Geoscience

Dr. Denise Meeks

tucsonkosmicgirl@gmail.com

http://denisemeeks.com/science/notebooks/notebook_geoscience.pdf

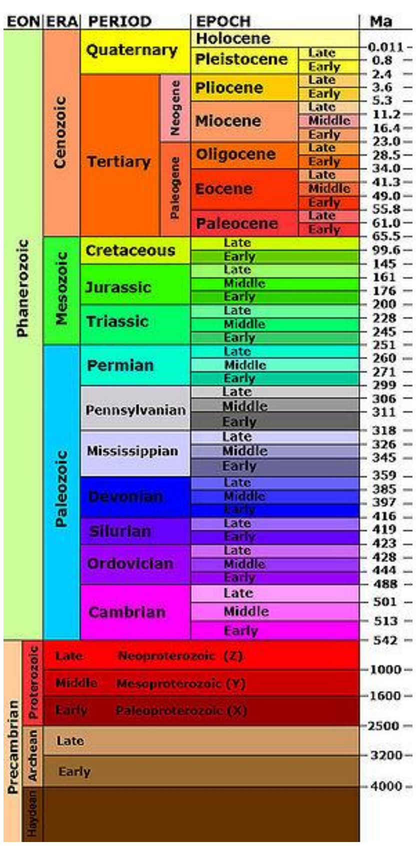
Geoscience: Geologic Principles (1)

- Principle of Uniformitarianism - geologic processes observed in operation that modify the Earth's crust at present have worked in much the same way over geologic time
- Principle of Intrusive Relationships - when an igneous intrusion cuts across a formation of sedimentary rock, it can be determined that the igneous intrusion is younger than the sedimentary rock
- Principle of Cross-cutting Relationships - faults are younger than the rocks they cut
- Principle of Inclusions and Components - if inclusions are found in a formation, then the inclusions must be older than the formation that contains them

Geoscience: Geologic Principles (2)

- Principle of Original Horizontality - deposition of sediments occurs as essentially horizontal beds
- Principle of Superposition - sedimentary rock layer in a tectonically undisturbed sequence is younger than the one beneath it and older than the one above it
- Principle of Faunal Succession - As organisms exist at the same time period throughout the world, their presence or (sometimes) absence may be used to provide a relative age of the formations in which they are found

Geoscience: Geologic Time Scale (1)



(Image source: https://commons.wikimedia.org/wiki/File:Geologic_time_scale.jpg, United States Geological Survey, public domain)

Geoscience: Geologic Time Scale (2)

eon	description
Chaotian	began with Solar System formation; Earth from planetesimals
Hadean	frequent bombardment; Mars-sized body struck Earth, resulting in the creation of the Moon; outgassing of first atmosphere, oceans; extensive volcanism; formation of first crust; atmosphere and oceans form
Archean	diverse microbial life in primordial oceans; continental shields developed from volcanic activity; anaerobic atmosphere enabled Archaea to develop; plate tectonics followed regime of continental drift; cyanobacteria produced oxygen as metabolic by-product; eventual build-up of oxygen eventually proved fatal to many life-forms
Proterozoic	atmosphere changed from reducing to oxygenated; original anaerobic inhabitants driven into a few restricted refuges; rise of aerobic prokaryote and eukaryotic life; stromatolites common; modern continental drift began; formation of Rodinia; several extensive ice ages and "Snowball Earth;" appearance of first metazoan
Paleozoic	atmospheric oxygen reached present levels, generating ozone shield; age of invertebrates, fish, tetrapods, and reptiles; life emerged from sea to land, pteridophyte and later gymnospermous plants flourished; mild to tropical conditions with warm shallow seas; continents clustered into Pangea; increasing aridity; end of the great Carboniferous swamps and unique flora and fauna; ended by Permian mass-extinction
Mesozoic	dinosaurs; terrestrial megafauna; diverse sea-reptiles ruled the oceans; invertebrates, ammonites extremely diverse; pterosaurs and later birds; mammals remained small; warm, tropical climate; Pangea broke up into Laurasia and Gondwana; modern forms of corals, insects, new fishes and flowering plants; dinosaurs and many other animals abruptly died out at end of Cretaceous
Cenozoic	mammals; current continents emerged; initial tropical conditions replaced by colder drier climate, rise of grazing mammals; anthropoid apes that culminated in the australopithecine hominids of Africa; decreasing temperatures and a polar landmass of Antarctica resulted in a new Ice Age; rise of Homo erectus, Neanderthal and Cro-Magnon; extinction of Megafauna, and civilization

(Source: http://palaeos.com/timescale/index.html, M. Alan Kazlev, CC)

Geoscience: Chemical Abundance of Earth

symbol	element	percent
O	oxygen	46.6
Si	silicon	27.7
Al	aluminum	8.1
Fe	iron	5.0
Ca	calcium	3.6
Na	sodium	2.8
K	potassium	2.6
Mg	magnesium	2.1

Geoscience: Rock Cycle

1 = magma;
2= crystallization
3 = igneous rocks;
4 = erosion;
5 = sedimentation;
6 = sediments & sedimentary rocks;
7 = tectonic burial and metamorphism;
8 = metamorphic rocks;
9 =melting

(Image source: https://en.wikipedia.org/wiki/Rock_cycle#/media/File:Rockcycle.jpg, Woudloper/Woodwalker, public domain)

Geoscience: Igneous Rocks

rock name	origin	grain Size	color
andesite	extrusive	fine	intermediate, medium
basalt	extrusive	fine	mafic, dark
diorite	intrusive	coarse	intermediate, medium, dark
gabbro	intrusive	coarse	mafic, medium
granite	intrusive	coarse	felsic, light
obsidian	extrusive	very fine	dark
pumice	lava, ash	fine	felsic, medium
rhyolite	extrusive	fine	light
syenite	intrusive	coarse	light, dark, looks like granite without quartz
tuff	pyroclast/extrusive	fine, holes	medium

Geoscience: Sedimentary Rocks

rock name	color	hardness	composition silica/calcite	fossils
arkose	dark rose	<2.5	silica, sand	no
conglomerate	rose, gray	5.5> >4.5	boulders, pebbles, resembles concrete	
coquina	whitish tan	softer than glass	carbonate, limestone	yes
fossil limestone	pale gray	softer than glass	calcite	yes
micrite limestone	white, mocha, red	5.5> >4.5	calcite, carbonate	
oil shale	black, gray	softer than glass	silt and organic debris	yes
oolitic limestone		softer than glass	calcite, $CaCO_3$, carbonate	invertebrates
sandstone	sandy	>5.5	calcite, calcium carbonate, silica, or iron	animals, plants
shale (black or grey)	black, gray	softer than glass	quartz and clay	plant fossils, bones, fish
siltstone		harder than glass	clays and muds	
travertine	white		calcium carbonate	no

Geoscience: Metamorphic Rocks

rock name	luster	hardness	color	texture and grain size	composition
gneiss	non-metallic	>5.5	grayish white	coarse	magmatites, granites
hornfels	non-metallic	<3.5	dull black	fine- grained	quartz, mica, pyroxene
marble	non-metallic	5.5> >4.5	milky white	variable grain size	calcite, calcium carbonate
phyllite	non-metallic		pale grayish green	medium	garnetporphyroblasts
quartzite	glassy	7	dark rose	variable grain size	quartz grains
schist, mica	non-metallic	=5.0	gray	medium to coarse-grained	sparkles
slate, plate	non-metallic	<2.5	dull gray	fine-grained	compression of mud

Geoscience: Minerals

<u>mineral</u>: naturally occurring object, stable at room temperature, represented by a single chemical formula, usually abiogenic (not resulting from the activity of living organisms), has ordered atoms

<u>mineral characteristics</u>: color, crystal habit (geometric shape of crystals), cleavage (minerals break along particular planes of weakness), fracture (minerals also break in places where they aren't weak), tenacity (refers to resistance to breaking), hardness, luster (character of the light reflected), streak (color of the mineral when it is scratched or powdered), diaphaneity (ability of light to pass through), specific gravity (ratio of the density of a mineral to the density of water), fluorescence (emission of light by a substance that has absorbed light or other electromagnetic radiation), magnetism

Geoscience: Mineral Groups

group	elements	notation and information
carbonate	carbon and oxygen	CO_3
halide	fluorine or chlorine	F or Cl
hydroxide	oxygen and hydrogen	OH together
native	carbon	C by itself
oxide	oxygen	anything with O
phosphate	phosphorus and oxygen	PO_4
silicate	silicon and oxygen	Si and O
sulfate	sulfur and oxygen	SO_4
sulfide	sulfur	S without O

Geoscience: Special Properties of Minerals

Property	Minerals
fluorescence: emission of visible light by a mineral exposed to ultraviolet light; emission ends when exposure ends.	**barite, calcite, fluorite, sphalerite**
phosphorescence: emission of visible light when exposed to ultraviolet light; emission continues after exposure ends.	**calcite**
thermoluminescence: some minerals to glow when they are heated.	**apatite, calcite, feldspars, fluorite.**
triboluminescence: some minerals glow when crushed, struck, scratched, or rubbed.	**calcite, feldspars, fluorite, micas, and quartz.**

Geoscience: Mineral Crystal Systems

cubic	**3 equal axes, mutually perpendicular, a = b = c** $\alpha = \beta = \gamma = 90^0$
tetragonal	**3 perpendicular axes, only 2 equal, a = b ≠ c,** $\alpha = \beta = \gamma = 90^0$
hexagonal	**3 equal coplanar at 120^0, 4^{th} unequal axis perpendicular to their plane, a = b ≠ c,** $\alpha = \beta = 90^0$, $\gamma = 120^0$
rhombohedral	**3 equal axes not at right angles, a = b = c,** $\alpha = \beta = \gamma \neq 90^0$
orthorhombic	**3 unequal axes all perpendicular, a ≠ b ≠ c,** $\alpha = \beta = \gamma = 90^0$
monoclinic	**3 unequal axes, 1 perpendicular to the other 2, a ≠ b ≠ c,** $\alpha = \gamma = 90^0 \neq \beta$
triclinic	**3 perpendicular unequal axes, a ≠ b ≠ c,** $\alpha \neq \beta \neq \gamma \neq 90^0$

Geoscience: Moh's Scale of Mineral Hardness

hard-ness	mineral	composition	absolute hardness	common objects
1	talc	$Mg_3Si_4O_{10}(OH)_2$	1	
2	gypsum	$CaSO_4 \cdot 2H_2O$	2	fingernail
3	calcite	$CaCO_3$	9	penny
4	fluorite	CaF_2	21	
5	apatite	$Ca_5(PO_4)_3(OH\text{-},Cl\text{-},F\text{-})$	48	knife
6	orthoclase feldspar	$KAlSi_3O_8$	72	glass
7	quartz	SiO_2	100	steel file
8	topaz	Al_2SiO_4 $(OH\text{-},F\text{-})_2$	200	
9	corundum	Al_2O_3	400	
10	diamond	C	1500	

Geoscience: Mineral Groups, Hardness, Formula, Luster (1)

mineral	group	hardness	formula	luster
augite	silicate	5.5-6	$(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)2O_6$	non-metallic
barite	sulfate	3-3.5	$BaSO_4$	non-metallic
bauxite	hydroxide	2.3-2.7	Fe0(OH) and $Al_2O_32H_2O$	non-metallic,earthy
biotite	silicate	less than 3.5	$K(Mg,Fe)_3(Al,Fe)Si_3O_{10}(OH,F)_2$	non-metallic
calcite	carbonate	3	$CaCO_3$	non-metallic
chalcopyrite	sulfide	3.5-4	Cu_5FeS_2	metallic
corundum	oxide	9	Al_2O_3	vitreous to adamantine
dolomite	carbonate	3.5-4	$CaMg(CO_3)_2$	non-metallic
fluorite	halide	4	CaF_2	non-metallic
galena	sulfide	2.5	PbS	metallic
graphite	native element	1-2	C	metallic
gypsum	sulfate	2	$CaSO_4 2H_2O$	non-metallic
halite	halide	2	NaCl	vitreous

Geoscience: Mineral Groups, Hardness, Formula, Luster (2)

mineral	group	hardness	formula	luster
hematite	oxide	5-6	Fe_2O_3	non-metallic, earthy
hornblende	silicate	5-6	$Ca_2(Mg,Fe)_4Al(Si_2Al)O_{22}(OH,F)_2$	vitreous
magnetite	oxide	5.5-6.5	$FeFe_2O_4$	metallic
malachite	carbonate	between 3 and 4	$Cu_2CO_3(OH)_2$	non-metallic
microcline potassium feldspar	silicate	6-6.6	$KalSi_3O_8$	non-metallic, vitreous
muscovite	silicate	2.5-4	$Kal_2(Si_3Al)O_{10}(OH,F)_2$	non-metallic, pearly
olivine	silicate	6.5-7	$Mg_2SiO_4Fe_2SiO_4$	vitreous
plagioclase feldspar	silicate	6 to 7	$(Na,Ca)(Si,Al)_4O_8$	non-metallic
pyrite	sulfide	6-6.5	FeS_2	metallic
quartz	oxide	7	SiO_2	vitreous
staurolite	silicate	7-7.5	$(Fe,Mg,Zn)_2Al_9(Si,Al)_4O_{22}(OH)_2$	vitreous toresinous
talc	silicate	1	$MgSi_4O_{10}(OH)_2$	dull to greasy

Geoscience: Mineral Specific Gravity, Color, Uses (1)

mineral	specific gravity	color	uses
augite	3.23-3.52	gray	ore of lithium, making steel
barite	4.5	white, orange	copper ore for pipes, electrical circuits, coins, ammunition, gemstone
bauxite	2.3-2.7	variable, tannish	aluminum ore
biotite	2.7-3.4	black	fire-resistant tiles, rubber, paint
calcite	2.71	gray, white	antacid, fertilizer, cement
chalcopyrite	4.3-4.4	brassy yellow	copper ore for pipes, electrical circuits, coins, ammunition, gemstone
corundum	4.0-4.1	many	abrasive powders to polish lenses, gemstone
dolomite	2.85	pale rose	magnesium ore, soft abrasive, used to make paper
fluorite	3.1-3.3	purple, green, white	fluorine source for processing aluminum

Geoscience: Mineral Specific Gravity, Color, Uses (2)

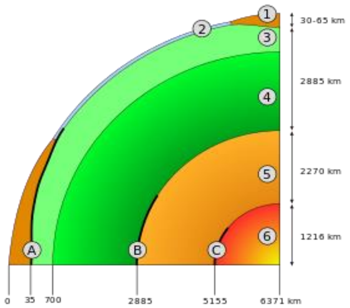
mineral	specific gravity	color	uses
galena	7.58	gray	lead or for TV glass, auto batteries, solder, ammunition, paint
graphite	2.1-2.3	gray	lubricant, pencils, fishing rods
gypsum	2.32	milky white	plaster-of-paris, wallboard, drywall, art sculptures
halite	2.1-2.2	clear, green, orange, reddish	salt, water softeners, sodium ore
hematite	5.26	brown	red pigment, iron ore, steel tools, vehicles, nails and bolts, bridges
hornblende	3.28-3.41	green, greenish brown, black	fire-resistant clothing, tiles, brake linings
magnetite	5.2	brown	iron ore for steel, brass, bronze, vehicles, nails and bolts, bridges
malachite	4.0	grayish green	copper ore for pipes, electrical circuits, coins, ammunition, gemstone

Geoscience: Mineral Specific Gravity, Color, Uses (3)

mineral	specific gravity	color	uses
microcline potassium feldspar	2.55-2.63	rose	
muscovite	2.77-2.88	silvery	computer chip substrates, electrical insulation, roof shingles, makeup
olivine	3.27-4.23	green, greenish yellow	gemstone, magnesium ore
plagioclase feldspar	2.6-2.8	grayish white	ceramics, glass, enamel, soap, false teeth, scouring powder
pyrite	5	brassy yellow	sulfur ore, sulfuric acid, explosives, fertilizers, pulp processing, insecticides
quartz	2.65	variable	abrasive, glass, gemstone
staurolite	3.65-3.83	translucent to opaque	gemstone, “fairy crosses”
talc	2.58-2.83	gray, white	talcum powder, makeup, ceramics, paint, sculptures

Geoscience: Earth's Structure

1. continental crust
2. oceanic crust
3. upper mantle
4. lower mantle
5. outer core
6 inner core
A: Mohorovičić discontinuity
B. Gutenberg Discontinuity
C: Lehmann–Bullen discontinuity



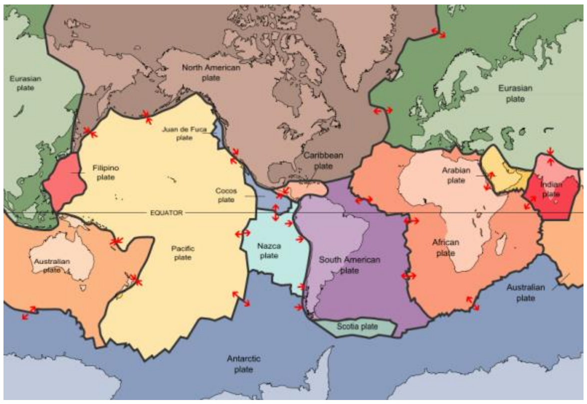
(Image source: https://en.wikipedia.org/wiki/Structure_of_the_Earth , Dake, CC BY-SA 2.5)

Geoscience: Geologic Processes

uniformitarianism: the assumption that the same natural laws and processes that operate in the universe now have always operated in the universe in the past and apply everywhere in the universe, processes include plate tectonics, erosion, glaciation, drought, desertification

catastrophism: theory that the Earth has been affected in the past by sudden, short-lived, violent events, possibly worldwide in scope processes include earthquakes, meteorite impacts, floods, tsunamis, blizzards, fires, hurricanes, tornadoes

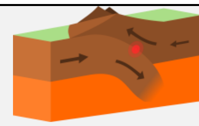
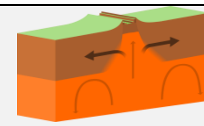
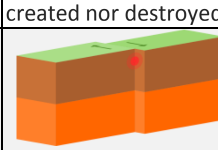
Geoscience: Earth Plates



(Image source: https://en.wikipedia.org/wiki/Plate_tectonics#/media/File:Plates_tect2_en.svg, USGS, public domain)

Geoscience: Plate Tectonics

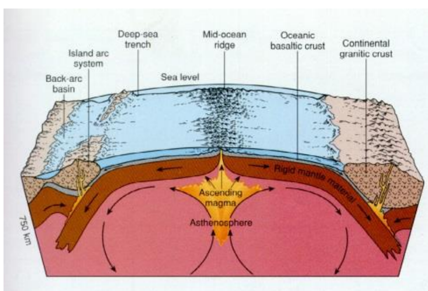
plate tectonics: theory that Earth's surface is made of pieces that move, collide, and slide past each other, resulting in earthquakes and volcanoes

convergent boundary	divergent boundary	transform boundary
two plates slide toward each other to form a subduction zone or a continental collision	two plates slide away from each other	two plates slide past each other along transform faults, where plates are neither created nor destroyed
		

(Images source: https://en.wikipedia.org/wiki/Plate_tectonics, Domdomegg, CC BY 4.0)

Geoscience: Sea Floor Spreading

sea floor spreading: process that occurs at mid-ocean ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge. Seafloor spreading helps explain continental drift in the theory of plate tectonics



Source: https://en.wikipedia.org/wiki/Seafloor_spreading) (Image source : https://blueteamscience.files.wordpress.com/2014/06/seafloor.jpg)

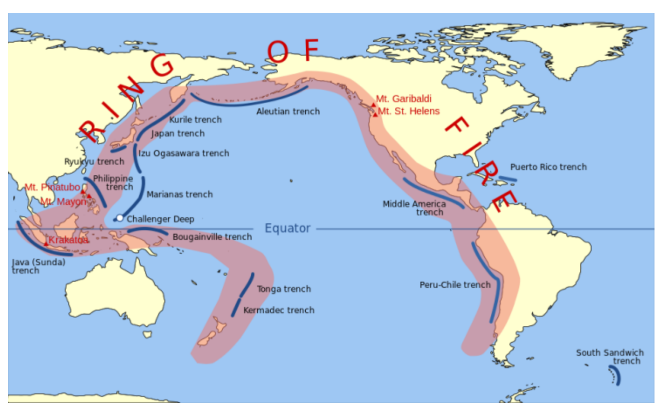
Geoscience: Earthquakes

- longitudinal P-waves (shock- or pressure waves): first waves from an earthquake to arrive at a seismograph; "P" can stand for either pressure as it is formed from alternating compressions and rarefactions or primary, since it has the highest velocity
- transverse S-waves (both body waves): moves as a shear or transverse wave, so motion is perpendicular to the direction of wave propagation; "S" can stand for either shear or secondary
- surface waves (Rayleigh and Love waves): span a wide frequency range, and the period of waves that are most damaging is usually 10 seconds or longer; can travel around the globe many times from the largest earthquakes; are caused when P waves and S waves come to the surface

(Source: https://en.wikipedia.org/wiki/Earthquake#Induced_seismicity)

Geoscience: Ring of Fire

(Image source: https://en.wikipedia.org/wiki/Ring_of_Fire#/media/File:Pacific_Ring_of_Fire.svg, Gringer , public domain)



Geoscience: Richter Scale (1)

magni-tude	descrip-tion	Mercalli intensity	average earthquake effects	average estimated frequency
1.0–1.9	micro	I	microearthquakes, rarely felt if at all;. recorded by seismographs	several million/year
2.0–2.9	minor	I to II	felt slightly by some people; no building damage	over one million/year
3.0–3.9		III to IV	often felt, rarely causes damage; shaking of indoor objects noticeable	over 100,000/year
4.0–4.9	light	IV to VI	noticeable shaking of indoor objects; felt by most people in area; slightly felt outside; no to minimal damage	10,000 to 15,000/year
5.0–5.9	mod-erate	VI to VIII	can cause damage to poorly constructed buildings; no to slight damage to other buildings; felt by everyone	1,000 to 1,500/year

Geoscience: Richter Scale (2)

magni-tude	descrip-tion	Mercalli intensity	average earthquake effects	average estimated frequency
6.0–6.9	strong	VII to X	well-built structures damaged; poorly designed structures severe damage	100 to 150/year
7.0–7.9	major	VIII or greater	most buildings damaged, some collapse; well-designed structures likely damaged	10 to 20/year
8.0–8.9	great		major building damage; damage to earthquake-resistant buildings; felt in large regions	one/year
9.0 and greater			at or near total destruction; severe damage to all buildings; permanent changes in ground topography	one per 10 to 50 years

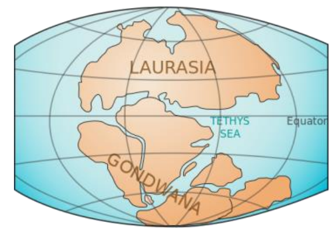
(Source: https://en.wikipedia.org/wiki/Richter_magnitude_scale)

Geoscience: Ancient Tectonic Plates (1)

- Columbia: likely existed approximately 2.5 to 1.6 billion years ago in Paleoproterozoic Era; assembly may have been completed by global-scale collisional events during 2.1–1.8 Ga; consisted of proto-cratons that made up cores of continents of Laurentia, Baltica, Ukrainian Shield, Amazonian Shield, Australia, and possibly Siberia, North China, and Kalaharia
- Euramerica: minor supercontinent created in Devonian by collision between the Laurentian, Baltica, and Avalonia cratons 433 million years ago
- Gondwana: believed to have sutured between about 570 and 510 million years ago; joined East Gondwana to West Gondwana. Gondwana formed prior to Pangaea, and later became part of it
- Kenorland: thought to have formed during Neoarchaean Era c. 2.72 billion years ago by accretion of Neoarchaean cratons and formation of new continental crust; comprised what later became Laurentia, Baltica, Western Australia and Kalaharia

