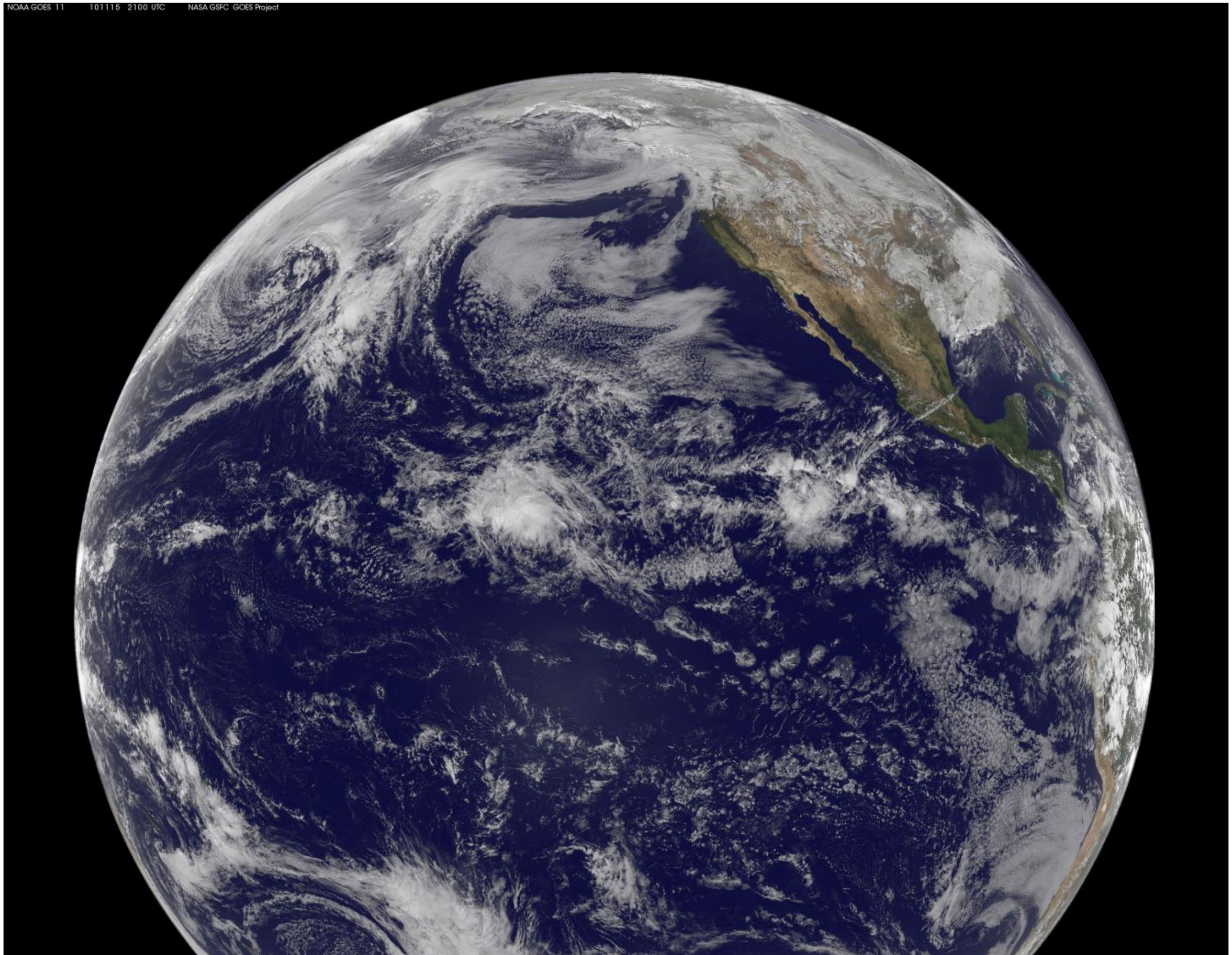
OCEAN NETWORKS CANADA

OCEAN RESPONSES TO CLIMATE CHANGE

Dr. Richard Dewey, ONC Associate Director, Science | Jan 2022

THE CLIMATE SYSTEM



The Climate is what you expect, the Weather is what you get.

The Earth:

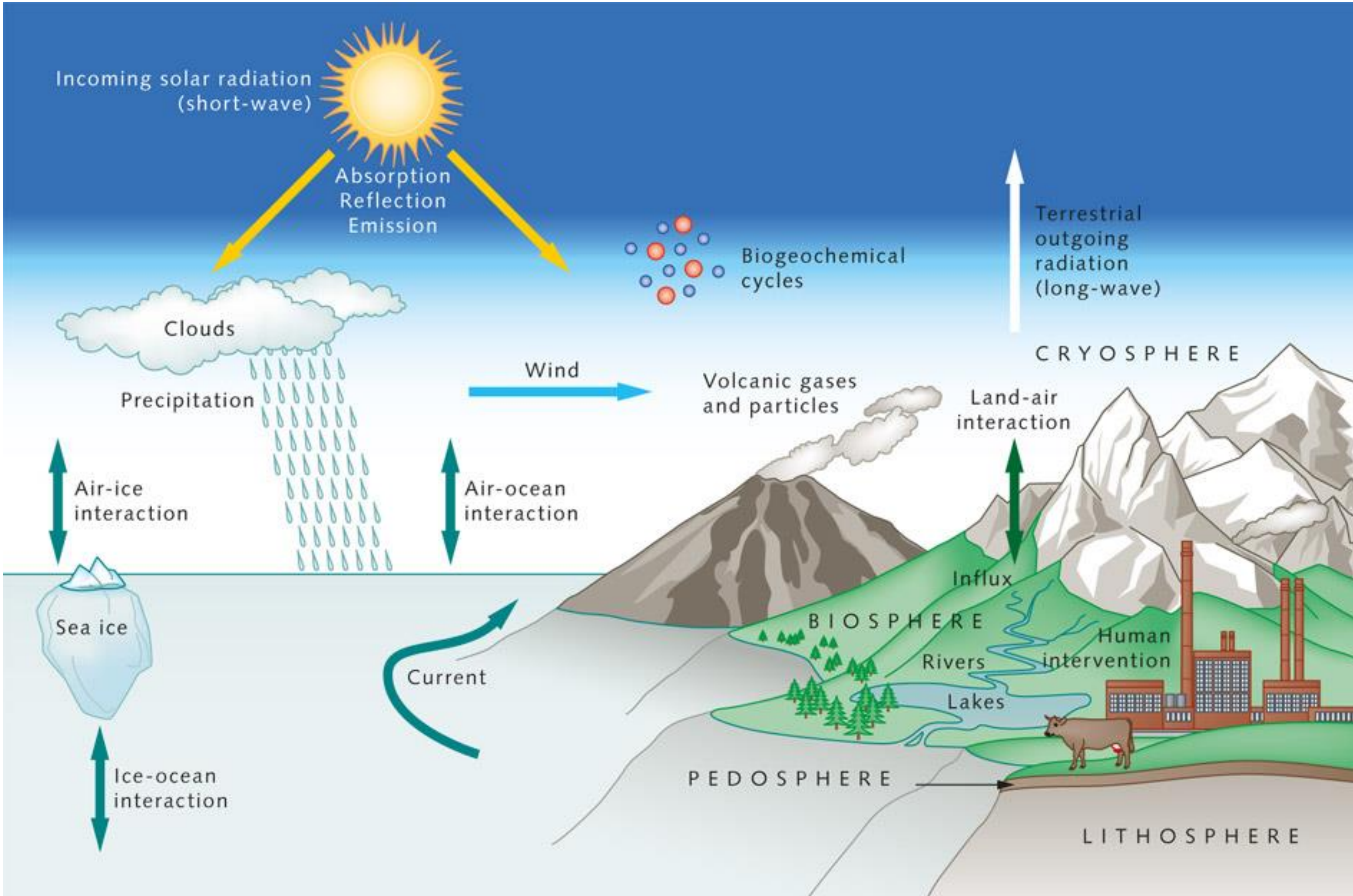
- 70% of surface covered by the ocean, 30% by land
- 10% covered by ice (land and sea)
- 60-70% covered by cloud
- The Ocean has a significant role moderating on our climate.

OCEAN RESPONSES TO CLIMATE CHANGE

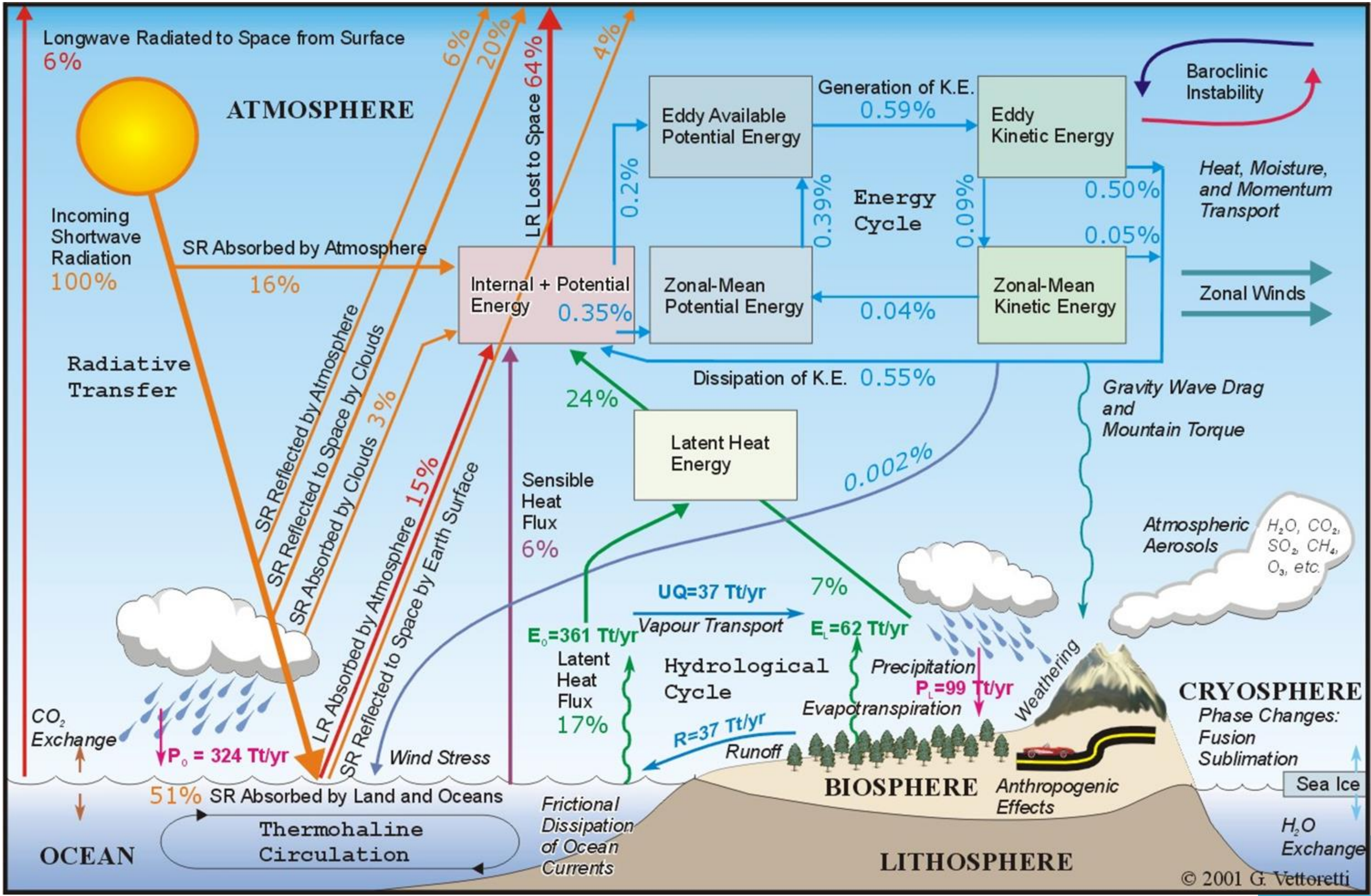
Outline:

1) The climate system and the ocean's role in moderating climate, regionally and globally
2) What we expected climate change might look like:
   - Gradual warming and shifting patterns/zones
3) What seems to be actually happening:
   - Heat waves, ocean acidification, and hypoxia
   - Sudden, abrupt, and significant "synoptic" events
4) Mitigating and Adapting to climate change
   - climate scenarios and solutions

THE CLIMATE SYSTEM



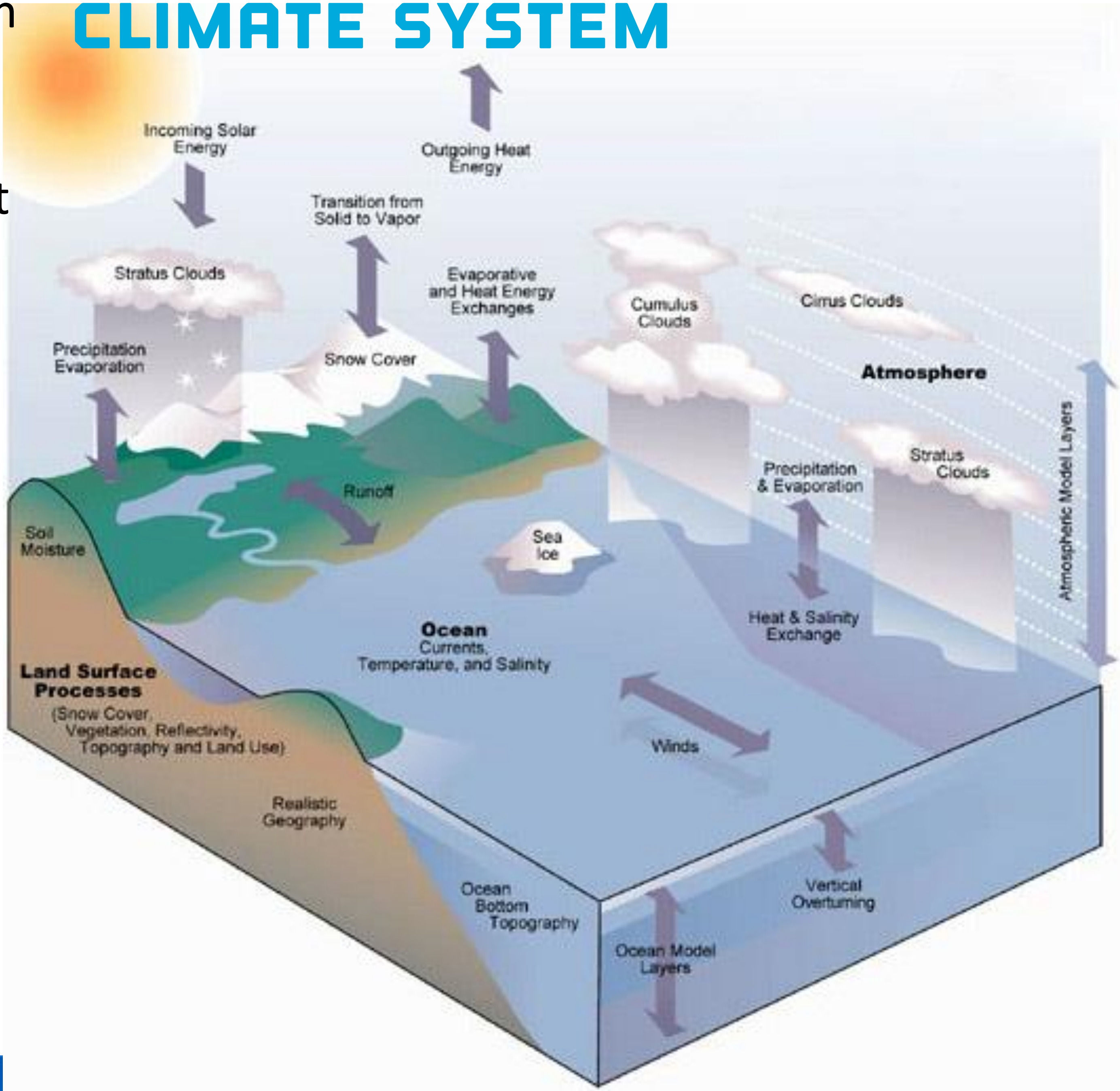
MODELLING THE CLIMATE SYSTEM



THE HYDROLOGY PART OF THE CLIMATE SYSTEM

We know that the ocean "moderates" climate, and is why Victoria and Winnipeg have different "climates".
Proximity to the ocean affects both heat and precipitation.

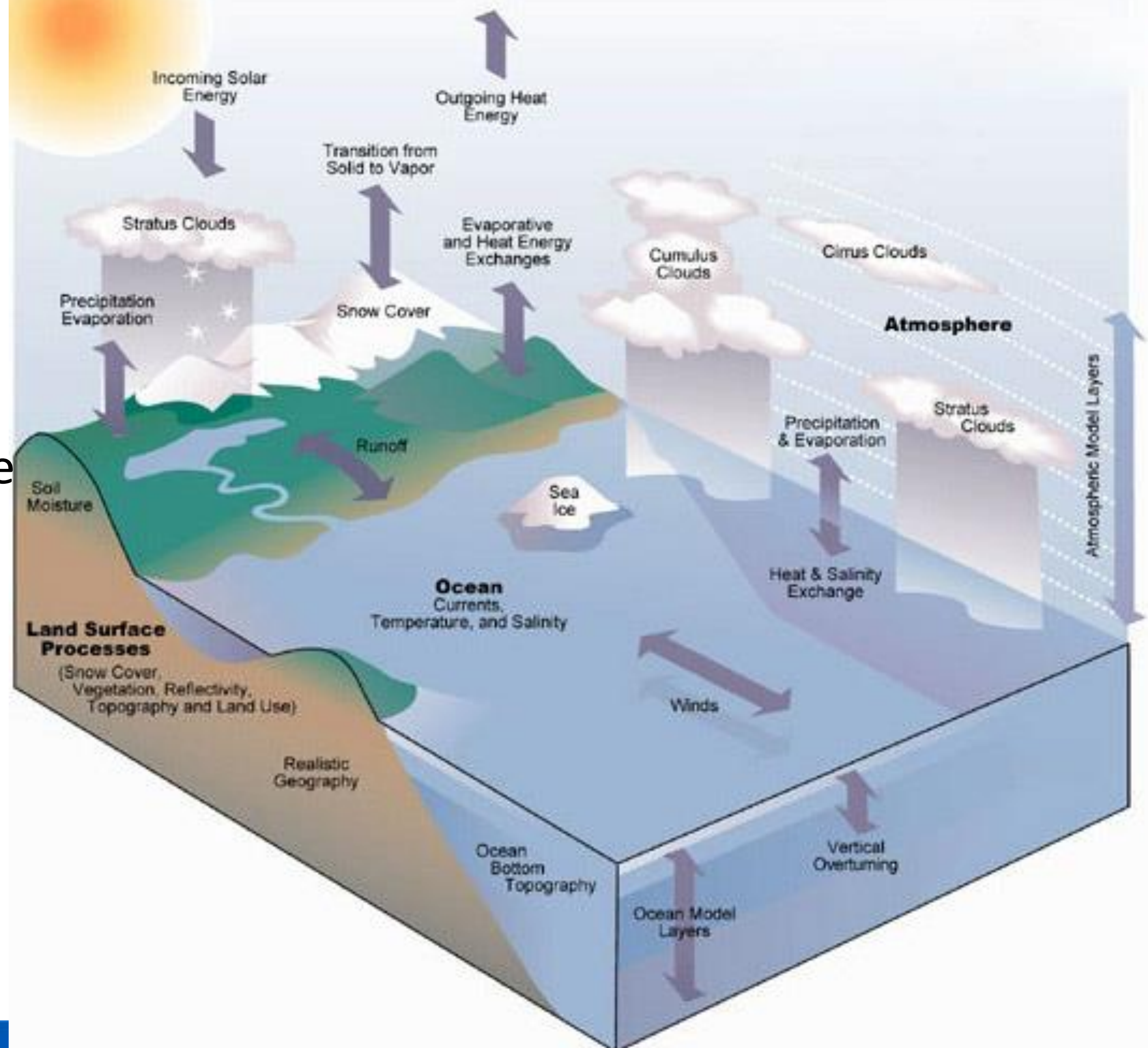
Because the specific heat (or inverse heat capacity) of water is roughly 4 times that of "land", it warms slowly per unit of heat energy absorbed.

