965SV_L01b

0. Ethics in science, plagiarism and AI

1. Microbes in the Marine Environment

2. Metabolic Diversity and Ecophysiology of Marine Microbes

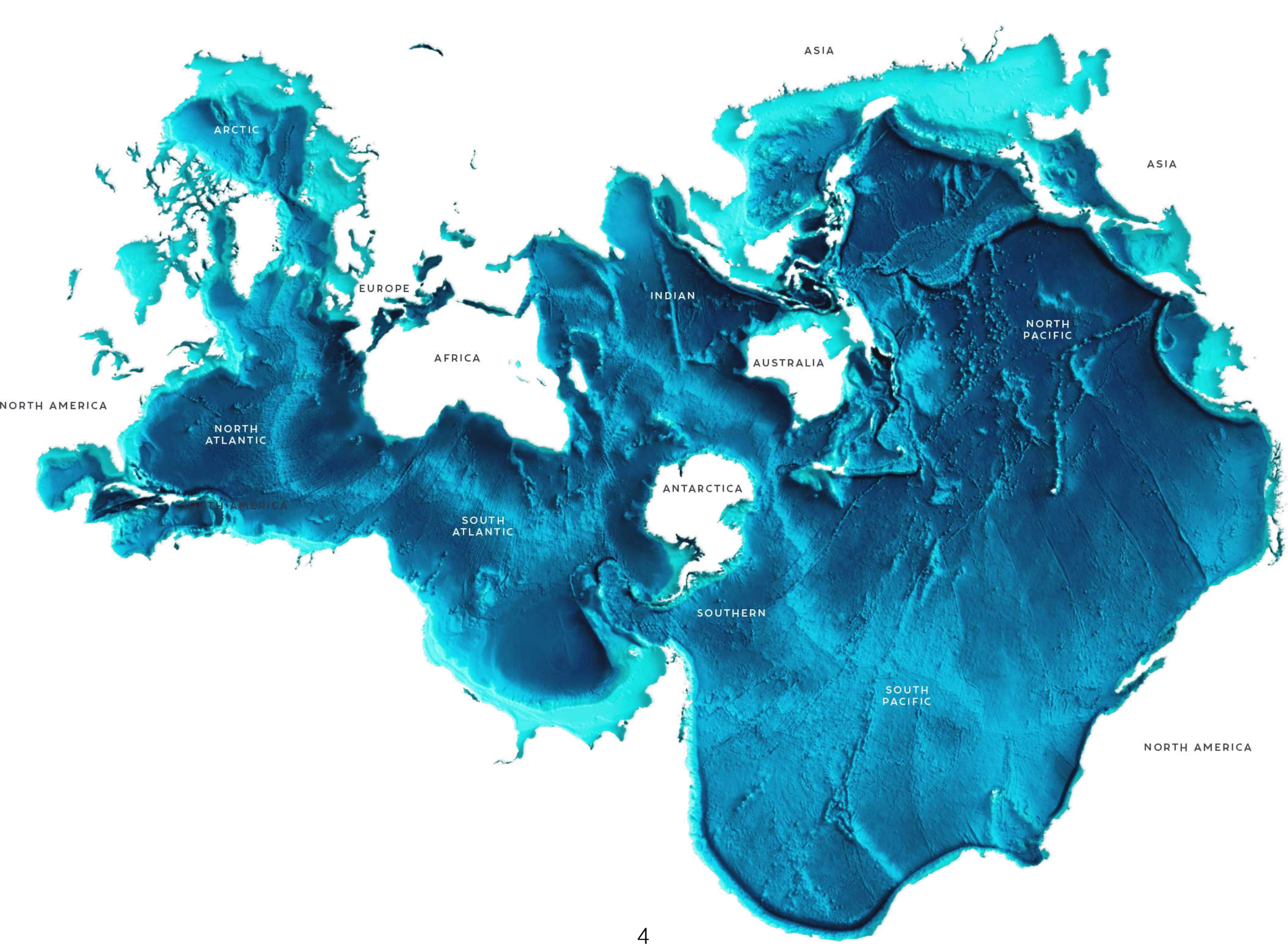
3. Diversity of Marine Bacteria, Archaea, Viruses and unicellular Eukaryotes

4. Microbes in Ocean Processes: Carbon and other nutrients

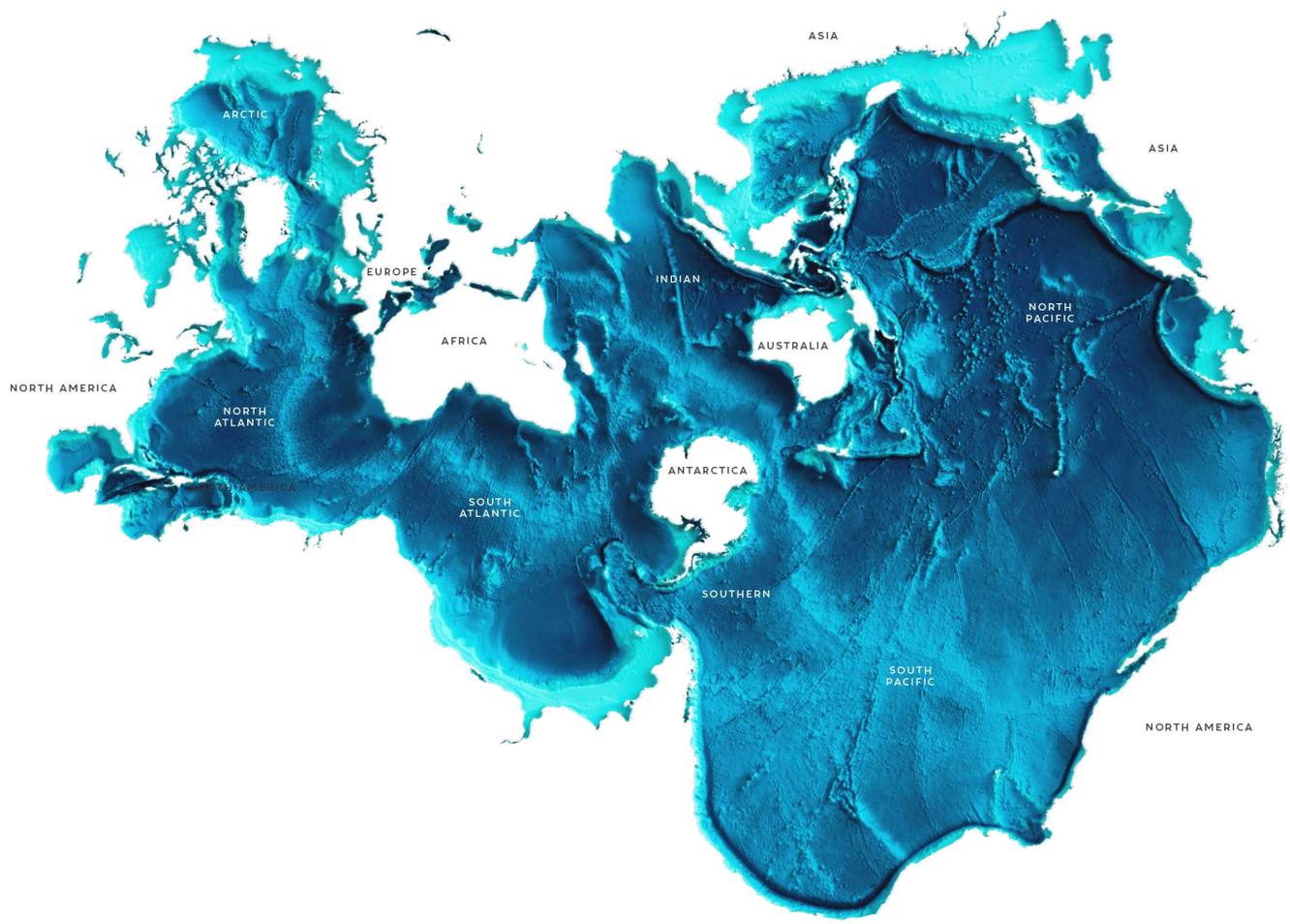
5. Marine Microbial Symbioses and Diseases

6. Marine Microbes, Climate and Society

1. Microbes in the Marine Environment


ASIA
ARCTIC
ASIA
EUROPE
INDIAN
NORTH
PACIFIC
AFRICA
AUSTRALIA
NORTH AMERICA
NORTH
ATLANTIC
ANTARCTICA
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PACIFIC
NORTH AMERICA

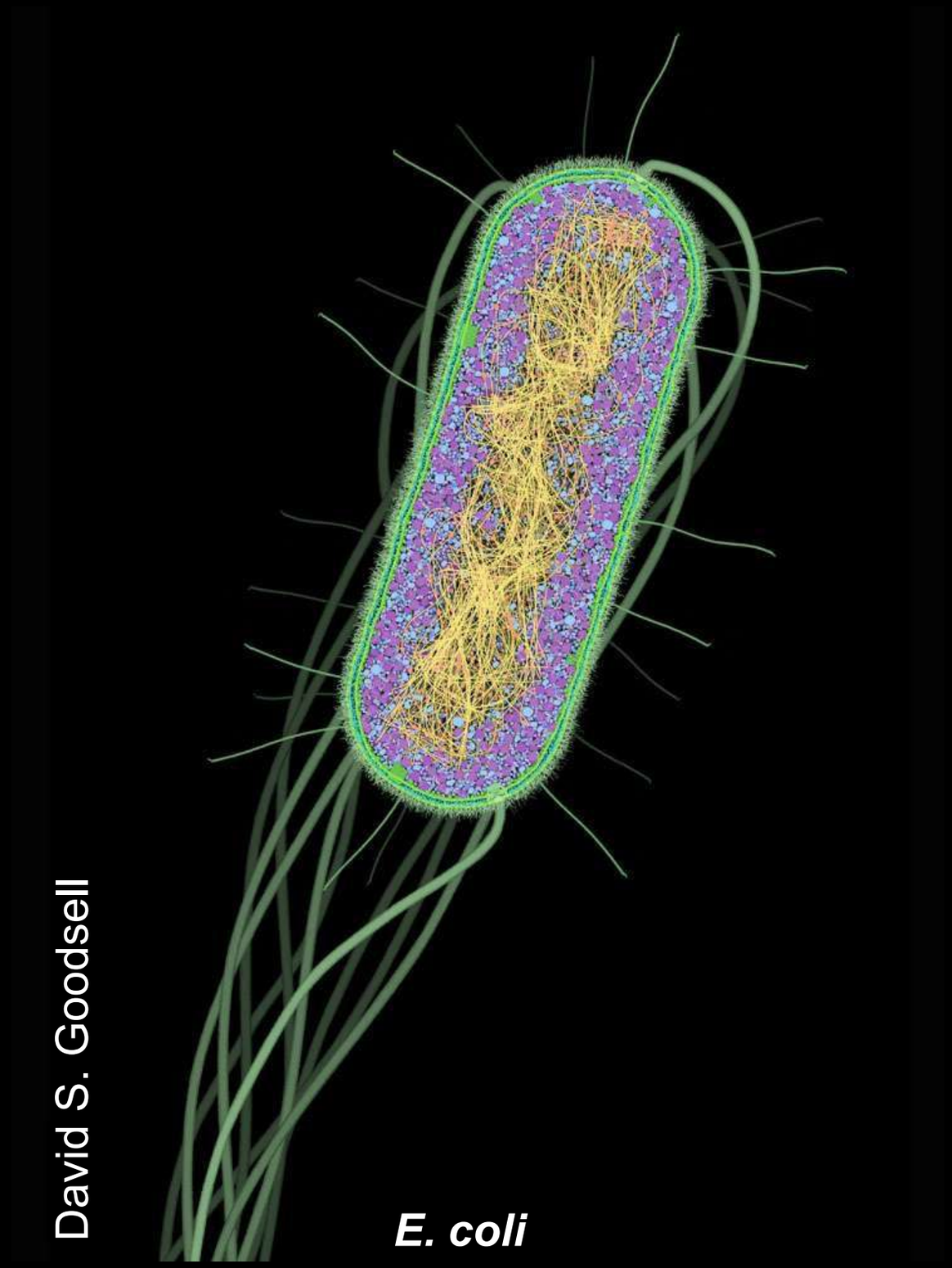
https://www.whoi.edu/ocean-learning-hub/multimedia/



The ocean is in between the cells



From micro to nanoscale….at their scale



David S. Goodsell

E. coli



Microscale

- Microbes live in a microbial world
- Microbes interact intimately with molecules
- Gradients are ephemeral in space and time
- Unknown is behind the corner…dark corner!
- On a face value, at the microscale all living things/organisms are the same —> sugars, proteins and lipids —> hot spot of organic matter
- All the surfaces are the same, due to the molecular coating

Microscale microbial habitats

TABLE 1>> EXAMPLES OF HOW THE MARINE ENVIRONMENT MAY BE DIVIDED INTO DIFFERENT MICROBIAL HABITATS

Criterion	Habitats
Presence of other organisms	Symbiotic
	Free-living
	Biofilm
Proximity to the ocean surface or sediments	Euphotic (0-150 m)
	Mesopelagic (150-1000 m)
	Bathopelagic (>1000 m)
	Benthos (sediments)
Concentration of nutrients and required growth substrates	Oligotrophic
	Mesotrophic
	Eutrophic

American Academy of Microbiology, 2005

Seawater = SW

Physics and Chemistry control microbial life

TABLE 2>> FACTORS THAT IMPACT MARINE MICROBIAL DIVERSITY

Factors	
> Turbulence	> Salinity
> Light	> pH
> Temperature	> UV and Solar flux
> Nutrients	> Presence of macro-organisms, such as invertebrates and macroalgae
> Surfaces and interfaces	
> Redox potential	
> Metals	

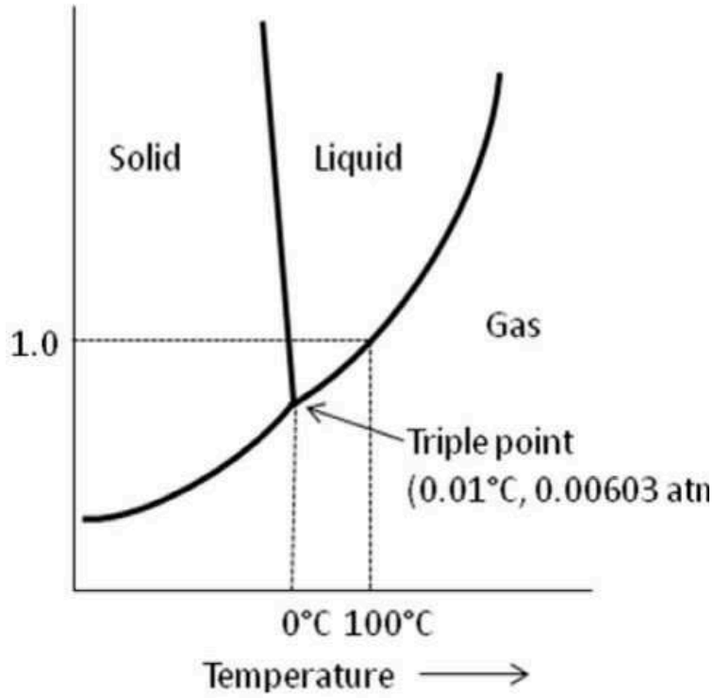
American Academy of Microbiology, 2005

“No water, no life. No blue, no green.”

