Air-sea interactions : air-sea gas exchanges

ATM2106

Composition of the Atmosphere near the surface

PERMANENT GASES			VARIABLE GASES			
Gas	Symbol	Percent (by Volume) Dry Air	Gas (and Particles)	Symbol	Percent (by Volume)	Parts per Million (ppm)*
Nitrogen	N_2	78.08	Water vapor	H_2O	0 to 4	
Oxygen	O_2	20.95	Carbon dioxide	CO_2	0.038	385*
Argon	Ar	0.93	Methane	CH_4	0.00017	1.7
Neon	Ne	0.0018	Nitrous oxide	N_2O	0.00003	0.3
Helium	He	0.0005	Ozone	O_3	0.000004	0.04†
Hydrogen	H_2	0.00006	Particles (dust, soot, etc.)		0.000001	0.01−0.15
Xenon	Xe	0.000009	Chlorofluorocarbons (CFCs)		0.00000002	0.0002

*For CO_2, 385 parts per million means that out of every million air molecules, 385 are CO_2 molecules.
†Stratospheric values at altitudes between 11 km and 50 km are about 5 to 12 ppm.

80 km

N : removed by biological processes on land and in the ocean.

: added to the atmosphere through the dealing of plant and animal matter.

O : removed through the organic matter decays and the combination with other substances.

: added during photosynthesis.

From Meteorology Today, 9th edition

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- Higher percentage of H_2O close to the surface in warm, steamy tropical locations.
- The H_2O percentage approaches to zero in the polar regions.
- Water vapor is associated with latent heat, an important source of energy.
- Water vapor is a potent greenhouse gas.

From Meteorology Today, 9th edition

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- Carbon dioxide occupies only 0.038% of the atmosphere.
- Its source is the decay of vegetation, volcanic eruptions and burning fossil fuels.
- The removal of CO_2 is done through photosynthesis by plants on land and in the ocean.
- It is also directly dissolved by the surface water.

From Meteorology Today, 9th edition

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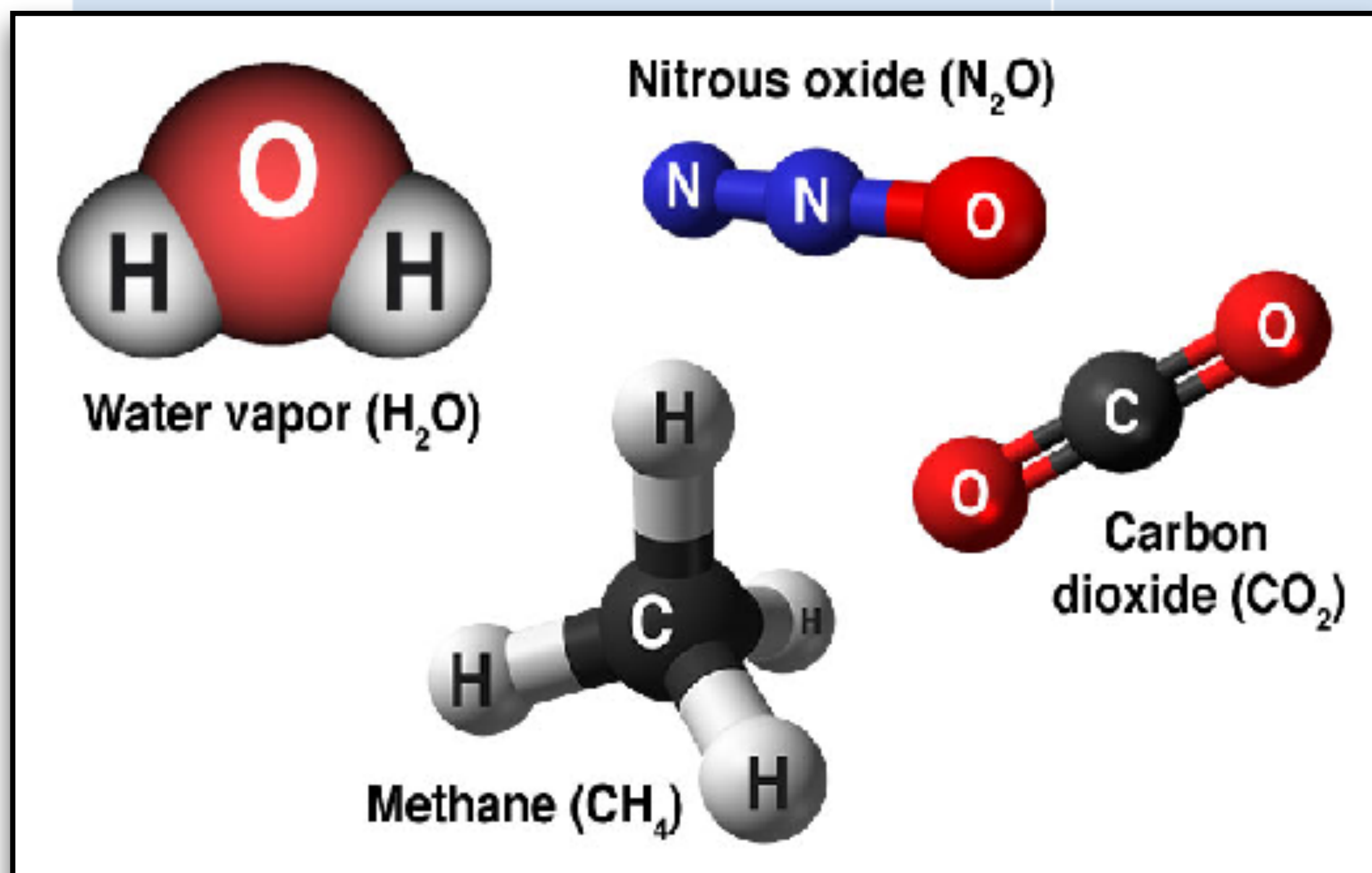
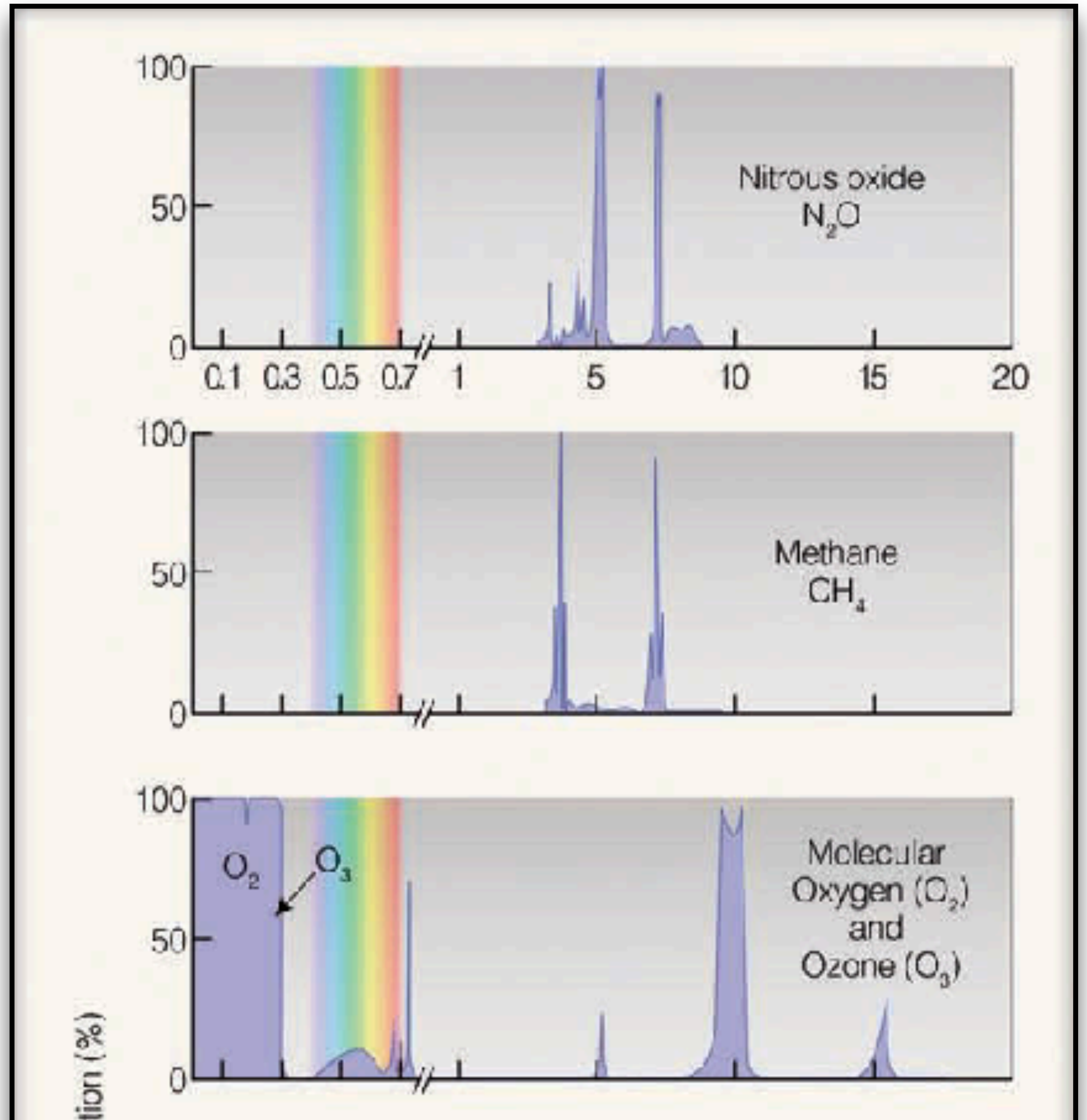
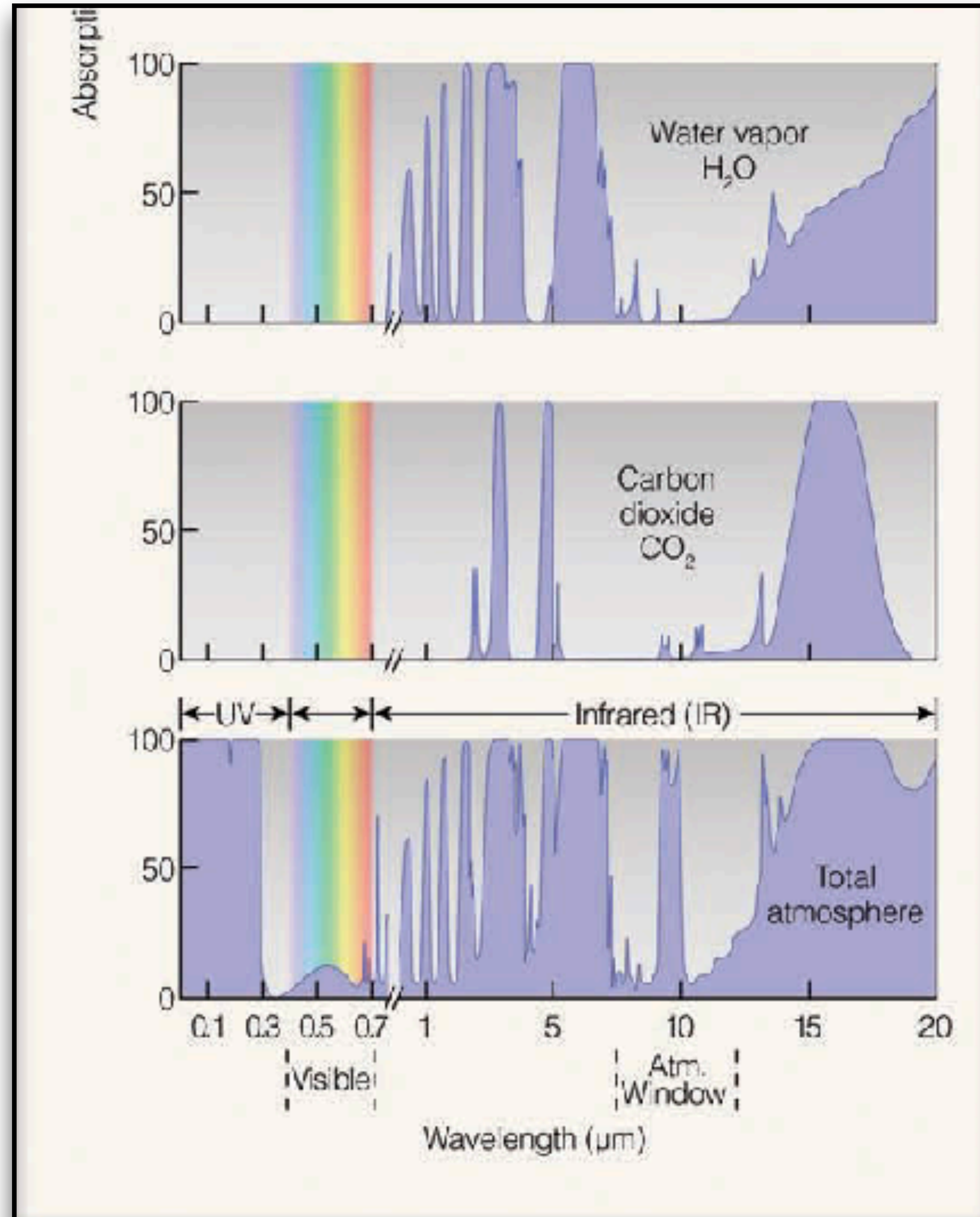