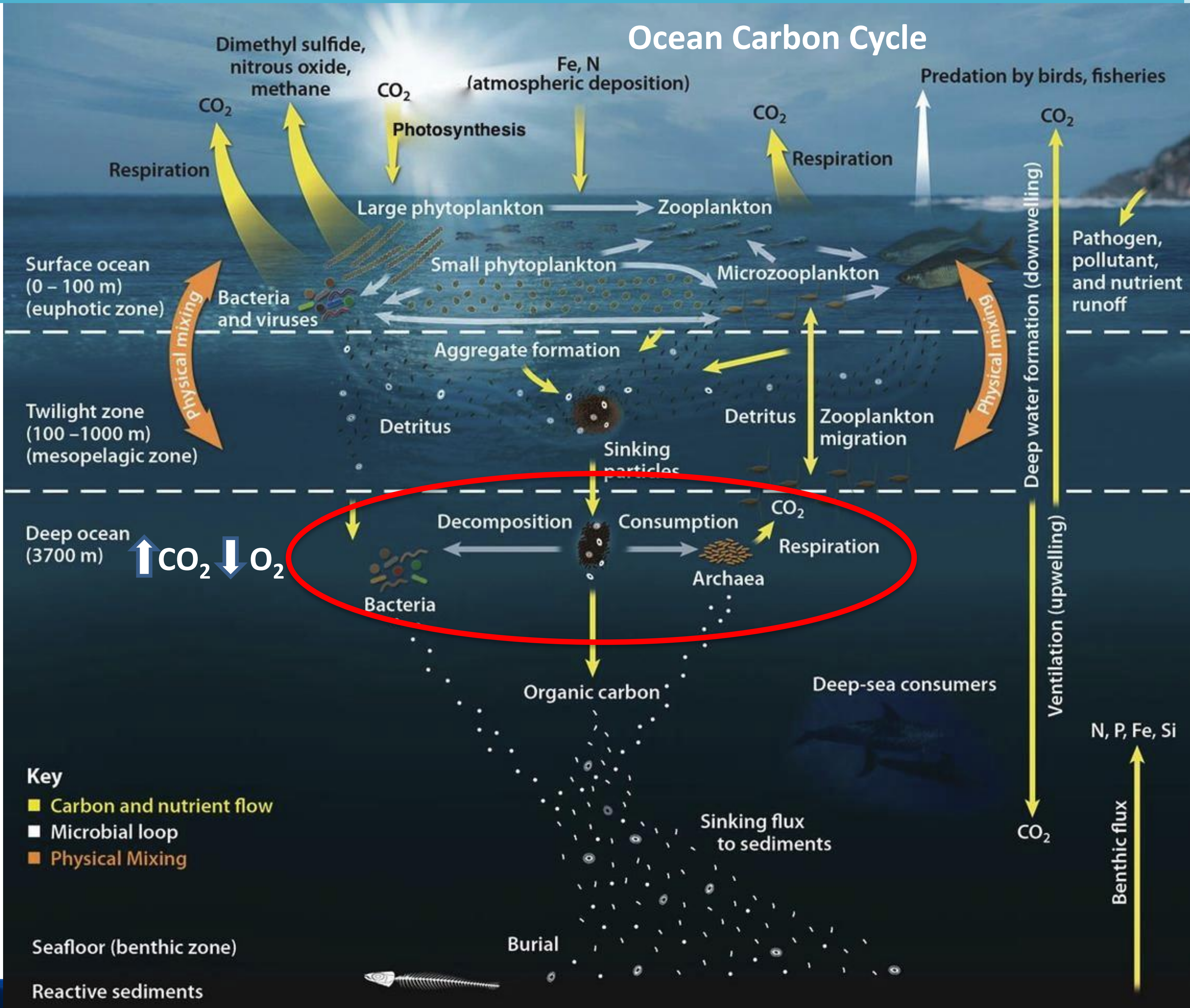


THE HYDROLOGY PART OF THE CLIMATE SYSTEM

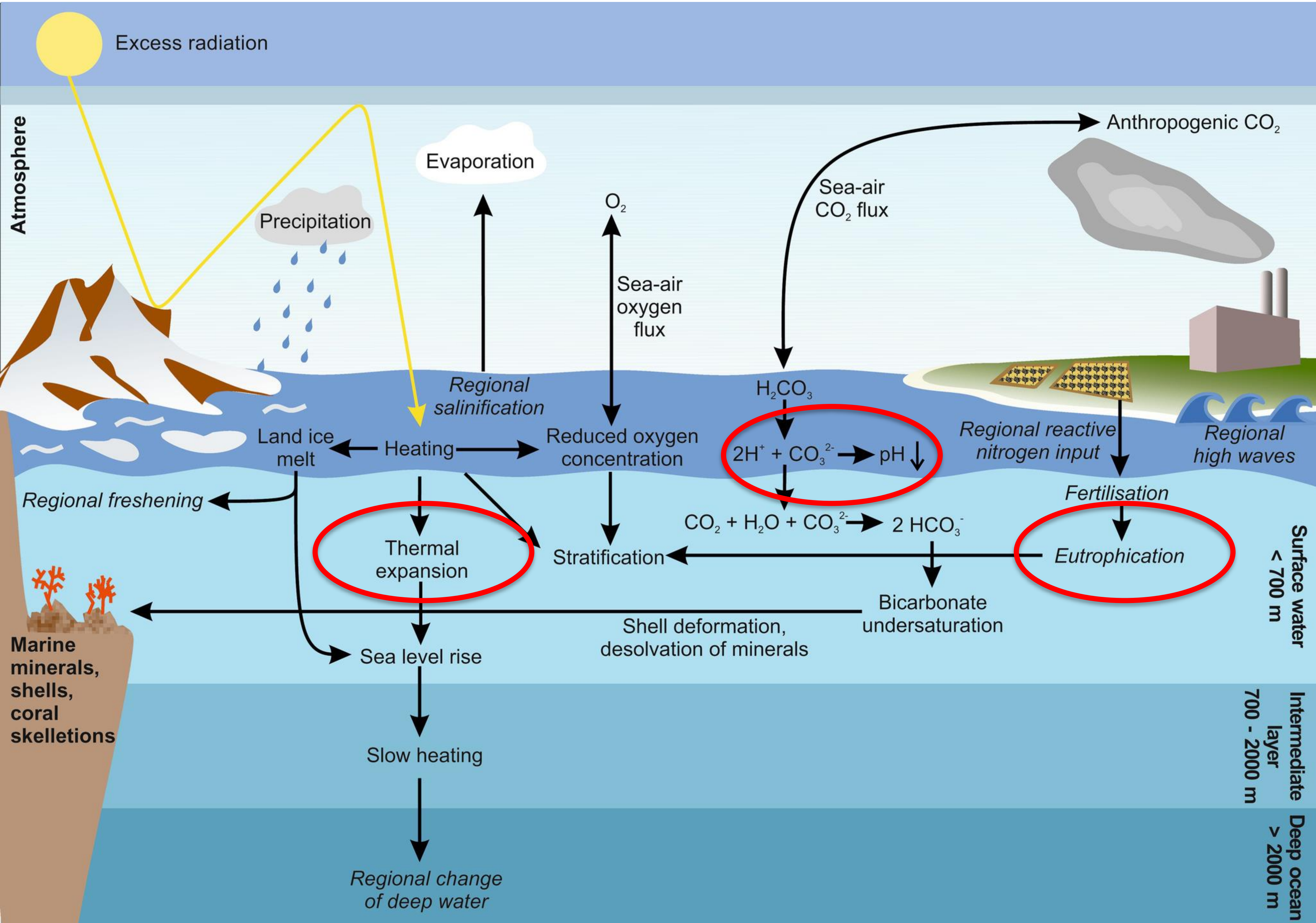
Subsequently, the ocean is absorbing “excess” heat, but its temperature is rising only slowly.

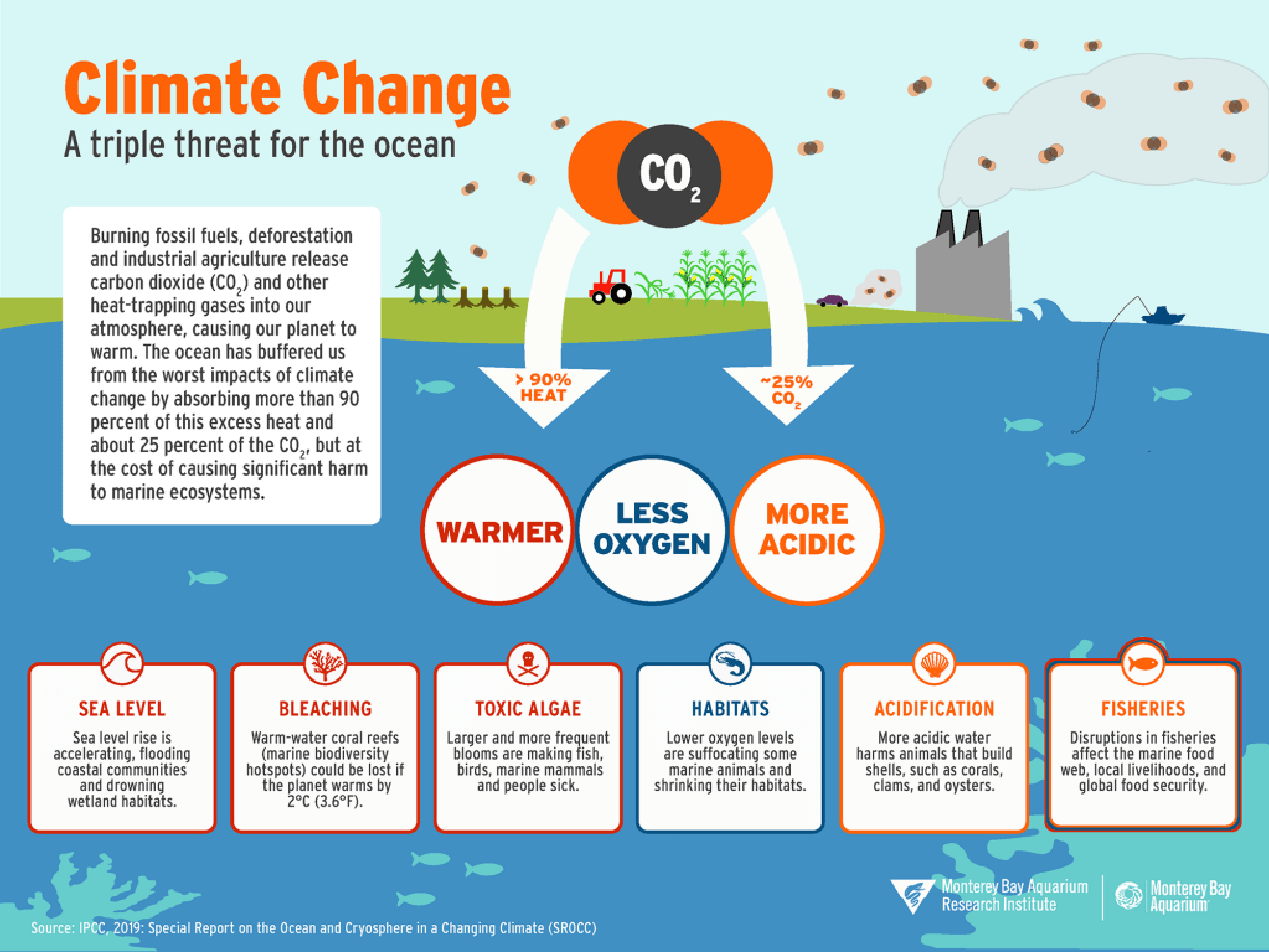
As a result the ocean has already “buffered” about 30% of the “forcing” driving climate change. Long-term consequences are thermal expansion (sea level rise), but also there are chemical changes, ocean acidification and hypoxia.



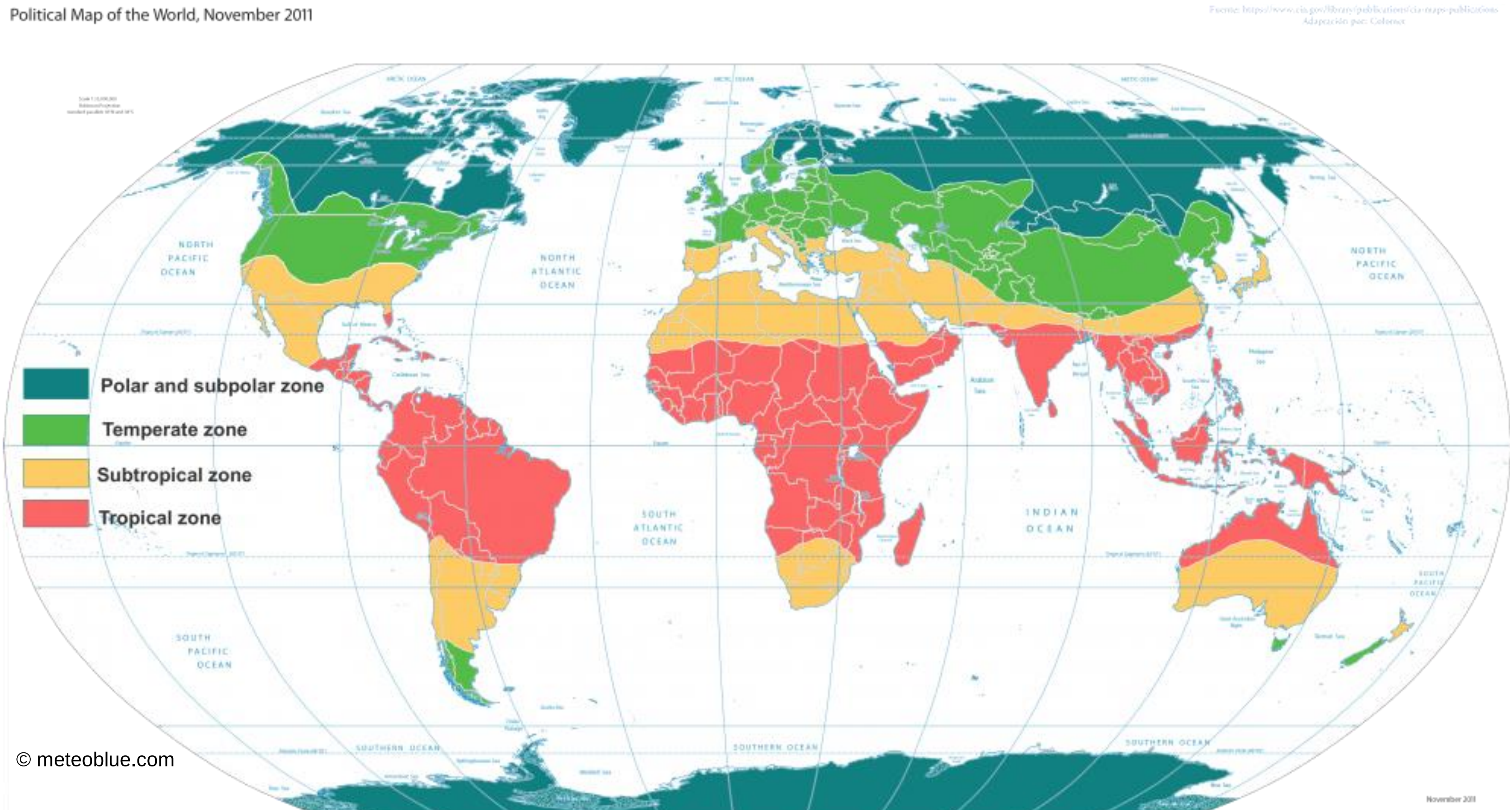

Ocean Carbon Cycle
Dimethyl sulfide, nitrous oxide, methane
CO_2
Respiration
CO_2
Photosynthesis
Fe, N (atmospheric deposition)
CO_2
Respiration
Predation by birds, fisheries
CO_2
Large phytoplankton
Zooplankton
Small phytoplankton
Microzooplankton
Bacteria and viruses
Pathogen, pollutant, and nutrient runoff
Surface ocean (0 – 100 m) (euphotic zone)
Physical mixing
Aggregate formation
Twilight zone (100 –1000 m) (mesopelagic zone)
Detritus
Detritus
Zooplankton migration
Sinking particles
Physical mixing
Deep water formation (downwelling)
Deep ocean (3700 m)
↑CO_2 ↓O_2
Decomposition
Consumption
CO_2
Respiration
Bacteria
Archaea
Ventilation (upwelling)
Organic carbon
Deep-sea consumers
N, P, Fe, Si
Key
Carbon and nutrient flow
Microbial loop
Physical Mixing
Sinking flux to sediments
CO_2
Benthic flux
Seafloor (benthic zone)
Burial
Reactive sediments

OCEAN RESPONSE




Climate Change
A triple threat for the ocean
Burning fossil fuels, deforestation and industrial agriculture release carbon dioxide (CO_2) and other heat-trapping gases into our atmosphere, causing our planet to warm. The ocean has buffered us from the worst impacts of climate change by absorbing more than 90 percent of this excess heat and about 25 percent of the CO_2, but at the cost of causing significant harm to marine ecosystems.
CO_2
> 90% HEAT
~25% CO_2
WARMER
LESS OXYGEN
MORE ACIDIC
SEA LEVEL
Sea level rise is accelerating, flooding coastal communities and drowning wetland habitats.
BLEACHING
Warm-water coral reefs (marine biodiversity hotspots) could be lost if the planet warms by 2°C (3.6°F).
TOXIC ALGAE
Larger and more frequent blooms are making fish, birds, marine mammals and people sick.
HABITATS
Lower oxygen levels are suffocating some marine animals and shrinking their habitats.
ACIDIFICATION
More acidic water harms animals that build shells, such as corals, clams, and oysters.
FISHERIES
Disruptions in fisheries affect the marine food web, local livelihoods, and global food security.
Monterey Bay Aquarium Research Institute
Monterey Bay Aquarium
Source: IPCC, 2019: Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)

