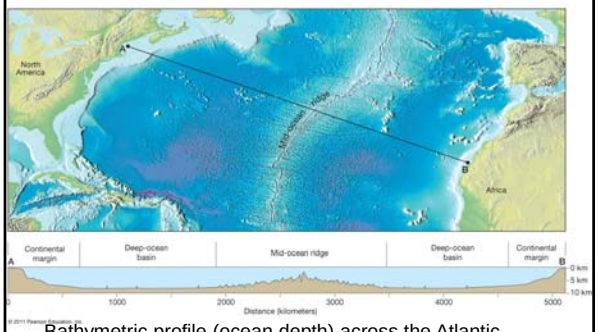


Bathymetry in northern Pacific Ocean area



Bathymetry in Hawaiian Islands area

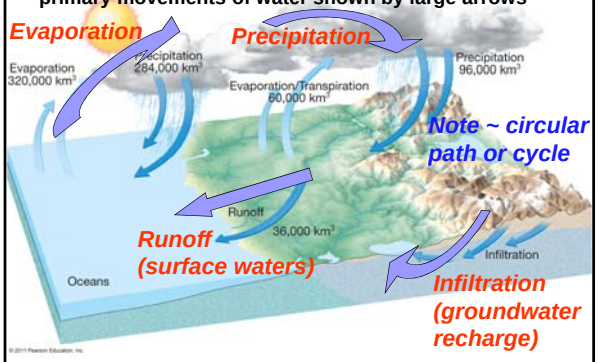
http://www.ngdc.noaa.gov/mgg/global/global.html



Bathymetric profile (ocean depth) across the Atlantic Ocean, Figure 9.16, text.

More on Water

Earth's Water Balance – the *Water Cycle* (Figure 3.6, text); primary movements of water shown by large arrows



How much water do we use each day?
(individual use – not industrial)
Daily use, family of 4

Use	Amount (liters/day)
Drinking, cooking	30 (1976 data)
Dishwasher	57
Toilet	363
Bathing	303
Laundry	130
Watering Plants	4
Sink, disposal	13
Total	900

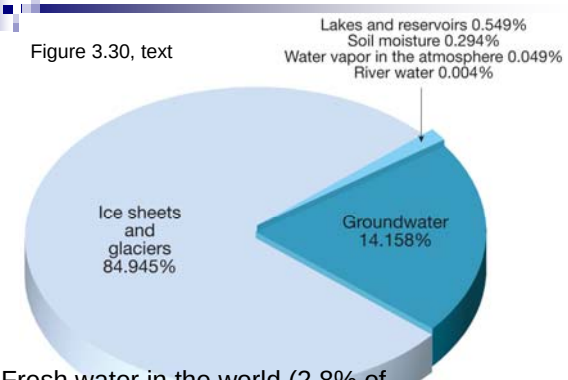
or, ≈ 240 liters/day!

(More recent data suggest that the amount is ≈ 350 liters/day)

"All the Water in the World"

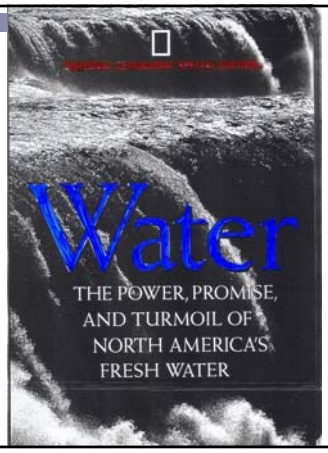
Category	% of total water	Amount scaled to 100L
Ocean	97.2%	97.2 L
Sea ice & glaciers	2.15	2.15
Groundwater	0.625	625 ml
Lakes, fresh	0.009	9 ml
Lakes, salty	0.008	8 ml
Atmospheric water vapor	0.001	1 ml
Rivers	0.0001	0.1 ml (about 2 drops)

Figure 3.30, text

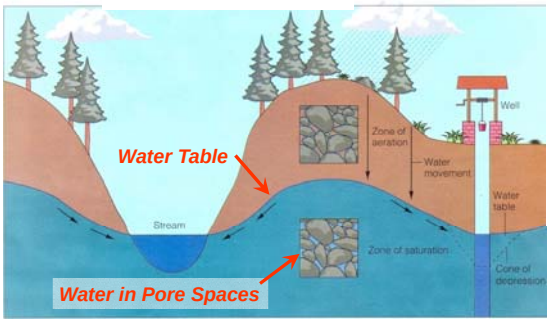


Fresh water in the world (2.8% of *all* water; remainder is sea water)

November, 1993 issue of National Geographic



Groundwater



Causes of Ocean Currents:

1. Tides (Earth, Moon, Sun gravitational attraction) cause surface waters to move

2. Trade winds (surface friction at ocean/ atmosphere interface)

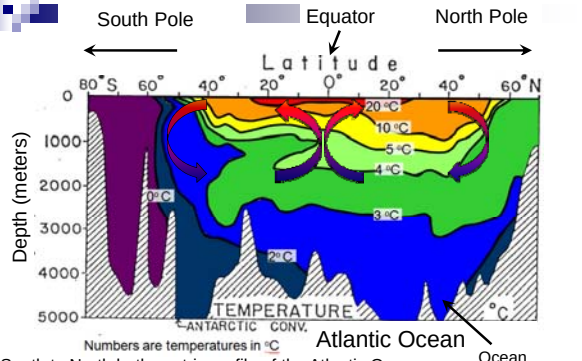
3. Temperature variations
   - -- Warm waters rise, cool waters sink due to density variations
   - -- Heating and cooling of waters related primarily to location (polar, mid-latitude, equatorial), climate, seasons and weather

Causes of Ocean Currents (continued):

4. Salinity variations (Excess evaporation in some locations leads to increased salinity, and therefore density, and sinking waters

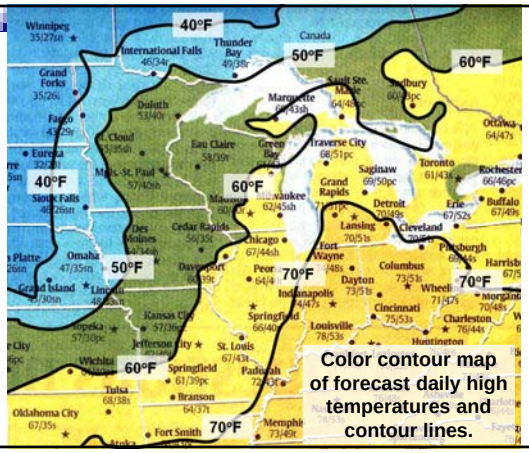
Results: Once water is moving, direction of the current is influenced by the ***Coriolis Effect*** (deflection to the right in N. hemisphere), the shape of the ocean basin and changes in one or more of the four causes of currents.

Currents cause mixing, dispersal, and, sometimes, concentration.

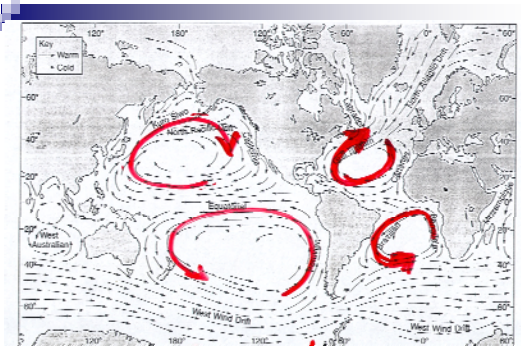


South to North bathymetric profile of the Atlantic Ocean and temperature contours (degrees C). Note that resulting currents (sinking cold, dense water near poles; arrows) cause "pole-ward" surface current.

Color contour map of forecast daily high temperature

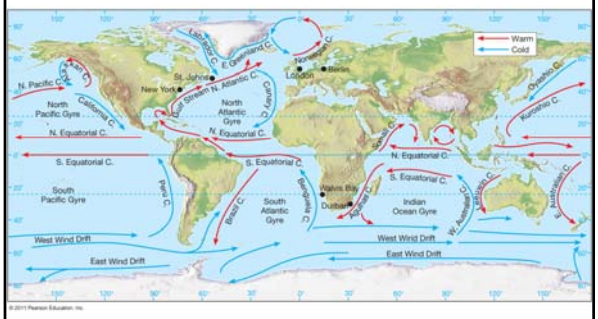


Color contour map of forecast daily high temperatures and contour lines.

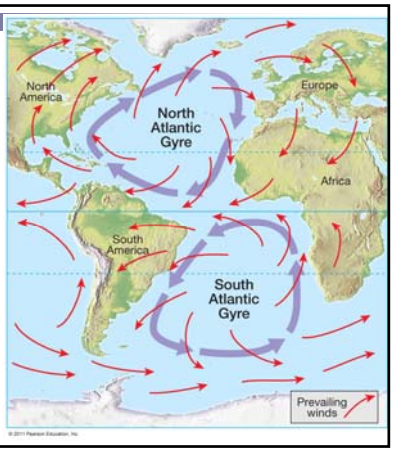


Primary surface ocean currents in Atlantic and Pacific Oceans. Deflection to the right in the Northern hemisphere cause clockwise circulation.

Major Ocean Currents – red arrows show warm currents, blue arrows show cold currents (text, Figure 10.2)



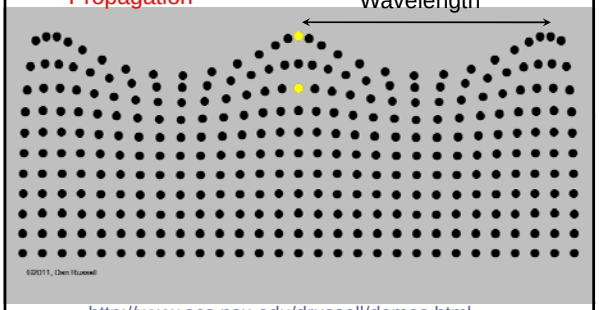
Major Ocean Currents (Text, Figure 10.2)



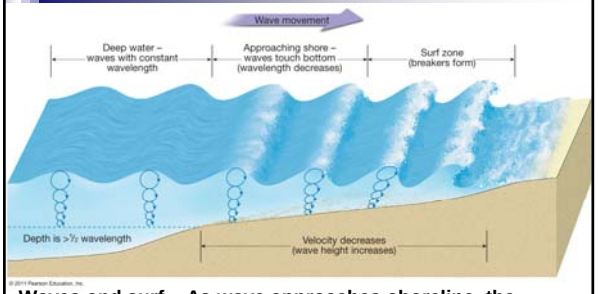
Water Wave – Prograde eliptical motion; wave penetrates to ~ ½ wavelength in depth

Propagation

Wavelength

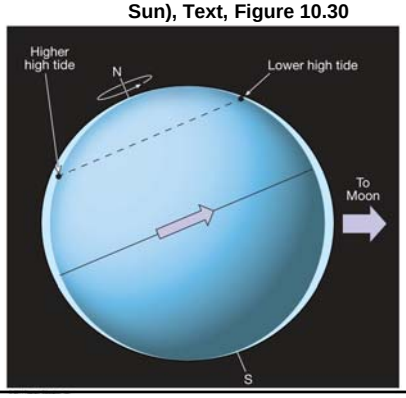


http://www.acs.psu.edu/drussell/demos.html



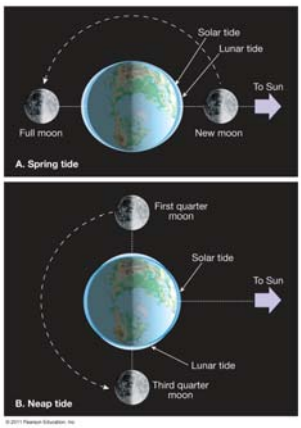
Waves and surf – As wave approaches shoreline, the wavelength shortens and the amplitude increases (conservation of energy). Sam effect occurs with tsunami waves but the wavelength are much, much longer so energy can be greater (Text, Figure 10.11)

Tides (gravitational attraction of the Moon and the Sun), Text, Figure 10.30



Spring and Neap Tides. Gravitational attraction of the Moon and the Sun cause ocean tides. Earth's rotation every 24 hours causes ~ two high and two low tides in a day at any location.

