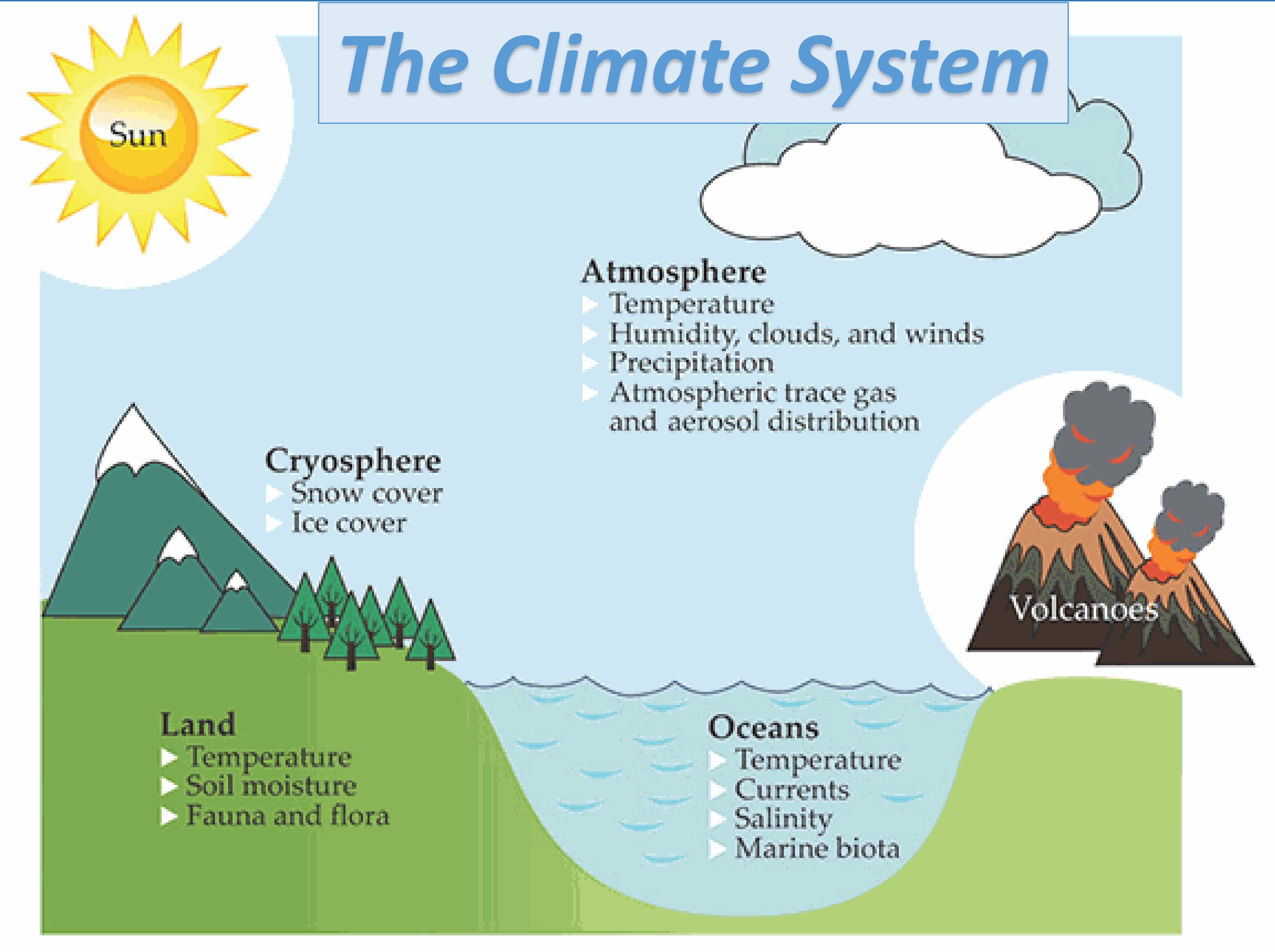
Climate Science and Global Climate Change

Session 3

- Landmasses
- Oceans
- Ice sheets and polar caps

Spring 2018
Univ. of Arizona OLLI
Lockwood Carlson PhD

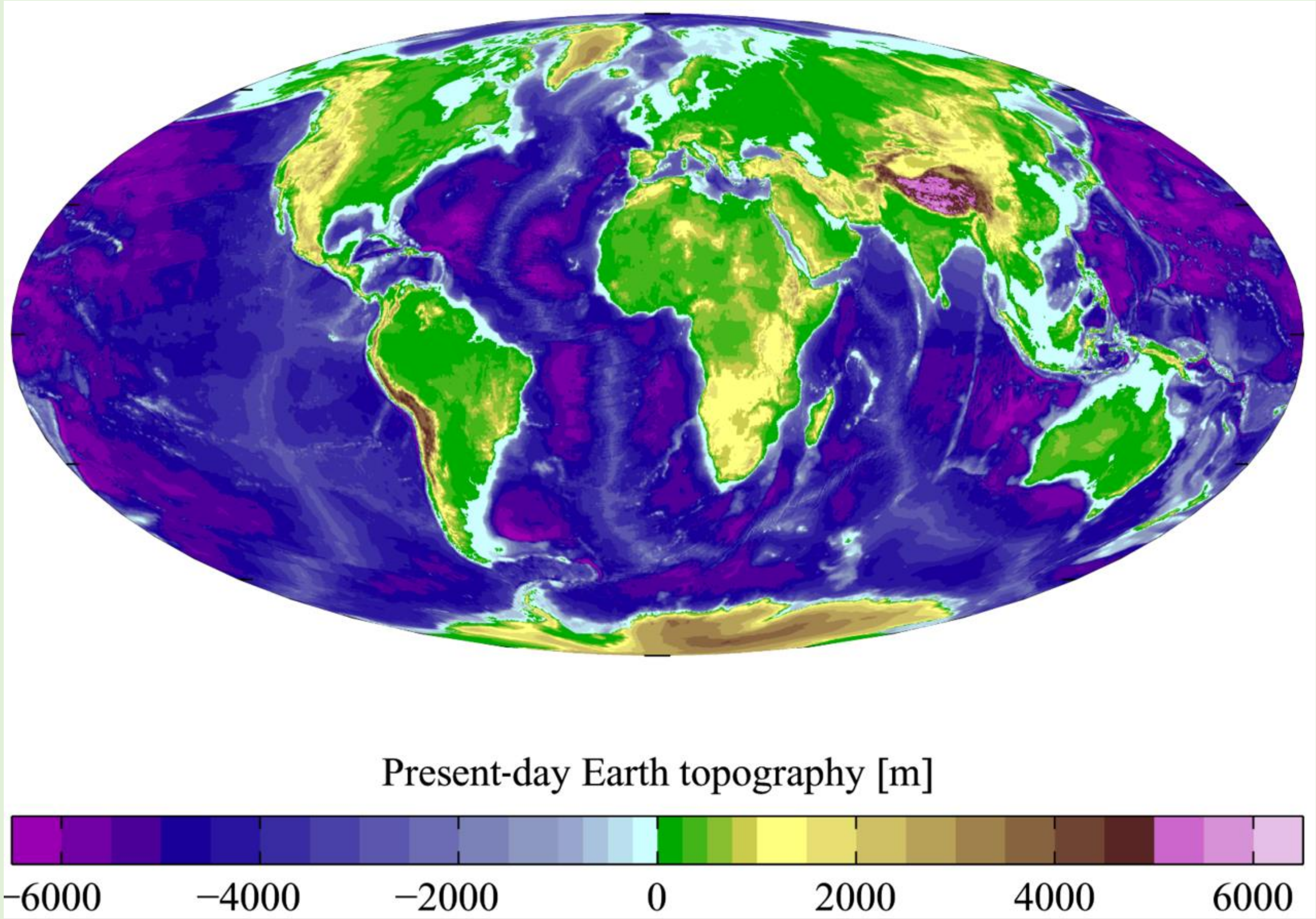
The Climate System



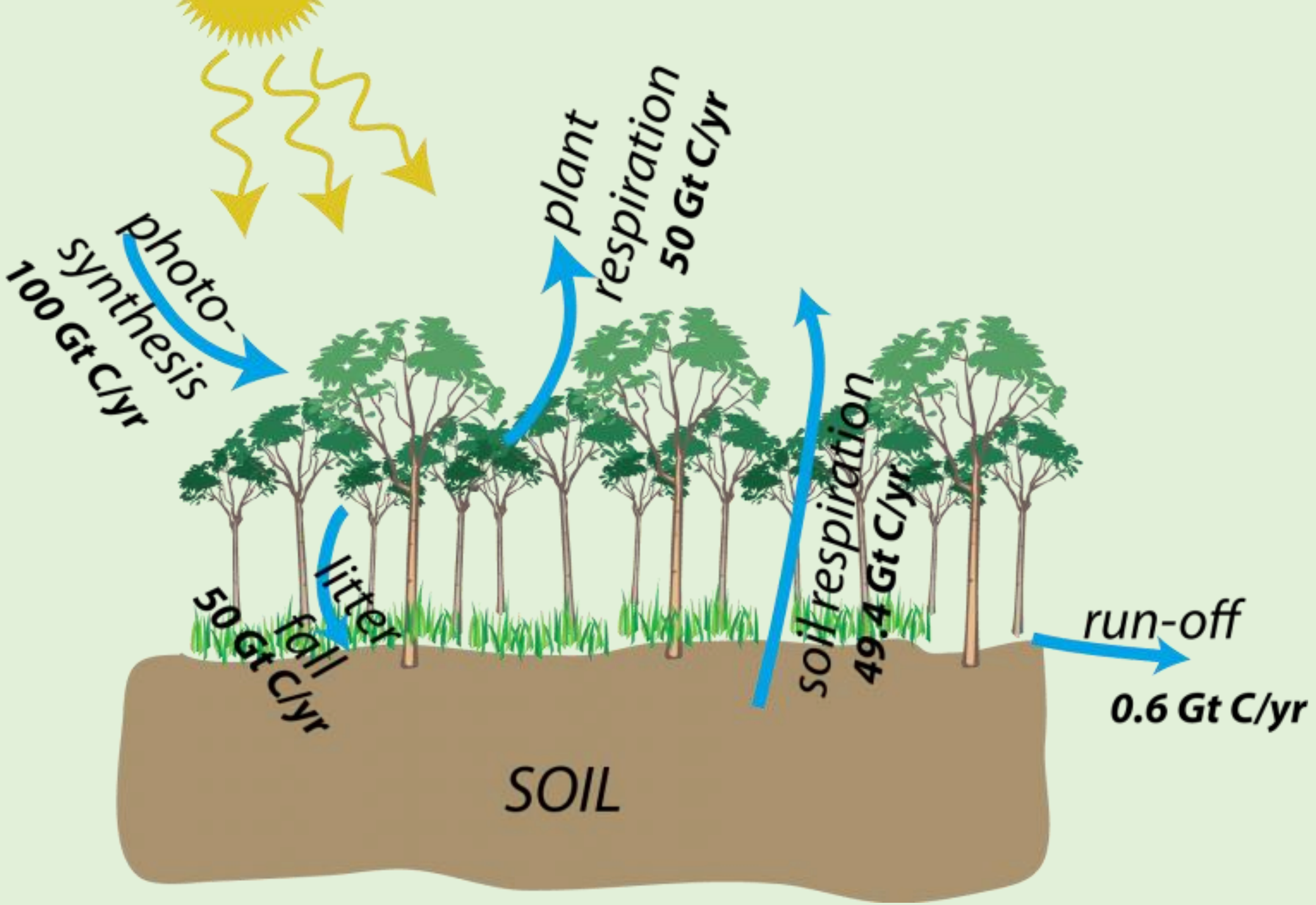
The climate system consists of the atmosphere, cryosphere, land, and oceans, each of which can be characterized by a set of state variables. Climate change is said to occur when a **forcing** generates an intercomponent flux of energy, mass, or momentum that inflicts prolonged changes to one or more state variables. The forcing may originate from within the climate system itself or from a source such as solar, volcanic, or human activity. (Adapted from ref. 4 .)