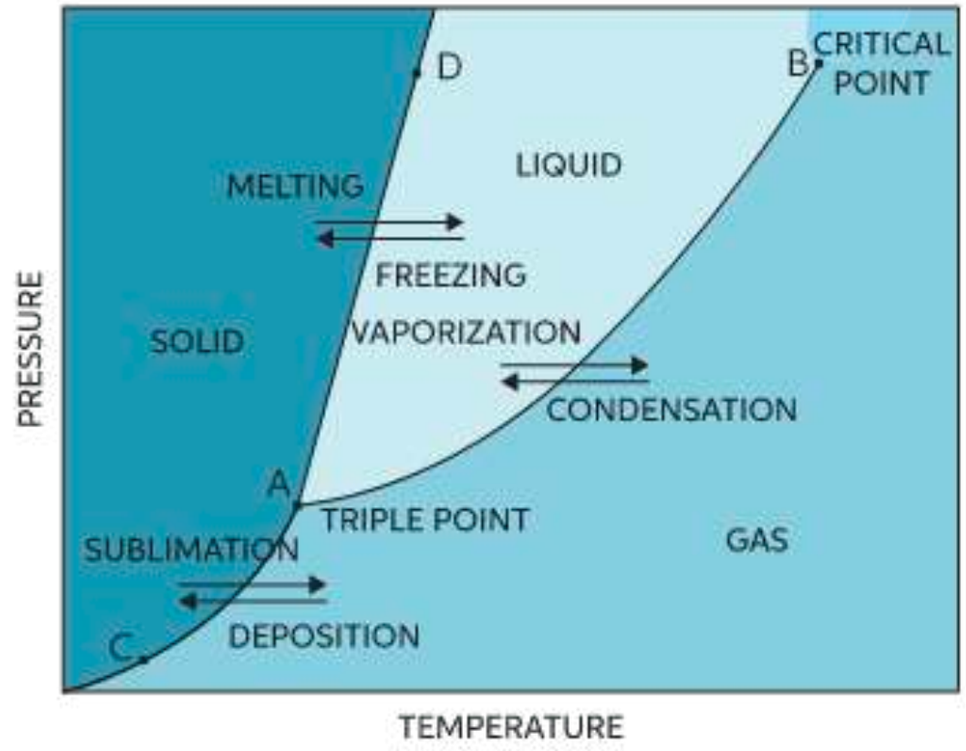


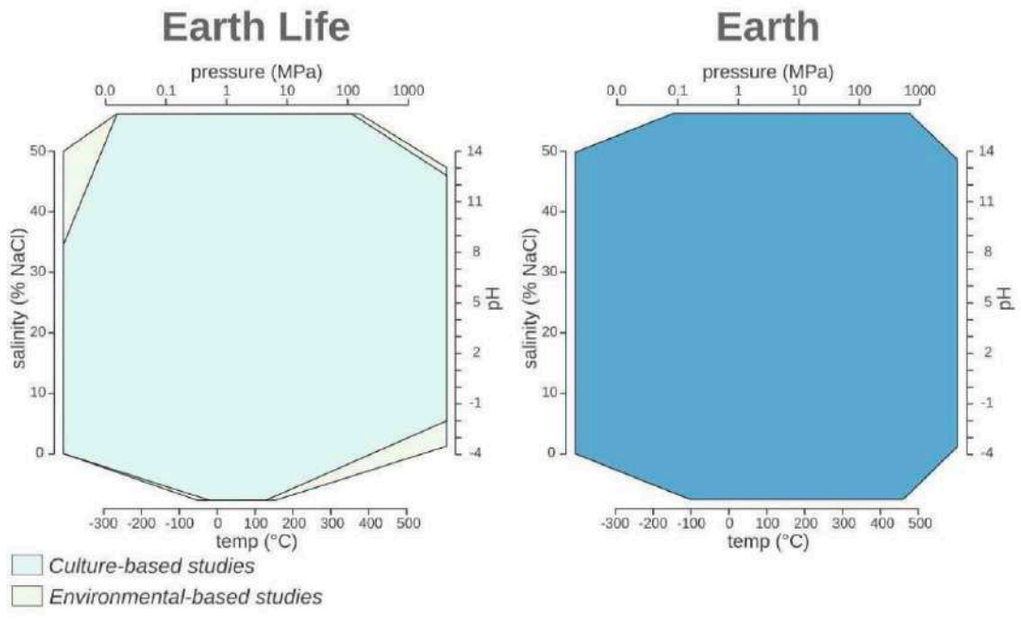
—Dr. Sylvia Earle

State of water



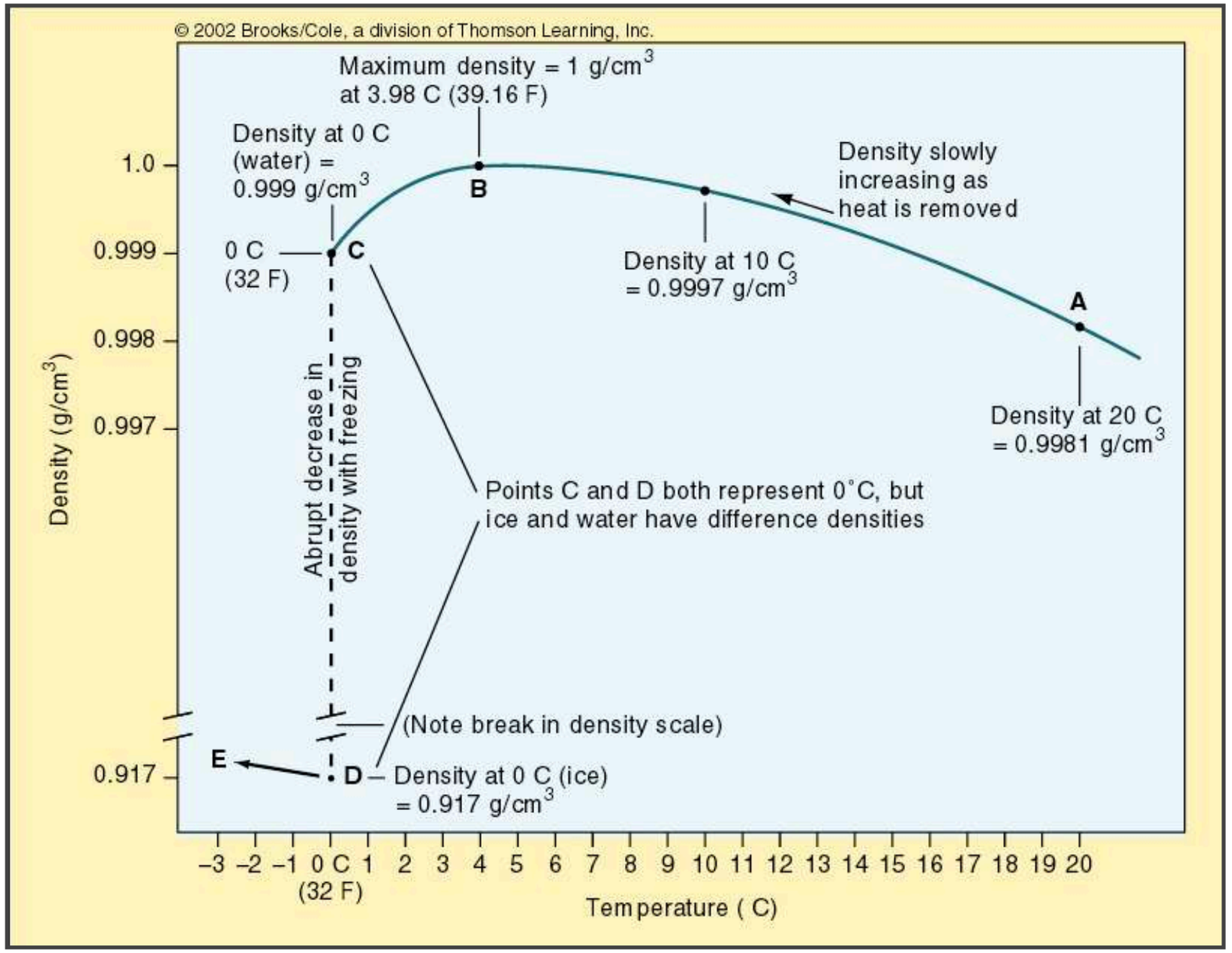
Merino et al. 2019





- Earth is a unique environment
- Microbial adaptations for the 3 state of water
- Microbes are alive in/on ice and in clouds, sea spray aerosol particles

- Freezing point of seawater is ~ -1.8°C
- Density continually increases to freezing point



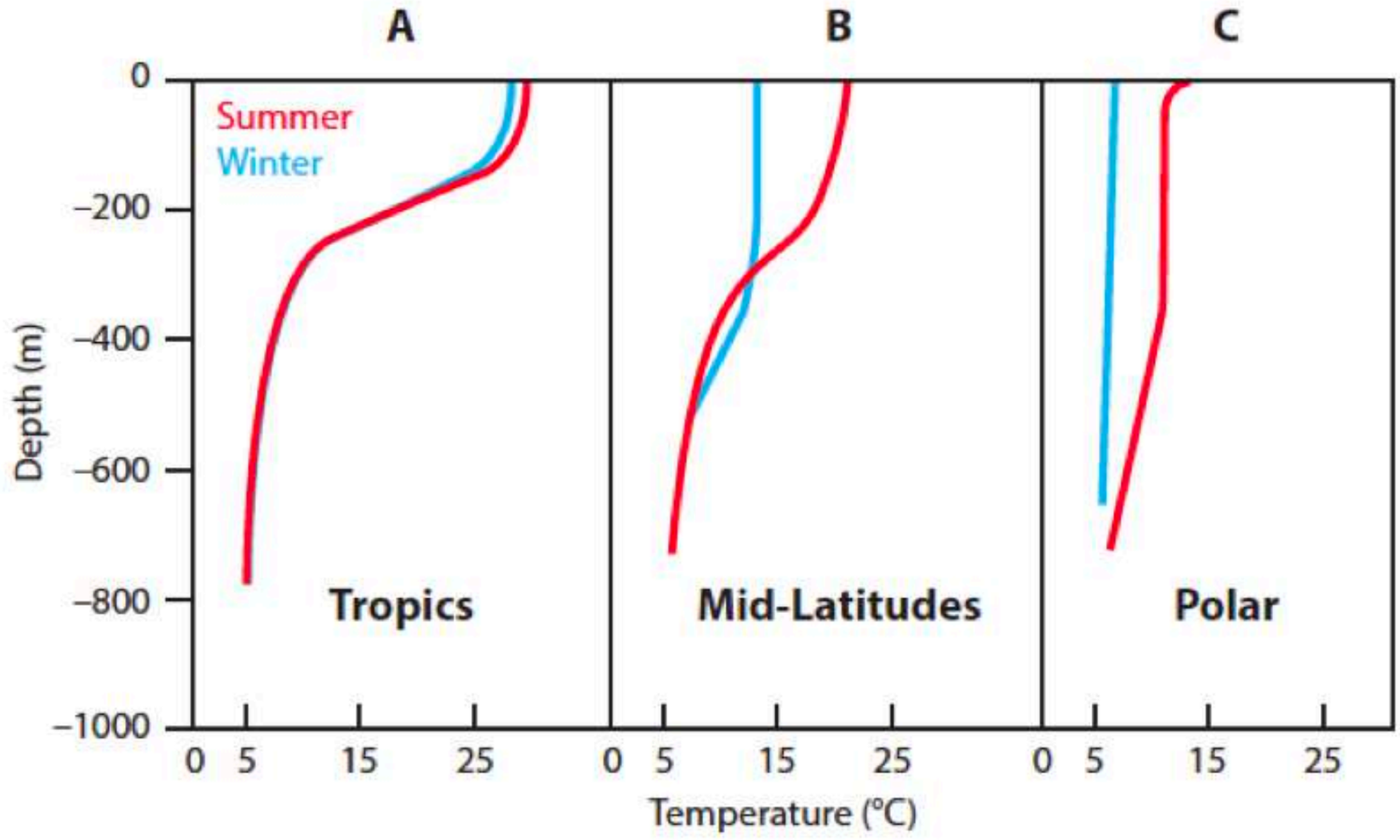
- SW freezing point < pure water freezing point
- Ice floats on water !

Triple point of water



Temperature

https://manoa.hawaii.edu/exploringourfluidearth



Idealized vertical temperature ocean profiles in July and January (A) near the equator, (B) at approximately 45° N or S latitude, and (C) near the poles. Image by Byron Inouye

High-variability at surface and seasonal cycles

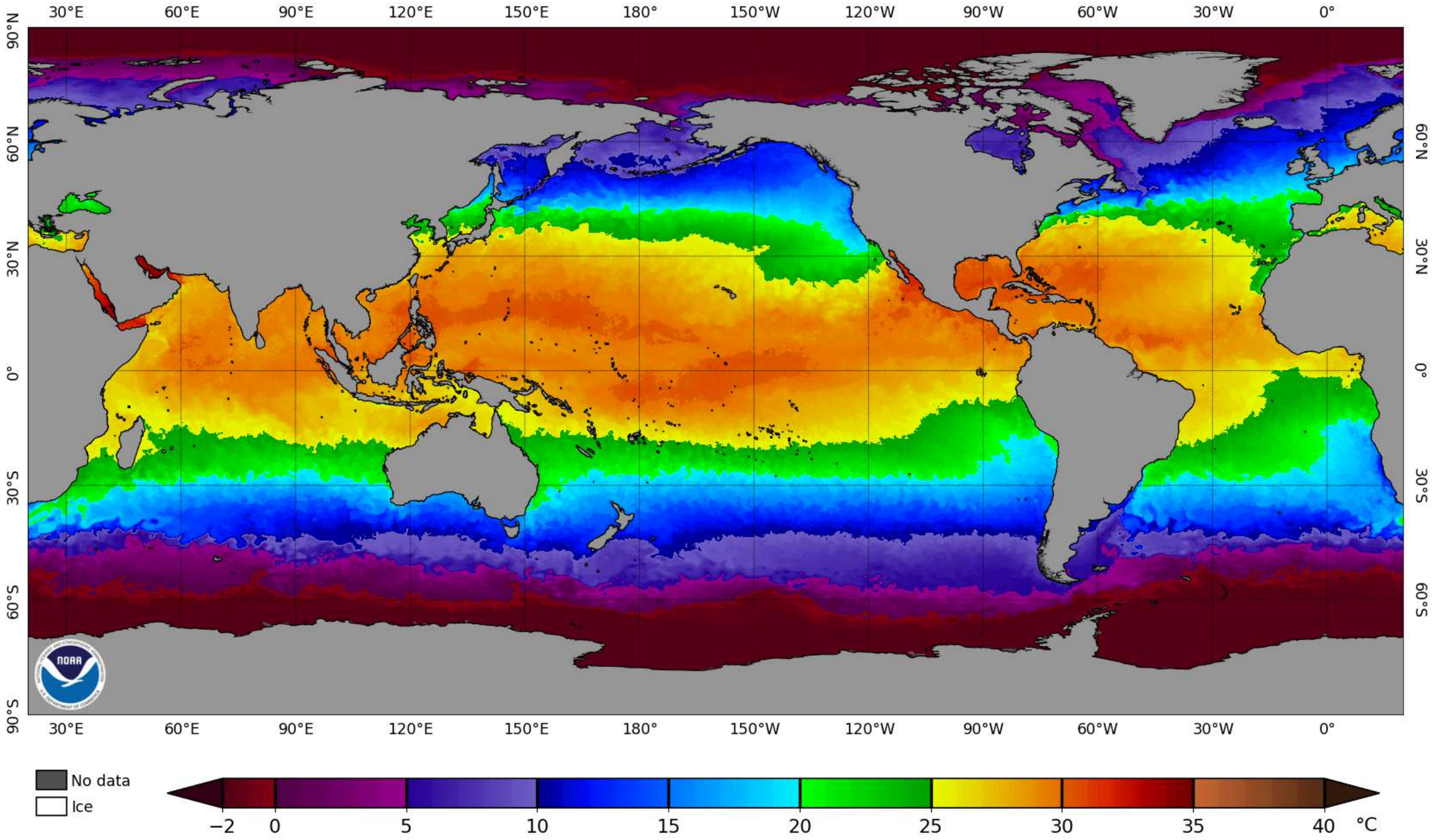
The **thermocline** is the zone where there is a rapid temperature change

The thermocline is also called a **transition zone** because it has characteristics of both the surface- and deep-water layers

- Sunlight —> longer wavelengths —> since the beginning of pre-cellular life
- Optimal range for life
- Temperature dictates chemical reaction rates —> growth
- Microbial adaptations at high and low temperature (e.g. cold or heat-shock proteins, membrane fluidity)

Ocean Surface Temperature

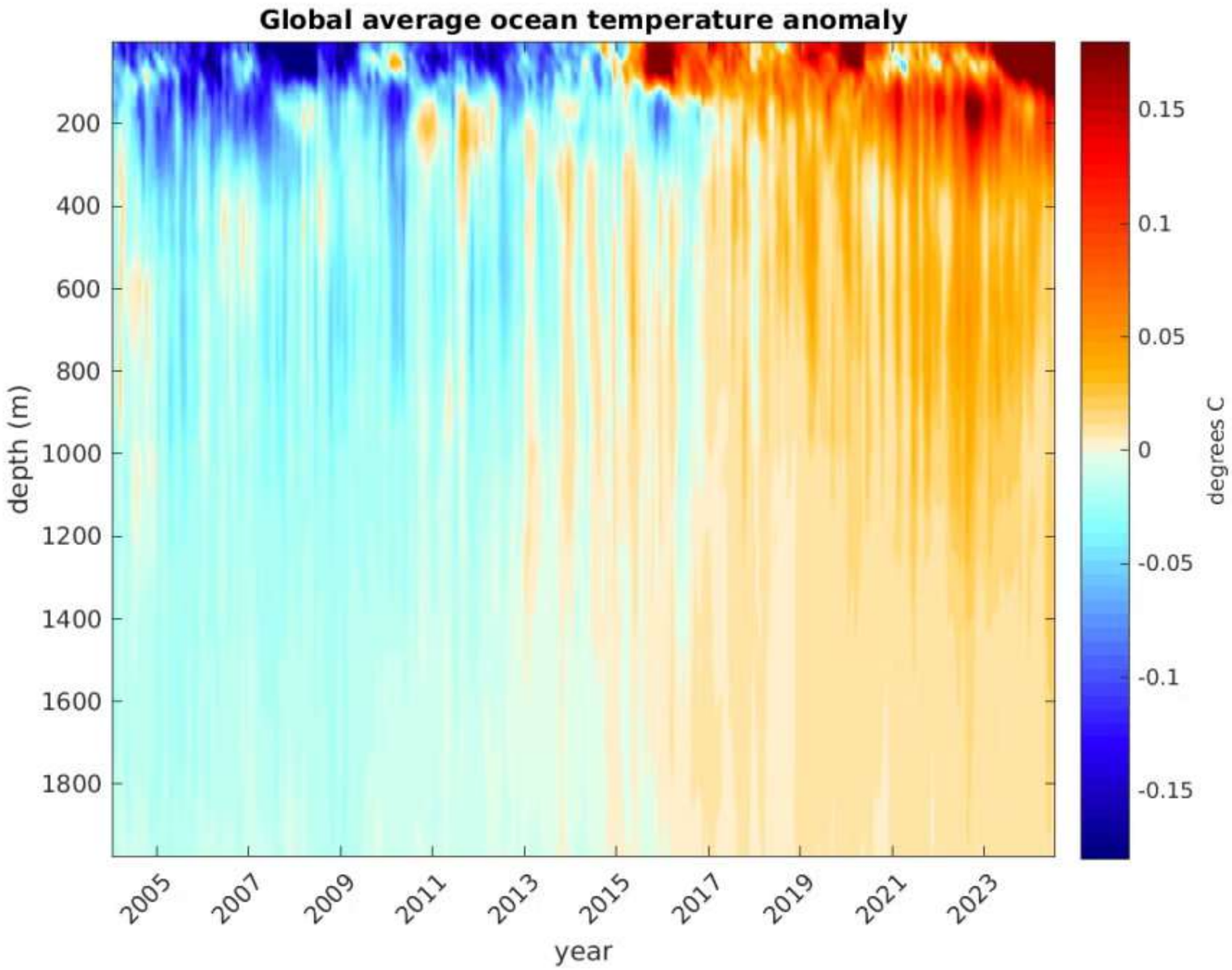
NOAA 5KM Blended Sea Surface Temperature - NIGHT-ONLY 2026-09-25

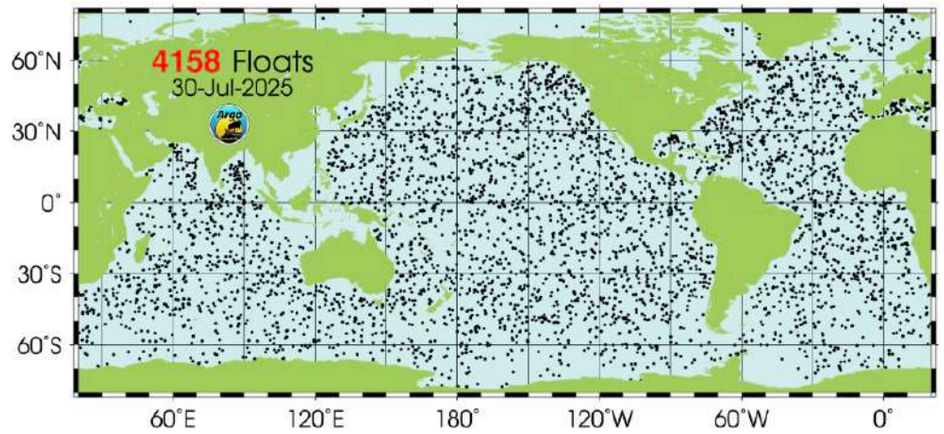


No data
Ice

−2 0 5 10 15 20 25 30 35 40 °C

NOAA





The temperature anomalies (relative to the entire period) of the global ocean averaged over depth.

The upper few hundred meters have signatures on interannual variability, predominantly due to ENSO (El Niño-Southern Oscillation (ENSO)), whereas the deep ocean shows a consistent warming trend illustrating the ocean's uptake of heat.