Geoscience: Ancient Tectonic Plates (2)

- Laurasia: the more northern of two supercontinents, with Gondwana, that formed part of the Pangaea supercontinent around 335 to 175 million years ago; it separated from Gondwana 215 to 175 Mya, beginning in the late Triassic period, during the breakup of Pangaea, drifting farther north after the split
- Nena: ancient minor supercontinent that consisted of the cratons of Arctica, Siberia, Baltica, and East Antarctica; it formed about 1.95 billion years ago but became part of the global supercontinent Columbia around 1.82 billion years ago



TRIASSIC
200 million years ago

(Image source: https://en.wikipedia.org/wiki/Laurasia#/media/File:Laurasia-Gondwana.svg, LennyWikidata, CC BY 3.0)

Geoscience: Ancient Tectonic Plates (3)

- Pangaea: supercontinent that existed during the late Paleozoic and early Mesozoic eras; assembled from earlier continental units approximately 335 Mya; it began to break apart about 175 million years ago; much of Pangaea was in the southern hemisphere and surrounded by a superocean, Panthalassa; last supercontinent to have existed and first to be reconstructed by geologists

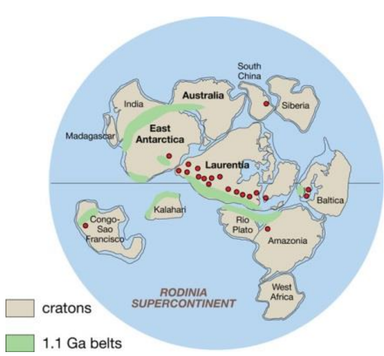
(Image source: https://en.wikipedia.org/wiki/Pangaea#/media/File:Pangaea_continents.svg, Kieff, CC BY-SA 3.0)

Geoscience: Ancient Tectonic Plates (4)

- Pannotia: was a relatively short-lived Neoproterozoic supercontinent that formed at the end of the Precambrian during the Pan-African orogeny, 650–500 Ma and broke apart 560 Ma with the opening of the Iapetus Ocean; formed when Laurentia was located adjacent to the two major South American cratons, Amazonia and Río de la Plata; the opening of the Iapetus Ocean separated Laurentia from Baltica, Amazonia, and Río de la Plata
- Proto-Laurasia: Laurasia is known as a Mesozoic phenomenon, but today it is believed that the same continents that formed the later Laurasia also existed as a coherent supercontinent after the breakup of Rodinia around 750 million years ago; this is referred to as Proto-Laurasia

Geoscience: Ancient Tectonic Plates (5)

- Rodinia: Neoproterozoic supercontinent that was assembled 1.3–0.9 billion years ago and broke up 750–600 million years ago; formed formed at c. 1.0 Ga by accretion and collision of fragments produced by breakup of an older supercontinent, Columbia, assembled by global-scale 2.0–1.8 Ga collisional events



(Image source: https://en.wikipedia.org/wiki/Rodinia#/media/File:Rodinia_reconstruction.jpg, John Goodge, public domain)

Geoscience: Ancient Tectonic Plates (6)

- Ur: proposed supercontinent that formed in the Archean 3.1 billion years ago
- Vaalbara: an Archean supercontinent that consisted of the Kaapvaal craton, today located in eastern South Africa, and the Pilbara craton, today found in north-western Western Australia; the two cratons are made of 3.6±2.7 Ga-old crust, making Vaalbara the oldest supercontinent on Earth

(Source: https://en.wikipedia.org/wiki/List_of_tectonic_plates)

Geoscience: Craters

- impact: caused by two celestial bodies impacting each other, such as a meteorite hitting a planet
- volcanic: roughly circular depression in the ground caused by volcanic activity
- caldera: large cauldron-like depression formed following the evacuation of a magma chamber/reservoir
- subsidence: from an underground (usually nuclear) explosion
- maar: a relief crater caused by a phreatic eruption or explosion
- pit: crater that forms through sinking of the surface,not as a vent for lava
- crater lake: a lake that forms in a volcanic crater or caldera
- explosion: a hole formed in the ground produced by an explosion near or below the surface
- machtesh: a crater-like formation created by erosion

(Source: https://en.wikipedia.org/wiki/Crater)

Geoscience: Volcanoes (1)

hot spot: volcanic area formed by mantle plumes, columns of hot material rising from the core-mantle boundary in a fixed space that causes large-volume melting

fissure vent: linear volcanic vent through which lava erupts, usually without explosive activity; often a few meters wide, may be many kilometers long; can cause large flood basalts which run first in lava channels and lava tubes

shield volcano: built of fluid lava flows; named for low profile, resembling a warrior's shield lying on the ground; steady accumulation of broad sheets of lava; low viscosity of mafic lava

lava dome: roughly circular mound-shaped protrusion resulting from slow extrusion of viscous lava; most preserved domes have high silica content; high viscosity preventing lava from flowing very far

Geoscience: Volcanoes (2)

cryptodome: formed when viscous lava is forced upward causing the surface to bulge; lava beneath the surface of the mountain created an upward bulge which slid down the north side of the mountain

cinder cone: built by ejecta from a volcanic vent, piling up around the vent in the shape of a cone with a central crater; are of different types, depending upon the nature and size of the fragments ejected during the eruption; types include stratocones, spatter, tuff, and cinder

stratovolcano: conical, built up by many layers of hardened lava, tephra, pumice, and volcanic ash; characterized by a steep profile and periodic explosive eruptions and effusive eruptions; some have collapsed craters called calderas

Geoscience: Volcanoes (3)

supervolcano: produces a volcanic eruption with an ejecta mass greater than 10^{15} kg (10^{12} t); occurs when magma in the mantle rises into the crust but unable to break through; pressure builds in a large magma pool until the crust can't contain the pressure

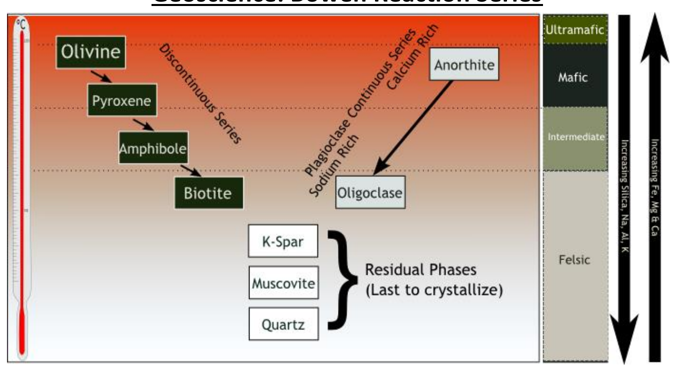
submarine volcano: underwater vents or fissures in the Earth's surface from which magma can erupt; many located near areas of tectonic plate movement, known as mid-ocean ridges, which are estimated to account for 75% of Earth's magma output

subglacial volcano: produced by eruptions beneath a glacier or ice sheet, melted into a lake by rising lava

mud volcano: formations created by geo-exuded mud or slurries, water, and gases; not true igneous volcanoes; produce no lava

(Source: https://en.wikipedia.org/wiki/Volcano)

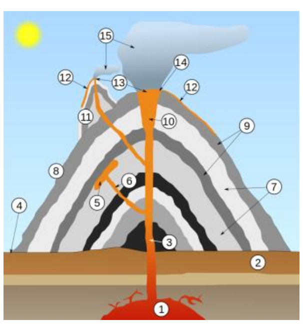
Geoscience: Bowen Reaction Series



(Image source: https://en.wikipedia.org/wiki/Bowen%27s_reaction_series#/media/File:Bowen%27s_Reaction_Series.png, Colivine, CC0)

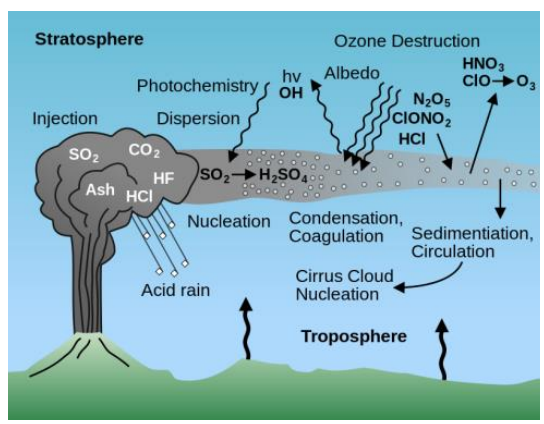
Geoscience: Stratovolcano

1. large magma chamber
2. bedrock
3. conduit (pipe)
4. base
5. sill
6. dike
7. layers of ash emitted by the volcano
8. flank
9. layers of lava emitted by the volcano
10. throat
11. parasitic cone
12. lava flow
13. vent
14. crater
15. ash cloud



(Image source: https://en.wikipedia.org/wiki/Volcano#/media/File:Volcano_scheme.svg, MesserWoland, CC BY-SA 3.0)

Geoscience: Effects of Volcanoes



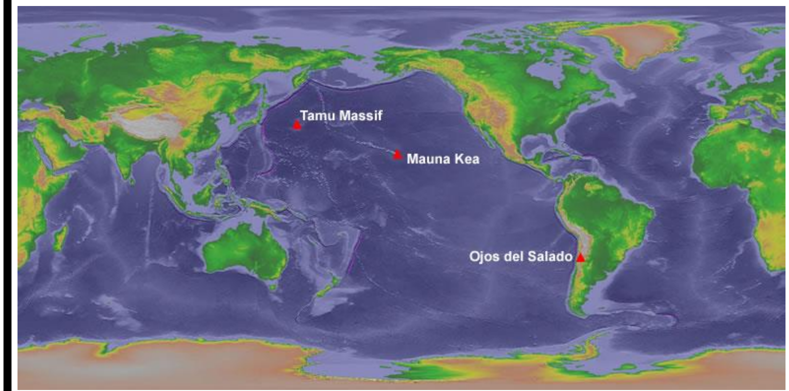
(Image source: https://en.wikipedia.org/wiki/Volcano#/media/File:Volcanic_injection.svg, cflm, public domain)

Geoscience: Earth's Largest Volcanoes (1)

name	description	location	dimensions	last eruption
Tamu Massif	most massive	under the Pacific, about 1,600 km east of Japan	volume 2.5 million km^3; 310,800 km^2 footprint	144 million years ago
Mauna Kea	tallest	Big Island of Hawai'i, home to the highest observatories in the world	base is 6,000 m below sea level; summit 4,205 m above sea level	3,600 years ago
Ojos del Salado	highest summit elevation	Argentina-Chile border near the Atacama Desert	6,893 m high	1,300 years ago

(Source: http://geology.com/records/largest-volcano/)

Geology: Earth's Largest Volcanoes (2)



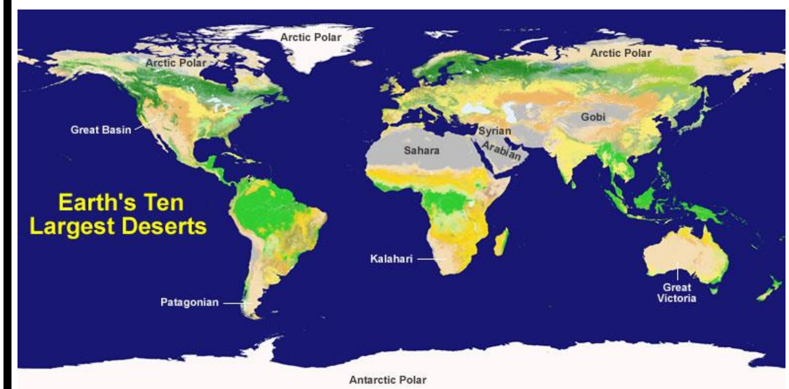
(Image source: http://geology.com/records/largest-volcano/)

Geology: Earth's 10 Largest Deserts (1)

name	type of	surface area	location
Antarctic	polar	5.5 million mi^2	Antarctica
Arctic	polar	5.4 million mi^2	Alaska, Canada, Greenland, Iceland, Norway, Sweden, Finland, Russia
Sahara	subtropical	3.5 million mi^2	Northern Africa
Arabian	subtropical	1 million mi^2	Arabian Peninsula
Gobi	cold winter	500,000 mi^2	China, Mongolia
Patagonian	cold winter	260,000 mi^2	Argentina
Great Victoria	subtropical	250,000 mi^2	Australia
Kalahari	subtropical	220,000 mi^2	South Africa, Botswana, Namibia
Great Basin	cold winter	190,000 mi^2	United States
Syrian	subtropical	190,000 mi^2	Syria, Iraq, Jordan, Saudi Arabia

(Source: http://geology.com/records/largest-desert.shtml)

Geoscience: Earth's 10 Largest Deserts (2)



(Image source: http://geology.com/records/largest-desert.shtml, NOAA, public domain)

Geoscience: Continents and Oceans

(Image source: https://ourhomeworkhelp.wordpress.com/category/maps/, free for personal and educational use)

Geoscience: Oceans

ocean	area (km^2) / (%)	volume (km^3) / (%)	average depth (m)	coastline (km)
Pacific	168,723,000 / 46.6	669,880,000 / 50.1	3,970	135,663
Atlantic	85,133,000 / 23.5	310,410,900 / 23.3	3,646	111,866
Indian	70,560,000 / 19.5	264,000,000 / 19.8	3,741	66,526
Southern	21,960,000 / 6.1	71,800,000 / 5.4	3,270	17,968
Arctic	15,558,000 / 4.3	18,750,000 / 1.4	1,205	45,389

(Source: https://en.wikipedia.org/wiki/Ocean)

Geoscience: Water Masses (1)

upper waters (0–500 m or 0–1,600 ft)		
water mass	temperature	salinity
Atlantic Subarctic Upper Water (ASUW)	0.0–4.0 C	34.0–35.0
Western North Atlantic Central Water (WNACW)	7.0–20 C	35.0–36.7
Eastern North Atlantic Central Water (ENACW)	8.0–18.0 C	35.2–36.7
South Atlantic Central Water (SACW)	5.0–18.0 C	34.3–35.8

Geoscience: Water Masses (2)

intermediate waters (500–1,500 m or 1,600–4,900 ft)		
water mass	temperatures	salinity
Western Atlantic Subarctic Intermediate Water (WASIW)	3.0–9.0 °C	34.0–35.1
Eastern Atlantic Subarctic Intermediate Water (EASIW)	3.0–9.0 °C	34.4–35.3
Mediterranean Water (MW)	2.6–11.0 °C	35.0–36.2
Arctic Intermediate Water (AIW)	−1.5–3.0 °C	34.7–34.9

Geoscience: Water Masses (3)

deep and abyssal waters (1,500 m–bottom or 4,900 ft–bottom)		
water mass	temperature	salinity
North Atlantic Deep Water (NADW)	1.5–4.0 °C	34.8–35.0
Antarctic Bottom Water (AABW)	−0.9–1.7 °C	34.64–34.72
Arctic Bottom Water (ABW)	−1.8 to −0.5 °C	34.85–34.94

(Source: https://en.wikipedia.org/wiki/Atlantic_Ocean)

Geoscience: Pacific Ocean (1)

- largest and deepest of Earth's oceanic divisions
- born 750 million years ago at breakup of Rodinia, generally called Panthalassic Ocean until breakup of Pangea, about 200 million years ago
- oldest Pacific Ocean floor is only about 180 million years old
- extends from the Arctic Ocean in the north to the Southern Ocean in the south

(Image source: https://en.wikipedia.org/wiki/Pacific_Ocean, public domain)

Geoscience: Pacific Ocean (2)

- bounded by Asia and Australia in west and Americas in the east
- both center of Water Hemisphere and Western Hemisphere are here
- equator subdivides it into North Pacific Ocean and South Pacific Ocean
- Galapagos and Gilbert Islands are on equator but considered to be totally within South Pacific
- reaches greatest east-west width at about 5^0 N latitude, between Indonesia to Columbia, halfway around world, more than 5 times diameter of Moon
- shrinking by about 2.5 cm per year on three sides, about 0.52 km^2/year
- contains several long seamount chains, formed by hotspot volcanism, including Hawaiian–Emperor seamount chain and Louisville Ridge

Geoscience: Pacific Ocean (3)

- in shallow waters of continental shelves off coasts of Australia and New Zealand, petroleumand natural gas are extracted, and pearls are harvested along coasts of Australia, Japan, Papua New Guinea, Nicaragua, Panama, and the Philippines, although in sharply declining volume in some cases
- quantity of small plastic fragments floating in north-east Pacific Ocean increased a hundredfold between 1972 and 2012
- along western margins: Celebes Sea, Coral Sea, East China Sea, Phillipine Sea, Sea of Japan, South China Sea, Sulu Sea, Tasman Sea, Yellow Sea
- joining on the west: Indonesian Seaway, Strait of Malacca, Torres Strait, Indian Ocean
- joining on the east: Drake Passage, Strait of Magellan, Atlantic Ocean
- on the north: Bering Strait, Arctic Ocean

Geoscience: Pacific Ocean (4)

- straddles the 180th meridian
- West Pacific is in Eastern Hemisphere
- East Pacific is in Western Hemisphere
- Southern Pacific includes Southern Indian Ridge crossing south of Australia turning into Pacific-Antarctic Ridge, north of South Pole, merges with another ridge to form Eastern Pacific Rise which connects to another ridge south of North America which overlooks Juan de Fuca Ridge
- tradewinds in southern and eastern Pacific are steady
- conditions in Northern Pacific vary, cold winter temperatures on east coast of Russia contrasting with milder weather off British Columbia during winter due to preferred flow of ocean currents
- in tropical and subtropical Pacific, El Niño Southern Oscillation (ENSO) affects weather

Geoscience: Pacific Ocean (5)

- to determine phase of ENSO, most recent three-month sea surface temperature average for area approximately 3,000 km to east of Hawai'i is calculated, and if more than 0.50C above or below normal then El Niño or La Niña is considered to be occurring
- in tropical western Pacific, monsoon and related wet season during summer months contrast with dry winds in winter which blow over from Asian landmass
- hosts two most active tropical cyclone basins, the northwest Pacific, and eastern Pacific
- Pacific hurricanes form south of Mexico, sometimes striking western Mexican coast and occasionally southwestern U.S. between June and October
- typhoons form in northwestern Pacific and move into southeast and east Asia from May to December

Geoscience: Pacific Ocean (6)

- tropical cyclones form in South Pacific basin, where they can impact island nations
- in Arctic, icing from October to May can be hazardous to ships
- persistent fog from June to December
- climatological low in Gulf of Alaska keeps southern coast wet and mild in winters
- Westerlies and associated jet stream within Mid-Latitudes can be strong, especially in Southern Hemisphere, due to temperature differences between tropics and Antarctica, which has coldest planet temperatures
- in Southern Hemisphere, because of stormy and cloudy conditions associated with extratropical cyclones riding jet stream, Westerlies are referred to as Roaring Forties, Furious Forties, and Shrieking Sixties, according to latitude
- first mapped by Abraham Ortelius

Geoscience: Pacific Ocean (7)

- andesite line is a petrologic boundary, separating deeper, mafic igneous rock of Central Pacific Basin from partially submerged continental areas of felsic igneous rocks, follows western edge of islands off California, passes south of Aleutian arc, along eastern edge of Kamchatka Peninsula, Kuril Islands, Japan, Mariana Islands, Solomon Islands, New Zealand's North Island
- dissimilarity continues northeastward along western edge of Andes Cordillera along South America to Mexico, returning to islands off California
- Indonesia, Phillipines, Japan, New Guinea, New Zealand lie outside andesite line
- within andesite line are most deep troughs, submerged volcanic mountains, oceanic volcanic islands that characterize Pacific Basin

Geoscience: Pacific Ocean (8)

- inside andesite line basaltic lavas flow out of rifts to build huge, dome-shaped volcanic mountains, which eroded, form island arcs, chains, and clusters
- outside andesite line, volcanism is explosive
- Ring of Fire is world's foremost belt of explosive volcanism
- only ocean which is almost totally bounded by subduction zones

(Source: https://en.wikipedia.org/wiki/Pacific_Ocean)

Geoscience: Atlantic Ocean (1)

- separates "Old World" from "New World"
- occupies an elongated, S-shaped basin extending longitudinally between Eurasia and Africa to east, and Americas to west
- connected in north to Arctic Ocean, to Pacific Ocean in southwest, Indian Ocean in southeast, and Southern Ocean in south
- opening of ocean coincided with initial breakup of Pangaea

(Image source:https://en.wikipedia.org/wiki/Atlantic_Ocean, public domain)

Geoscience: Atlantic Ocean (2)

- Equatorial Counter Current subdivides it into North Atlantic Ocean and South Atlantic Ocean
- bounded on west by North and South America
- connects to Arctic Ocean through Denmark Strait, Greenland Sea, Norwegian Sea, Barents Sea
- on east, boundaries are Europe, Strait of Gibraltar, where it connects to Mediterranean Sea and Black Sea, both of which also touch Asia and Africa
- in southeast, Atlantic merges into Indian Ocean
- 20^0 east meridian, running south from Cape Agulhas to Antarctica defines border
- has irregular coasts indented by bays and seas, including Baltic Sea, Black Sea, Caribbean Sea, Davis Strait, Denmark Strait, part of Drake Passage, Gulf of Mexico, Labrador Sea, Mediterranean Sea, North Sea, Norwegian Sea, almost all of Scotia Sea

Geoscience: Atlantic Ocean (3)

- dominated by a submarine mountain range, Mid-Atlantic Ridge (MAR), which runs from 870N, 300 km south of the North Pole, to the subantarctic Bouvet Island at 420S
- MAR rises 2 to 3 km above surrounding ocean floor
- its rift valley is divergent boundary between North American and Eurasian plates in North Atlantic and South American and African plates in South Atlantic
- MAR produces basaltic volcanoes in Eyjafjallajökull, Iceland, and pillow lava on ocean floor
- depth of water at apex of ridge less than 2,700 m
- bottom of ridge is three times as deep
- MAR intersected by two perpendicular ridges: Azores-Gibraltar Transform Fault, boundary between Nubian and Eurasian plates, intersects MAR at Azores Triple Junction, on either side of Azores microplate near 40^0N

Geoscience: Atlantic Ocean (4)

- nameless boundary, between North American and South American plates intersects MAR near Fifteen-Twenty Fracture Zone at approximately 16^0N
- most of MAR is underwater, but at surface, produced volcanic islands
- continental shelves wide off Newfoundland, southern-most South America, and north-eastern Europe
- carbonate platforms dominate large areas, including Blake Platea and Bermuda Rise
- surrounded by passive margins
- active margins form deep Puerto Rico Trench and in the western Pacific and South Sandwich Trench in South Atlantic
- numerous submarine canyons off north-eastern North America, western Europe, and north-western Africa
- some canyons extend along continental rises and into abyssal plains

Geoscience: Atlantic Ocean (5)