- Greenhouse gases strongly absorb a portion of the earth's outgoing radiant energy.

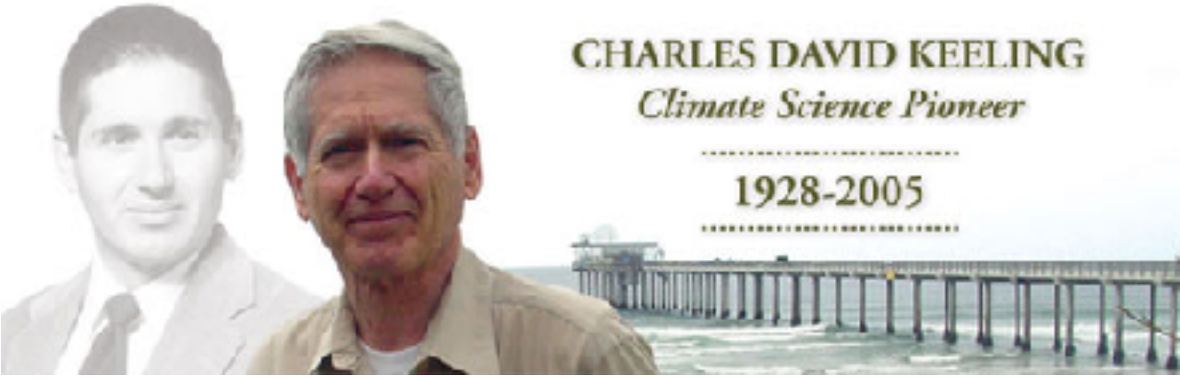
Image from https://climate.nasa.gov/causes/