NOAA

National Centers for Environmental Information
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

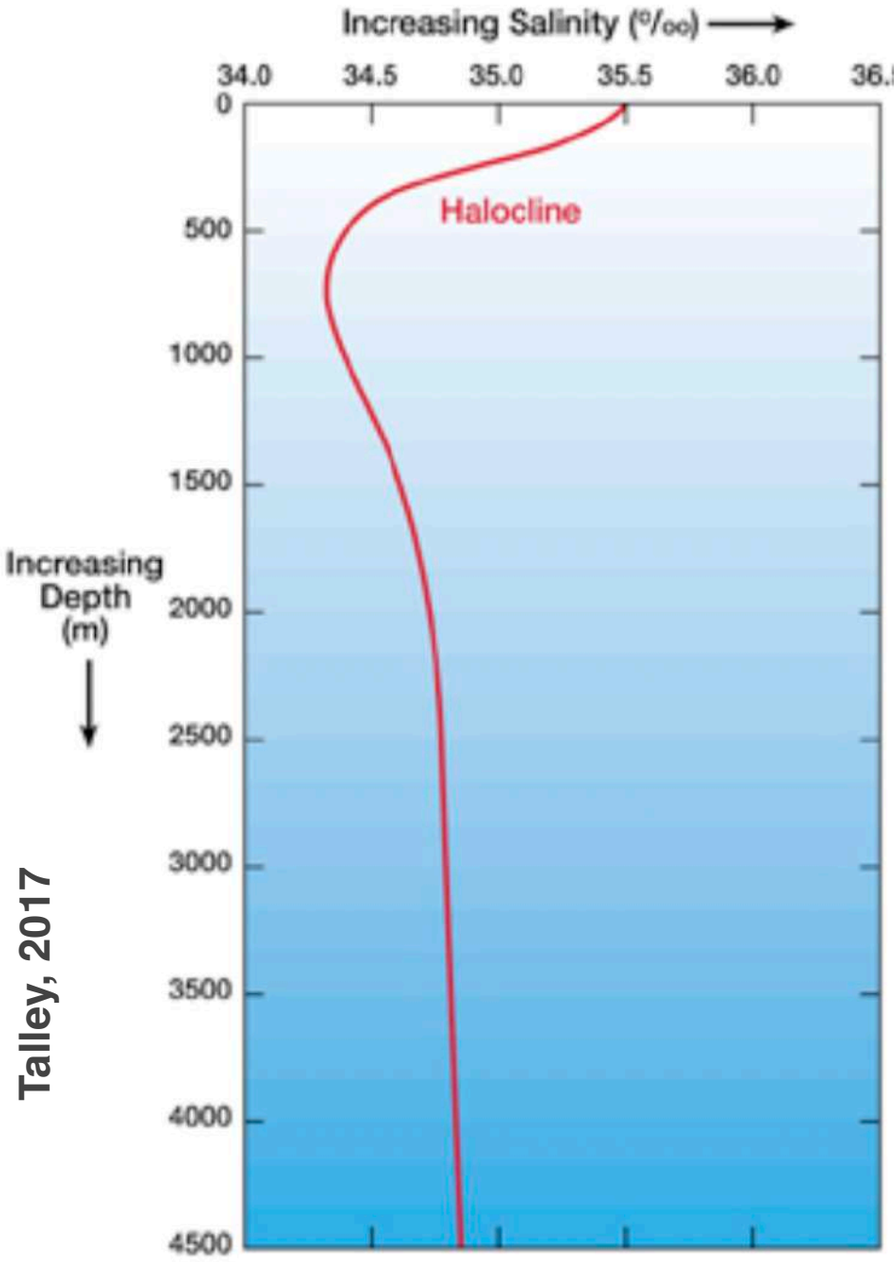
A temperature anomaly is the difference between an observed temperature and a long-term average baseline temperature for a specific place and time.
A **positive anomaly** means the observed temperature was **warmer** than the baseline, while a **negative anomaly** means the observed temperature was **cooler** than the baseline

Salinity

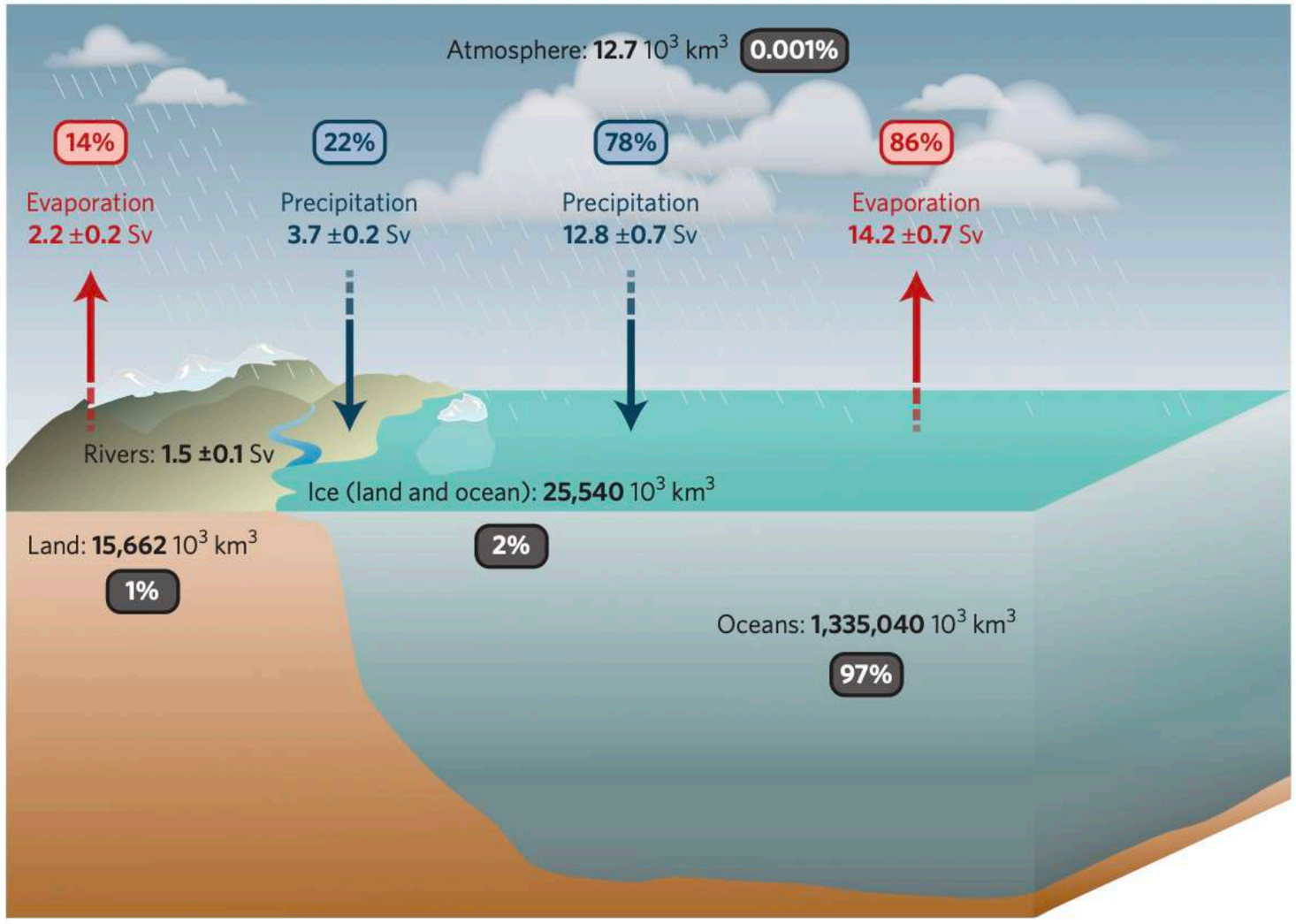
- Number of grams of salts per kilogram of seawater, in parts per thousand or without units
- Geological time-scale dissolution of minerals into ocean
- **Parts per thousand:** how many parts, or grams, of salt there are per thousand parts, or kilogram (1,000 g), of seawater, ‰, ppt

$$\text{Salinity in ppt} = \frac{\text{grams of dissolved salts}}{\text{1,000 grams of seawater}}$$

- Average SW salinity is ~ 35 grams per kilogram (g/kg), or 35 ppt
- Seawater ranges: 33 - 38 ppt
- Freshwater lakes, rivers, and streams contain some dissolved matter —1 ppt or less
- Hydrogen and oxygen atoms in water molecules make up about 96.5 % SW mass
- In SW solution, ~ 3.5 % of the mass is made up of dissolved solutes like Na^+ and Cl^-
- **The constant addition of dissolved substances into the ocean over billions of years has made the ocean salty**



Talley, 2017

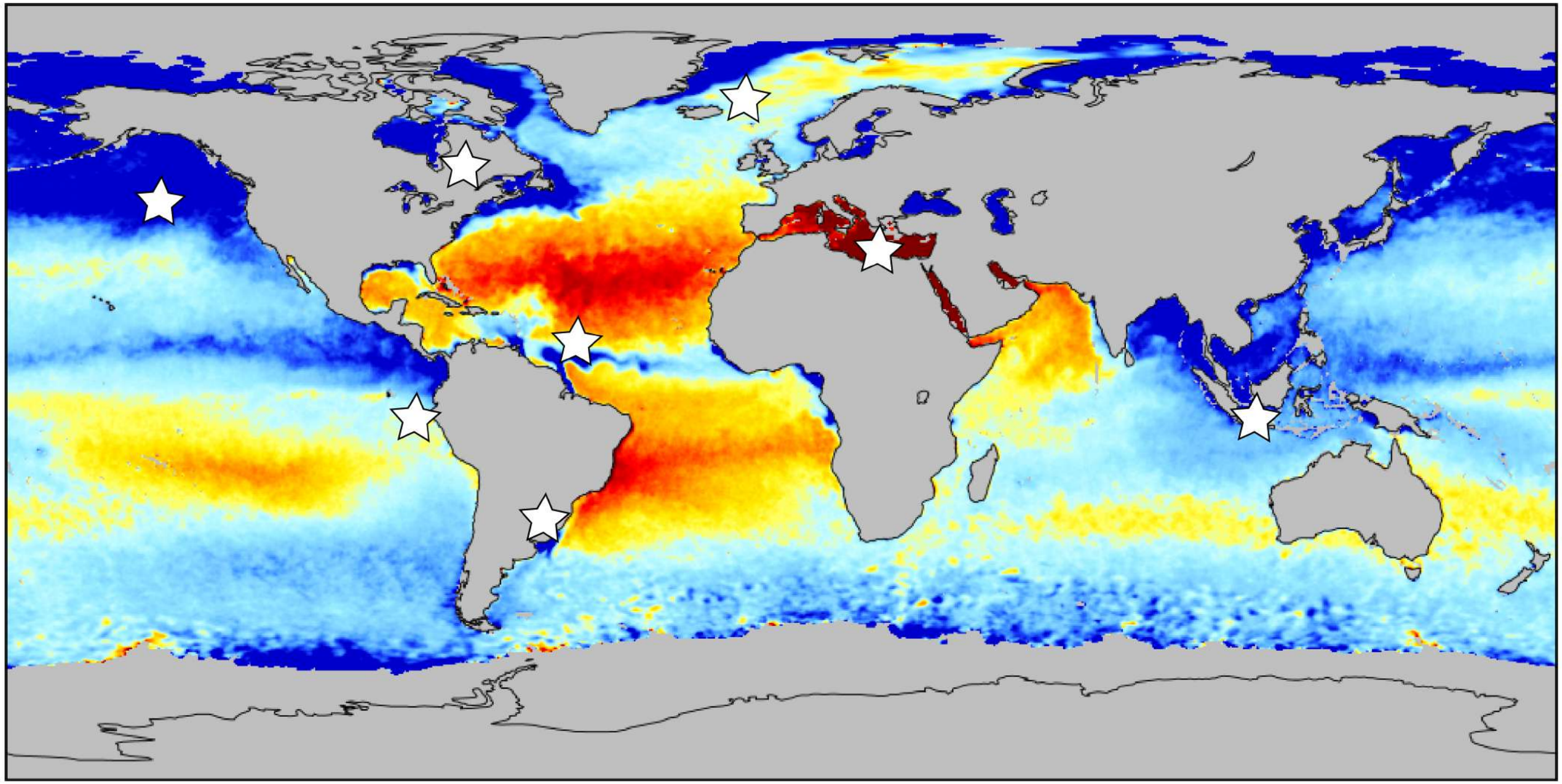


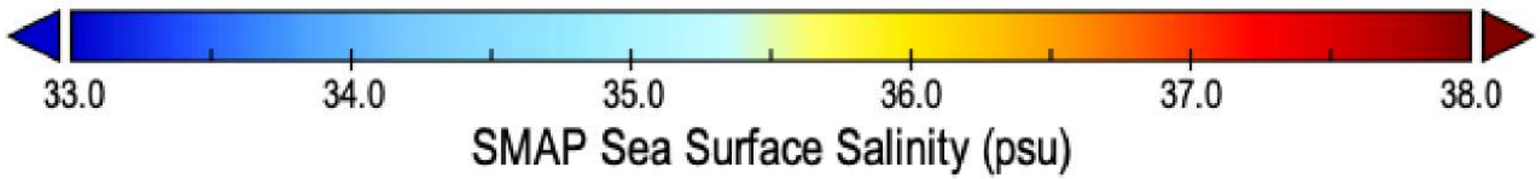
Durack et al., 2016

Figure 1 | The global water cycle — the oceanic perspective. Reservoirs are represented by grey boxes with units 10^3 km^3. Fluxes are represented by arrows and the red and blue boxes with units of Sv (Sverdrups; 10^6 m^3 s^{-1}). Data from refs 2, 31–35.

- Optimal range for life
- Brackish water to brine lakes in ocean
- Na^+ pump for movement and membrane transport of microbes *vs.* H^+
- Microbial adaptations at high and low salt —> osmotic pressure —> pumping out or making cytoplasm more saline
- Human pathogens (0.9%) can't survive at 3.5% salinity

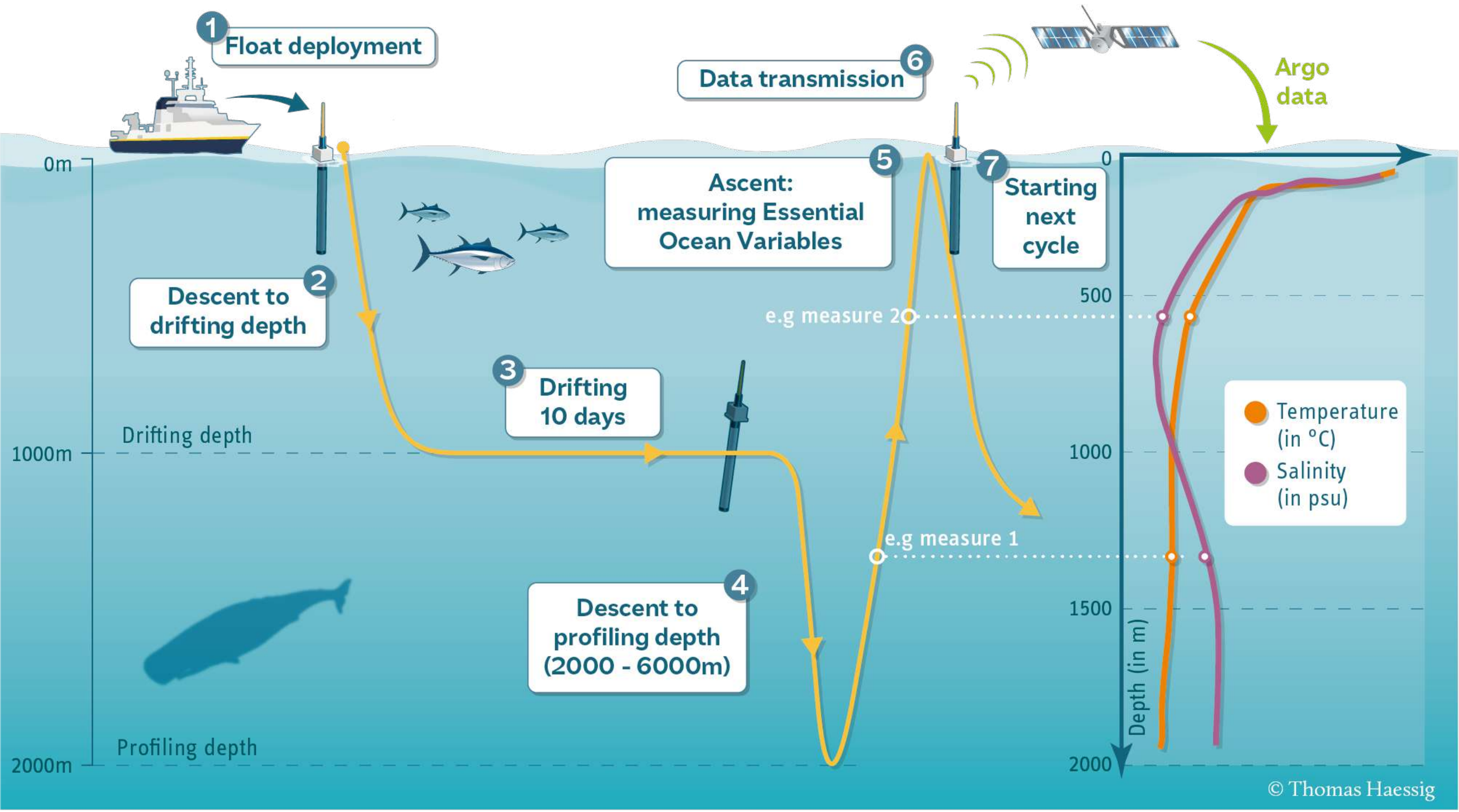
Ocean Surface Salinity





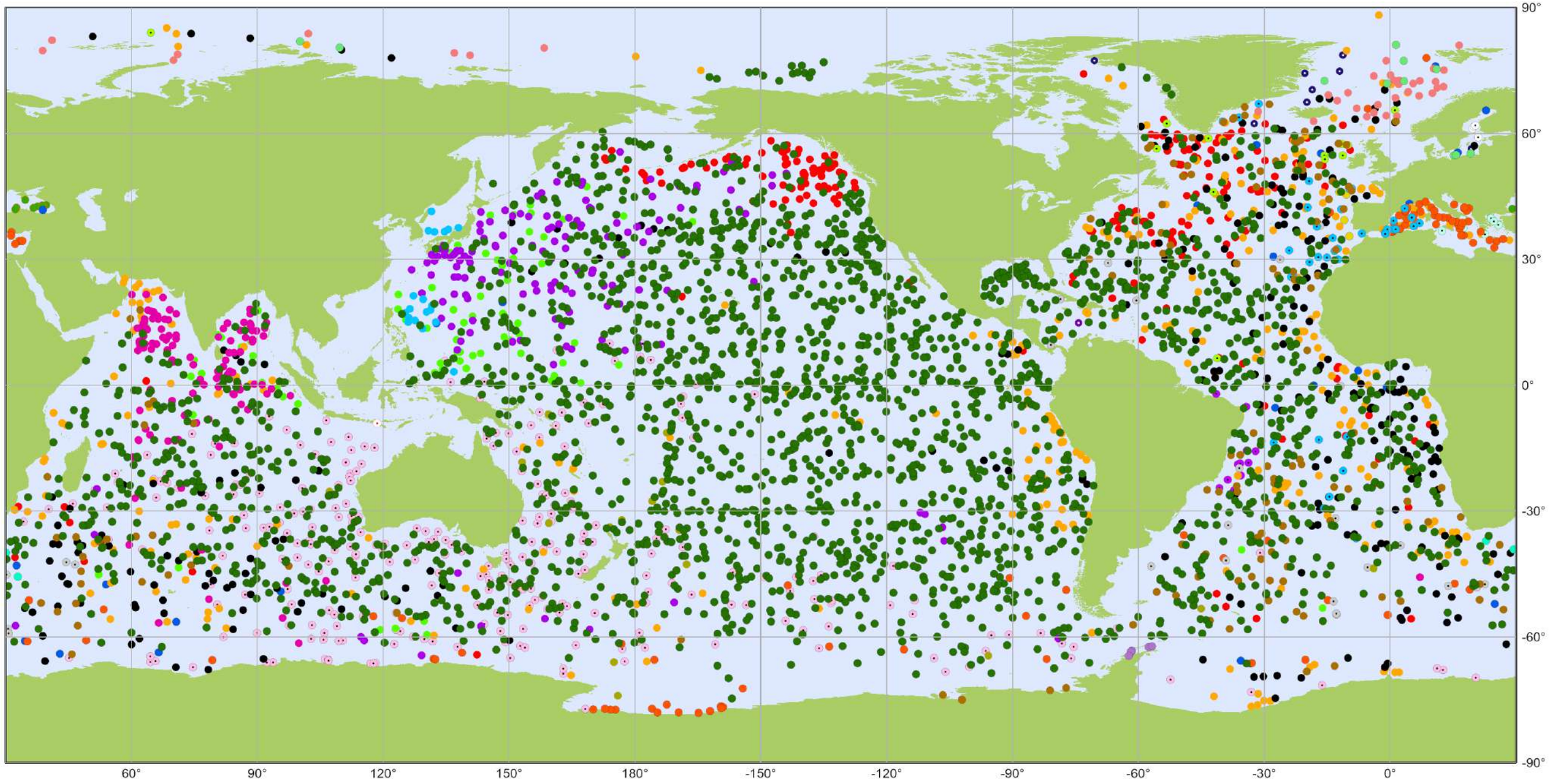
The map shows sea surface salinity during September 2017. It is based on Soil Moisture Active Passive (SMAP) data processed using the Jet Propulsion Laboratory's Combined Active-Passive (JPL CAP) retrieval algorithm.