- surface water temperatures range from -20C to over 300C, with maximum temperatures near equator and minimum near polar regions
- from October to June, surface is usually covered with sea ice in Labrador Sea, Denmark Strait, and Baltic Sea
- Coriolis effect circulates North Atlantic water clockwise direction, counter-clockwise in South Atlantic
- south tides are semi-diurnal, two high tides every 24 lunar hours
- North Atlantic oscillation above 40^0N latitude
- saltiest ocean, surface water salinity in open ocean ranges from 33 to 37 parts per thousand by mass and varies with latitude and season
- evaporation, precipitation, river inflow, and sea ice melting affect surface salinity
- lowest salinity values just north of equator because of heavy tropical rainfall

Geoscience: Atlantic Ocean (6)

- in general, lowest salinity values in high latitudes and along coasts where rivers enter
- maximum salinity values occur at about 250 north and south in subtropical regions with low rainfall and high evaporation
- high surface salinity is maintained by Agulhas Leakage/Rings which brings salty Indian Ocean waters into South Atlantic, and "Atmospheric Bridge," which evaporates subtropical Atlantic waters
- clockwise warm water North Atlantic Gyre occupies northern Atlantic and counter-clockwise warm-water South Atlantic Gyre appears in southern Atlantic
- in North Atlantic surface circulation dominated by Gulf Stream, which flows north-east from North American coast, at Cape Hatteras, North Atlantic Current, branch of the Gulf Stream which flows northward from Grand Banks, and Subpolar Front, an extension of North Atlantic Current

Geoscience: Atlantic Ocean (7)

- system of current transport warm water into North Atlantic, which keeps North Atlantic temperatures warm
- North Atlantic Subpolar Gyre governed by ocean currents from marginal seas and regional topography
- Subpolar Gyre forma important part of global thermocline circulation, eastern portion includes eddying branches of North Atlantic Current, which transports warm, saline water from subtropics
- water cooled during winter, forms return currents that merge along eastern continental slope of Greenland where they form intense current which flows around continental margins of Labrador Sea
- Southern Atlantic dominated by anti-cyclonic southern tropical gyre
- South Atlantic Central Water originates in this gyre
- Antarctic Intermediate Water originates in upper layers of circumpolar region, near Drake Passage and Falkland Islands

Geoscience: Atlantic Ocean (8)

- warmest zones stretch across the Atlantic north of equator
- coldest zones are in high latitudes, with coldest regions corresponding to areas covered by sea ice
- Gulf Stream and its northern extensions toward Europe, North Atlantic Drift, may influence climate
- Gulf Stream helps moderate winter temperatures along coastline of southeastern North America
- Gulf Stream keeps extreme temperatures from occurring on Florida Peninsula
- in higer latitudes, North Atlantic Drift warms atmosphere over oceans, keeping British Isles and north-western Europe mild and cloudy
- icebergs common from February to August in Davis Strait, Denmark Strait, and northwestern Atlantic, have also been spotted as far south as Bermuda and Madeira

Geoscience: Atlantic Ocean (9)

- ships subject to superstructure icing in extreme north from October to May
- persistent fog can be maritime hazard from May to September
- hurricanes can be a maritime hazard north of the equator from May to December
- southeast cost of U.S., especially Virginia and North Carolina coasts, has long history of shipwrecks
- Bermuda Triangle believed to be the site of numerous aviation and shipping incidents, but Coast Guard records do not support this
- hurricane activity increased in last decades because of increased sea surface temperatures, changes attributed to Atlantic Multidecadal Oscillation and climate change
- Atlantic meridional overturning circulation slowed down by 30% between 1957 and 2004
- ocean mixing layer plays role in heat storage

Geoscience: Atlantic Ocean (10)

- deep layers affected over millennia and have capacity about 50 times of mixed layer
- heat uptake provides time lag for climate change
- endangered marine species include the manatee, seals, sea lions, turtles, whales
- drift net fishing can kill dolphins, albatrosses, seabirds, including petrels, hastening the fish stock decline and contributing to international disputes
- municipal pollution comes from eastern U.S., southern Brazil, and eastern Argentina
- oil pollution in the Caribbean Sea, Gulf of Mexico, Lake Maracaibo, Mediterranean Sea, and North Sea; and industrial waste and municipal sewage pollution in the Baltic Sea, North Sea, and Mediterranean Sea

(Source: https://en.wikipedia.org/wiki/Atlantic_Ocean)

Geoscience: Indian Ocean (1)

- delimited from Atlantic Ocean by the 20° east meridian, running south from Cape Agulhas, and from Pacific Ocean by meridian of 146°55'E, running south from the southernmost point of Tasmania; northernmost extent of the Indian Ocean is approximately 30° north in the Persian Gulf
- youngest major ocean
- includes Red Sea and Persian Gulf
- continental shelves are narrow, averaging 200 kilometers width

(Image source: https://en.wikipedia.org/wiki/Indian_Ocean, public domain)

Geoscience: Indian Ocean (2)

- exception found off Australia's western coast, shelf width exceeds 1,000 km
- warmest ocean; long-term ocean temperature records show a rapid, continuous warming, at about 0.7–1.2 C during 1901–2012
- warming is about 3 times faster than the warming observed in the Pacific
- research indicates that human induced greenhouse warming, and changes in the frequency and magnitude of El Niño events are a trigger to this strong warming in the Indian Ocean
- entire ocean in Eastern Hemisphere
- center of Eastern Hemisphere is in this ocean
- deepest point is Diamantina Deep in Diamantina Trench, at 8,047 m
- Sunda Trench has depth of 7,258–7,725 m
- north of 50° south latitude, 86% of the main basin is covered by pelagic sediments, of which more than half are globigerina ooze

Geoscience: Indian Ocean (3)

- remaining 14% is layered with terrigenous sediments
- glacial outwash dominates the extreme southern latitudes
- major choke points include Bab el Mandeb, Strait of Hormuz, Lombok Strait, Strait of Malacca, and Palk Strait
- seas include Gulf of Aden, Andaman Sea, Arabian Sea, Bay of Bengal, Great Australian Bight, Laccadive Sea, Gulf of Mannar, Mozambique Channel, Gulf of Oman, Persian Gulf, Red Sea
- artificially connected to Mediterranean Sea through Suez Canal, which is accessible via Red Sea
- also includes Gulf of Mannar, Gulf of Aden, Gulf of Aqaba, Gulf of Tadjoura, Gulf of Bahrain, Gulf of Carpentaria, Gulf of Kutch, Gulf of Khambat, Gulf of Oman, Indonesian Seaway including Malacca, Sunda and Torres Straits, Laccadive Sea, Sea of Zanj

Geoscience: Indian Ocean (4)

- climate north of equator affected by monsoon climate
- strong north-east winds blow from October until April; from May until October south and west winds prevail.
- in Arabian Sea, violent Monsoon brings rain to the Indian subcontinent
- in southern hemisphere, winds generally milder, but summer storms near Mauritius can be severe
- when monsoon winds change, cyclones sometimes strike shores of Arabian Sea and Bay of Bengal
- large rivers flowing into the Indian Ocean are Zambezi, Shatt al-Arab, Indus, Godavari, Krishna, Narmada, Ganges, Brahmaputra, Jubba and Irrawaddy
- currents mainly controlled by the monsoon
- two large gyres, one in northern hemisphere flowing clockwise and one south of the equator moving anticlockwise, including Agulhas Current and Agulhas Return Current, constitute the dominant flow pattern

Geoscience: Indian Ocean (5)

- during winter monsoon currents in the north are reversed.
- Deep water circulation controlled primarily by inflows from Atlantic Ocean, Red Sea, and Antarctic currents
- north of 20° south latitude minimum surface temperature is 22^{0}C, exceeding 28^{0}C to east. Southward of 40° south latitude, temperatures drop quickly
- precipitation and evaporation leads to salinity variation in all oceans
- salinity variations are driven by: river inflow mainly from the Bay of Bengal, fresher water from Indonesian Throughflow; and saltier water from Red Sea and Persian Gulf
- surface water salinity ranges from 32 to 37 parts per 1000, highest occurring in the Arabian Sea and in a belt between southern Africa and south-western Australia

Geoscience: Indian Ocean (6)

- pack ice and icebergs are found throughout the year south of about 65° south latitude
- average northern limit of icebergs is 45° south latitude
- has active spreading ridges that are part of the worldwide system of mid-ocean ridges
- spreading ridges meet at Rodrigues Triple Point with Central Indian Ridge, including Carlsberg Ridge, separate African Plate from Indian Plate
- Southwest Indian Ridge separating African Plate form Antarctic Plate; and Southeast Indian Ridge separating Australian Plate from Antarctic Plate
- Central Ridge runs north on the in-between across of Arabian Peninsula and Africa into Mediterranean Sea series of ridges and seamount chains produced by hotspots pass over Indian Ocean

Geoscience: Indian Ocean (5)

- Réunion hotspot, active 70–40 million years ago, connects Réunion and Mascarene Plateau to Chagos-Laccadive Ridge and Deccan Traps in north-western India
- Kerguelen hotspot, 100–35 million years ago, connects Kerguelen Islands and Kerguelen Plateau to Ninety East Ridge and Rajmahal Traps in north-eastern India
- Marion hotspot, 100–70 million years ago, possibly connects Prince Edward Islands to Eighty Five East Ridge
- these hotspot tracks have been broken by the still active spreading ridges
- hosts one of largest concentration of phytoplankton blooms in summer, due to strong monsoon winds monsoonal wind forcing leads to a strong coastal and open ocean upwelling, which introduces nutrients into upper zones where sufficient light is available for photosynthesis and phytoplankton production

Geoscience: Indian Ocean (6)

- phytoplankton blooms support the marine ecosystem, as base of marine food web, and eventually larger fish species
- ocean accounts for second largest share of most economically valuable tuna catch
- study on phytoplankton changes indicates a decline of up to 20% in the marine phytoplankton during past six decade
- tuna catch rates have also declined abruptly during past half century, mostly due to increased industrial fisheries, with ocean warming adding further stress to fish species
- endangered marine species include dugong, seals, turtles, and whales

Geoscience: Indian Ocean (7)

- Indian Ocean garbage patch discovered in 2010 covering at least 5 million square kilometers riding the southern Indian Ocean Gyre; this vortex of plastic garbage constantly circulates the ocean from Australia to Africa, down the Mozambique Channel, and back to Australia in a period of six years, except for debris that get indefinitely stuck in the center of gyre
- in 2016, UK researchers from Southampton University identified six new animal species at hydrothermal vents beneath the Indian Ocean; new species were a "Hoff" crab, a "giant peltospirid" snail, a whelk-like snail, a limpet, a scaleworm and a polychaete worm
- sea lanes considered among most strategically important in the world with more than 80 percent of the world's seaborne trade in oil transits through this ocean and its vital choke points, with 40 percent passing through Strait of Hormuz, 35 percent through the Strait of Malacca and 8 percent through Bab el-Mandab Strait

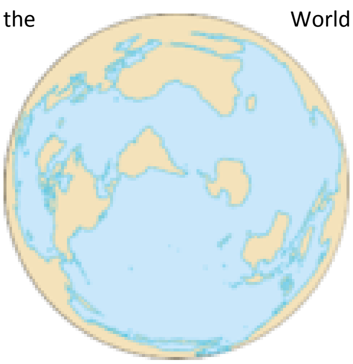
Geoscience: Indian Ocean (8)

- provides major sea routes connecting Middle East, Africa, and East Asia with Europe and Americas
- carries heavy traffic of petroleum and petroleum products from the oil fields of Persian Gulf and Indonesia
- large reserves of hydrocarbons are being tapped in offshore areas of Saudi Arabia, Iran, India, and Western Australia
- estimated 40% of the world's offshore oil production comes from this ocean
- beach sands rich in heavy minerals, and offshore placer deposits actively exploited by bordering countries, particularly India, Pakistan, South Africa, Indonesia, Sri Lanka, and Thailand
- Port of Singapore is busiest port, located in the Strait of Malacca where it meets the Pacific

(Source: https://en.wikipedia.org/wiki/Indian_Ocean)

Geoscience: Southern Ocean (1)

- comprises the southernmost waters of the World Ocean, generally taken to be south of 60° S latitude and encircling Antarctica
- ocean zone is where cold, northward flowing waters from Antarctic mix with warmer subantarctic waters
- geographers disagree on the Southern Ocean's northern boundary or even existence, considering the waters as various parts of the Pacific, Atlantic, and Indian Oceans



(Image source: https://en.wikipedia.org/wiki/Southern_Ocean, public domain)

Geoscience: Southern Ocean (2)

- body of water which lies south of northern limit of circulation formed when Antarctica and South America moved apart, opening Drake Passage, roughly 30 million years ago
- separation of continents allowed formation of Antarctic Circumpolar Current
- differs from other oceans in that its largest boundary, northern boundary, does not abut a landmass, instead, northern limit is with Atlantic, Indian and Pacific Oceans
- much of its water differs from water in the other oceans
- water gets transported around Southern Ocean rapidly because of Antarctic Circumpolar Current which circulates around Antarctica
- water in Southern Ocean south of, for example, New Zealand, resembles water in the Southern Ocean south of South America more closely than it resembles water in Pacific Ocean

Geoscience: Southern Ocean (3)

- typical depths of between 4,000 and 5,000 m over most of its extent with only limited areas of shallow water
- greatest depth of 7,236 m occurs at the southern end of the South Sandwich Trench, at 60°00'S, 024 W
- Antarctic continental shelf appears generally narrow and unusually deep, its edge lying at depths up to 800 m, compared to a global mean of 133 m
- equinox to equinox in line with the sun's seasonal influence, Antarctic ice pack fluctuates from an average minimum of 2.6 million square kilometers in March to about 18.8 million square kilometers in September
- subdivisions include Weddell Sea, Lazarev Sea, Riiser-Larsen Sea, Cosmonauts Sea, Cooperation Sea, Davis Sea, Tryoshnikova Gulf, Mawson Sea, Dumont D'Urville Sea, Somov Sea, Ross Sea, McMurdo Sound, Amundsen Sea, Bellingshausen Sea, part of Drake Passage, Bransfield Strait, and part of Scotia Sea

Geoscience: Southern Ocean (4)

- probably contains large, and possibly giant, oil and gas fields on continental margin
- Placer deposits, accumulation of valuable minerals such as gold, formed by gravity separation during sedimentary processes are also expected to exist
- manganese nodules, rock concretions on the sea bottom formed of concentric layers of iron and manganese hydroxides around a core, expected to exist
- may be microscopically small and is sometimes completely transformed into manganese minerals by crystallization
- icebergs can form at any time during the year

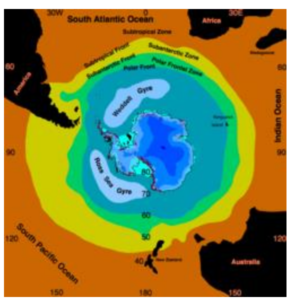
Geoscience: Southern Ocean (5)

- Antarctic Circumpolar Current moves perpetually eastward , joining itself; 21,000 km long; world's longest ocean current, transporting 130 million cubic meters per second of water, 100 times the flow of all world's rivers
- types of water masses not produced elsewhere in oceans of Southern Hemisphere; Antarctic Bottom Water, a very cold, highly saline, dense water forming under sea ice; Antarctic Convergence, encircling Antarctica, where cold northward-flowing Antarctic waters meet relatively warmer waters of subantarctic
- Antarctic waters predominantly sink beneath subantarctic waters, while associated zones of mixing and upwelling create a zone very high in nutrients
- nurture high levels of phytoplankton with associated copepods and Antarctic krill, and resultant foodchains supporting fish, whales, seals, penguins, albatrosses and a wealth of other species

Geoscience: Southern Ocean (6)

- Antarctic Convergence considered best natural definition of northern extent of Southern Ocean
- strong westerly (eastward) winds blow around Antarctica, driving significant flow of water northwards, creating coastal upwelling
- since no continents in band of open latitudes between South America and tip of Antarctic Peninsula, some water is drawn up from great depths
- Southern Ocean upwelling may represent primary means by which deep dense water is brought to surface
- shallower, wind-driven upwelling also found off west coasts of North and South America, northwest and southwest Africa, southwest and southeast Australia, all associated with oceanic subtropical high pressure circulations.
- some models suggest that broad-scale upwelling occurs in tropics, as pressure driven flows converge water toward the low latitudes where it is diffusively warmed from above

Geoscience: Southern Ocean (7)



- Ross Gyre and Weddell Gyre exist within Southern Ocean; both rotate clockwise
- gyres are formed by interactions between Antarctic Circumpolar Current and Antarctic Continental Shelf
- sea ice persists in central area of Ross Gyre
- some evidence that global warming has resulted in some decrease of salinity of waters of Ross Gyre since 1950s
- due to Coriolis effect acting to left in Southern Hemisphere and resulting Ekman transport away from centers of Weddell Gyre, very productive due to upwelling of cold, nutrient rich water

(Image source and source: https://en.wikipedia.org/wiki/Southern_Ocean, CC BY-SA 2.5)

Geoscience: Arctic Ocean (1)

- smallest and shallowest
- some oceanographers call it Arctic Mediterranean Sea or Arctic Sea, classifying it a mediterranean sea or estuary of Atlantic Ocean
- can be seen as the northernmost part of the all-encompassing World Ocean
- located mostly in Arctic north polar region in the middle of Northern Hemisphere
- almost completely surrounded by Eurasia and North America

(Image source: https://en.wikipedia.org/wiki/Arctic_Ocean, public domain)

Geoscience: Arctic Ocean (2)

- partly covered by sea ice throughout year and almost completely in winter. surface temperature and salinity vary seasonally as ice cover melts and freezes
- salinity is the lowest on average of the five major oceans, due to low evaporation, heavy fresh water inflow from rivers and streams, and limited connection and outflow to surrounding oceanic waters with higher salinities.
- summer shrinking of ice has been quoted at 50%
- U.S. National Snow and Ice Data Center (NSIDC) uses satellite data to provide a daily record of Arctic sea ice cover melting rate compared to an average period and specific past years

Geoscience: Arctic Ocean (3)

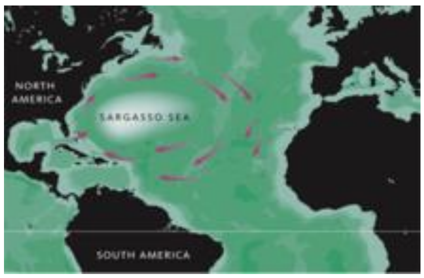
- surrounded by Eurasia, North America, Greenland, and several islands
- includes Baffin Bay, Barents Sea, Beaufort Sea, Chukchi Sea, East Siberian Sea, Greenland Sea, Hudson Bay, Hudson Strait, Kara Sea, Laptev Sea, White Sea connected to Pacific Ocean by Bering Strait and to Atlantic Ocean through Greenland Sea and Labrador Sea
- bordering countries are Russia, Norway, Iceland, Greenland, Canada and U.S.
- includes continental shelves of Canadian Arctic shelf, underlying Canadian Arctic Archipelago, Russian continental shelf, sometimes called "Arctic Shelf" because it is greater in extent
- Russian continental shelf consists of three separate, smaller shelves: Barents Shelf, Chukchi Sea Shelf and Siberian Shelf
- Siberian Shelf is largest such shelf in the world; holds large oil and gas reserves

Geoscience: Arctic Ocean (4)

- underwater Lomonosov Ridge, divides deep sea North Polar Basin into Eurasian Basin, between 4,000 and 4,500 m deep, and Amerasian Basin, about 4,000 m deep
- bathymetry of ocean bottom marked by fault block ridges, abyssal plains, ocean deeps, and basins
- average depth of the Arctic Ocean is 1,038 m; deepest point is Litke Deep in Eurasian Basin, at 5,450 m
- two major basins subdivided by ridges into the Canada Basin, between Alaska/Canada and Alpha Ridge, Makarov Basin, between the Alpha and Lomonosov Ridges, Amundsen Basin, between Lomonosov and Gakkel ridges, and Nansen Basin, between the Gakkel Ridge and the continental shelf that includes Franz Josef Land

(Source: https://en.wikipedia.org/wiki/Arctic_Ocean)

Geoscience: Sargasso Sea



- defined as area where two species of Sargassum(S. fluitans and natans) float, an area 4,000 km wide and encircled by Gulf Stream, North Atlantic Drift, and North Equatorial Current
- population of seaweed probably originated from Tertiary ancestors on European shores of former Tethys Ocean and has
- maintained itself by vegetative growth, floating in ocean for millions of years

(Image source and source: https://en.wikipedia.org/wiki/Atlantic_Ocean, public domain)

Geoscience: Mediterranean Sea (1)

- connected to Atlantic Ocean, surrounded by Mediterranean Basin and almost completely enclosed by land: on north by Southern Europe and Anatolia, on south by North Africa, and on east by Levant
- evidence indicates that around 5.9 million years ago, Mediterranean was cut off from Atlantic and was partly or completely desiccated over a period of some 600,000 years before being refilled by Zanclean flood about 5.3 million years ago

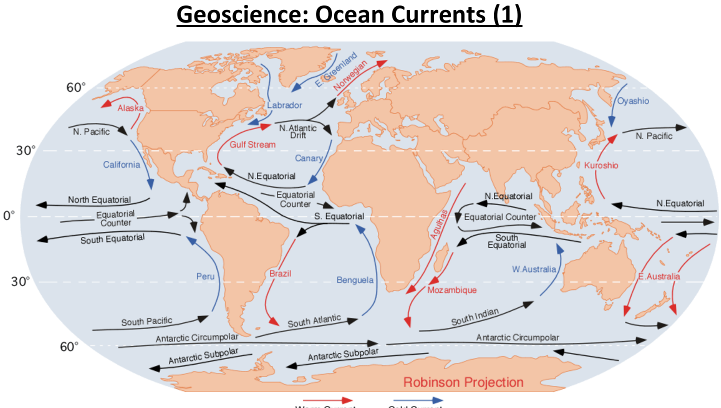
(Source: https://en.wikipedia.org/wiki/Mediterranean_Sea, CC BY-SA 4.0)

Geoscience: Mediterranean Sea (2)

- average depth of 1,500 m; deepest recorded point is 5,267 m in Calypso Deep in Ionian Sea
- sea is bordered on north by Europe, east by Asia, and in south by Africa
- located between latitudes 30° and 46° N and longitudes 6° W and 36° E
- west-east length, from the Strait of Gibraltar to Gulf of Iskenderun, on southwestern coast of Turkey, is approximately 4,000 km
- sea's average north-south length, from Croatia's southern shore to Libya, is approximately 800 km
- was an important route for merchants and travellers of ancient times that allowed for trade and cultural exchange between emergent peoples of the region

(Source: https://en.wikipedia.org/wiki/Mediterranean_Sea)

Geoscience: Ocean Currents (1)



(Image source: https://en.wikipedia.org/wiki/Ocean_current#/media/File:Corrientes-oceanicas.png, Dr. Michael Pidwirny, public domain)

Geoscience: Ocean Currents (2)

ocean current: continuous, directed movement of seawater generated by forces acting upon this mean flow, such as breaking waves, wind, Coriolis effect, cabbeling, temperature and salinity differences

large-scale surface ocean currents: driven by global wind systems fueled by solar energy; transfer heat from tropics to the polar regions; influence local and global climate; warm Gulf Stream originating in tropical Caribbean carries about 150 times more water than Amazon River; current moves along U.S. East Coast across the Atlantic Ocean towards Europe; heat from Gulf Stream keeps much of Northern Europe significantly warmer than other places equally as far north

rip currents: serious hazards that pose daily threats to surf zone swimmers and waders in all coastal regions; rip currents cause more than 100 drowning fatalities each year, and 80% of all rescues on surf beaches nationwide are rip current related; can occur along any beach with breaking waves, may become especially hazardous during high-surf conditions

