Global Water Cycle

➢ Hydrologic Cycle

- Hydrologic **Cycle** : a model for where water is stored on Earth & how it moves from one place to another
  - The hydrologic cycle is powered by the sun
  - Understanding how water travels between Earth's surface & atmosphere is crucial to being able to predict the climate & the availability of water in various parts of the world, & to formulating plans to help people adapt to climate changes brought about by global warming.

- Hydrologic **Reservoirs**: where the water is stored

TABLE 6-1 Reservoirs of the hydrosphere

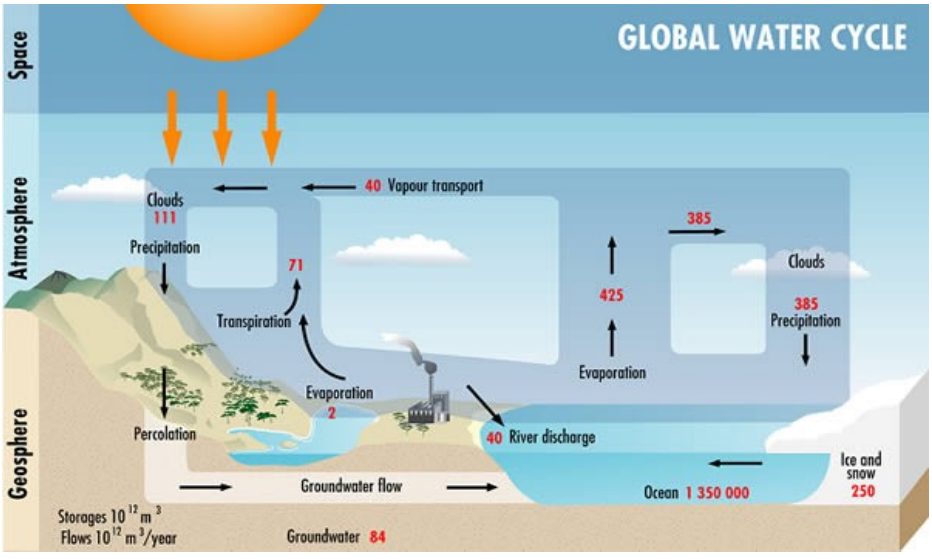
Reservoir	Volume (10^6 km^3)	Percent of total
Oceans and sea ice	1400	95.96
Glaciers and land ice	43.4	2.97
Surface waters		
Lakes	0.125	0.009
Rivers	0.0017	0.0001
Subsurface waters		
Groundwater	15.3	1.05
Soil Moisture	0.065	0.0045
Atmosphere	0.0155	0.001
Biosphere	0.002	0.0001
Total	**1459**	**100**

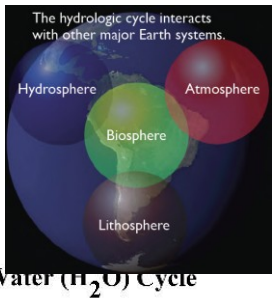
(Berner and Berner, 1987, 1996; Drever, 1988)

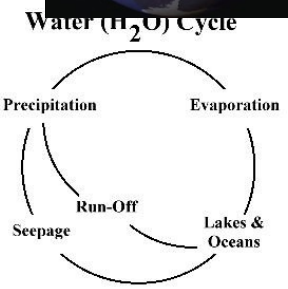
- **Ocean** Reservoir: all waters contained within the ocean basins, including sea ice
  - divided into the **mixed layer**, the **thermocline layer**, & the **abyssal layer**
  - each layer transports & exchanges water in different ways
- **Land** Reservoirs: all surface waters within the lakes, rivers, streams, & ponds
- **Ice** & **Snow** Reservoir: includes all of the land-fast ice, glaciers, snow, & permafrost
- **Subsurface** Reservoir: includes all of the water in underground caverns & in the soil, sediments, & permeable rock