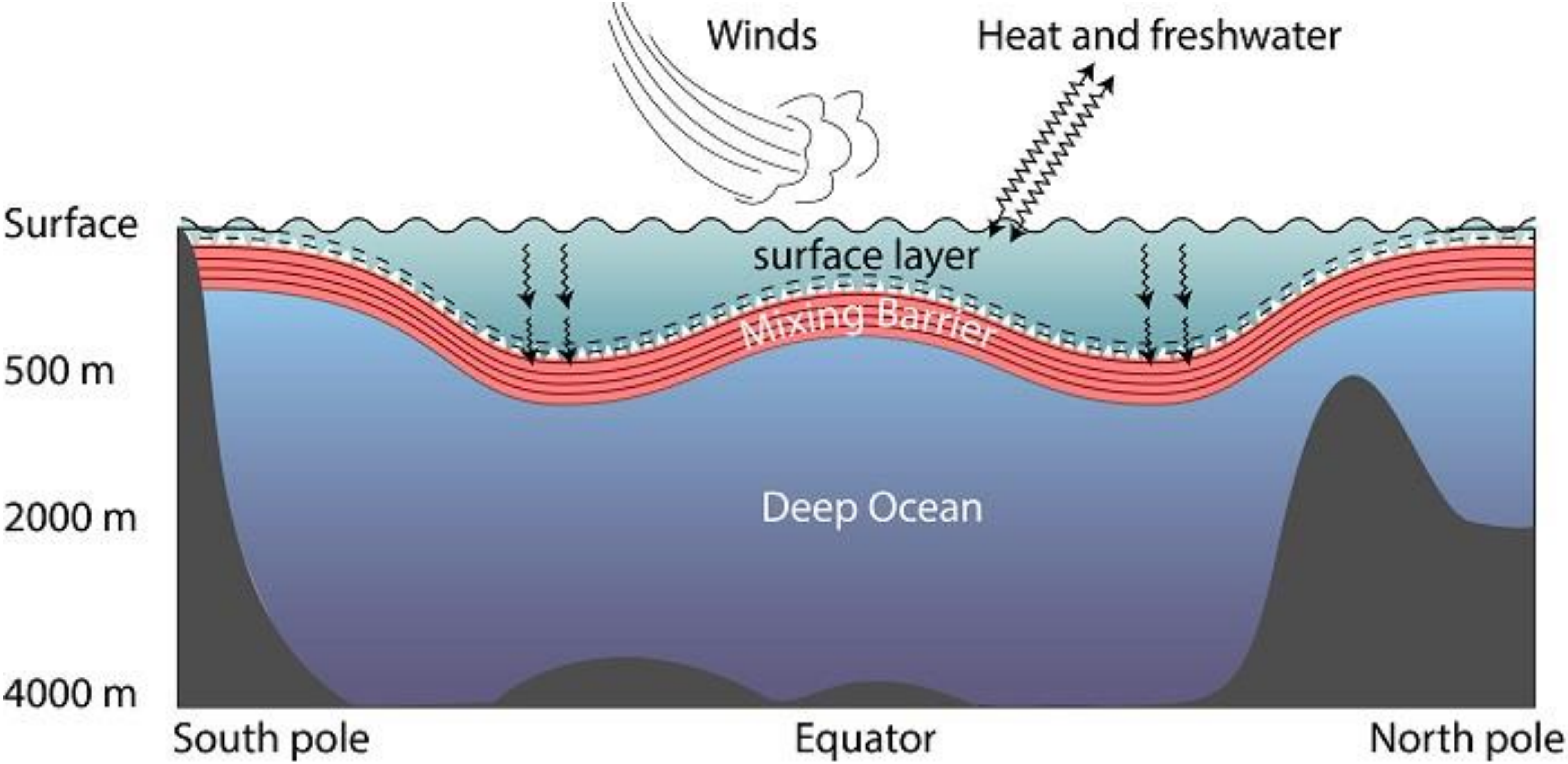
THE CLIMATE "ZONES"



Climate Change: Gradual shift of climate zones poleward

Recent records suggest warming at about 2°C /century

OCEAN RESPONSE

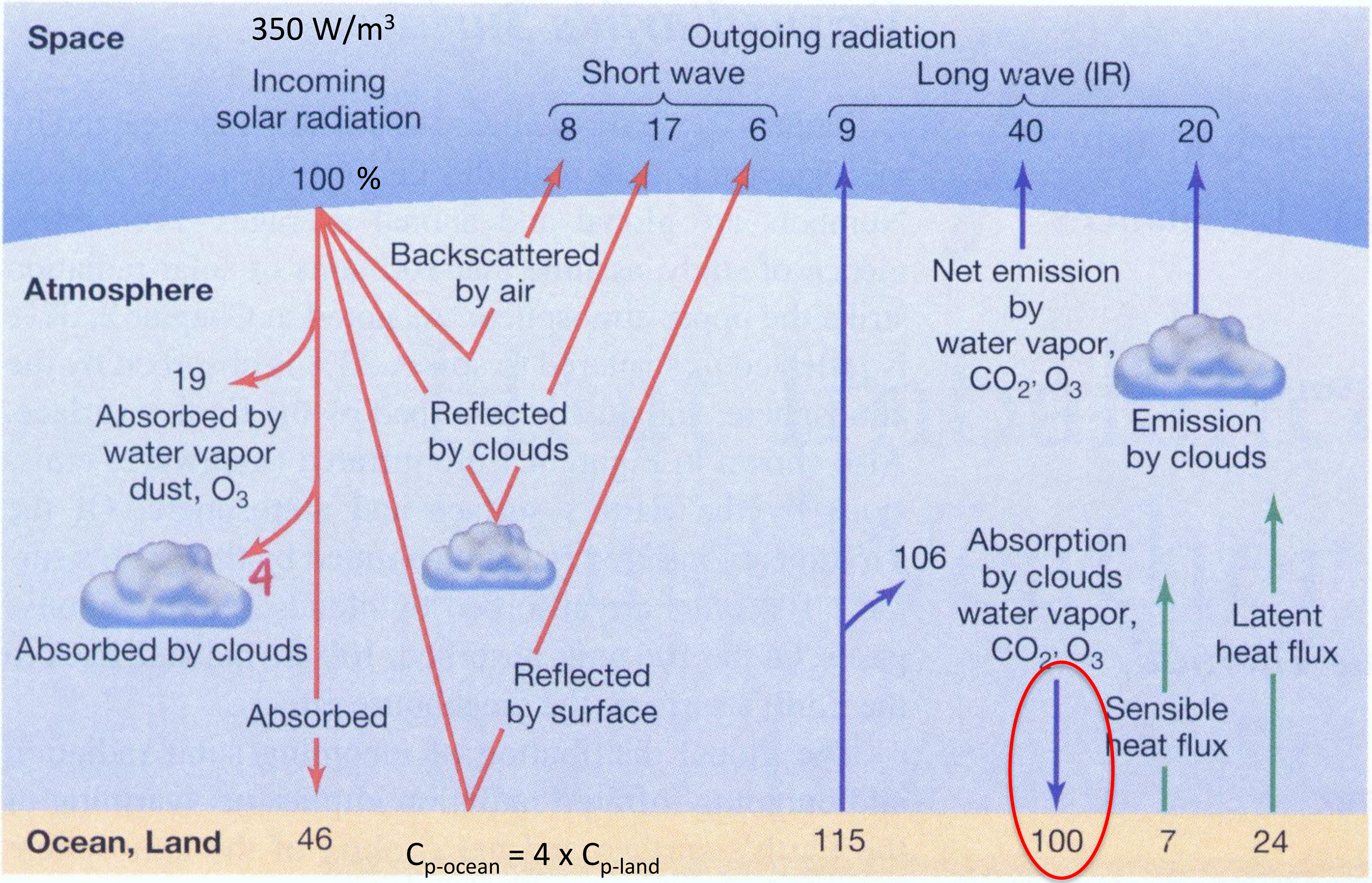


Even as little as 20 years ago, most oceanographers assumed that most of the "changes" (impacts) would be confined to the "upper" ocean, depths less than 200-300m.

We now know, that is not the case.

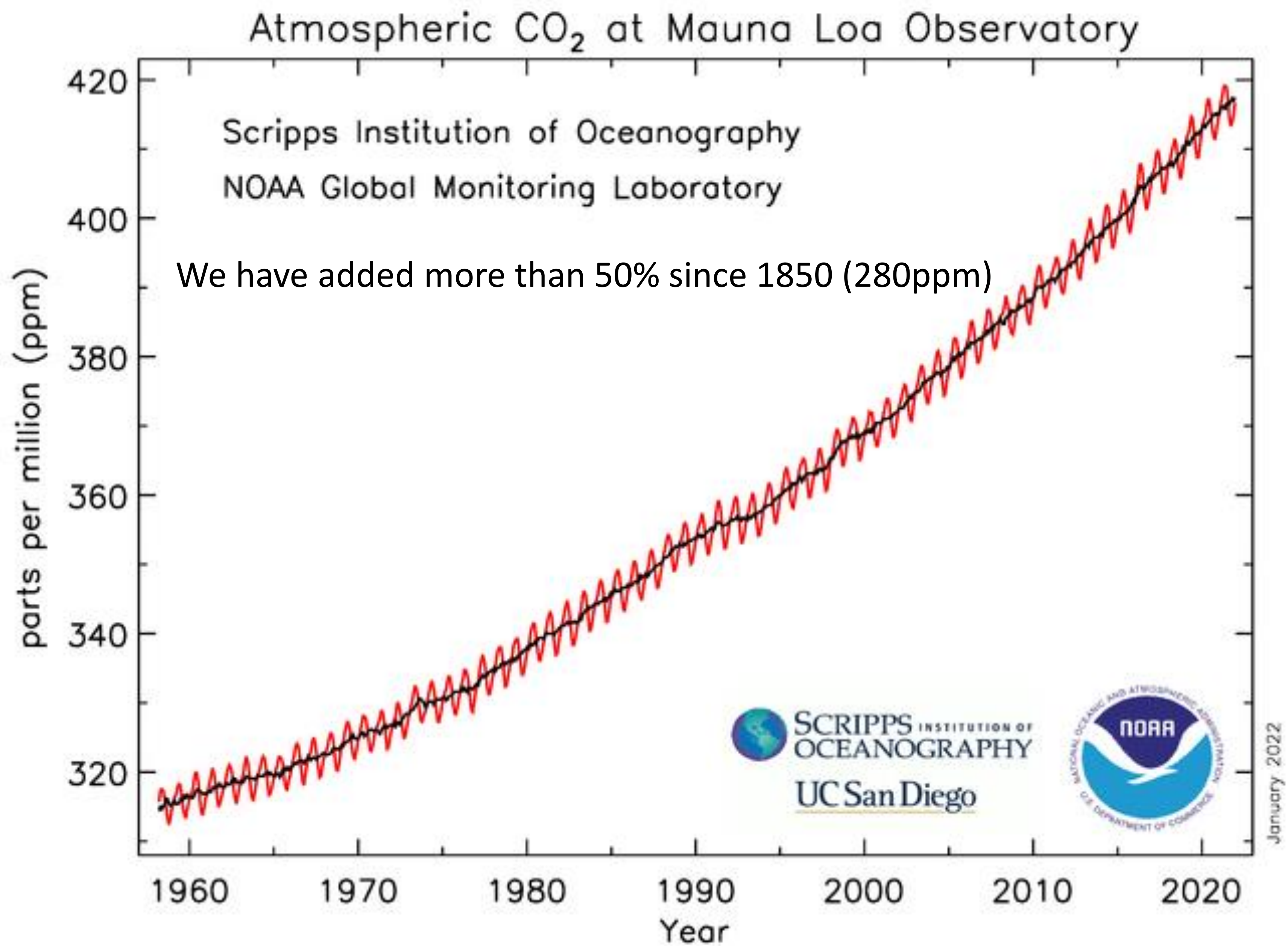
But let's backup and review the prime driver of climate change

THE GREENHOUSE EFFECT

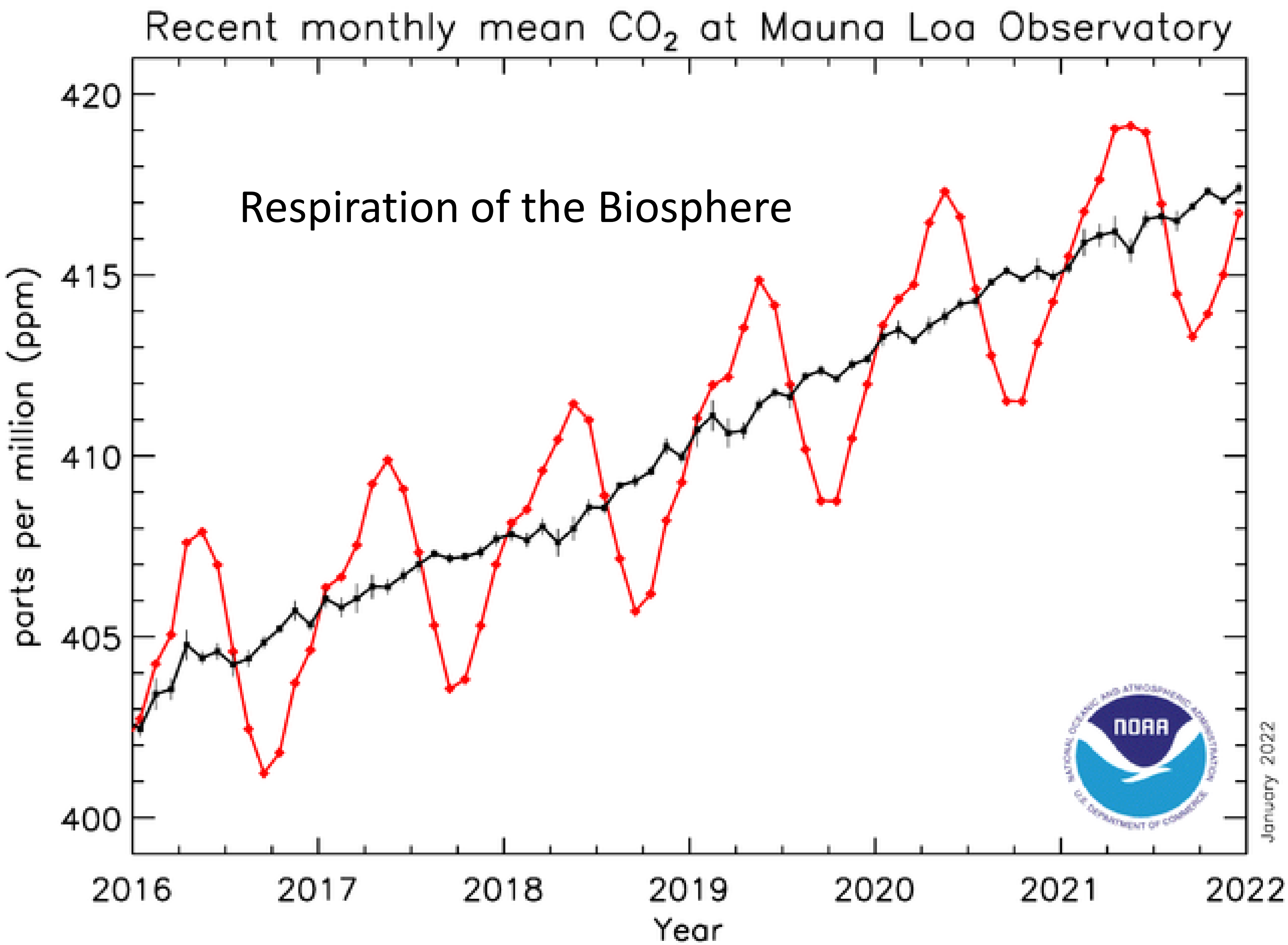


$C_{p\text{-ocean}} = 4 \times C_{p\text{-land}}$

CLIMATE CHANGE: ADDITIONAL CARBON

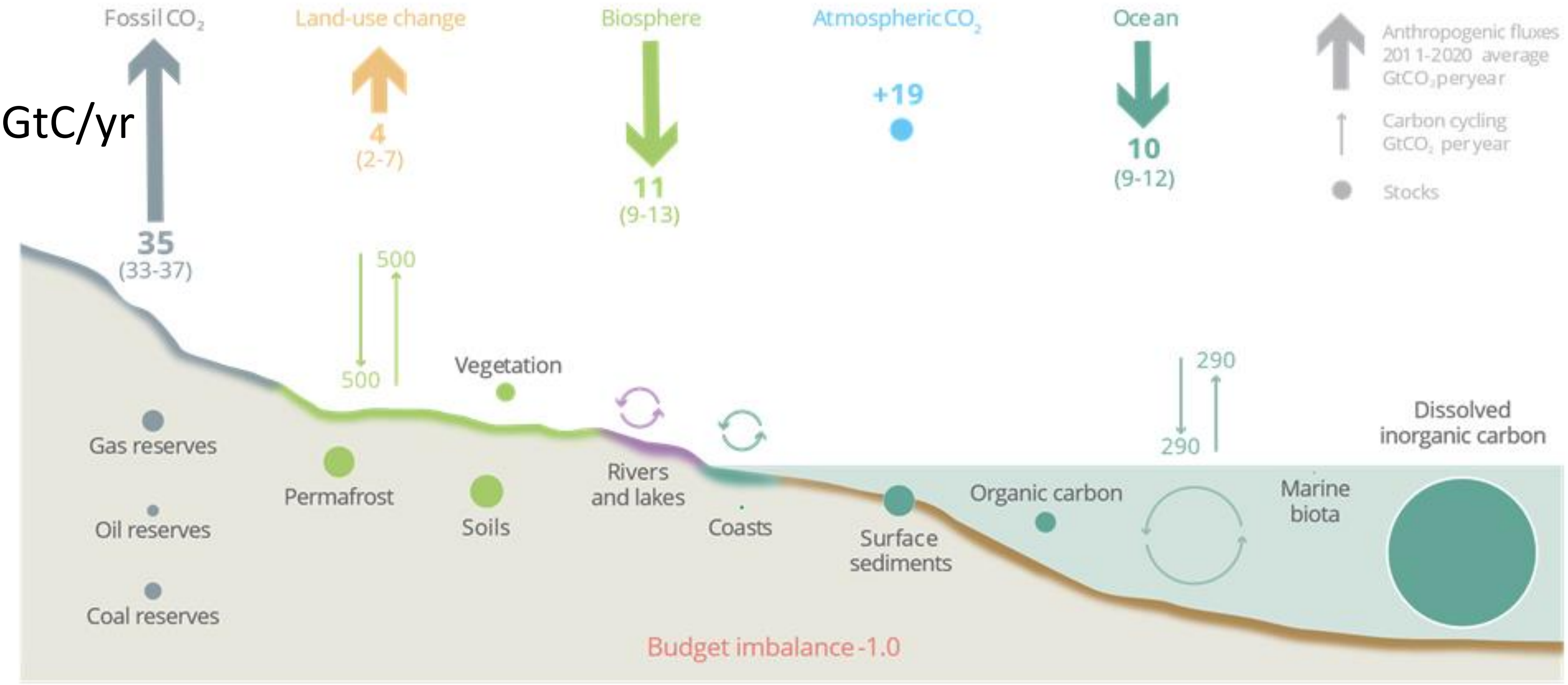


CLIMATE CHANGE: ADDITIONAL CARBON

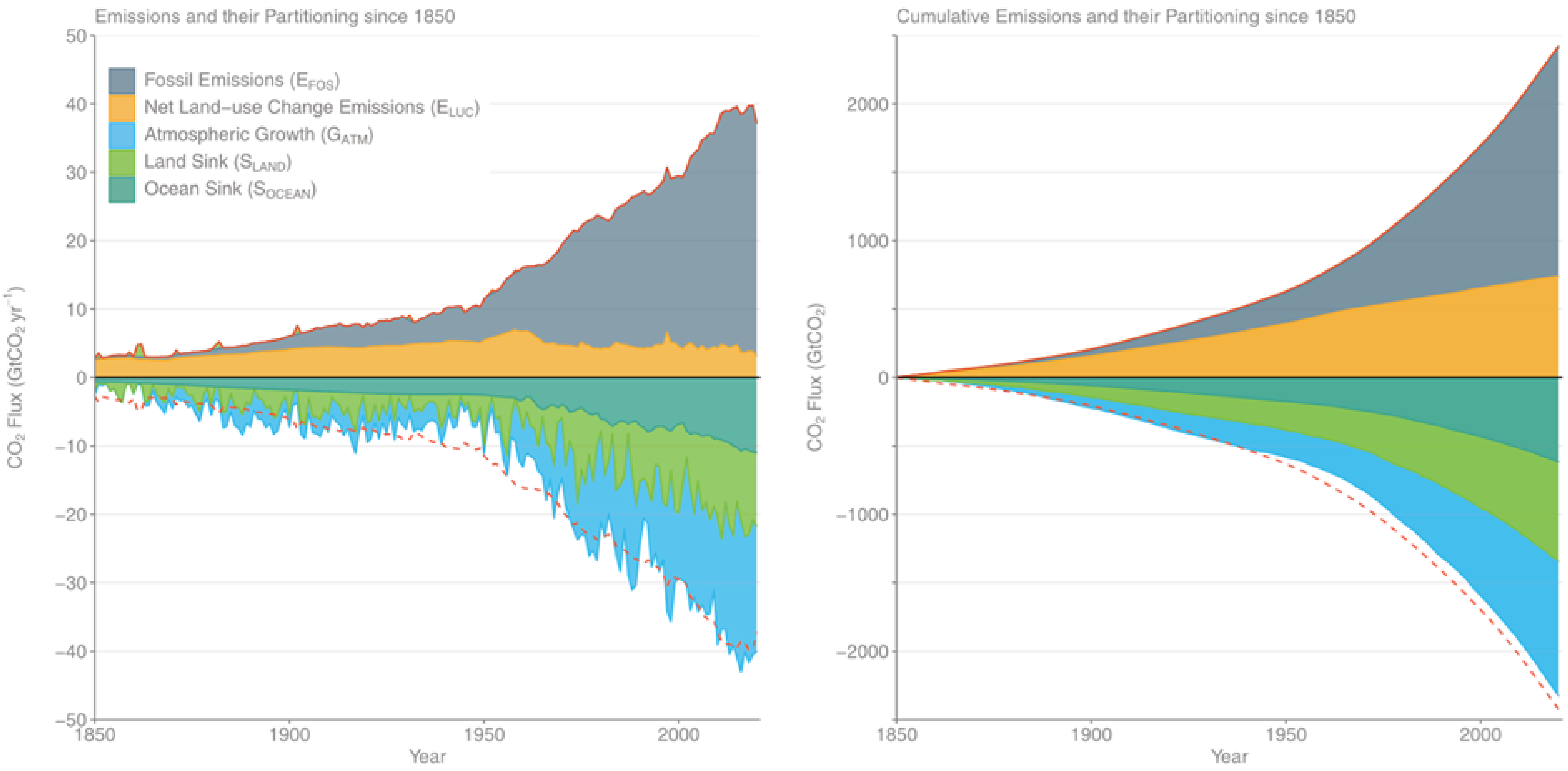


The latest (2021) carbon reservoir and exchange rates (Friedlingstein et al, 2022)