Revolution of the Moon (~28 day period), ~23 degree tilt of the Earth, and irregular coastlines result in variations in tidal amplitudes. (Text, Figure 10.31)



Solar and lunar tide in 24 hours and 50 minutes

0 hrs

https://oceanservice.noaa.gov/education/kits/tides/media/supp_tide05.html

Spring Tides

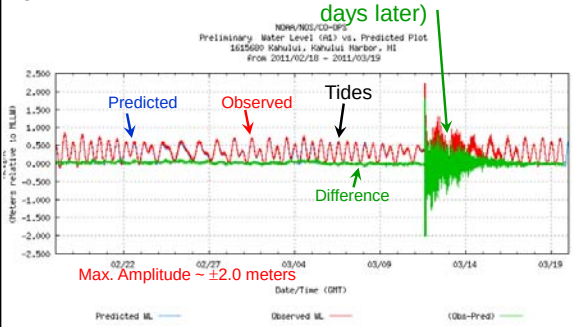
Solar and lunar tide in one lunar month (note: Earth's rotation is not shown)

https://oceanservice.noaa.gov/education/kits/tides/media/supp_tide06a.html

Solar Tides
Lunar Tides

Kahului, Maui Tide data, February 18 - March 20, 2011 GMT

Tsunami (still propagating through Pacific Ocean 7 days later)



Bay of Fundy tides, up to ~16 meters
(http://www.planetware.com/map/bay-of-fundy-tide-levels-map-cdn-cdn15.htm)

Extreme tides in the Bay of Fundy, Nova Scotia

Extreme tides in the Bay of Fundy, Nova Scotia (L&T 2014, Figure 10.26; also see Figure 10.29, text)

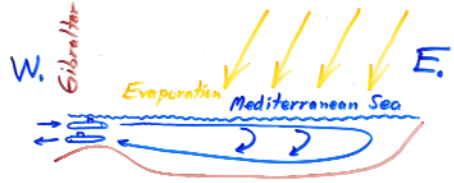
Extreme tides in the Bay of Fundy, Nova Scotia Videos

http://www.youtube.com/watch?v=u3LtEF9WPt4

http://www.youtube.com/watch?v=5W2sM1Ma7YA

Location of the Mediterranean Sea (note ~ 35 degrees N latitude) and the Strait of Gibraltar (arrow).

West to East cross section showing currents in the Mediterranean Sea caused by excess evaporation and "closed" ocean basin. Shallow waters become more saline through evaporation and then sink. Surface flow from the Atlantic (from the west) provides relatively low salinity surface waters. Result is a density-driven current.



Low density surface waters flow into the Mediterranean past Gibraltar due to sinking of high salinity waters caused by evaporation; the deep, high density waters flow out into the Atlantic. Result is a density-driven current.

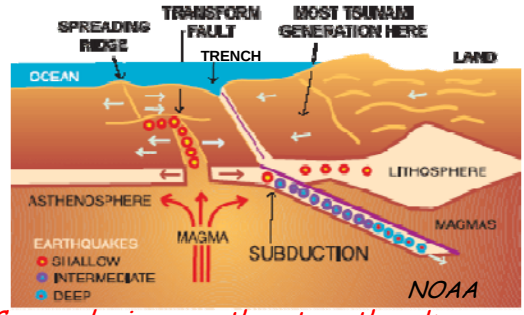
Ocean current discovery during World War II resulted in strategic military advantage.

Tsunamis can be generated by:

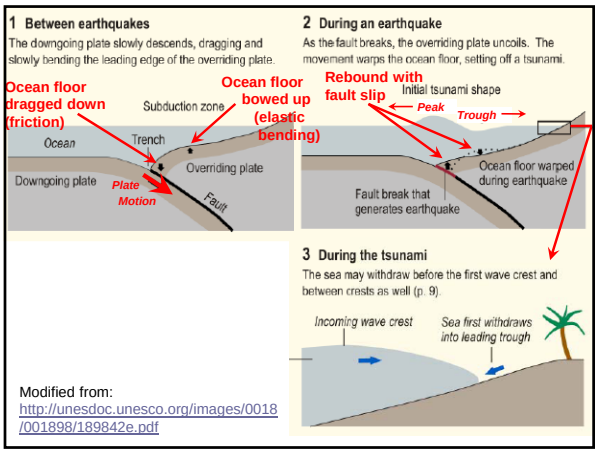
1. *Large Earthquakes (megathrust events such as Sumatra, Dec. 26, 2004, Japan, Mar. 11, 2011)*
2. *Underwater or coastal volcanic eruptions (Krakatoa, 1883)*
3. *Comet or asteroid impacts (evidence for tsunami deposits from the Chicxulub impact 65 mya)*
4. *Large landslides that extend into water (Lituya Bay, AK, 1958)*
5. *Large undersea landslides (evidence for prehistoric undersea landslides in Hawaii and off the east coast of North America)*

http://web.ics.purdue.edu/~braile/new/SumatraEQandTsunami122604New.ppt

1. Megathrust Earthquake - Schematic plate tectonic setting for tsunami generation



Commonly, in mega-thrust earthquakes, a very large area of the ocean floor is uplifted

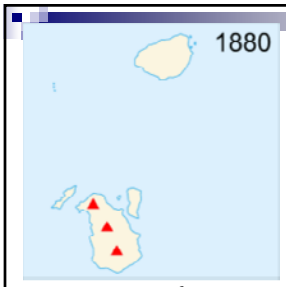


Modified from:
http://unesdoc.unesco.org/images/0018/001898/189842e.pdf

2. Undersea Volcanic Eruption

Eruption of Krakatoa, 1883 – Location: Sunda Strait

http://en.wikipedia.org/wiki/Krakatoa



Eruption of Krakatoa, 1883 – a mostly undersea volcano

Time sequence of Krakatoa activity – 1880-2005

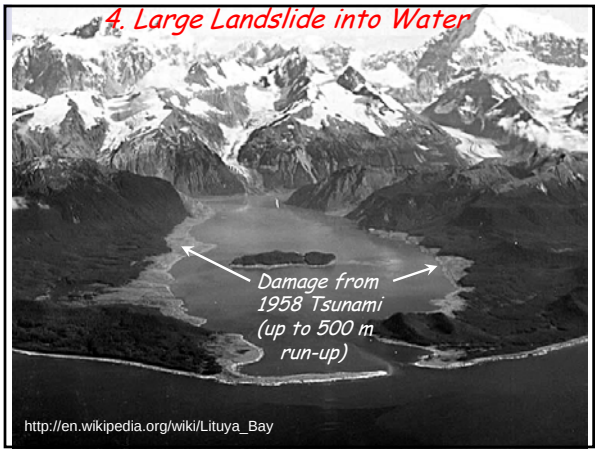
Anak Krakatoa ("child of Krakatoa")

http://en.wikipedia.org/wiki/Krakatoa

3. Impact Event in Ocean

http://news.bbc.co.uk/nol/shared/spl/hi/pop_ups/07/sci_nat_enl_1189018470/img/1.jpg

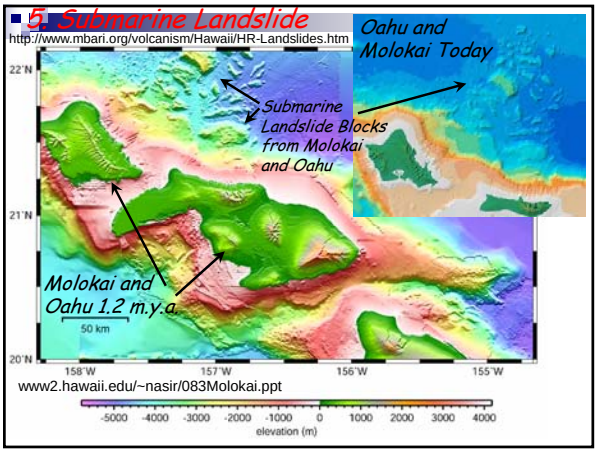
4. Large Landslide into Water



http://en.wikipedia.org/wiki/Lituya_Bay

5. Submarine Landslide

http://www.mbari.org/volcanism/Hawaii/HR-Landslides.htm



www2.hawaii.edu/~nasir/083Molokai.ppt

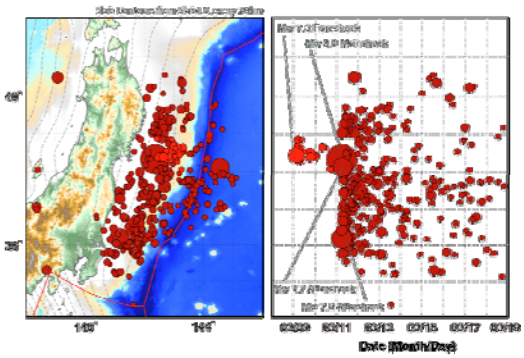
Chedi Resort, Phuket, Thailand, wave height ~4+ m (?, from estimates of water level from beach umbrellas on grassy area above the beach)

Banda Aceh, Sumatra, before tsunami
http://geo-world.org/tsunami/

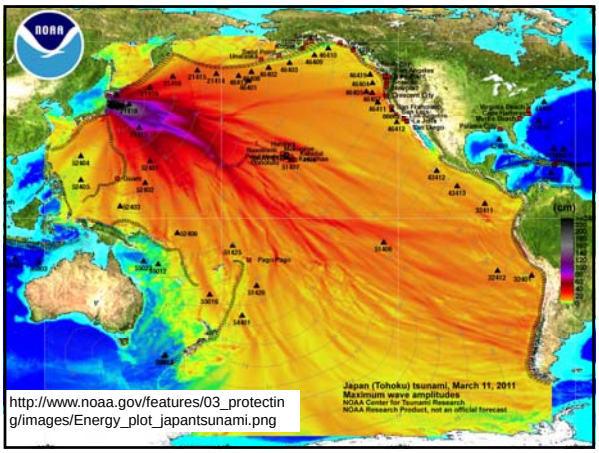
Banda Aceh, Sumatra, after tsunami
Also: http://www.digitalglobe.com/

Up to 10 m high tsunami waves hit coastal area near Sendai, in northern Honshu, Japan

Tohoku, Japan Earthquake: Aftershock (and Foreshock) Sequence, 03/08/11 - 03/16/11



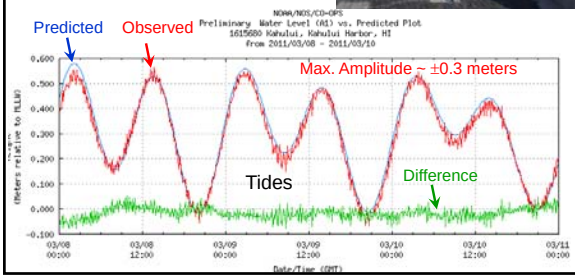
Note that the magnitudes of the 2011/03/11 06:15 (Mw 7.9) and 2011/03/11 06:25 (Mw 7.7) aftershocks were updated from earlier, lower estimates. Updates occurred on 03/16 and 03/18, respectively.



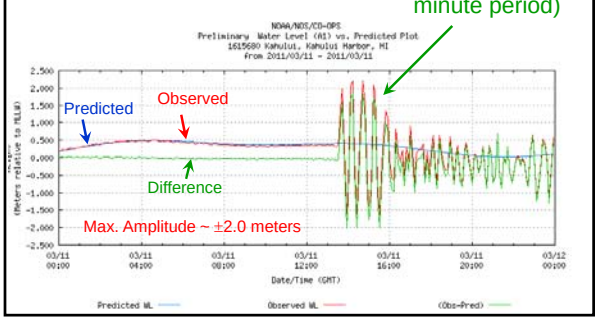
http://www.noaa.gov/features/03_protecting/images/Energy_plot_japantsunami.png

Kahului, Maui Tide data, March 8 – March 10, 2011 GMT

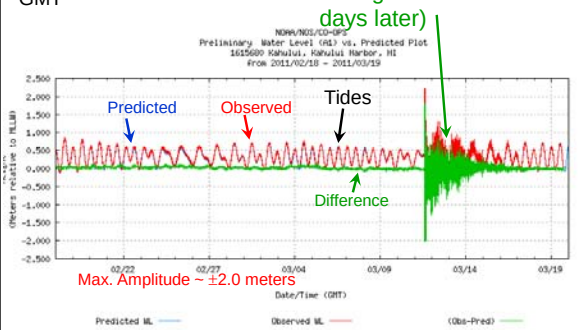
(http://tidesandcurrents.noaa.gov/index.shtml, http://tidesandcurrents.noaa.gov/station_retrieve.shtml?type=Tide+Data)



Kahului, Maui Tide data, March 11, 2011 GMT



Kahului, Maui Tide data, February 18 - March 20, 2011 GMT



Tsunami Videos:

Tsunami wave spills over seawall, smashes boats, cars
http://www.youtube.com/watch?v=5-zfCBCq-8I&feature=player_embedded#at=22

Massive Quake Triggers Tsunami in Japan
http://www.youtube.com/watch?v=1XpSLiPHLPk&feature=player_embedded

Japan Earthquake 3.11.2011 - Tsunami hits
http://www.youtube.com/watch?v=s8L2kikyVzk&feature=player_embedded

TSUNAMI SENDAI AIRPORT (JAPAN 3/11/11)
http://www.youtube.com/watch?v=k6agTZo3E5Y&feature=related

First tsunami waves hit Hawaii islands, California coast after Japan 2011 earthquake
http://www.youtube.com/watch?v=FEeHkr5ew3c&feature=related