Geoscience: Ocean Currents (3)

deep ocean currents: differences in water density, resulting from variability of water temperature and salinity, also cause ocean currents; process is known as thermohaline circulation; in cold regions, such as the North Atlantic Ocean, ocean water loses heat to the atmosphere and becomes cold and dense; when ocean water freezes, forming sea ice, salt is left behind causing surrounding seawater to become saltier and denser; dense-cold-salty water sinks to ocean bottom; surface water flows in to replace the sinking water, which in turn becomes cold and salty enough to sink, starting global conveyer belt, a connected system of deep and surface currents that circulate around the globe on a 1000 year time span; global set of ocean currents is a critical part of Earth's climate system as well as the ocean nutrient and carbon dioxide cycles

(Source: http://www.noaa.gov/resource-collections/ocean-currents)

Geoscience: Ekman Transport (1)

Ekman transport: the 90° net transport of the surface layer of a fluid, the layer affected by wind, by wind forcing

- in northern hemisphere, transport occurs at 90° clockwise from wind direction, in southern hemisphere it occurs at a 90° counterclockwise
- surface currents flow at a 45° angle to the wind due to a balance between Coriolis force and the drags generated by the wind and the water
- factor in coastal upwelling regimes, nutrient supply for fishing markets
- wind in these regimes blows parallel to coast
- because surface water flows away from coast, must be replaced with water from below
- in shallow coastal waters, normally not fully formed and wind events that cause upwelling episodes are typically rather short, leads to many variations in the extent of upwelling

Geoscience: Ekman Transport (2)

- at work in equatorial upwelling, where, in both hemispheres, trade wind component towards the west
- causes net transport of water towards the pole, and a trade wind component towards the east causes a net transport of water away from poles
- on smaller scales, cyclonic winds induce Ekman transport which causes net divergence and upwelling, or Ekman suction; anti-cyclonic winds cause net convergence and downwelling, or Ekman pumping
- also factor in circulation of ocean gyres; causes water to flow toward center of gyre in all locations, creating a sloped sea-surface, and initiating geostrophic flow

(Source: https://en.wikipedia.org/wiki/Ekman_transport)

Geoscience: Seawater Solutes

salt ion	ions in seawater 0/00	ions by weight 0/0
chloride Cl^-	18.980	55.04
sodium Na^+	10.556	30.61
sulfate SO_4^{2-}	2.649	7.68
magnesium Mg^{2+}	1.272	3.69
calcium Ca^{2+}	0.400	1.16
potassium K^+	0.380	1.10
bicarbonate HCO_3^-	0.140	0.41
bromide Br^-	0.065	0.19
boric acid H_3BO_3	0.026	0.07
strontium Sr^{2+}	0.013	0.04
fluoride F^-	0.001	0.00
total	34.482	99.99

(Source: Oceanography, Paul R. Pinet, p. 128)

Geoscience: Effects of Salinity on Sea Water

- density of water increases almost linearly with salinity; for salinities > 24.7 0/00, maximum density temperature, 3.980C for freshwater, is lowered to below freezing point of freshwater
- addition of salt water lowers freezing point to -1.910C at 35 0/00; hydrated salt ions interfere with arrangement of H2O moleculesinto orderly,crystalline ice lattice
- as water salinity increases,vapor pressure drops, meaning that freshwater evaporates at a faster rate than seawater; condition is a consequence of hydrated ions, which hold on to water molecules, making their vaporization more difficult
- flow rate of solutions through semipermeable membranes, such as cell walls of organisms, depends on osmotic pressure; osmotic pressure of water rises as sea level increases

Geoscience: Waves

wave	period	wavelength	wave type	cause
capillary	<0.1 s	< 2 cm	deep or shallow	local winds
chop	1 s - 10 s	1 m – 10 m	deep or shallow	local winds
swell	10 s - 30 s	up to hundreds of m	deep or shallow	distant storm
seiche	10 m – 10 hr	up to hundreds of km	shallow	wind, tsunami, tidal resonance
tsunami	10 min – 60 min	up to hundreds of km	shallow	submarine disturbance
tide	12.4 hr – 24.8 hr	thousands of km	shallow	gravitational attraction of Sun and Moon
internal	min to hr	up to hundreds of km	deep or shallow	disturbance at pycnocline

(Source: Oceanography, Paul R. Pinet, p. 202)

Geoscience: Marine Pollution and Debris

marine pollution: generic term for the harmful entry into the ocean of chemicals or particles; main culprits are those using rivers for disposing of waste; rivers then empty into ocean, often also bringing chemicals used as fertilizers in agriculture; excess of oxygen-depleting chemicals in the water leads to hypoxia and creation of a dead zone
marine debris: also known as marine litter, is human-created waste that has ended up floating in a lake, sea, ocean, or waterway; oceanic debris tends to accumulate at the center of gyres and coastlines, frequently washing aground where it is known as beach litter

(Source: https://en.wikipedia.org/wiki/Pacific_Ocean)

Geoscience: Earth's 10 Longest Rivers (1)

river	length (km)	drainage area (km^2)	average discharge (m^3/	outflow to	location
Amazon–Ucayali–Apurímac	6,992	7,050,000	209,000	Atlantic Ocean	South America
Nile–Kagera	6,853	3,254,555	2,800	Mediterr-anean	Africa
Yangtze	6,300	1,800,000	31,900	East China Sea	China
Mississippi–Missouri–Jefferson	6,275	2,980,000	16,200	Gulf of Mexico	U.S., Canada
Yenisei–Angara–Selenge	5,539	2,580,000	19,600	Kara Sea	Russia Mongolia

Geoscience: Earth's 10 Longest Rivers (2)

river	length (km)	drainage area (km^2)	average discharge (m^3/	outflow to	location
Yellow River	5,464	745,000	2,110	Bohai Sea	China
Ob–Irtysh	5,410	2,990,000	12,800	Gulf of Ob	Russia, Kazakhstan, China, Mongolia
Paraná – Río de la Plata	4,880	2,582,672	18,000	Río de la Plata	South America
Congo–Chambeshi	4,700	3,680,000	41,800	Atlantic Ocean	Africa
Amur–Argun	4,444	1,855,000	11,400	Sea of Okhotsk	Russia, China, Mongolia

(Source: https://en.wikipedia.org/wiki/List_of_rivers_by_length)

Geoscience: Earth's Biggest Lakes (1)

name	countries with shoreline	area (km^2)	length (km)	maximum depth (m)	water volume (km^3)
Caspian Sea	Kazakhstan, Russia, Turkmenistan, Azerbaijan, Iran	436,000	1,199	1,025	78,200
Superior	Canada, United States	82,100	616	406.3	12,100
Victoria	Uganda, Kenya, Tanzania	68,870	322	84	2,750
Huron	Canada, United States	59,600	332	229	3,540
Michigan	United States	58,000	494	281	4,900

Geoscience: Earth's Biggest Lakes (2)

name	countries with shoreline	area (km^2)	length (km)	maximum depth (m)	water volume (km^3)
Tanganyika	Burundi, Tanzania, Zambia, Democratic Republic of the Congo	32,600	676	1,470	18,900
Baikal	Russia	31,500	636	1,637	23,600
Great Bear Lake	Canada	31,000	373	446	2,236
Malawi	Malawi, Mozambique, Tanzania	29,500	579	706	8,400
Great Slave	Canada	27,000	480	614	1,560

(Source: https://en.wikipedia.org/wiki/List_of_lakes_by_area)

Geoscience: Water Cycle (1)

1. The water cycle has no starting point, but we can begin in the oceans, since that is where most of Earth's water exists.
2. The sun, which drives the water cycle, heats water in the oceans.
3. Some of it evaporates as vapor into the air; a relatively smaller amount of moisture is added as ice and snow sublimate directly from the solid state into vapor.
4. Rising air currents take the vapor up into the atmosphere, along with water from evapotranspiration, which is water transpired from plants and evaporated from the soil.
5. The vapor rises into the air where cooler temperatures cause it to condense into clouds.
6. Air currents move clouds around the globe, and cloud particles collide, grow, and fall out of the sky as precipitation.

Geoscience: Water Cycle (2)

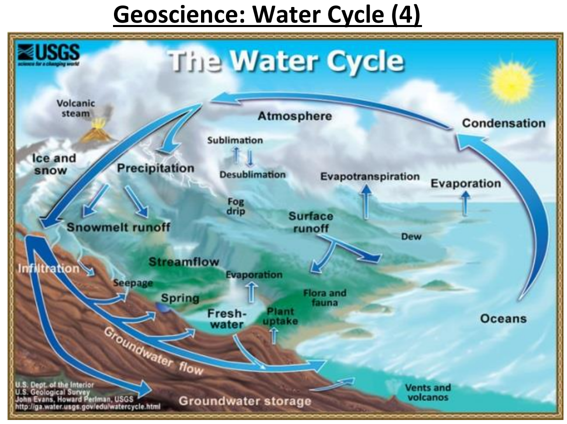
7. Some precipitation falls as snow and can accumulate as ice caps and glaciers, which can store frozen water for thousands of years.
8. Snowpacks in warmer climates often thaw and melt when spring arrives, and the melted water flows overland as snowmelt.
9. Most precipitation falls back into the oceans or onto land, where, due to gravity, the precipitation flows over the ground as surface runoff.
10. A portion of runoff enters rivers in valleys in the landscape, with streamflow moving water towards the oceans.
11. Runoff, and groundwater seepage, accumulate and are stored as freshwater in lakes.
12. Not all runoff flows into rivers, though. Much of it soaks into the ground as infiltration

Geoscience: Water Cycle (3)

13. Some of the water infiltrates into the ground and replenishes aquifers (saturated subsurface rock), which store huge amounts of freshwater for long periods of time.
14. Some infiltration stays close to the land surface and can seep back into surface-water bodies (and the ocean) as groundwater discharge, and some groundwater finds openings in the land surface and emerges as freshwater springs.
15. Yet more groundwater is absorbed by plant roots to end up as evapotranspiration from the leaves.
16. Over time, though, all of this water keeps moving, some to reenter the ocean, where the water cycle "begins."

(Source: https://en.wikipedia.org/wiki/Water_cycle)

Geoscience: Water Cycle (4)



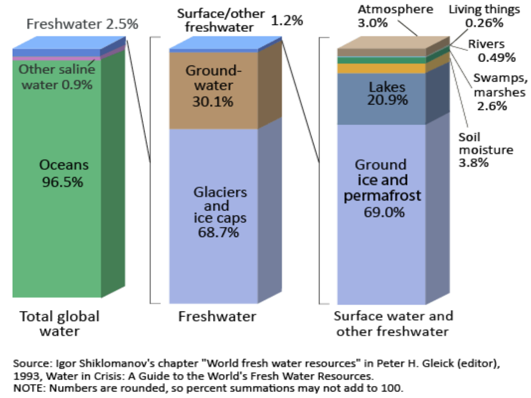
(Image source: https://water.usgs.gov/edu/watercycle.html, John Evans and Howard Periman, public domain)

Geoscience: Earth's Water (1)

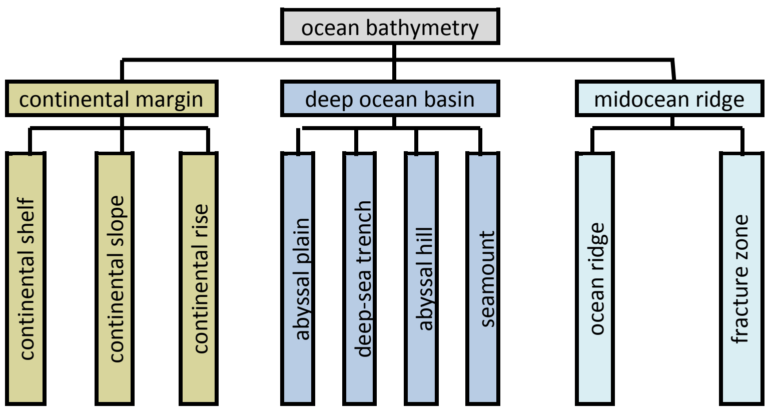
water source	volume in km^3	% of fresh	% of total
oceans, seas, & bays	1,338,000,000	--	96.5
ice caps, glaciers, permanent snow	24,064,000	68.7	1.74
ground water	23,400,000	--	1.69
fresh	10,530,000	30.1	0.76
saline	12,870,000	--	0.93
soil moisture	16,500	0.05	0.001
ground Ice, permafrost	300,000	0.86	0.022
lakes	176,400	--	0.013
fresh	91,000	0.26	0.007
saline	85,400	--	0.006
atmosphere	12,900	0.04	0.001
swamp water	11,470	0.03	0.0008
rivers	2,120	0.006	0.0002
biological water	1,120	0.003	0.0001

Geoscience: Earth's Water (2)

(Source for (1) and Image source: https://water.usgs.gov/edu/earthwherewater.html, public domain)



Geoscience: Bathrythmic Provinces



(Source: Oceanography, Paul R. Pinet, 1992, p. 31)

Geoscience: Bathrythmic Features

feature	width	relief	water depth	bottom gradient
continental shelf	<300 km	<20 m	<150 m	< 1:1000,~0.5^0
continental slope	<150 km	locally >2 km	drops from 100+- 2,000+ m	~1:40, 3-6^0
continental rise	<300 km	<40 m	1.5-5 km	1:1,000-1:700, 0.5^0-1^0
submarine canyon	1-15 km	20-2,000 m	20-2,000 m	<1:40, 3-6^0
deep-sea trench	30-100 km	>2 km	5,000-12,000 m	---
abyssal hills	100-100,000 m	1-900 m	---	---
seamounts	2-100 km	>900 m	---	---
abyssal plains	1-1,000 km	0	>3 km	1 : 1,000, 1 : 10,000, <0.5^0
ocean-ridge flank	500-1,500 km	<1 km	>3 km	---
ocean-ridge crest	500-1,000 km	<2 km	2-4 km	---

Geoscience: Continental Margin (1)

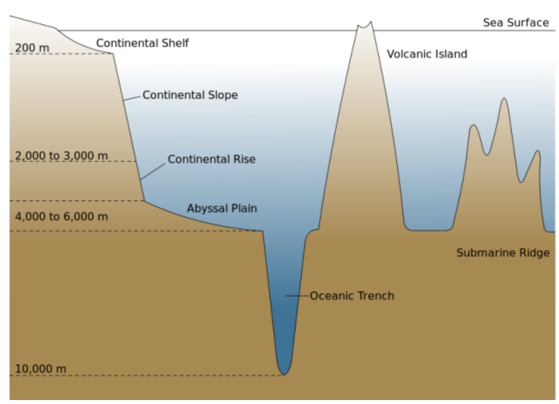
<u>continental margin</u>: comprises a steep continental slope followed by the flatter continental rise; sediment from the continent above cascades down the slope and accumulates as a pile of sediment at the base of the slope, called the continental rise

<u>continental shelf</u>: underwater landmass extending from a continent, resulting in an area of relatively shallow water; many shelves exposed during glacial and interglacial periods; shelf surrounding an island is known as an insular shelf

<u>continental slope</u>: plunges at an average angle of about 4^0 to water depths of 2 to 3 km; huge submarine canyons are cut into many continental slopes which are chutes for sediment transport from continental margins to deep ocean basins

<u>continental rise</u>: nearly flat plain bordering the continent; slopes gently toward the ocean basin; at the bottom of each continental slope, ocean floor flattens to a 1^0 gradient; some extend more than 500 km from the base to water depths approaching 4,000 m (Source: Oceans, Paul R. Pinet, 1992)

Geoscience: Continental Margin (2)



(Image source: https://en.wikipedia.org/wiki/Continental_rise#/media/File:Oceanic_basin.svg, Chris_huh, public domain)

Geoscience: Deep-Ocean Basins (1)

<u>deep ocean basin</u>: varied topography; ranging from flat palns to towering, steep-sided mountain peaks

<u>abyssal plain</u>: flattest area on Earth; slope less than 1 meter per kilometer; broad aprons of land-derived sediments that have buried irregular, volcanic topography; sediment thickness of 100 m to more than 1,000 m

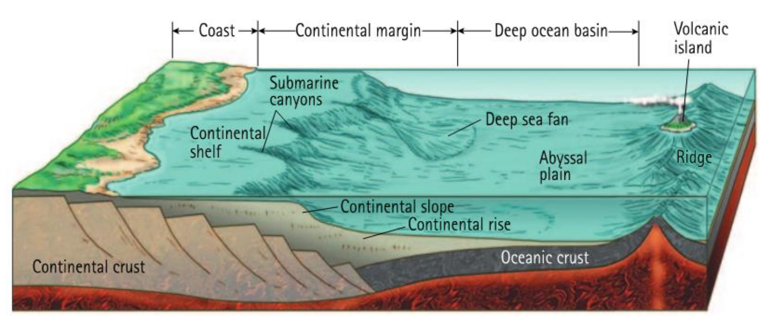
deep-sea trenches: relatively steep-sided narrow basins; can be 3 to 5 km deeper than the surrounding ocean floor; occur at the bases of continental slopes

<u>abyssal hill</u>: low dome or elongated hill no more than 900 m high and 100 m to 100 km wide; composed of volcanic rocks and may be covered by fine-grained sediment

<u>seamount</u>: extinct volcano, rises more than 900 m above the ocean floor; flat-topped seamounts, called guyots, were once volcanoes, but have eroded peaks

(Source: Oceans, Paul R. Pinet, 1992)

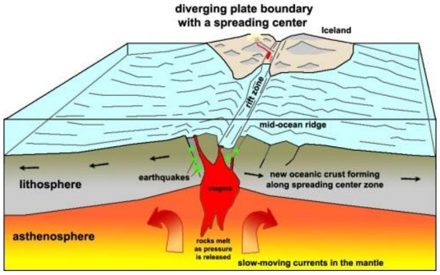
Geoscience: Deep-Ocean Basins (2)



(Image source: http://www.quasargroupconsulting.com/Encyclopedia/EarthScience/Geology/oceanBasin.php)

Geoscience: Midocean Ridge

midoean ridge: longest and most continuous mountain belt on Earth; extends for 60,000 km; occupies almost one-third of the ocean floor
ocean ridge: summit of each ridge is either broadly convex or occupied by a rift valley
fracture zone: parallel series of linear valley and elongated, faulted hills arranged perpendicular to the axid of midocean ridges; 10 to 100 km in length



(Source: Oceans, Paul R. Pinet, 1992)
(Image source: http://gotbooks.miracosta.edu/geology/images/spreading_center.jpg)

Geoscience: Deep Sea Trenches

trench	ocean	maximum depth
Mariana Trench	Pacific Ocean	11,034 m
Tonga Trench	Pacific Ocean	10,882 m
Philippine Trench	Pacific Ocean	10,545 m
Kuril–Kamchatka Trench	Pacific Ocean	10,542 m
Kermadec Trench	Pacific Ocean	10,047 m
Izu-Bonin Trench (Izu-Ogasawara Trench)	Pacific Ocean	9,810 m
Japan Trench	Pacific Ocean	9,504 m
Puerto Rico Trench	Atlantic Ocean	8,800 m
South Sandwich Trench	Atlantic Ocean	8,428 m
Peru–Chile Trench or Atacama Trench	Pacific Ocean	8,065 m

(Source: https://en.wikipedia.org/wiki/Oceanic_trench)

Geoscience: Marine Sediments (1)

terrigenous/lithogenous sediment: sedimentary debris produced by weathering and erosion of rocks on land
bigenic sediment: grains derived from the hard parts of organisms, such as skeletal debris, shells, and teeth
cosmogenous/extraterrestrial sediment: tiny grains, typically small, magnetic spheres and silicate chondrules, originating from outer space; extraterrestrial debris
hydrogenous/authigenic sediment: material, such as manganese nodules, precipitated by chemical or biochemical reactions to sea water
volcanic sediment: material, such as ash, ejected from volcanoes

(Source: Oceanography, Paul R. Pinet, p. 86)

Geoscience: Marine Sediments (2)

bulk emplacement: terrigenous debris transported by rivers enter ocean basin along its edges; bulk deposited at shoreline and inner continental shelf
pelagic sediment: deposits composed of small particles of clay and silt that have settled out of suspension far from influence of land; biogenic or inorganic origin
hydrogenous deposits: chemical precipitates that form in place within an ocean basin

(Source: Oceanography, Paul R. Pinet, pp. 97, 99, 105)

Geoscience: Earth's Atmosphere Layers (1)

troposphere: lowest layer; where all weather occurs; contains approximately 75% of atmospheric mass and 99% of the total mass of water vapor and aerosols; average depths of the troposphere are 20km (12 mi) in the tropics, 17 km (11 mi) in mid latitudes, 7 km (4.3 mi) in polar regions in winter
tropopause: border between the troposphere and stratosphere
stratosphere: above troposphere, below mesosphere; contains about 20% of atmospheric mass; warmer layers higher and cooler layers closer to the Earth due to absorption of Sun's ultraviolet radiation by ozone stratosphere; near the equator; starts at 18 km (11 mi); at mid latitudes, it starts at 10–13 km (6.2–8.1 mi) and ends at 50 km (31 mi); at poles; starts at about 8 km (5.0 mi); temperatures vary within the stratosphere with the seasons, in particular with the polar night (winter)
stratopause: between the stratosphere and mesophere; highest temperatures

Geoscience: Earth's Atmosphere Layers (2)

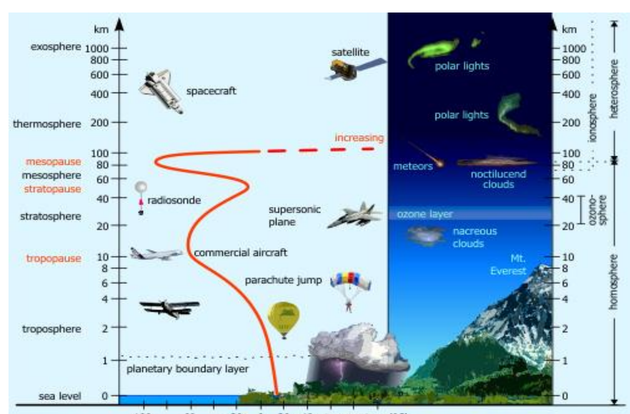
mesosphere: above stratosphere, below thermosphere; temperature decreases as altitude increases; exact upper and lower boundaries vary by latitude and season; lower boundary usually located at about 50 kilometers above the Earth's surface and higher boundary usually at heights near 100 kilometers, except at middle and high latitudes in summer where it descends to 85 kilometers
mesopause: boundary between mesosphere and thermosphere; can be coldest temperatures below −143 °C (−225°F; 130 K)
thermosphere: above mesosphere, below exosphere; ultraviolet radiation causes photoionization/photodissociation, creating ions in ionosphere; begins about 85 kilometers (53 mi) above the Earth; temperatures increase with altitude due to absorption of highly energetic solar radiation and are highly dependent on solar activity; can rise to 2,000°C (3,630°F)
thermopause: temperature can range up to absolute zero to 987.548^{0}C (1,810°F)

Geoscience: Earth's Atmosphere Layers (3)

exosphere: above the thermosphere; highest layer, atmosphere thins out and merges with interplanetary space; hydrogen present throughout the exosphere, with some helium, carbon dioxide, and atomic oxygen near its base; may be considered a part of outer space
ionosphere: region of Earth's upper atmosphere, from about 60 km (37 mi) to 1,000 km (620 mi); includes thermosphere and parts of mesosphere and exosphere; ionized by solar radiation, plays an important part in atmospheric electricity ; forms the inner edge of the magnetosphere; . influences radio propagation to distant places on Earth

Geoscience: Earth's Atmosphere Layers (4)

(Image source: http://www.theozonehole.com/atmosphere.htm, Ozone Hole, Inc.)