Citation: Phys. Today **69**, 11, 40 (2016)

Earth's Landmasses

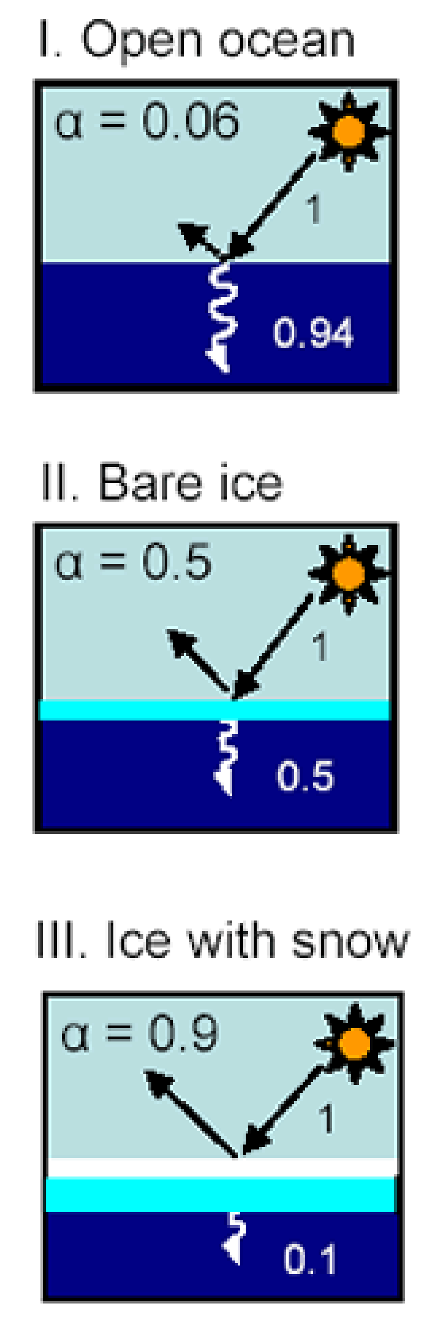


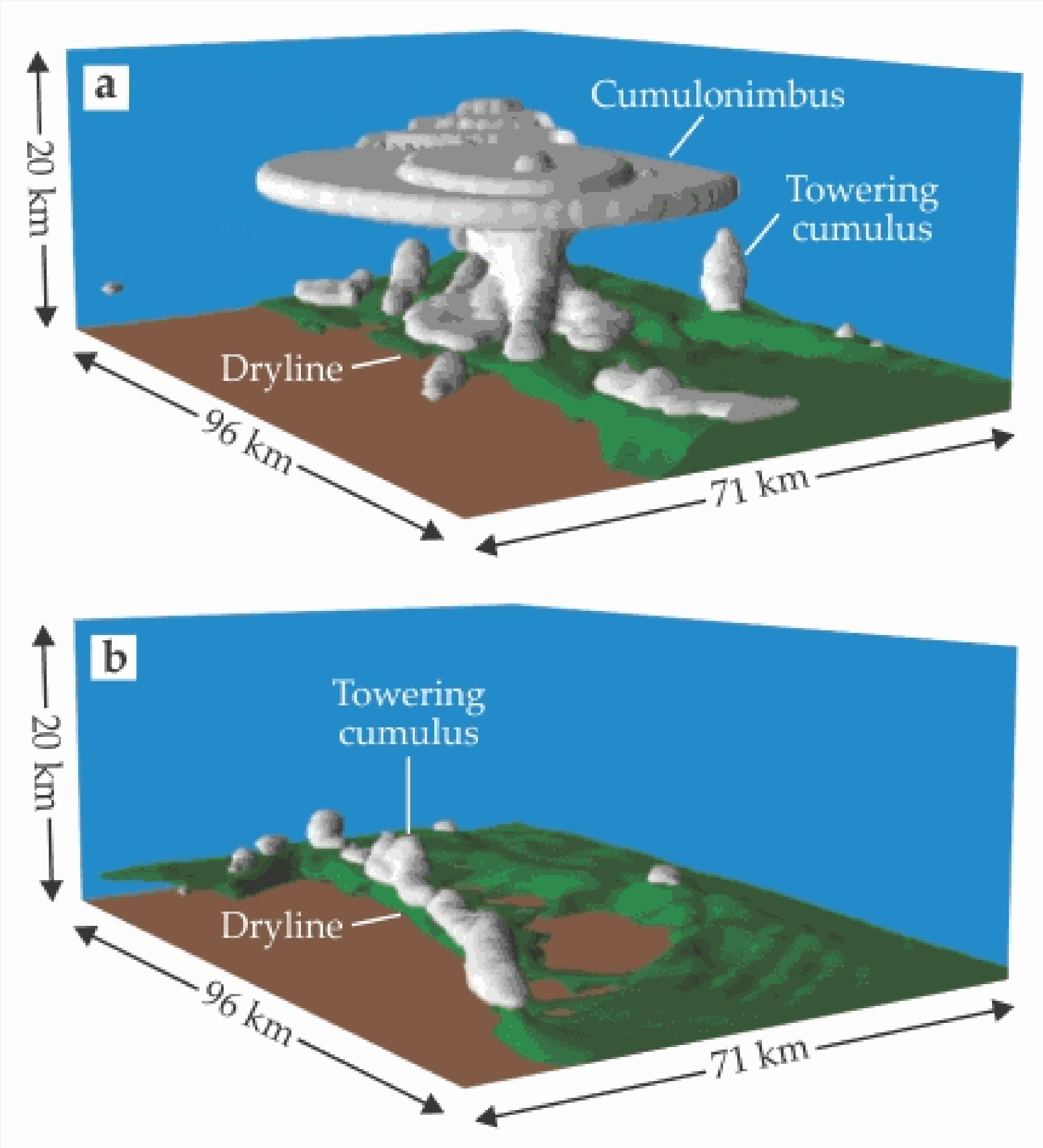
Terrestrial Processes of Carbon Flow



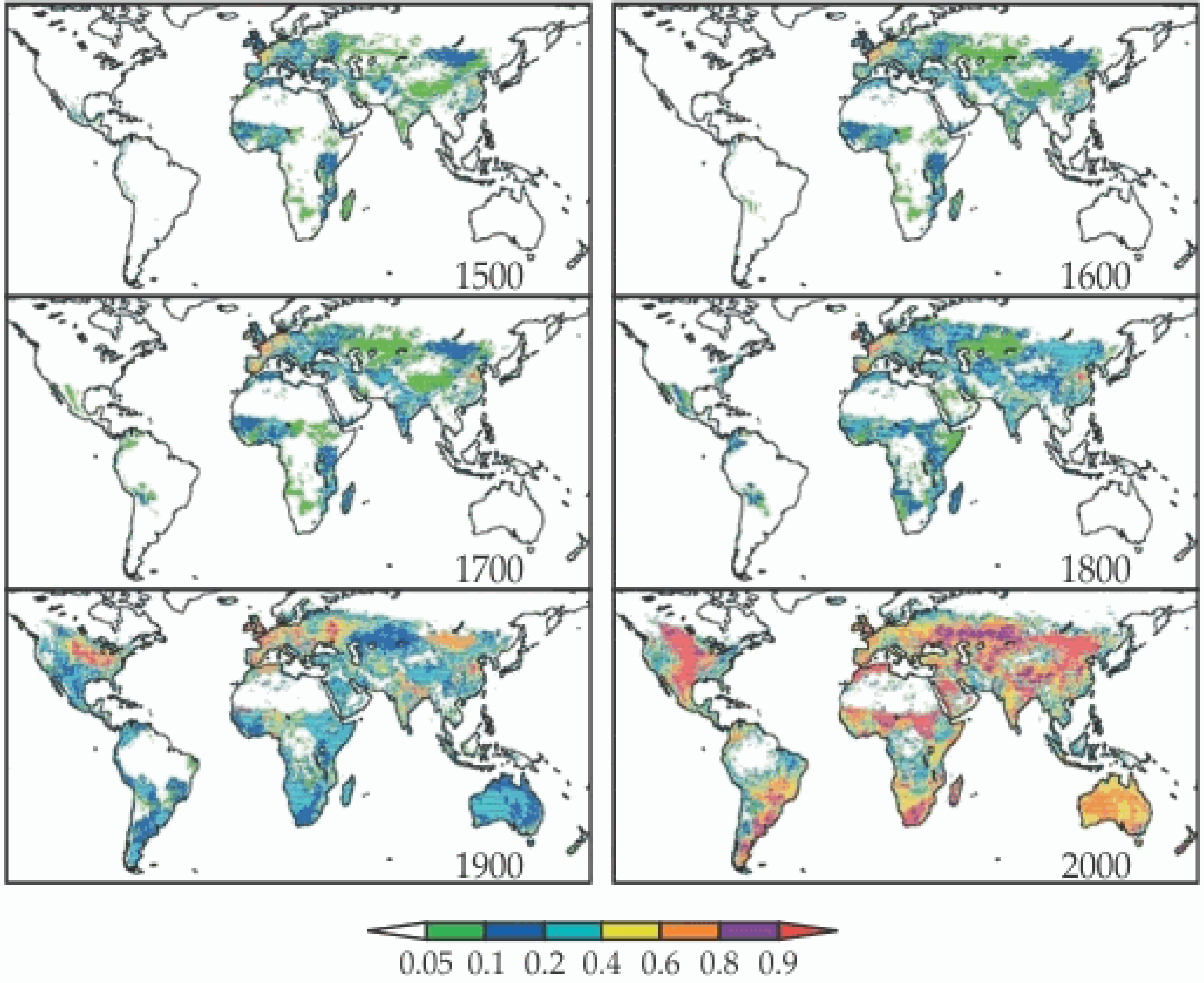
Earth's Landmasses

f



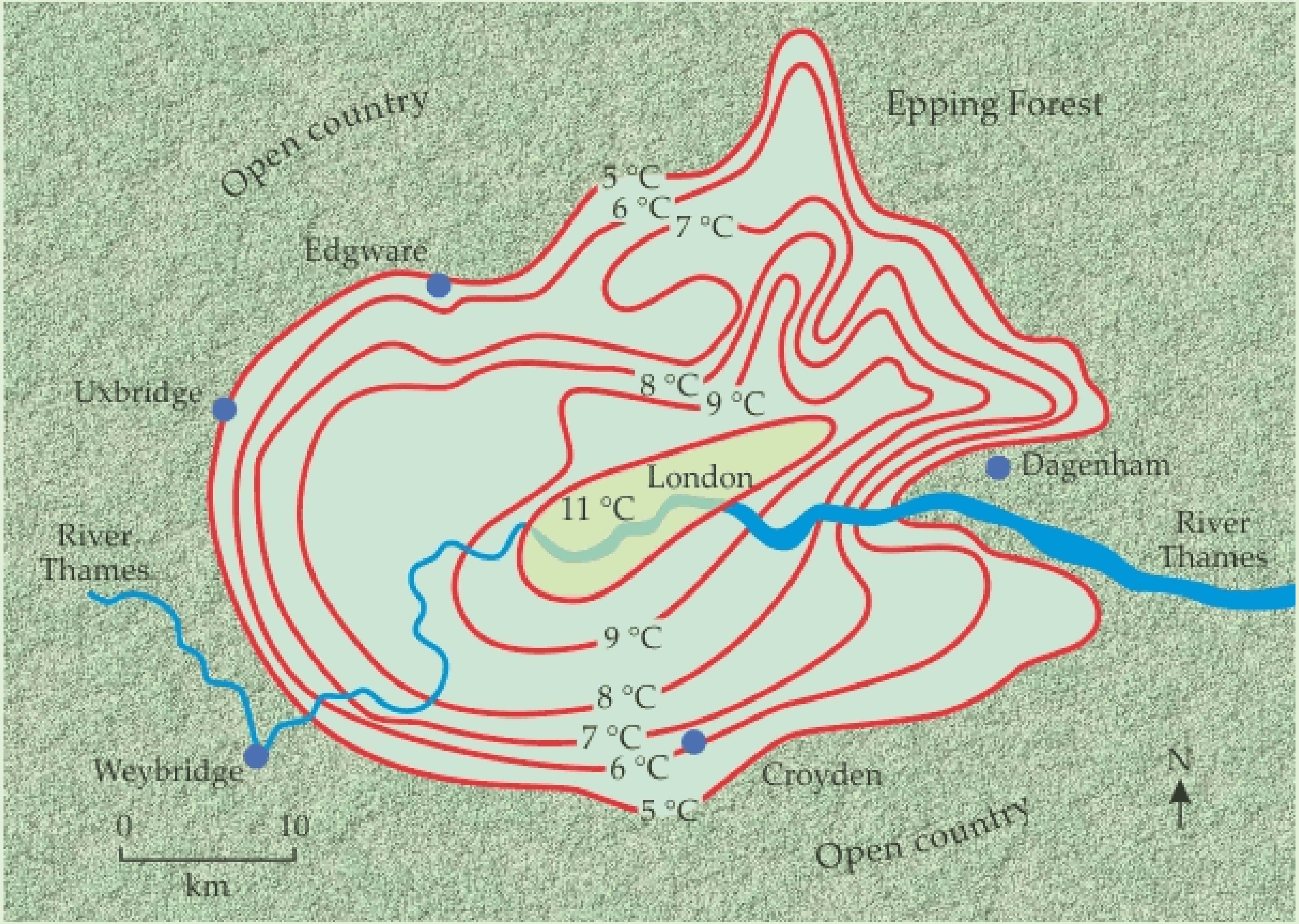


Simulations of atmospheric conditions over a 7000 km^2 swath of the US Great Plains on 15 May 1991 demonstrate **the intimate link between the landscape and weather patterns**. **(a)** A simulation of the terrain in its actual state—covered with a mix of shortgrass, farmland, and brush—predicts the formation of rain-generating cumulonimbus clouds. (That model prediction bore out in real life.) The dryline marks the boundary between the moist eastern air (green) and the dry desert air (brown) to the west. **(b)** In an alternate scenario where the land is covered entirely by dry shortgrass, towering cumulus clouds form but no storms develop. (Courtesy of Conrad Ziegler, NOAA.)
Citation: Phys. Today **69**, 11, 40 (2016)



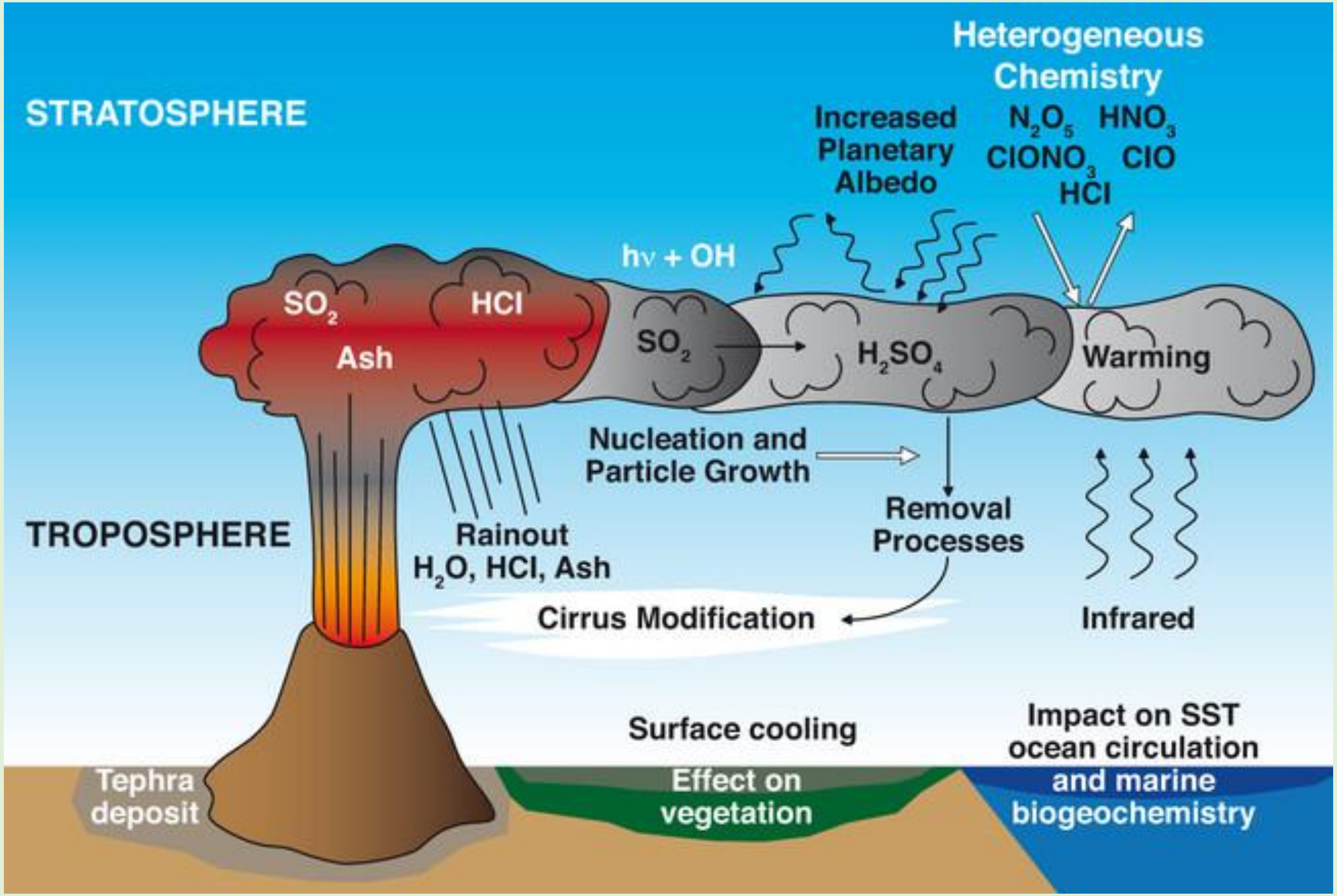
Earth's natural landscape has been increasingly converted to cropland and pasture over the past 500 years. The color key gives the local relative fraction of land converted to agricultural use. The analysis techniques used to create the map continue to undergo refinement. For example, in Australia too much landscape is shown as pasture. (Adapted from ref. 5 .)

Citation: Phys. Today **69**, 11, 40 (2016)



The urban heat-island effect, driven largely by the replacement of forests with roads and buildings, gives rise to temperatures in London that are as much as 6 °C warmer than those in the surrounding open country. Shown here are the low temperatures on a typical day in May. (Adapted from ref. 18 .)