Absorption of radiation by gases

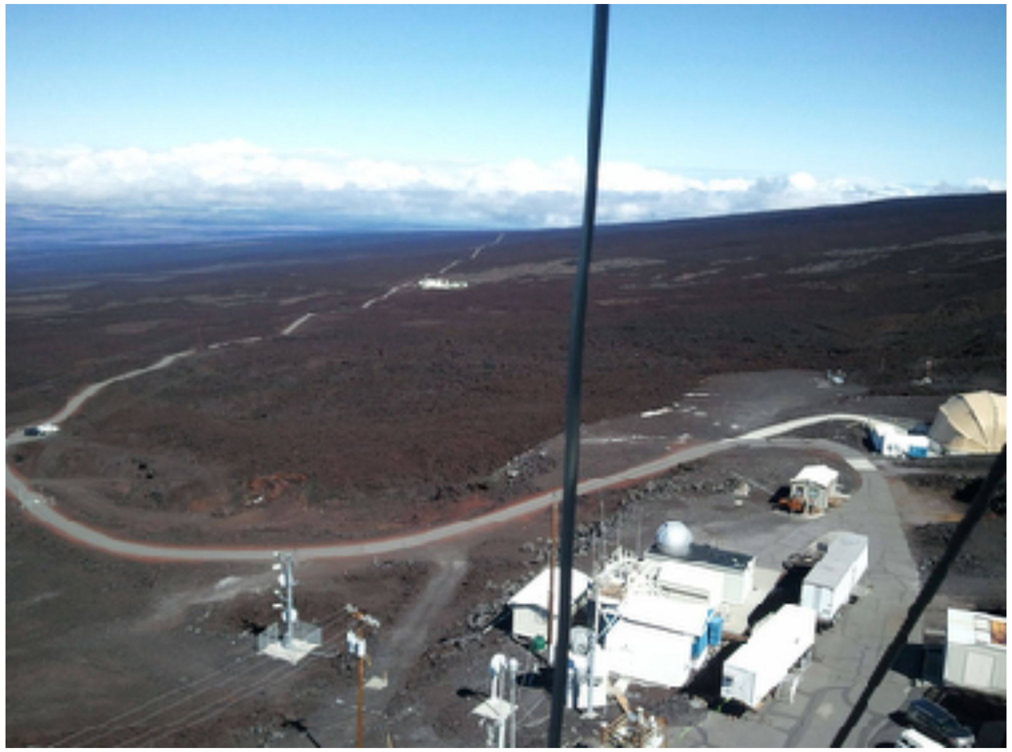




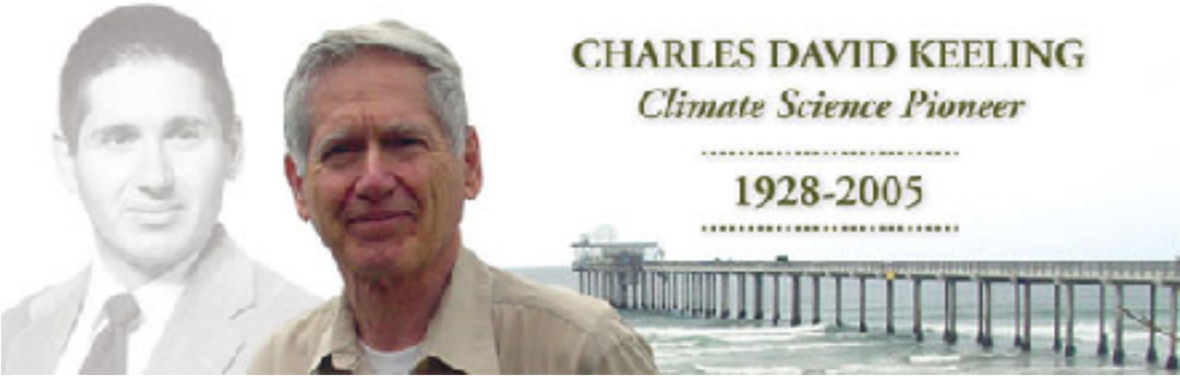
Measuring CO_2



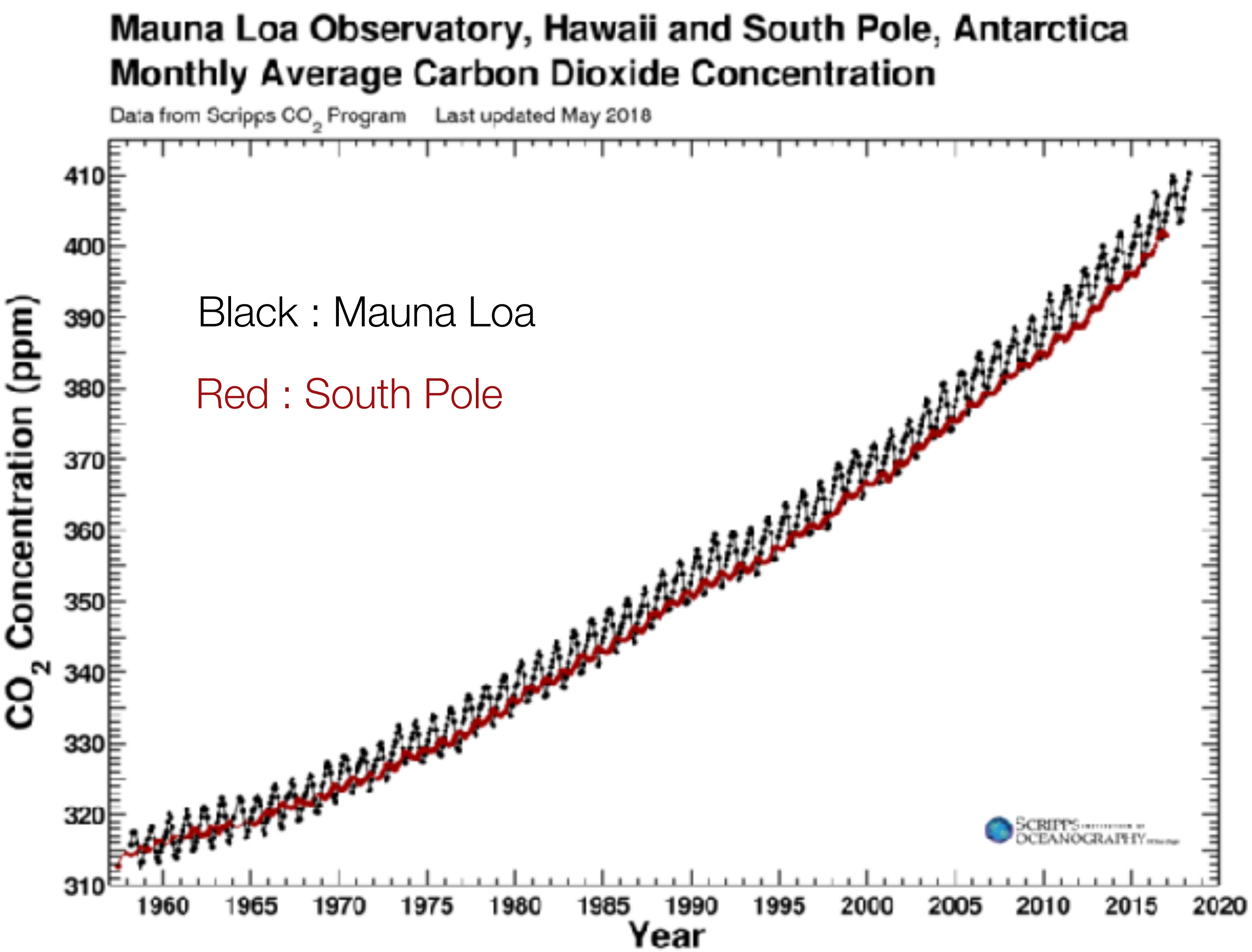
- Keeling curve
  - In 1953, Charles Keeling came up with the way to precisely measure CO_2 in the air.
  - Started to measure CO_2 and find diurnal cycle of CO_2.
  - In March 1958, he set up his instrument at Mauna Loa, Hawaii where there was no vegetation.
  - video



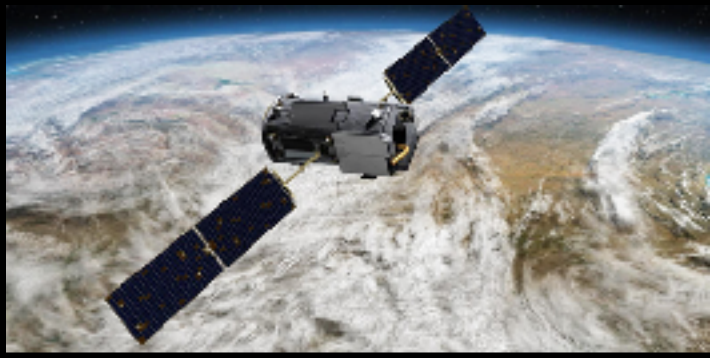
Measuring CO_2



- Keeling curve
  - Seasonal cycle of CO2 concentration
  - Long-term trend
  - Video #1
  - Video #2



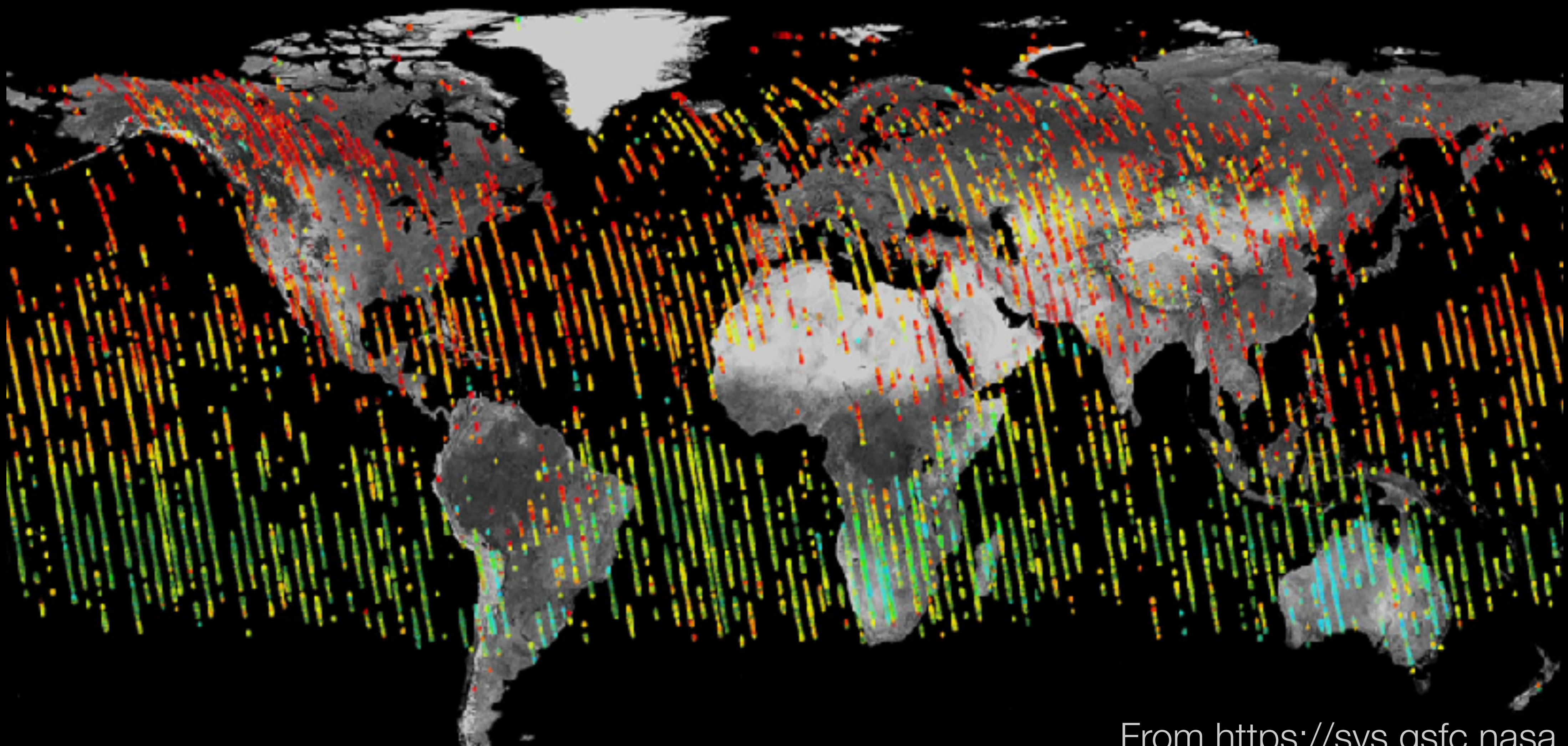
From http://scrippsco2.ucsd.edu/graphics_gallery/mauna_loa_and_south_pole/mauna_loa_and_south_pole



Measuring CO_2

- Since 1996, the satellite started to measure CO_2 from the space.