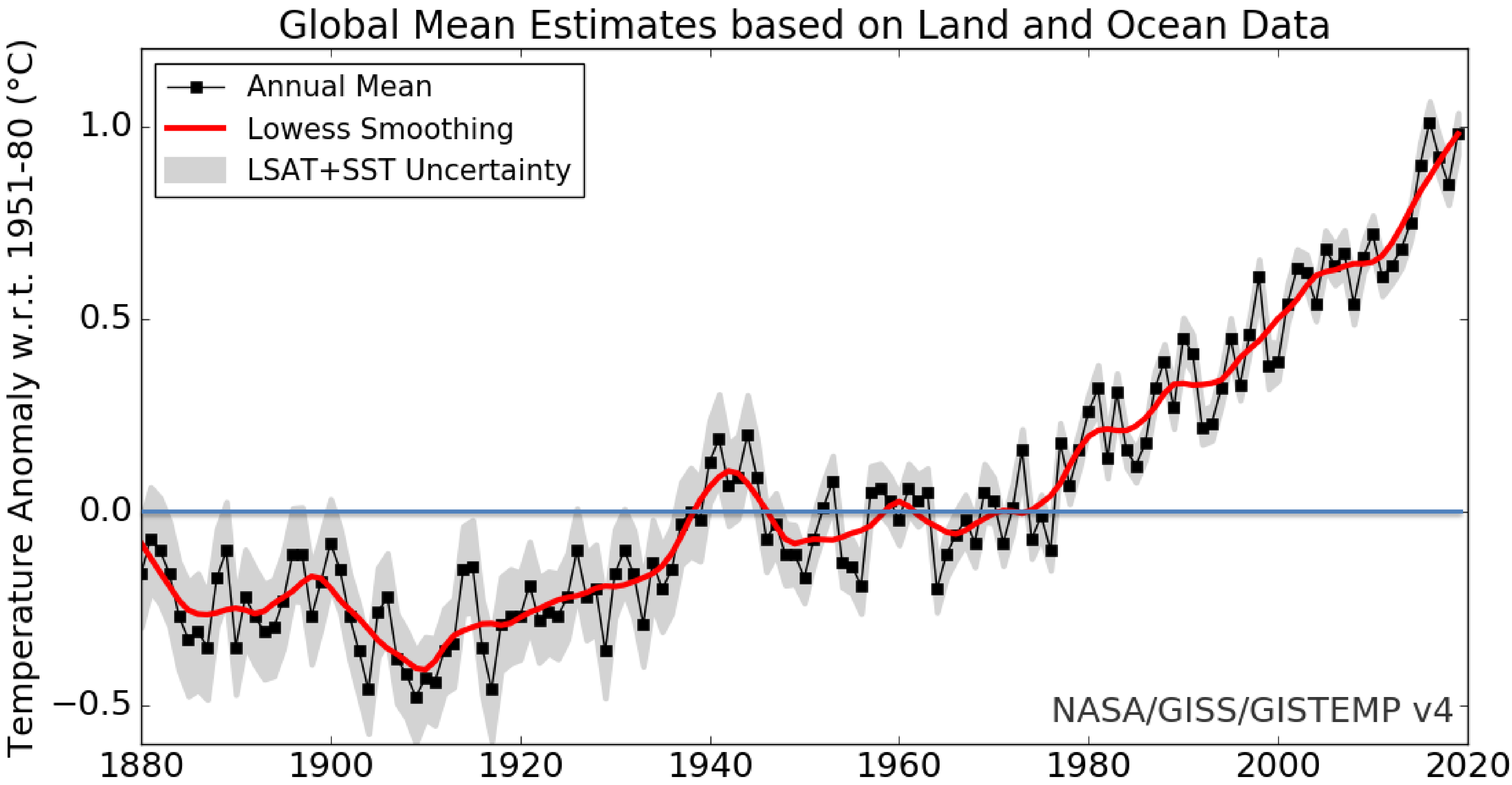
GtC/yr



The latest (2021) carbon growth rates (Friedlingstein et al, 2022)

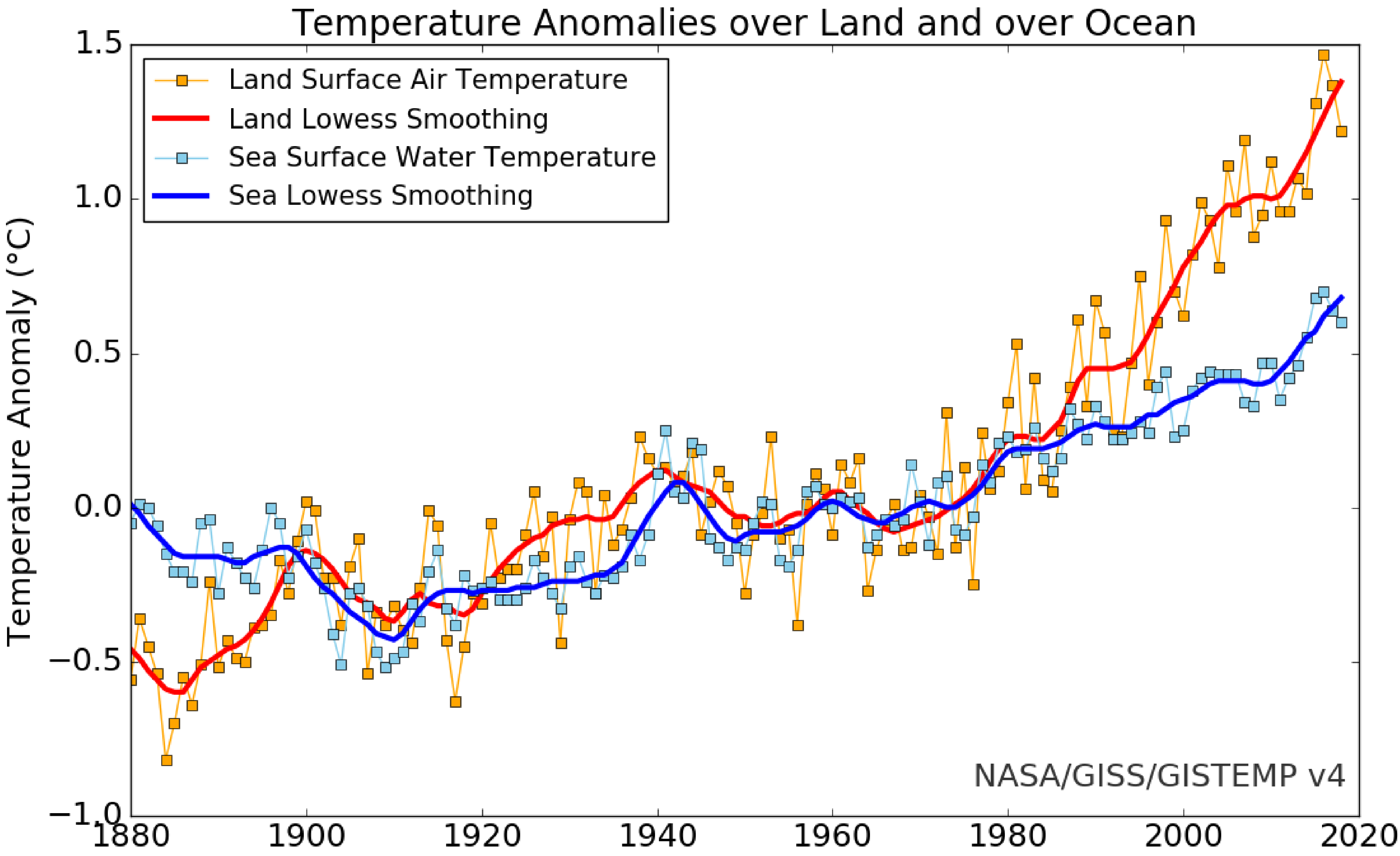


CLIMATE CHANGE



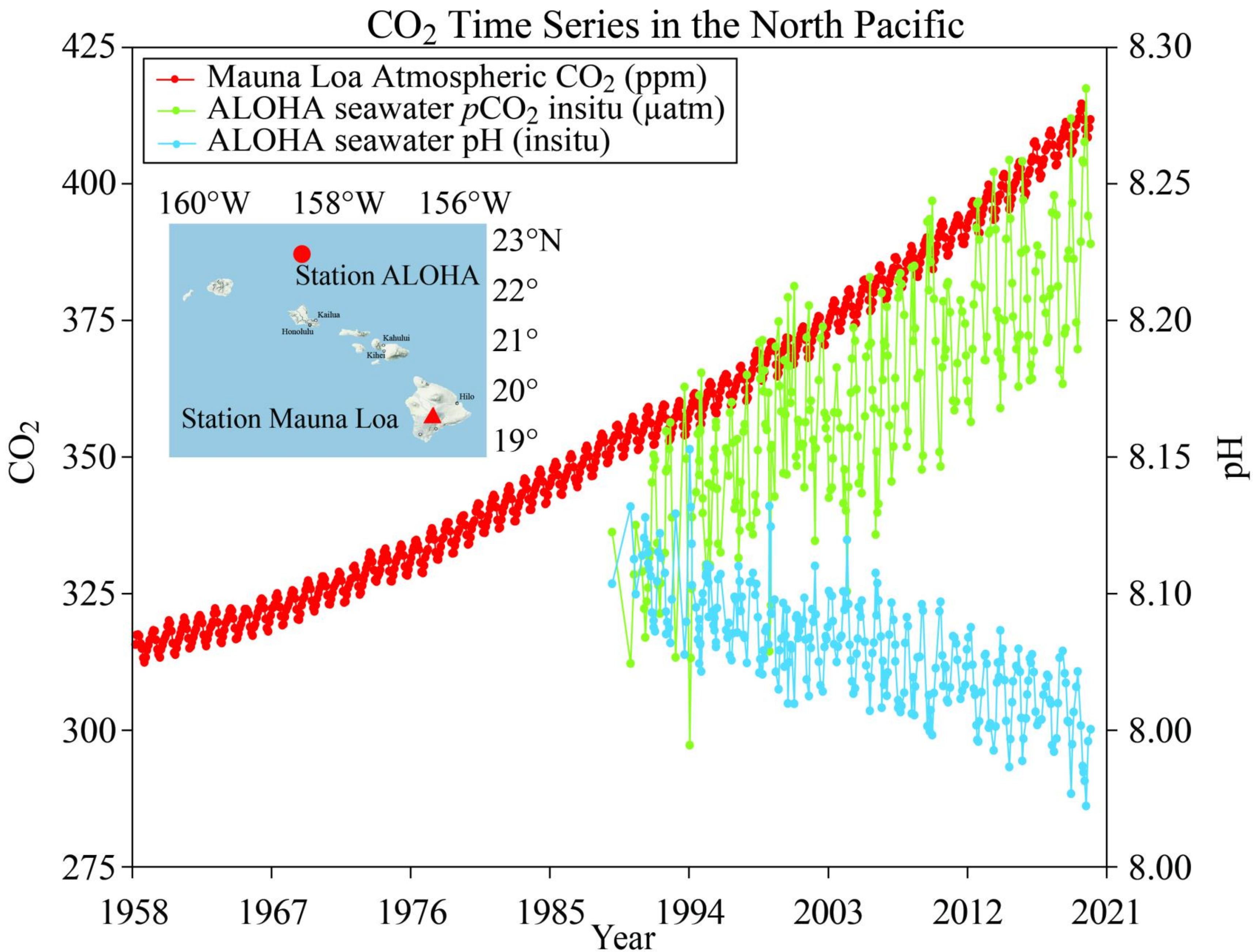
https://data.giss.nasa.gov/gistemp/

THE CLIMATE: LAND VS OCEAN



Ocean Heat Increase ~150 zetaJoules in 30 years

CLIMATE CHANGE: OCEAN ACIDIFICATION



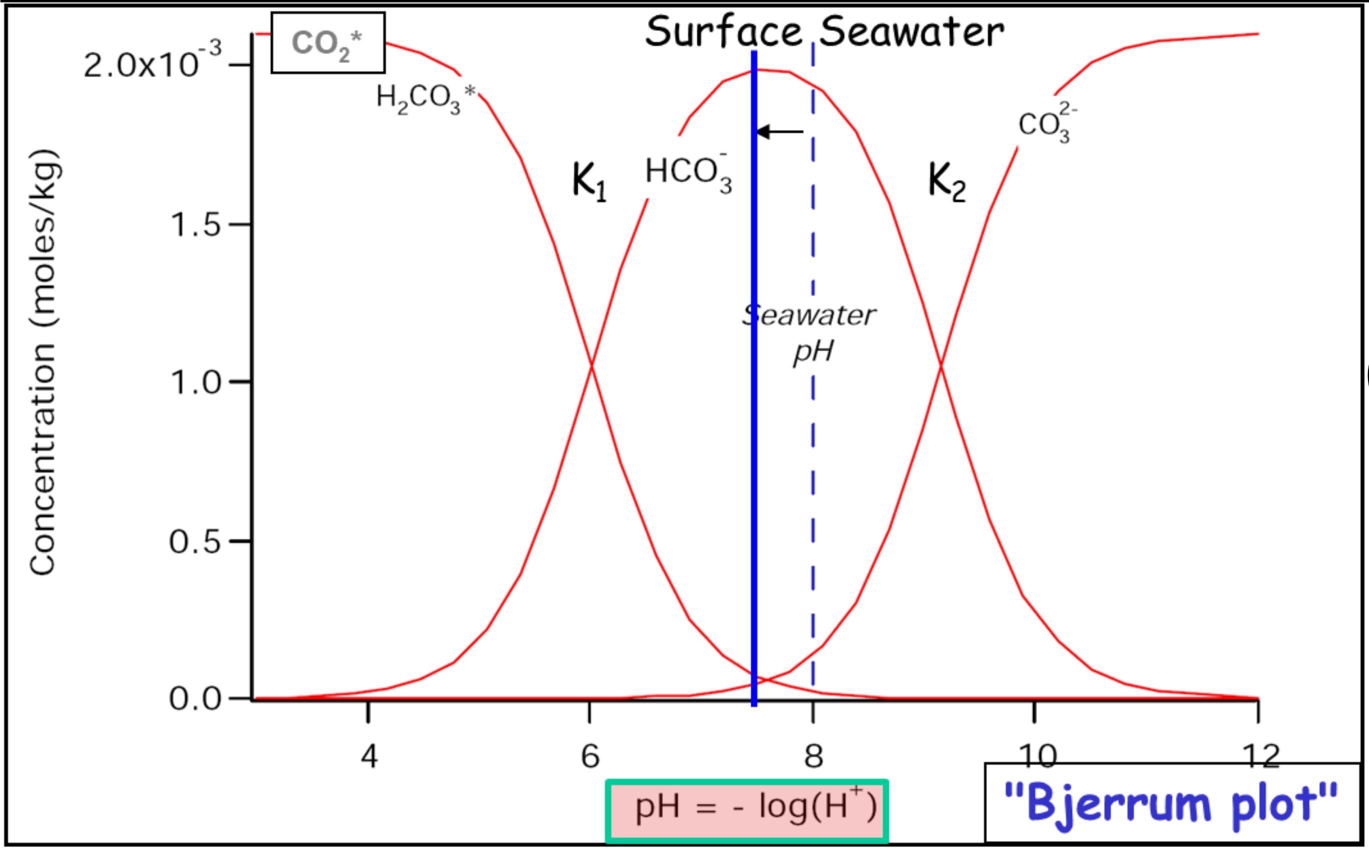
Data: Mauna Loa (ftp://aftp.cmdl.noaa.gov/products/trends/co2/co2_mm_mlo.txt) ALOHA (http://hahana.soest.hawaii.edu/hot/hot-dogs/bextraction.html)
ALOHA pH & pCO_2 are calculated at in-situ temperature from DIC & TA (measured from samples collected on Hawaii Ocean Times-series (HOT) cruises) using co2sys (Pelletier, v25b06) with constants: Lueker et al. 2000, KSO4: Dickson, Total boron: Lee et al. 2010, & KF: seacarb