Citation: Phys. Today **69**, 11, 40 (2016)

Volcanoes and Global Warming



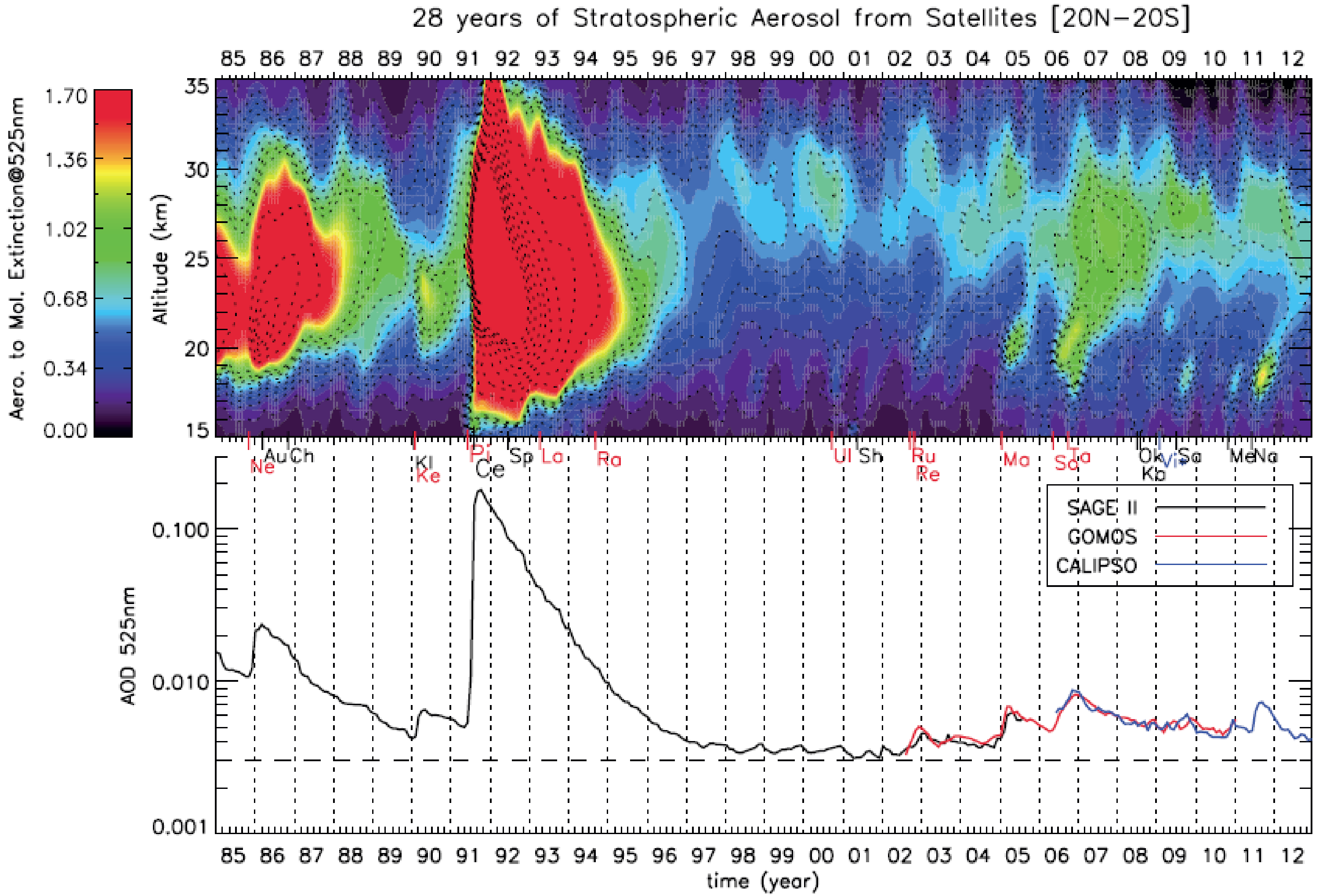


Figure 8.13 | (Top) Monthly mean extinction ratio (525 nm) profile evolution in the tropics [20°N to 20°S] from January 1985 through December 2012 derived from Stratospheric Aerosol and Gas Experiment (SAGE) II extinction in 1985–2005 and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) scattering ratio in 2006–2012, after removing clouds below 18 km based on their wavelength dependence (SAGE II) and depolarization properties (CALIPSO) compared to aerosols. Black contours represent the extinction ratio in log-scale from 0.1 to 100. The position of each volcanic eruption occurring during the period is displayed with its first two letters on the horizontal axis, where tropical eruptions are noted in red. The eruptions were Nevado del Ruiz (Ne), Augustine (Au), Chikurachki (Ch), Kliuchevskoi (Kl), Kelut (Ke), Pinatubo (Pi), Cerro Hudson (Ce), Spur (Sp), Lascar (La), Rabaul (Ra), Ulawun (Ul), Shiveluch (Sh), Ruang (Ru), Reventador (Re), Manam (Ma), Soufrière Hills (So), Tavurvur (Ta), Okmok (Ok), Kasatochi (Ka), Victoria (Vi*—forest fires with stratospheric aerosol injection), Sarychev (Sa), Merapi (Me), Nabro (Na). (Updated from Figure 1 from Vernier et al., 2011.) (Bottom) Mean stratospheric aerosol optical depth (AOD) in the tropics [20°N to 20°S] between the tropopause and 40 km since 1985 from the SAGE II (black line), the Global Ozone Monitoring by Occultation of Stars (GOMOS) (red line), and CALIPSO (blue line). (Updated from Figure 5 from Vernier et al., 2011.)