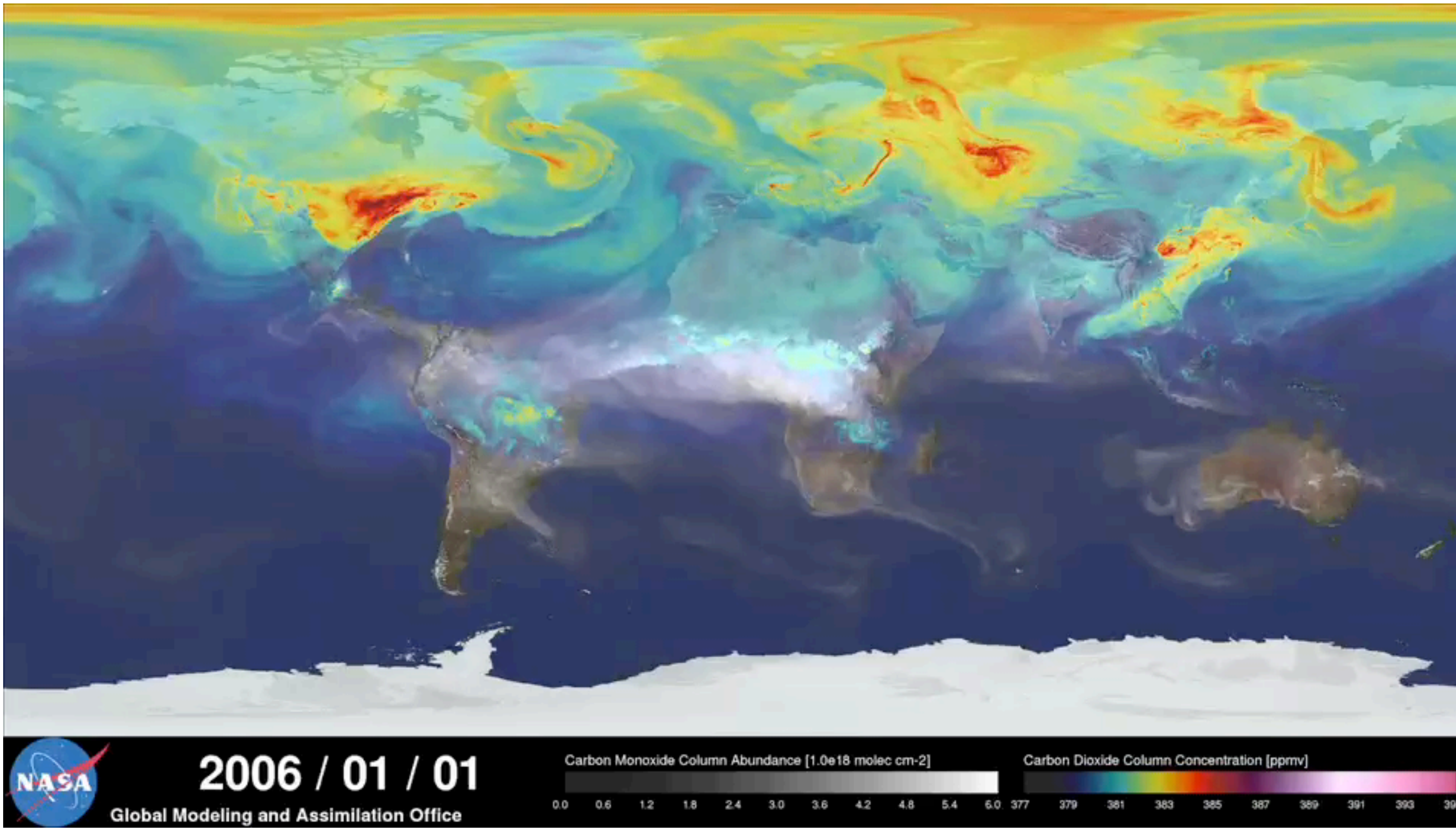
The OCO-2 satellite circles Earth every 99 minutes, and collects carbon dioxide measurements over a narrow ground track each orbit.



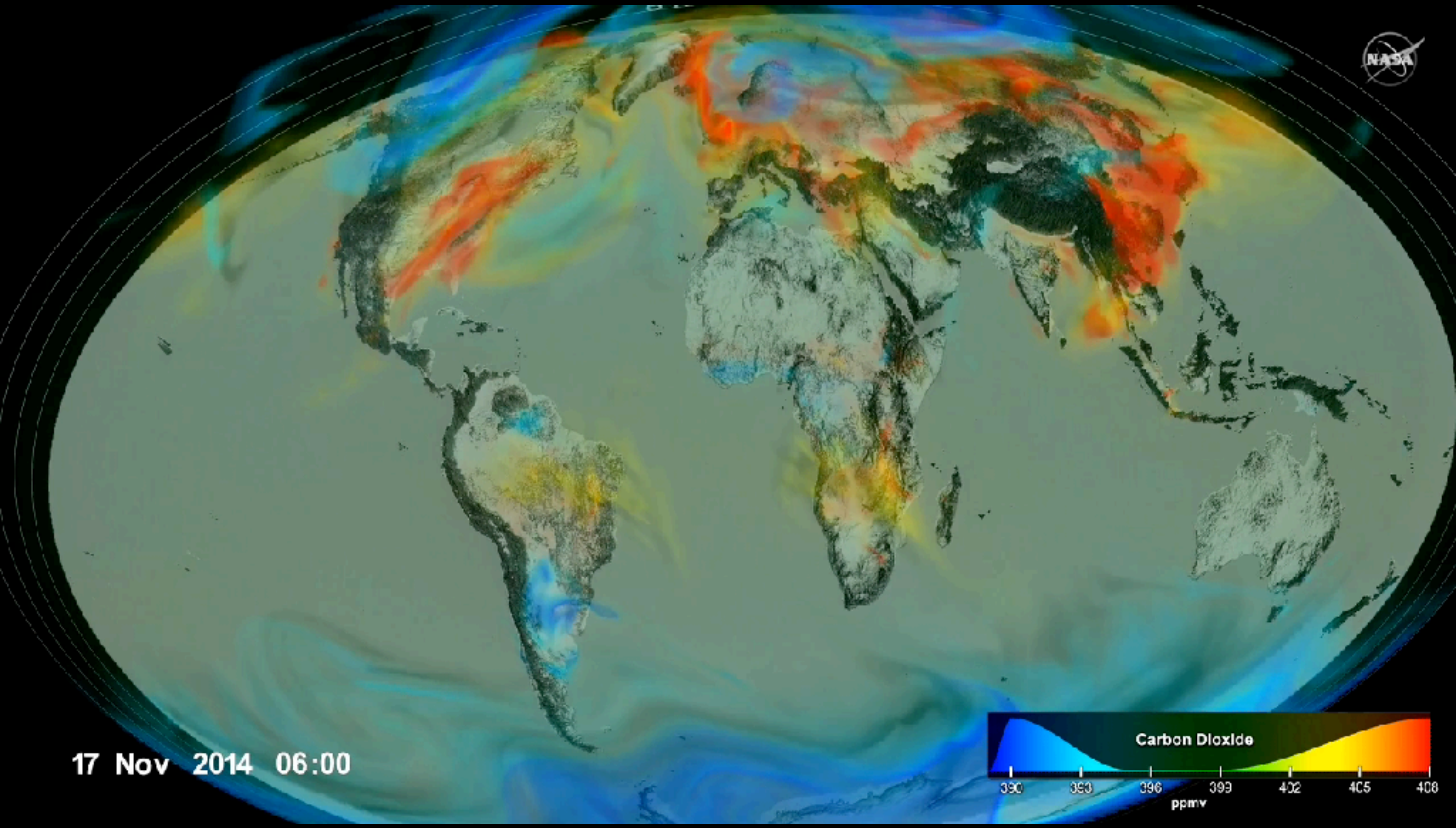
From https://svs.gsfc.nasa.gov/12072

Modeling of CO_2

a NASA supercomputer model called GEOS-5



Using observations from NASA's Orbiting Carbon Observatory (OCO-2) satellite, scientists developed a model of the behavior of carbon in the atmosphere from September 1, 2014 to August 31, 2015.

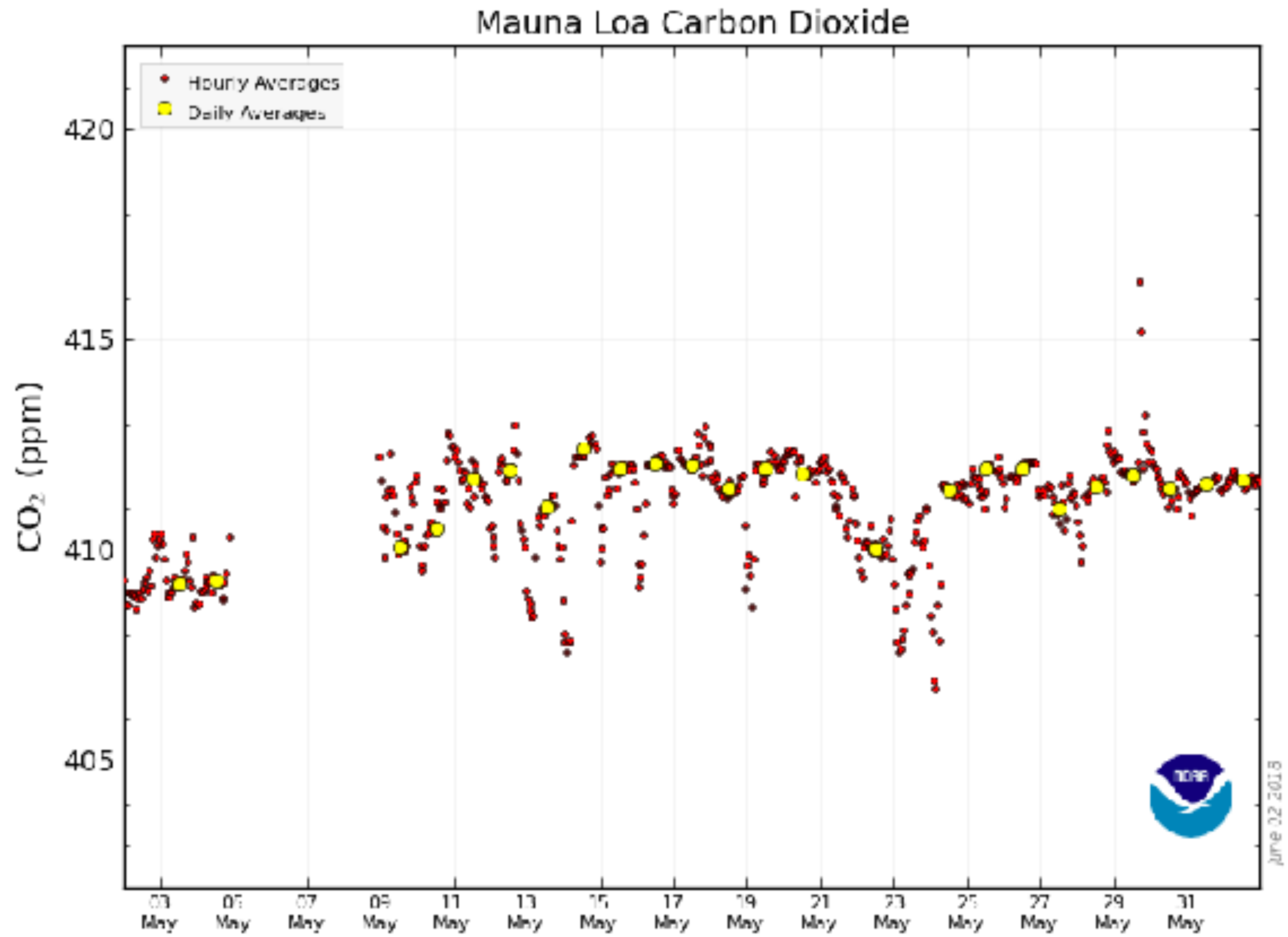


From https://svs.gsfc.nasa.gov/12445

The Current CO_2 level

June 01:	411.68 ppm
May 31:	411.61 ppm
May 30:	411.47 ppm
May 29:	411.80 ppm
May 28:	411.54 ppm

Last Updated: June 2, 2018



From https://www.esrl.noaa.gov/gmd/ccgg/trends/monthly.html

The global carbon cycle

Unit : Gigaton

The Global Carbon Cycle

Air-sea CO_2 exchange

f(wind speed,...) ← → f(T, S, carbon, ...)