ARGO: how to measure S and T



https://argo.ucsd.edu/about/

ARGO



Argo

National contributions- 4387 operational floats

August 2026

Latest location of operational floats (data distributed within the last 30 days)

- AUSTRALIA (286)
- BRAZIL (11)
- BULGARIA (10)
- CANADA (204)
- CHINA (77)
- COLOMBIA (1)
- DENMARK (8)
- EUROPE (27)
- FINLAND (4)
- FRANCE (312)
- GERMANY (278)
- GREECE (6)
- INDIA (118)
- INDONESIA (1)
- IRELAND (12)
- ITALY (95)
- JAPAN (146)
- NETHERLANDS (26)
- NEW ZEALAND (16)
- NORWAY (38)
- POLAND (11)
- PORTUGAL (4)
- SOUTH AFRICA (4)
- KOREA, REPUBLIC OF (19)
- SPAIN (37)
- UK (142)
- UKRAINE (6)
- USA (2488)

Generated by ocean-ops.org, 2026-09-04
Projection: Plate Carree (-150.0000)

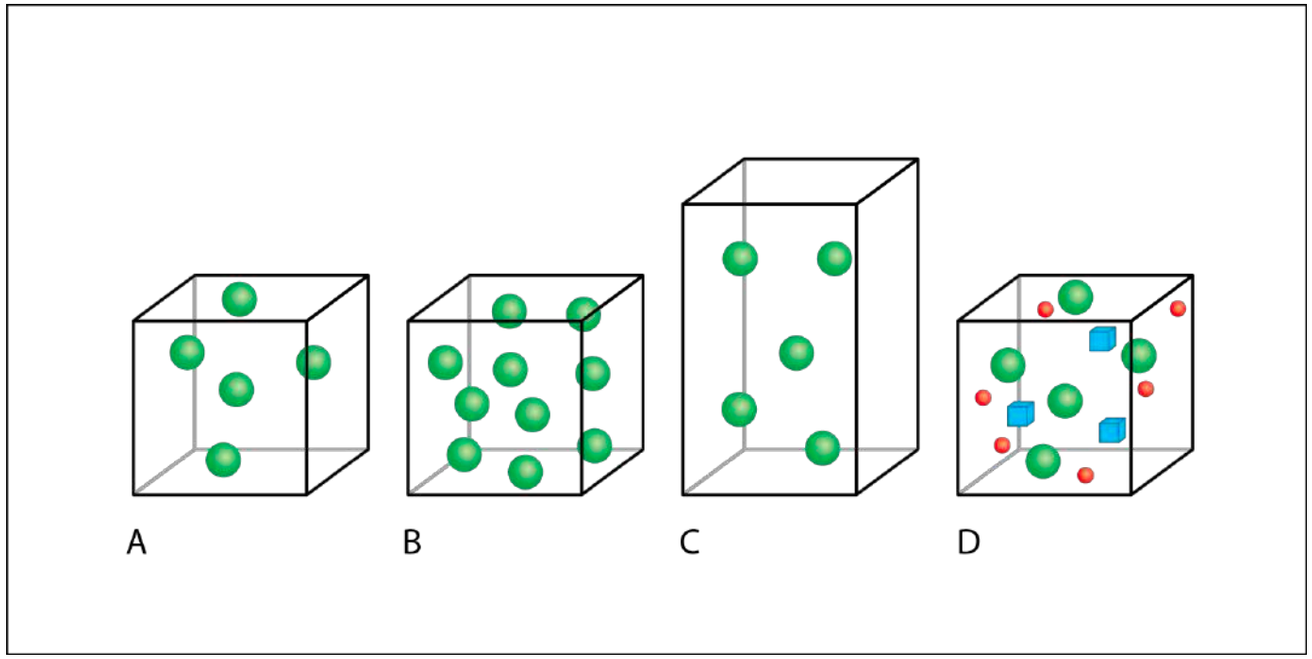
Density

EXPLORING OUR FLUID EARTH
Teaching Science as Inquiry

Density is a measure of how much mass there is in a given **volume** or amount of space

The density of any substance is calculated by dividing the mass of the matter by the volume of the matter

$$\text{density} = \frac{\text{mass}}{\text{volume}}$$



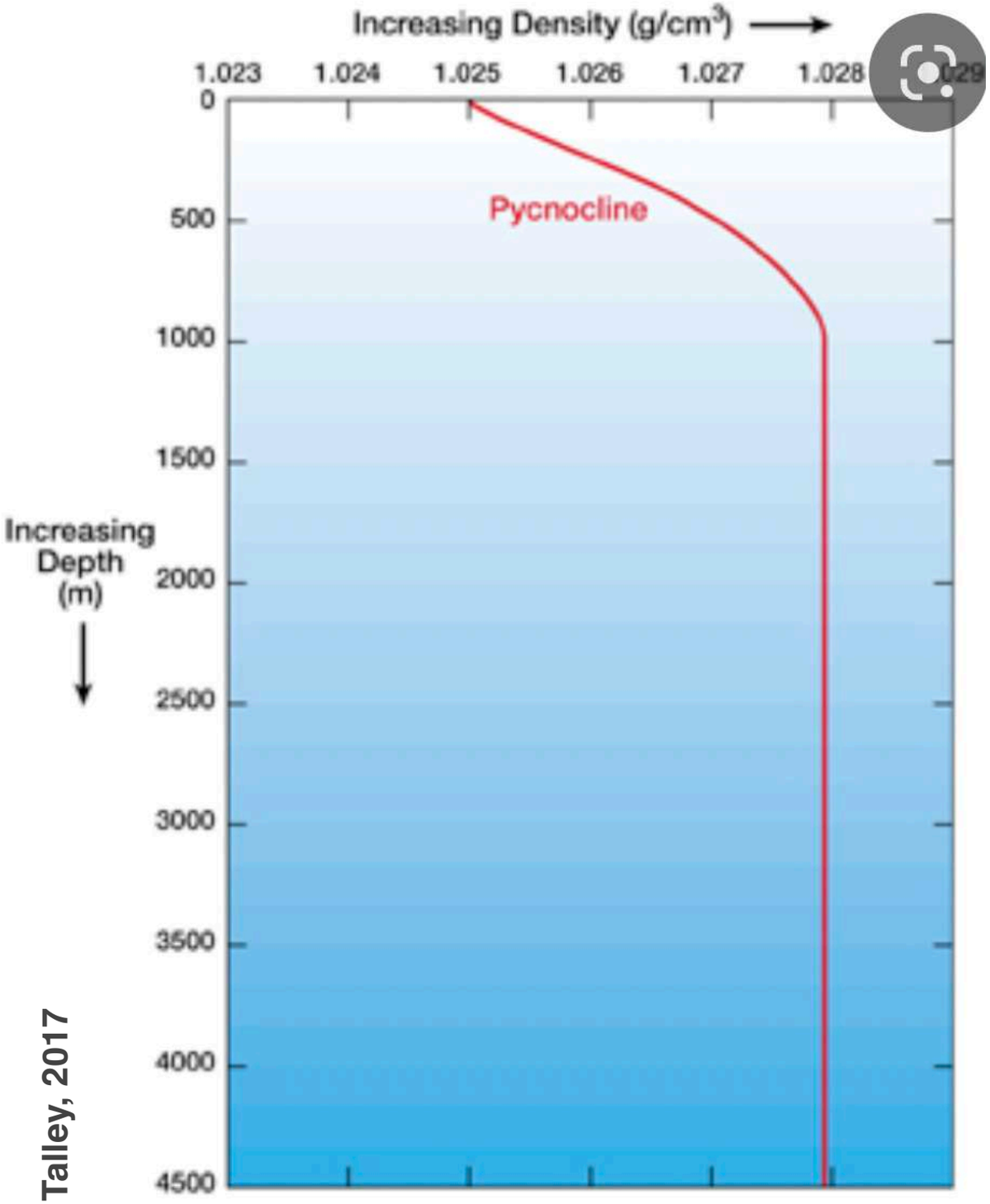
If the amount of matter is increased without changing the volume, —> density increases

If volume increases without an increase in mass, —> density decreases

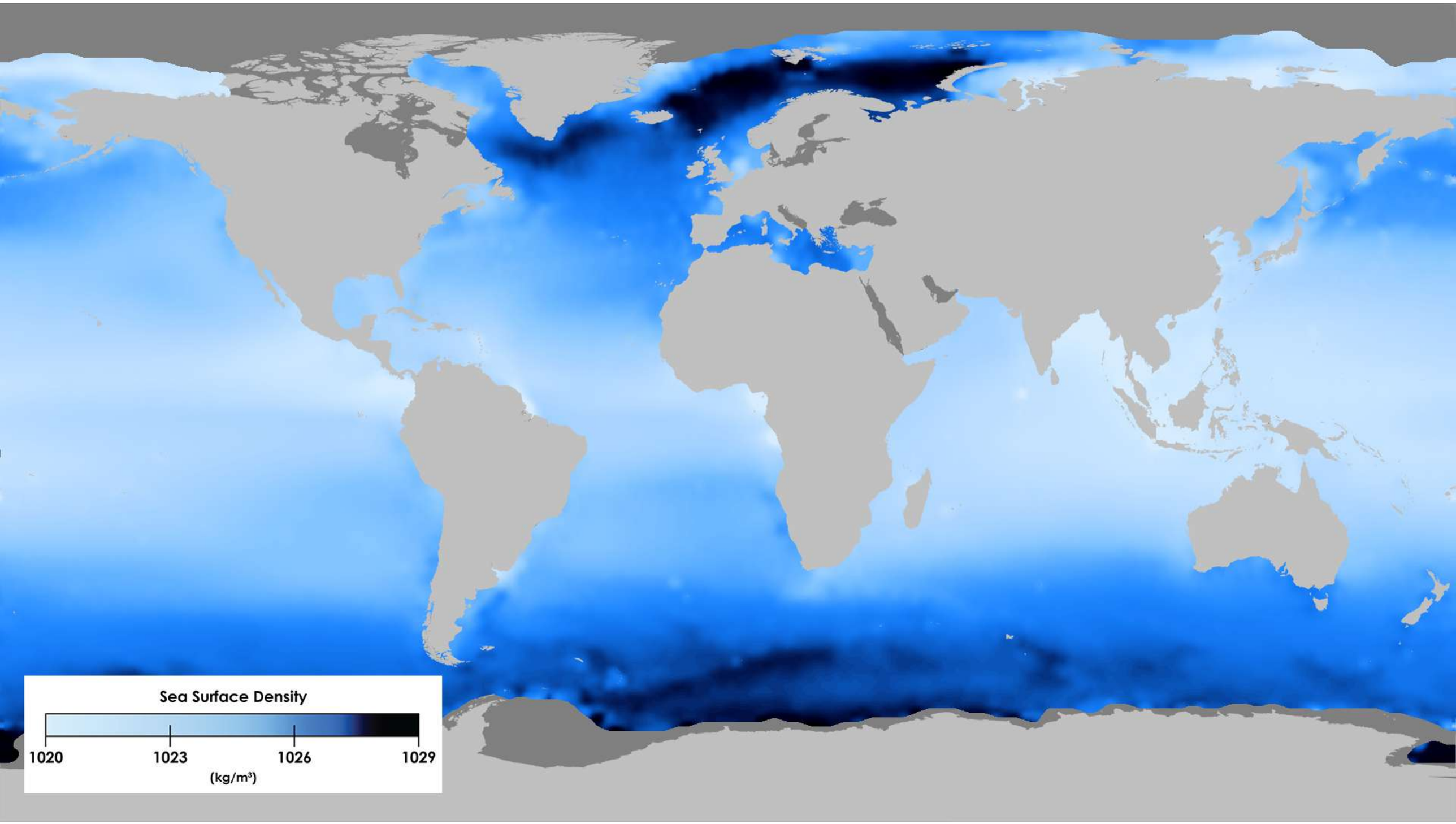
Adding additional matter to the same volume also increases density, even if the matter added is a different type of matter

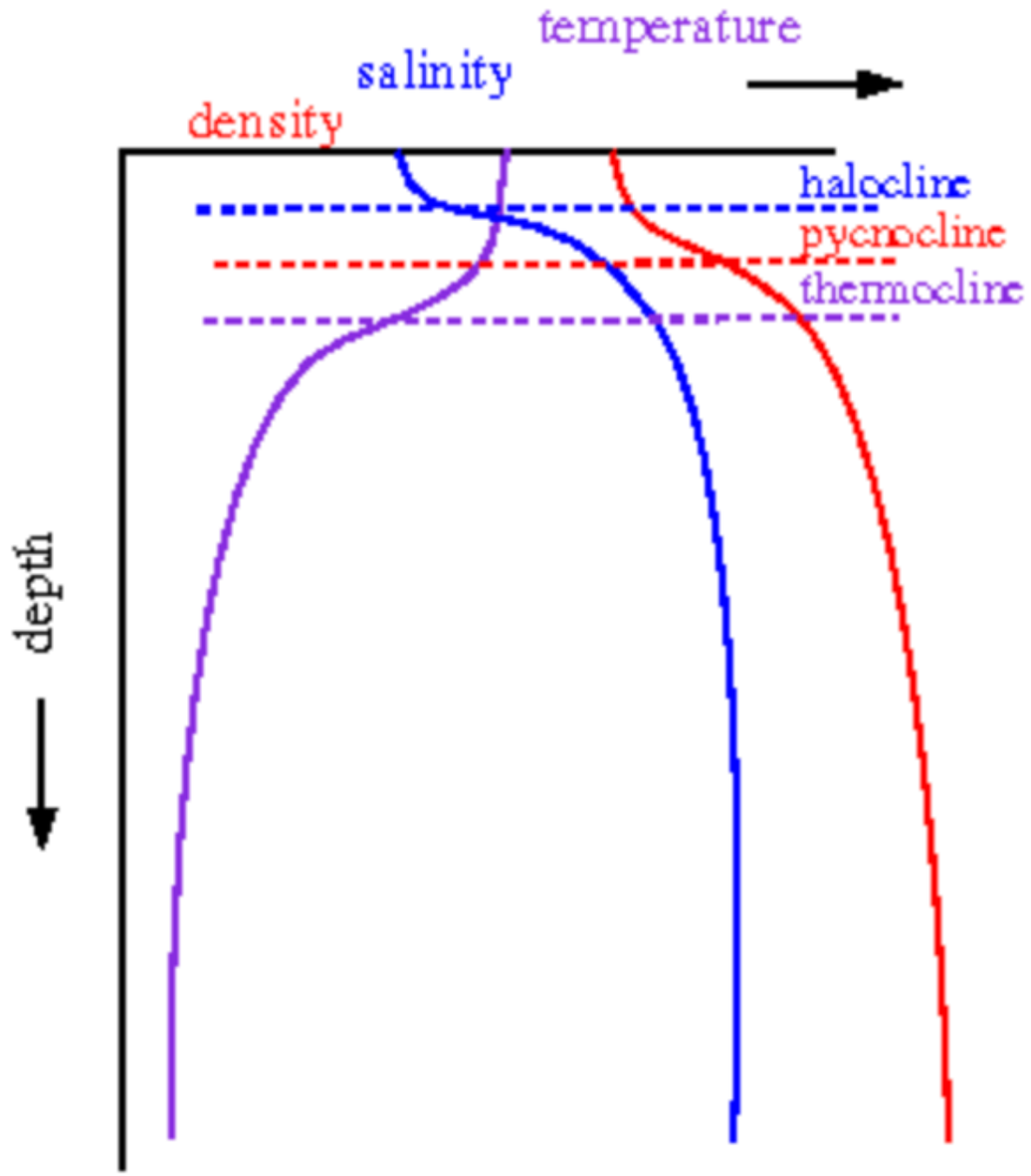
When salt is dissolved in fresh water, the density of the water increases because the mass of the water increases

When the water is heated, it expands, increasing in volume —> density decreases



- Temperature, salinity and pressure influence density
- Fresh water density is 1 g/cm3 at 4°C but the addition of salts and other dissolved substances increases surface SW density between 1.02 - 1.03 g/cm^3
- SW density can be increased by reducing its temperature, increasing its salinity, or increasing the pressure
- Density of pure bacterial cultures ranged from 1.035 to 1.093 g/cm^3 —> *ergo* bacteria will sink
- Strategy to change buoyancy due to gas vacuoles —> not to sink out
- Cell buoyant density is controlled by the osmoregulatory system not by growth rate


Sea Surface Density
1020
1023
1026
1029
(kg/m³)



Thermocline
Halocline
Pycnocline

- The layer in the ocean in which a rapid change in **temperature** with height occurs is the **thermocline**.

- The region in which a rapid change in **salinity** with height occurs is called the **halocline**.

- Changes in temperature and salinity result in a sharp change in **density** with height at the **pycnocline**.

https://atoc.colorado.edu/~fasullo/1060/lectures/lec13d.html

Variable	Ocean Range	Ocean Mean	Required Accuracy
Temperature	-2°C to 40°C	3.5°C	±0.002°C
Absolute Salinity	0 g/kg to 42 g/kg	34.9 g/kg	±0.002 g/kg
Pressure	0 dbar to 11000 dbar	1850 dbar	< ±3 dbar
In-situ Density	1000 to 1060 kg/m^3	1036 kg/m^3	±0.004 kg/m^3

Table 1. Ocean state variables, their typical ranges and mean values in the ocean, and the accuracy to which they are measured (or estimated) in the deep ocean. Pressures in the ocean are usually measured in dbar (decibars), with values offset to read zero at the surface. Pressure values expressed in this way are numerically similar (within 2%) to depth in meters below the surface. That is, the pressure at a depth of 1000 meters is about 1000 dbars.