AR5 WG1 Ch. 8

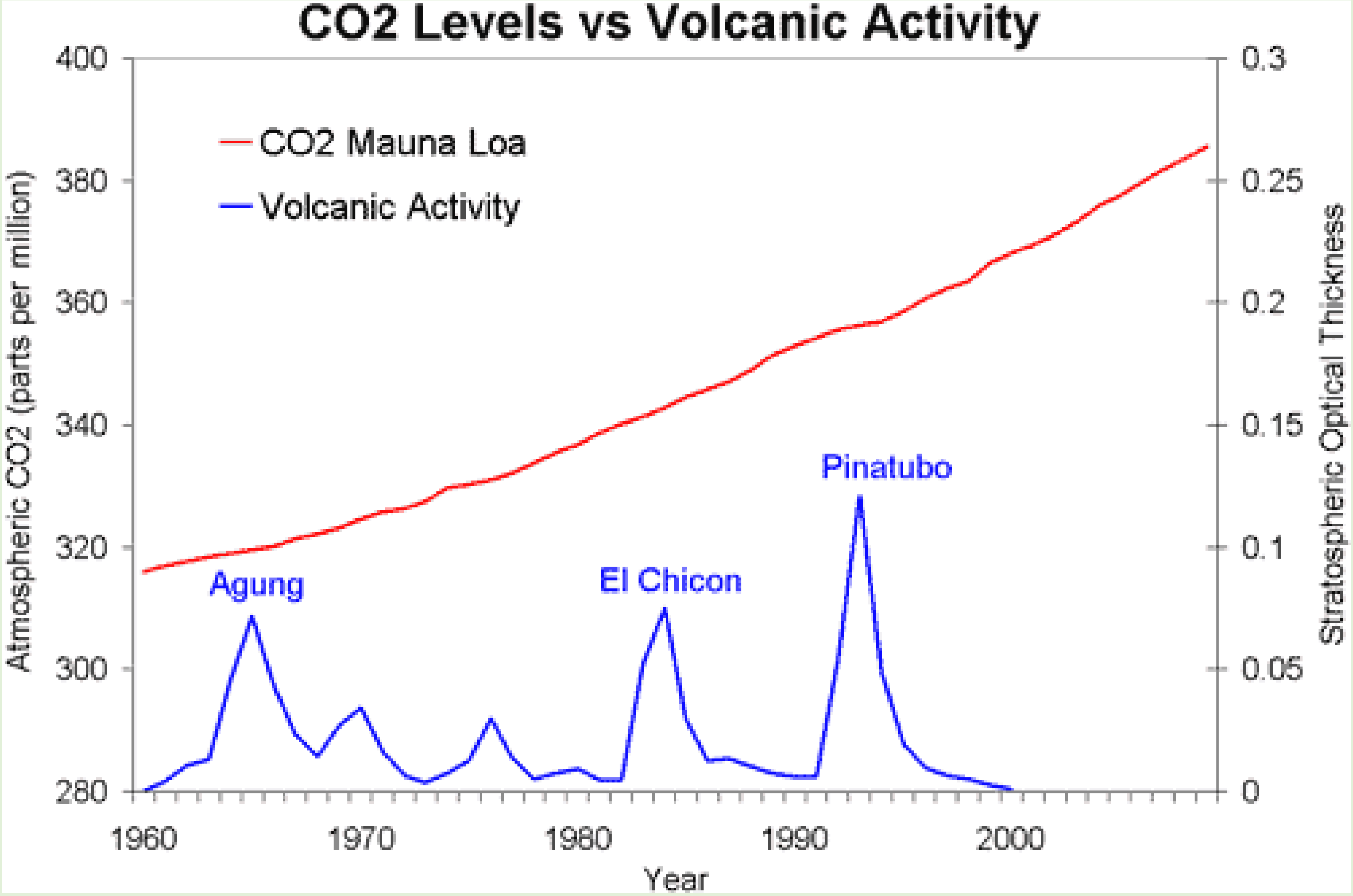
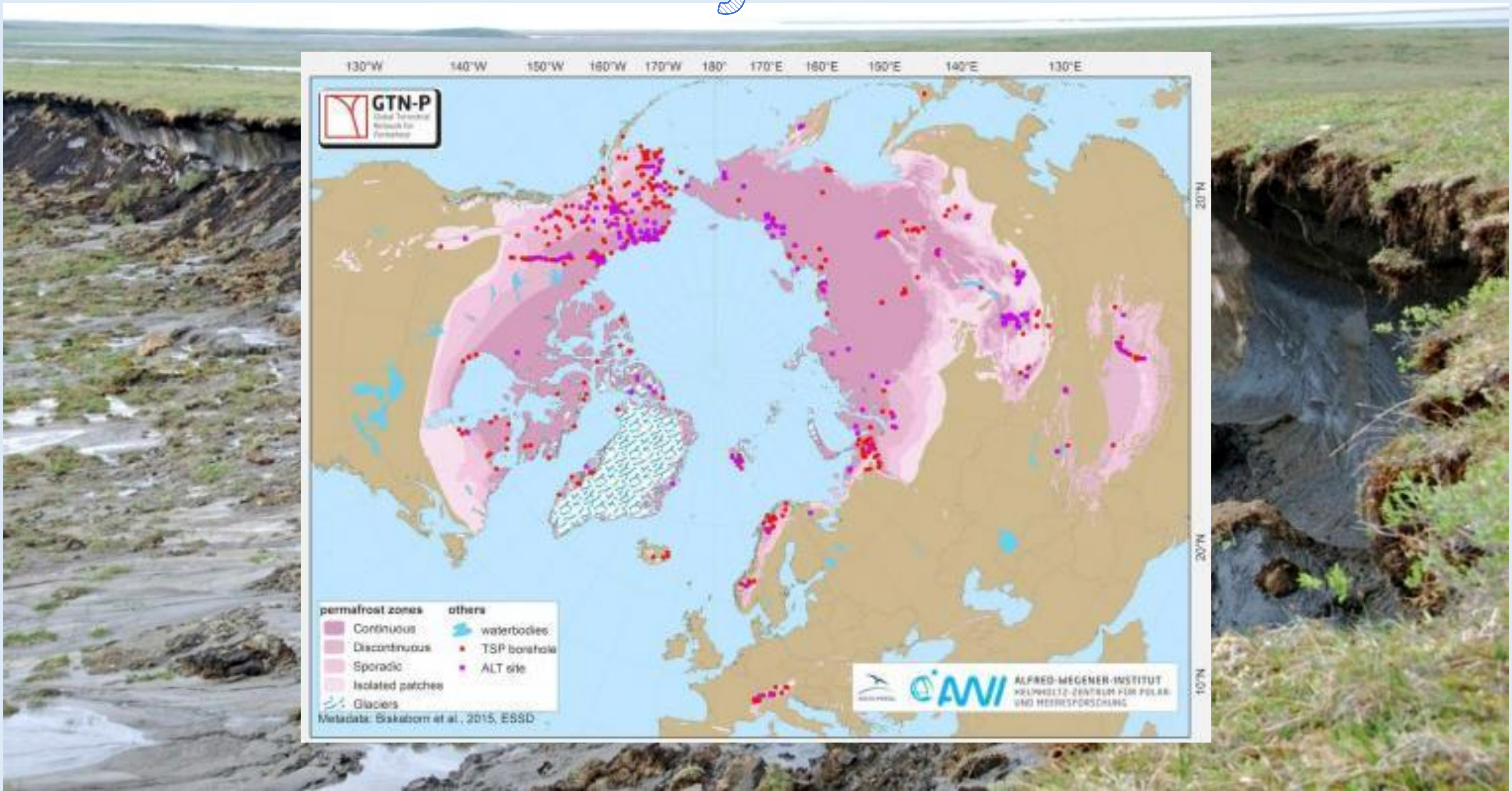


Figure 1: Atmospheric CO2 levels measured at Mauna Loa, Hawaii (NOAA) and Stratospheric Aerosol Optical Thickness at 50nm (NASA GISS).

The Mount Pinatubo eruption emitted 42 million tonnes of CO2 (Gerlach et al 1996). Compare this to human emissions in 1991: 23 billion tonnes of CO2 (CDIAC). The strongest eruption over the last half-century amounted to 0.2% of human CO2 emissions in that year.

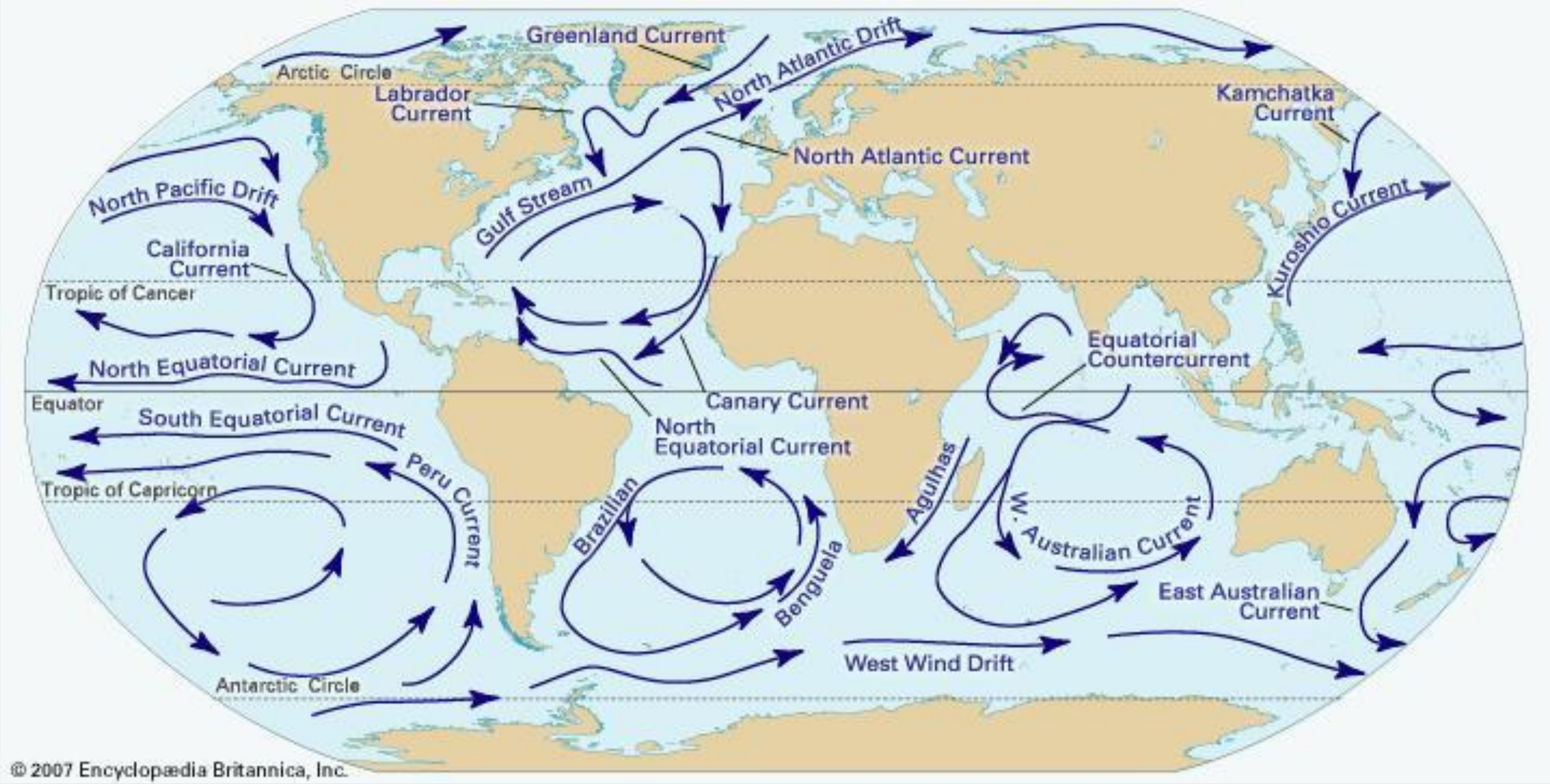
https://www.skepticalscience.com/volcanoes-and-global-warming-intermediate.htm