The Natural Absorption of CO_2 is Resulting in **Ocean Acidification**

Carbon Dioxide — K_1 — Bicarbonate — K_2 — Carbonate

$$CO_2 + H_2O \overset{K_1}{\leftrightarrow} HCO_3^- + H^+ \overset{K_2}{\leftrightarrow} CO_3^{2-} + 2H^+$$

$$CO_2 + H_2O + CO_3^{2-} \Rightarrow 2HCO_3^-$$



Aragonite Saturation

$$\frac{[Ca^{2+}]\times[CO_3^{2-}]}{[CaCO_3]} = \Omega$$

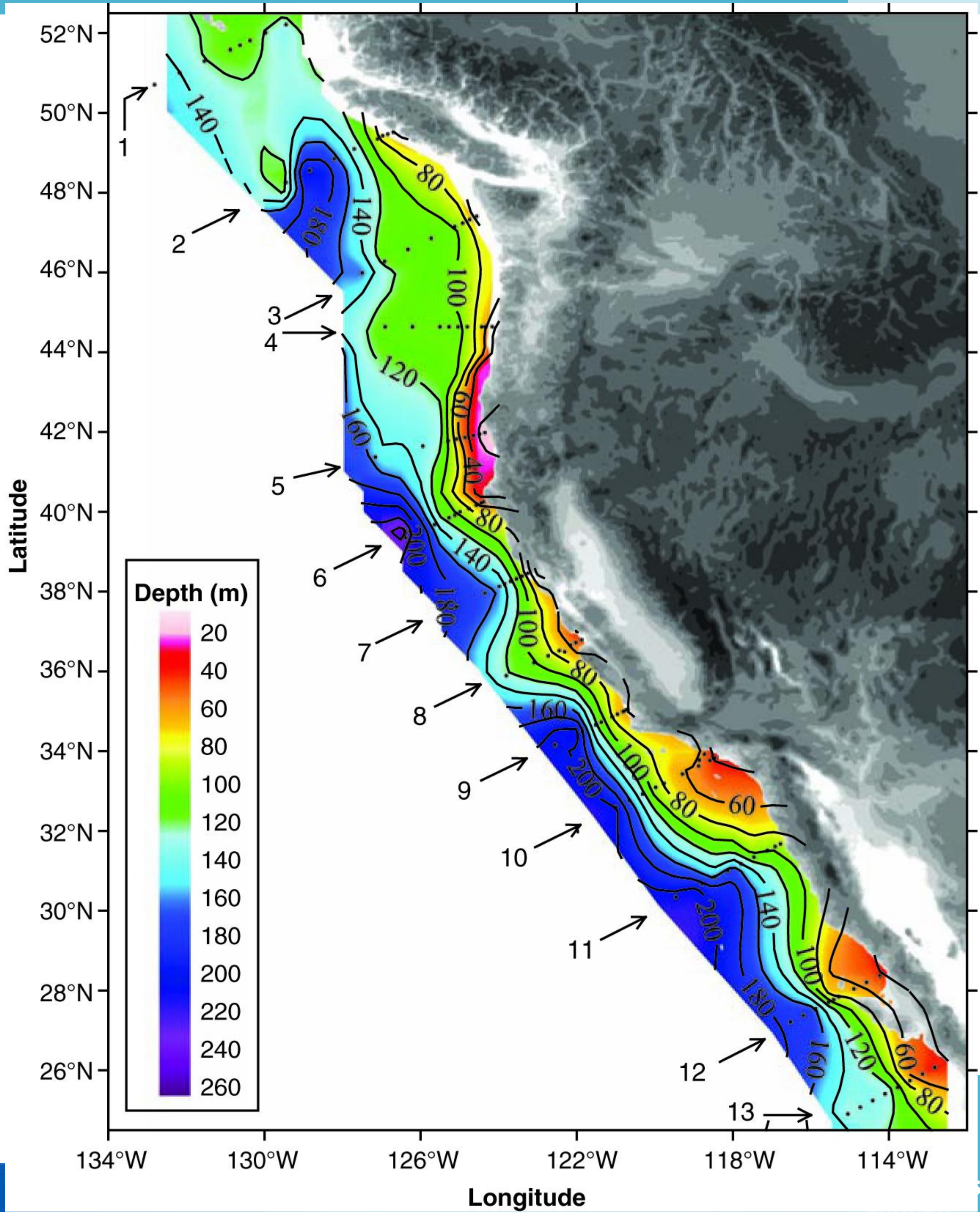
When $\Omega > 1$ (supersaturation) it is easy to build calcium shells.

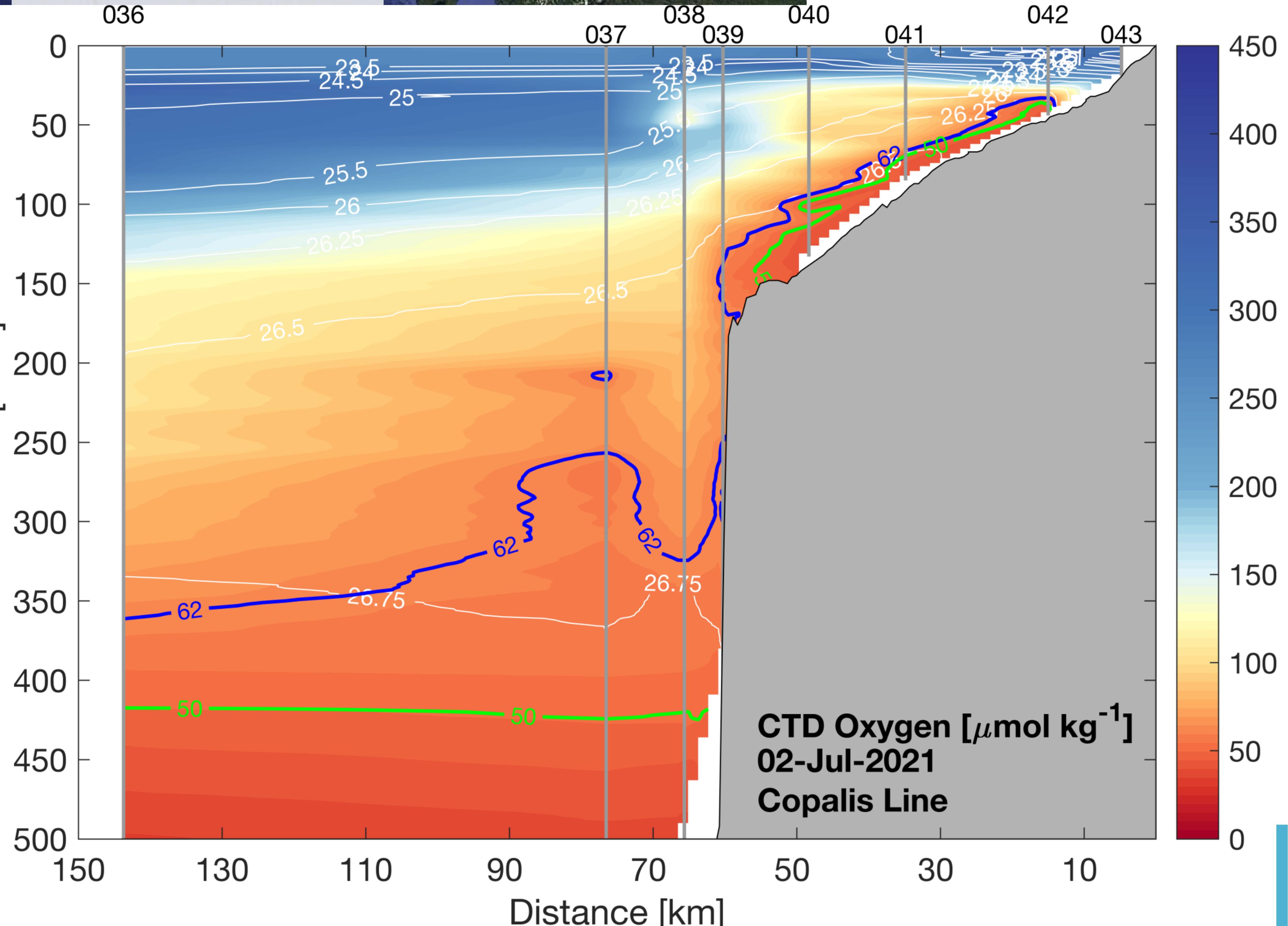
When $\Omega < 1$ shells dissolve.

Since the industrial revolution, 25% of the excess CO_2 has been absorbed by the ocean. Along the NA coast, high CO_2/low pH waters are now regularly upwelling at the coast.

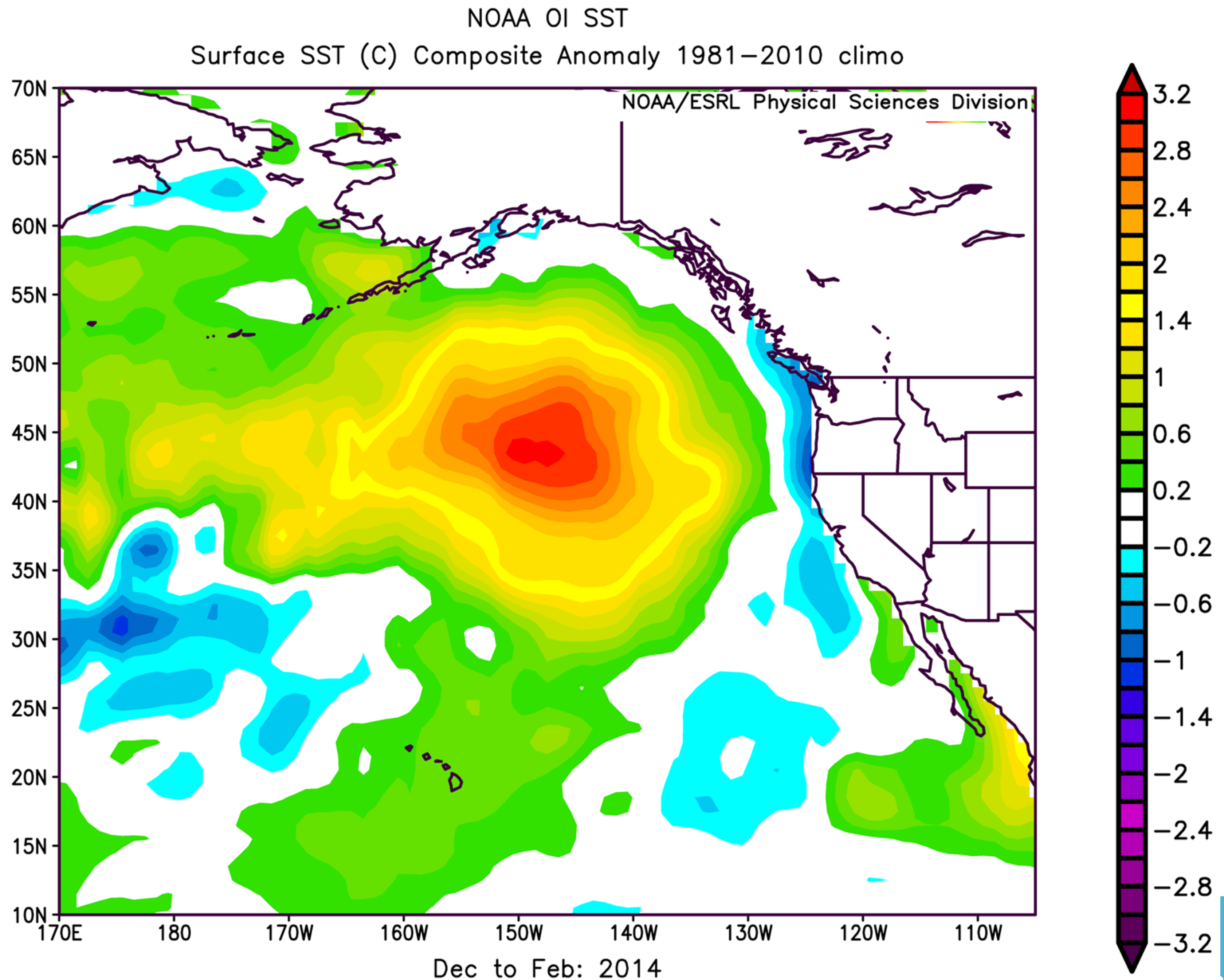
2007 (Feely, PMEL) survey of shallowing acidic waters off the west coast.

Plotted here is the depth of "corrosive" ($\Omega<1$), low pH (<7.75) waters upwelling along the coast in May-June 2007.




036
037
038
039
040
041
042
043
CTD Oxygen [μmol kg-1]
02-Jul-2021
Copalis Line
Distance [km]
150
130
110
90
70
50
30
10
0
50
100
150
200
250
300
350
400
450
500
62
50
26.75
26.5
26.25
26
25.5
25
24.5
23.5

The Warming Ocean: The Blob of 2014



http://www.esrl.noaa.gov/psd/ ~ 1 zetaJoule (10^{21}J)