- Hydrologic **Pathways**: how water moves from one reservoir to another
  - **Evaporation** : evaporation of seawater leaves the salts behind, thereby ↑ **salinity**
    -
  - **Precipitation** : Adds freshwater, thereby ↓ **salinity**
    -
  - **Freezing** : Formation of ice leaves behind salts, called **brine rejection**, thereby ↑ **salinity**
    -
  - **Melting** : Melting of ice adds freshwater & ↓ **salinity**
    -
  -

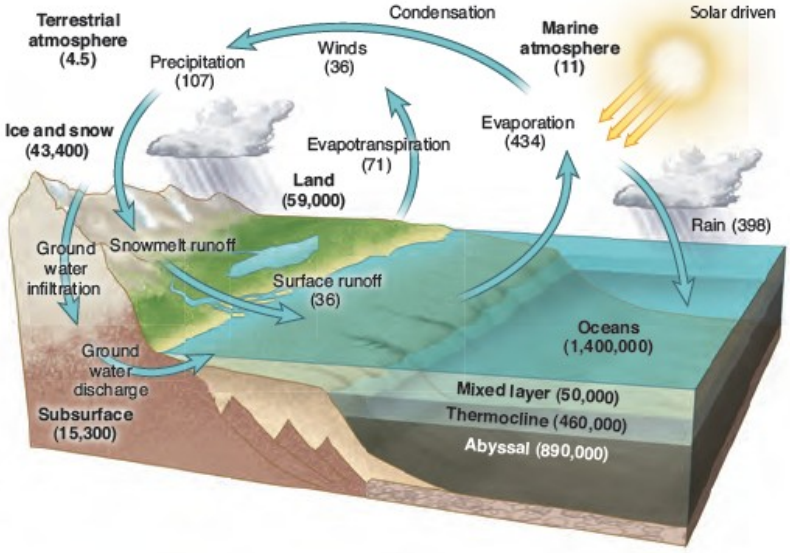
- Hydrologic **Rate Processes**: rate at which water is transported between reservoirs by a particular process