Crescent City CA March 11 2011 Tsunami Time Lapse video
http://www.youtube.com/watch?v=ai6pPk0VHDY

Crescent City Takes Tsunami Toll
http://www.youtube.com/watch?v=SPqCX1FUdU0

Tsunami rocks boats in Santa Cruz harbor
http://www.youtube.com/watch?v=cswolureeF4

Wall of Water Slams Japanese Town
http://news.yahoo.com/video/world-15749633/wall-of-water-slams-japanese-town-24518186

Kailua Kona Tsunami Time Lapse 2011 Bay Front
http://www.youtube.com/watch?v=YjCV182S5y4&feature=player_embedded

Japanese Earthquake Tsunami Wave arrives in Emeryville CA
http://www.youtube.com/watch?v=jdMDCLwblkY&feature=player_embedded

Tsunami Near Sendai Airport

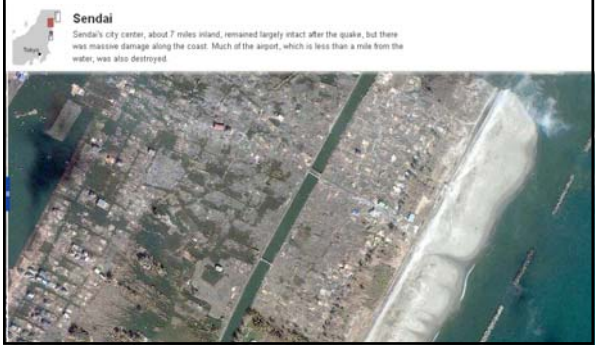
Tsunami Damage Near Sendai

Tsunami Damage from the Tohoku [Northern Honshu, Japan] M9.0 Earthquake of March 11 – Satellite View before Tsunami

http://www.nytimes.com/interactive/2011/03/13/world/asia/satellite-photos-japan-before-and-after-tsunami.html

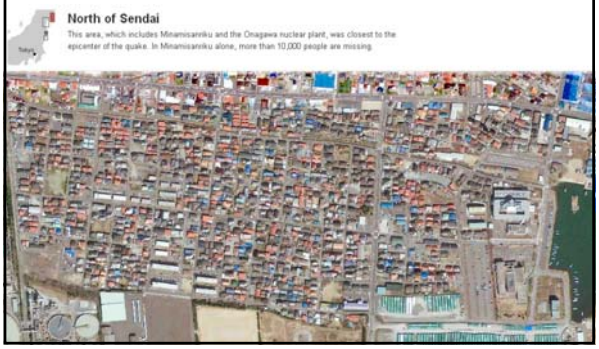
Tsunami Damage from the Tohoku [Northern Honshu, Japan] M9.0 Earthquake of March 11 – Satellite View after Tsunami

http://www.nytimes.com/interactive/2011/03/13/world/asia/satellite-photos-japan-before-and-after-tsunami.html



Tsunami Damage from the Tohoku [Northern Honshu, Japan] M9.0 Earthquake of March 11 – Satellite View before Tsunami

http://www.nytimes.com/interactive/2011/03/13/world/asia/satellite-photos-japan-before-and-after-tsunami.html



Tsunami Damage from the Tohoku [Northern Honshu, Japan] M9.0 Earthquake of March 11 – Satellite View after Tsunami

http://www.nytimes.com/interactive/2011/03/13/world/asia/satellite-photos-japan-before-and-after-tsunami.html

Earthquake and Tsunami Safety

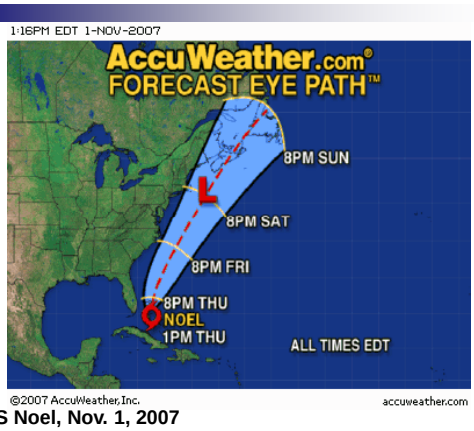
- *Earthquake safety* – "Duck and cover".
- *Tsunami safety* (when in a coastal, near-sea-level area; two situations: local EQ or distant EQ):
- If you feel strong shaking for 15+ seconds; after shaking, move to higher ground.
- If there is a tsunami warning, or if you observe unusual waves (appear to be large and rapid tidal changes, or water recedes), move to higher ground.
- Do not return until event is over; a tsunami includes multiple waves sometimes separated by 10-30 minutes and may last for hours.

Shoreline Processes:

1. Erosion and deposition along beach are natural and inevitable processes.
2. Long term effects:
   - -- Sea level rise and fall
   - -- Uplifting or subsiding (sinking) coastlines
3. Effects of human-made structures:
   - -- Coastal development
   - -- Dune & beach nourishment
   - -- Breakwaters, groins

Shoreline Processes (continued):

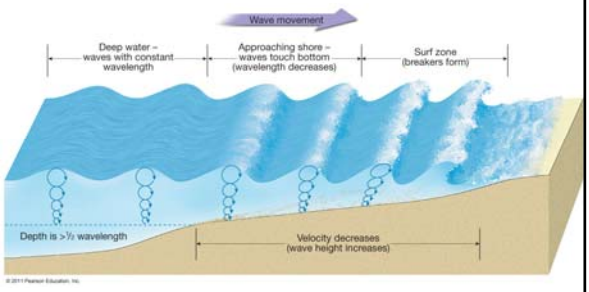
4. Surf and tidal zone susceptible to storm damage (most erosion during storms)
5. ~75% of US population lives in counties adjacent to shorelines



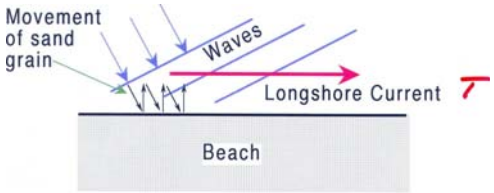
TS Noel, Nov. 1, 2007

Beach erosion in Florida, TS Noel, Nov. 1, 2007

Wave moving onto shore (text, Figure 10.11)

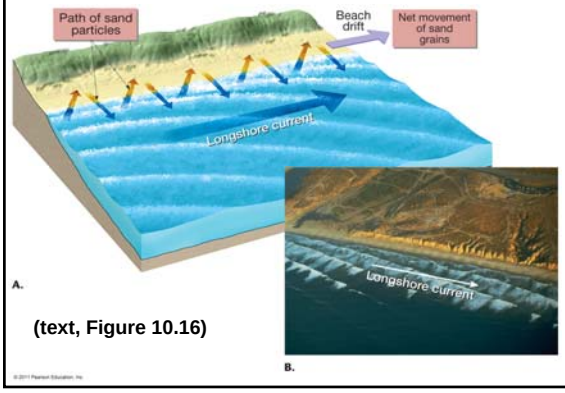


6. Longshore current – most important factor in beach erosion and deposition



(see Figure 10.16, text)

The longshore current



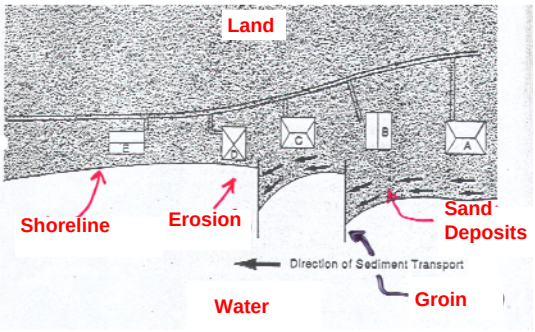
(text, Figure 10.16)

Shoreline Processes (continued):

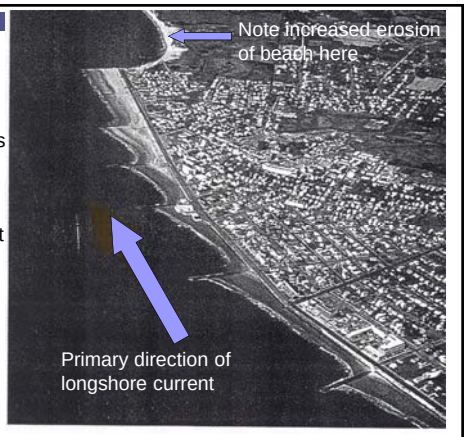
7. Shoreline "protection"
   - -- Beach nourishment
   - -- Armoring – seawalls, groins, etc.

(see p. 308-320 of text)

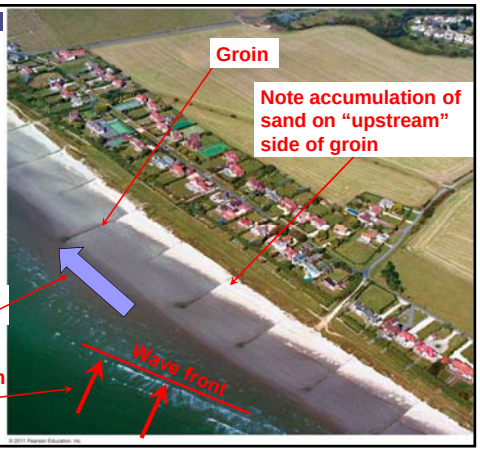
Longshore current interrupted by groins which partially prevent movement of sand and result in erosion "downstream"



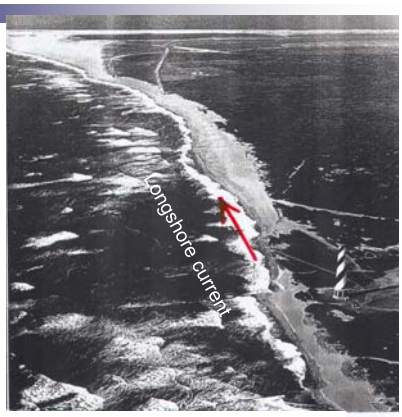
Cape May, NJ, view looking south; groins protect the shoreline in front of buildings but cause increased erosion to south.



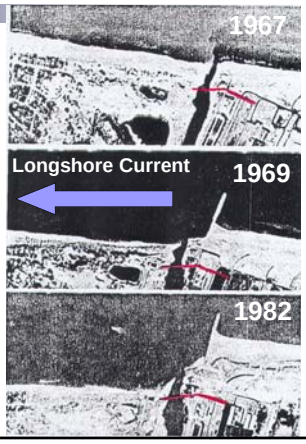
Series of groins protecting beach near Chichester, Sussex, England (Figure 10.25, text).



U.S. Atlantic coast, view looking south; ~ 400 m of beach erosion in the past 100 years. Groins built to protect lighthouse which is now endangered again.

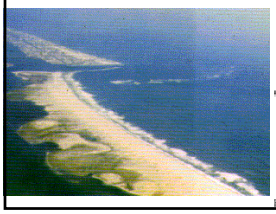


Beach erosion on shoreline of Lake Michigan, Burns/Portage Waterway, Michigan City, IN (red line marks road and bridge)



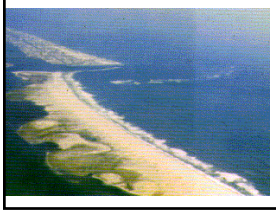
Barrier island, Ocean City, Maryland

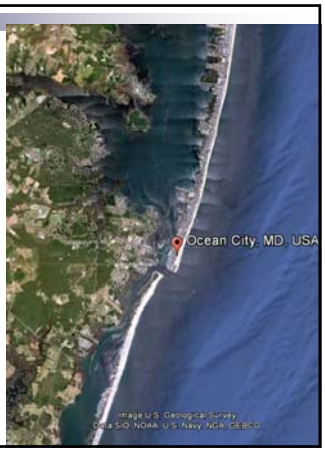
(http://pubs.usgs.gov/circ/c1075/conflicts.html)



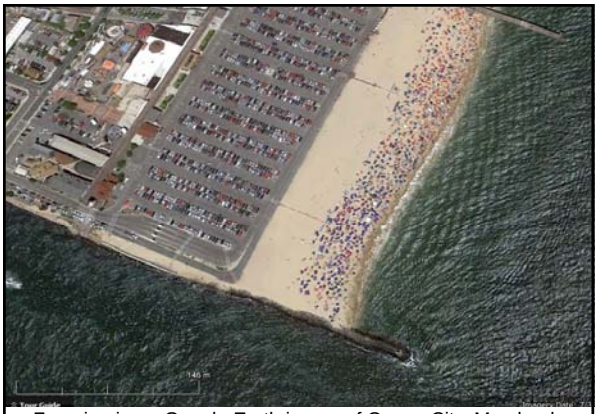
Barrier island, Ocean City, Maryland

(http://pubs.usgs.gov/circ/c1075/conflicts.html, and Google Earth image)