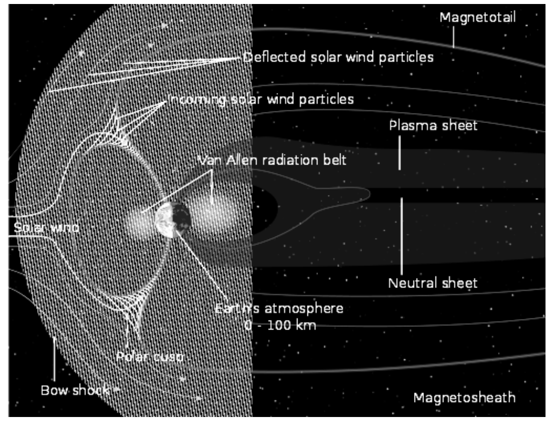


Geoscience: Magnetosphere (1)

magnetosphere: over Earth's equator, magnetic field lines become almost horizontal, then return to reconnect at high latitudes, .where magnetic field is distorted by solar wind and solar magnetic field; on Earth's day side, magnetic field significantly compressed by solar wind to approximately 65,000 kilometers (40,000 mi); Earth's bow shock is about 17 kilometers (11 mi) thick and located about 90,000 kilometers (56,000 mi) from Earth; magnetopause exists at a distance of several hundred kilometers above Earth's surface; Earth's magnetopause allows solar wind particles to enter; magnetic field lines break and reconnect, solar wind particles are able to enter the magnetosphere; on Earth's night side, the magnetic field extends in the magnetotail, which lengthwise exceeds 6,300,000 kilometers (3,900,000 mi); Earth's magnetotail is primary source of polar aurora

Geoscience: Magnetosphere (2)

(Image source: https://en.wikipedia.org/wiki/Magnetosphere#/media/File:Structure_of_the_magnetosphere-en.svg, NASA and Aaron Kaase, public domain)



Geoscience: Terrestrial Coordinates

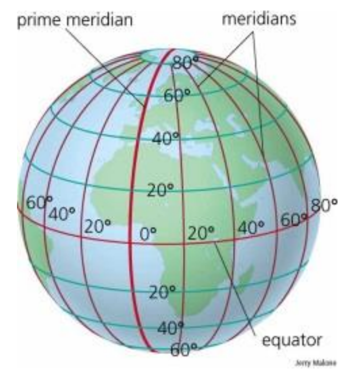
equator: imaginary line on Earth's surface equidistant from the North Pole and South Pole, dividing the Earth into the Northern Hemisphere and Southern Hemisphere; it is about 40,075 kilometers long; about 78.7% lies across water and 21.3% lies over land

latitude: geographic coordinate that specifies the north-south position of a point on the Earth's surface; it is is an angle which ranges from 0° at the Equator to 90° north or south) at the poles; . lines of constant latitude, called parallels, run east–west as circles parallel to the equator

longitude: geographic coordinate that specifies the east-west position of a point on the Earth's surface; .it is an angle expressed in degrees, denoted by the letter λ; meridians, lines running from the North Pole to the South Pole, connect points with the same longitude.

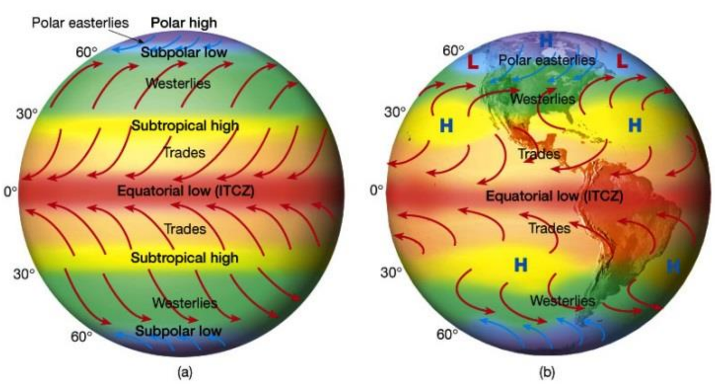
Geoscience: Latitude and Longitude

Prime Meridian:passes through the Royal Observatory, Greenwich, England; was allocated the position of zero degrees longitude;.the longitude of other places is measured as the angle east or west from the Prime Meridian, ranging from 0° at the Prime Meridian to +180° eastward and −180° westward



(Image source: https://socratic.org/questions/what-is-the-prime-meridian-1, Jerry Malone)

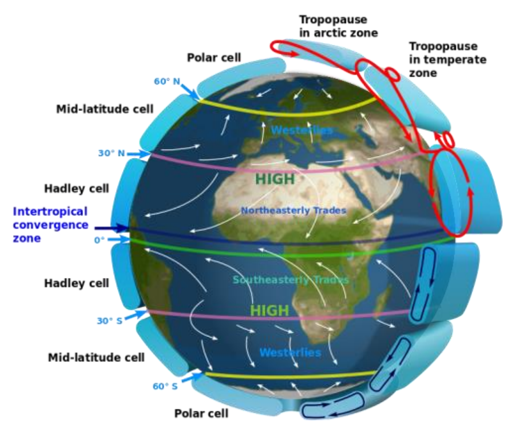
Geoscience: Atmospheric Circulation (1)



(Image source: The Atmosphere, 8th edition, Lutgens and Tarbuck, 8th edition, 2001)

Geoscience: Atmospheric Circulation (2)

(image source: https://en.wikipedia.org/wiki/Hadley_cell#/media/File:Earth_Global_Circulation_-_en.svg, Kaidor, CC BY-SA 3.0)



Geoscience: Atmospheric Composition

symbol	atom/molecule	percent
N_2	molecular nitrogen	78.084
O_2	molecular oxygen	20.946
Ar	argon	0.9340
CO_2	carbon dioxide	0.0407
Ne	neon	0.001818
He	helium	0.000524
CH_4	methane	0.00018
Kr	krypton	0.000114
H_2	molecular hydrogen	0.000055

Geoscience: Earth's Spheres

asthenosphere: Earth layer is between 100 and 200 km below the surface, but may extend as deep as 400 km, the weak or soft zone in the upper mantle

biosphere: the sum of all ecosystems integrating all living beings and their relationships, interaction with the elements of the lithosphere, hydrosphere, and atmosphere

cryosphere: the sphere consists of portions of Earth's surface covered by sea ice, lake ice, river ice, snow cover, glaciers, ice caps and ice sheets, and frozen ground

hydrosphere:

lithosphere: Earth's solid, outermost layer and includes the crust and the uppermost mantle; lies above the asthenosphere

pedosphere: Outermost layer of the Earth that is composed of soil and subject to soil formation processes; exists at the interface of the lithosphere, atmosphere, hydrosphere and biosphere

Geoscience: International Standard Atmosphere (1)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
-2000	301.2	1.2778	1.2067	1.253	2.636	347.9
-1500	297.9	1.2070	1.1522	1.301	2.611	346.0
-1000	294.7	1.1393	1.0996	1.352	2.585	344.1
-500	291.4	1.0748	1.0489	1.405	2.560	342.2
0	288.15	1.01325	1.0000	1.461	2.534	340.3
500	284.9	0.9546	0.9529	1.520	2.509	338.4
1000	281.7	0.8988	0.9075	1.581	2.483	336.4
1500	278.4	0.8456	0.8638	1.646	2.457	334.5
2000	275.2	0.7950	0.8217	1.715	2.431	332.5
2500	271.9	0.7469	0.7812	1.787	2.405	330.6
3000	268.7	0.7012	0.7423	1.863	2.379	328.6

Geoscience: Standard Atmosphere (2)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
3500	265.4	0.6578	0.7048	1.943	2.353	326.6
4000	262.2	0.6166	0.6689	2.028	2.327	324.6
4500	258.9	0.5775	0.6343	2.117	2.301	322.6
5000	255.7	0.5405	0.6012	2.211	2.275	320.5
5500	252.4	0.5054	0.5694	2.311	2.248	318.5
6000	249.2	0.4722	0.5389	2.416	2.222	316.5
6500	245.9	0.4408	0.5096	2.528	2.195	314.4
7000	242.7	0.4111	0.4817	2.646	2.169	312.3
7500	239.5	0.3830	0.4549	2.771	2.142	310.2
8000	236.2	0.3565	0.4292	2.904	2.115	308.1
8500	233.0	0.3315	0.4047	3.046	2.088	306.0

Geoscience: International Standard Atmosphere (3)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
9000	229.7	0.3080	0.3813	3.196	2.061	303.8
9500	226.5	0.2858	0.3589	3.355	2.034	301.7
10000	223.3	0.2650	0.3376	3.525	2.007	299.8
10500	220.0	0.2454	0.3172	3.706	1.980	297.4
11000	216.8	0.2270	0.2978	3.899	1.953	295.2
11500	216.7	0.2098	0.2755	4.213	1.952	295.1
12000	216.7	0.1940	0.2546	4.557	1.952	295.1
12500	216.7	0.1793	0.2354	4.930	1.952	295.1
13000	216.7	0.1658	0.2176	5.333	1.952	295.1
13500	216.7	0.1533	0.2012	5.768	1.952	295.1
14000	216.7	0.1417	0.1860	6.239	1.952	295.1

Geoscience: International Standard Atmosphere (4)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
14500	216.7	0.1310	0.1720	6.749	1.952	295.1
15000	216.7	0.1211	0.1590	7.300	1.952	295.1
15500	216.7	0.1120	0.1470	7.895	1.952	295.1
16000	216.7	0.1035	0.1359	8.540	1.952	295.1
16500	216.7	0.09572	0.1256	9.237	1.952	295.1
17000	216.7	0.08850	0.1162	9.990	1.952	295.1
17500	216.7	0.08182	0.1074	10.805	1.952	295.1
18000	216.7	0.07565	0.09930	11.686	1.952	295.1
18500	216.7	0.06995	0.09182	12.639	1.952	295.1
19000	216.7	0.06467	0.08489	13.670	1.952	295.1
19500	216.7	0.05980	0.07850	14.784	1.952	295.1

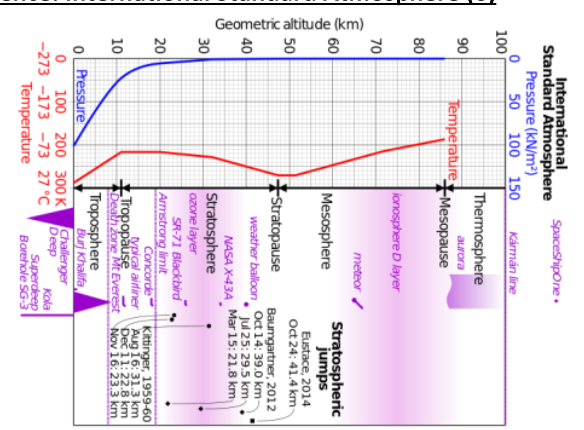
Geoscience: International Standard Atmosphere (5)

elevation z (m)	temper-ature T (K)	pressure p (bar)	relative density ρ/ρ_o	kinematic viscosity $\nu \times 10^{-5}$ (m^2/s)	thermal conductivity $k \times 10^{-2}$ (W/m K)	speed of sound c (m/s)
20000	216.7	0.05529	0.07258	15.989	1.952	295.1
22000	218.6	0.04047	0.05266	22.201	1.968	296.4
24000	220.6	0.02972	0.03832	30.743	1.985	297.7
26000	222.5	0.02188	0.02797	42.439	2.001	299.1
28000	224.5	0.01616	0.02047	58.405	2.018	300.4
30000	226.5	0.01197	0.01503	80.134	2.034	301.7

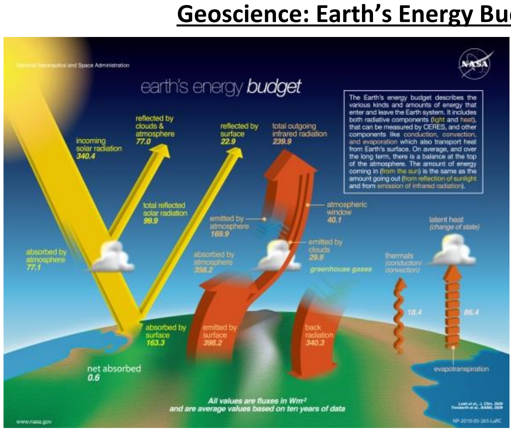
(Source: https://en.wikipedia.org/wiki/International_Standard_Atmosphere)

Geoscience: International Standard Atmosphere (6)

(Image source: https://en.wikipedia.org/wiki/International_Standard_Atmosphere#/media/File:Comparison_International_Standard_Atmosphere_space_diving.svg, Cmglee, CC BY-SA 3.0)



Geoscience: Earth's Energy Budget

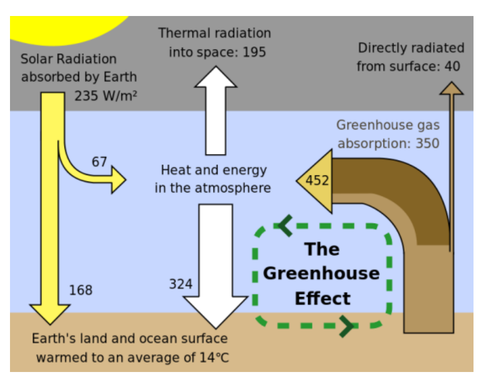


(Image source: https://upload.wikimedia.org/wikipedia/commons/b/bb/The-NASA-Earth%27s-Energy-Budget-Poster-Radiant-Energy-System-satellite-infrared-radiation-fluxes.jpg, NASA, public domain)

Geoscience: Greenhouse Effect

greenhouse effect: the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere

(Image source: https://en.wikipedia.org/wiki/Greenhouse_effect#/media/File:Greenhouse_Effect.svg, Robert A. Rohde, GDFL 1.2)



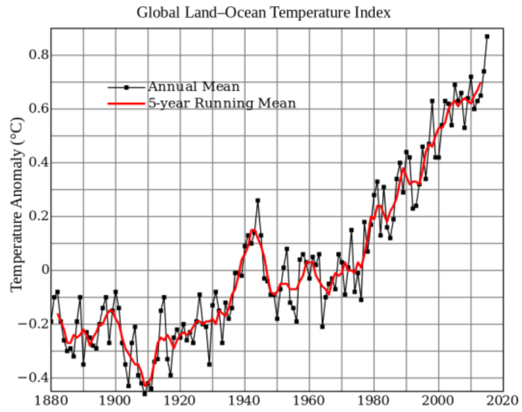
Geoscience: Global Warming and Climate Change (1)

<u>climate</u>: long-term weather patterns, usually averaged over 30 years

Global warming and climate change are terms for the observed century-scale rise in the average temperature of the Earth's climate system and its related effects. Multiple lines of scientific evidence show that the climate system is warming. Although the increase of near-surface atmospheric temperature is the measure of global warming often reported in the popular press, most of the additional energy stored in the climate system since 1970 has gone into the oceans. The rest has melted ice and warmed the continents and atmosphere. Many of the observed changes since the 1950s are unprecedented over tens to thousands of years.

(Source: https://en.wikipedia.org/wiki/Global_warming)

Geoscience: Global Warming and Climate Change (2)



(Image source: https://en.wikipedia.org/wiki/Global_warming#/media/File:Global_Temperature_Anomaly.svg, NASA, public domain)

Geoscience: Carbon Cycle (1)

carbon dioxide produced when carbon compounds burned :

$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

carbon dioxide as a by-product of sugar fermentation:

$C_6H_{12}O_6(aq) \rightarrow 2C_2Cl_2H_5OH(aq) + 2CO_2(g)$

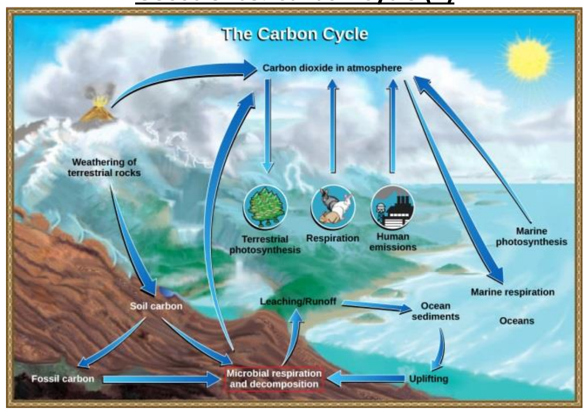
carbohydrates consumed by animals, which release carbon dioxide:

$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$

carbon dioxide removed from the atmosphere by photosynthetic plants and certain microorganisms:

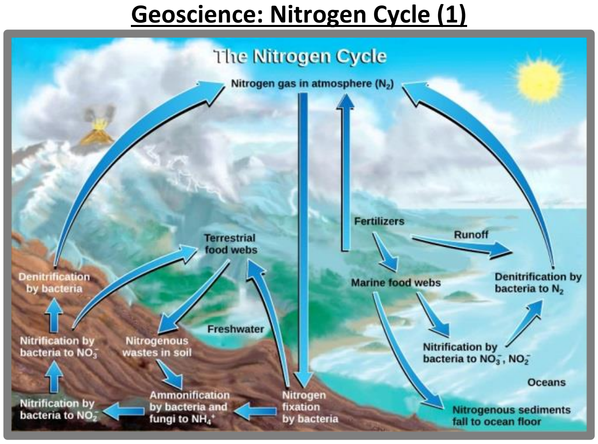
$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$

Geoscience: Carbon Cycle (2)



(Image source: USGS, John M. Evans and Howard Perlman, public domain)

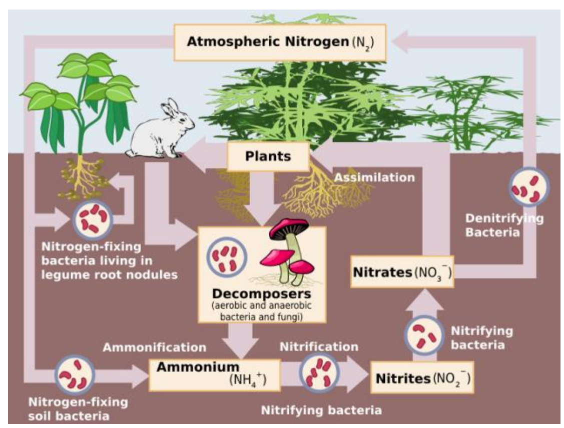
Geoscience: Nitrogen Cycle (1)



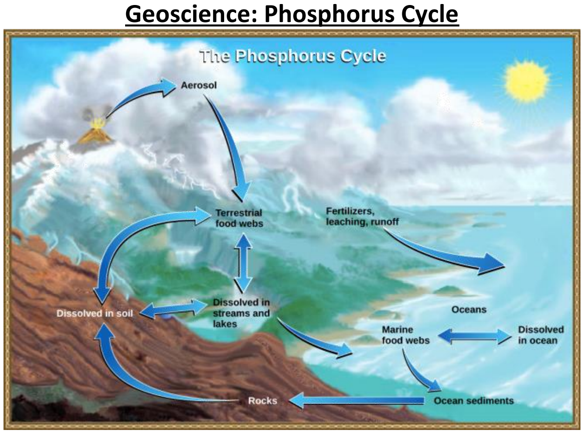
(Image source: USGS, John M. Evans and Howard Perlman, public domain)

Geoscience: Nitrogen Cycle (2)

(Image source: https://en.wikipedia.org/wiki/Nitrogen_cycle#/media/File:Nitrogen_Cycle.svg, Johann Dréo, CC BY-SA 3.0)

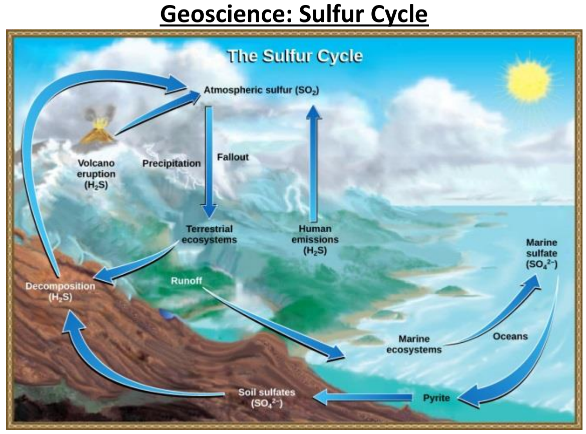


Geoscience: Phosphorus Cycle



(Image source: USGS, John M. Evans and Howard Perlman, public domain)

Geoscience: Sulfur Cycle



(Image source: USGS, John M. Evans and Howard Perlman, public domain)

Geoscience: Köeppen Climate Classification System (1)

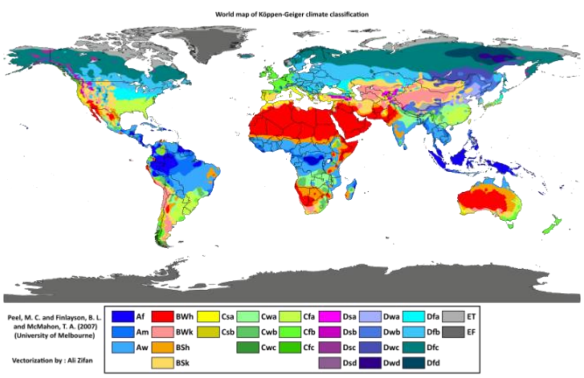
- Group A: Tropical/megathermal climates
  - Tropical rainforest (Af)
  - Tropical monsoon (Am)
  - Tropical wet and dry or savanna (Aw)
- Group B: Dry (arid and semiarid) climates
  - Desert BW: Hot desert (BWh), Cold desert (BWk)
  - Steppe climate (Semiarid) BS: Hot steppe (BSh), Cold steppe (BSk)
- Group C: Temperate/mesothermal climates
  - Dry-summer or Mediterranean climates (Csa, Csb,Csc)
  - Temperate or subtropical hot summer climates (Cfa, Cwa)
  - Maritime temperate climates or Oceanic climates (Cwb, Cwc, Cfb, Cfc)
  - Maritime subarctic climates or subpolar oceanic climate (Cfc)
  - Temperate highland climates with dry winters (Cwb, Cwc)

Geoscience: Köeppen Climate Classification (2)

- Group D: Continental/microthermal climates
  - Hot summer continental climates (Dsa, Dwa, Dfa)
  - Warm summer continental or hemiboreal climates (Dsb, DwbDfb)
  - Continental subarctic or boreal (taiga) climates (Dsc, Dwc, Dfc)
  - Continental subarctic climates with extremely severe winters (Dsd, Dwd, Dfd)
- Group E: Polar and alpine climates
  - Tundra climate (ET)
  - Ice cap climate (EF)

(Source: https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification)

Geoscience: Köeppen Climate Classification (3)



(Image source: https://en.wikipedia.org/wiki/K%C3%B6ppen_climate_classification#/media/File:World_Koppen_Classification_(with_authors).svg, Peel, M. C., Finlayson, B. L., and McMahon, T. A., CC BY-SA 4.0)