Permafrost

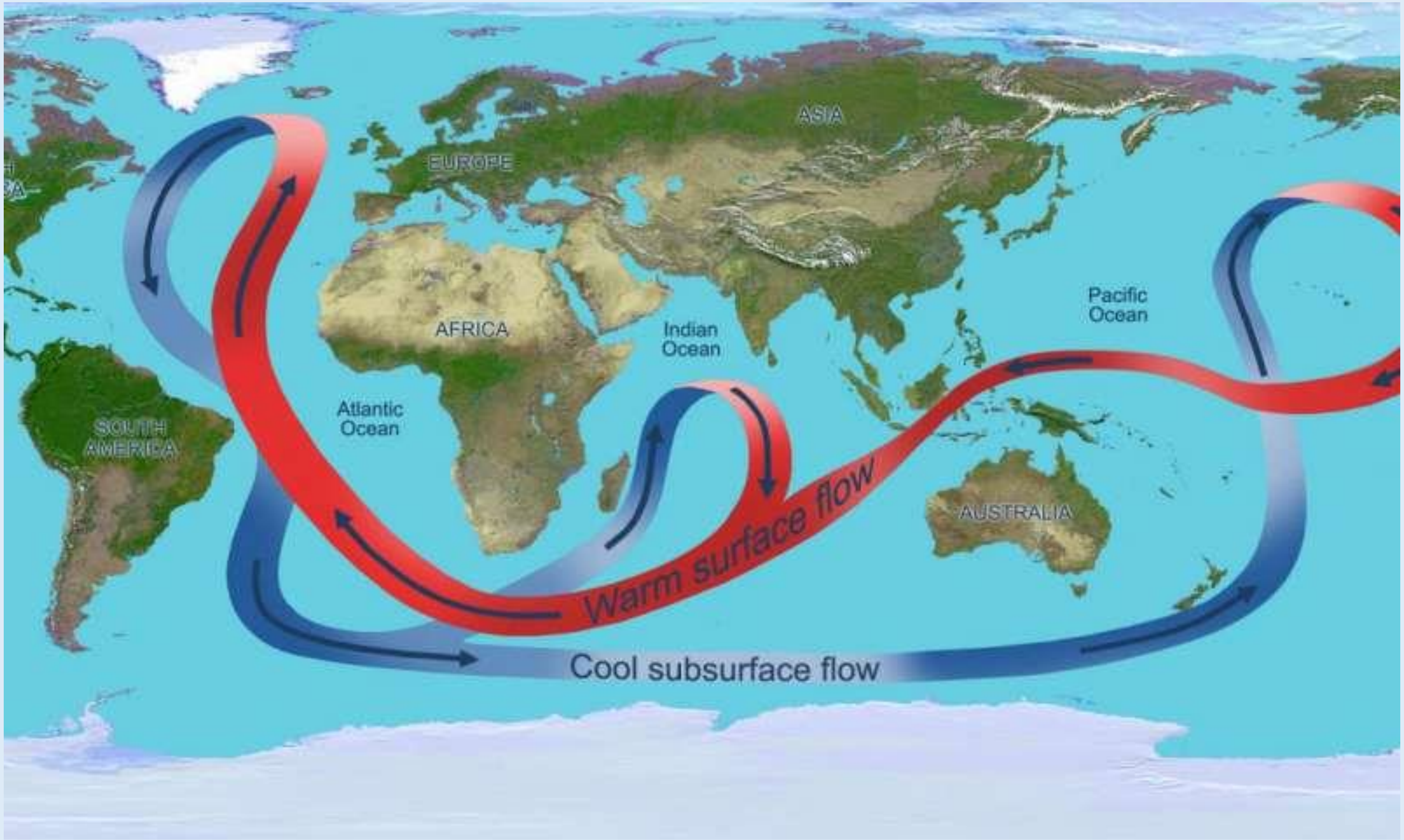


GTN-P
permafrost zones
Continuous
Discontinuous
Sporadic
Isolated patches
Glaciers
others
waterbodies
TSP borehole
ALT site
Metadata: Biskaborn et al., 2015, ESSD
ALFRED-WEGENER-INSTITUT


OCEANS



Greenland Current
North Atlantic Drift
Arctic Circle
Labrador Current
Kamchatka Current
North Atlantic Current
North Pacific Drift
Gulf Stream
Kuroshio Current
California Current
Tropic of Cancer
Equatorial Countercurrent
North Equatorial Current
Equator
Canary Current
South Equatorial Current
North Equatorial Current
Peru Current
Agulhas
Tropic of Capricorn
Brazilian
W. Australian Current
Benguela
East Australian Current
West Wind Drift
Antarctic Circle



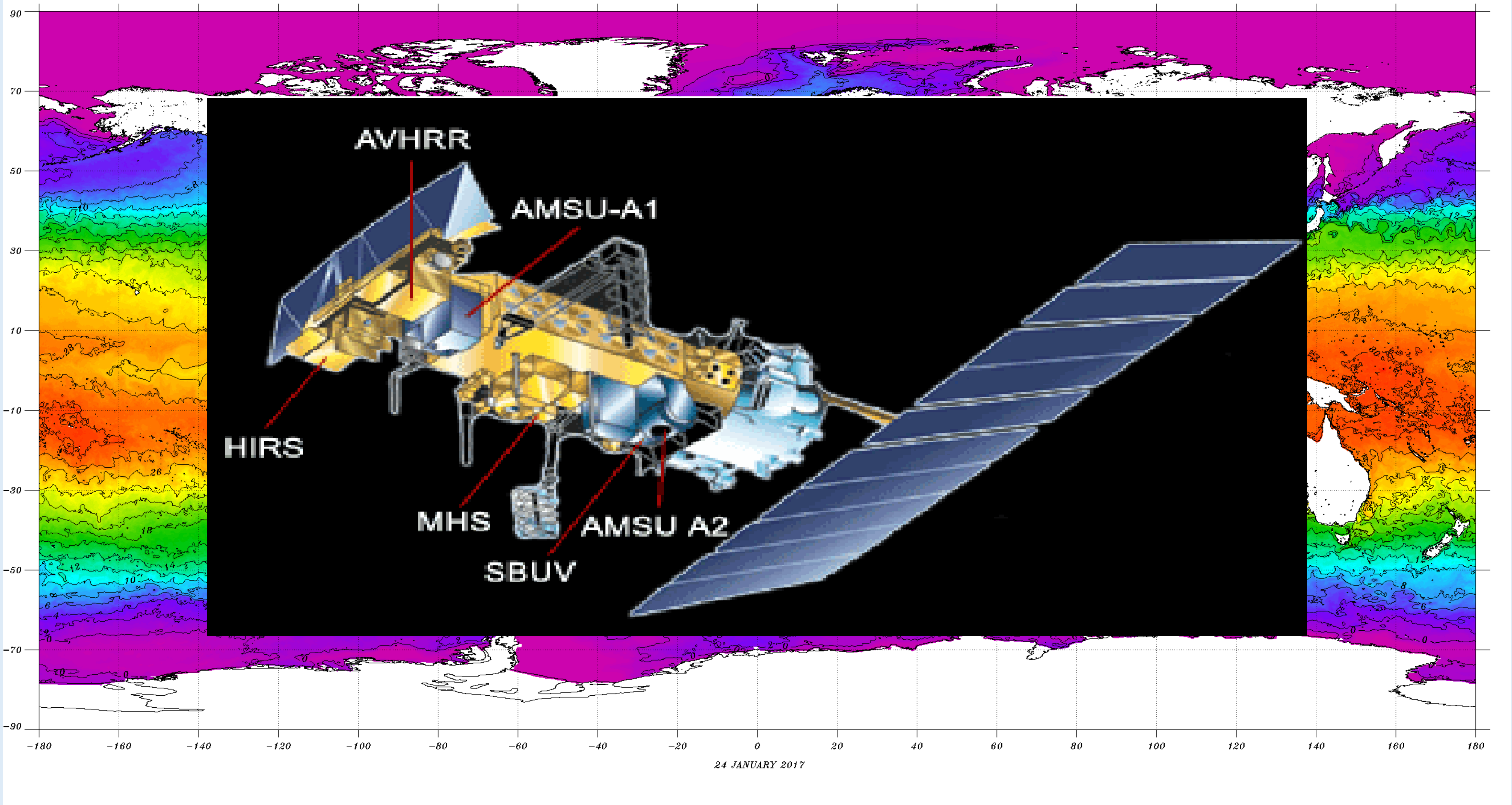
The global ocean overturning circulation, shown here in a simplified illustration, distributes heat through the oceans. In the Atlantic Ocean, the circulation carries warm water (red arrows) northward near the surface and cold deep water (blue arrows) southward. Credit: NASA/JPL