Typical Conditions: Atmosphere and Ocean NEP

January

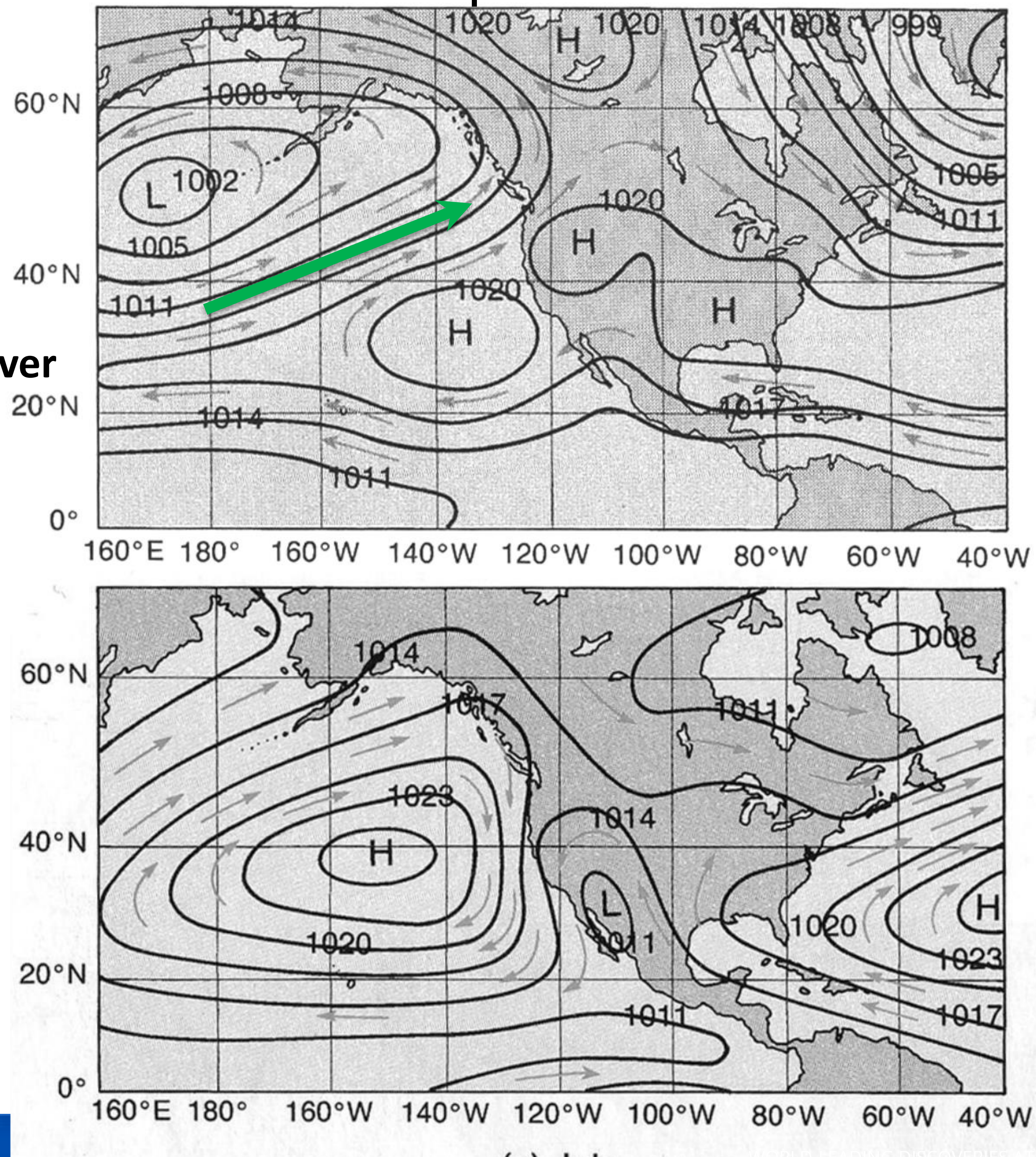
The Pineapple Express Atmospheric River

Storm Track

Aleutian Low

July

North Pacific High



(a) July

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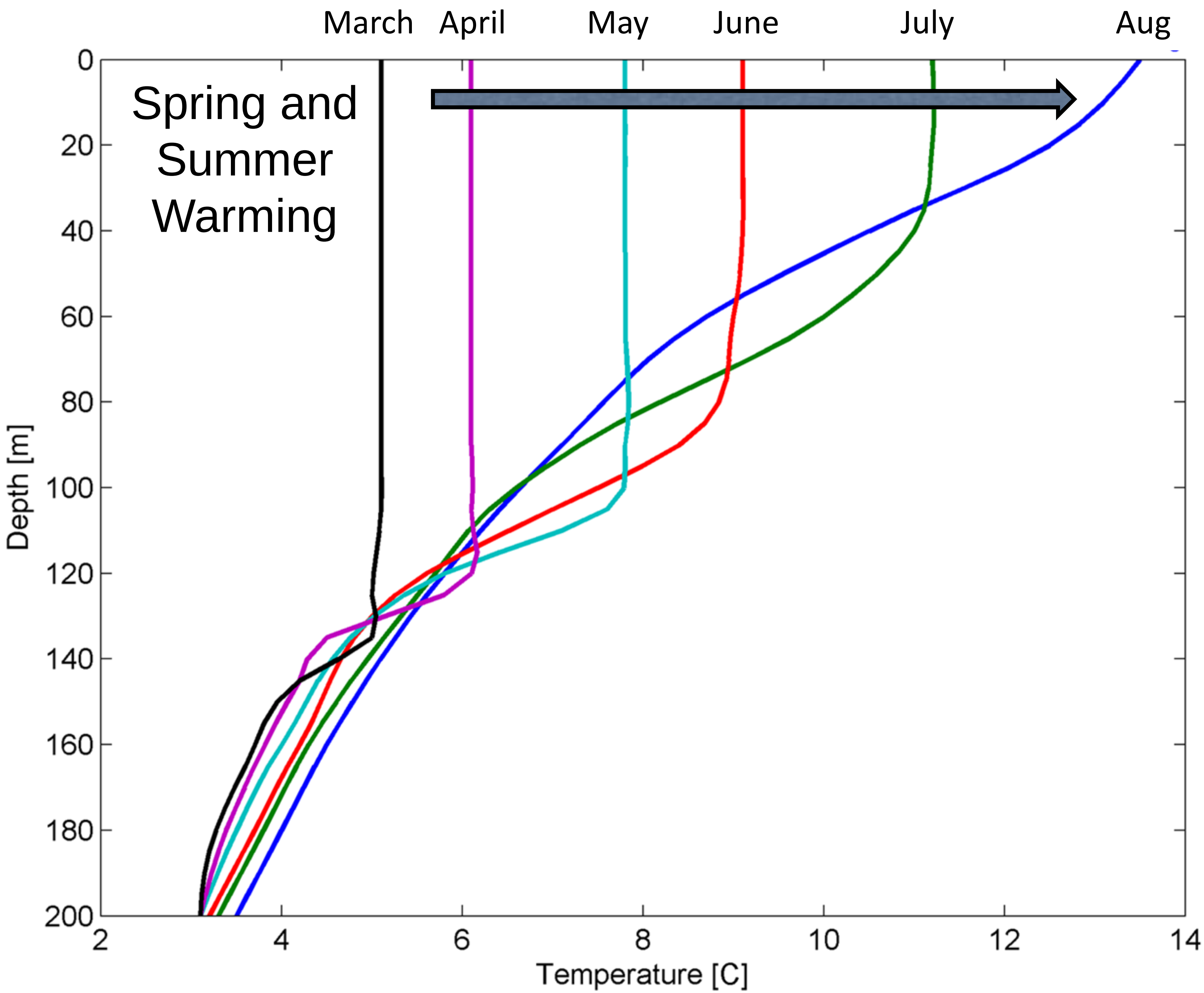
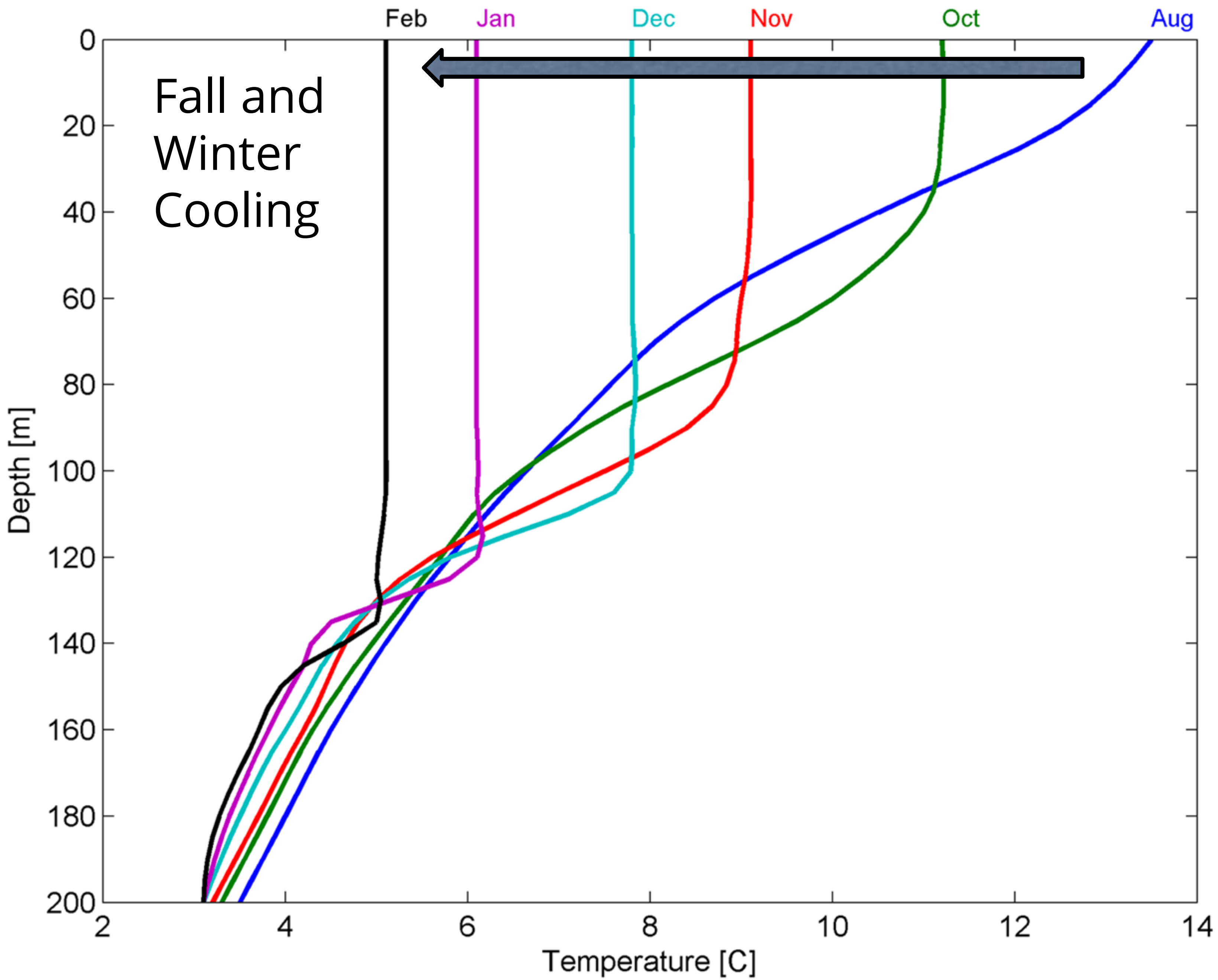
Typical Aleutian Low Winds and Storms → Good surf along Vancouver Island (Oct-Nov)

Surfing competition at Tofino, Vancouver Island, Nov 2005.

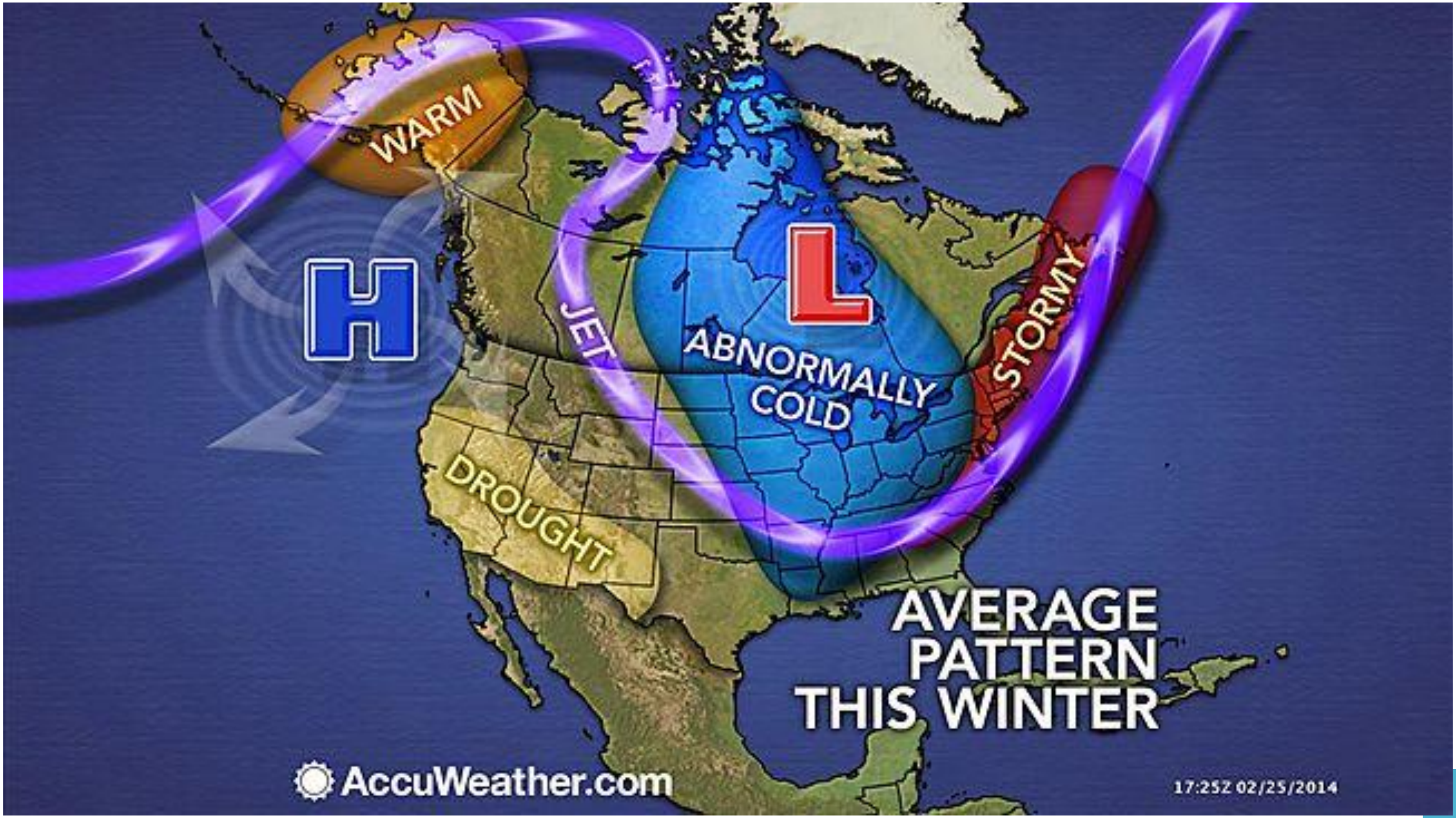

March
April
May
June
July
Aug
Spring and Summer Warming
0
20
40
60
80
100
120
140
160
180
200
Depth [m]
2
4
6
8
10
12
14
Temperature [C]


Feb
Jan
Dec
Nov
Oct
Aug
Fall and Winter Cooling
Depth [m]
0
20
40
60
80
100
120
140
160
180
200
2
4
6
8
10
12
14
Temperature [C]

2013-2014

Large Scale Atmospheric Circulations/Strom Tracks

- Arctic Vortex (Weak Arctic Low)
- Omega Blocking (Ridiculously Resilient Ridge)



The winter of 2013-14 had:

Weak Aleutian Low

High pressure ridge,

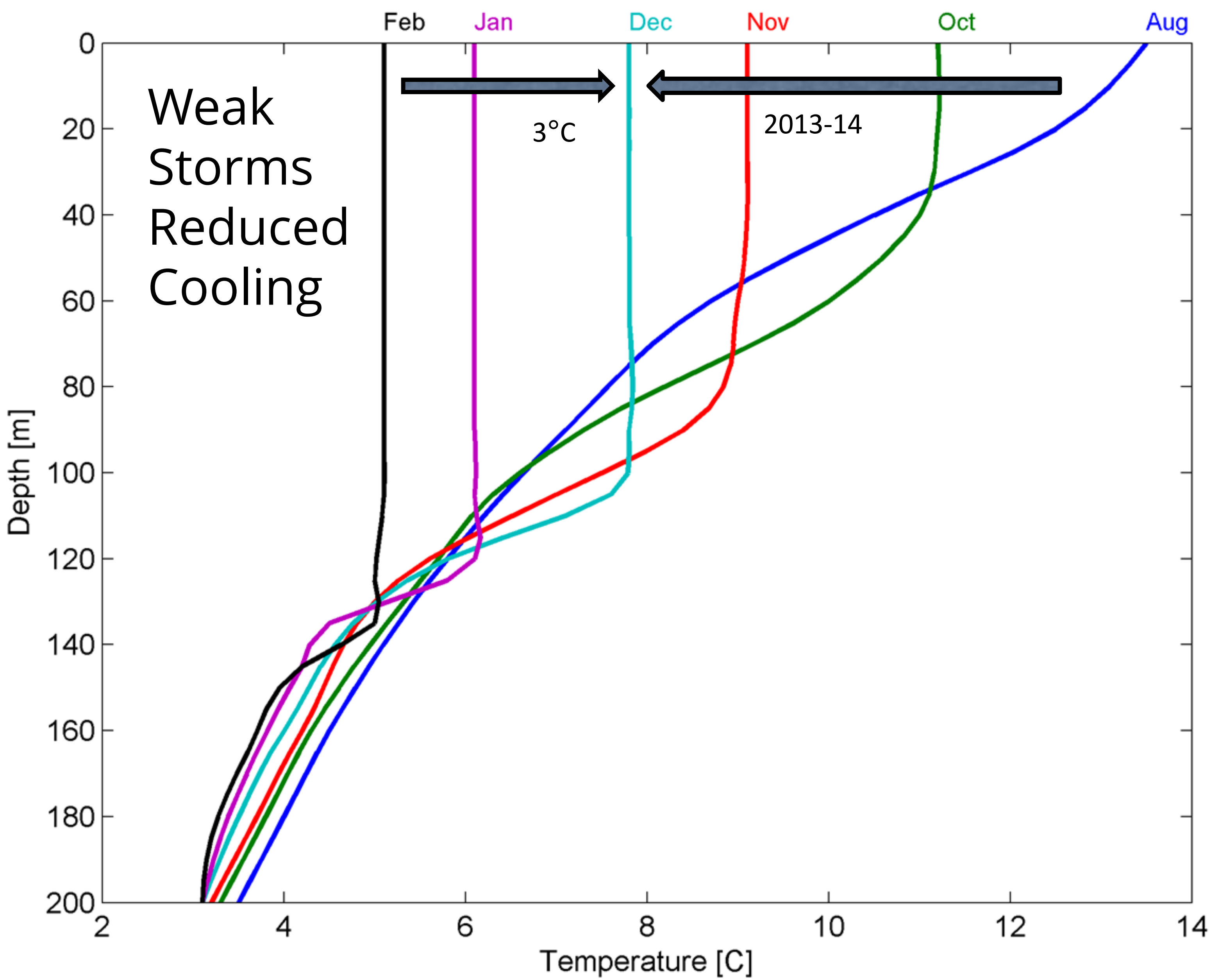
Reduced winds,

Fewer storms,

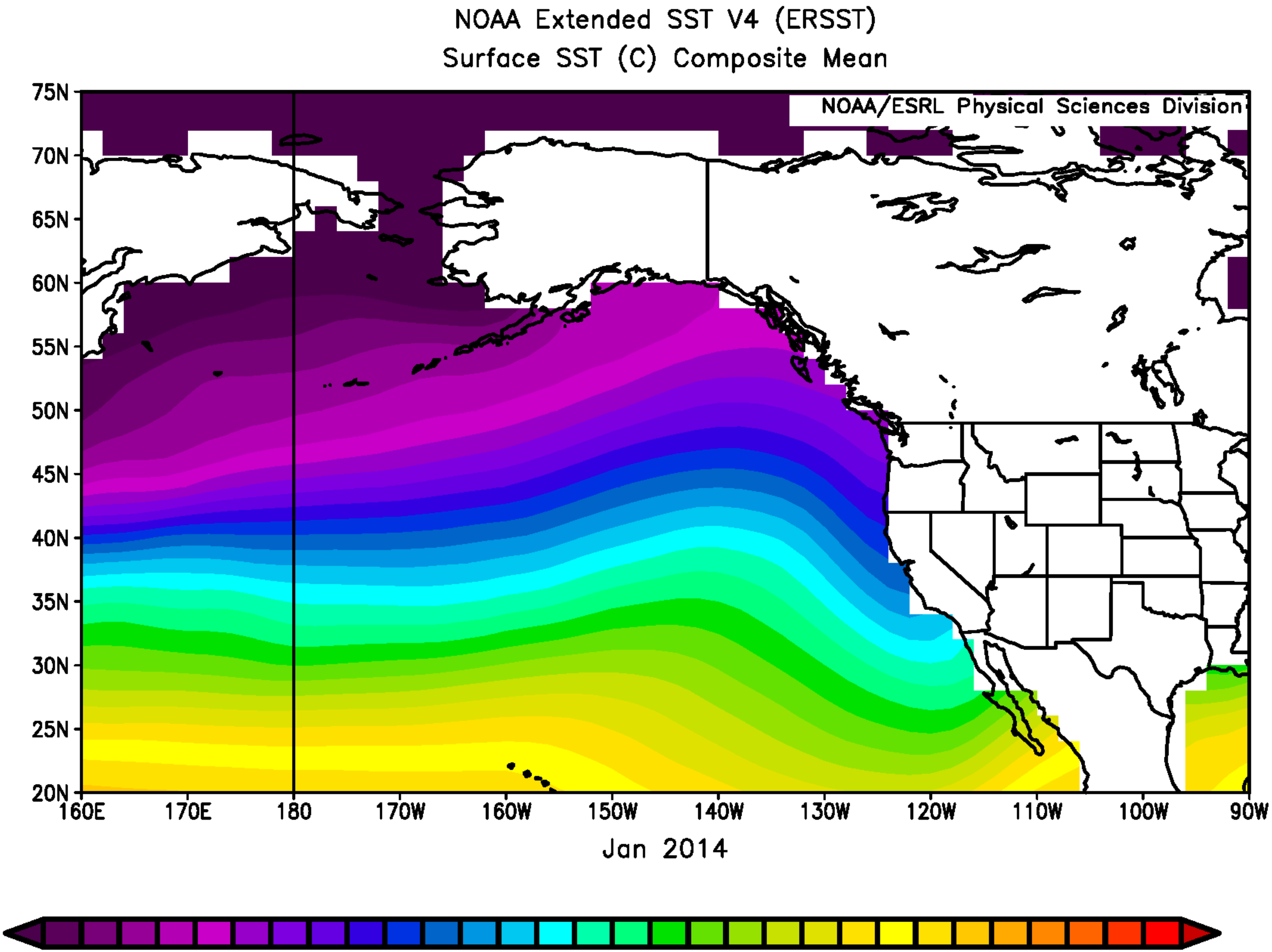
Reduced waves,

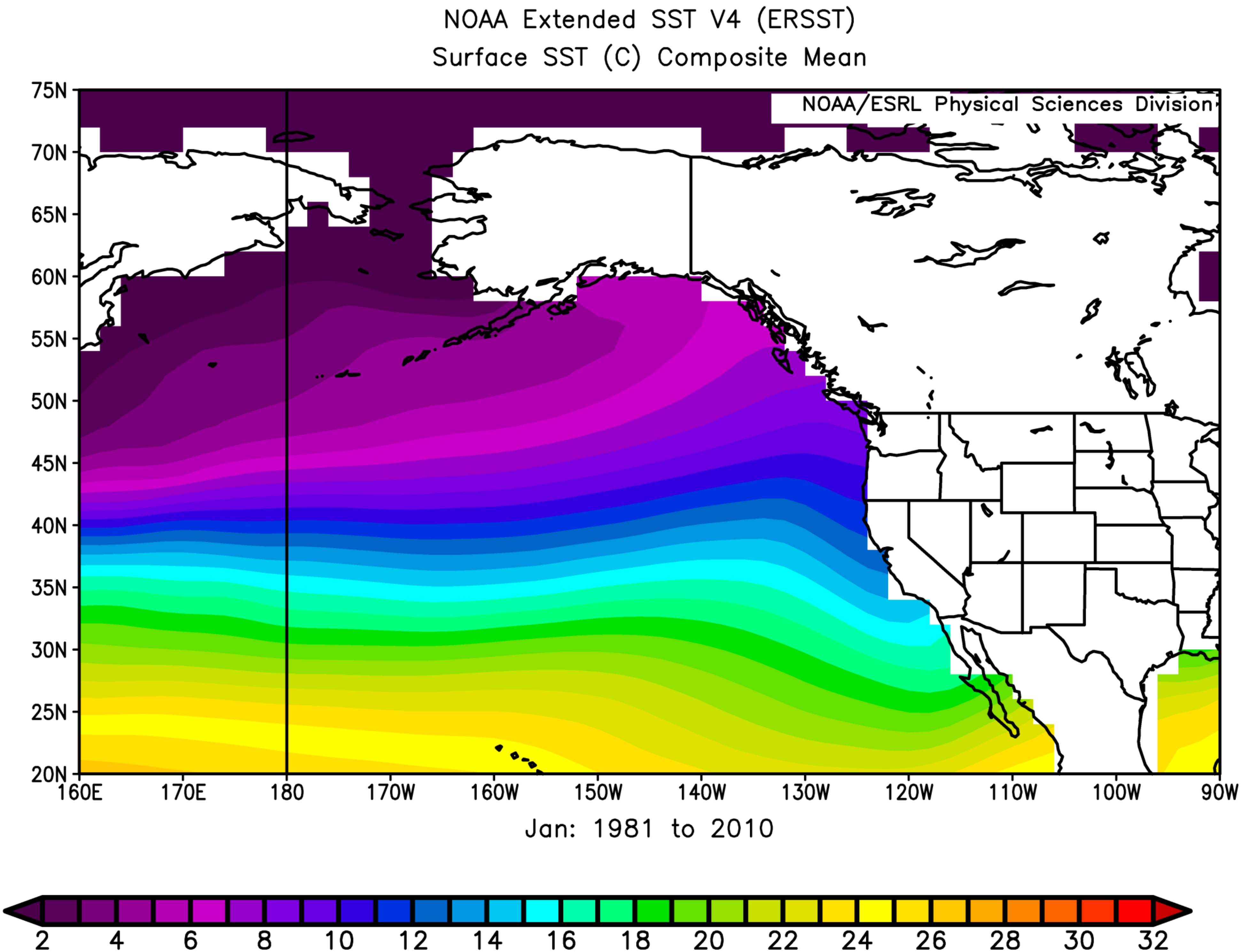
Poor Surfing ☹

The surfers knew something was happening (in Nov ’13) before the oceanographers (~April ’14)