Geoscience: Weather Instruments

weather: the state of the atmosphere, to the degree that it is hot or cold, wet or dry, calm or stormy, clear or cloudy
anemometer: measures wind speed
barometer: measures atmospheric pressure
hygrometer: measures the water vapor content in the air
pyranometer: measures solar irradiance and solar radiation flux density from the hemisphere above within a wavelength range 0.3 µm to 3 µm
rain gauge: measures the amount of fallen rain
sling psychrometer: measures relative humidity using the cooling effect of evaporation
thermometer: measures temperature
wind vane: indicates the direction from which the wind blows

Geoscience: Weather Map

weather map: displays various meteorological features across a particular area at a particular point in time and has various symbols which all have specific meanings
isotherm: shows temperature gradients
isotach: shows equal wind speeds; on a constant pressure surface of 300 or 250 hPa show where the jet stream is located; use of constant pressure charts at the 700 and 50 hPa level can indicate tropical cyclone motion
station model: symbolic illustration showing the weather occurring at a given reporting station
synoptic scale feature: one whose dimensions are large in scale, more than several hundred kilometers in length
(Source: https://en.wikipedia.org/wiki/Weather_map)

Geoscience: Weather Systems (1)

region	name	pressure	weather and winds
Equator (0°)	Doldrums (ITCZ) (equatorial low)	low	cloudy, precipitation; hurricane breeding ground; light, variable
0°–30° N and S	Trade winds (easterlies)	-	summer wet, winter dry; pathway for tropical disturbances, NE in NH, SE in SH
30°N and S	Horse latitudes	high	light, variable
30°–60° N and S	Prevailing Westerlies		winter wet, summer dry; pathway for subtropical high and low pressure; SW in NH, NW in SH

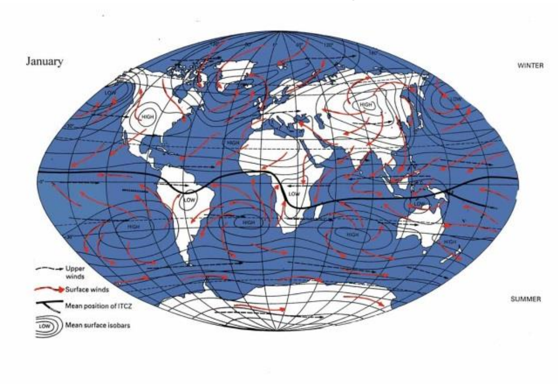
Geoscience: Weather Systems (2)

region	name	pressure	weather and winds
60° N and S	Polar front	low	stormy, cloudy weather zone; ample precipitation; variable
60°–90° N and S	Polar easterlies	-	cold polar air with very low temperatures; NE in NH, SE in SH
90° N and S	Poles	high	cold, dry air, sparse participation, S in NH, N in SH

(Source: https://en.wikipedia.org/wiki/Weather)

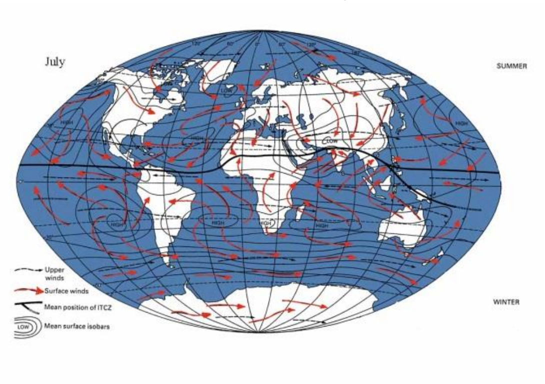
weather: state of the atmosphere, the degree that it is hot, cold, wet, dry, calm, stormy, clear, cloudy, refers to day-to-day temperature and precipitation activity

Geoscience: Weather Systems (3)



(Image source: http://u18439936.onlinehome-server.com/judd.curran/geography/outline2.htm, University of St. Andrews)

Geoscience: Weather Systems (4)



(Image source: http://u18439936.onlinehome-server.com/judd.curran/geography/outline2.htm, University of St. Andrews)

Geoscience: Air Masses (1)

air masses: move because of differences in temperature
cyclone: large scale air mass that rotates around a strong center of low atmospheric pressure; counter-clockwise in the Northern Hemisphere, clockwise in the Southern Hemisphere; surface low
anticyclone: a large-scale circulation of winds around a central region of high atmospheric pressure; clockwise in the Northern Hemisphere, counterclockwise in the Southern Hemisphere; surface high
trough: elongated regions of low pressure
ridge: elongated regions of high pressure

Geoscience: Air Masses (2)

aerosol: liquid and solid particles suspended in the atmosphere
ozone: inorganic molecule with the chemical formula O_3
albedo: ratio of radiation reflected from the surface to the incident radiation expressed as a number between 0 and 1
stable air: air that resists vertical movement
unstable air: air that rises to reach an altitude where its temperature reaches that of its surroundings
adiabatic temperature change: temperature changes in which heat is neither added or subtracted
environmental lapse rate: rate at which atmospheric temperature decreases with an increase in altitude

Geoscience: Air Masses (3)

air mass	source region	temperature/ moisture	stability	associated weather
cA	Arctic basin and Greenland ice cap	very cold and dry	stable	cold waves in winter
cP	interior Canada and Alaska	very cold and dry in winter	stable entire year	a. cold waves in winter; b. produces lake effect snow
mP	North Pacific	mild, cool, and humid entire year	unstable in winter, stable in summer	a. low clouds and showers in winter; b. heavy orographic precipitation on western mountains in winter; c. low stratus and fog along coast in summer

Geoscience: Air Masses (4)

air mass	source region	temperature/ moisture	stability	associated weather
mP	Northwestern Atlantic	cold and humid in winter, cool and humid in summer	unstable in winter, stable in summer	a. occasional “nor easter” in winter; b. occasional periods of clear, cool weather in summer
cT	Northern interior Mexico and southwestern U.S., summer	hot and dry	unstable	a. hot, dry and cloudless, rarely influences other regions; b. occasional drought to southern Great Plains

Geoscience: Air Masses (5)

air mass	source region	temperature/ moisture	stability	associated weather
mT	Gulf of Mexico, Caribbean Sea, western Atlantic	warm and humid entire year	unstable entire year	a. in winter usually moves northward bringing precipitation; b. in summer, hot and humid with frequent cumulus and thunderstorms
mT	subtropical Pacific	warm and humid entire year	stable entire year	a. in winter brings fog, drizzle; b. in summer ocassionally reaches western U.S., moisture source

(Source: The Atmosphere, Lutgens & Tarbuck, 2004, 9th ed.)

Geoscience: Air Lifting Systems

1. orographic lifting: air is forced to rise over a mountain-related barrier
2. frontal wedging: warmer, less dense air is forced over cooler, denser air
3. convergence: a pile-up of horizontal air flow results in upward movement
4. localized convective uplifting: unequal surface heating causes localized pockets of air to rise because of their buoyancy

(Source: Atmospheres, Lutgens & Tarbuck, 2004, 9th ed.)

Geoscience: Weather Fronts (1)

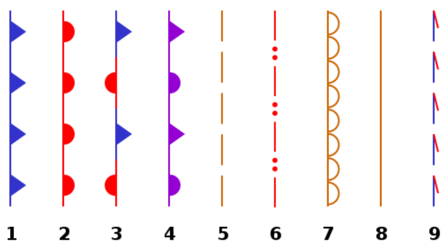
front: transition between air masses of different densities; bring changes in temperature, dew point, winds, and pressure
cold front: located at the leading edge of the temperature drop off; normally lies within a sharp surface trough; move faster than warm fronts; northwest winds carry colder, dryer air; pushes under warm air
warm front: at the leading edge of a homogeneous warm air mass; moves more slowly than the cold front which usually follows; winds behind the front will shift to the south in the Northern Hemisphere; rises over colder, denser air; can form rain
occluded front: formed when a cold front overtakes a warm front; usually forms around mature low-pressure areas; boundary of cold, cool, and warm fronts; precipitation is like that of a cold front

Geoscience: Weather Fronts (2)

stationary front: a non-moving boundary between two air masses; tend to remain in the same area for extended periods of time
dry line: boundary between air masses with significant moisture differences
squall line: organized areas of thunderstorm activity not only reinforce pre-existing frontal zones, but can outrun cold fronts in a pattern where the upper level jet splits apart into two streams
sea breeze front: created by a sea breeze, also known as a convergence zone, convergence zone; cold air from the sea meets the warmer air from the land and creates a boundary like a shallow cold front
land breeze front: if land becomes cooler than adjacent sea surface temperature, air pressure over the water will be lower than that of land, setting up a land breeze blowing from land to sea, as long as the environmental surface wind pattern is not strong enough to oppose it
(Source: https://learn.weatherstem.com/modules/learn/lessons/69/index.html)

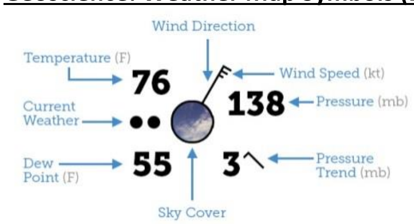
Geoscience: Weather Fronts (3)

1. cold front
2. warm front
3. stationary front
4. occluded front
5. surface trough
6. squall/shear line
7. dry line
8. tropical wave
9. trowel



(Image source: https://en.wikipedia.org/wiki/Weather_front#/media/File:NWS_weather_fronts.svg, public domain)

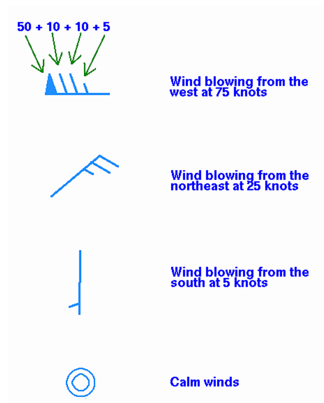
Geoscience: Weather Map Symbols (1)



- circle indicates directiion in which wind is blowing; barbs indicate direction from which it blew, and is wind direction used by meteorologists
- when decoding pressure insert decimal point left of last digit, add 900 or 1000 and pick value closes to 1000 mb

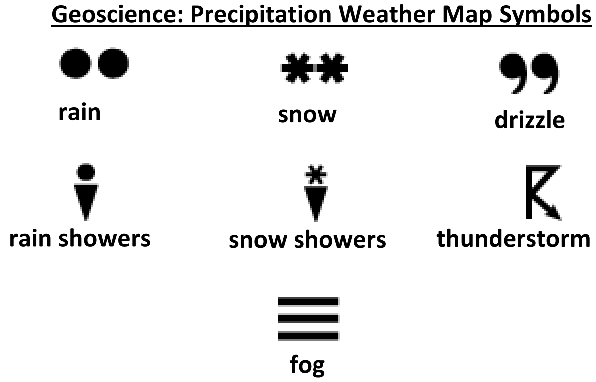
(Image source: https://learn.weatherstem.com/modules/learn/lessons/69/07.html, WeatherSTEM)

Geoscience: Weather Map Symbols (2)



(Image source: https://en.wikipedia.org/wiki/Weather_map#/media/File:Wind_barbs.gif, public domain)

Geoscience: Precipitation Weather Map Symbols



(Images source: http://www.srh.noaa.gov/jetstream/synoptic/wxmaps.html, National Oceanic and Atmospheric Administration, public domain)

Geoscience: Wind Weather Map Symbols

Speed (knots)	Symbol	Speed (knots)	Symbol
Less than 1		33–37	
1–2		38–42	
3–7		43–47	
8–12		48–52	
13–17		53–57	
18–22		58–62	
23–27		98–102	
28–32		103–107	

(Image source: https://blog.wdtinc.com/do-you-know-how-to-read-a-weather-map, WDT)

Geoscience: Humidity (1)

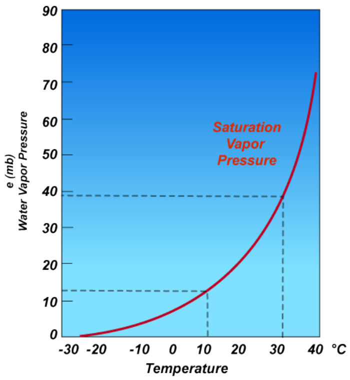
humidity: term used to describe the amount of water vapor in the air
absolute humidity: mass of water vapor in a given column of air
vapor pressure: that part of the total atmospheric pressure attributable to its water vapor content
specific humidity: mass of water vapor divided by total mass of air
relative humidity: ratio of the air's actual water vapor content compared with the amount of water vapor required for saturation at that temperature and pressure; requires less water vapor to attain high relative humidity at low temperatures; more water vapor is required to attain high relative humidity in warm or hot air
mixing ratio: mass of water vapor/mass of dry air

Geoscience: Humidity (2)

dew point temperature: temperature at which a parcel of air would need to be cooled to reach saturation
wet bulb temperature: temperature a parcel of air would have if it were cooled to saturation, 100% relative humidity by the evaporation of water into it, with the latent heat supplied by the parcel; lowest temperature air can reach by evaporating water into it; always lower than the air temperature

Geoscience: Pressure (1)

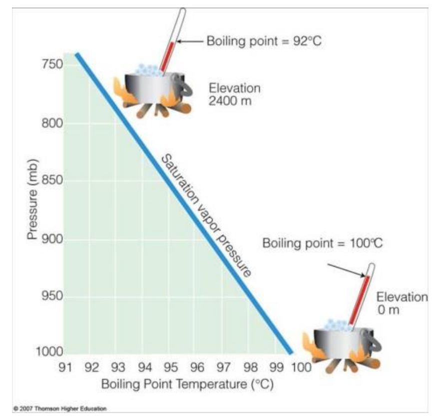
vapor pressure: partial pressure due to water vapor
partial pressure: total pressure of an air parcel due to the sum of the partial pressures of each gas
saturation vapor pressure: balance reached when the number of water molecules returning to the surface equals the number leaving



(Image source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter4/es_temp.html, Dr. Nolan Atkins, Lyndon State College)

Geoscience: Pressure (2)

(Image source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter4/es_boil.html, Dr. Nolan Atkins, Lyndon State College)



Geoscience: Winds (1)

scale	time scale	distance scale	examples
macroscale			
planetary	weeks or longer	1,000 - 40,000 km	Westerlies, Trade Winds
synoptic	days to weeks	100 – 5,000 km	midlatitude cyclones, anticyclones, hurricanes
mesoscale	minutes to hours	1- 100 km	thunderstorms, tornadoes, land-sea breeze
microscale	seconds to minutes	< 1 km	turbulence, dust devils, gusts

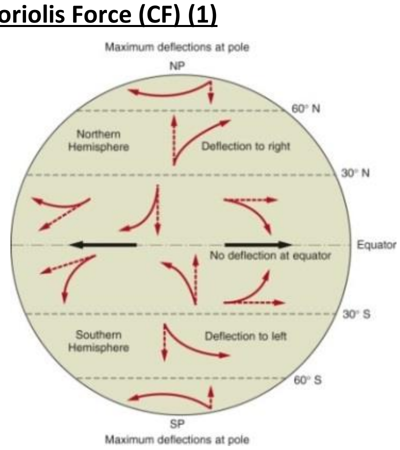
(Source: Atmospheres, Lutgens & Tarbuck, 2004, 9th ed.)

Geoscience: Winds (2)

land breeze: develops because land cools more quickly than the sea
sea breeze: develops as cooler air over the water moves onto the land
jet stream: narrow ribbons of high speed winds that extend for thousands of kilometers
temperature inversion: a situation in which the atmosphere is very stable and the mixing depth is significantly restricted
El Niño: warm phase of the El Niño Southern Oscillation (ENSO), associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific between approximately the International Date Line and 120°W, including off the Pacific coast of South America
La Niña: El Niño counterpart, part of the El Niño–Southern Oscillation climate pattern; sea surface temperature across the equatorial Eastern Central Pacific Ocean will be lower than normal by 3 to 5°C; in the U.S. an appearance of La Niña happens for at least five months of La Niña conditions

Geoscience: Coriolis Force (CF) (1)

Coriolis force: inertial force acting on objects in motion relative to rotating reference frame; in reference frame with clockwise rotation, force acts to left of motion of object; in one with counterclockwise rotation, force acts to right; does not affect rigid objects attached to Earth



(Image source: http://www.geogrify.net/GEO1/Lectures/Circulation/AirPressure.html)

Geoscience: Coriolis Force (CF) (2)

Coriolis force $CF = 2v_g\ \Omega \sin\phi$

v_g = geostrophic wind speed

Ω = Earth's angular velocity, 7.29 x 10-5 radians/second

ϕ = latitude

- perpendicular, and to right of direction in which wind is blowing to in northern hemisphere
- perpendicular, and to left of the direction in which wind is blowing to in southern hemisphere
- can only change wind direction, not wind speed
- no Coriolis force when wind is calm
- zero at the equator, which explains why no hurricanes at equator

Geoscience: Pressure Gradient Force (PGF)

- direction is always directed from high to low pressure
- always perpendicular to the isobars
- pressure gradient is larger where the isobars are closer together
- pressure gradient force is larger than Coriolis force when wind speed is low
- can cause stationary air to start moving

magnitude of PGF = $\frac{1}{\rho}\frac{\Delta P}{\Delta x} = \frac{1}{\rho}\frac{P_{high} - P_{low}}{x_{high} - x_{low}}$

ρ = air density

P_{high} = high pressure $\quad$ x_{high} = location of high

P_{low} = low pressure $\quad$ x_{low} = location of low

Geoscience: Geostrophic Winds

- when isobars are straight, parallel lines and the only two forces acting on an air parcel are the pressure gradient force (PGF) and the Coriolis force (CF), the winds are geostrophic
- the PGF and CF are equal in magnitude and in opposite directions
- geostrophic wind is always parallel to isobars

$CF = 2v_g\,\Omega\sin\phi \qquad PGF = \frac{1}{\rho}\frac{\Delta P}{\Delta x} \qquad CF = PGF$

$2v_g\,\Omega\sin\phi = \frac{1}{\rho}\frac{\Delta P}{\Delta x} \qquad v_g = \frac{1}{2\rho\Omega\sin\phi}\frac{\Delta P}{\Delta x}$

(Source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter8/parc_anim.html, Dr. Nolan Atkins, Lyndon State College)

Geoscience: Gradient Flow Around Highs and Lows (1)

$$\frac{1}{\rho}\frac{\Delta P}{\Delta x} + 2v_g\,\Omega\sin\phi + \frac{v^2}{r} = 0$$

v = centripetal velocity

r = location of the air parcel relative to the center of the pressure system

(Source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter8/gradient.html, Dr. Nolan Atkins, Lyndon State College)

Geoscience: Effect of Friction Around Highs and Lows (2)

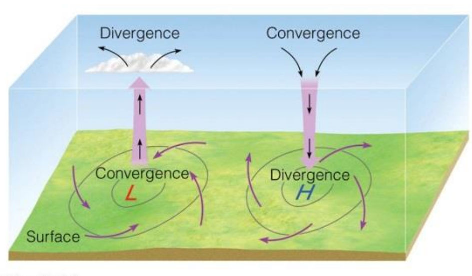
- friction slows winds
- as a result, CF becomes smaller than the PGF
- winds cross the isobars, directed at lower pressure centers
- frictional force is in the opposite direction to the wind direction
- friction + CF + PGF = 0
- effect of friction on wind is dominant near the surface, in boundary layer
- less friction over water than over land
- can only decrease wind speed

boundary layer: extends from the surface to about 1 to 1.5 km above the ground

(Source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter8/fr_aloft_gr.html, Dr. Nolan Atkins, Lyndon State College)

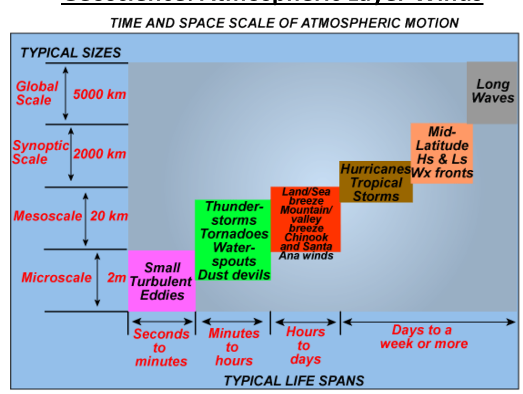
Geoscience: Effect of Friction Around Highs and Lows (3)

- at center of surface low, air converges, then must rise
- at center of surface high, air diverges, and must be coming from aloft due to sinking motion
- can expect cloudy, raining weather near a surface low
- can expect clear, dry weather near a surface high



(Image source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter8/fr_l_h_weath.html, Dr. Nolan Atkins, Lyndon State College)

Geoscience: Atmospheric Layer Winds



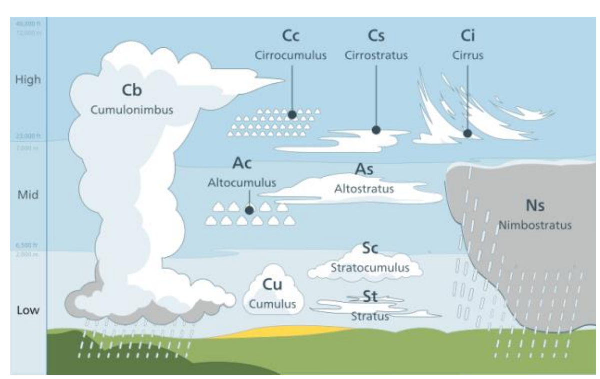
(Image source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter9/scales.html, Dr. Nolan Atkins, Lyndon State College)

Geoscience: Clouds (1)

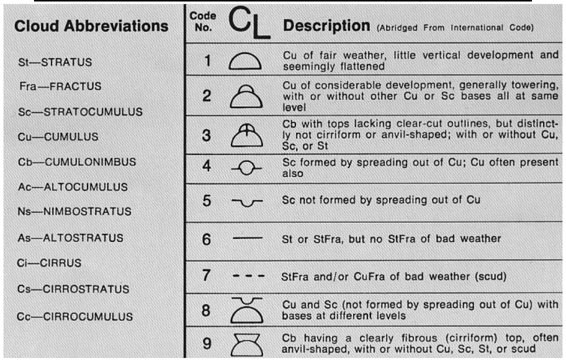
classification of major types	stratiform	cirriform	strato-cumuliform	cumuliform	cumulo-nimbiform
extreme level (mesosphere)		nocti-lucent			
very high level (stratosphere)		nacreous			
high-level	cirrostratus	cirrus	layered cirrocumulus	tufted cirrocumulus	
mid-level	altostratus		layered altocumulus	tufted altocumulus	
low-level	stratus		strato-cumulus	small cumulus	
multi-level/vertical	nimbo-stratus			moderate cumulus	
towering vertical				towering cumulus	cumulo-nimbus

Geoscience: Clouds (2)

(Source for (1) and image source: https://en.wikipedia.org/wiki/List_of_cloud_types#/media/File:Cloud_types_en.svg, Valentin de Bruyn, CC BY-SA 3.0)



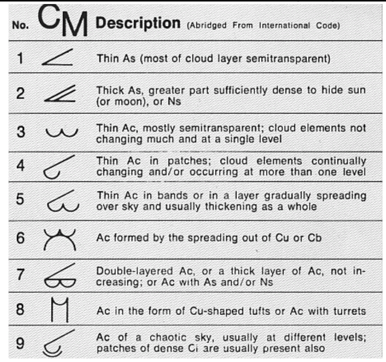
Geoscience: Cloud Weather Map Symbols (1)