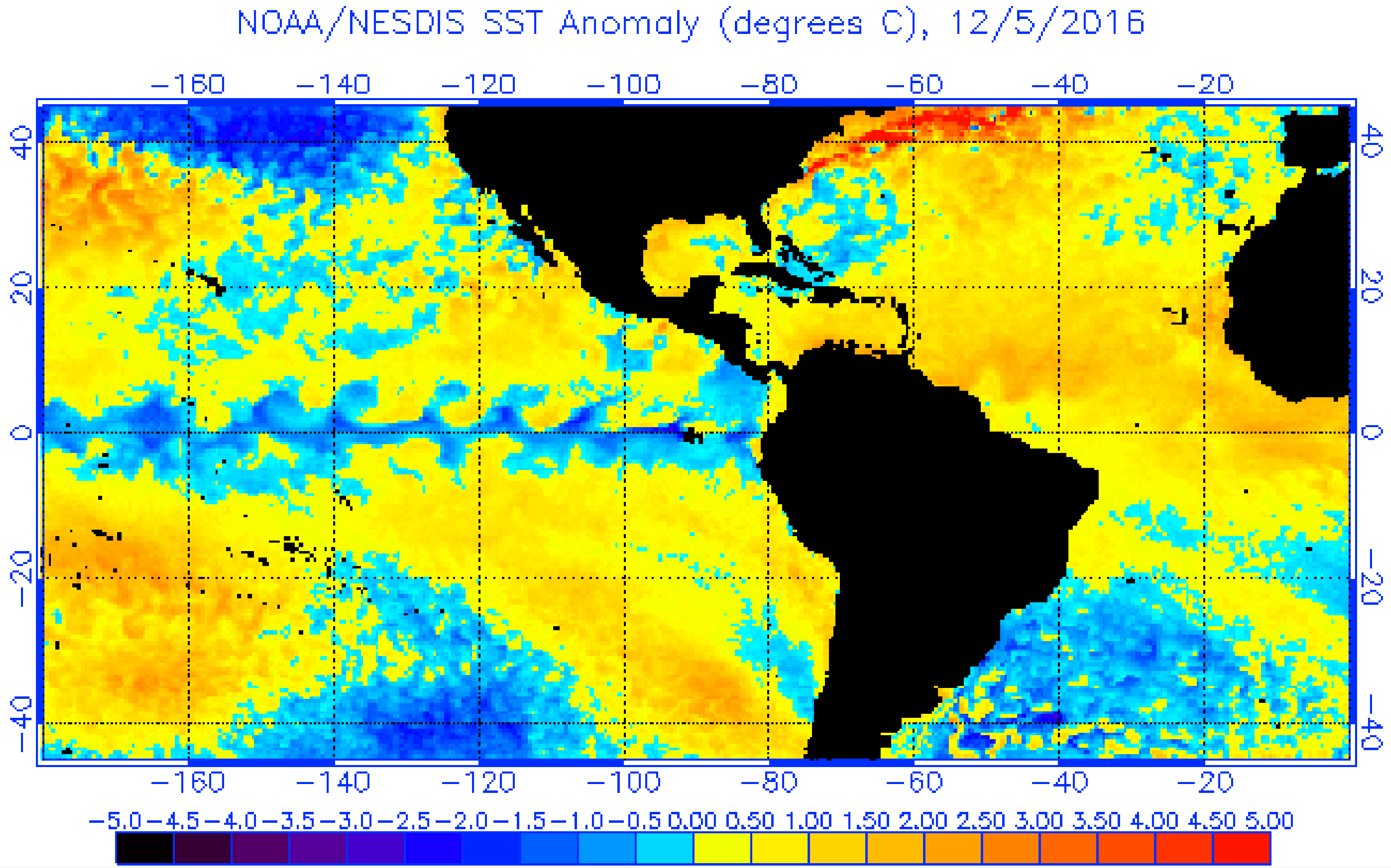
Read more at: http://phys.org/news/2016-06-ocean-circulation-implicated-abrupt-climate.html#jCp

…so you want to measure the temp of the surface of the planet? how to do this? Oceans dominate, are more homogeneous, somewhat mixed (equilibrated), high specific heat, etc.

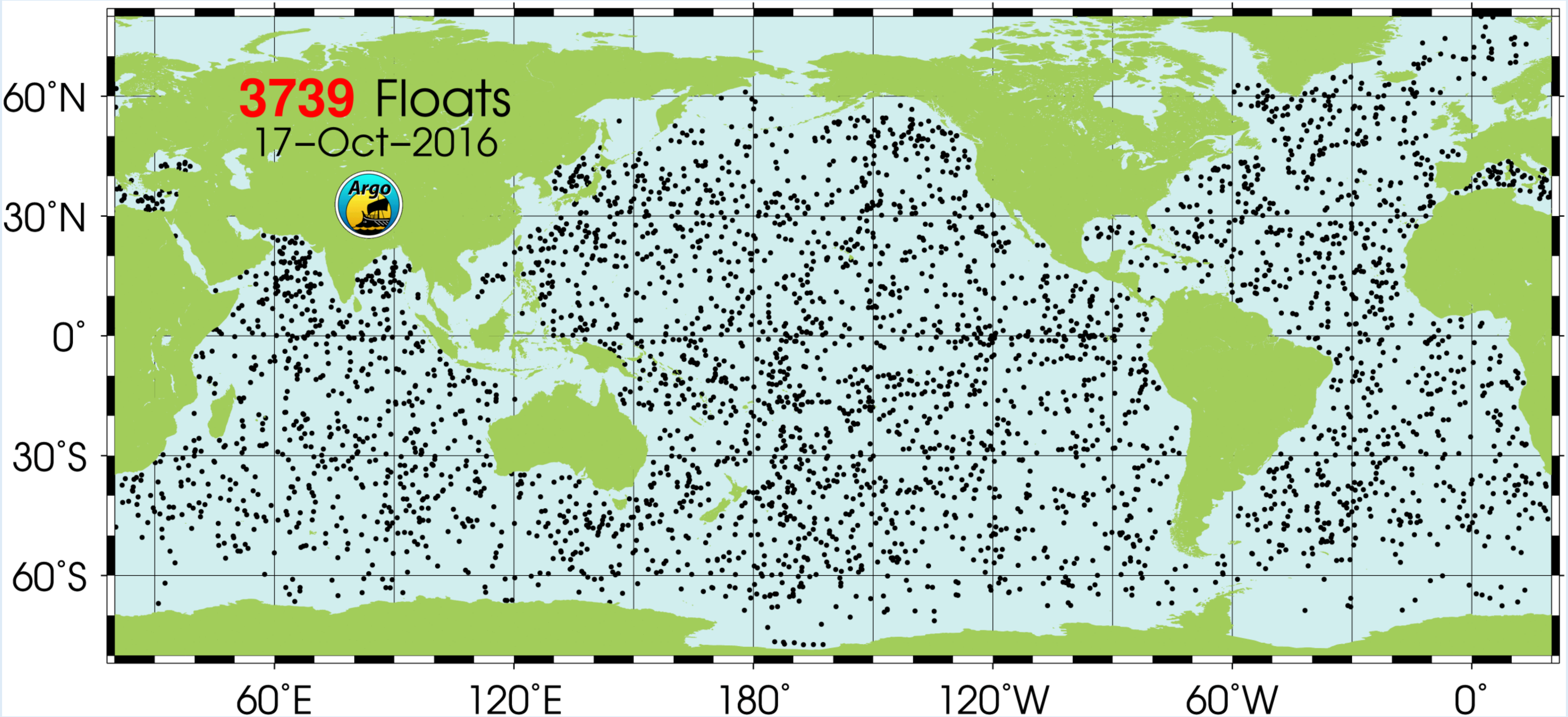
So use
old bucket data,
ship intake data,
newer buoy data,
add satellite data,
and then *Argo* data.....