Zooming in on Google Earth image of Ocean City, Maryland

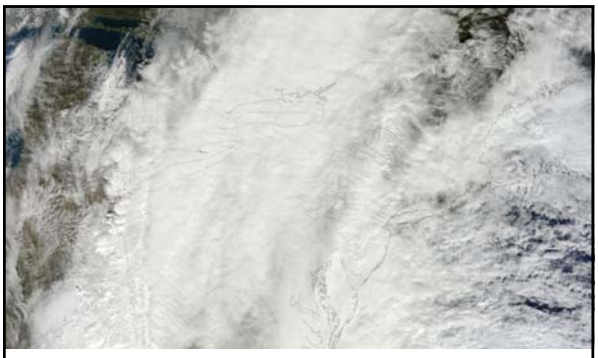


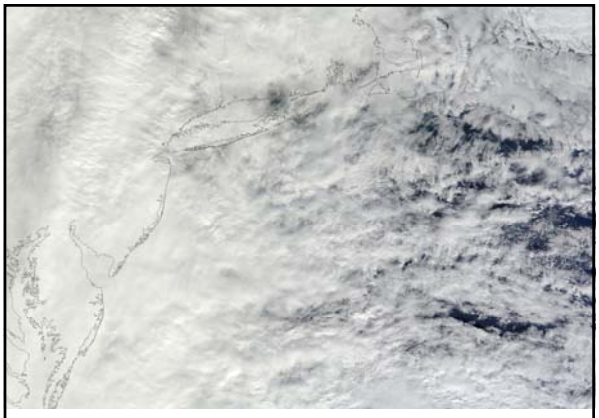
Zooming in on Google Earth image of Ocean City, Maryland

http://www1.ncdc.noaa.gov/pub/data/images/2011-Landfalling-Hurricanes-11x17.pdf

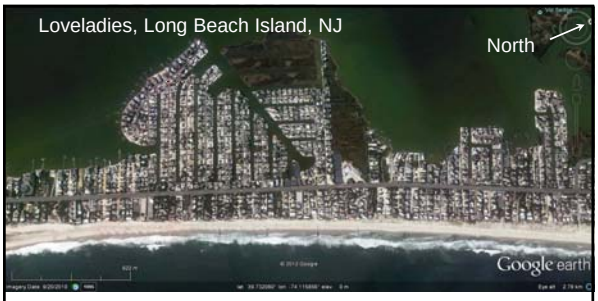
Hurricane Sandy – Oct. 29, 2012

http://en.wikipedia.org/wiki/Hurricane_Sandy

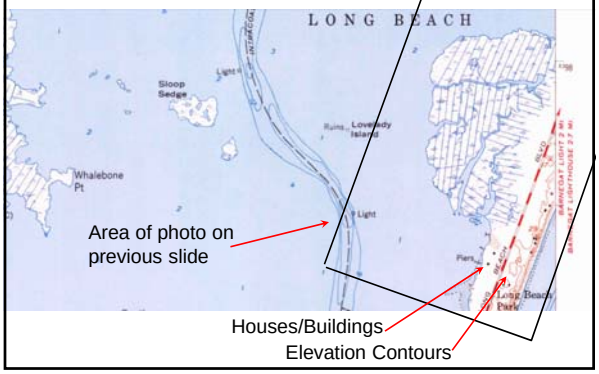




Hurricane Sandy Damage – Mantoloking, NJ
http://en.wikipedia.org/wiki/Hurricane_Sandy



USGS Topo Map (NJ Ship Bottom) 1952



Houses built on very low elevation barrier island can be damaged or destroyed by storm surge, high winds and wave action from hurricanes or tropical storms such as "super-storm Sandy."

The original high resolution photo can be viewed at http://www.nasa.gov/mission_pages/hurricanes/archives/2012/h2012_Sandy.html.

Houses built on very low elevation barrier island can be damaged or destroyed by storm surge, high winds and wave action from hurricanes or tropical storms such as "super-storm Sandy."

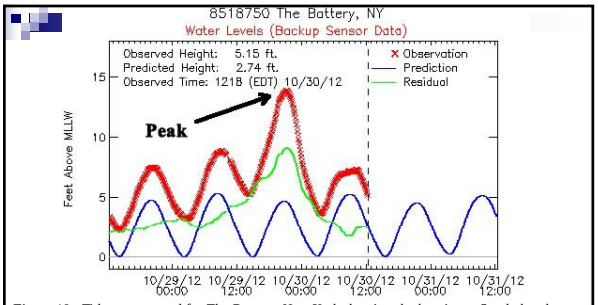


Figure 19. Tide gage record for The Battery, New York showing the hurricane Sandy local storm surge sea level (red symbols). Note that the observed sea level is the sum of the normal tide (blue line and the surge (residual, green line). Because the maximum surge occurred (coincidentally) during high tide, it was larger than if it had occurred during normal or low tide. From: http://www.washingtonpost.com/blogs/capital-weather-gang/post/hurricane-sandy-recap-historic-storm-from-storm-surge-to-snow/2012/10/31/9a7c56d8-2362-11e2-ac85-e669876c6a24_blog.html. *Additional information on shoreline buildings and Hurricane Sandy can be found at:* http://web.ics.purdue.edu/~braile/EAS100online/NE.Hurricanes.pdf.

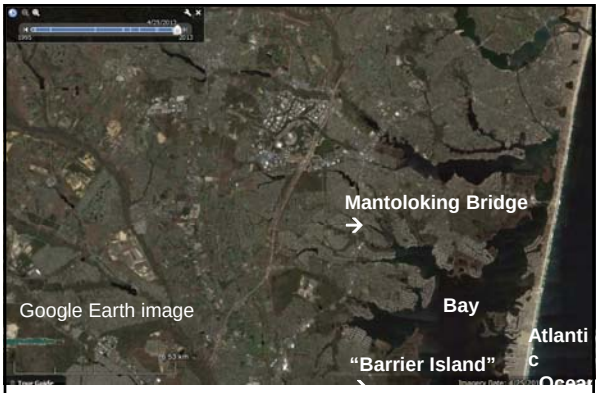
Additional information on shoreline processes – March, 2014, L. Braile

We have discussed the Ocean City, Maryland beach nourishment shoreline protection program, and shoreline effects of super storm Sandy, in class. Additional information on shoreline processes, northeastern U.S. hurricanes, damage from Sandy are illustrated here and in the NE.Hurricanes.pdf document below.

http://web.ics.purdue.edu/~braile/EAS100online/NE.Hurricanes.pdf

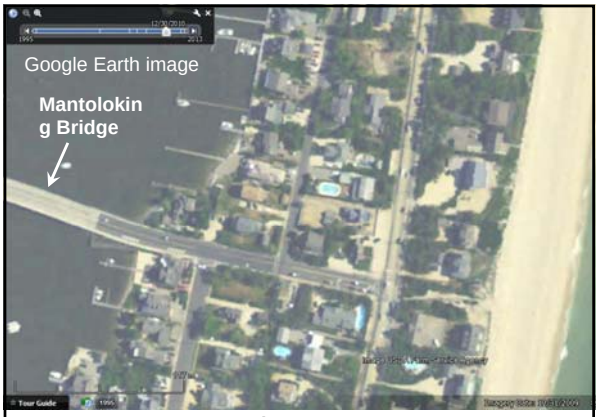
Sandy caused about 60 billion dollars in damages. Much of the damage was to houses such as in the Long Beach and Mantoloking areas of New Jersey. This raised the longstanding issue of whether people should be compensated to rebuild their homes or if these near-sea-level, coastal areas should be "off-limits" to building.

Coastal area and barrier islands, East coast of U.S.



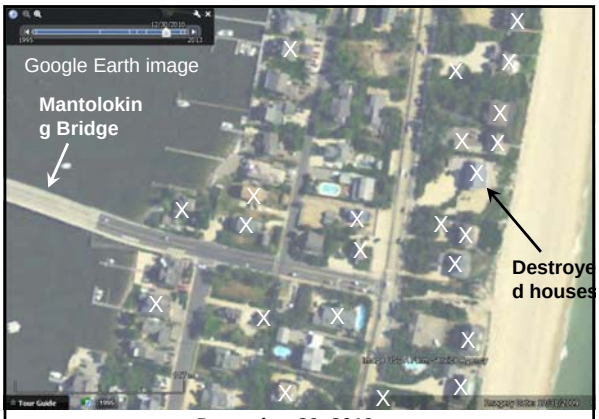
Mantoloking, NJ, April 25, 2013, note many houses near shorelines

December 30, 2010 November 3, 2012 April 25, 2013



December 30, 2010

November 3, 2012



December 30, 2010

April 25, 2013

April 25, 2013 – About 22 of 37 houses (X) in this area from December 30, 2010 image were destroyed by Sandy

Ocean Pollution:

"Eighty percent of pollution to the marine environment comes from the land. One of the biggest sources is called nonpoint source pollution, which occurs as a result of runoff. Nonpoint source pollution includes many small sources, like septic tanks, cars, trucks, and boats, plus larger sources, such as farms, ranches, and forest areas. Millions of motor vehicle engines drop small amounts of oil each day onto roads and parking lots. Much of this, too, makes its way to the sea." (http://oceanservice.noaa.gov/facts/pollution.html)

1. Natural:
   - Oil seeps
   - Black smokers
   - Algae (some is toxic to fish and shellfish, "red tide")

So, we often focus on the "big spills" that occur occasionally. However, there are also natural sources of ocean pollution and, the pollution from the land, mostly from human activities (as stated above), is the largest source.

2. Human caused:
   - Oil spills*
   - Chemicals (runoff -- oil, fertilizers, pesticides, industrial waste)
   - Sewage (dumping and runoff)
   - Solids (metals, plastics)
   - Acid Rain and other airborne pollution

* We often focus on oil spills in the ocean as they are often large events and "make the news," however, the information in the previous slide shows that pollution from the land is far more significant!

Oil Spills

A large percentage of ocean pollution is related to production of **energy** – oil (spills on oceans, waterways, and on land), burning of fuels (oil, natural gas, gasoline, coal). So, a discussion of use of fossil fuel energy is appropriate.

The following slides are related to **energy** and **pollution,** details and data/statistics that can't be fully memorized. However, there is a "take-away" message for nearly every slide. One cannot understand these subjects without some recognition of these details/data.

Energy Basics - Energy Units and Conversions:

BTU Content of Common Energy Units

1 barrel (42 gallons) of crude oil = 5,800,000 Btu
1 gallon of gasoline = 124,000 Btu
1 gallon of heating oil or diesel fuel = 139,000 Btu
1 cubic foot of natural gas = 1,026 Btu
1 gallon of propane = 91,000 Btu
1 short ton of coal = 20,681,000 Btu
1 kilowatthour of electricity = 3,412 Btu

U.S. Units		Equivalent Metric Units
1 British thermal unit (Btu)	=	1,055.055 joules (J)
1 calorie (cal)	=	4.1868 joules (J)
1 kilowatthour (kWh)	=	3.6 megajoules(MJ)

What's a million Btu (10^6 Btu) of energy?

Coal 1,000,000 Btu = 1066.5 megajoules = 0.045 metric tonnes

Electricity 1,000,000 Btu = 293.1 kilowatthours (kWh) (about 6 days of home electricity use, other than heating)

Natural Gas 1,000,000 Btu = 27.7 cubic meters = 977.5 cubic feet (~ 1 tcf) = 10 therms (about 3 days of natural gas home heating)

Crude Oil 1,000,000 Btu = 0.172 barrel = 27.3 liters = 7.22 gallons

Gasoline 1,000,000 Btu = 30.43 liters = 8.040 gallons (about "half a tank of gas" in vehicle)

Diesel Fuel/Heating Oil 1,000,000 Btu = 27.29 liters = 7.21 gallons

What's a million Btu (10^6 Btu) of energy?