Cloud Abbreviations	Code No.	Description (Abridged From International Code)
St—STRATUS	1	Cu of fair weather, little vertical development and seemingly flattened
Fra—FRACTUS	2	Cu of considerable development, generally towering, with or without other Cu or Sc bases all at same level
Sc—STRATOCUMULUS	3	Cb with tops lacking clear-cut outlines, but distinctly not cirriform or anvil-shaped; with or without Cu, Sc, or St
Cu—CUMULUS	4	Sc formed by spreading out of Cu; Cu often present also
Cb—CUMULONIMBUS	5	Sc not formed by spreading out of Cu
Ac—ALTOCUMULUS	6	St or StFra, but no StFra of bad weather
Ns—NIMBOSTRATUS	7	StFra and/or CuFra of bad weather (scud)
As—ALTOSTRATUS	8	Cu and Sc (not formed by spreading out of Cu) with bases at different levels
Ci—CIRRUS	9	Cb having a clearly fibrous (cirriform) top, often anvil-shaped, with or without Cu, Sc, St, or scud
Cs—CIRROSTRATUS		
Cc—CIRROCUMULUS		

(Image source: https://en.wikipedia.org/wiki/Weather_map#/media/File:Lowcloudsymbols.gif, public domain)

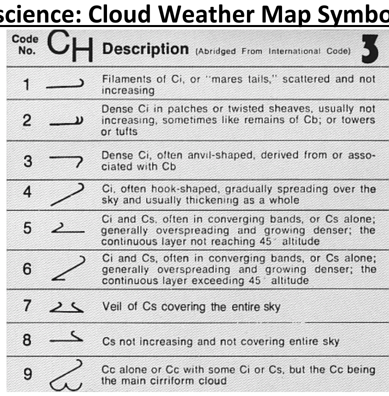
Geoscience: Cloud Weather Map Symbols (2)



No.	CM Description (Abridged From International Code)
1	Thin As (most of cloud layer semitransparent)
2	Thick As, greater part sufficiently dense to hide sun (or moon), or Ns
3	Thin Ac, mostly semitransparent; cloud elements not changing much and at a single level
4	Thin Ac in patches; cloud elements continually changing and/or occurring at more than one level
5	Thin Ac in bands or in a layer gradually spreading over sky and usually thickening as a whole
6	Ac formed by the spreading out of Cu or Cb
7	Double-layered Ac, or a thick layer of Ac, not increasing; or Ac with As and/or Ns
8	Ac in the form of Cu-shaped tufts or Ac with turrets
9	Ac of a chaotic sky, usually at different levels; patches of dense Ci are usually present also

(Image source: https://en.wikipedia.org/wiki/Weather_map#/media/File:Midcloudcymbols.gif, public domain)

Geoscience: Cloud Weather Map Symbols (3)



Code No.	CH Description (Abridged From International Code) 3
1	Filaments of Ci, or "mares tails," scattered and not increasing
2	Dense Ci in patches or twisted sheaves, usually not increasing, sometimes like remains of Cb; or towers or tufts
3	Dense Ci, often anvil-shaped, derived from or associated with Cb
4	Ci, often hook-shaped, gradually spreading over the sky and usually thickening as a whole
5	Ci and Cs, often in converging bands, or Cs alone; generally overspreading and growing denser; the continuous layer not reaching 45° altitude
6	Ci and Cs, often in converging bands, or Cs alone; generally overspreading and growing denser; the continuous layer exceeding 45° altitude
7	Veil of Cs covering the entire sky
8	Cs not increasing and not covering entire sky
9	Cc alone or Cc with some Ci or Cs, but the Cc being the main cirriform cloud

(Image source: https://en.wikipedia.org/wiki/Weather_map#/media/File:Highcloudsymbols.gif, public domain)

Geoscience: Precipitation

type	size	state	description
mist	0.0005 to 0.05 mm	liquid	large enough to be felt
drizzle	less than 0.5 mm	liquid	small, uniform, from stratus clouds
rain	0.5 to 5 mm	liquid	produced by nimbostratus or cumulonimbus clouds
sleet	0.5 to 5 mm	solid	small, spherical or lumpy ice particles
glaze	layers 1 mm to 2 mm	solid	supercooled raindrops freeze
rime	variable	solid	ice feathers that point into the wind
snow	1 mm to 2 mm	solid	crystalline, platy, or needle-like
hail	5 mm to 10 cm or larger	solid	hard, rounded pellets
graupel	2 mm to 5 mm	solid	soft hail that forms as rime collects on snow crystals

Geoscience: Cloud Detection (1)

1. If the cloud is *bright white on infrared* then it is a high cloud or has a cloud top that is developed high into the troposphere.

2. If a cloud is *bright white on visible but is not bright on infrared* then it is likely this is a cloud that is close to the earth's surface. This can happen when there is a thick layer of fog or stratus near the surface.

3. If cloud is *seen on visible but very hard to see on infrared* then it could be a layer of fog or shallow stratus near the surface.

4. Thunderstorms show *bright white on both visible and infrared*. A thick cloud will be bright white on visible and cold cloud tops will show bright white on infrared. Look for other features also to make sure it is a thunderstorm such as anvil blowoff, overshooting top and extremely textured on visible imagery

Geoscience: Cloud Detection (2)

5. If a cloud is *not very white on visible* then it is likely a thin cloud. If a cloud is *not very white on infrared* then it is likely a cloud near the surface or it is a very thin cloud.

6. When the sun is close to setting, clouds will not show up as white on visible imagery due to less reflection.

7. Wispy looking clouds on visible that are very white on infrared are likely high level clouds such as cirrus or anvil blowoff.

8. Cumulus clouds have a lumpy texture. Stratus clouds have a flat texture especially on infrared. Cirrus clouds tend to be thin and show up white on infrared.

(Source: https://www.theweatherprediction.com/habyhints2/512/)

Geoscience: Fog (1)

fog: low-lying, local moisture that reduces visibility to less than 1 km

radiation fog: formed by the cooling of land after sunset by infrared thermal radiation in calm conditions with a clear sky

- cooling ground then cools adjacent air by conduction, causing air temperature to fall below the dew point
- In perfect calm, the fog layer can be less than a meter thick, but turbulence can promote a thicker layer
- occurs at night, and usually doesn't last long after sunrise, but it can persist all day in the winter months especially in areas bounded by high ground
- most common in autumn and early winter
- includes tule fog

Geoscience: Fog (2)

ground fog: obscures less than 60% of the sky and does not extend to the base of any overhead clouds

- term usually a synonym for radiation fog which is very shallow
- in some cases the depth of the fog is on the order of tens of centimeters over certain kinds of terrain with the absence of wind

advection fog: occurs when moist air passes over a cool surface by advection, wind, and is cooled

- common as a warm front passes over an area with significant snow-pack
- most common at sea when moist air encounters cooler waters, including areas of cold water upwelling, as along the California coast
- strong enough temperature difference over water or bare ground can also cause this

Geoscience: Fog (3)

evaporation fog: also called steam fog, forms over bodies of water overlain by much colder air and is a convective phenomenon

- can also lead to steam devils
- lake effect fog is of this type, sometimes in combination with other causes like radiation fog
- tends to differ from most advective fog formed over land, resulting in fog which can be quite a bit denser, deeper, and looks fluffy from above

frontal fog: forms near a front when raindrops, falling from relatively warm air above a frontal surface, evaporate into cooler air close to the Earth's surface and cause it to become saturated

.

Geoscience: Fog (4)

ice fog: forms in very low temperatures and can be the result of other mechanisms mentioned here, as well as the exhalation of moist warm air by herds of animals

- can be associated withdiamond dust form of precipitation, in which very small crystals of ice form and slowly fall
- often occurs during blue sky conditions which can cause many types of halos and other results of refraction of sunlight by the airborne crystals

freezing fog: deposits rime, is composed of droplets of supercooled water which freezes to surfaces on contact

Geoscience: Fog (5)

precipitation fog: also called frontal fog, forms as precipitation falls into drier air below the cloud

- liquid droplets evaporate into water vapor
- water vapor cools and at the dewpoint
- it condenses and fog forms

hail fog: sometimes occurs in the vicinity of significant accumulations due to decreased temperature and increased moisture leading to saturation in a very shallow layer near the surface

- most often occurs when there is a warm, humid layer atop the hail and when wind is light
- tends to be localized but can be extremely dense and abrupt
- may form shortly after the hail falls; when the hail has had time to cool the air and as it absorbs heat when melting and evaporating

Geoscience: Fog (6)

upslope fog: forms when moist air is going up the slope of a mountain or hill which condenses into fog on account of adiabatic cooling, and to a lesser extent the drop in pressure with altitude

(Source: https://en.wikipedia.org/wiki/Fog)

Geoscience: Rainbows (1)

rainbow: meteorological phenomenon caused by reflection, refraction, and dispersion of sunlight in water droplets resulting in a spectrum of light appearing in the sky

- takes the form of multicolored circular arc
- always appear in the section of sky directly opposite the Sun
- can be full circles
- observer normally sees only an arc formed by illuminated droplets above the ground, and centered on a line from the Sun to the observer's eye

primary rainbow: arc shows red on the outer part and violet on the inner side

- caused by light being refracted when entering water droplet, then reflected inside on the back of the droplet and refracted again when leaving it
- not located specific distance from the observer, but from an optical illusion caused by any water droplets viewed from a certain angle relative to a light source

Geoscience: Rainbows (2)

- not an object and cannot be physically approached
- impossible for an observer to see a rainbow from water droplets at any angle other than 42 degrees from the direction opposite the light source
- even if an observer sees another observer who seems "under" or "at the end of" a rainbow, the second observer will see a different rainbow, farther off, at the same angle as seen by the first observer

double rainbow: second arc seen outside the primary arc

- has the order of its colors reversed, with red on the inner side of the arc
- caused by light being reflected twice on inside of droplet before leaving it

twinned rainbow: appears as two rainbow arcs that split from a single base

- colors in the second bow, rather than reversing as in a secondary rainbow, appear in the same order as the primary rainbow

full-circle rainbow: usually visible only from a high viewpoint such as a high building or an aircraft

Geoscience: Rainbows (3)

supernumerary rainbow: faintly colored bands seen bordering violet edge of a rainbow

- slightly detached from the main bow
- become successively fainter along with distance from it
- pastel colors, mainly of pink, purple, green hues rather than usual spectrum
- effect apparent when water droplets have a diameter of about 1 mm or less
- smaller the droplets, the broader the supernumerary bands become, and less saturated the colors

reflected rainbow: may appear in the water surface below the horizon

- sunlight is first deflected by the raindrops, and then reflected off the body of water, before reaching the observer
- frequently visible, at least partially, even in small puddles

Geoscience: Rainbows (4)

reflection rainbow: may be produced where sunlight reflects off a body of water before reaching the raindrops if the water body is large, quiet over its entire surface, and close to the rain curtain

- appears above the horizon
- intersects the normal rainbow at the horizon
- its arc reaches higher in the sky, with its center as high above the horizon as the normal rainbow's center is below it
- rarely visible

monochrome rainbow: occasionally a shower may happen at sunrise or sunset, where the shorter wavelengths like blue and green have been scattered and essentially removed from the spectrum

- further scattering may occur due to the rain, and the result can be the rare and dramatic single color, likely red

(Source: https://en.wikipedia.org/wiki/Rainbow)

Geoscience: Mirages (1)

mirage: naturally occurring optical phenomenon in which light rays are bent to produce a displaced image of distant objects or the sky

inferior mirage: located under the real object

- real object is the blue sky or any distant, therefore bluish, object in that same direction
- causes observer to see bright and bluish patch on the ground in the distance
- light rays coming from a particular distant object all travel through nearly the same air layers, are bent over about the same amount
- rays from top of the object will arrive lower than those from bottom
- image usually upside down, enhancing the illusion that the sky image seen in the distance is really a water or oil puddle acting as a mirror not stable
- hot air rises, cooler, denser air descends, layers will mix, turbulence
- may be vibrating, vertically extended, double, usually no more than a degree high

Geoscience: Mirages (2)

heat haze: refers to the inferior mirage experienced when viewing objects through a layer of heated air; for example, viewing objects across hot asphalt or through the exhaust gases produced by jet engines

- when appearing on roads due to the hot asphalt, often referred to as a highway mirage
- convection causes the temperature of the air to vary, and the variation between the hot air at the surface of the road and the denser cool air above it creates a gradient in the refractive index of the air
- produces a blurred shimmering effect, which affects the ability to resolve objects
- effect increased when image is magnified through a telescope or telephoto lens

Geoscience: Mirages (3)

superior mirage: occurs when the air below the line of sight is colder than the air above it

- unusual arrangement called a temperature inversion since warm air above cold air is the opposite of the normal temperature gradient of atmosphere
- light rays are bent down, and so the image appears above the true object
- in general less common than inferior mirages
- tend to be more stable, as cold air has no tendency to move up and warm air has no tendency to move down
- quite common in polar regions, especially over large ice sheets
- also occur at more moderate latitudes, but weaker and less stable
- can be right-side up or upside down, depending on the object distance and temperature
- image may appear as a distorted mixture of up and down parts

(Source: https://en.wikipedia.org/wiki/Mirage)

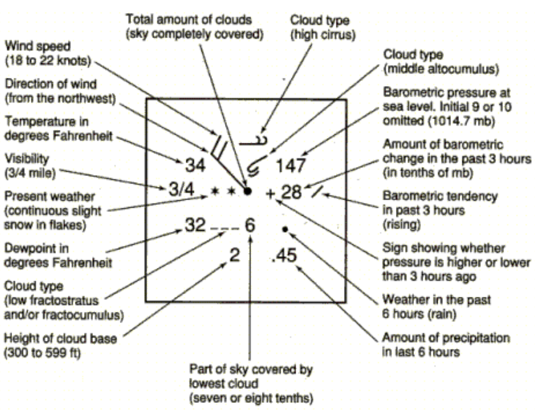
Geoscience: Sundogs

sundog: also called mock sun, formally called a parhelion is an atmospheric optical phenomenon that consists of a bright spot to the left and/or right of the Sun

- two sun dogs often flank the Sun within a 22 degree halo
- member of the family of halos, caused by the refraction of sunlight by ice crystals in the atmosphere
- typically appear as a pair of subtly colored patches of light, around 22 degrees to the left and right of the Sun, and at the same altitude above the horizon as the Sun
- can be seen anywhere in the world during any season, but are not always obvious or bright
- best seen and most conspicuous when the Sun is near the horizon

(Source: https://en.wikipedia.org/wiki/Sun_dog)

Geoscience: Station Model Plot



(Image source: https://en.wikipedia.org/wiki/Surface_weather_analysis#/media/File:Station_model, public domain)

Geoscience: Station Model Corrections

station pressure = (sea level pressure) x $e^{-elevation/(temperature \times 29.263)}$

sea level pressure = station pressure / $e^{-elevation/(temperature \times 29.263)}$

- pressure changes by about 10 mb for every 100 meters of elevation change

elevation = station altitude in meters

temperature in Kelvins

29.263 m/K = 1000 g/kg x R / (M_{air} x g)

R = 8.314 j/mol K

M_{air} = molecular weight of air, 29.97 grams/mol

(Source: http://www.sandhurstweather.org.uk/barometric.pdf, Sandhurst Weather)

Geoscience: Mid-latitude Cyclones

- provide global heat transport
- redistribute energy in the atmosphere
- are often significant weather producers
- studied extensively by a group of Norwegian meteorologists who developed the Polar Front Theory after WW I
- explosive cyclogenesis often occurs during the winter months off the U.S. east coast
- tends to occur over the eastern slope of the Rockies, the Great Basin Area, Gulf of Mexico, Atlantic Coast east of the Caroliinas
- summer storms derive most of their energy from the latent heat released during cloud formation
- energy for winter cyclones derived from temperature and density difference between cold air masses from Arctic and warm air masses from tropics

(Source: http://www-das.uwyo.edu/~zwang/atsc2000/Ch13.pdf)

Geoscience: Upper Level Waves and Surface Storms

- direction and speed of the cyclone is closely approximated by speed and direction of flow at 500 mb, referred to as the steering level
- cyclone moves in direction of 500 mb winds
- cyclone moves with speed – ½ 500 mb wind speed
- flow aloft appears to be important for development and propagation of cyclones and anticyclones

(Source: http://www-das.uwyo.edu/~zwang/atsc2000/Ch13.pdf)

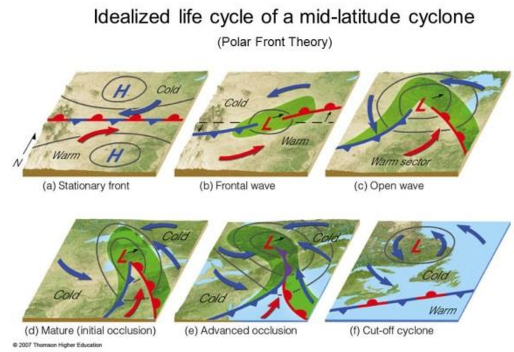
Geoscience: Polar Front Theory

cyclogenesis: development and strengthening of surface low pressure areas in middle latitudes of the globe
cyclone: near circular air flow in same direction as rotating Earth, counterclockwise in northern hemisphere, clockwise in southern hemisphere

- development of a front, known as frontogenesis
- a wave develops on the front
- a cyclonic circulation, area of low pressure, becomes established
- cold front overtakes the warm front, initial stage of an occlusion
- development of the occluded front continues and cyclone reaches mature stage
- lifetime of a cyclone is about 3 to 5 days from initial wave to dissipating stage

(Source: http://www.zamg.ac.at/eumetrain/EUMeTrain2006/Finland_Lithuania/Content/theory1.htm)

Geoscience: Cyclogenesis



(Image source: http://slideplayer.com/slide/8109415/)

Geoscience: Tilted Vertical Structure of Developing Wave Cyclone

- deep pressure systems extending from surface to tropopause
- example of a "cold core low"
- upper level low must be located north and west of a surface low; area of of low pressure must tilt to the northwest with height
- area of divergence must be directly above surface low
- if divergence aloft then convergence at surface, will the low deepen or decay depends on which is stronger

(Source: http://www-das.uwyo.edu/~zwang/atsc2000/Ch13.pdf)

Geoscience: Anticyclone

- upper level high must be located south and west of the surface high
- the area of high pressure must tilt to the southwest with height
- area of convergence must be directly above the surface high
- if convergence aloft is greater than divergence at surface, pressure at surface will increase and high will intensify
- if convergence aloft is less than divergence at the surface, pressure at surface will decrease and the high will decrease in intensity

(Source: http://www-das.uwyo.edu/~zwang/atsc2000/Ch13.pdf)

Geoscience: Thunderstorms (1)

thunderstorm: also known as an electrical storm, lightning storm, or thundershower, characterized by presence of lightning and its acoustic effect on the Earth's atmosphere, known as thunder

- occur in association with cloud cumulonimbus clouds
- usually accompanied by strong winds, heavy rain, and sometimes snow, sleet, hail, or, no precipitation
- may line up in a series or become a rainband, known as a squall line
- strong or severe thunderstorms, known as supercells, rotate as do cyclones
- most move with mean wind flow through troposphere
- vertical wind shear sometimes causes a deviation in their course at a right angle to wind shear direction

Geoscience: Thunderstorms (2)

- result from the rapid upward movement of warm, moist air, along a front
- as warm, moist air moves upward, it cools, condenses, and forms a cumulonimbus cloud that can reach heights of over 20 kilometers
- as rising air reaches its dew point, temperature, water vapor condenses into water droplets or ice, reducing pressure locally within thunderstorm cell
- precipitation falls long distance through clouds toward Earth
- as droplets fall, they collide with others and become larger
- falling droplets create a downdraft as storm pulls cold air with it; cold air spreads out at the Earth's surface, occasionally causing strong winds commonly associated with thunderstorms

Geoscience: Thunderstorms (3)

- can form and develop in any geographic location but most frequently within mid-latitudes, where warm, moist air from tropical latitudes collides with cooler air from polar latitudes
- responsible for the development and formation of many severe weather phenomena
- damage mainly inflicted by downburst winds, large hailstones, and flash flooding caused by heavy precipitation
- stronger thunderstorm cells are capable of producing tornadoes and waterspouts

(Source: https://en.wikipedia.org/wiki/Thunderstorm)

Geoscience: Thunderstorm Stages (1)

cumulus stage: developing stage; moisture masses lifted upwards into atmosphere

- trigger for lift can be solar illumination, where ground heating produces thermals, or where two winds converge forcing air upwards, or where winds blow over terrain of increasing elevation
- moisture carried upward cools into liquid drops due to lower temperatures at high altitude, which appear as cumulus clouds
- as water vapor condenses, latent heat released, which warms air, causing it to become less dense than surrounding, drier air
- air rises in updraft through convection, creating low-pressure zone within and beneath forming storm
- approximately 500 million kilograms of water vapor lifted into the Earth's atmosphere

Geoscience: Thunderstorm Stages (2)

mature stage: warmed air continues to rise until it reaches area of warmer air and can rise no farther at tropopause

- air forced to spread out, giving the storm a characteristic anvil shape, resulting in cumulonimbus incus cloud
- water droplets coalesce into larger, heavier ice particles, fall, melt as rain
- If updraft strong, droplets held aloft, become large, don't melt, fall as hail
- while updrafts present, falling rain drags surrounding air, creates downdrafts
- simultaneous presence of updraft and downdraft mark mature stage, produce cumulonimbus clouds
- internal turbulence, strong winds, severe lightning, possibly tornadoes
- if little wind shear, storm will rapidly enter dissipating stage, "rain itself out"
- if sufficient change in wind speed or direction, downdraft will be separated from updraft, storm may become supercell, can sustain itself for hours

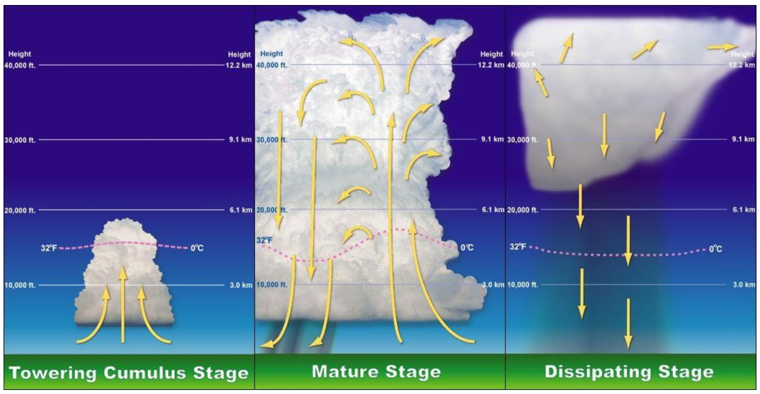
Geoscience: Thunderstorm Stages (3)

dissipation stage: thunderstorm dominated by downdraft

- if atmospheric conditions don't support super cellular development, stage occurs quickly, approximately 20–30 minutes into thunderstorm life
- downdraft will push down out of thunderstorm, hit the ground and spread out, downburst phenomenon
- cool air carried to ground by the downdraft cuts off thunderstorm inflow
- updraft disappears and thunderstorm dissipates
- in an atmosphere with virtually no vertical wind shear weakens as soon as they send out an outflow boundary in all directions, which then quickly cuts off inflow of relatively warm, moist air, and kills thunderstorm's further growth
- downdraft the ground creates an outflow boundary, causing downbursts
- stronger the outflow boundary, stronger resultant vertical wind shear

(Source: https://en.wikipedia.org/wiki/Thunderstorm)

Geoscience: Thunderstorm Stages (4)