Advanced very-high-resolution radiometer

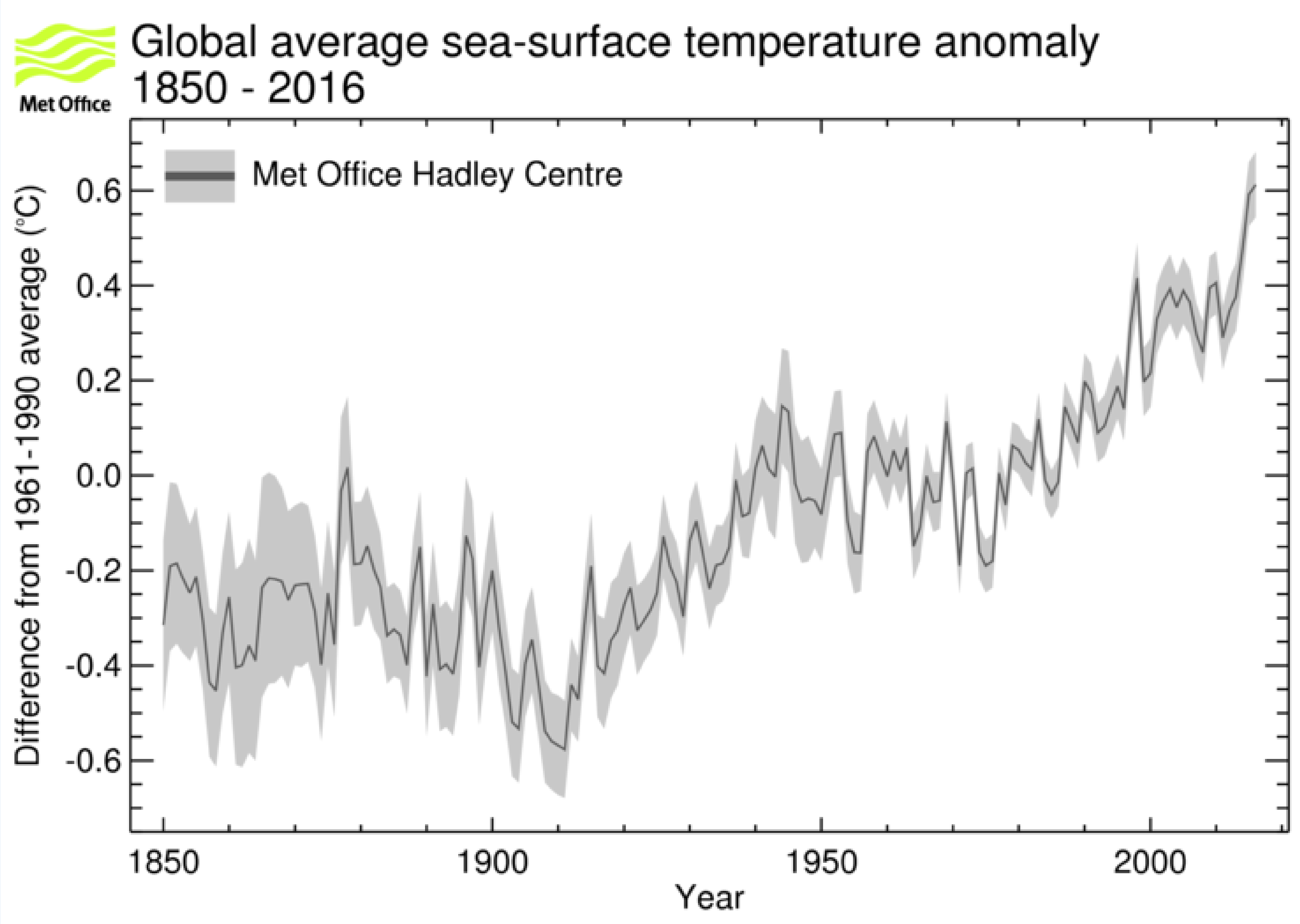




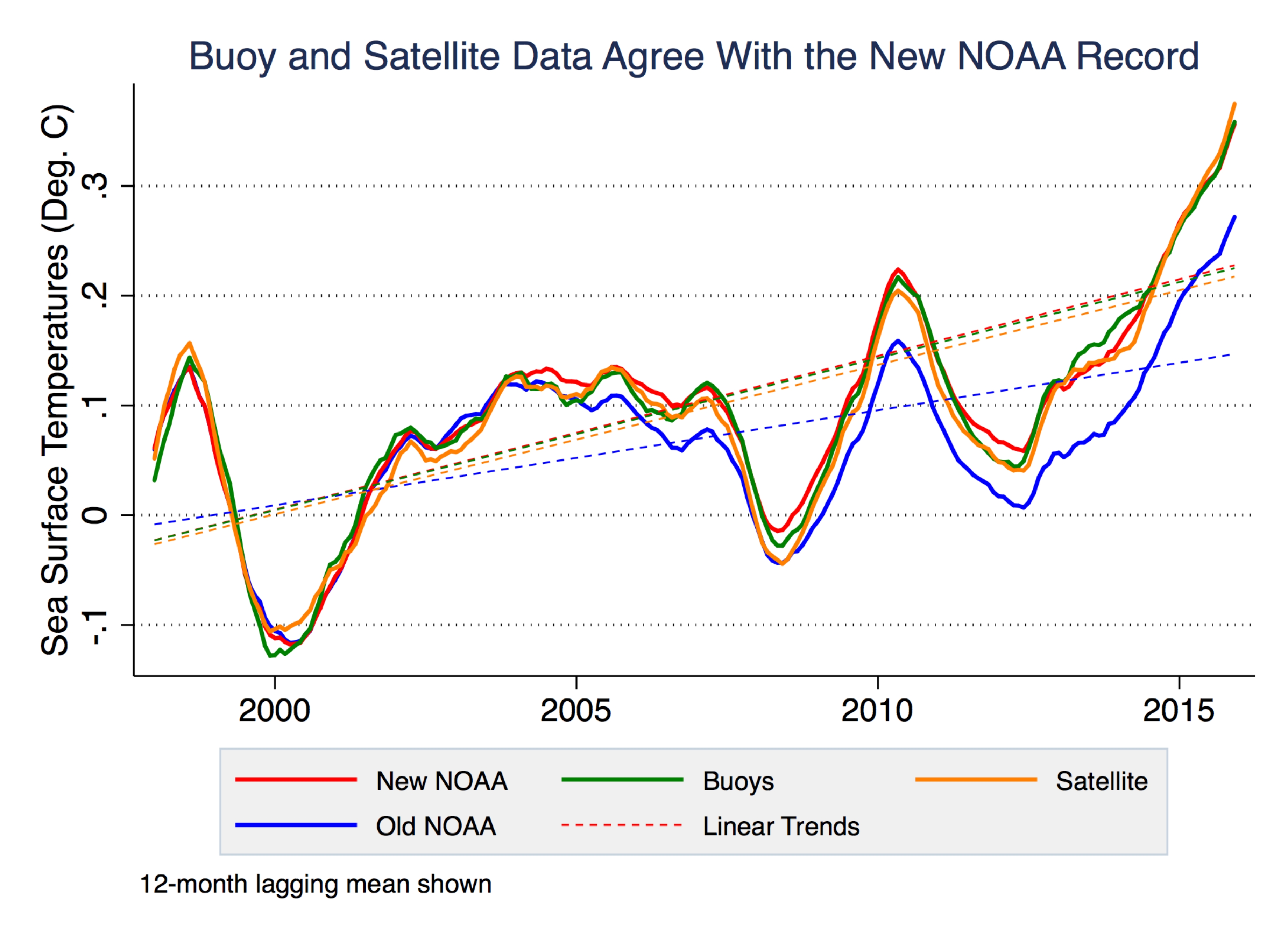
http://www.ospo.noaa.gov/Products/ocean/sst/anomaly/anim_2mw.html



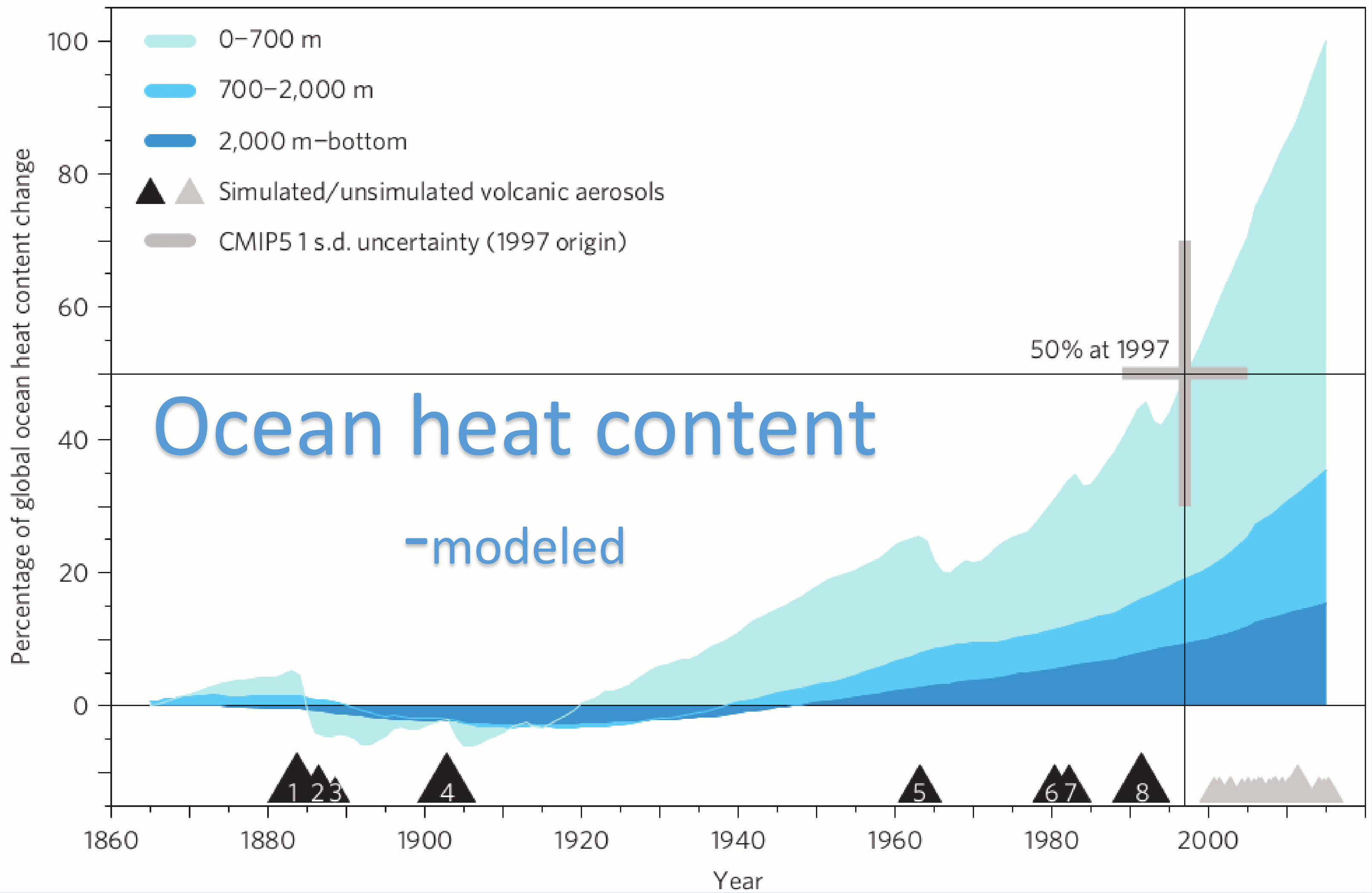
Argo float network for ocean temperature monitoring



Global average sea-surface temperature anomaly
1850 - 2016
Met Office
Met Office Hadley Centre
Difference from 1961-1990 average (°C)
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1850
1900
1950
2000
Year