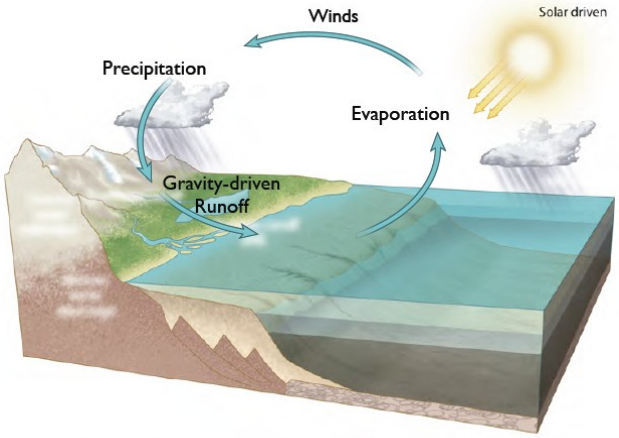




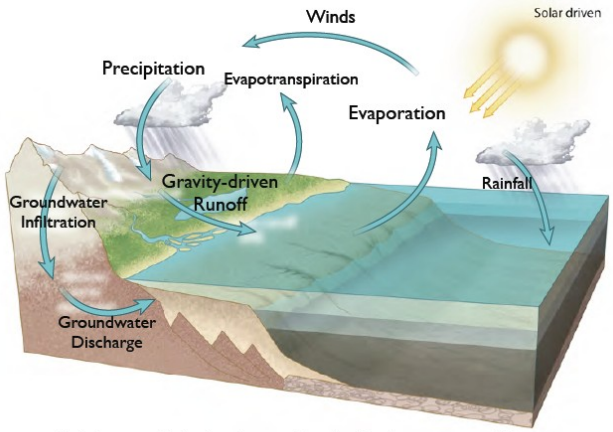


The Hydrologic Cycle

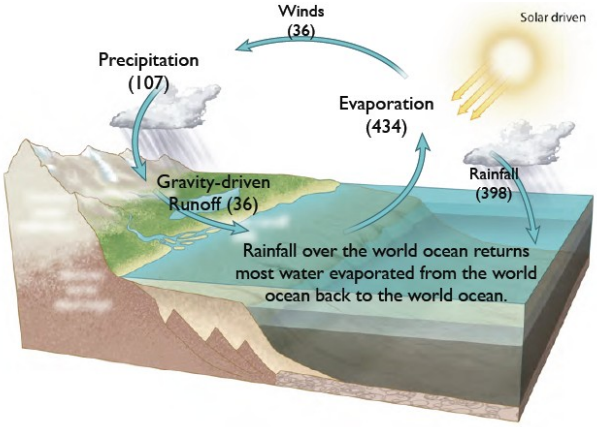




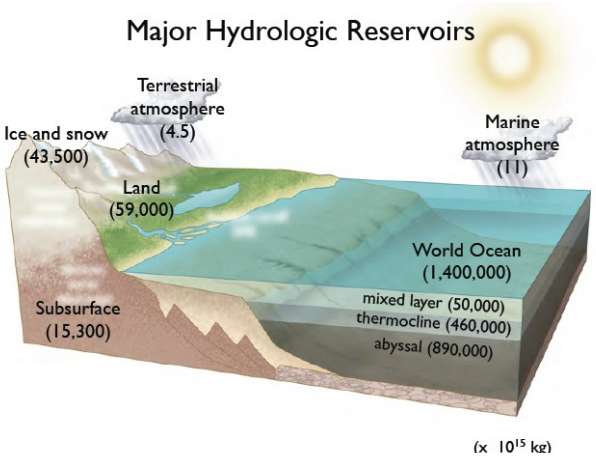
Major Hydrologic Cycle Pathways and Processes