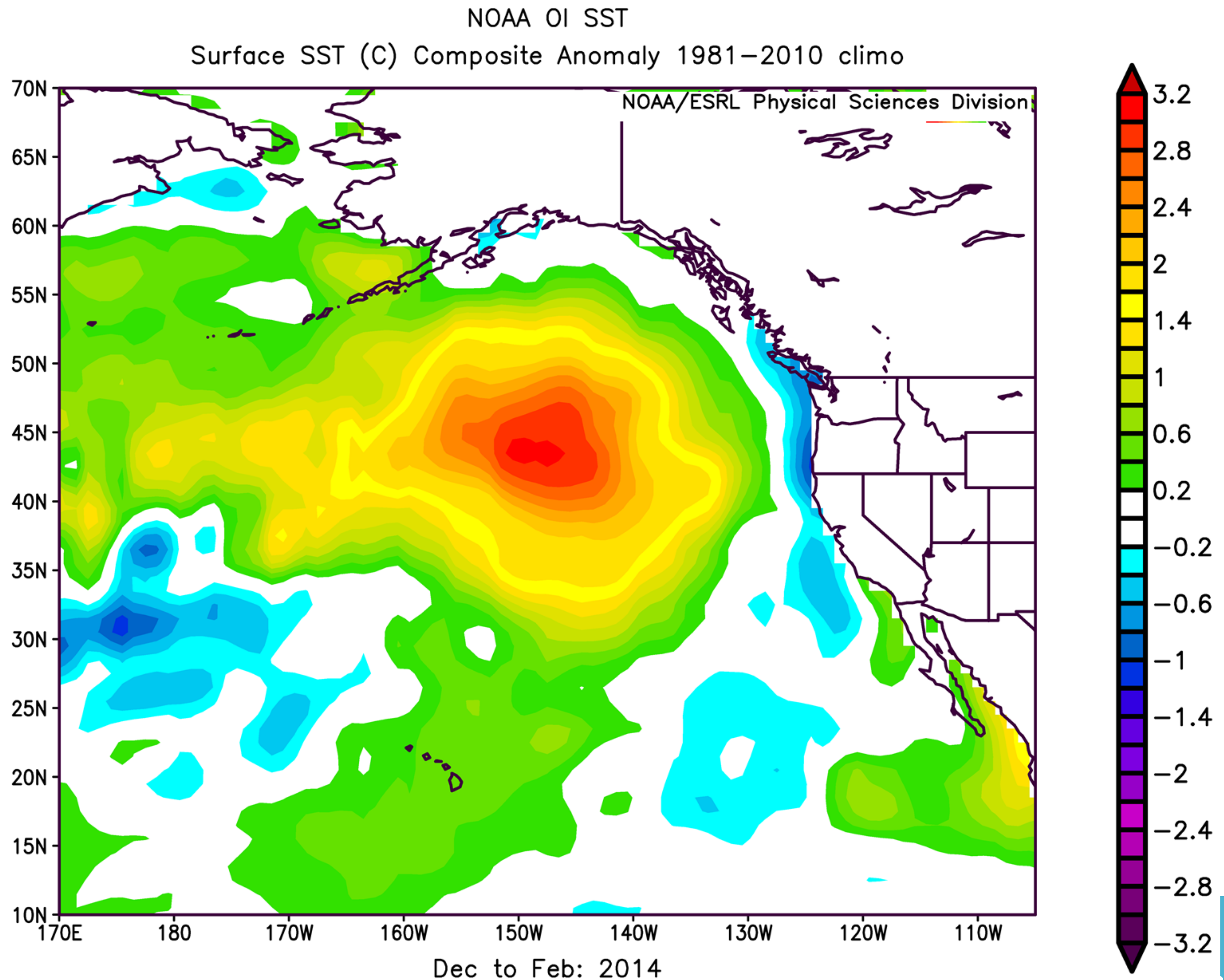


Feb
Jan
Dec
Nov
Oct
Aug
Weak Storms Reduced Cooling
3°C
2013-14
Depth [m]
Temperature [C]
0
20
40
60
80
100
120
140
160
180
200
2
4
6
8
10
12
14


NOAA Extended SST V4 (ERSST)
Surface SST (C) Composite Mean
NOAA/ESRL Physical Sciences Division
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
160E
170E
180
170W
160W
150W
140W
130W
120W
110W
100W
90W
Jan 2014
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

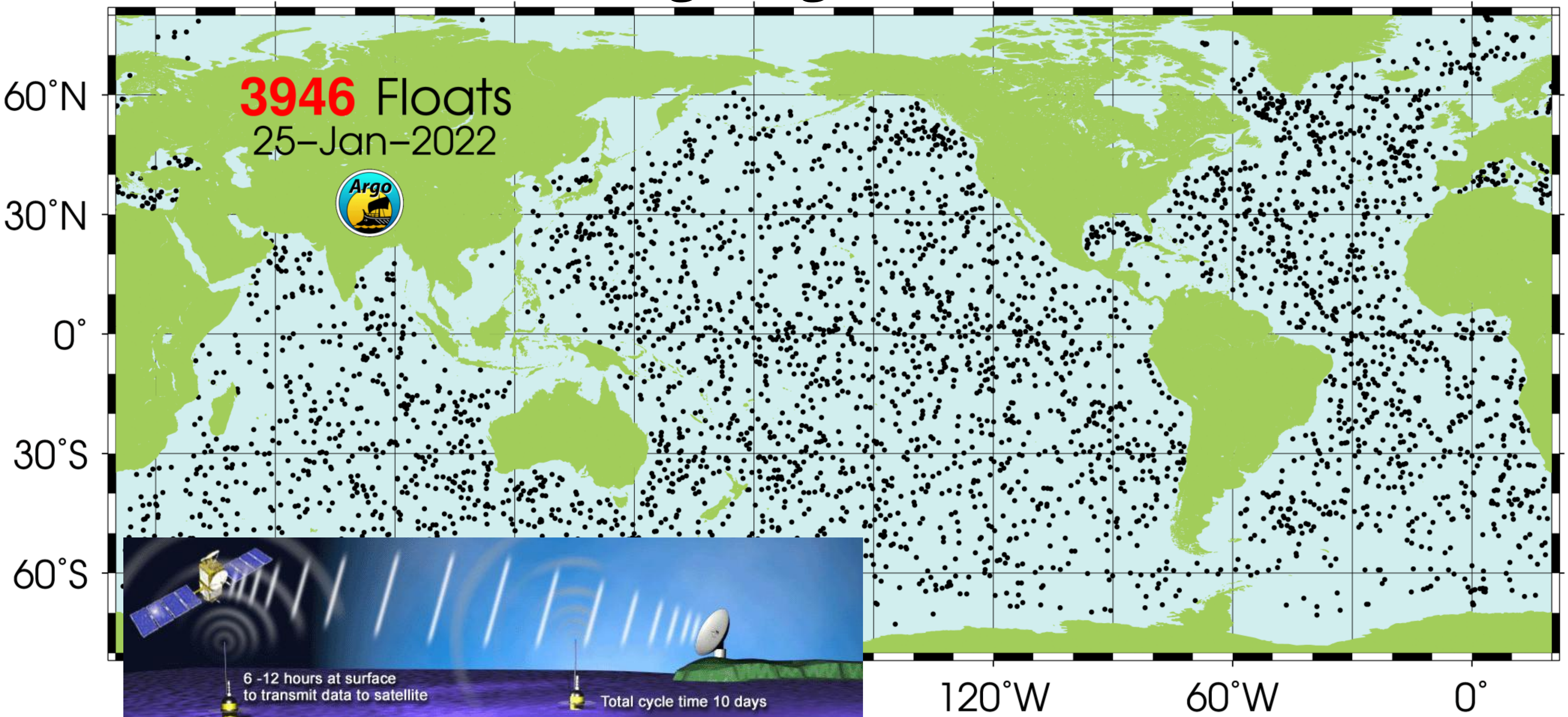

NOAA Extended SST V4 (ERSST)
Surface SST (C) Composite Mean
NOAA/ESRL Physical Sciences Division
75N
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
160E 170E 180 170W 160W 150W 140W 130W 120W 110W 100W 90W
Jan: 1981 to 2010
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32

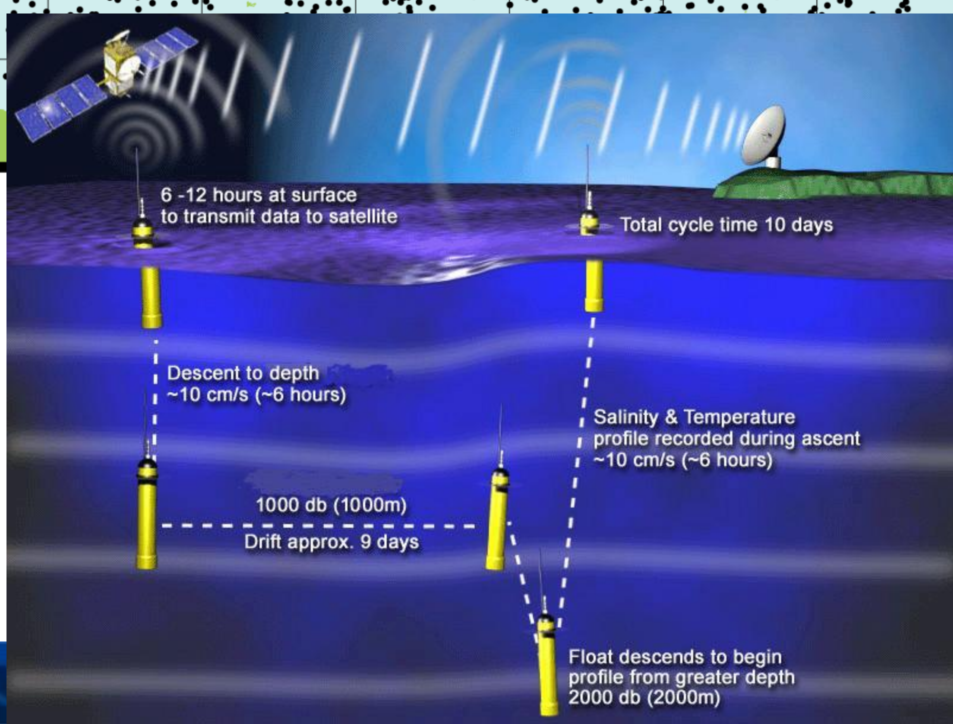
The Blob of 2014



http://www.esrl.noaa.gov/psd/ ~10^{21} J

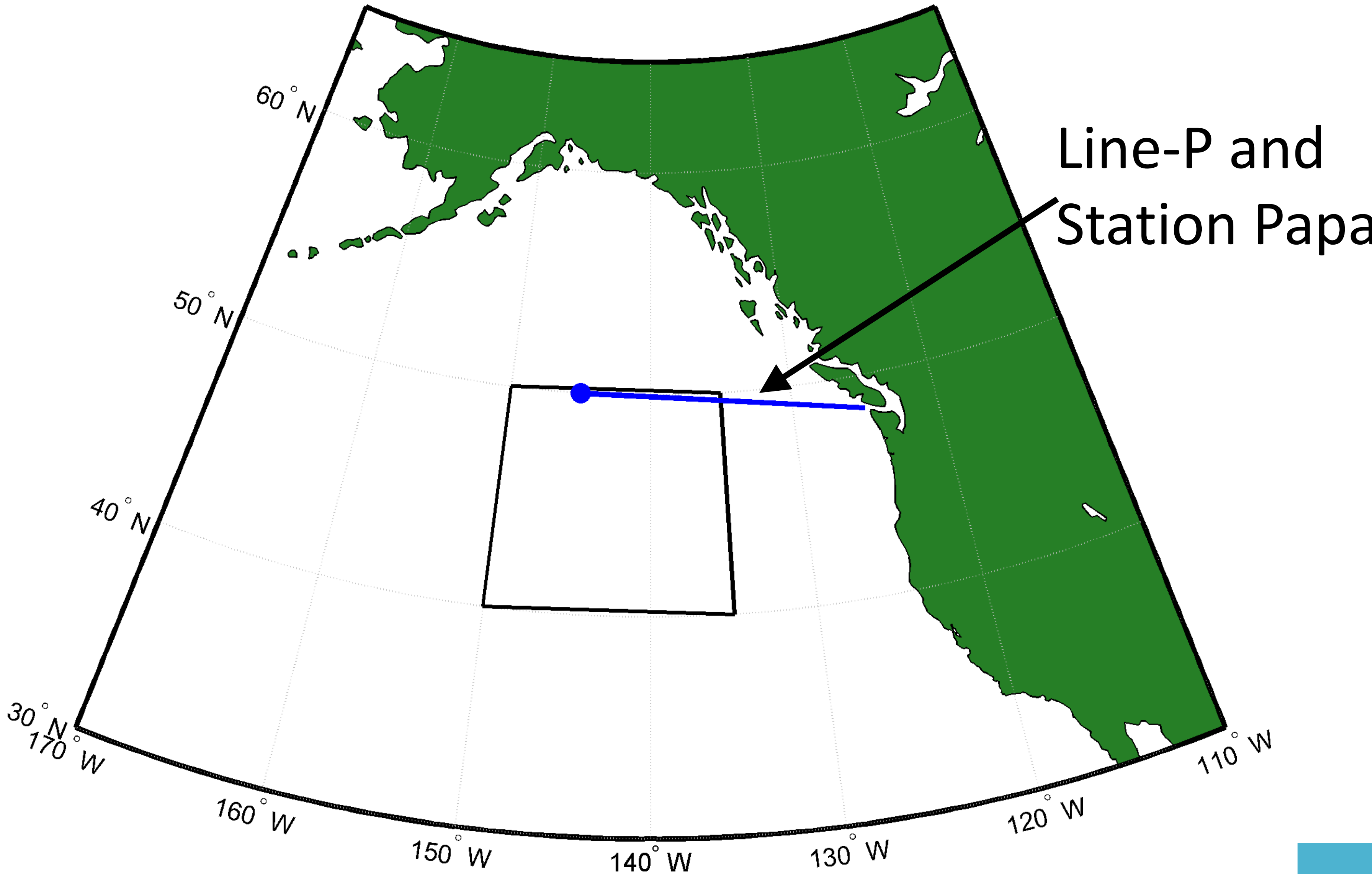
Sub-Surface Warming? Argo Ocean Drifters

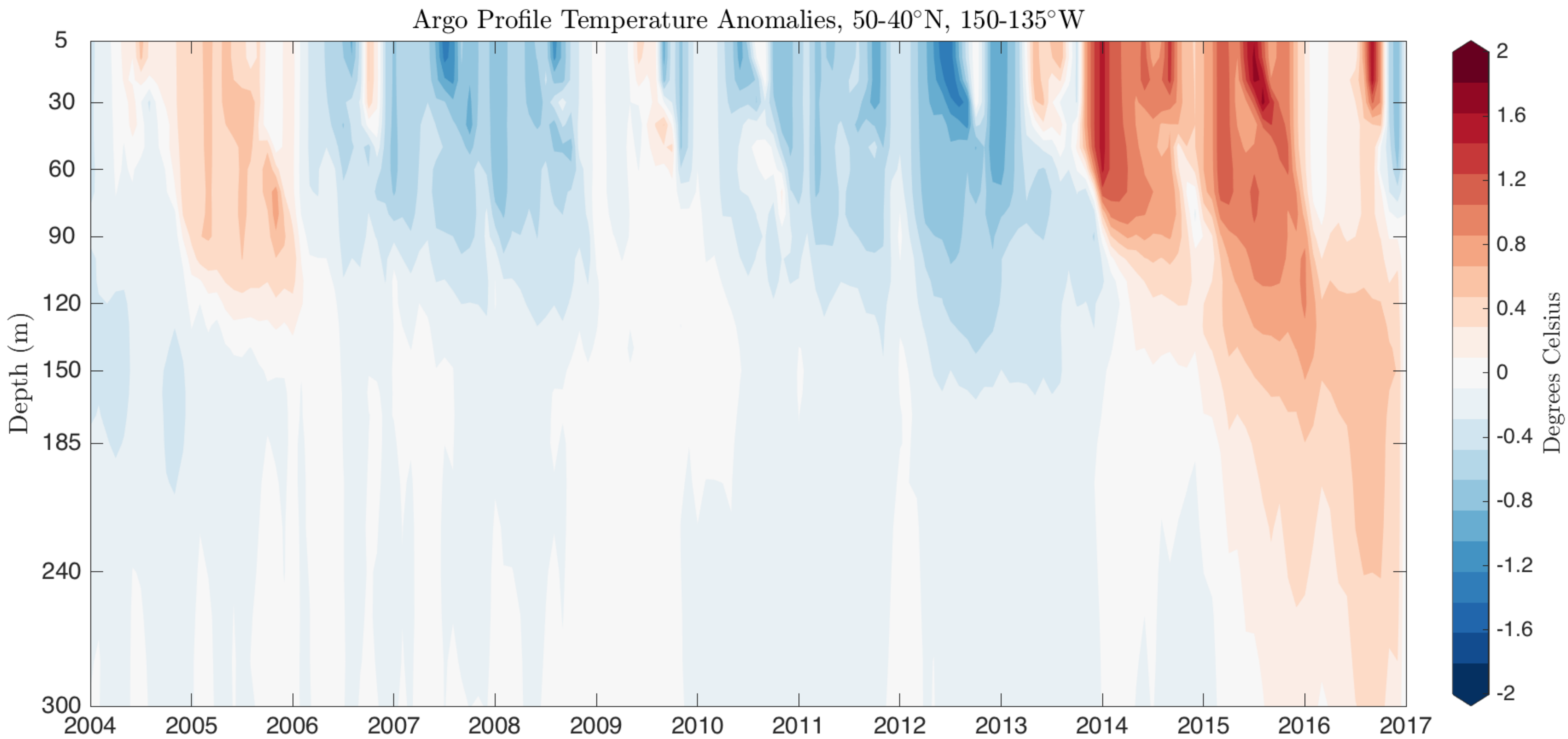




Argo (autonomous) floats, profile the ocean and report on the upper 1000m every two weeks.