In the U.S., we use about 100 "Quads" (100 quadrillion, or 100 x 10^{15} Btus per year of energy

Million	**1,000,000**	**10^6**
Billion	**1,000,000,000**	**10^9**
Trillion	**1,000,000,000,000**	**10^{12}**
Quadrillion	**1,000,000,000,000,000**	**10^{15}**

Commonly used energy quantities/units:
MBTU – Million BTUs
Quads (10^{15} BTUs)
MTOE – Million tons of Oil Equivalent
MBDOE – Million Barrels per Day of Oil Equivalent

Online energy information resources

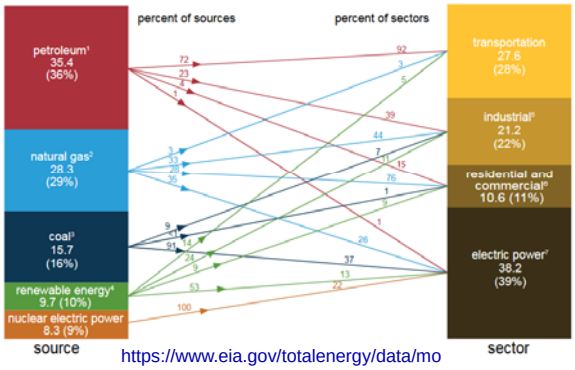
U.S. Energy Information Administration (DOE): https://www.eia.gov/
Annual Energy Outlook: https://www.eia.gov/outlooks/aeo/
Annual Energy Review: https://www.eia.gov/totalenergy/data/annual/

ExxonMobil: http://cdn.exxonmobil.com/~/media/global/files/outlook-for-energy/2017/2017-outlook-for-energy.pdf

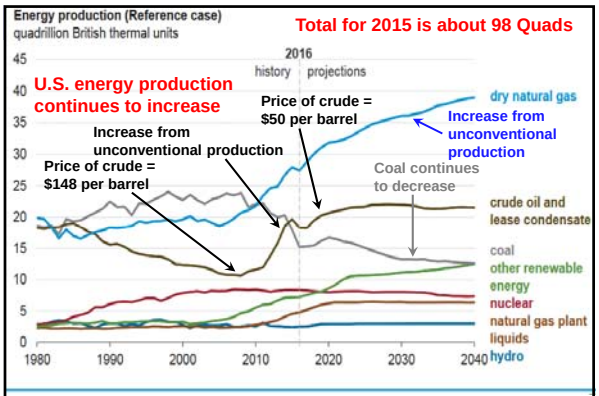
BP: BP Statistical Review of World Energy: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review-2017/bp-statistical-review-of-world-energy-2017-full-report.pdf
BP Energy Outlook 2017: https://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2017/bp-energy-outlook-2017.pdf

Related Abbreviations: EIA – Energy Information Administration; **BP** – British Petroleum; **OECD** – The Organisation for Economic Co-operation and Development (http://www.oecd.org/about/); 35 member countries, many of the world's most advanced countries.

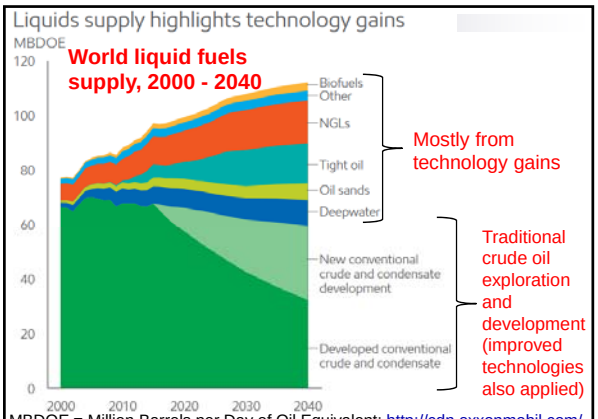
U.S. primary energy consumption by source and sector, 2015
Total = 97.7 quadrillion British thermal units (Btu)



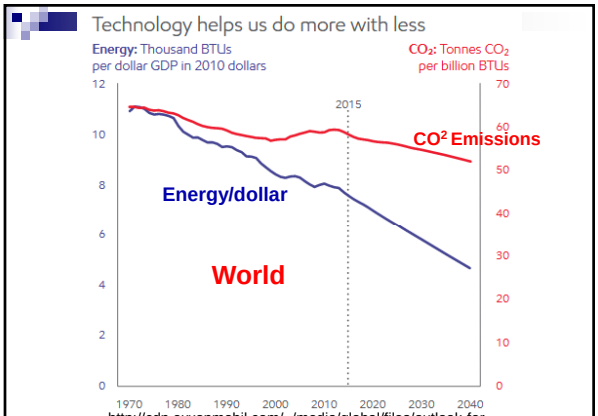
https://www.eia.gov/totalenergy/data/monthly/pdf/flow/css_2015_energy.pdf



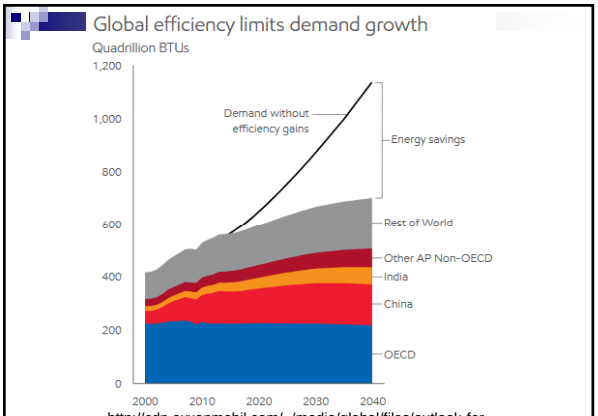
https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf
(with some additions)



MBDOE = Million Barrels per Day of Oil Equivalent; http://cdn.exxonmobil.com/~/media/global/files/outlook-for-energy/2017/2017-outlook-for-energy.pdf



http://cdn.exxonmobil.com/~/media/global/files/outlook-for-energy/2017/2017-outlook-for-energy.pdf



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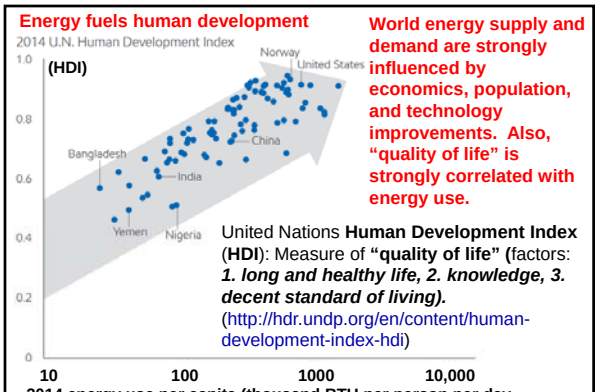

World energy supply and demand are strongly influenced by economics, population, and technology improvements. Also, "quality of life" is strongly correlated with energy use.

United Nations **Human Development Index** (**HDI**): Measure of **"quality of life"** (factors: ***1. long and healthy life, 2. knowledge, 3. decent standard of living).*** (http://hdr.undp.org/en/content/human-development-index-hdi)

http://cdn.exxonmobil.com/~/media/global/files/outlook-for-energy/2017/2017-outlook-for-energy.pdf

Some facts about oil – past, present, and future outlook

- The world has used about 1 trillion barrels of oil (1 barrel = 42 gallons ~ 159 liters).
- There are ~ 4 trillion barrels (*of conventional oil*) remaining (proved reserves ~1.7 trillion bbl., 2015).
- Current consumption: World ~ 88 million barrels/day = 32 billion barrels/yr; US ~ 19 million barrels/day = 6.8 billion barrels/yr (19 million barrels/day!). We also use ~24 Tcf (trillion cubic feet) of natural gas and over 1 Billion tons of coal per year.
- Use of unconventional oil (heavy oil, gas hydrates, oil sands, gas to liquid) and coal gasification resources (with appropriate technology and policy to limit environmental impacts) could greatly extend the use of fossil fuels.

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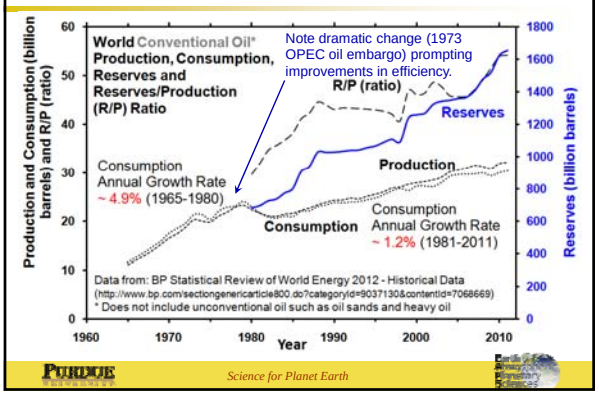
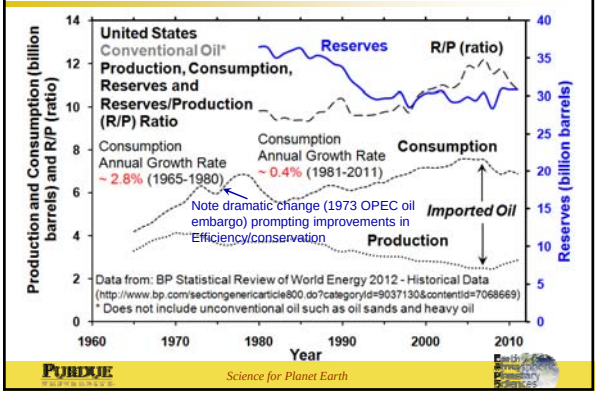
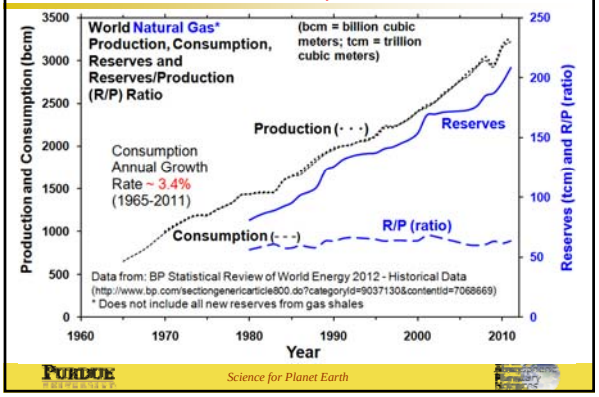
World Oil Production, Consumption, etc., 1965-2011:



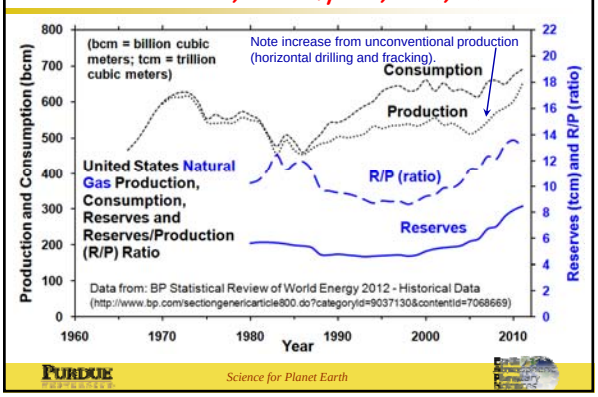
U.S. Oil Production, Consumption, etc., 1965-2011:



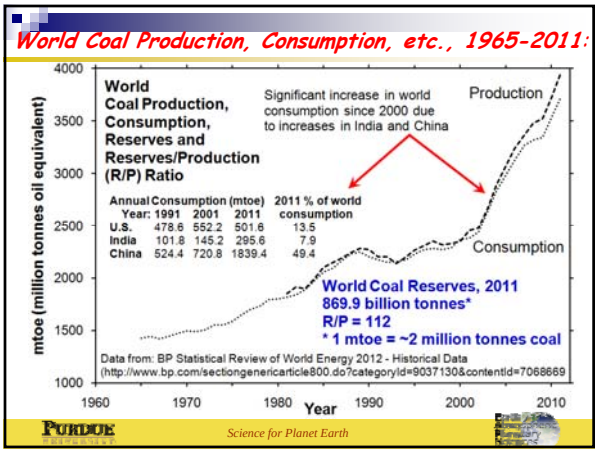
World Gas Production, Consumption, etc., 1965-2011:



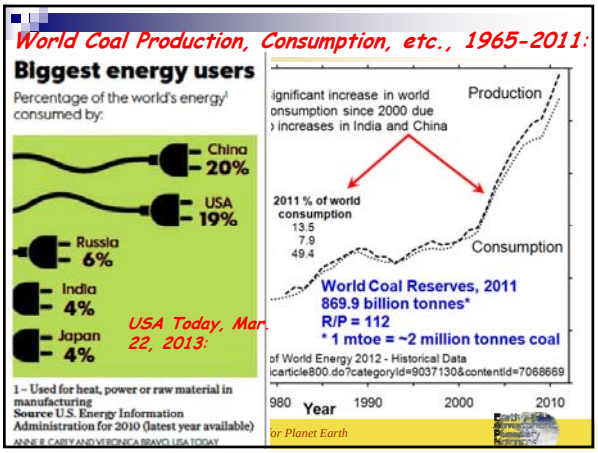
U.S. Gas Production, Consumption, etc., 1965-2011:



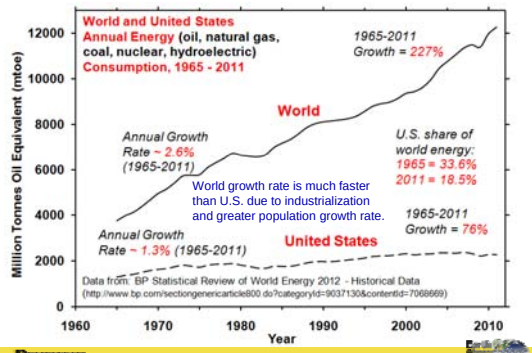
World Coal Production, Consumption, etc., 1965-2011:

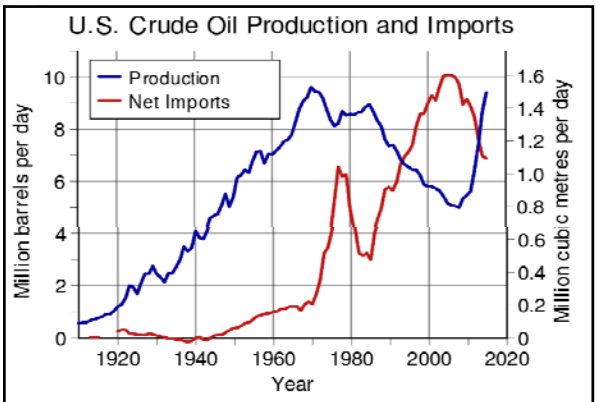


World Coal Production, Consumption, etc., 1965-2011:



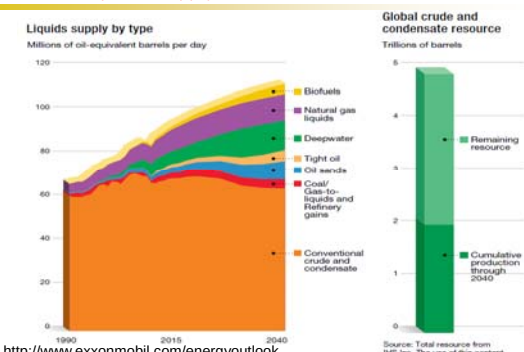
World and U.S. Energy Consumption, 1965-2011:



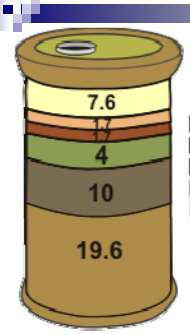


https://en.wikipedia.org/wiki/Peak_oil

World oil (liquids) supply 1990-2040 and reserves:



http://www.exxonmobil.com/energyoutlook



One Barrel of Crude Oil (42 gallons)

- Other Products
- Liquefied Petroleum Gas (LPG)
- Heavy Fuel Oil
- Jet Fuel
- Diesel Fuel & Heating Oil
- Gasoline

In 2016, U.S. consumption was 19.63 million barrels per day (liquid fuels; 7.19 billion barrels per year).

Resource Production versus Time

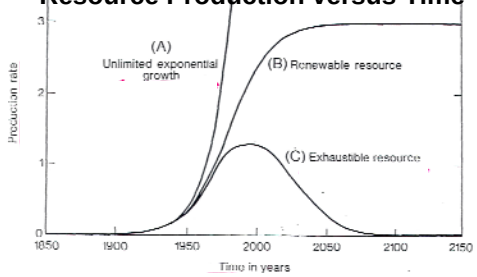
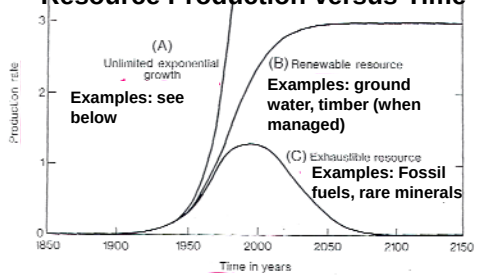
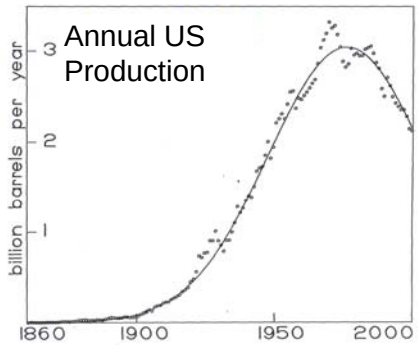


FIGURE 6.4. Schematic growth curves for extraction and/or consumption of a commodity, such as a natural resource (after Hubbert 1985, figure 4.34). Examples from the power industry might include solar and/or fusion energy (A), biomass conversion and/or geothermal energy (B), and petroleum, natural gas, and coal derived energy (C). The ordinate (left-hand axis) can also be considered to represent a population, inasmuch as numbers of people and total consumption are correlated.

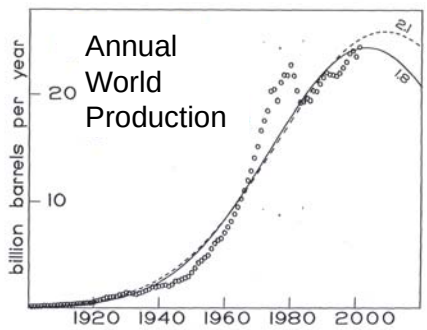
Resource Production versus Time



Examples of "unlimited" growth: fruit fly reproduction experiment; inexpensive product that "catches on" with consumers (mini rubber bands).

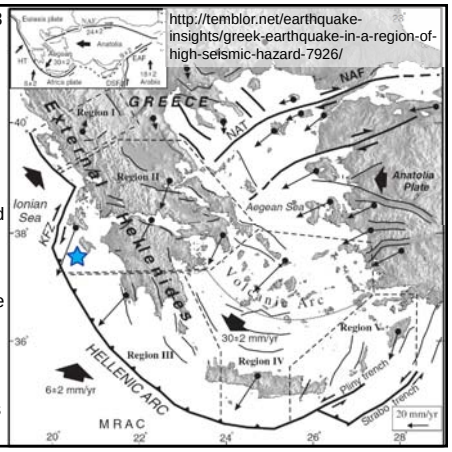


Annual production of U.S. crude oil (circles) with the best-fitting Gaussian curve superimposed as a solid line. Production from Alaska and from offshore oil fields is included.

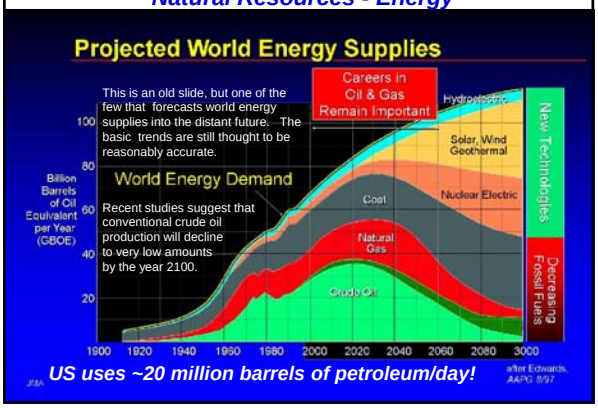


Annual production of world oil (circles), with Gaussian curves corresponding to total eventual oil recovery of 1.8 and 2.1 trillion barrels. A steeper rising curve with its top chopped off by market limitations would make a better fit.

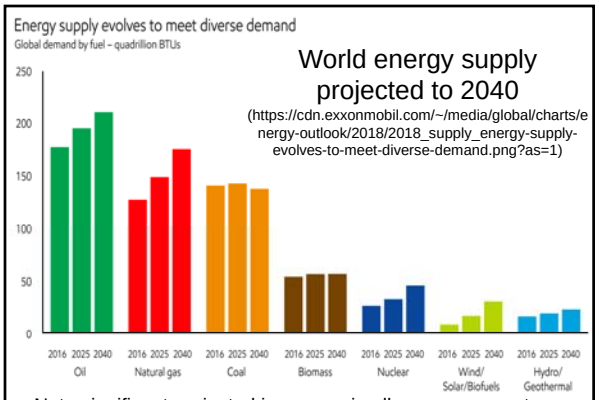
October 25, 2018 M6.8 earthquake (blue star) along the Hellenic Arc subduction zone, near Greece. Note the North Anatolia Fault (NAF) which extends eastward to Turkey (see inset map) and is a large strike slip fault similar to the San Andreas. Also note the significant tectonic complexity of this region.



Natural Resources - Energy

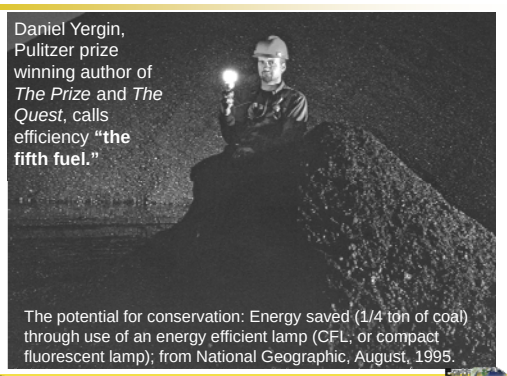


US uses ~20 million barrels of petroleum/day!



Note significant projected increases in all sources except coal and biomass

Conservation (efficiency) as a Strategy:



Daniel Yergin, Pulitzer prize winning author of *The Prize* and *The Quest*, calls efficiency **"the fifth fuel."**

The potential for conservation: Energy saved (1/4 ton of coal) through use of an energy efficient lamp (CFL, or compact fluorescent lamp); from National Geographic, August, 1995.

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- Oil and natural gas are found in underground reservoirs (in "traps") in the pore spaces (the spaces between small grains, such as in sandstone) in porous rock.

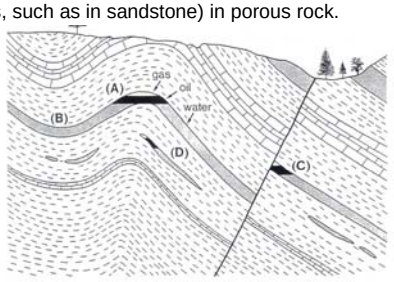
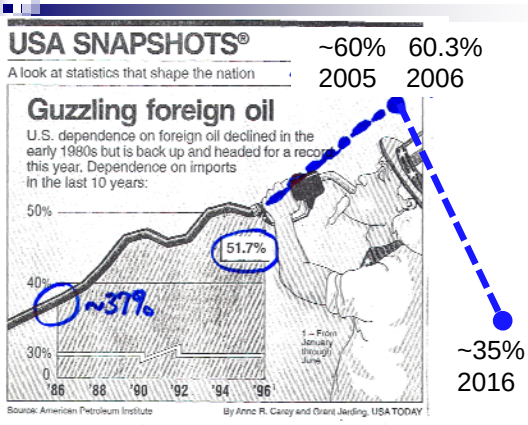
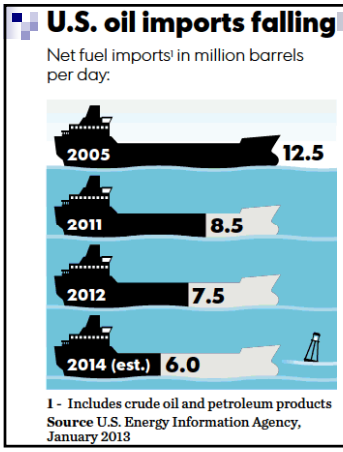


FIGURE 6.8. Schematic cross section of porous, hydrocarbon-bearing sandstones (stippled pattern) interlayered with limestones (brick pattern) and impermeable shales (dashed pattern). The strata are folded and faulted; in addition, some lenses of sandstone occur surrounded by impervious shale. Gas, being least dense, occurs in voids between the sand grains at high levels in structural and stratigraphic traps, oil next, and water—the dominant interstratal fluid—being the densest, occupies interstices in the sandstone reservoir at lower portions of the section.





U.S. oil imports (millions of barrels per day) decrease due to increased domestic production (USA Today, Feb. 18, 2013).

Ocean Pollution Prevention & Reduction:

1. Reduce Number of Spills:
   - Stricter regulations
   - Improved training
   - Improved technology (GPS, etc)
2. Reduce Magnitude of Spills
   - Improved tanker hull design (double bottom, double hull, zero pressure loading)
   - Improve rapid response capability

Oil Spill Recovery Methods:

1. Booms and skimmers
2. Burning
3. Steam cleaning beach
4. Dispersants
5. Bioremediation (bacteria, sometimes aided by added fertilizers)
6. Evaporation (natural)

NATIONLINE

200,000 gallons of oil spills in Gulf of Mexico

Nearly 200,000 gallons of fuel oil spread 20 miles into the Gulf of Mexico and washed up on the coast of Galveston Island before winds died down enough Tuesday to begin a cleanup. Winds gusting up to 50 mph Monday grounded a 275-foot barge, rupturing two of its 12 tanks. The winds hampered immediate efforts to contain the oil. Crews began emptying the remaining 500,000 gallons from the barge and started using oil-eating microbes to clean up the spill. Officials said some crabs were killed but bird deaths were kept down by firing cannons to scare them away from the coast.

Galveston County Daily News

Galveston cleanup: A worker rakes gobs of fuel oil.