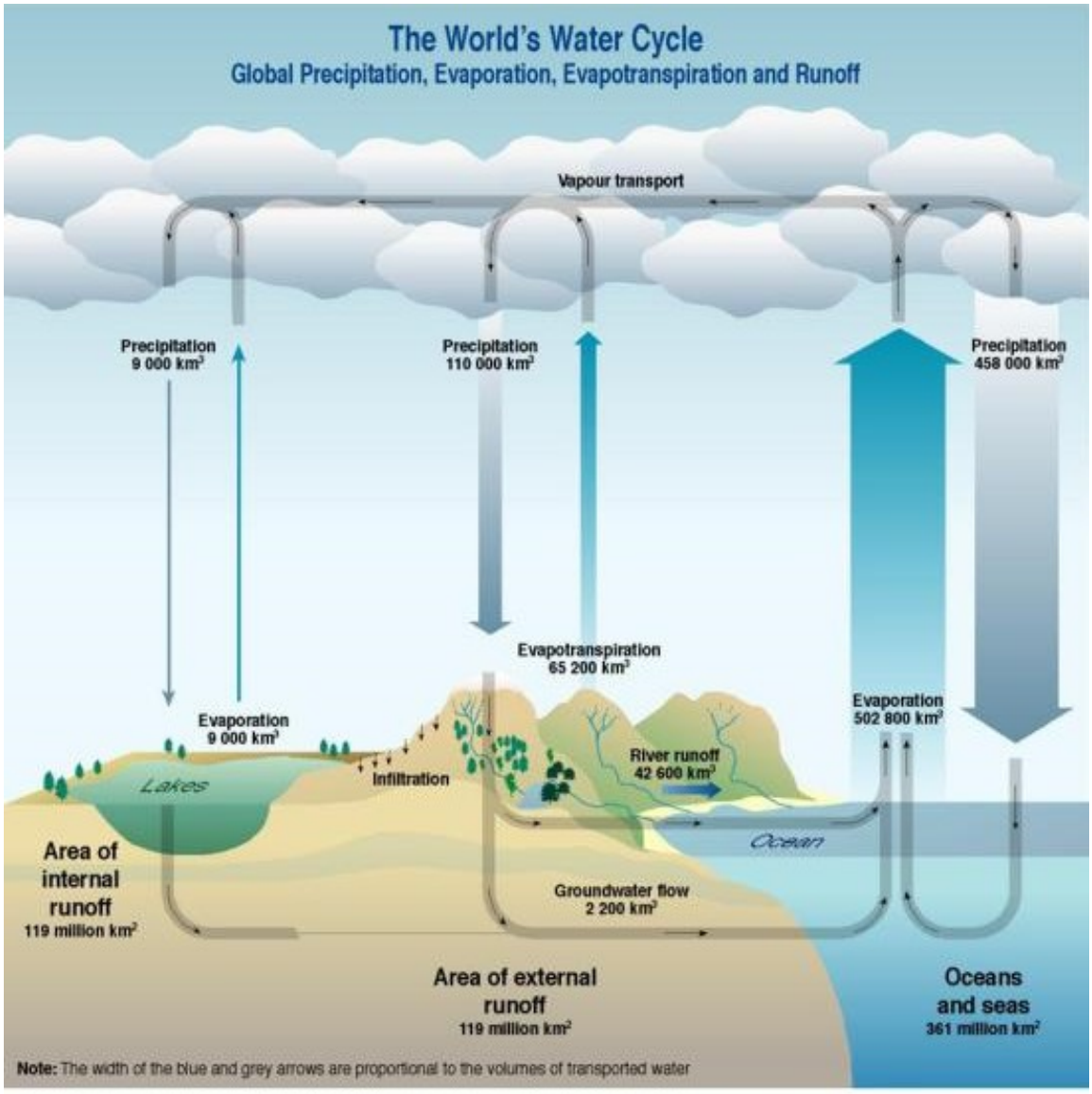


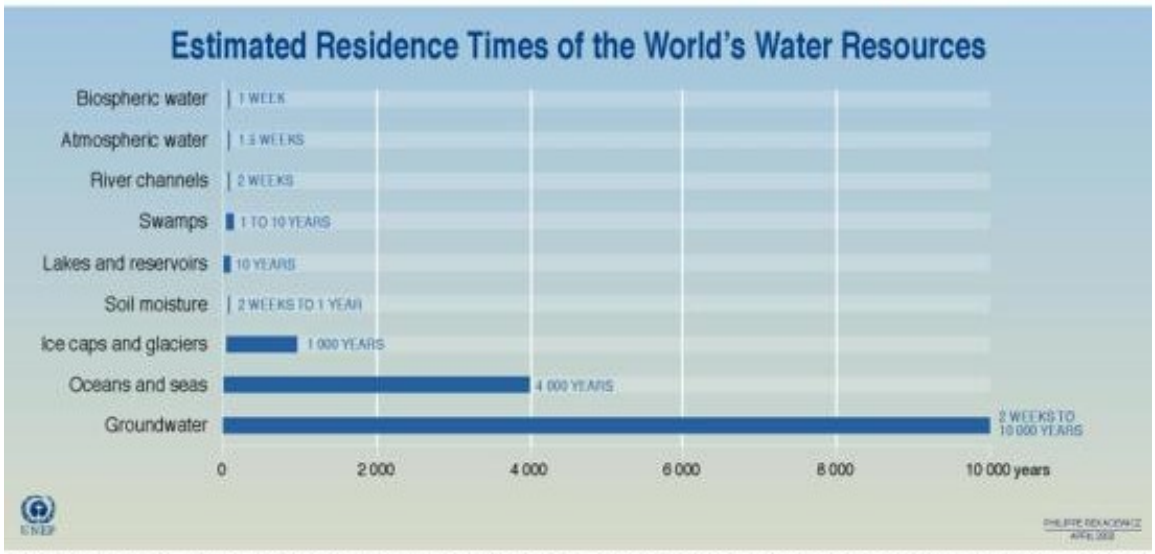
Additional Hydrologic Cycle Pathways and Processes