Sub-surface temperatures from Argo floats

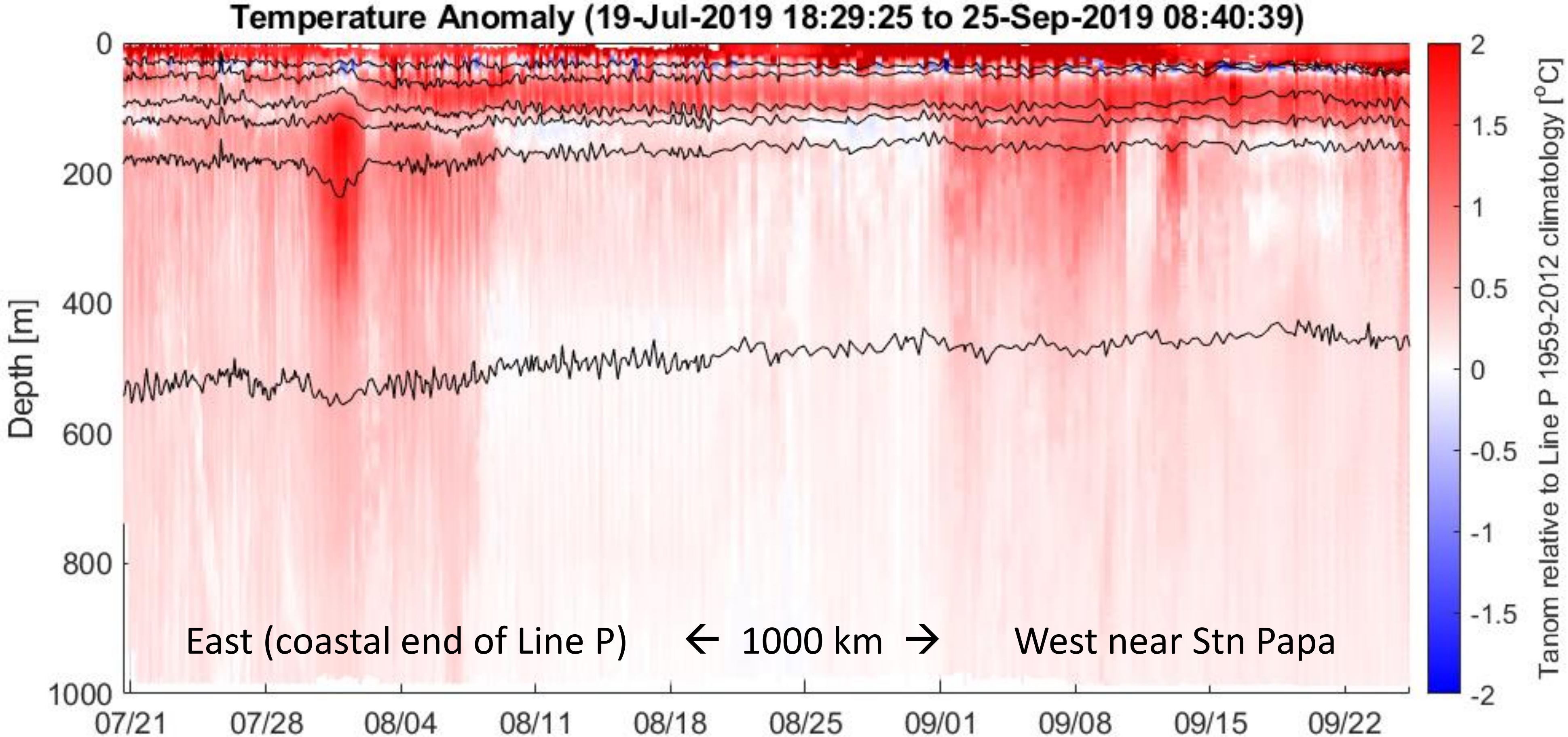




Generated by Dillon Amaya, Scripps

Surface signature gone (exported to the coast) by early 2017, but significant heat remains at depth. Recent observations (2019-21), anomalous heat (0.5-1.0°C) has penetrated to depths of 500-700m. In four years, upper 1000m has heated significantly.

BY 2019 HEAT IS PENETRATING TO 1000M!



So… 1) The Ocean is warming (top-down) to significant depths

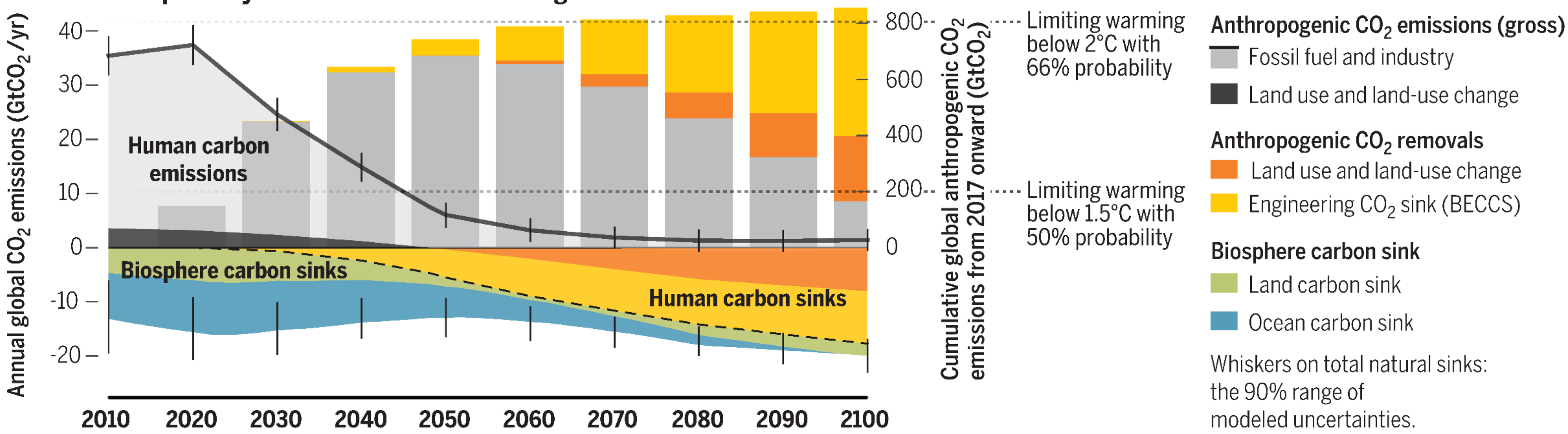
2) The Ocean is absorbing CO_2 and becoming more acidic

3) The extra carbon requires more respiration, lowering O_2

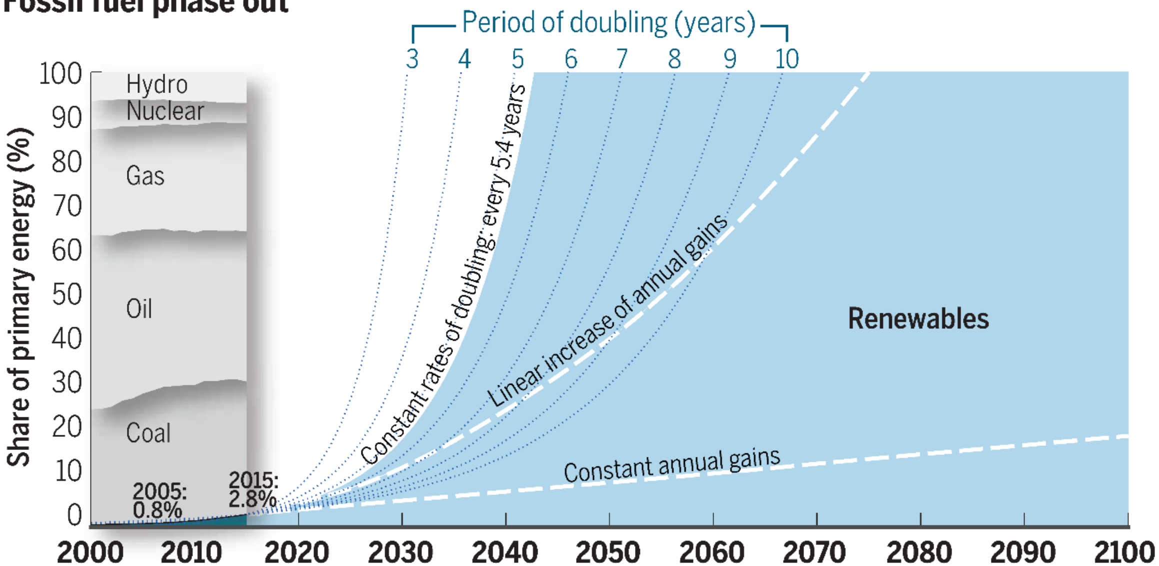
→ Mitigation and Adaptation

THE SCALE OF THE PROBLEM

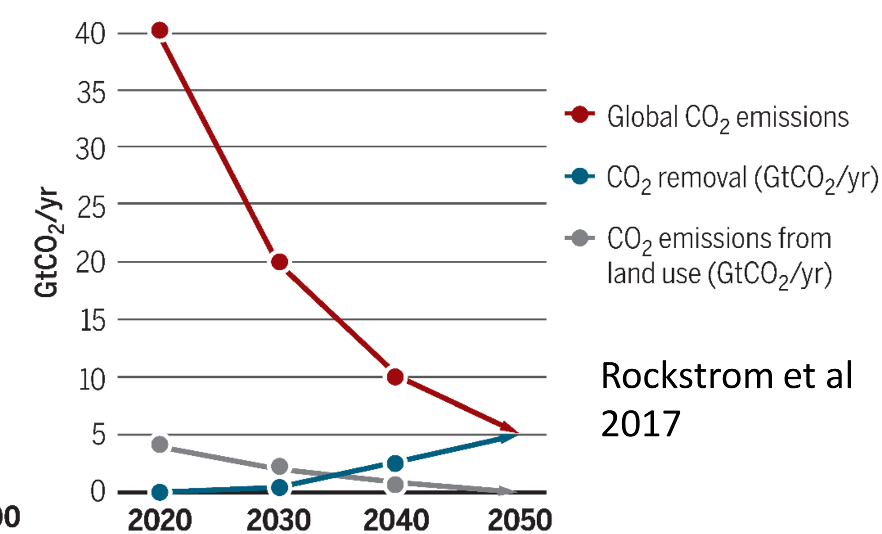
Decarbonization pathway consistent with the Paris agreement



Fossil fuel phase out



Global carbon law guiding decadal pathways



(**Top**) A deep decarbonization scenario scientifically consistent with the Paris Agreement (*3*) and its associated carbon fluxes as computed with a simple carbon cycle and climate model (*13*). The "carbon law" scenario of halving emissions every decade is marginally more ambitious than the scenario presented. Meeting the Paris Agreement goals will require bending the global curve of CO_2 emissions by 2020 and reaching net-zero emissions by 2050. It furthermore depends on rising anthropogenic carbon sinks, from bioenergy carbon capture and storage (BECCS) engineering (yellow) and land use (orange), as well as sustained natural sinks, to stabilize global temperatures. This scenario is broadly consistent

Mitigation (& Adaptation)
Ocean-Based Carbon Removal and Sequestration

Mitigation: Actions (or inactions, e.g. coal, oil, and gas development) taken to avoid, reduce, and/or minimize the harmful impacts associated with increasing atmospheric CO_2 levels and climate change.

0) Reduce CO_2 Emissions
   - Must happen regardless of other mitigation actions
   - Mitigation should not provide "a pass" on emission reductions
1) Protection (and possibly enhancement) of natural carbon sinks (ecosystems)
2) Improve efficiency, distribution, economies, habits, etc.
3) Enhanced carbon capture and long-term storage (sequestration)
4) Change the GHG forcing: albedo, solar shading, geoengineering, etc.

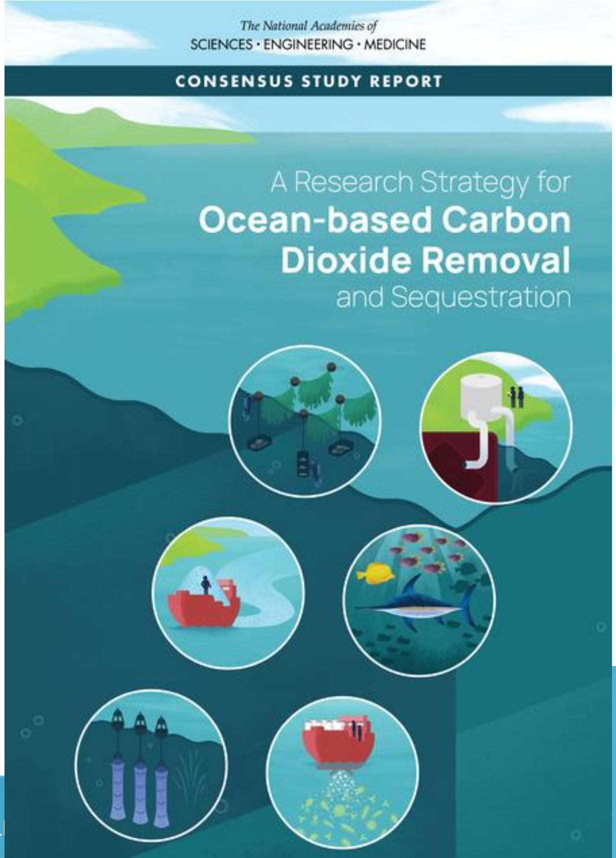
A recent (2021) report prepared for the US National Academies of Sciences, Engineering, and Medicine:

"A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration"

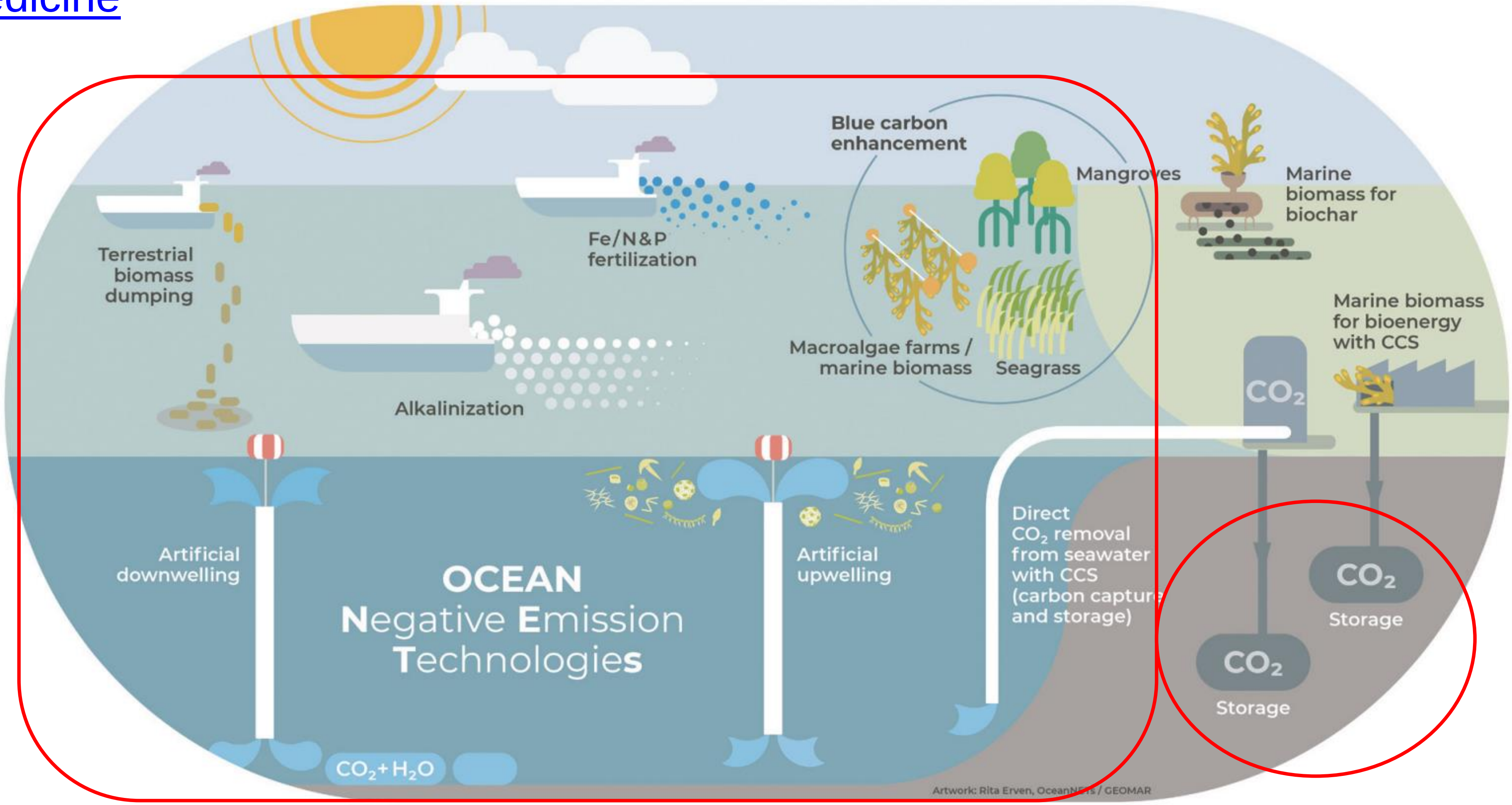
- 300 pages (but still limited and incomplete)
- Most urgent issues, for a few likely/proposed solutions
- Identified the potential costs, benefits, and risks

Reviewed six (6) major categories:

1) Ocean fertilization
2) Artificial up- and down-welling
3) Seaweed cultivation
4) Recovery of critical ecosystems
5) Alkalinity enhancement
6) Electrochemical approaches



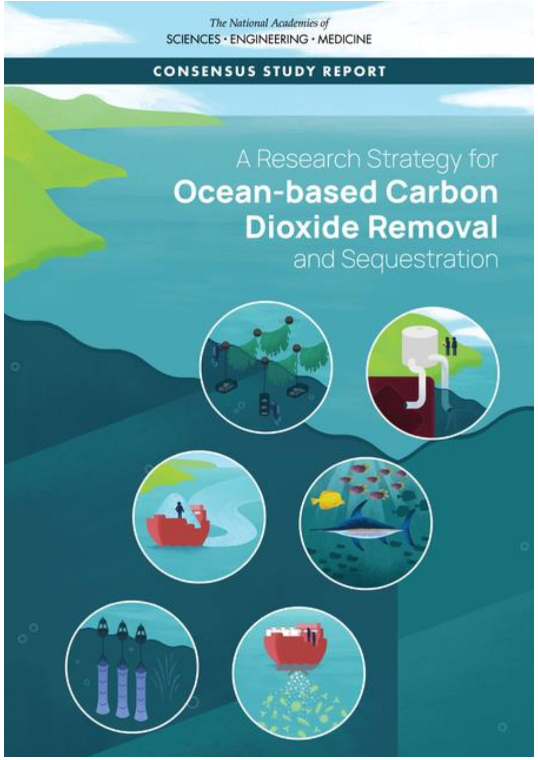
"Natural processes on land and ocean have removed roughly 55% of emitted CO_2, but it may be possible to enhance both the uptake and longer-term sequestration potential of these processes" – National Academies of Sciences, Engineering, and Medicine



Ocean Negative Emission Technologies (NETs) explored by Ocean Visions

Many NETs approaches are concepts with potentially high disbenefits

"A Research Strategy for Ocean-based Carbon Dioxide Removal and Sequestration"



While the solutions were taken seriously and given a fair assessment, there are few without:

1) Significant/critical **gaps** in knowledge
2) Significant **costs/feasibility** in scaling
3) Significant environmental **side-effect risks**

Only "restoring and maintaining key ecosystems" has few downsides, and should be pursued regardless of net capture and sequestration potential.

However, despite the "apparent" cost,
we can either pay now or pay more later.

SUMMARY: CLIMATE CHANGE AND THE OCEAN

We are seeing rapid changes (adjustments) in the atmosphere and ocean beyond what we might have "expected" (gradual heating/shifts), resulting in major weather and ecosystem impacts on time scales of seasons rather than decades.

Measured ocean responses:

- Warming ocean, deep below surface mixed layer! (thermal expansion may be much faster than thought)
- Increased DIC and ocean acidification (low pH)
- Expanding hypoxic waters upwelling along the coast

Things to watch for:

- More marine heat waves (The Blob 2, it's a franchise)
- Multiple stressors on marine ecosystems (pH, O_2)
- Feed backs between A-O causing changes in weather patterns
    - Changes in heat domes and "atmospheric rivers"

CLIMATE CHANGE AND THE OCEAN

Closing thoughts:

Question: Are the weather/ocean patterns we see now a result of climate change?

Answer: The weather and ocean we observe now has been influenced by recent changes to the climate.

The climate is what you expect,
the (changing climate influenced) weather
is what you get.

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