(Image source: https://en.wikipedia.org/wiki/Thunderstorm, NOAA, public domain)

Geoscience: Thunderstorm Types (1)

single cell: applies to a single thunderstorm with one main updraft; also known as air-mass thunderstorms, normally last 20 to 30 minutes

- typical summer thunderstorms in many temperate locales
- also occur in cool unstable air that often follows the passage of a cold front from the sea during winter
- within a cluster of thunderstorms, "cell" refers to each separate principal updraft
- occasionally form in isolation, as occurrence of one thunderstorm can develop an outflow boundary that sets up new thunderstorm development
- rarely severe and result of local atmospheric instability; hence the term "air mass thunderstorm"
- when such storms have brief period of severe weather associated with them, known as a pulse severe storm, poorly organized and occur randomly making them difficult to forecast

Geoscience: Thunderstorm Types (2)

multi-cell clusters: most common type of thunderstorm development; mature thunderstorms are found near the center of the cluster, while dissipating thunderstorms exist on their downwind side

- multicell storms form as clusters of storms but may then evolve into one or morem squall lines
- while each cell of the cluster may only last 20 minutes, cluster itself may persist for hours at a time
- often arise from convective updrafts in or near mountain ranges and linear weather boundaries, such as strong cold fronts or troughs of low pressure. these type of storms are stronger than single-cell storm, yet much weaker than supercell storm
- hazards with the multicell cluster include moderate-sized hail, flash flooding, and weak tornadoes

Geoscience: Thunderstorm Types (3)

multicell lines: squall line is an elongated line of severe thunderstorms that can form along or ahead of cold front

- in early 20th century, term was used as a synonym for cold front
- contains heavy precipitation, hail, lightning, strong straight winds, possibly tornadoes and waterspouts
- severe weather in the form of strong straight-line winds can be expected in areas where the squall line itself is in the shape of bow echo, within portion of line that bows out the most
- tornadoescan be found along waves within a line echo wave pattern, or LEWP, where mesoscale low pressure areas present
- some bow echoes in the summer are called derechos, move fast
- on back edge of rain shield, wake low can form, a mesoscale low pressure area that forms behind the mesoscale high pressure system normally present under the rain canopy, sometimes associated with a heat burst

Geoscience: Thunderstorm Types (4)

supercells: large, usually severe, quasi-steady-state storms forming in environment where wind speed or wind direction varies with height, "wind shear"

- have separate downdrafts and updrafts, where associated precipitation not falling through updraft, with a strong, rotating updraft, a "mesocyclone"
- normally have powerful updrafts that top of the supercell storm cloud or anvil can break through troposphere and reach into lower levels of stratosphere
- can be 24 kilometers wide
- at least 90 percent of supercells cause severe weather
- can produce destructive tornadoes, extremely large hailstones, straight-line winds, flash floods
- most tornadoes occur from this type of thunderstorm
- strongest type of thunderstorm

Geoscience: Thunderstorm Types (5)

severe thunderstorms: classed as severe if winds reach at least 93 kilometers per hour, hail is 25 millimeters in diameter or larger, or if funnel clouds or tornadoes are reported

- although a funnel cloud or tornado indicates a severe thunderstorm, a tornado warningis issued in place of a severe thunderstorm warning
- severe thunderstorm warning is issued if a thunderstorm becomes severe, or will soon turn severe
- can occur from any type of storm cell, however, multicell, supercell, and squall lines represent the most common forms of thunderstorms that produce severe weather

Geoscience: Thunderstorm Types (6)

mesoscale convective systems: thunderstorms complex becomes organized on scale larger than individual thunderstorms, smaller than extratropical cyclones, normally persists for several hours or more, forming near fronts

- may include tropical cyclones, squall lines, lake-effect snow events, polar lows, and Mesoscale Convective Complexes (MCCs)
- most develop overnight and continue through next day
- forms during warm season over land noted across North America, Europe, and Asia, with maximum activity during late afternoon and evening
- forms that develop in tropics found in either ITCZ or monsoon troughs, generally within warm season between spring and fall
- more intense systems form over land than over water
- exception is lake-effect snow bands, which form due to cold air moving across relatively warm bodies of water, fall through spring

Geoscience: Thunderstorm Types (7)

- polar lows are a second special class of MCS, forming at high latitudes during cold season
- once parent MCS dies, later thunderstorm development can occur in connection with its remnant mesoscale convective vortex (MCV)
- mesoscale convective systems are important to U.S. rainfall climatology over Great Plains since they bring the region about half of their annual warm season rainfall

(Source: https://en.wikipedia.org/wiki/Thunderstorm)

Geoscience:Tropical Cyclones (1)

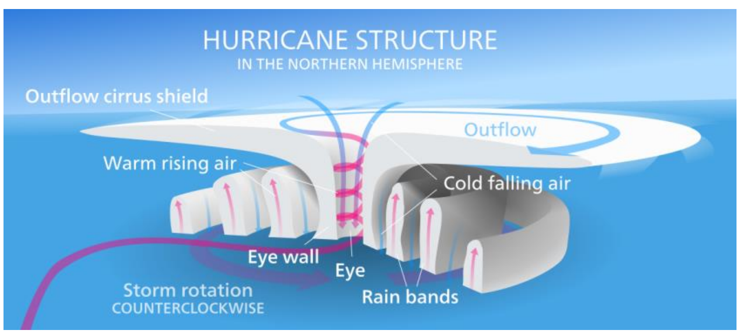
tropical cyclone: rapidly rotating storm system characterized by a low-pressure center, a closed low-level atmospheric circulation, strong winds, and a spiral arrangement of thunderstorms that produce heavy rain
depending on its location and strength, a tropical cyclone is referred to by different names, including hurricane
hurricane: tropical cyclone that occurs in the Atlantic Ocean and northeastern Pacific Ocean
typhoon: tropical cyclone that occurs in the northwestern Pacific Ocean

- in the south Pacific or Indian Ocean, comparable storms are referred to simply as “tropical cyclones” or “severe cyclonic storms”
- winds blow counterclockwise in Northern Hemisphere and blow clockwise in Southern Hemisphere
- derive their energy through evaporation of water from ocean surface, which recondenses into clouds and rain when moist air rises and cools to saturation

Geoscience:Tropical Cyclones (2)

near-surface wind field characterized by air rotating rapidly around a center of circulation, while also flowing radially inwards
at outer edge of storm, air may be nearly calm
due to Earth’s rotation, air has non-zero absolute angular momentum; as air flows radially inward, begins to rotate to conserve angular momentum
at an inner radius, air begins to ascend to top of the troposphere; this radius is typically coincident with inner radius of eyewall, and has strongest near-surface winds; known as radius of maximum winds
once aloft, air flows away from storm's center, producing cirrus clouds
wind speeds low at center, increase rapidly moving outwards to radius of maximum winds, then decay more gradually with radius to large radii
wind field often exhibits additional variability due to effects of localized processes, thunderstorm activity, horizontal flow instabilities
in vertical direction, winds strongest near surface and decay with height
(Source: https://en.wikipedia.org/wiki/Tropical_cyclone)

Geoscience:Tropical Cyclones (3)



(Image source: https://en.wikipedia.org/wiki/Tropical_cyclone, CC BY 3.0)

Geoscience:Tropical Cyclones (4)

basin	season start	season end	tropical cyclones
North Atlantic	June 1	November 30	12.1
Eastern Pacific	May 15	November 30	16.6
Western Pacific	January 1	December 31	26.0
North Indian	January 1	December 31	4.8
South-West Indian	July 1	June 30	9.3
Australian region	November 1	April 30	11.0
Southern Pacific	November 1	April 30	7.3

(Source: https://en.wikipedia.org/wiki/Tropical_cyclone)

Geoscience: Tornadoes (1)

tornado: rapidly rotating column of air that is in contact with both Earth’s surface and a cumulonimbus cloud or, in rare cases, base of a cumulus cloud; often referred to as twisters, whirlwinds or cyclones

- blow counterclockwise in the Northern Hemisphere and clockwise in the Southern
- most have wind speeds less than 110 miles per hour, are F0 or F1, are about 250 feet across, travel SW to NE in U.S., a few miles before dissipating
- most extreme tornadoes can attain wind speeds of more than 300 mph, are more than two miles in diameter, stay on ground for dozens of miles
- various types of tornadoes include multiple vortex tornado, landspout, and waterspout
- waterspouts characterized by spiraling funnel-shaped wind current, connecting to large cumulus or cumulonimbus cloud; generally classified as non-supercellular tornadoes that develop over water

Geoscience: Tornadoes (2)

- spiraling columns of air frequently develop in tropical areas close to equator, and are less common at high latitudes
- other tornado-like phenomena include gustnado, dust devil, fire whirls, steam devil
- have been observed and documented on every continent except Antarctica
- most occur in Tornado Alley region of U.S., although they can occur nearly anywhere in North America
- occasionally occur in south-central and eastern Asia, northern and east-central South America, Southern Africa, northwestern and southeast Europe, western and southeastern Australia, and New Zealand
- most occur in the afternoon
- can be detected before or as they occur through the use of Pulse-Doppler radar by recognizing patterns in velocity and reflectivity data, such as hook echoes or debris balls, as well as storm spotters’ efforts

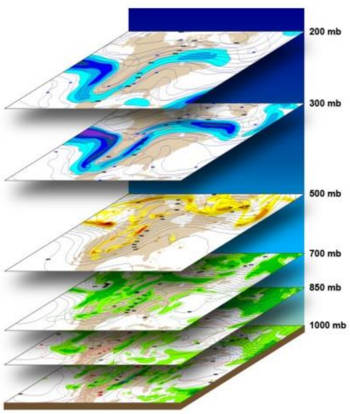
(Source: https://en.wikipedia.org/wiki/Tornado)

Geoscience: Fujita Scale

scale	wind speed km/hr	wind speed mph	relative frequency	average damage path in meters	potential damage
F0	64-116	40–72	38.9%	10-50	light
F1	117-180	73–112	35.6%	30-150	moderate
F2	181–253	113–157	19.4%	110-250	significant
F3	254–332	158–206	4.9%	200-500	severe
F4	333–418	207–260	1.1%	400-900	devastating
F5	419–512	261–318	<0.1%	1,100	incredible

(Source: https://en.wikipedia.org/wiki/Fujita_scale)

Geoscience: Pressure Versus Elevation Plots (1)



(Image source: http://www.srh.noaa.gov/jetstream/constant/verses.html, National Weather Service)

Geoscience: Pressure Versus Elevation Plots (2)

- constant pressure maps because the air pressure, dew point depression, wind speed and wind direction plotted on a map are measured at the same pressure level above each station
- common upper-air constant pressure maps include 850 mb, 700 mb, 300 mb, 250 mb, and 200 mb

pressure	height	example in meters
850 mb	1 + digits	534 → 1534 m
700 mb	2 or 3 + digits	972 → 2972 m, 013 → 3013 m
500 mb	digits + 0	543 → 5430 m
300 mb	digits + 0	912 → 9120 m
200 mb	1 + digits + 0	102 → 11020 m

(Sources: https://uni.edu/storm/downloads/Level2/Upper%20air%20plots-12.pdf, STORM Project, http://weather.unisys.com/upper_air/details.php, UNISYS Weather)

Geoscience: Pressure Versus Elevation Plot Uses (1)

pressure	usage
850 mb	amount of moisture is critical to precipitation forecasts; can be provided by the relative humidity or the precipitable water value
700 mb	top of the lower atmosphere; low enough in atmosphere where elevation of some of Rockies mountains will be higher than this level; values for heights of 700 mb in this region estimated as if there were no mountains; no value for wind, temperature and relative humidity; getting into the portion of atmosphere where looking for both moisture and vertical motion to find and forecast precipitation. For moisture, the 700 mb chart will indicate the relative humidity

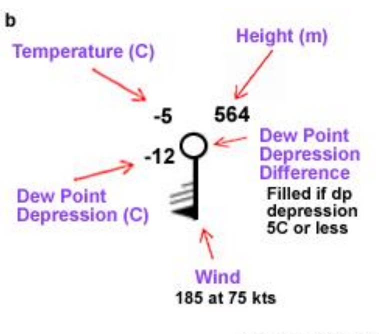
Geoscience: Pressure Versus Elevation Plot Uses (2)

pressure	usage
500 mb	top choice of meteorologists; considered middle of atmosphere; provides vorticity and relative humidity
300 mb	primarily used to locate the jet stream
200 mb	primarily used to locate the jet stream

(Source: http://www.srh.noaa.gov/jetstream/constant/constant_intro.html, National Weather Service)

Geoscience: Upper Air Station Model

- air temperature: in ^{0}C, plotted to upper left
- dew point depression: in ^{0}C, plotted to the lower left, difference between the temperature and the dew point, dewpoint always lss than or equal to the air temperature
- height: plotted to upper right
- wind speed: in knots



(Image source: https://uni.edu/storm/downloads/Level2/Upper%20air%20plots-12.pdf, STORM Project)

Geoscience: Upper Air Data

pressure	approximate height		approximate temperature	
sea level	0 m	0 ft	15^{0}C	59^{0}F
1000 mb	100 m	300 ft	15^{0}C	59^{0}F
850 mb	1,500 m	5,000 ft	5^{0}C	41^{0}F
700 mb	3,000 m	10,000 ft	-5^{0}C	23^{0}F
500 mb	5,000 m	18,000 ft	-20^{0}C	-4^{0}F
300 mb	9,000 m	30,000 ft	-45^{0}C	-49^{0}F
200 mb	12,000 m	40,000 ft	-55^{0}C	-67^{0}F
100 mb	16,000 m	53,000 ft	-56^{0}C	-69^{0}F

(Source: http://weather.unisys.com/upper_air/details.php, UNISYS Weather)

Geoscience: Long Waves in Upper Level Flow

long waves: fundamental feature on an unevenly heated rotating spherical planet

- also referred to as Rossby waves
- usually 4 to 6 are found around the globe at any given time
- wavelength varies between 4,000 and 8,000 km
- are generally stationary or move very slowly east or west

(Source: http://www-das.uwyo.edu/~zwang/atsc2000/Ch13.pdf)

Geoscience: Short Waves in Upper Level Flow

short waves: embedded in the long waves
move quickly to the east

- weaken when moving to a long-wave ridge
- strengthen when they move to a long-wave trough
- readily observable at mid-levels, 500 mb chart
- are an important ingredient for development and intensification of a mid-latitude cyclone, through baroclinic instability

(Source: http://www-das.uwyo.edu/~zwang/atsc2000/Ch13.pdf)

Geoscience: 500 mb Weather Maps

- especially useful for studying winter weather patterns in mid-latitudes, beteween 30^0 and 60^0 latitude
- height contours are at the height of the 500 mb pressure surface in meters above sea level
- height contours generally fall between 4,600 meters and 6,000 meters
- ridges aloft are associated with highs at the surface
- troughs aloft are associated with lows at the surface
- air pressure decreases more slowly in a warm column of air than in a cold column of air
- warmer than average temperatures can be expected underneath ridges and colder than everage temperatures can be expected underneath troughs

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/info500mb.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Map Winds

- wind blows parallel to height contours with lower heights to the left of the wind direction
- if you are moving with the 500 mb level wind at your back, lower 500 mb heights will be toward your left and higher 500 mb heights will be toward your right
- during the winter in the U.S., 500 mb winds generally blow from west to east, but follow the wavy pattern of height contours
- air temperature generally gets colder toward the north and 500 mb heights generally get lower
- general west to east air motion at 500 mb height weakens in summer as temperature differences between tropics and Arctic become weaker

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/info500mbII.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Map Vorticity (1)

vorticity: counterclockwise or clockwise spin
shear: change in wind speed over some horizontal distance
curvature: change in wind direction orver some horizontal distance, resulting in counterclockwise or clockwise curvature
Coriolis: spinning motion created by Earth's rotation; maximum at the poles and zero at the equator
absolute vorticity: = shear + curvature + Coriolis force
positive shear vorticity: wind speed increasing when moving away from center point of trough
positive curvature vorticity: counterclockwise curvature in the wind flow; occurs in trough and shortwaves
increasingly positive earth vorticity: south to north movement of air; Coriolis force increases when moving from equator to poles

Geoscience: 500 mb Weather Map Vorticity (2)

negative shear vorticity: wind speed decreasing when moving away from center point of trough
negative curvature vorticity: clockwise curvature in the wind flow; occurs in ridges
decreasingly positive earth vorticity: north to south movement of air; Coriolis force decreases, becomes less positive, from the poles to the equator

(Source: http://www.theweatherprediction.com/charts/500/basics/, Jeff Haby)

Geoscience: 500 mb Weather Map Highs (1)

closed high: most often found near the apex of a ridge; generally indicate warm and fair conditions; for a given location, if 500 mb height on map is close to average, then temperature is expected to be about average; if 500 mb height lower than average height, then lower than average temperatures expected; if the 500 mb height higher than average height, then higher than average temperatures expected

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/info500mb.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Map Highs (2)

blocking high: typically a summertime occurrence, responsible for major heat waves; any precipitation is usually shunted around the periphery of the high pressure area; high pressure aloft causes the air to subside or sink; downward motion compresses and warms the air in the lower atmosphere while simultaneously trapping heat rising from the earth's surface, leading to heat waves; skies are usually clear due to the downward motion of air; will eventually weaken when a short wave moves over the top of the high causing it to decrease with an end to the heat wave

(Source: http://www.srh.noaa.gov/jetstream/constant/basic.html)

Geoscience: 500 mb Weather Map Lows (1)

closed low: region of low heights around which one or more closed height contours are drawn; indicates pool of colder air surrounded by warmer air; most often found in trough bases; often associated with precipitation and change toward cooler conditions

cutoff low: becomes completely detached from the main westerly wind currents at 500 mb; may remain detached from the westerlies for days while exhibiting very little forward, eastern progress; may move to the west, or retrograde, opposite the prevailing flow; often difficult for weather models to predict their motion; frequently common in extreme southwestern U.S. and coastal Pacific waters off the coast of California; can produce rain and high elevation snow in Arizona

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/p500mb.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Map Highs and Lows (1)

omega block: upper air pattern looks like the Greek letter omega (Ω); combination of two cutoff lows with one blocking high sandwiched between them; because of their size, often quite persistent and can lead to flooding and drought conditions depending upon ones location under the pattern; cooler temperatures and precipitation accompany the lows while warm and clear conditions prevail under the high

rex block: characterized by high pressure system located pole-ward of a low pressure system; will remain nearly stationary until one of the height centers changes intensity, unbalancing the high-over-low pattern; unsettled, stormy weather usually found near low pressure while dry conditions are typical with high pressure; strong, particularly persistent rex blocks can cause flooding near low pressure part and short-term drought under high pressure part

(Source: http://www.srh.noaa.gov/jetstream/constant/basic.html)

Geoscience: 500 mb Weather Map Troughs (1)

- 500 mb surface will be located at higher levels further south and at lower levels further north
- troughs and ridges don't have to have north-south orientation
- best way to identify troughs and ridges is to visualize 2-dimensional wind trajectory based on the 500 mb height pattern
- wind trajectory traces the motion of air
- troughs and closed lows make counterclockwise turns
- ridges and closed highs make clockwise turns
- wind speed is faster where height lines are closer together, and slower where they are spaced farther apart
- winds at 500 mb are referred to as "steering level" winds

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/info

Geoscience: 500 mb Weather Map Troughs (2)

- Northern Hemisphere 500 mb troughs can be identified as regions where air flow makes counterclockwise turn
- where the 500 mb air flow transitions from a counterclockwise curve to a straighter flow, just after the air has gone through a trough, is region where rising air motion happens, favoring cloud development and precipitation
- common for areas of precipitation to wrap around closed lows
- 500 mb maps do not include information about moisture or water vapor

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/info500mbII.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Maps Clouds and Precipitation

- clouds and precipitation most likely to occur just downwind or downstream from location of 500 mb troughs, region just after wind has gone through trough and starts heading to next ridge, since rising air motion is forced in this part of flow pattern
- rising motion means air moves vertically upward
- clouds and precipitation will develop where air rises, if sufficient water vapor
- sinking air motion is forced over areas downstream of ridges
- clouds do not develop where air is sinking or moving vertically downward
- fair weather most likely in these areas

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/info500mbII.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Map Rules

- stronger winds increase divergence; the more closely spaced height lines, the stronger the divergence downwind of troughs
- the more amplified the trough/ridge pattern, the stronger the divergence downwind of troughs
- the sharper the curvature of a trough, the stronger the divergence downwind of the trough
- the orientation of trough axis with respect to a north-south line; troughs that are oriented along a northwest-southeast line have a "negative tilt;" troughs oriented along a northeast-southwest line have a "positive tilt"

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/p500mb.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Map Longwaves

longwave: define large-scale weather patterns

- higher the temperature, higher the height of the 500 mb level
- more pronounced the ridge/trough, the more above/below average the temperatures will be
- larger the amplitude of a 500 mb wave pattern, the greater the temperature contrast between a trough and a ridge
- usually between 2 and 7 longwaves encircle the Northern Hemisphere at any given time
- average size of a longwave is a few thousand kilometers, about width of U.S.
- explains why there is a pattern where it is warm in the eastern U.S. and cold in the western U.S. or vice versa

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/p500mb.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Map Shortwaves

shortwave: smaller wiggles or waves superimposed on the longwave pattern

- smaller regions of warm/cold temperature contrasts and forced rising or sinking vertidal motion
- have a much sharper curvature than longwaves, stronger divergence and forced rising motion
- indicate the position of a strong weather system, especially if sharply curved
- typically flow through the longwave pattern following the longwave wind direction but at a slower speed
- shortwaves generally move along at about half the speed of 500 mb winds
- tend to strengthen as they move into the regions just downstream of a longwave trough and weaken as they move into the region just downstream of a longwave ridge

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/p500mb.html, Dale Ward, University of Arizona)

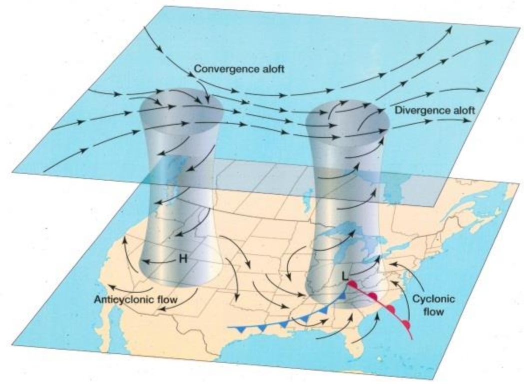
Geoscience: 500 mb Weather Map Divergence and Convergence (1)

divergence: occurs when horizontal winds cause a net outflow of air from a region, where more air leaves a vertical air column than enters it
convergence: occurs when horizontal winds cause a net inflow of air from a region, where more air enters a vertical air column than leaves it
zonal pattern: about average temperatures are found everywhere and that strong areas of precipitation are unlikely
amplified pattern: more extreme weather expected, colder under deep troughs, warmer under large ridges, with strong areas of precipitation possible just beyond trough positions

- amount of winter-type storm precipitation depends on atmospheric dynamics and how strongly air forced to rise and availability of water vapor
- if air contains a lot of water vapor, little lifting required for precipitation

(Source: http://www.atmo.arizona.edu/students/courselinks/fall14/atmo336/lectures/sec1/p500mb.html, Dale Ward, University of Arizona)

Geoscience: 500 mb Weather Map Divergence and Convergence (2)



(Image source: http://u18439936.onlinehome-server.com/judd.curran/geography/outline2.htm)