Rates of Exchange in 10^{15} kg year^{-1}





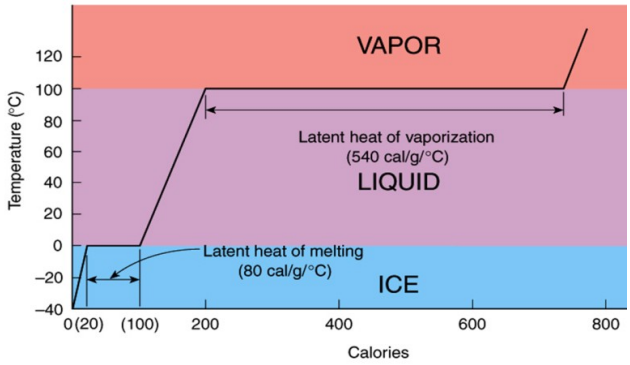


Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational, Scientific and Cultural Organisation (UNESCO, Paris), 1999; Max Planck, Institute for Meteorology, Hamburg, 1994; Freeze, Allen, John, Cherry, *Groundwater*, Prentice-Hall: Engle wood Cliffs NJ, 1979.

➢ Properties of Water

- Water is a **polar molecule** → accounting for water's unusual properties.
- Water exists on Earth in **all 3 phases** (it's the only substance to do this)
- Ice Floats !
- Water has very **high Heat Capacity**
- The Oceans moderate global temperatures.
- Absorption, Refraction, & Reflection play important roles in Light & Sound transmission in the ocean.
- Most of Earth's free water is in the ocean

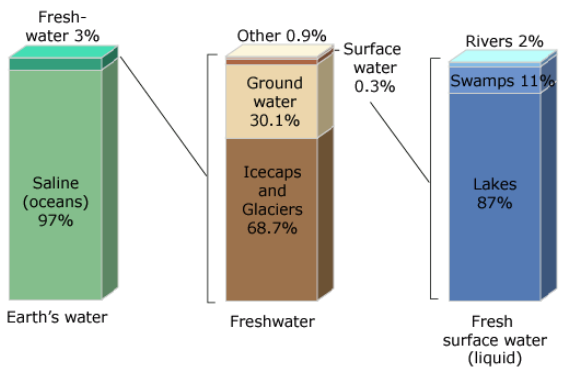
Property	Comparison	Importance	Notes
★ Physical State	Only substance to naturally occur in all three states	Considerably more abundant at Earth's surface as all other substances combined	
Surface Tension	Highest of all common liquids	Controls drop and bubble formation	High surface tension → why insects can walk on water
Thermal Expansion	Expands upon freezing	Ice floats	Unusual that when it freezes it expands, while everything else becomes denser & sinks as they freeze
Latent Heat	Highest except for ammonia	Thermostatic effect at freezing point	"**Thermostatic effect**" it takes a lot of heat to change water into ice
Heat of Evaporation	Highest of all substances	Heat and water transfer between ocean and atmosphere	
Heat Capacity	Highest except for liquid ammonia	Prevents extreme ranges in ocean temperatures	
Dissolving Power	Best Solvent	All substances dissolve in water	Everything will eventually dissolve in water
Transparency	High in the Visible Low in UV and Infrared	Photosynthesis Absorption of Solar energy	High transparency in the visible is important for photosynthesis Low transparency in the IR → high absorption in the atmosphere



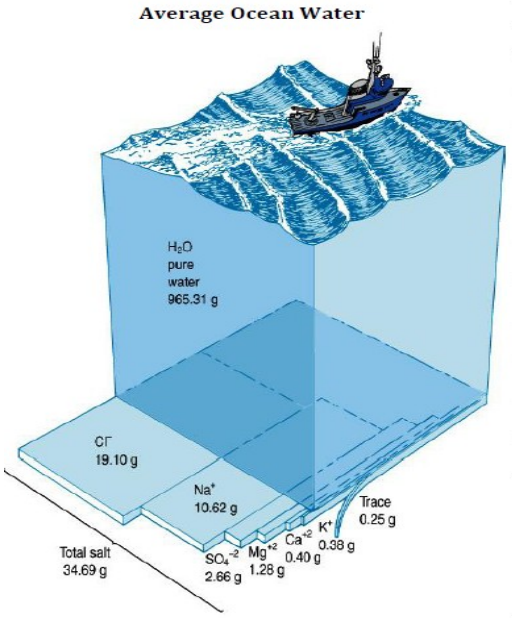
- **Where did water come from?**
  - **Outgassing as Earth Cooled**: all the water came from the processes of the Earth's formation
  - **Comet impacts**: more recent theories indicate a more constant in port of water