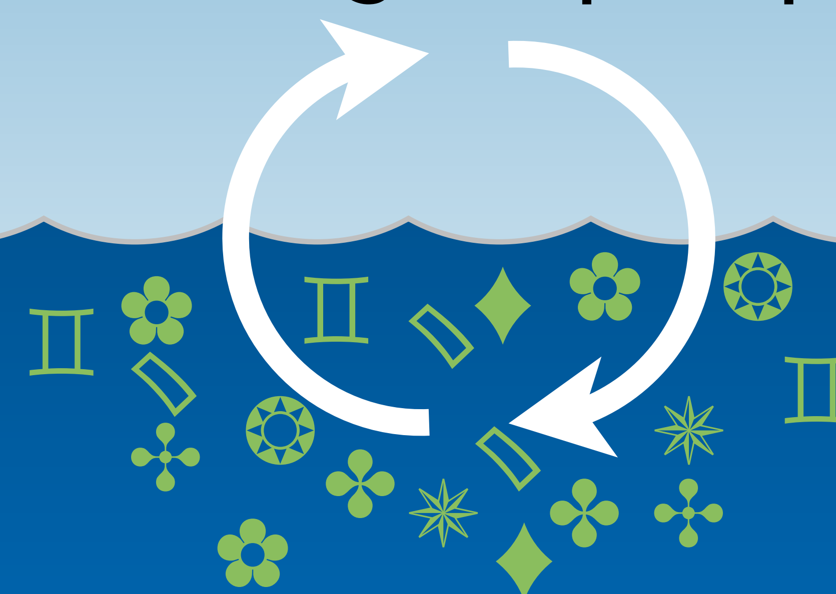
$$CO_2 \text{ flux} = K_w\,(pCO_{2,ocean} - pCO_{2,atmosphere})$$

Solubility pump

$CO_2 + H_2O \rightarrow H_2CO_3$ → Carbonic acid

$H_2CO_3 \rightarrow H^+ + HCO_3^-$ → Bicarbonate

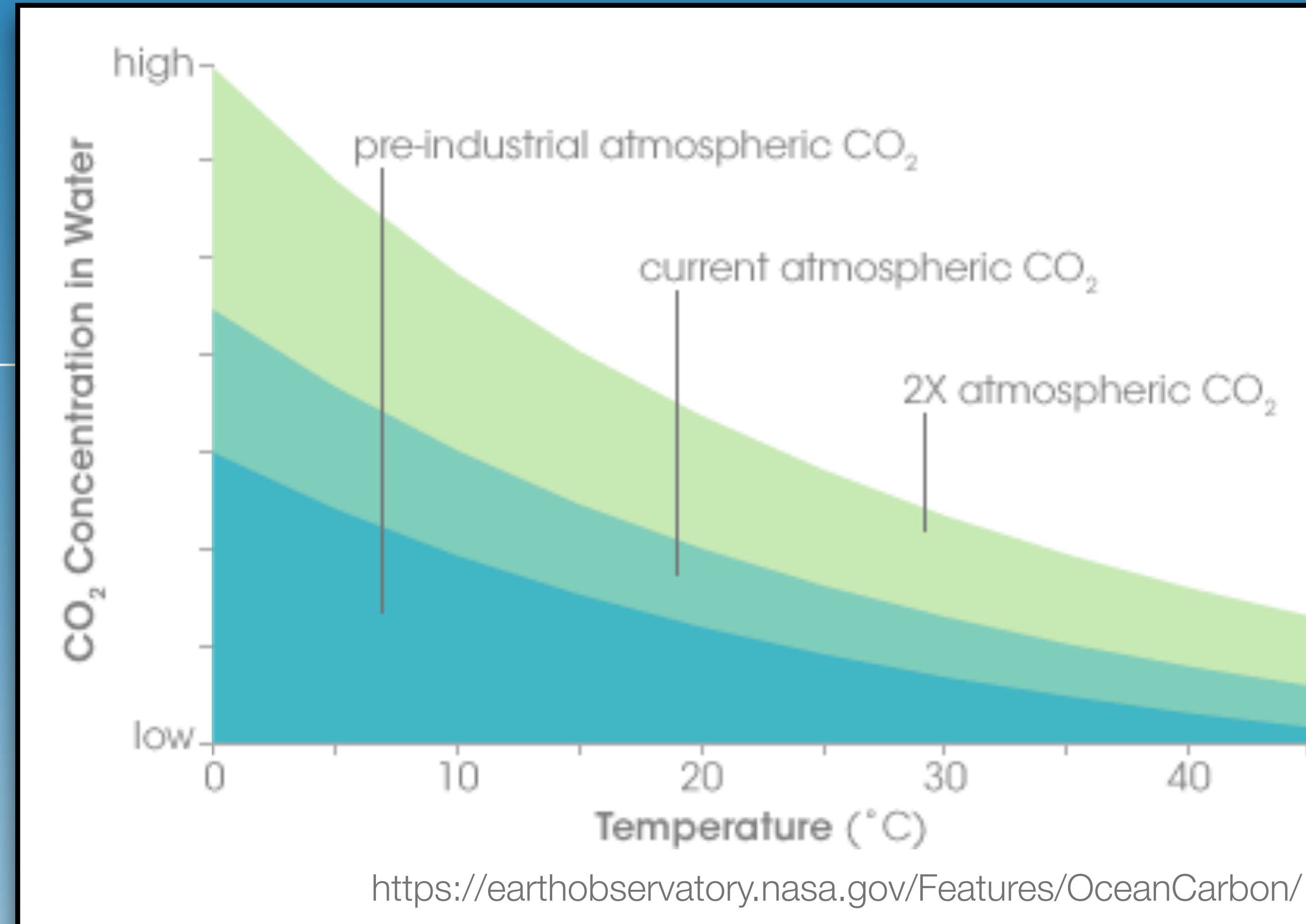
Biological pump



Data from IPCC AR4 WG1 and the figure redrawn from NOAA PMEL Carbon Program

Air-sea CO_2 exchange

Video



Solubility pump

Carbonic acid

$CO_2 + H_2O \rightarrow H_2CO_3$

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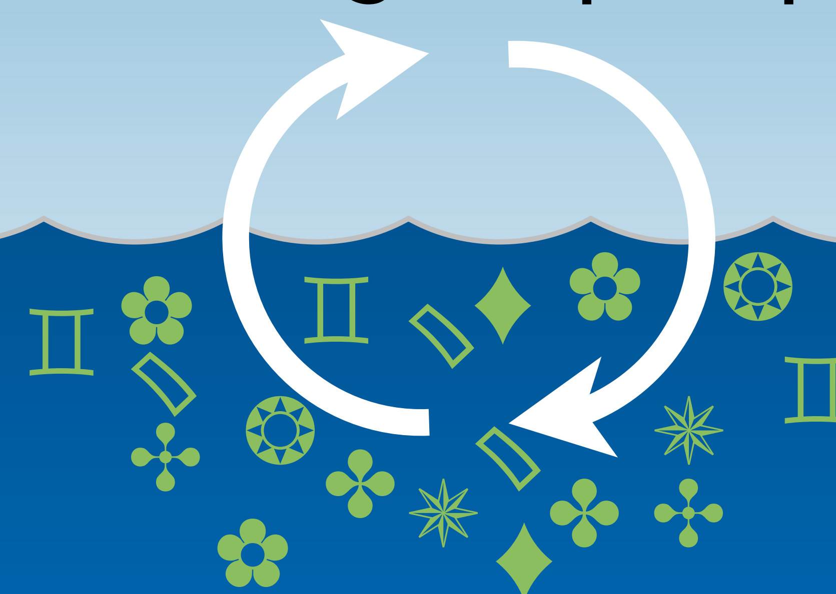
Bicarbonate