Oil spills into Texas waters

By Kevin Bartram, The Galveston County Daily News via AP

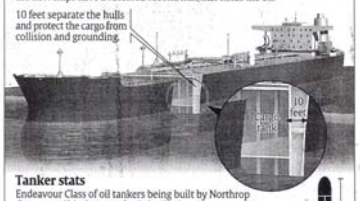
Barge aground: Winds gusting up to 60 knots hampered efforts to clean up about 170,000 gallons of fuel oil that spilled into the Houston Ship Channel and Galveston Bay. Bad weather caused the barge to run aground and break apart, closing the channel briefly.

$42 million damage so far: About 200 students from a nearby naval college help clean the oil-soaked sand near Caiôn on Wednesday.

Two hulls safer than one

USA Today 11/21/02

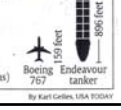
A new generation of oil tankers is being built to replace aging vessels and reduce the chance of disastrous spills. Instead of a conventional single hull, the new ships have a recessed second hull that holds the oil.



Tanker stats

Endeavour Class of oil tankers being built by Northrop Grumman Ship Systems for Polar Tankers Inc.

- **Length:** 896 feet
- **Width:** 152 feet
- **Displacement weight:** 125,000 tons
- **Speed:** 16 knots
- **Cargo tanks:** 12
- **Capacity:** 1 million barrels of oil (1 barrel = 42 gallons)

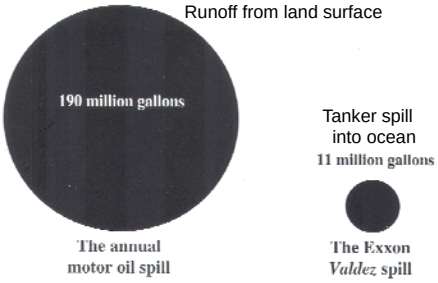


Source: Northrop Grumman Ship Systems

By Karl Gelles, USA TODAY

Other Pollution Sources:

Comparing Oil Spills



SOURCE: U.S. ENVIRONMENTAL PROTECTION AGENCY

International agreements in 1972 and 1988, not fully implemented until 1998, banned ocean dumping. However, dumping large amounts of raw sewage, sewage sludge, and other polluting and hazardous materials into the oceans is still occurring in many areas of the world.

280 times Exxon Valdez Spill!

Mid-Atlantic Sewage Sludge Probed

Every year since 1986, 8 million tons of raw sewage has been dumped into the ocean at the Mid-Atlantic Bight, an area 100 miles off the coasts of New York and New Jersey. Originally, this location was thought to be a safe dump site because of its considerable depth and strong ocean currents, which would prevent sewage from accumulating on the ocean floor. Recently, several scientists tested that assumption and found evidence for significant amounts of sewage accumulation at the dump site.

Scientific studies of the dump site, coordinated by NOAA's National Undersea Research Program, were presented at the American Geophysical Union's Ocean Science meeting January 27–31. The studies reveal the extent of sewage sludge accumulation at the Mid-Atlantic Bight and determine the environmental impact that significant accumula-

the dump site for signs of examined the urchins for ele nitrogen, and sulfur, which derived organic material (SD sea urchins collected from th 25% SDOM sulfur in their levels of sulfur indicate tha tively feeding on the sewag

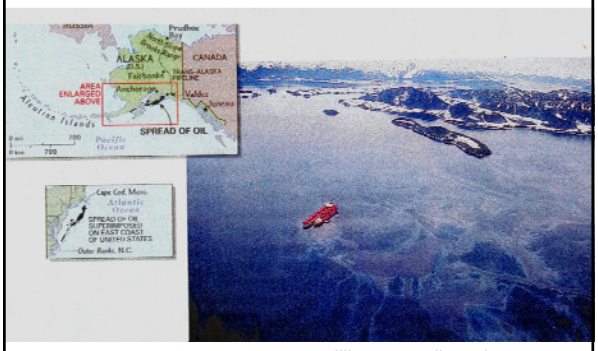
Geomagnetic Distur

National Oceanic and Atmo scientist Jo Ann Joselyn sa netic disturbances, which radio transmissions and t with electrical power distrib activities earlier this year, co al years.

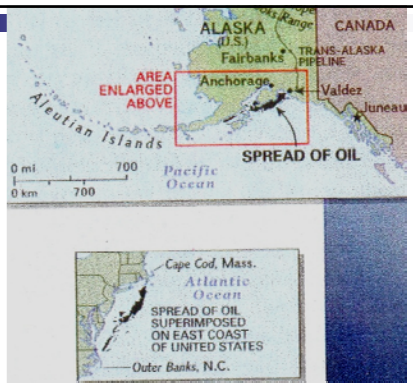
The number of geom

Earth in Space (AGU), February 1992

Plastics take a long time to deteriorate and are unsightly pollution and can cause deaths of animal life.



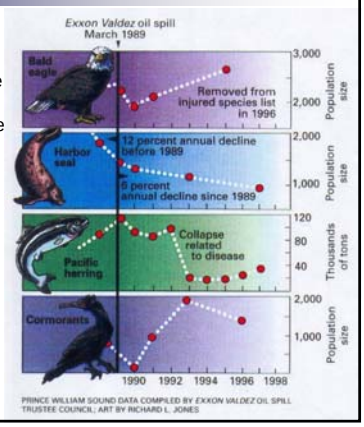
1989 Exxon Valdez oil spill – 11 to 38 million US gallons (260,000 to 900,000 barrels; (Wikipedia, National Geographic)



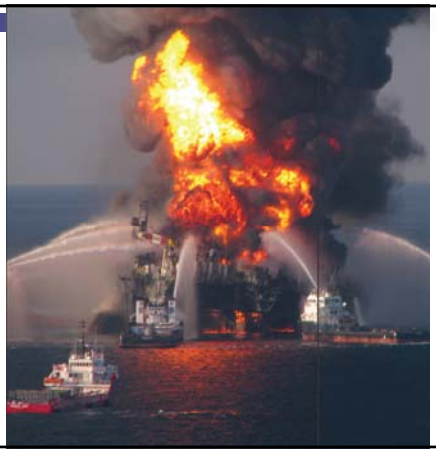
1989 Exxon Valdez oil spill – 11 to 38 million US gallons (260,000 to 900,000 barrels; (Wikipedia, National Geographic)

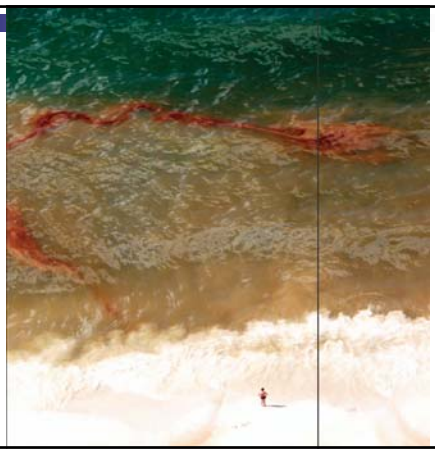
1989 Exxon Valdez oil spill – sea birds were particularly impacted by the spill (National Geographic)

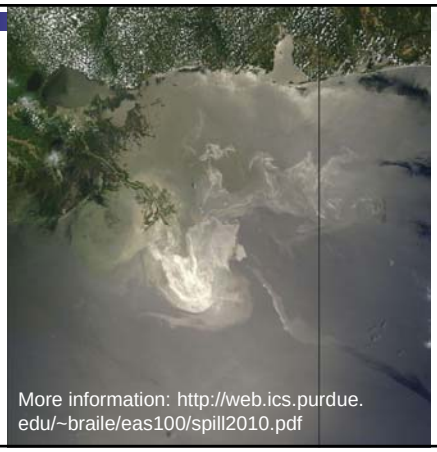
1989 Exxon Valdez oil spill – Some animal species were greatly affected by the spill, and others were not. These kinds of studies were significantly limited by lack of information on species health (increasing or decreasing populations – "baseline studies") from times before the spill (National Geographic) .



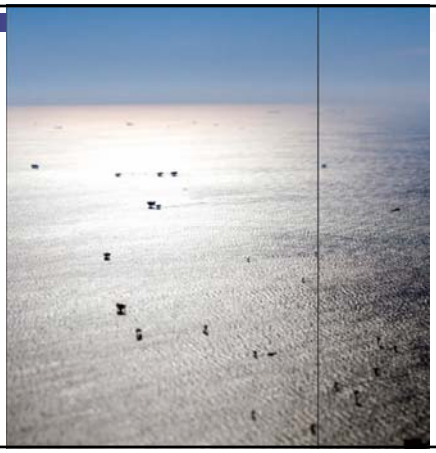
Information on Deepwater Horizon Spill, 2010:
http://web.ics.purdue.edu/~braile/eas100/spill2010.pdf

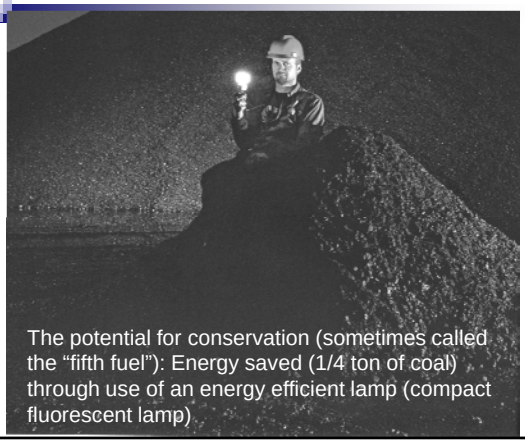






More information: http://web.ics.purdue.edu/~braile/eas100/spill2010.pdf





The potential for conservation (sometimes called the “fifth fuel”): Energy saved (1/4 ton of coal) through use of an energy efficient lamp (compact fluorescent lamp)

Saving Energy - A comparison of 60 Watt equivalent bulbs

Incandescent
60 W, 840 Lumens,
1000 hour lifetime

78% savings (4.6 times more efficient!!!!)

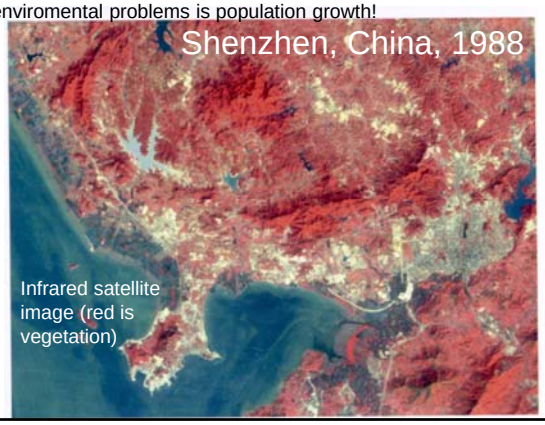
Compact Fluorescent
13 W, 825 Lumens,
8000 hour lifetime

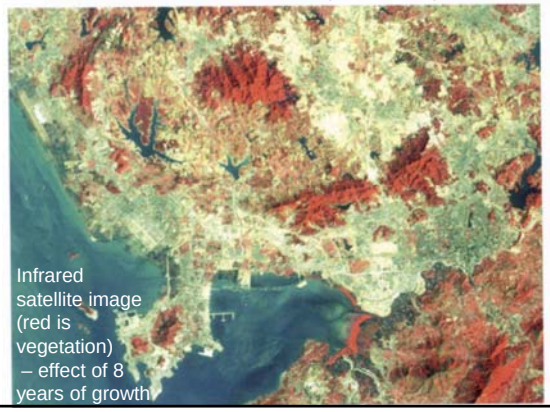
84% savings (6.3 times more efficient!!!!)

LED
9.5 W, 800 Lumens,
25,000 hour lifetime

About one fourth of the world's electricity use is for lighting, so increased efficiency would be a significant improvement in energy consumption.

Of course, some of the causes of ocean pollution and other enviromental problems is population growth!