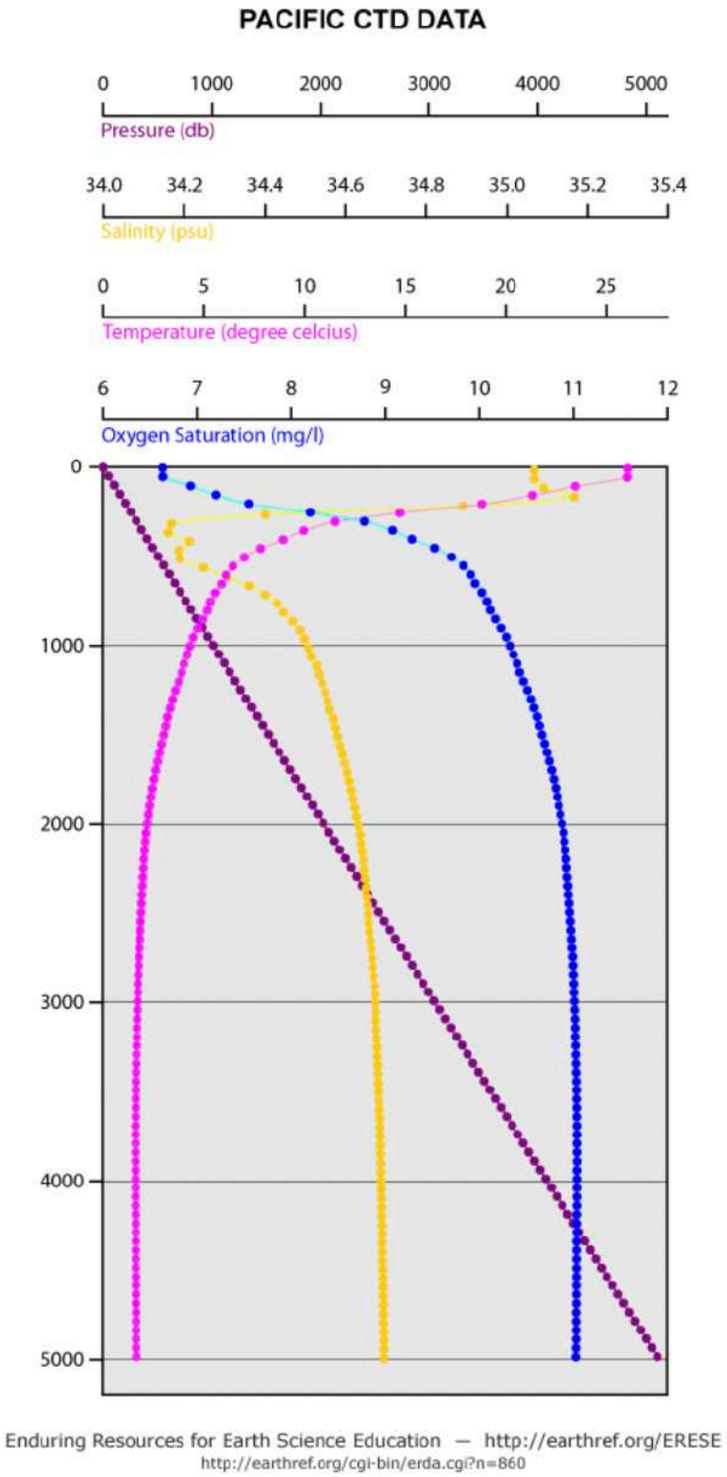
Accuracy - ability to measure compared with an absolute standard.
Precision - ability to measure consistently within a given data set (variance in the measurement itself due to instrument noise).
Generally the precision of oceanographic measurements is better than the accuracy

https://www.nature.com/scitable/knowledge/library/key-physical-variables-in-the-ocean-temperature-102805293/

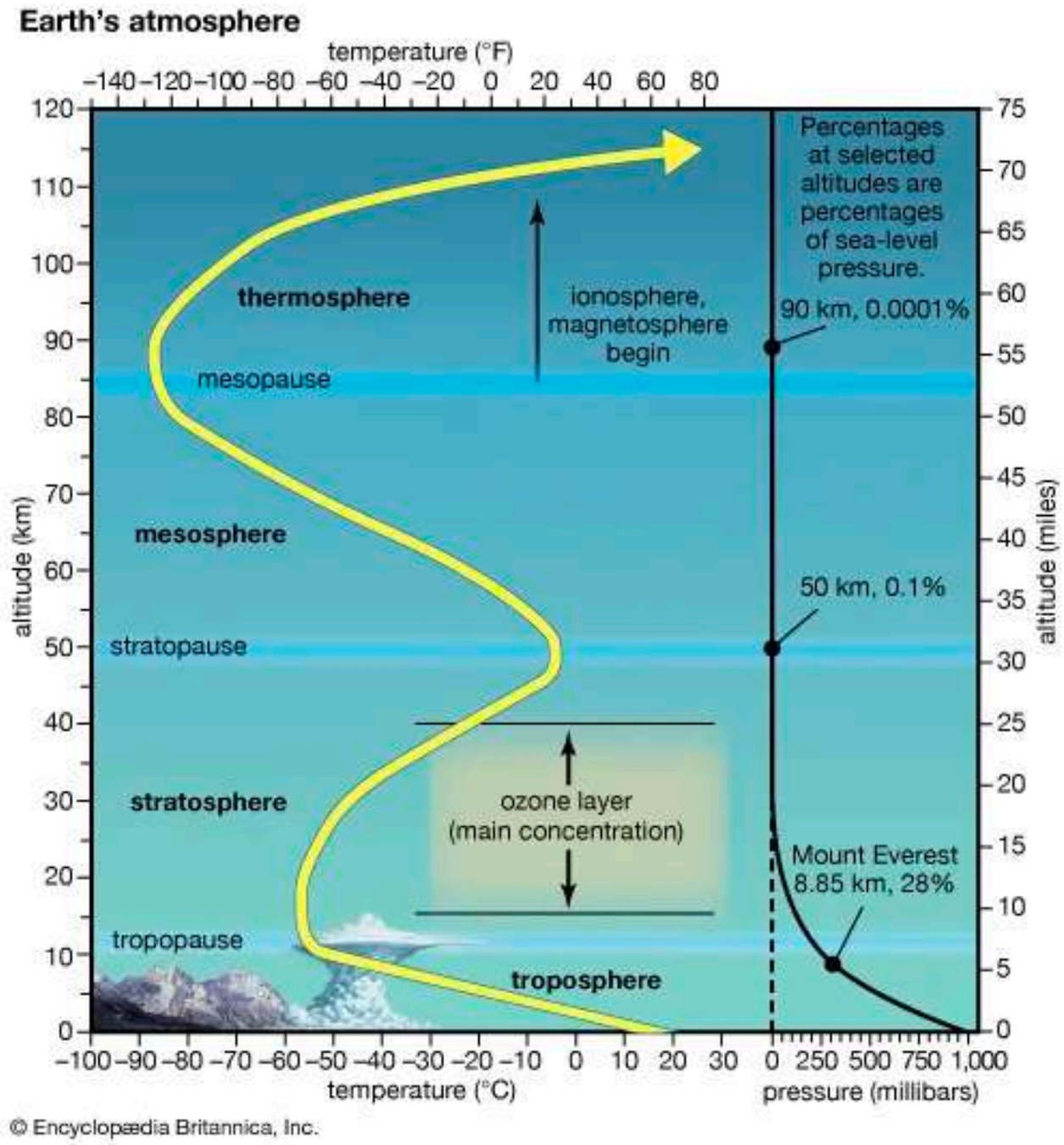
Pressure

Pressure (P) **is the force applied perpendicular to the surface of an object per unit area over which that force is distributed**

- Ocean average pressure is 38 MPa (1 MPa = 10 bar)
- Hydrostatic pressure originates from the weight of the water column and corresponds to 10 MPa/km
- In ocean, water presses against all sides of an object or organism —> feel equal pressure from all directions
- Atmospheric pressure is usually measured in bars. 1 bar = 10^6 dynes/cm^2 = 10^5 Pascal
- Ocean pressure is usually measured in decibars. 1 dbar = 10^-1 bar = 10^5 dyne/cm^2 = 10^4 Pascal.

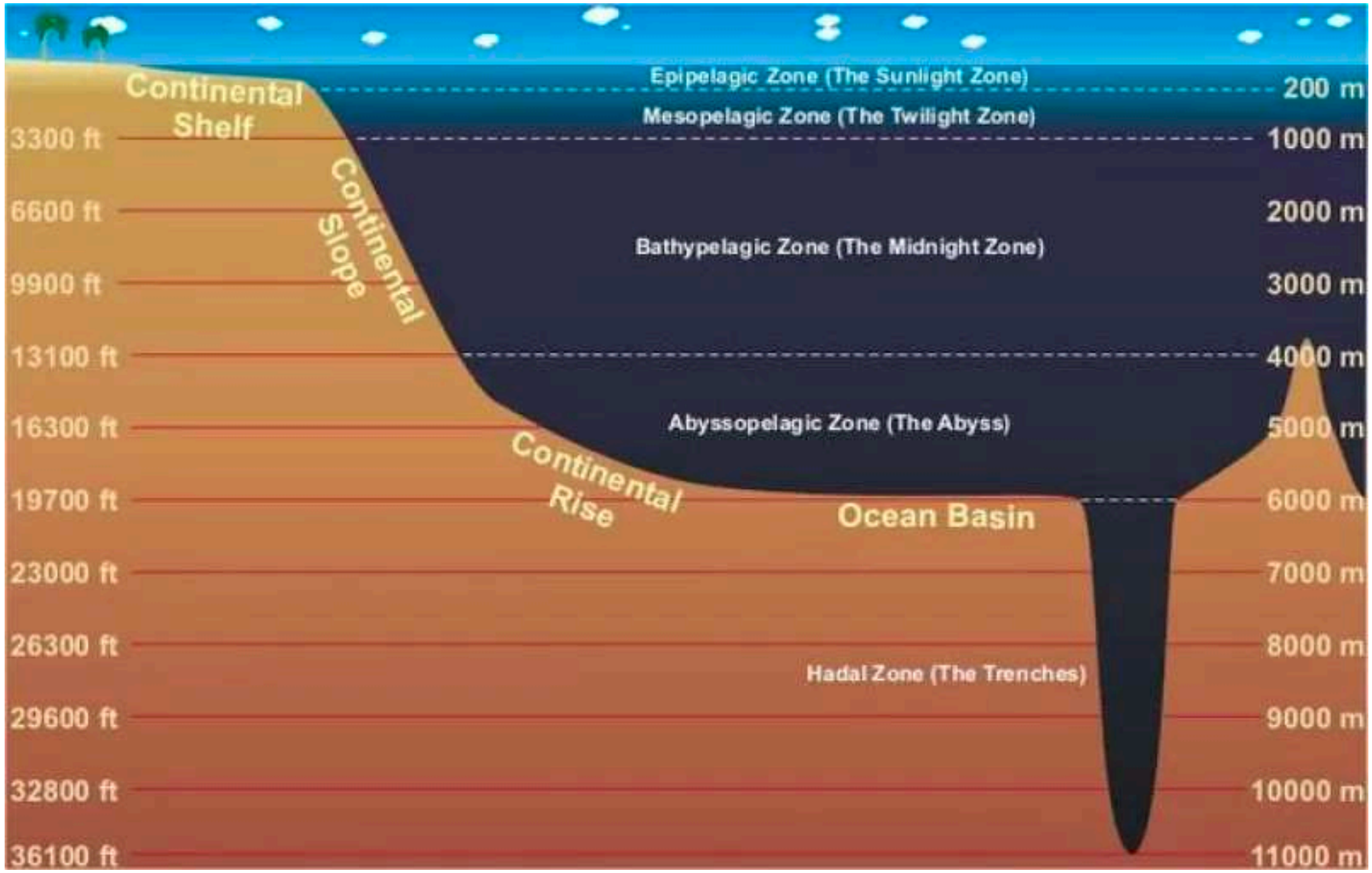


- Near the ocean's surface, that pressure is the same as on land
- This amount of pressure is called an atmosphere
- When the diver reaches 10 meters (33 feet), the pressure is double what it was at the surface



© Encyclopædia Britannica, Inc.

- For every 10 meters of water, hydrostatic pressure increases by one atmosphere
- At the average ocean depth (3,800 meters), pressure on the sea floor is 380 times > than at the surface
- In the deepest trenches, it's 1,100 times greater!
- Seawater is about 800 times more dense than air



0 m, 1 atm

100 atm

600 atm

1000 atm

NOAA

Megapascal (MPa) = 10 bar ≅ 9.9 atmospheres

Living under Pressure

- **Pressures affect the interatomic molecular bindings (such as Van der Waals, hydrogen bonding and hydrophobic interactions) altering conformations and structures of biomolecules and therefore, their physical properties (solubility, melting point, density), equilibrium states and processes' rate**

- Electrostatic and hydrophobic interactions are specifically affected by pressure

- Pressures > 2 GPa impact non-covalent interactions

- Due to pressure, the biological system is favouring the acquisition of more compact structural forms

- Besides the structural alterations in biomolecules, pressure also disturbs the equilibrium of (bio)chemical reactions—> changing 3D

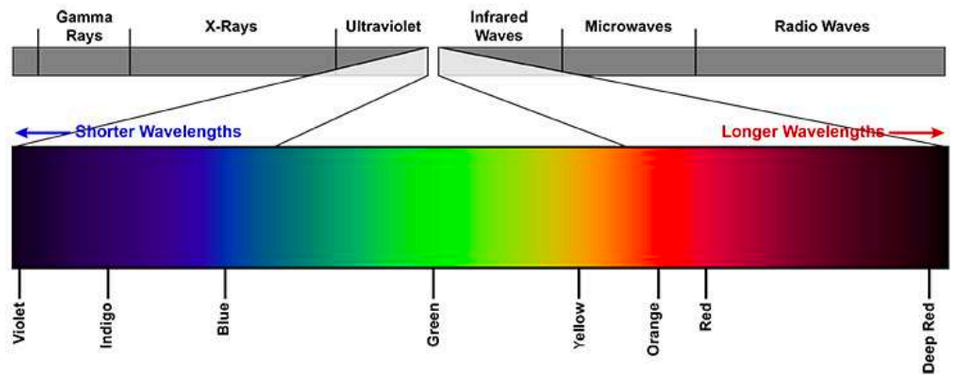
- With increasing pressure, lipid bilayers lose fluidity and became rapidly impermeable to water and other molecules, while protein–lipid interactions essential to the optimal function of the membrane are weakened

- **Adaptive strategies to survive at high pressure and low temperature**

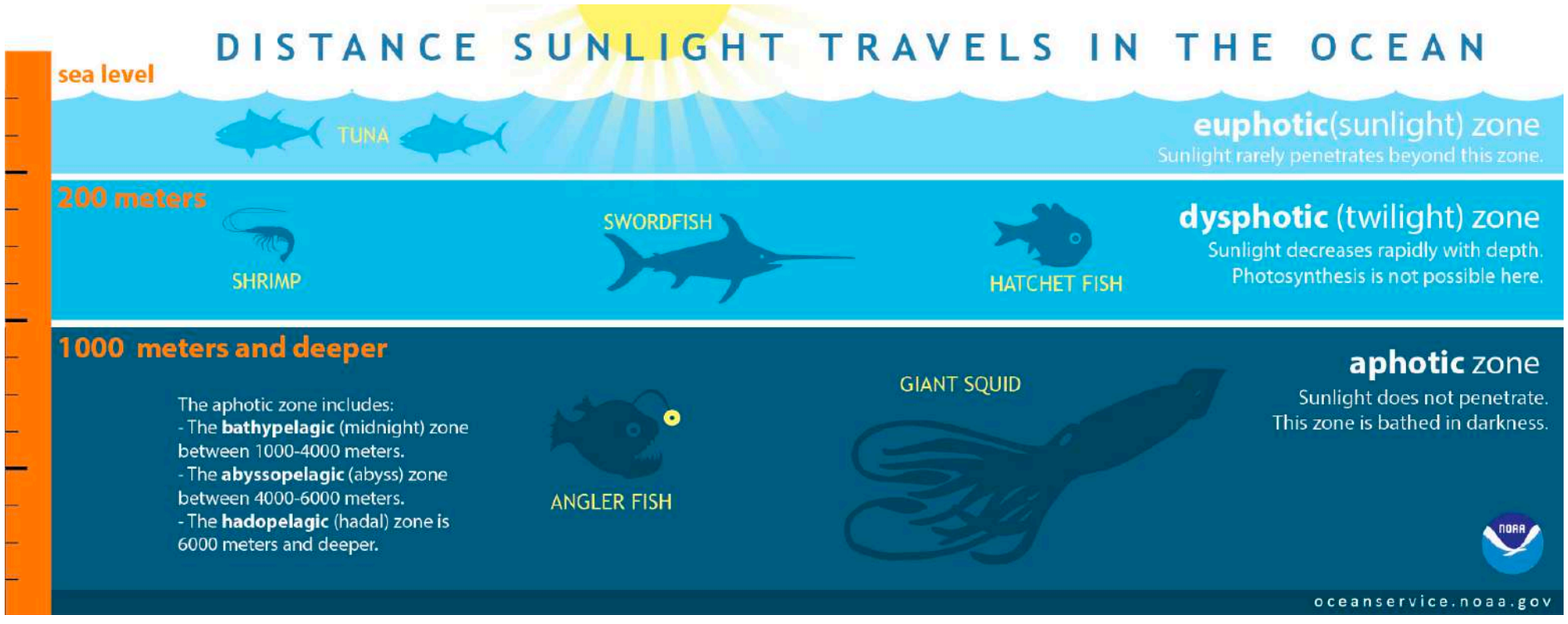
Table 1. Pressure sensitive processes detected in *E. coli* (Oger and Jebbar, 2010).