Biological pump



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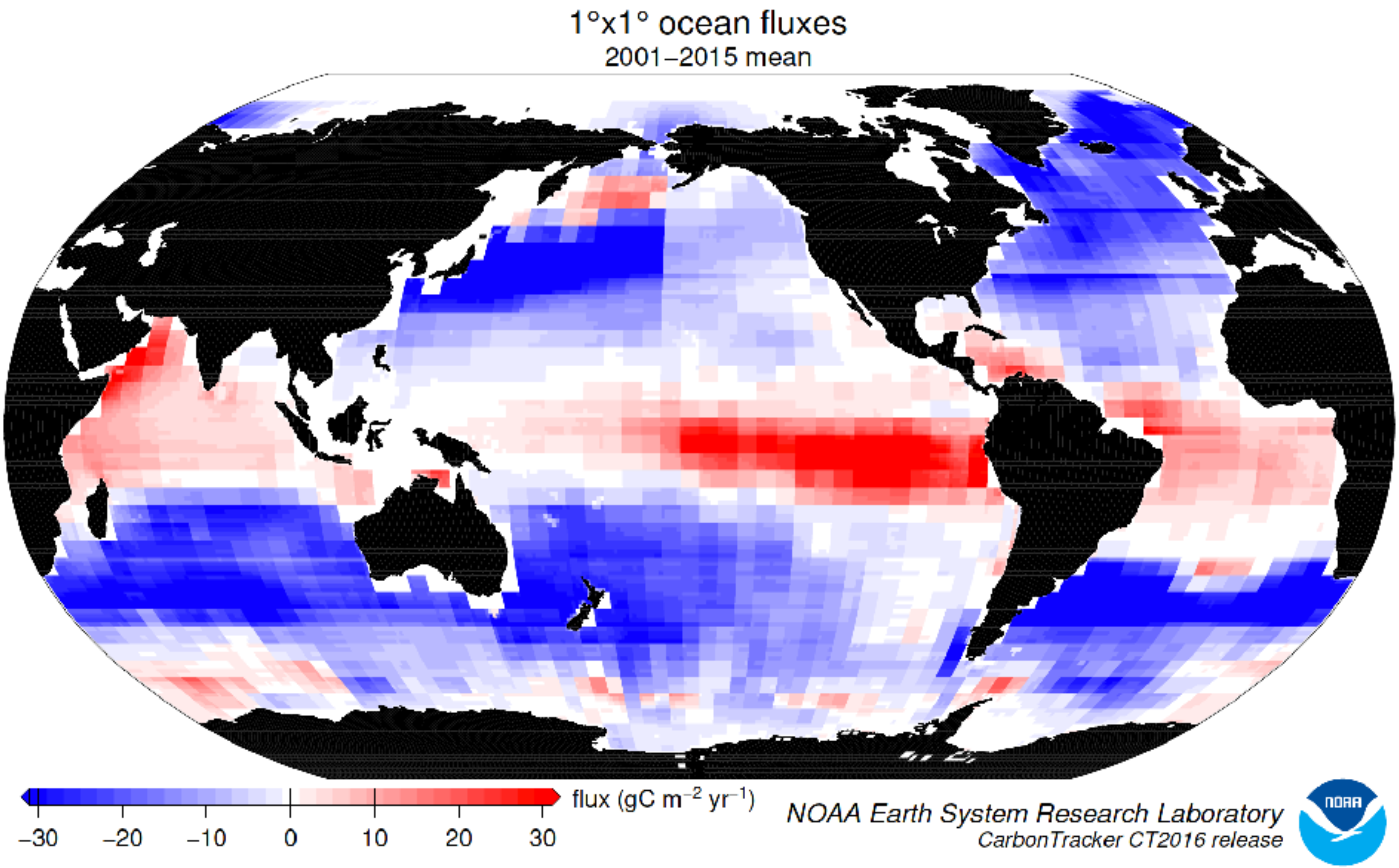
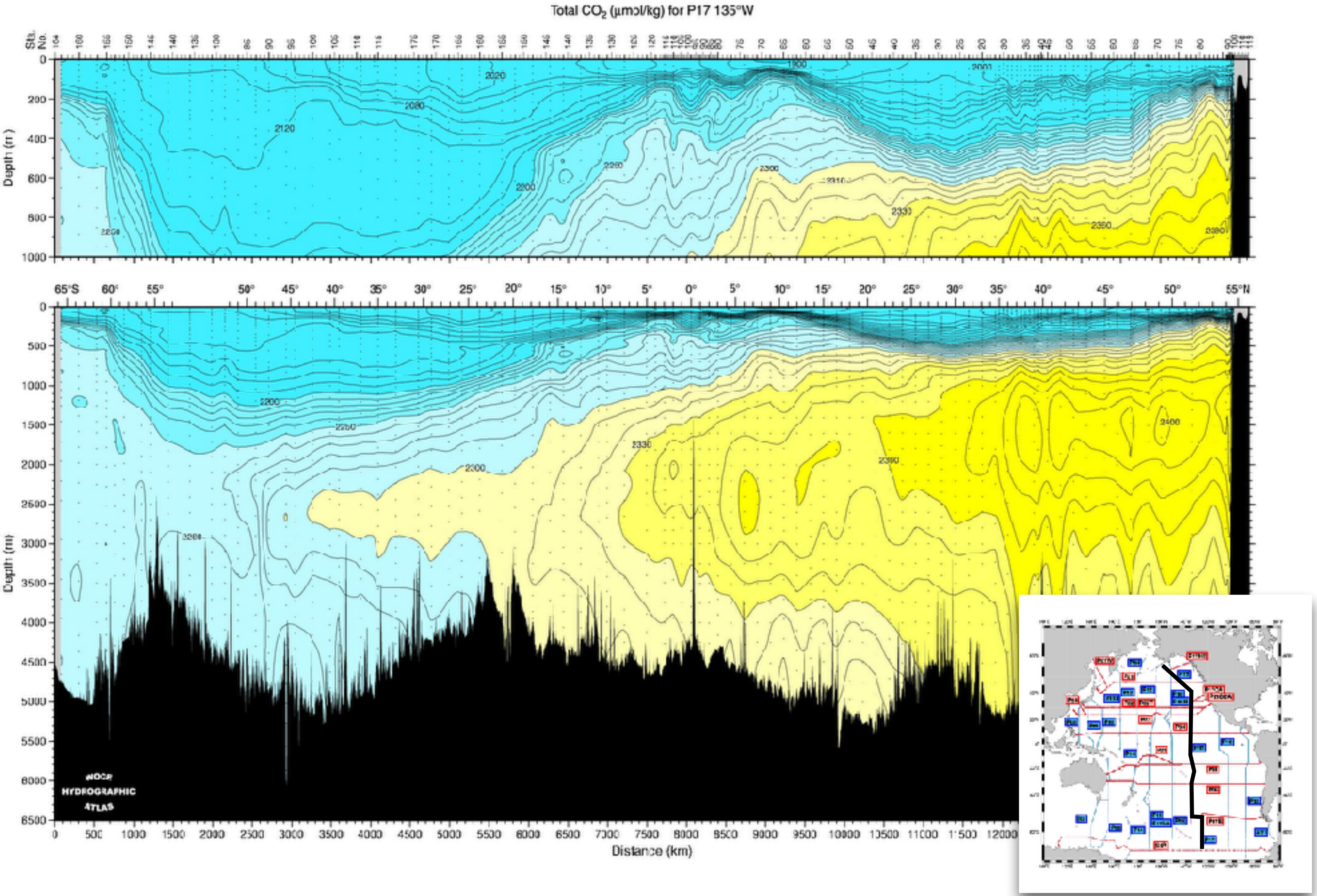
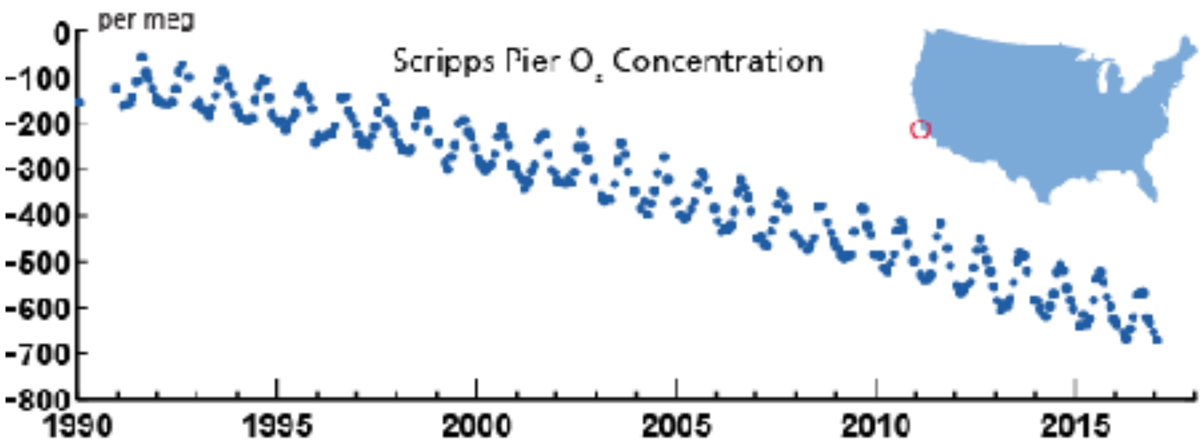