➢ Distribution of Earth's Water

Earth's Water Supply		
Reservoir	**Volume (km³)**	**% of Total Volume**
Atmospheric Water Vapor	15.3 x 10^3	0.001
Rivers and Lakes	510.0 x 10^3	0.036
Groundwaters	5,100.0 x 10^3	0.365
Glaciers & other Land Ice	22,950.0 x 10^3	1.641
Oceanic Water and Sea Ice	1,370,323.0 x 10^3	97.957
Total (Free Water)	1,398,898.3 x 10^3	
Hydrated Water	1 x 10^9 to 15 x 10^9	– estimated



- **Composition of Seawater**

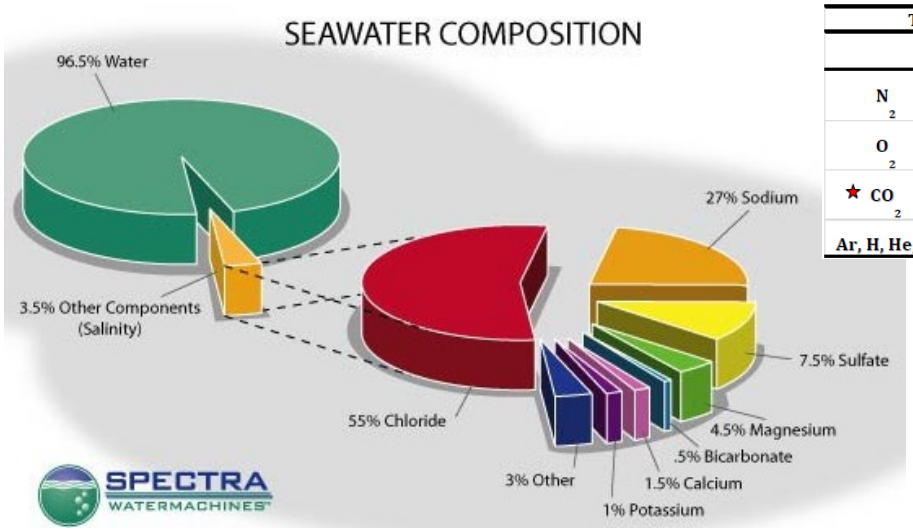


Dissolved Material in Seawater		
ION	Gram weight per kg	% by weight
★ Chloride – Cl^-	19.111	55.04
★ Sodium - Na^+	10.629	30.61
Sulfate – SO_4^{2-}	2.667	7.68
Magnesium - Mg^{2+}	1.281	3.96
Calcium - Ca^{2+}	0.403	1.16
Potassium- K^+	0.383	1.10
Bicarbonate - HCO_3^-	0.141	0.41
Bromide - Br^-	0.065	0.19
Boric Acid – $H_2BO_3^-$	0.026	0.07
Strontium - Sr^{2+}	0.013	0.04
Fluoride - F^-	0.001	0.00

S = 34.72

These First 7 Ions sum to 99.69%, all 11 Ions sum to 99.9%
(any variation in these numbers occurs in the 4 or 5th significant digit)

This concept is called the "**Law of Constant Proportions**,"
the ocean is well mixed & only really changes at the sources and sinks



The Most Common Dissolved Gases in the Ocean			
	% in Atmosphere	% in Surface Water	Ratio
N_2	78.1	47.5	0.6
O_2	20.9	36.0	1.7
★ CO_2	0.03	15.1	503.3
Ar, H, He, ...	0.97	1.4	1.5