Process	Pressure abolishing process (MPa)	References
Motility	10	Meganathan and Marquis (1973)
Substrate transport	26	Landau (1967)
Cell division	20–50	ZoBell (1970), Zobell and Cobet, 1962, Zobell and Cobet, 1964
Growth	50	Yayanos and Pollard (1969)
DNA replication	50	Yayanos and Pollard (1969)
Translation	60	Gross et al., 2005, Yayanos and Pollard, 1969
Transcription	77	Yayanos and Pollard (1969)
Viability	200	Pagán and Mackey (2000)

Solar radiations Light/Dark



- Electromagnetic radiation
- Present since the beginning of Earth, shorter day
- Changes in diel cycle length caused by rotation Earth over millennia
- Changes in light period in Antarctica and Arctic Ocean



- Visible sunlight makes up about 40 % of the total energy Earth receives from the sun
- The rest of the energy Earth receives from the sun is not visible
- About 50 % is infrared (IR) energy, 9% is ultraviolet (UV) energy, and 1% is X-rays or microwaves

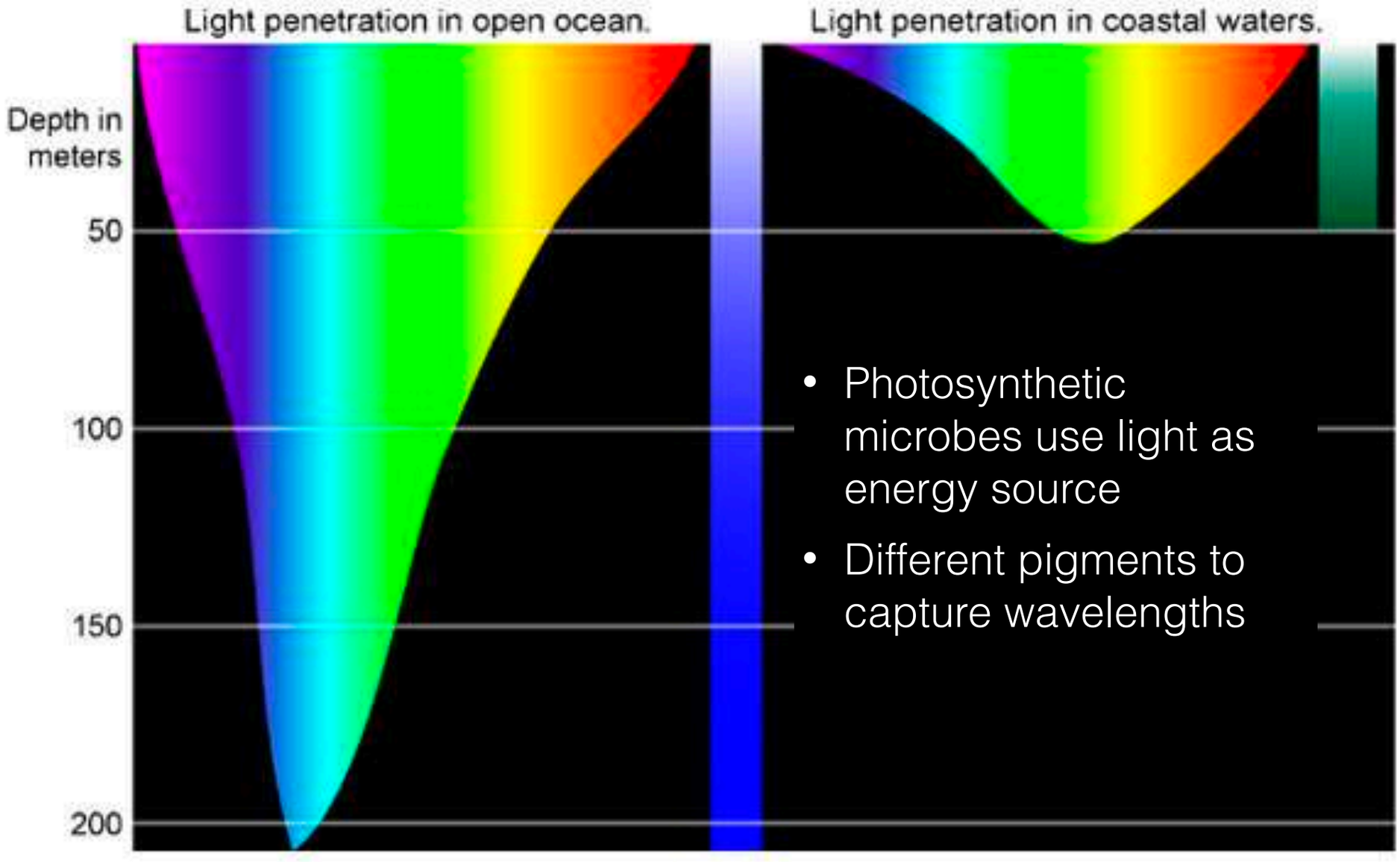
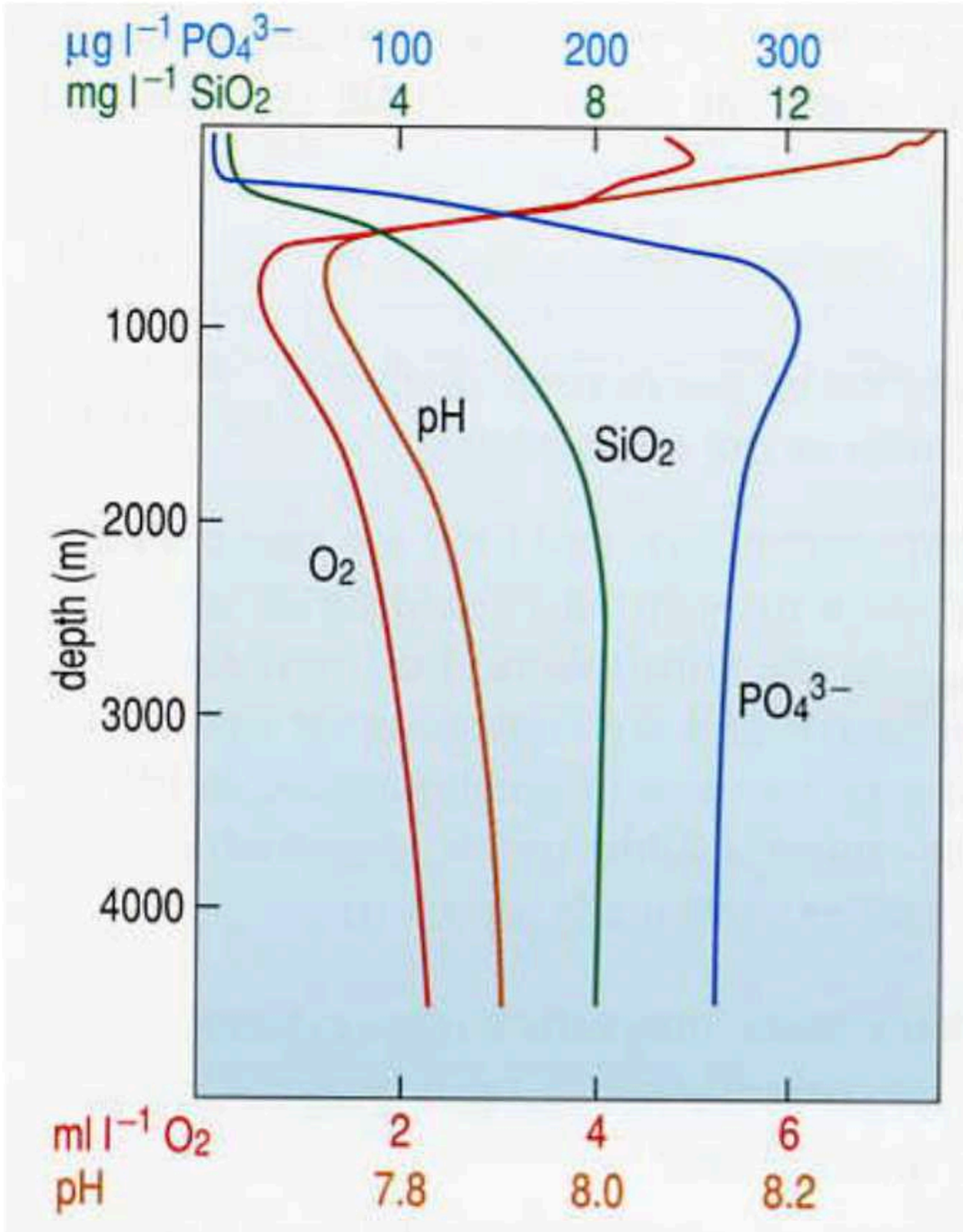


Image courtesy of Kyle Carothers, NOAA Ocean Exploration

- Depth at which different colors of light penetrate SW
- Water absorbs warm colors like reds and oranges (known as long wavelength light) and scatters the cooler colors (known as short wavelength light)

Oxygen

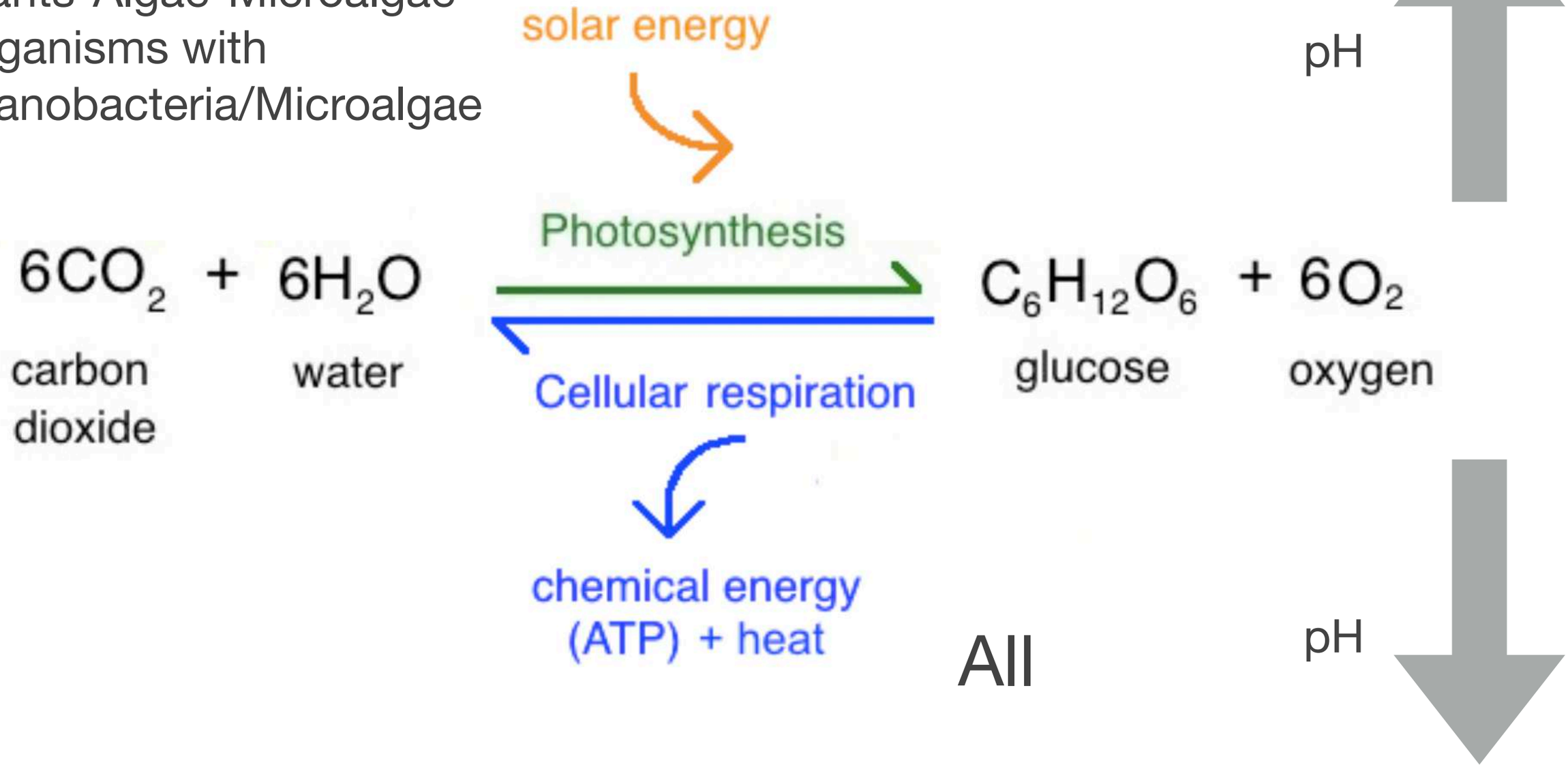
- Oxygen derives from biological activity —> by product of photosynthesis
- Every organism uses O_2 for aerobic respiration
- Primary producers (autotrophs) during the night behave like heterotrophs
- **Gases follows the Boyle laws for solubility: lower temperature more solubile**
- *Oxygen is used up by microbes to "respire"/ degrade organic matter —> remineralization of nutrients*
- **Surface water are rich in O_2 due to equilibrium with atmosphere and photosynthesis**
- Below the O_2 minimum, O_2 content begins to increase again with depth —> related to water circulation in the ocean



Talley, 2017

O_2-LIFE-CO_2

Cyanobacteria
Plants-Algae-Microalgae
Organisms with
cyanobacteria/Microalgae



pH

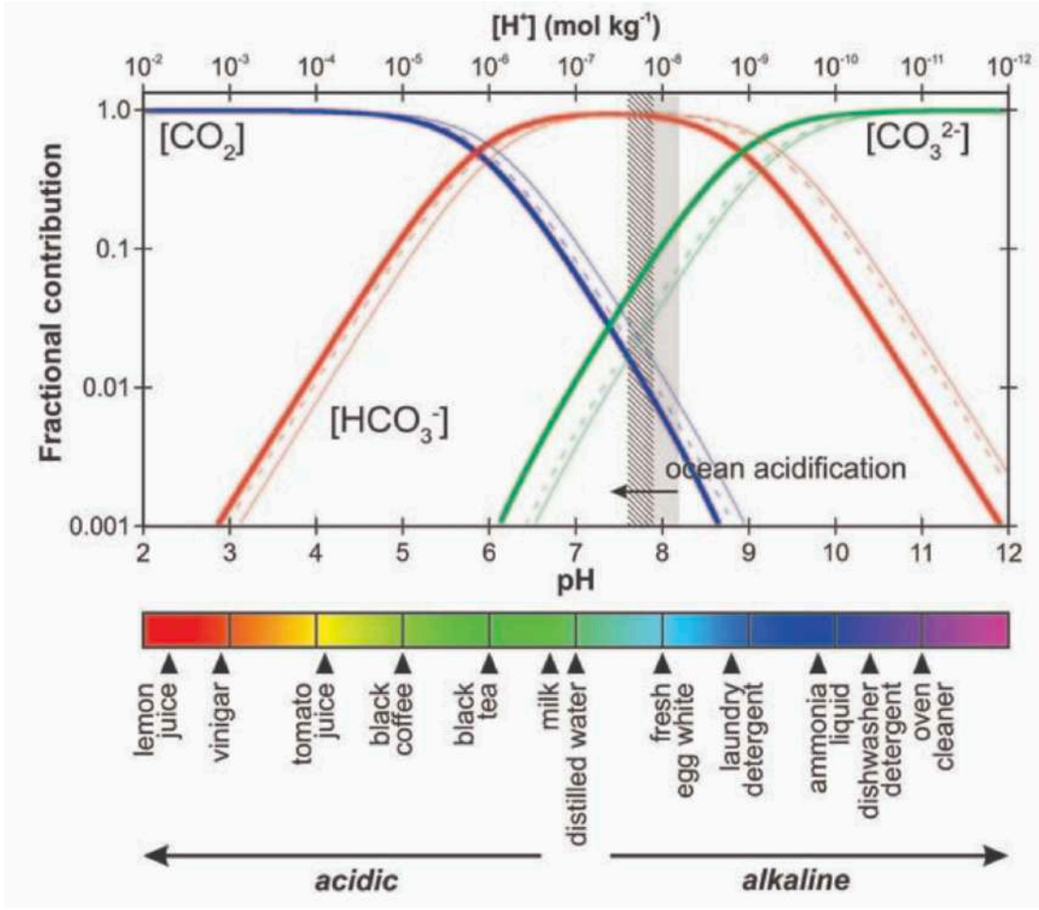
All

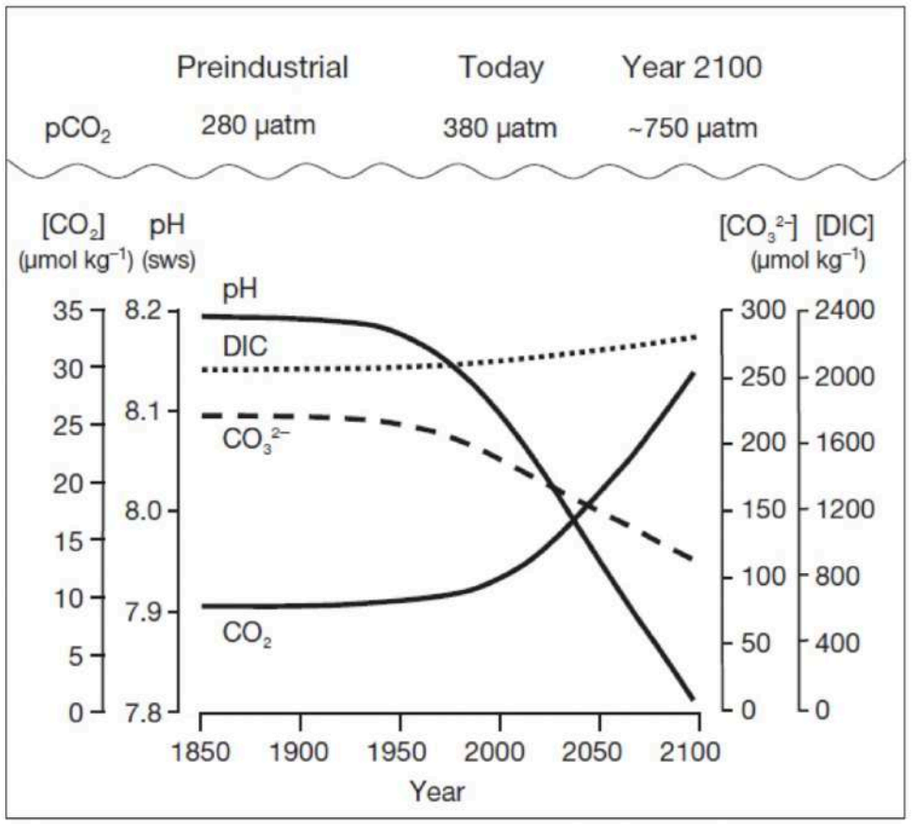
pH

pH

- pH is defined as the negative log of the hydrogen ion concentration
- pH range extends from zero to 14; 7 is neutral
- **Oceans take up CO_2 from the atmosphere and are responsible for absorbing around a third of the CO_2 emitted by fossil fuel burning, deforestation, and cement production since the industrial revolution (Sabine et al. 2004)**
- **Ocean acidification describes the lowering of seawater pH and carbonate saturation that result from increasing atmospheric CO_2 concentrations**

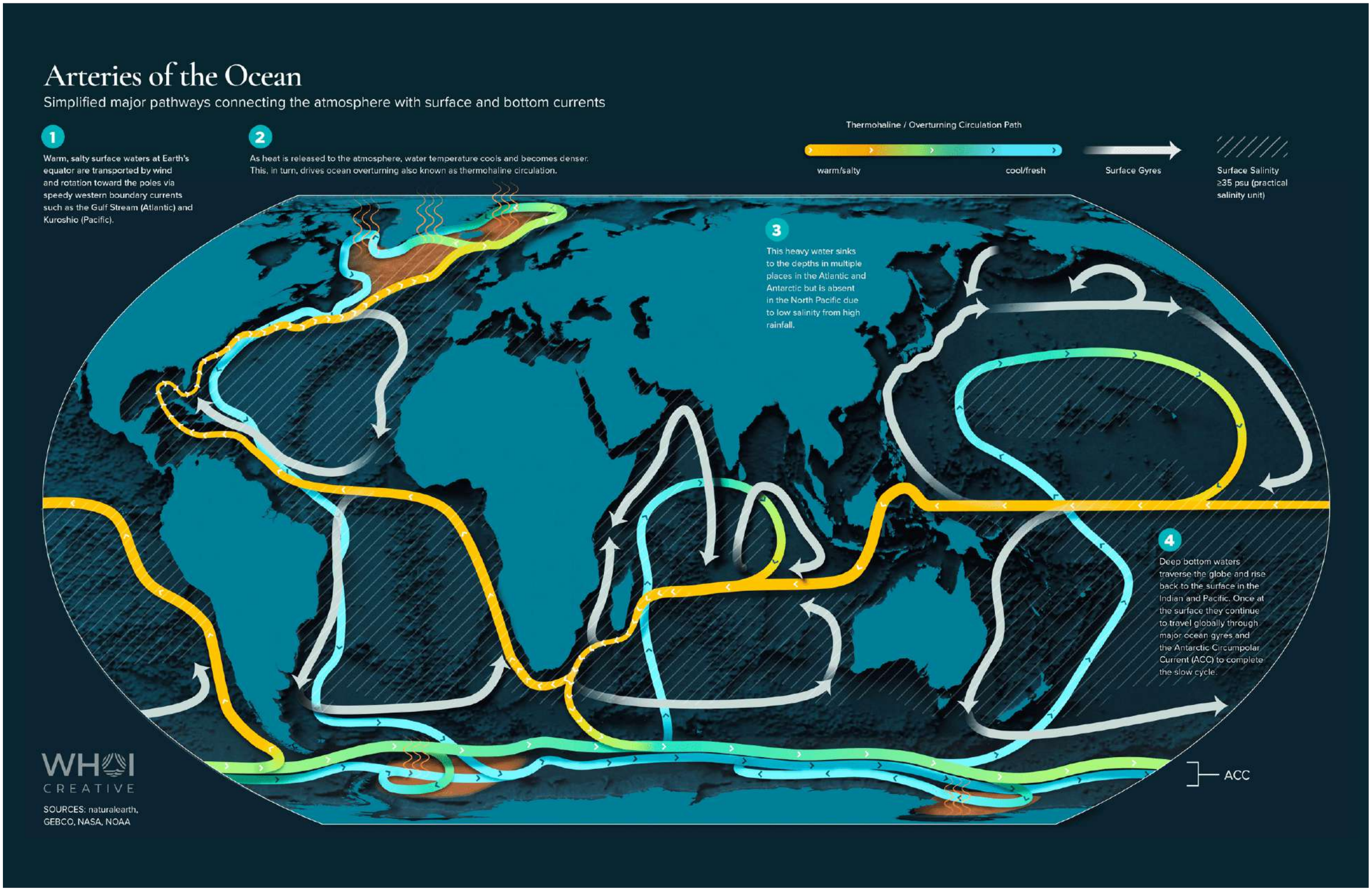
CO_2 (g) —> CO_2 (aq)
CO_2 (aq) + H_2O <—> HCO_3^-(aq) + H^+
HCO_3^-(aq) <—> CO_3^{2-} + H^+