Marine Biology:

1. Oceans contain very diverse and interesting marine life.
2. Oceans are vast ...

   ≈ 70% of Earth's surface

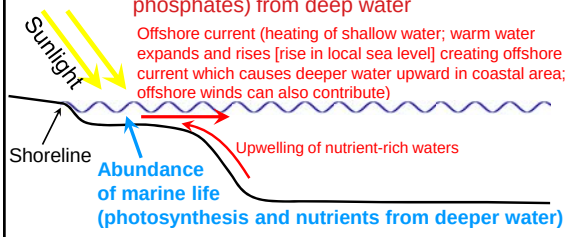
   ≈ 3700 m deep (average)

   But… Marine life is not evenly distributed in the oceans

Marine Life:

1. Base of "Food Chain" is Plankton -- organisms that drift passively with currents.
2. Types of Plankton:
   - Phytoplankton -- single cell plants which require photosynthesis, therefore, shallow water (and nutrients – nitrogen and phosphates)
   - Zooplankton -- animal plankton, typically 0.1 to 2 mm in size
   - Nanoplankton -- Phyto- or Zoo- plankton of 2 to 20 microns (0.002 to 0.020 mm)

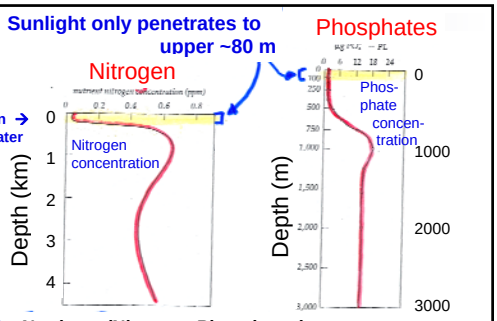
3. Most marine life exists in narrow, shallow, coastal zones because:
   - Sunlight, penetration to only about 80 m (photosynthesis)
   - Upwelling of nutrient-rich waters (nitrogen and phosphates) from deep water



Photosynthesis for plant plankton; only in shallow water where sunlight penetrates

Sunlight only penetrates to upper ~80 m

Nitrogen, Phosphates: Low concentration → in shallow water

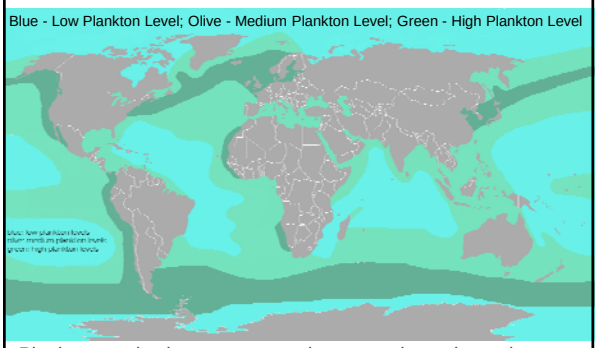


In open ocean → **Nutrients (Nitrogen, Phosphates) are concentrated at depth (several hundred meters or more)**

So, because both sunlight and nutrients are necessary for plant life (and therefore animal life), abundant marine life is mostly near coastlines where upwelling currents occur.

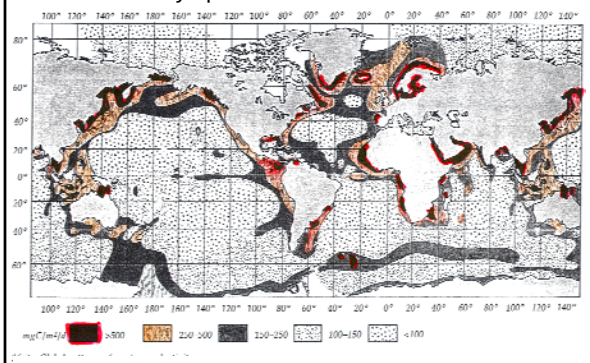
Plankton Production, generally higher near coasts

Blue - Low Plankton Level; Olive - Medium Plankton Level; Green - High Plankton Level

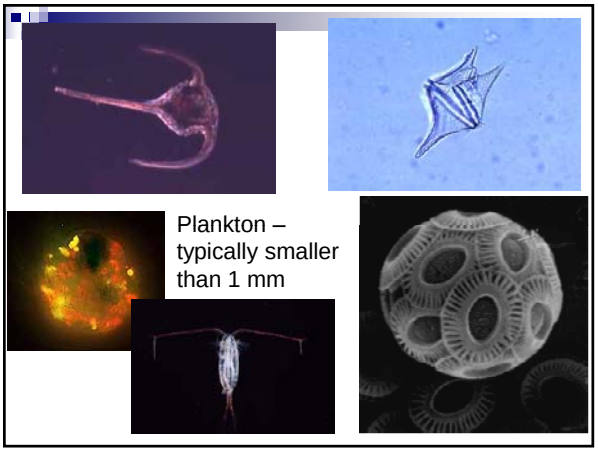


Plankton production concentrated near continental margins.
http://en.wikipedia.org/wiki/Plankton

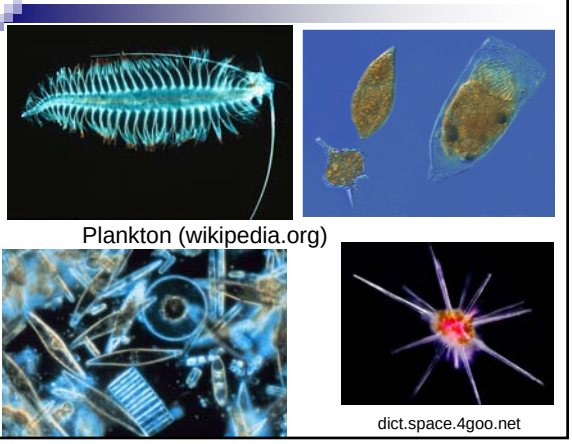
Phytoplankton Production



Phytoplankton production concentrated near continental margins.

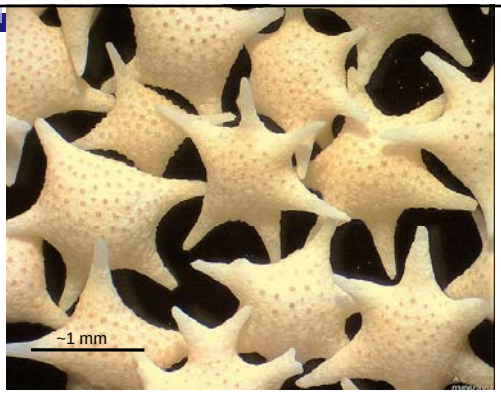


Plankton – typically smaller than 1 mm



Plankton (wikipedia.org)

dict.space.4goo.net

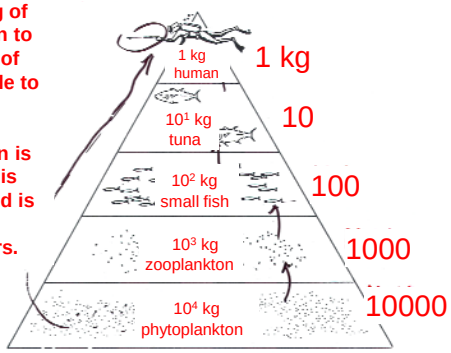


Plankton - Foraminifera *Baculogypsina sphaerulata* of Hatoma Island, Japan.
http://en.wikipedia.org/wiki/Plankton

"Food Chain"

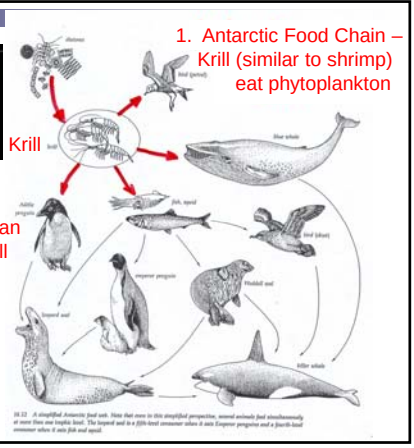
It takes 10^4 kg of phytoplankton to produce 1 kg of tuna for people to eat!

Phytoplankton is the base of this food chain and is produced in shallow waters.



Antarctic Krill
(wikipedia.org)

1. Antarctic Food Chain – Krill (similar to shrimp) eat phytoplankton



2. Many other ocean animals eat the Krill

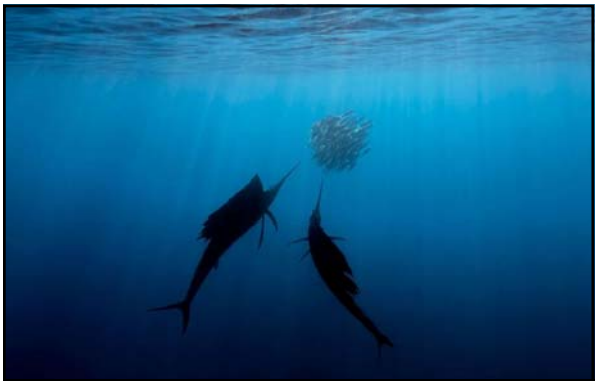
3. Many other ocean animals eat the animals that ate the Krill

4. and, …

Some interesting underwater photos of marine animals (from National Geographic, https://www.nationalgeographic.com/travel/lists/beautiful-underwater-photos-your-shot-gallery/) …

Behind this chaotic image is a well-orchestrated plan of attack. Photographer Greg Lecoeur explains that Cape gannets follow dolphins before plunging into the water at high speed to get their fill of sardines. Photograph by GREG LECOEUR, National Geographic Your Shot, https://www.nationalgeographic.com/travel/lists/beautiful-underwater-photos-your-shot-gallery/

Lecoeur had to wait patiently for this green turtle to be ready for its crisp close up. His patience paid off: "After a little while, the turtles were circling around us," he writes.
Photograph by GREG LECOEUR, National Geographic Your Shot
https://www.nationalgeographic.com/travel/lists/beautiful-underwater-photos-your-shot-gallery/



Shooting underwater has shown Guerin evidence of climate change in action. Shoals of fish like these, hunted by speedy sailfish and "essential [to] the survival of the other marine species are slowly disappearing," he writes. Photograph by FABRICE GUERIN, National Geographic Your Shot
https://www.nationalgeographic.com/travel/lists/beautiful-underwater-photos-your-shot-gallery/

Peacock bass fry “hover around their mom for protection against predators.” O’Neill describes peacock bass as excellent parents who “will protect their young against any threat.”
Photograph by MICHAEL O’NEILL, National Geographic Your Shot
https://www.nationalgeographic.com/travel/lists/beautiful-underwater-photos-your-shot-gallery/

Photographer Fabrice Guerin witnessed this humpback calf play as its mother quietly watched over it. “Suddenly,” he says, “she decided to move. They joined at the surface and the baby rubbed his mother like [giving her] a hug.”
Photograph BY FABRICE GUERIN, National Geographic Your Shot
https://www.nationalgeographic.com/travel/lists/beautiful-underwater-photos-your-shot-gallery/

In the near-freezing waters of northern Norway, Guerin bade his time in front of a shoal of herring in the hope of seeing an orca. To his surprise, this humpback whale appeared instead.
Photograph by FABRICE GUERIN, National Geographic Your Shot
https://www.nationalgeographic.com/travel/lists/beautiful-underwater-photos-your-shot-gallery/

Sintek credits the conservation efforts of a nearby village for the fact that divers can still witness such staggering numbers of bigeye trevally congregate annually in Baja California Sur's Cabo Pulmo Marine Park. Photograph by JASON SINTEK, National Geographic Your Shot
https://www.nationalgeographic.com/travel/lists/beautiful-underwater-photos-your-shot-gallery/

Additional interesting ocean photos …

http://www.lifedaily.com/26-terrifying-images-that-will-scare-you-out-of-the-ocean/4/

http://www.lifedaily.com/26-terrifying-images-that-will-scare-you-out-of-the-ocean/7/

Giant Jellyfish http://www.lifedaily.com/26-terrifying-images-that-will-scare-you-out-of-the-ocean/11/

Blobfish http://www.lifedaily.com/26-terrifying-images-that-will-scare-you-out-of-the-ocean/9/

Sawfish http://www.lifedaily.com/26-terrifying-images-that-will-scare-you-out-of-the-ocean/13/

Great ocean life videos in recent **PBS** series **Blue Planet II** (Ten 1-hr or more) https://www.bbcearth.com/blueplanet2/
(You can access and watch these from the links below)

1. Trailer-2 2:57 https://www.youtube.com/watch?v=kAphgHhlteM
Variety of ocean scenes, plants and animals

2. Seamount and sharks 4:15
https://www.youtube.com/watch?v=Iyq4U1k5rRc
Upwelling currents at seamount, plankton-feeding lantern fish and resulting feed for larger fish

3. Boiling Sea 2:11
https://www.youtube.com/watch?v=CqGfaUF0_c8
Shoal (school) of lantern fish forced to surface and devoured

4. Intelligence, Tusk Fish 2:51
https://www.youtube.com/watch?v=aSvoKZIvBCA
Tusk fish hunts and then uses a “tool” for feeding

5. Teamwork, Clown Fish 2:51
https://www.youtube.com/watch?v=aSvoKZIvBCA
Clownfish cooperate to create “nest” for eggs

6. Portuguese Man of War 3:55
https://www.youtube.com/watch?v=u_LU1GA6pu4
Portuguese Man of War navigates and stings prey

7. Cuttlefish 2:03 **
https://www.youtube.com/watch?v=K5CZ74ybnbE
Crab-eating cuttlefish abilities

8. Bird versus Fish 2:14 **
https://www.youtube.com/watch?v=h4pxLHG0Wzs
Giant trevally fish hunt flying birds

9. Worm Smithsonian 3:18 **
https://www.youtube.com/watch?v=K_7ByiYbCYM
Sand striker worm snatches fish

** Contains some mildly violent scenes