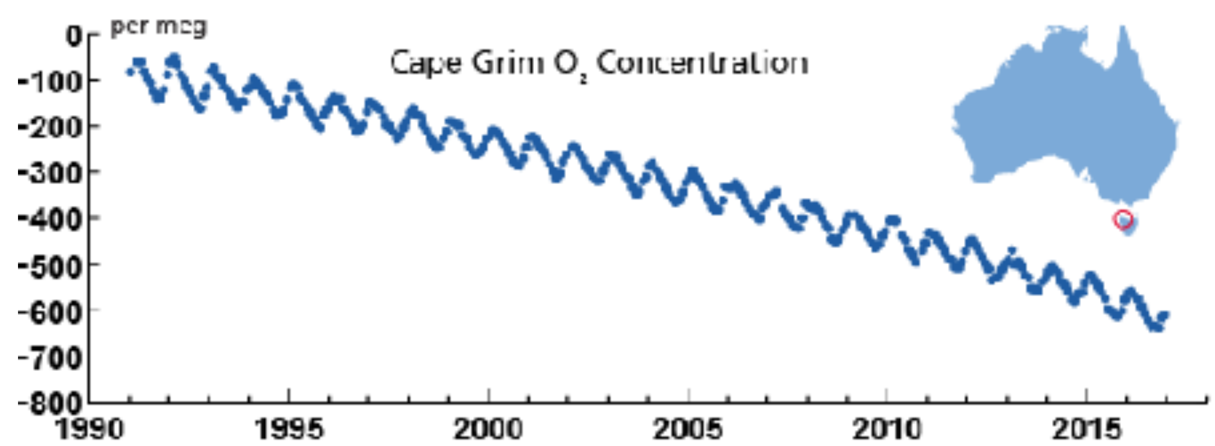
CO_2 in the ocean



Oxygen

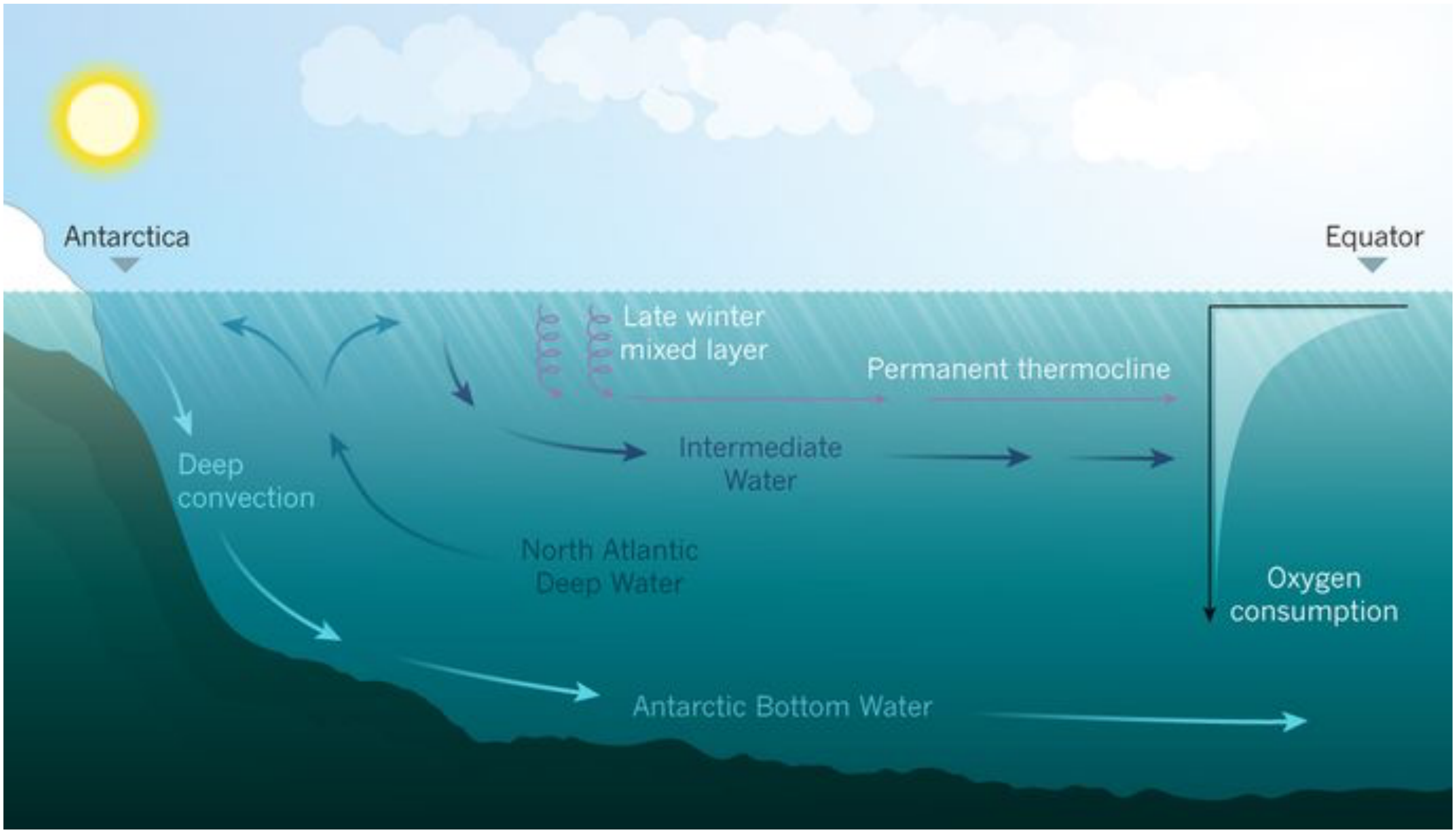
- O_2 is a major component of the atmosphere, comprising roughly 21% by volume.
- Oxygen levels are decreasing globally due to fossil fuel burning, although the changes are too small to have an impact on human health.
- On average, we lose 19 O_2 molecules out of every 1 million O_2 molecules each year.