Ocean circulation

https://salinity.oceansciences.org/learn-more.htm?id=92

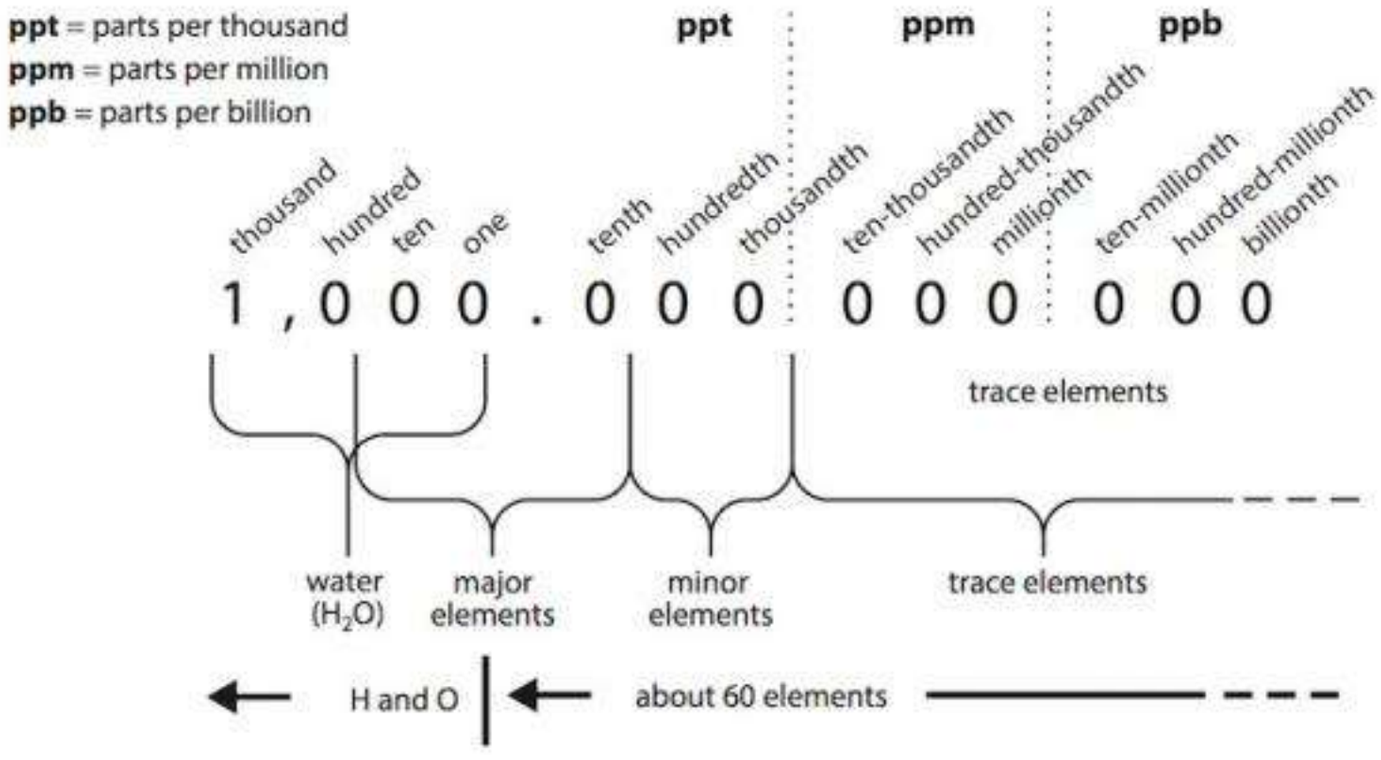


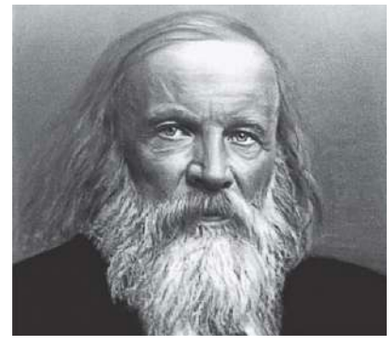
Elements

Other common units of concentration in aquatic science are parts per million (ppm), the number of grams of an element dissolved in 1,000,000 g of seawater and parts per billion (ppb), the number of grams of an element dissolved in 1,000,000,000 g of seawater

Elements with concentrations measured in ppm or ppb are called trace elements. For example, if 40 g of a trace element were found in 1,000,000 g of water, the trace element's concentration would be 40 ppm

$$\frac{\text{Mass pollutant in lake sample}}{\text{Total mass of lake mixture sample}} = \frac{40\text{ g}}{1000000\text{ g}} = 0.000040 = 40\text{ ppm}$$





ОПЫТЪ СИСТЕМЫ ЭЛЕМЕНТОВЪ.

ОСНОВАННОЙ НА ИХЪ АТОМНОМЪ ВѢСѢ И ХИМИЧЕСКОМЪ СХОДСТВѢ.

			Ti = 50	Zr = 90	? = 180.
			V = 51	Nb = 94	Ta = 182.
			Cr = 52	Mo = 96	W = 186.
			Mn = 55	Rh = 104,4	Pt = 197,1.
			Fe = 56	Ru = 104,4	Ir = 198.
			Ni = Co = 59	Pl = 106,6	Os = 199.
H = 1			Cu = 63,4	Ag = 108	Hg = 200.
	Be = 9,4	Mg = 24	Zn = 65,2	Cd = 112	
	B = 11	Al = 27,4	? = 68	Ur = 116	Au = 197?
	C = 12	Si = 28	? = 70	Sn = 118	
	N = 14	P = 31	As = 75	Sb = 122	Bi = 210?
	O = 16	S = 32	Se = 79,4	Te = 128?	
	F = 19	Cl = 35,6	Br = 80	I = 127	
Li = 7	Na = 23	K = 39	Rb = 85,4	Cs = 133	Tl = 204.
		Ca = 40	Sr = 87,6	Ba = 137	Pb = 207.
		? = 45	Ce = 92		
		?Er = 56	La = 94		
		?Yt = 60	Di = 95		
		?In = 75,6	Th = 118?		

Д. Менделѣевъ

Periodic table created by Mendeleev in 1869 with the title in the original Russian

Image by Byron Inuoye

Periodic Table of Elements in the Ocean

Group	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period																			
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	71 Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**																

***Lanthanides** Rare Earth Elements	*	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb
****Actinides**	**	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu								

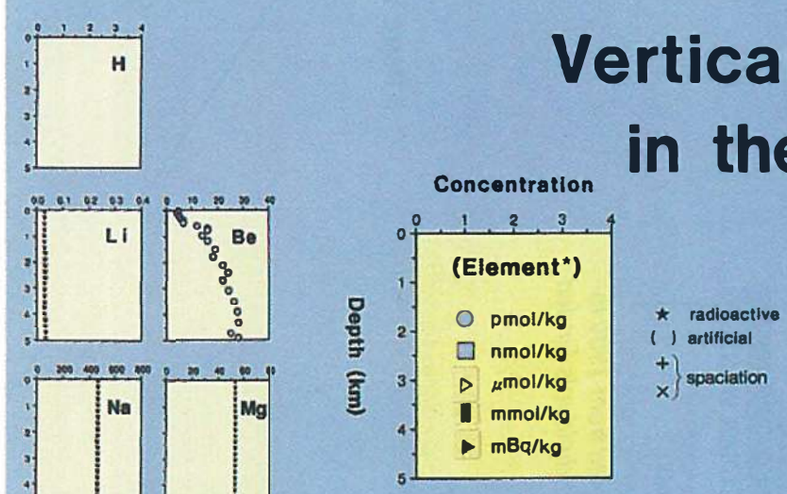
IN RED: ESSENTIAL ELEMENTS

MBARI
Monterey Bay Aquarium Research Institute

https://www.mbari.org/science/upper-ocean-systems/chemical-sensor-group/periodic-table-of-elements-in-the-ocean/

Vertical Profiles of Elements in the North Pacific Ocean

(compiled by Y. Nozaki, 1996)



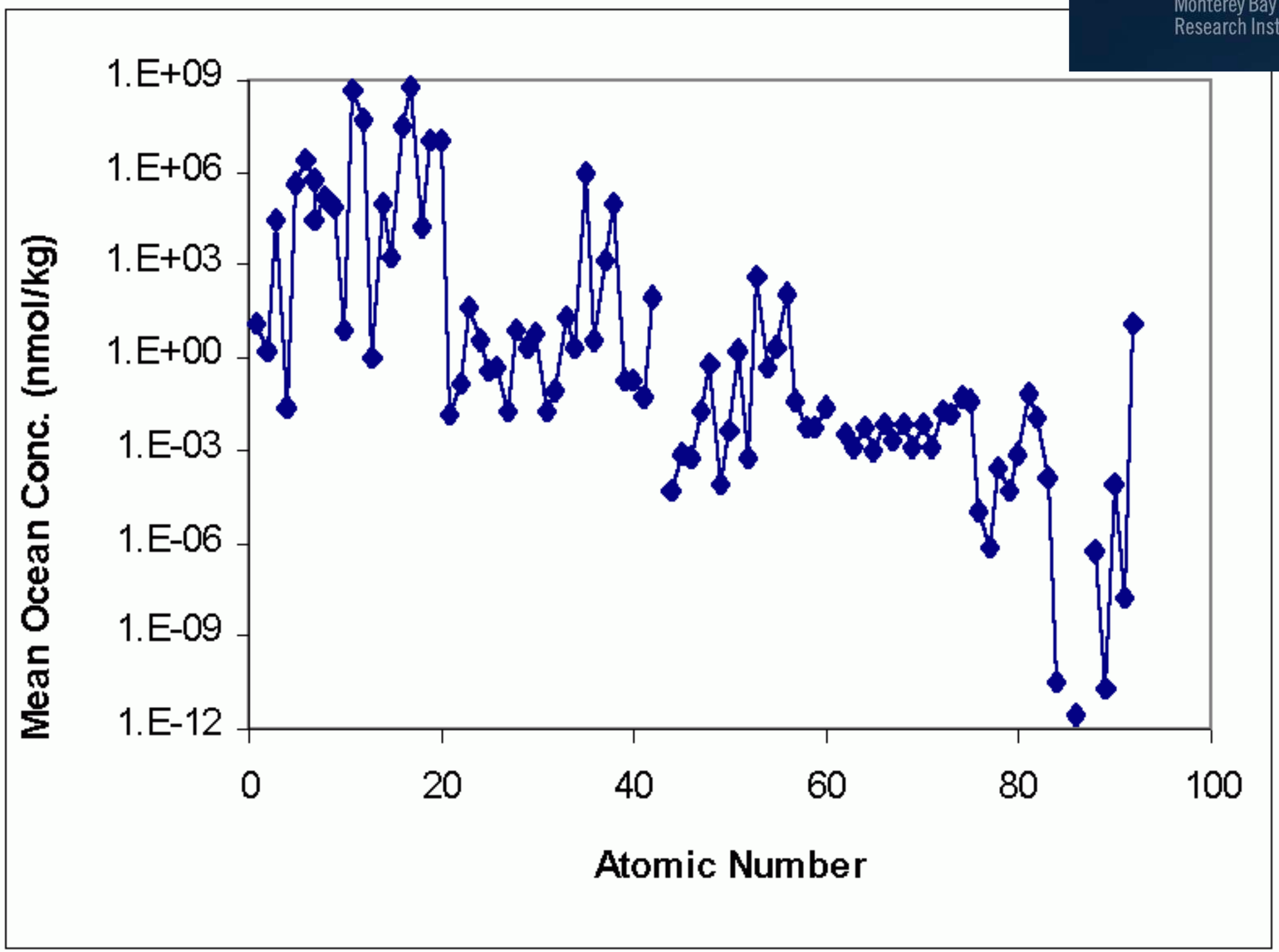
1A	2A	3A	4A	5A	6A	7A	8	1B	2B	3B	4B	5B	6B	7B	0
H															He
Li	Be									B	C	N	O	F	Ne
Na	Mg									Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe Co Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	(Tc*)	Ru Rh Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	L	Hf	Ta	W	Re	Os Ir Pt	Au	Hg	Tl	Pb	Bi	Po*	At*	Rn*
Fr*	Ra*	A													

1 2 3 4 5 6 7

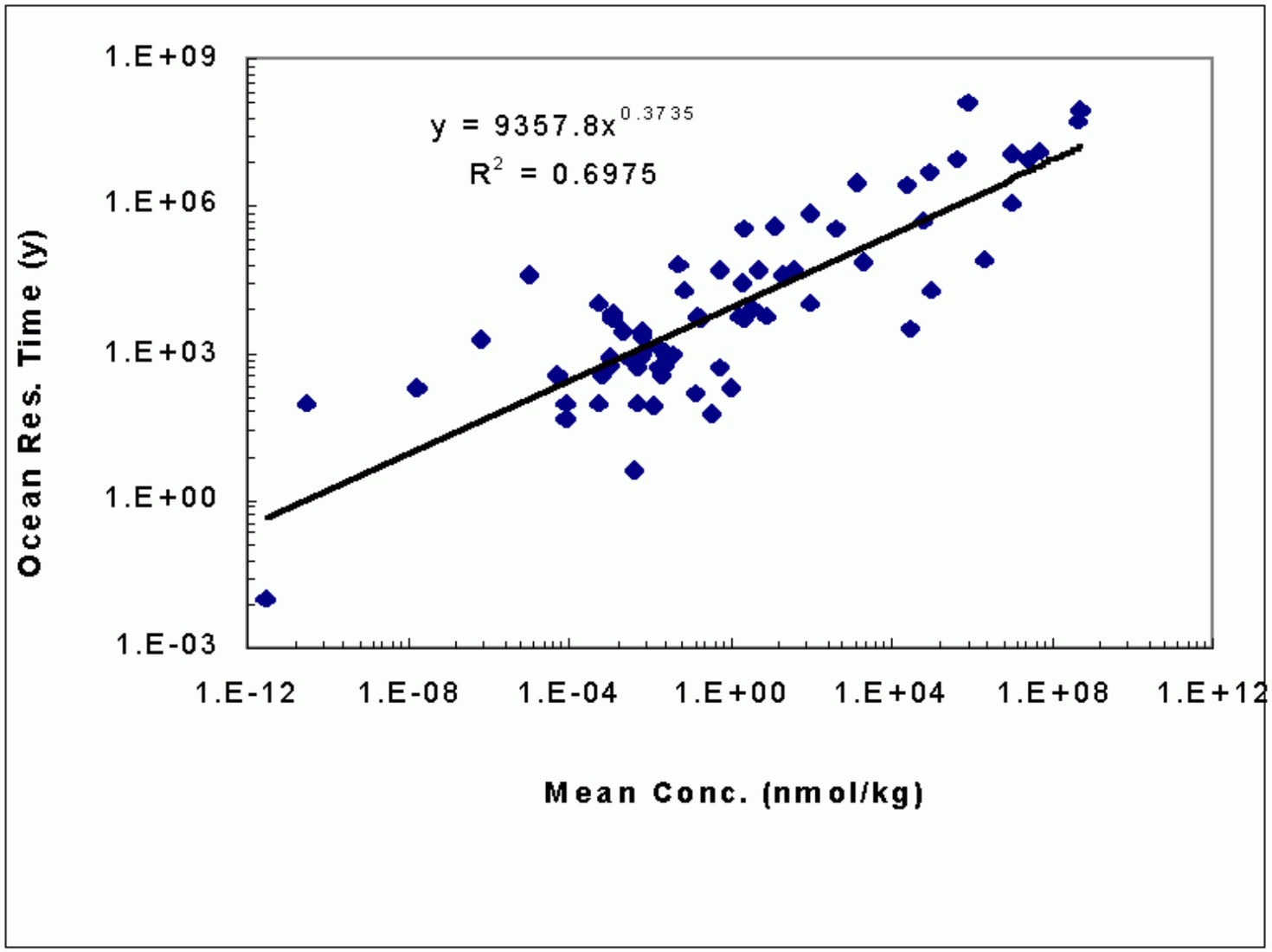
L	La	Ce	Pr	Nd	(Pm*)	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
A	Ac*	Th	Pa*	U*	(Np*)	(Pu*)	(Am*)	(Cm*)	(Bk*)	(Cf*)	(Es*)	(Fm*)	(Md*)	(No*)	(Lr*)

Eos, Vol. 78, No. 21, May 27, 1997

23249250, 1997, 21, Downloaded from https://agupubs.onlinelibrary.wiley.com/doi/10.1029/97EO00148 by Cochraneltalia, Wiley Online Library on [27/09/2026]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License



The concentration generally decreases with increasing atomic number.