Some Minor Constituents	
Lithium	170 parts per billion
Iodine	60
Molybdenum	10
Zinc	10
Iron	2
Aluminum	2
Copper	2
Manganes	2
Lead	0.003
Mercury	0.003
Gold	0.005

- **Physical Properties of Seawater**

Physical Properties of Seawater	
Increase with Increasing Salinity	Decrease with Increasing Salinity
- Density	★ Freezing Point
- Refractive Index	★ Temperature of Maximum Density
- Electrical Conductivity	★ Compressibility (pure H_2O can't be compressed much)
- Speed of Sound	- Solubility of Non-Reacting Gases
- Surface Tension (wake lasts longer in seawater than in freshwater)	- Specific Heat

pH of Seawater

pH – measure of the concentration of H+ ions

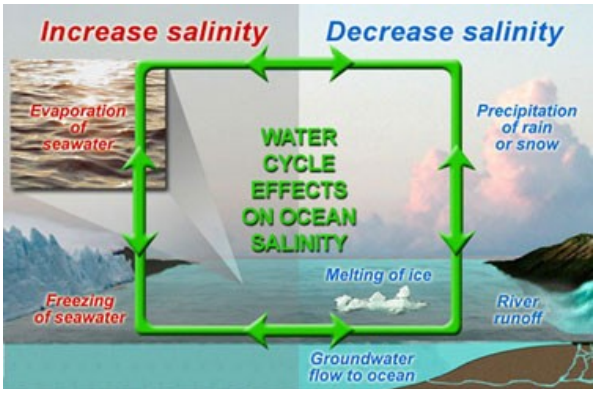
0	7	14
Acid	Neutral	Basic

pH of seawater = 7.5 to 8.1

The pH of seawater is buffered by dissolved CO_2

➢ Hydrologic Processes & Salinity

- all of these processes also **affect** the **Salinity** of **seawater**, which in turn will affect the density

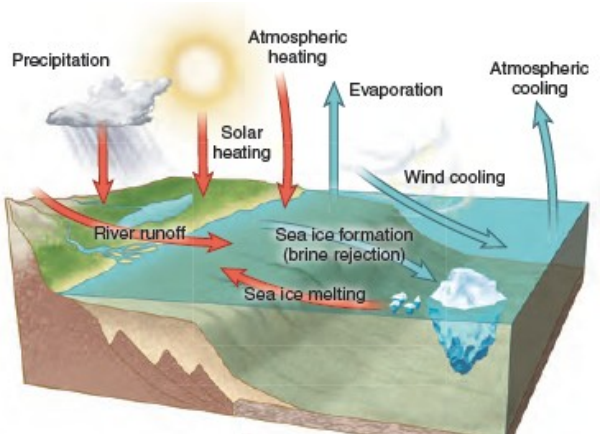


Processes that *Increase* Salinity
- Evaporation of surface waters
- Ice cooling (icebergs) of surrounding waters
- Brine Rejection during Sea Ice Formation
- Atmospheric cooling of surface waters by winds or heat exchange

Processes that *Decrease* Salinity
- Solar heating of surface waters
- Hydrothermal heating of bottom waters
- Rainfall & other forms of precipitation at sea
- Runoff of freshwater from land & underground
- Melting of sea ice or icebergs
- Atmospheric heating of surface waters

➢ Hydrologic Processes & Density

- all of these processes also **affect the density of seawater**, which has important **effects** on **ocean circulation**



Processes that *Raise* Density
- Evaporation of surface waters
- Ice cooling (icebergs) of surrounding waters
- Brine Rejection during Sea Ice Formation
- Atmospheric cooling of surface waters by winds or heat exchange

Processes that *Lower* Density
- Solar heating of surface waters
- Hydrothermal heating of bottom waters
- Rainfall & other forms of precipitation at sea
- Runoff of freshwater from land & underground
- Melting of sea ice or icebergs
- Atmospheric heating of surface waters

➢ Important Exchanges of Energy & Matter across the Air-Sea Interface