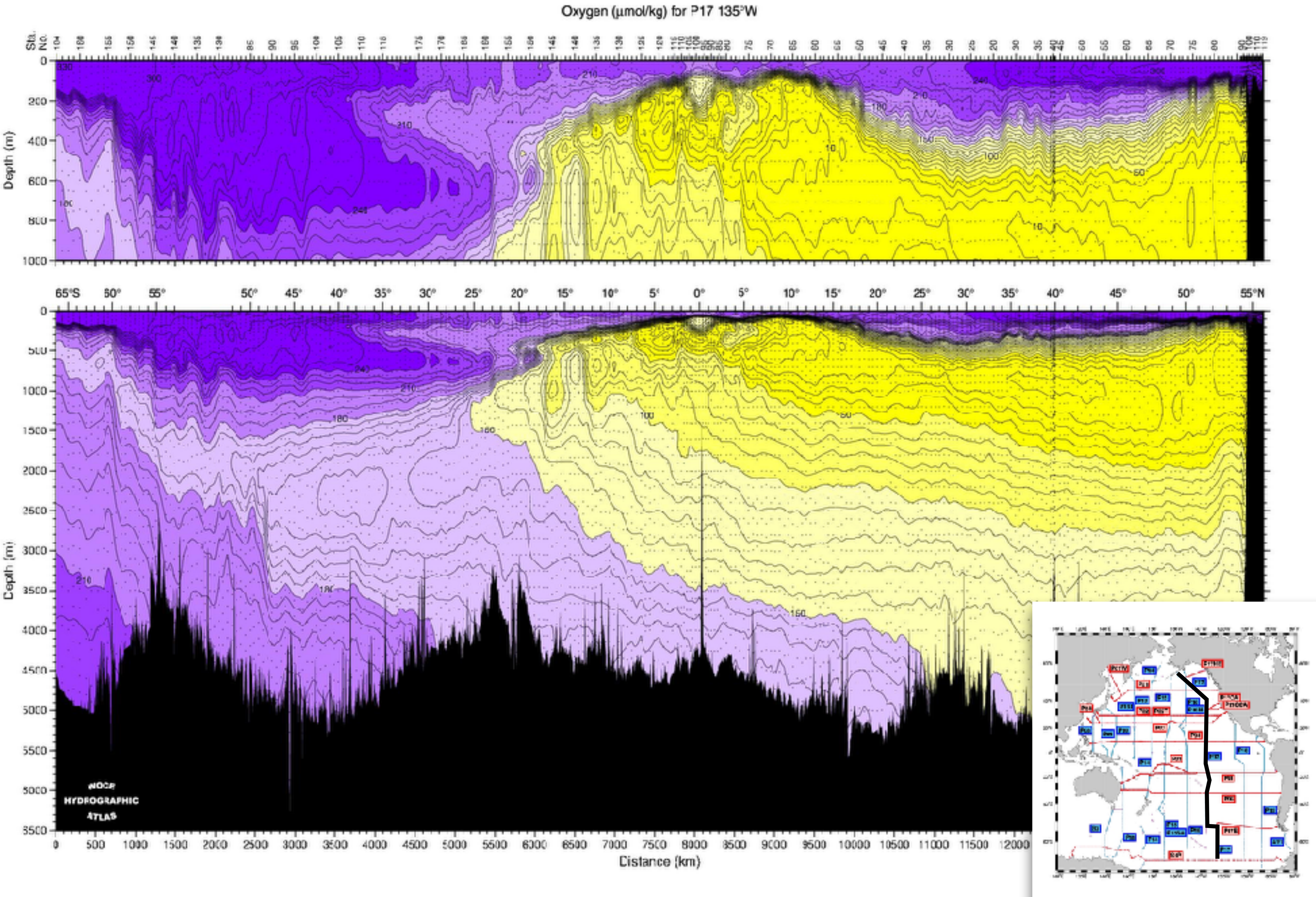
From http://scrippso2.ucsd.edu/index

Oxygen cycle in the water

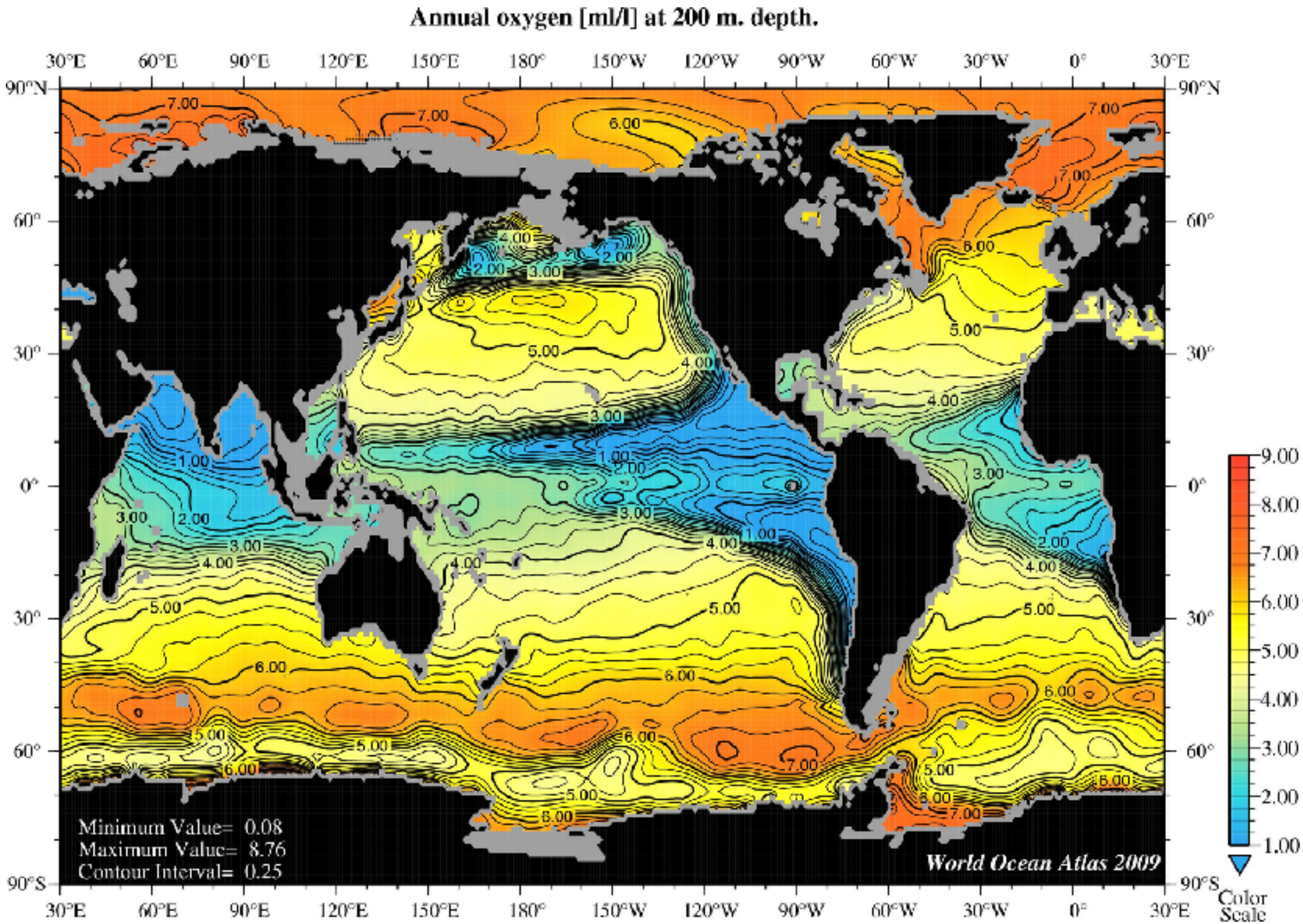


From https://media.springernature.com/m685/nature-static/assets/v1/image-assets/542303a-f1.jpg

O_2 in the ocean

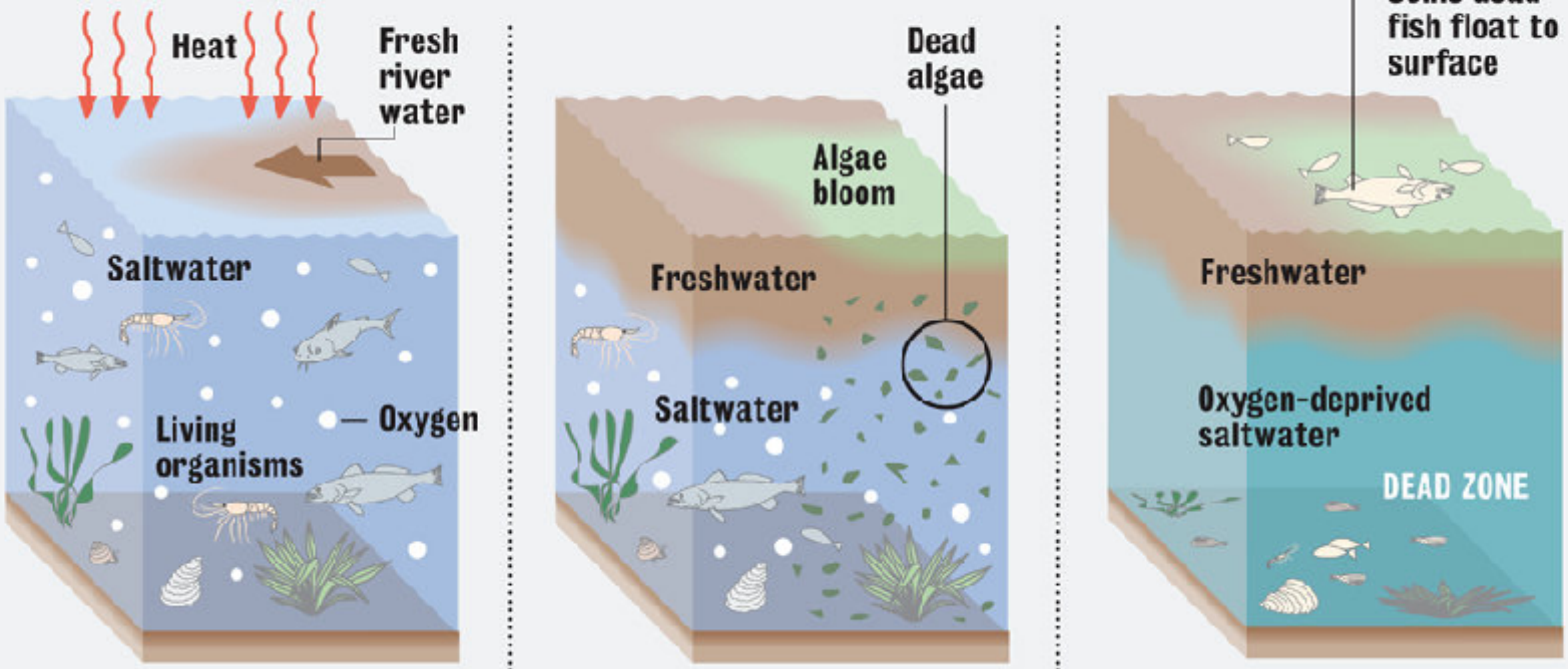


Oxygen at 200 m



Dead zone

HOW THE DEAD ZONE FORMS



1 During the spring, sun-heated freshwater runoff from the Mississippi River creates a barrier layer in the Gulf, cutting off the saltier water below from contact with oxygen in the air.

2 Nitrogen and phosphorus from fertilizer and sewage in the freshwater layer ignite huge algae blooms. When the algae die, they sink into the saltier water below and decompose, using up oxygen in the deeper water.

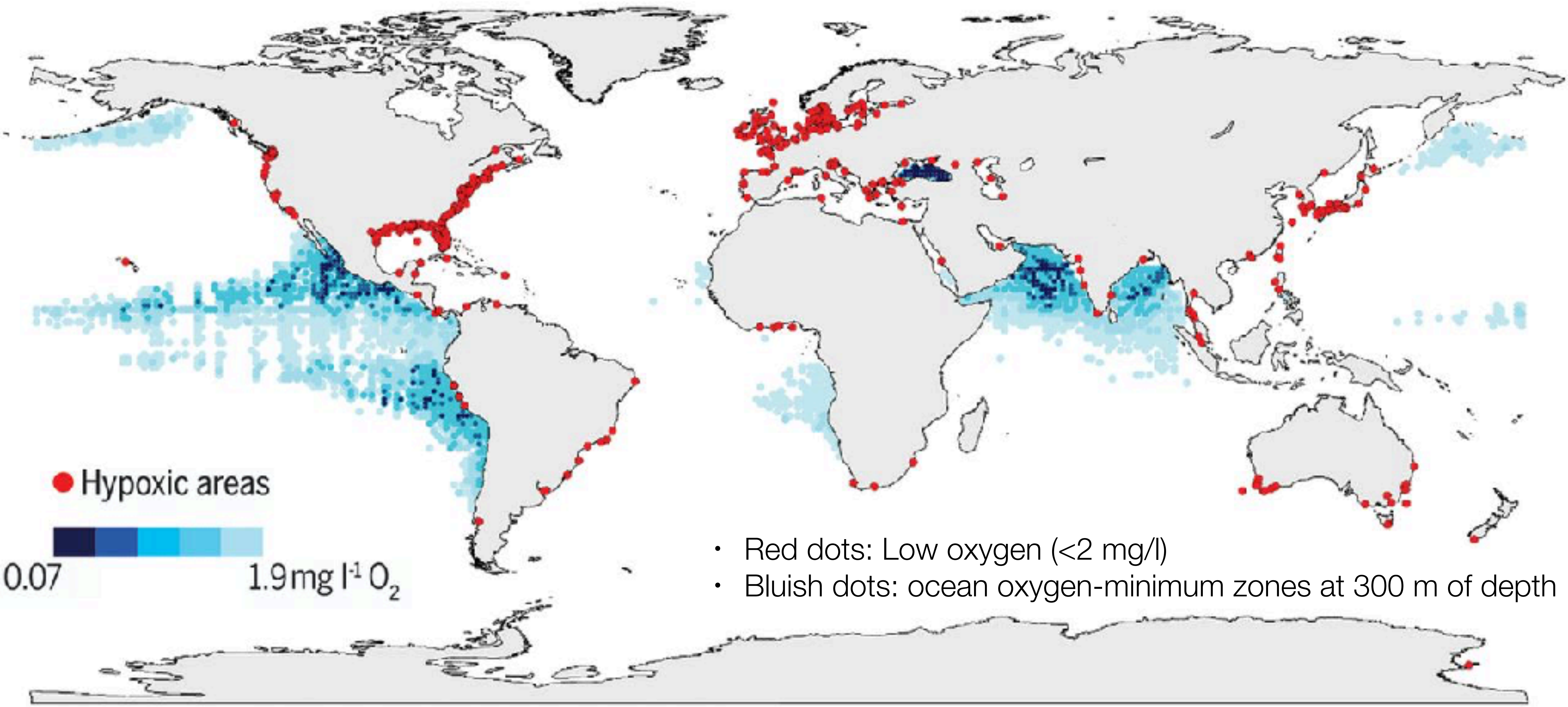
3 Starved of oxygen and cut off from resupply, the deeper water becomes a dead zone. Fish avoid the area or die in massive numbers. Tiny organisms that form the vital base of the Gulf food chain also die. Winter brings respite, but spring runoffs start the cycle anew.

Source: Staff research

STAFF GRAPHIC BY DAN SWENSON

Declining oxygen level in the water

The global map indicating coastal sites with hypoxic condition



- Red dots: Low oxygen (<2 mg/l)
- Bluish dots: ocean oxygen-minimum zones at 300 m of depth

From https://www.biosch.hku.hk/wp-content/uploads/2018/01/MY_DO_decline_eaam7240.full_.pdf