The residence time is generally longer for elements with higher concentrations.

$$\text{Residence Time} = \frac{\text{Total Amount (Inventory) of the Element in the Ocean}}{\text{Rate of Input or Removal}}$$

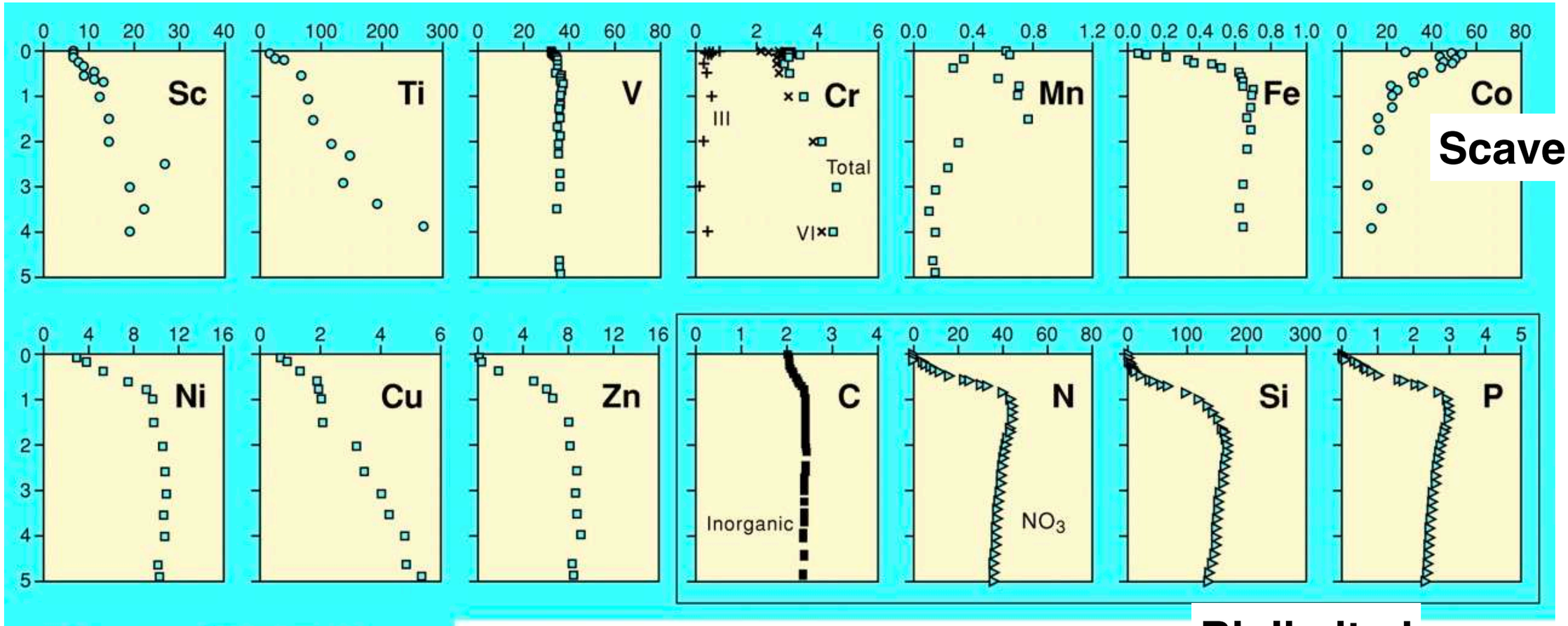
MBARI
Monterey Bay Aquarium Research Institute

Atomic #	Element	Mean Ocean	Atomic Mass	Mean Ocean	Mean Ocean	UNIT	Residence Time
		Conc.		Conc.	Conc		yrs
		ng/kg	g/mol	nmol/kg	Rational Units		
1	H+			1.20E+01	12	nmol/kg	
2	He	7.60E+00	4.0026	1.90E+00	1.9	nmol/kg	
3	Li	1.80E+05	6.9410	2.59E+04	25.9	µmol/kg	2,800,000
4	Be	2.10E-01	9.0122	2.33E-02	23	pmol/kg	1,000
5	B	4.50E+06	10.8110	4.16E+05	416	µmol/kg	9,600,000
6	C	2.70E+07	12.0110	2.25E+06	2.248	mmol/kg	83,000
7	N2	8.30E+06	14.0067	5.93E+05	590	µmol/kg	
7	NO3	4.20E+05	14.0067	3.00E+04	30	µmol/kg	3,000
8	O2	2.80E+06	15.9994	1.75E+05	175	µmol/kg	
9	F	1.30E+06	18.9984	6.84E+04	68	µmol/kg	500,000
10	Ne	1.60E+02	20.1797	7.93E+00	7.9	nmol/kg	
11	Na	1.08E+10	22.9898	4.69E+08	469	mmol/kg	55,000,000
12	Mg	1.28E+09	24.3050	5.27E+07	52.7	mmol/kg	13,000,000
13	Al	3.00E+01	26.9815	1.11E+00	1.11	nmol/kg	200
14	Si	2.80E+06	28.0855	9.97E+04	99.7	µmol/kg	20,000
15	PO4	6.20E+04	30.9738	2.00E+03	2	µmol/kg	69,000
16	SO4--	8.98E+08	32.0660	2.80E+07	28	mmol/kg	8,700,000

Atomic #	Element	Mean Ocean	Atomic Mass	Mean Ocean	Mean Ocean	UNIT	Residence Time
17	Cl-	1.94E+10	35.4527	5.46E+08	546	mmol/kg	87,000,000
18	Ar	6.20E+05	39.9480	1.55E+04	15.5	µmol/kg	
19	K	3.99E+08	39.0983	1.02E+07	10.2	mmol/kg	12,000,000
20	Ca	4.12E+08	40.0780	1.03E+07	10.27	mmol/kg	1,100,000
21	Sc	7.00E-01	44.9559	1.56E-02	16	pmol/kg	
22	Ti	6.50E+00	47.8800	1.36E-01	136	pmol/kg	150
23	V	2.00E+03	50.9415	3.93E+01	39	nmol/kg	50,000
24	Cr(VI)	2.10E+02	51.9960	4.04E+00	4	nmol/kg	8,000
25	Mn	2.00E+01	54.9380	3.64E-01	360	pmol/kg	60
26	Fe	3.00E+01	55.8470	5.37E-01	540	pmol/kg	500
27	Co	1.20E+00	58.9332	2.04E-02	20	pmol/kg	340
28	Ni	4.80E+02	58.6934	8.18E+00	8.2	nmol/kg	6,000
29	Cu	1.50E+02	63.5460	2.36E+00	2.4	nmol/kg	5,000

Nutrients

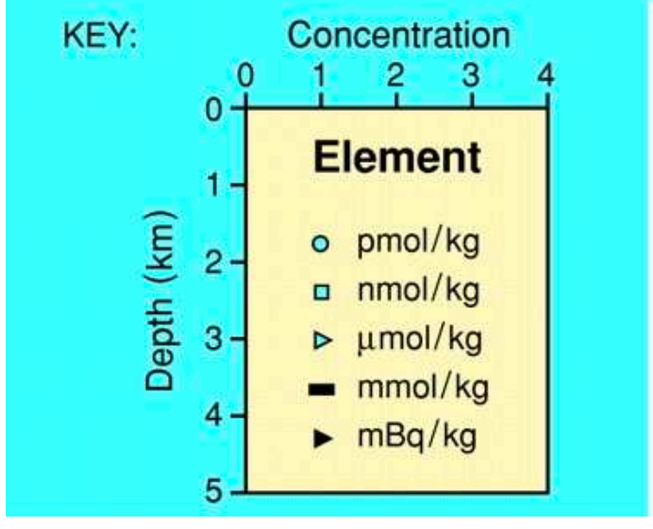
Conservative

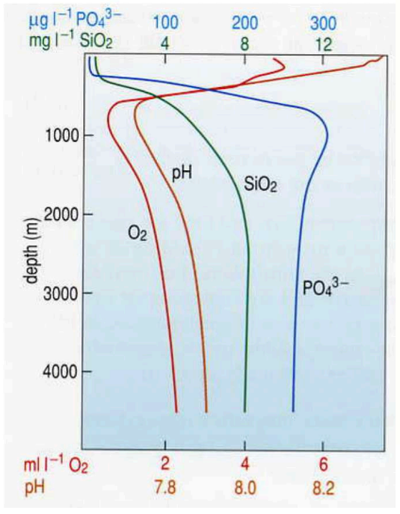


Scavenged

Biolimited

Nozaki, 2001



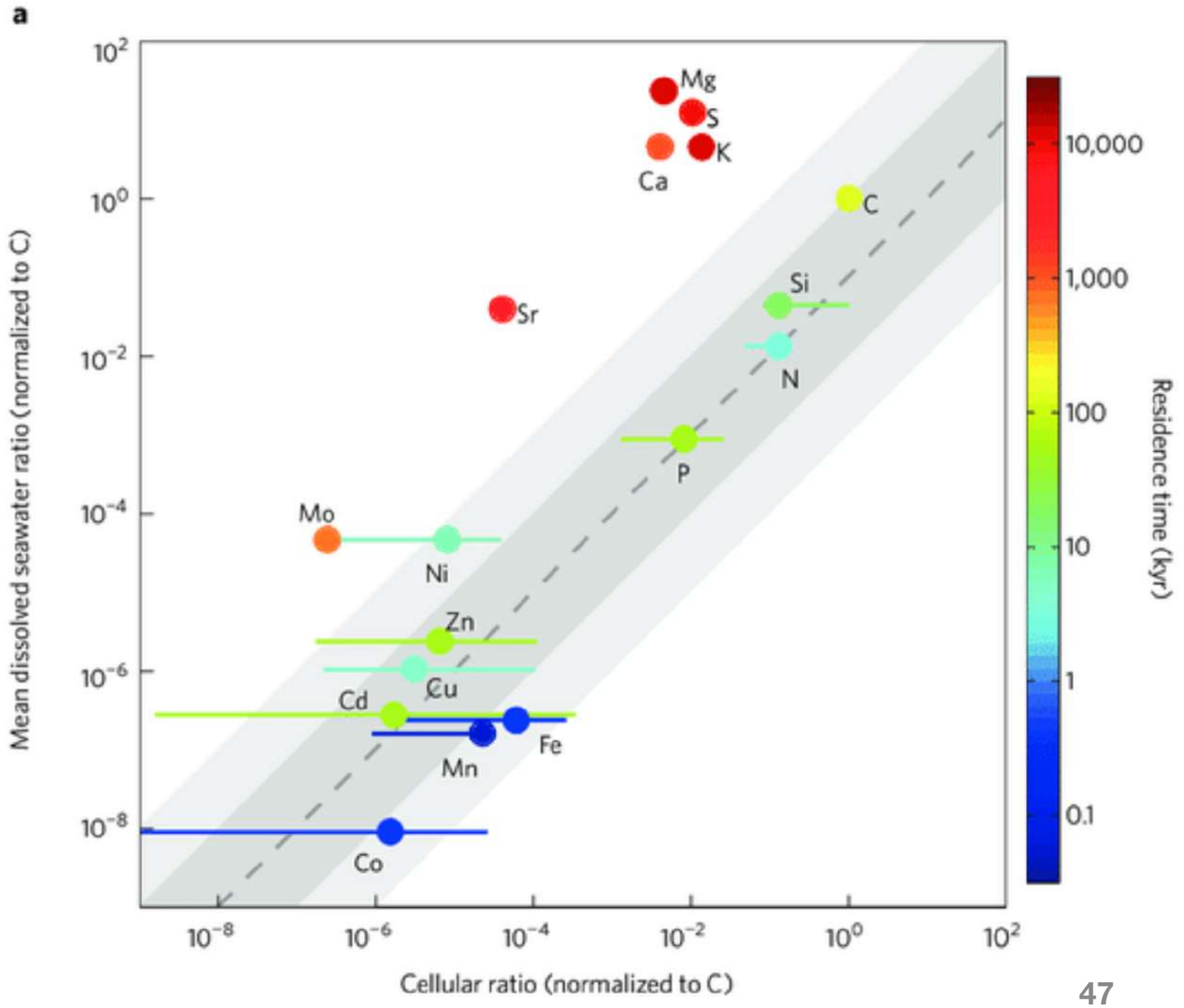


- Elements in the ocean derive from rocks
- Elements have different concentrations
- Elements have different profiles
- **Conservative Elements** are well mixed in SW since their residence times are >> the oceanic mixing time scale
- **Non-conservative elements -** Biological and other processes produce elemental concentrations that deviate from salinity-normalized concentrations in SW
- Profiles are related to biological activities

Comparisons between intracellular and dissolved SW elemental stoichiometry

Marine bacteria are enriched in Fe, P, N

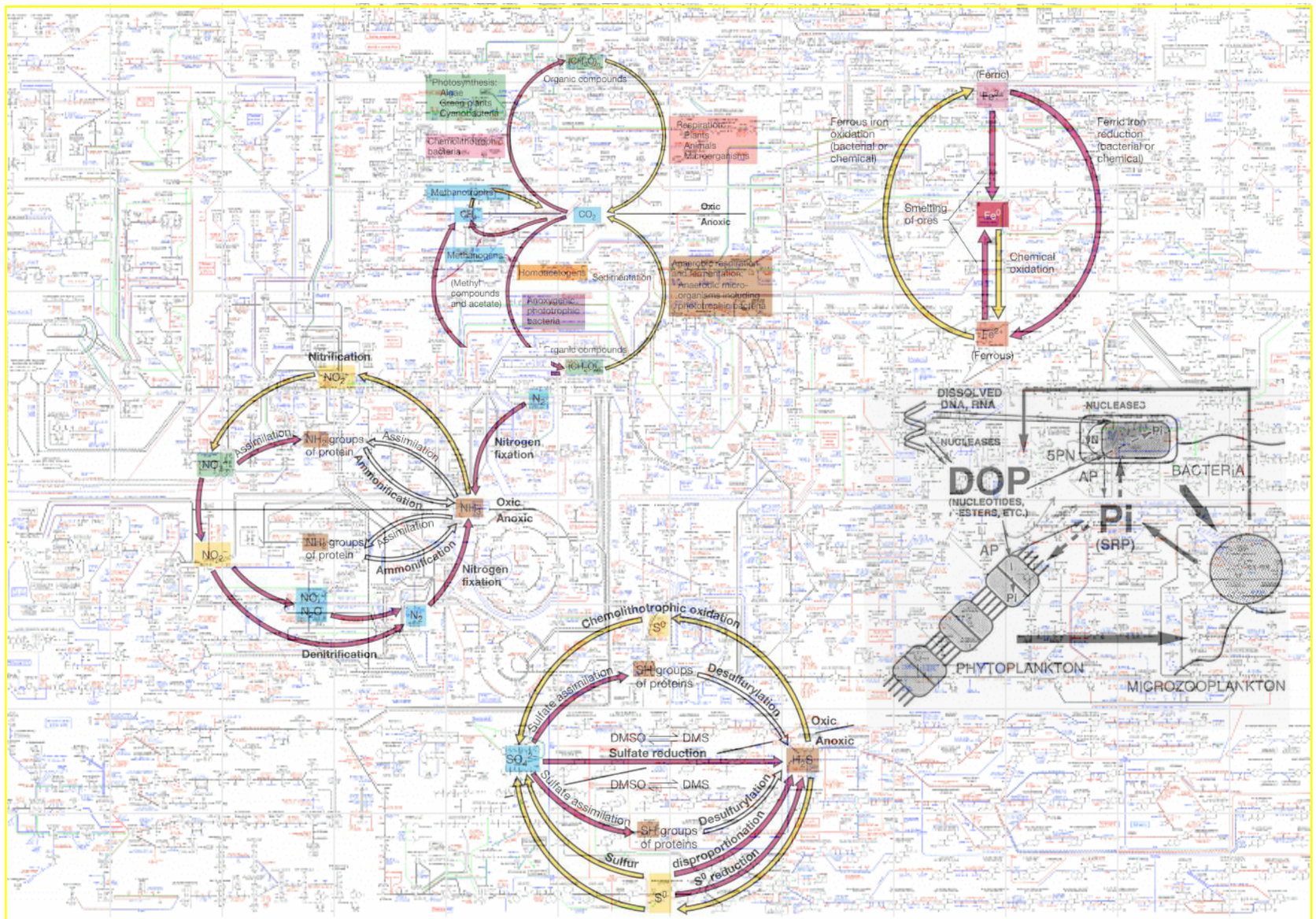
Elements to the top left of the shaded area are thus in great excess in sea water, and biological processing has little influence on their distribution, whereas some of those in the shaded regions have the potential to become limiting



Mills et al., 2013

Bacteria are master recyclers
Bacteria respire/utilise organic matter and give off nutrients to other organisms
Bacteria are the main forces in the biogeochemical cycles of the elements
ALL CYCLES are connected:

Carbon
Nitrogen
Iron
Sulfur
Phosphate
Pollutants

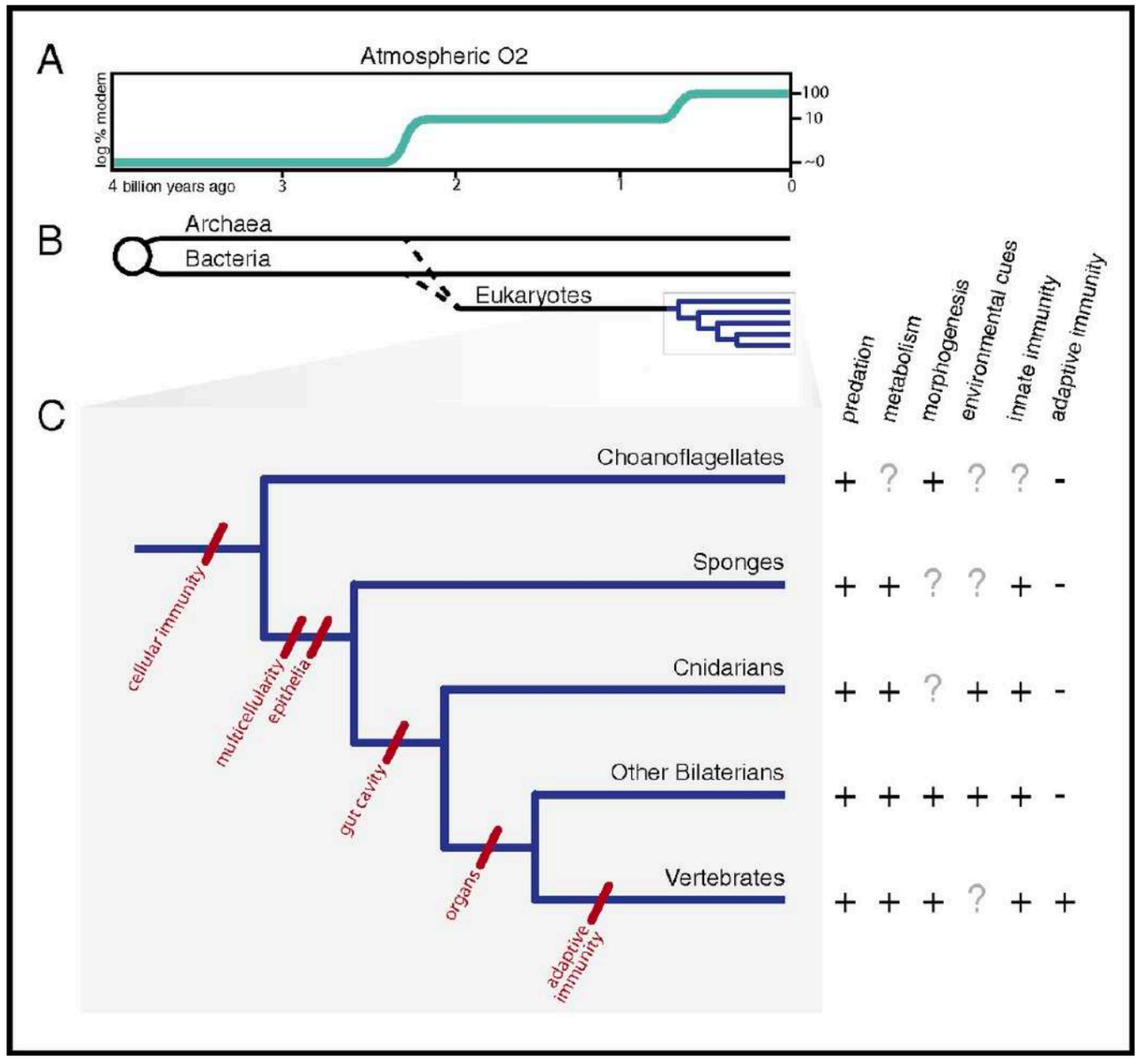


Madigan 10th edition

Redfield ratio or Redfield stoichiometry is the atomic ratio of carbon, nitrogen and phosphorus found in phytoplankton and throughout the deep oceans C:N:P = 106:16:1 (Redfield A.C. 1934)

Other micro/macro organisms as microbial habitats

Microorganisms form symbiotic partnerships with the vast majority of *animals and plant* living on earth and are increasingly recognised as being essential for overall ecosystem functioning



McFall-Ngai et al., 2013