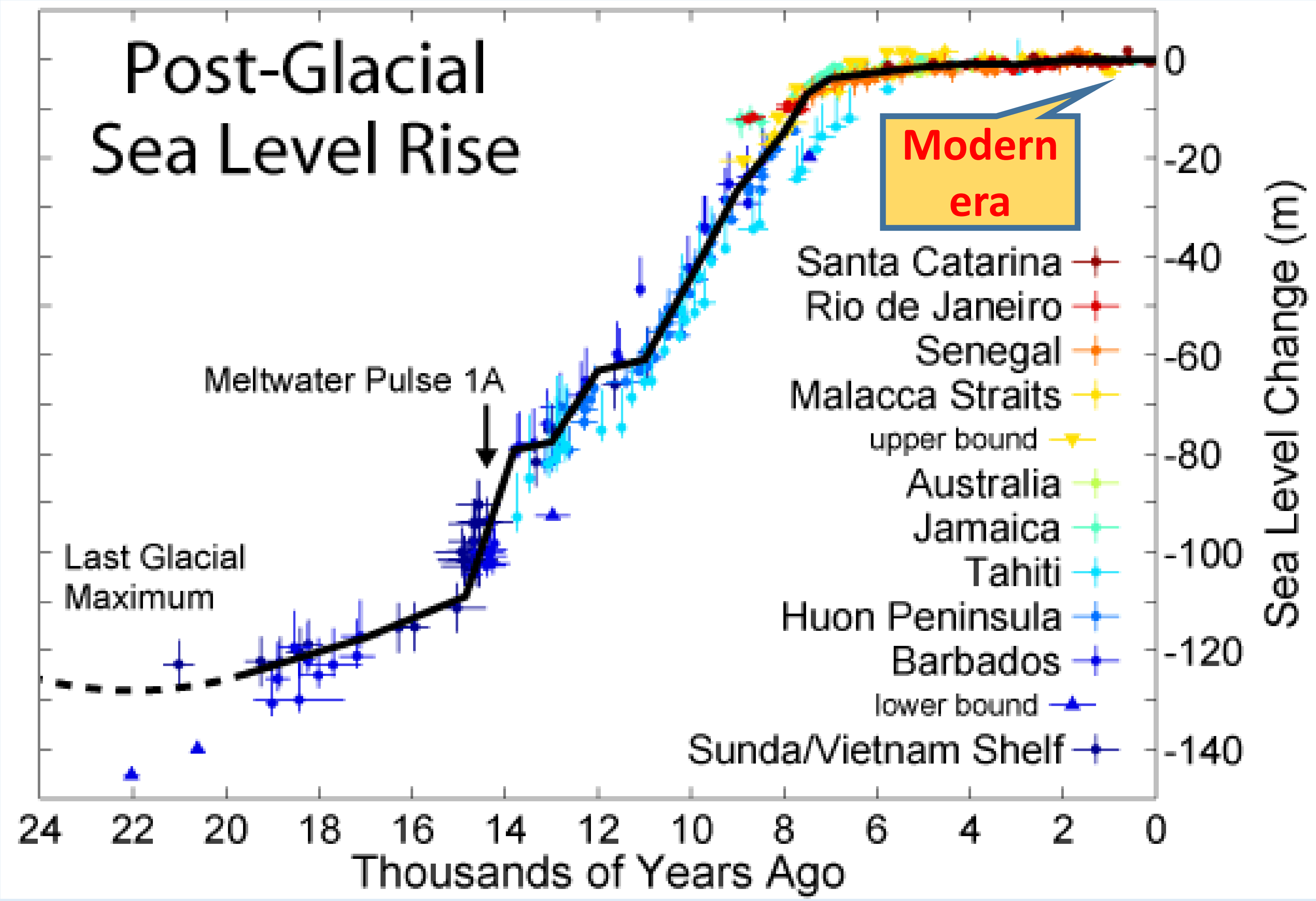


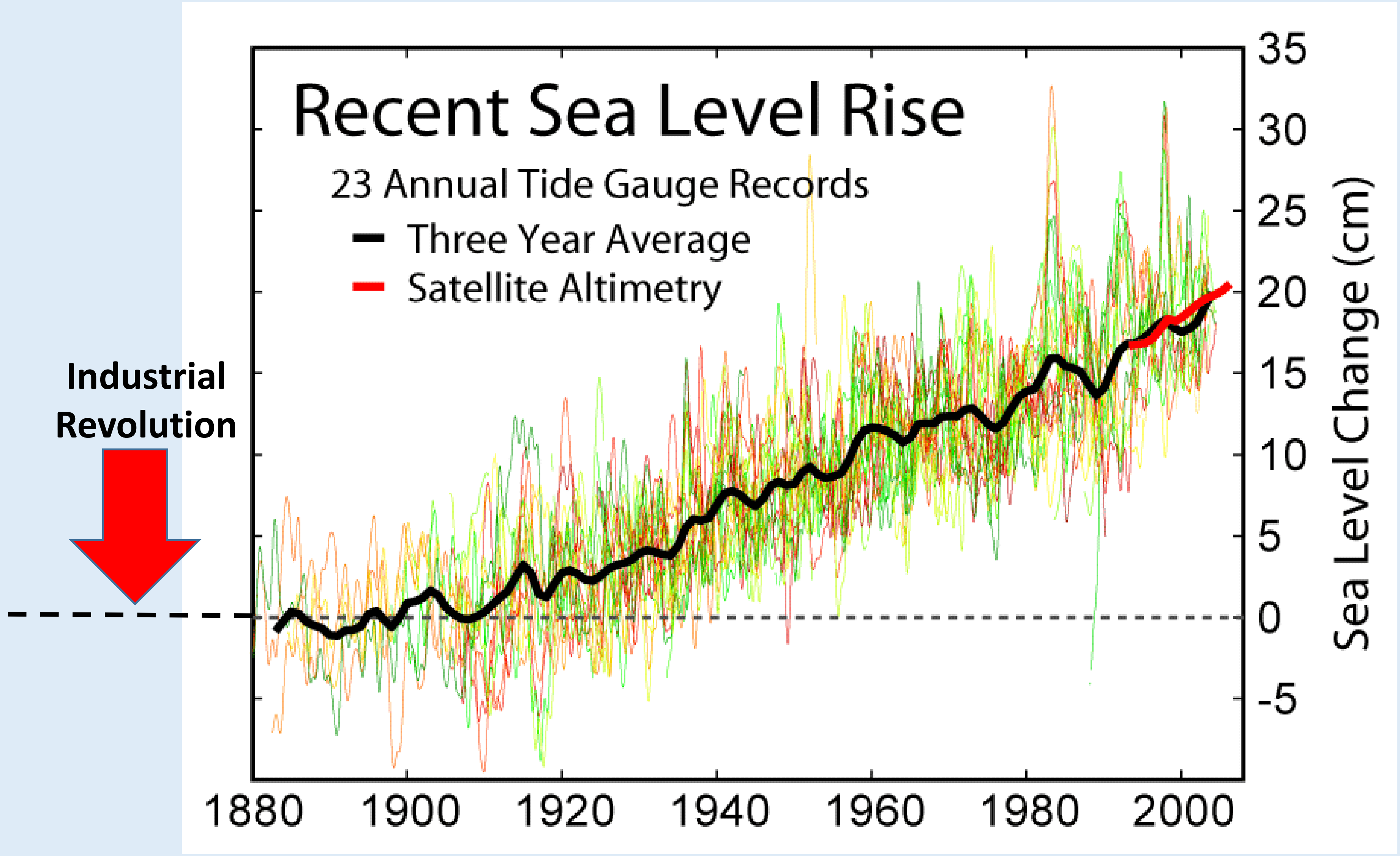
Buoy and Satellite Data Agree With the New NOAA Record
Sea Surface Temperatures (Deg. C)
.3
.2
.1
0
-.1
2000
2005
2010
2015
New NOAA
Buoys
Satellite
Old NOAA
Linear Trends
12-month lagging mean shown

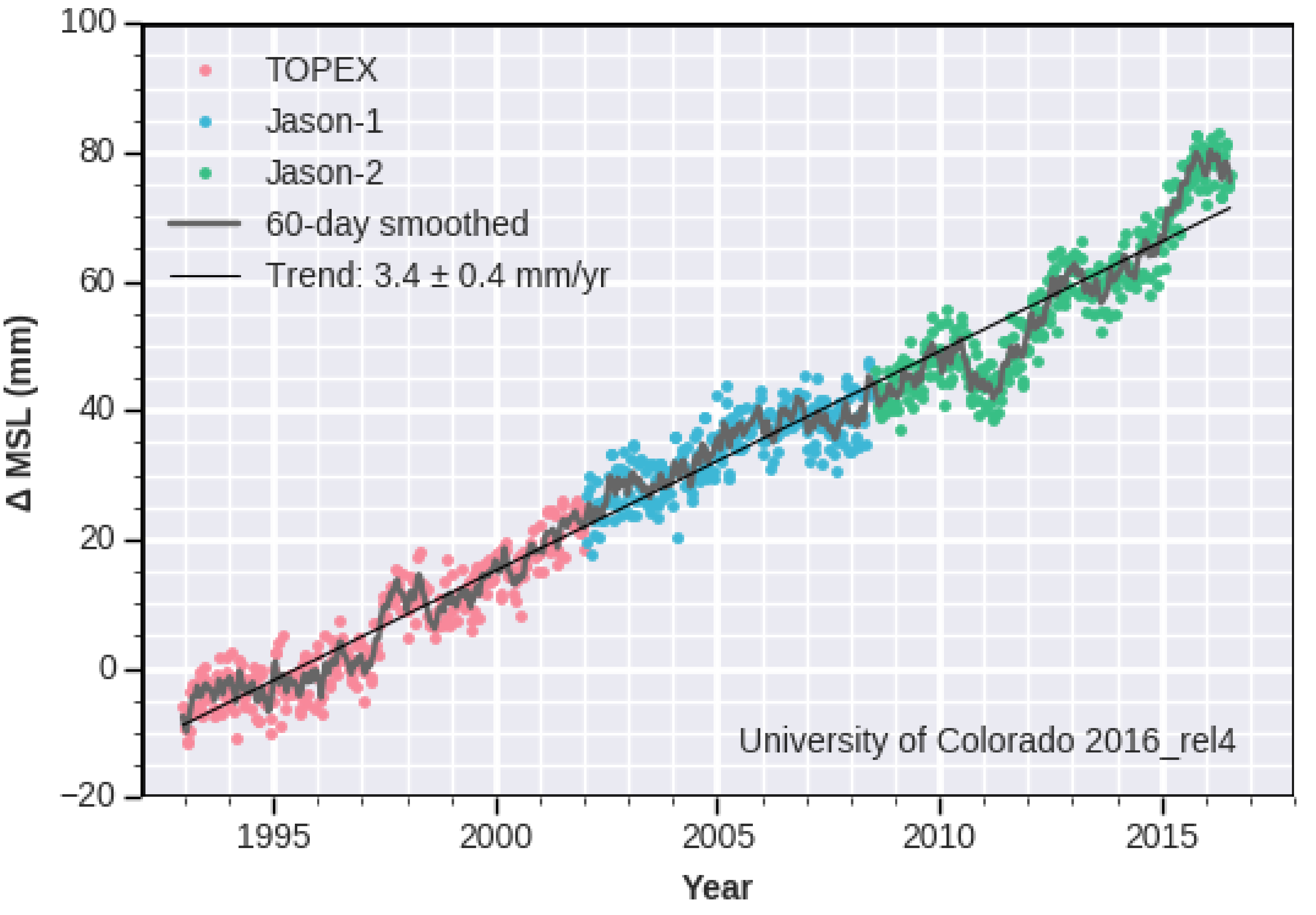


https://skepticalscience.com/Industrial-era-ocean-heat-uptake-has-doubled-since-1997.html

Figure 1 - The CMIP5 multi-model mean ocean heat content change from 1865 to 2015 expressed as a percentage for 3 ocean depth layers. The gray bars indicate the 1-standard deviation uncertainty and the black triangles along the bottom denote simulated large volcanic eruptions (which disperse light-scattering sulfate particles). Gray triangles show the many unsimulated small & moderate volcanic eruptions after 2000. Image from Gleckler et al (2016).

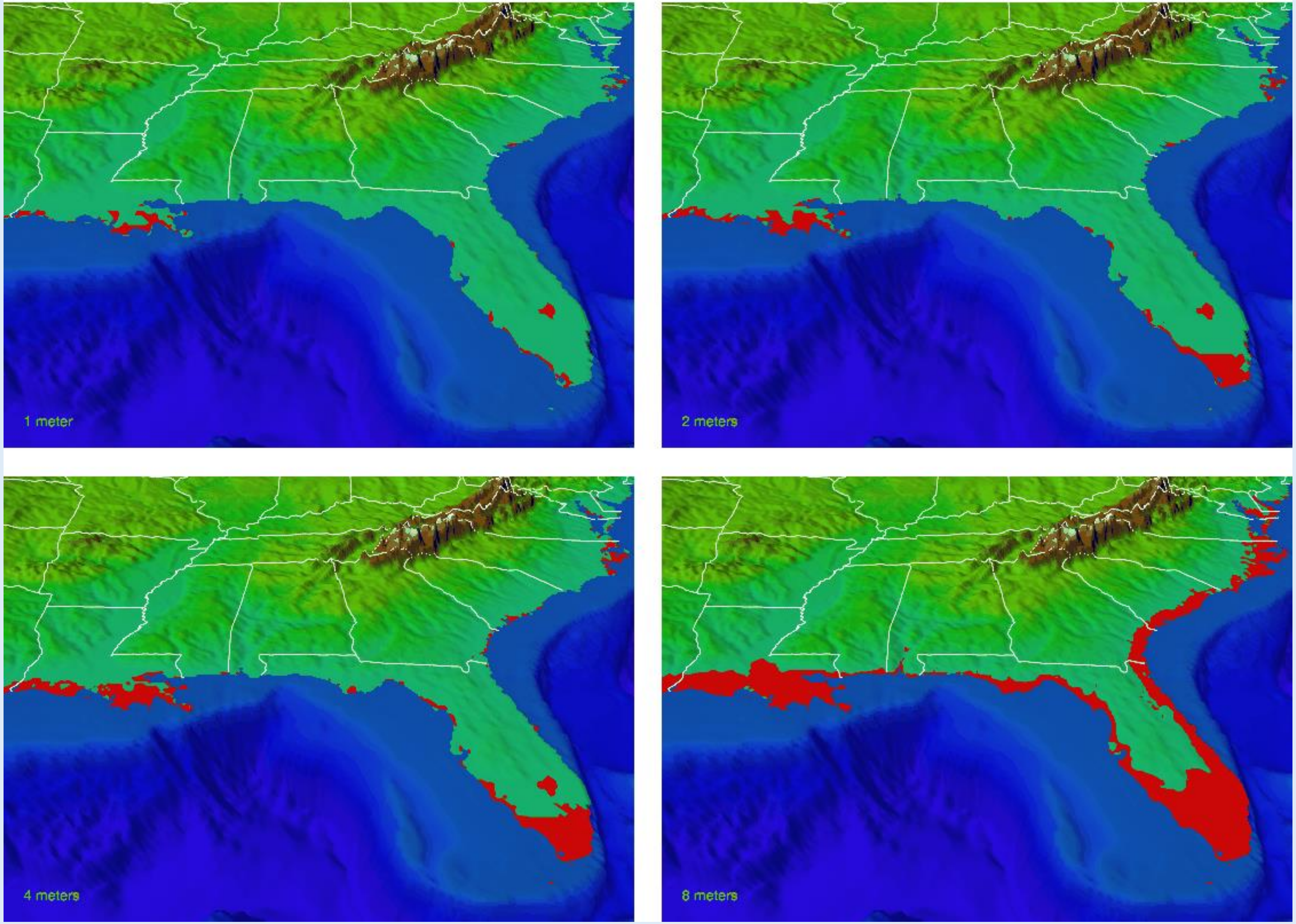

Post-Glacial
Sea Level Rise
Modern
era
Meltwater Pulse 1A
Last Glacial
Maximum
Santa Catarina
Rio de Janeiro
Senegal
Malacca Straits
upper bound
Australia
Jamaica
Tahiti
Huon Peninsula
Barbados
lower bound
Sunda/Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Sea Level Change (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago


Recent Sea Level Rise
23 Annual Tide Gauge Records
Three Year Average
Satellite Altimetry
Industrial
Revolution
35
30
25
20
15
10
5
0
-5
Sea Level Change (cm)
1880
1900
1920
1940
1960
1980
2000

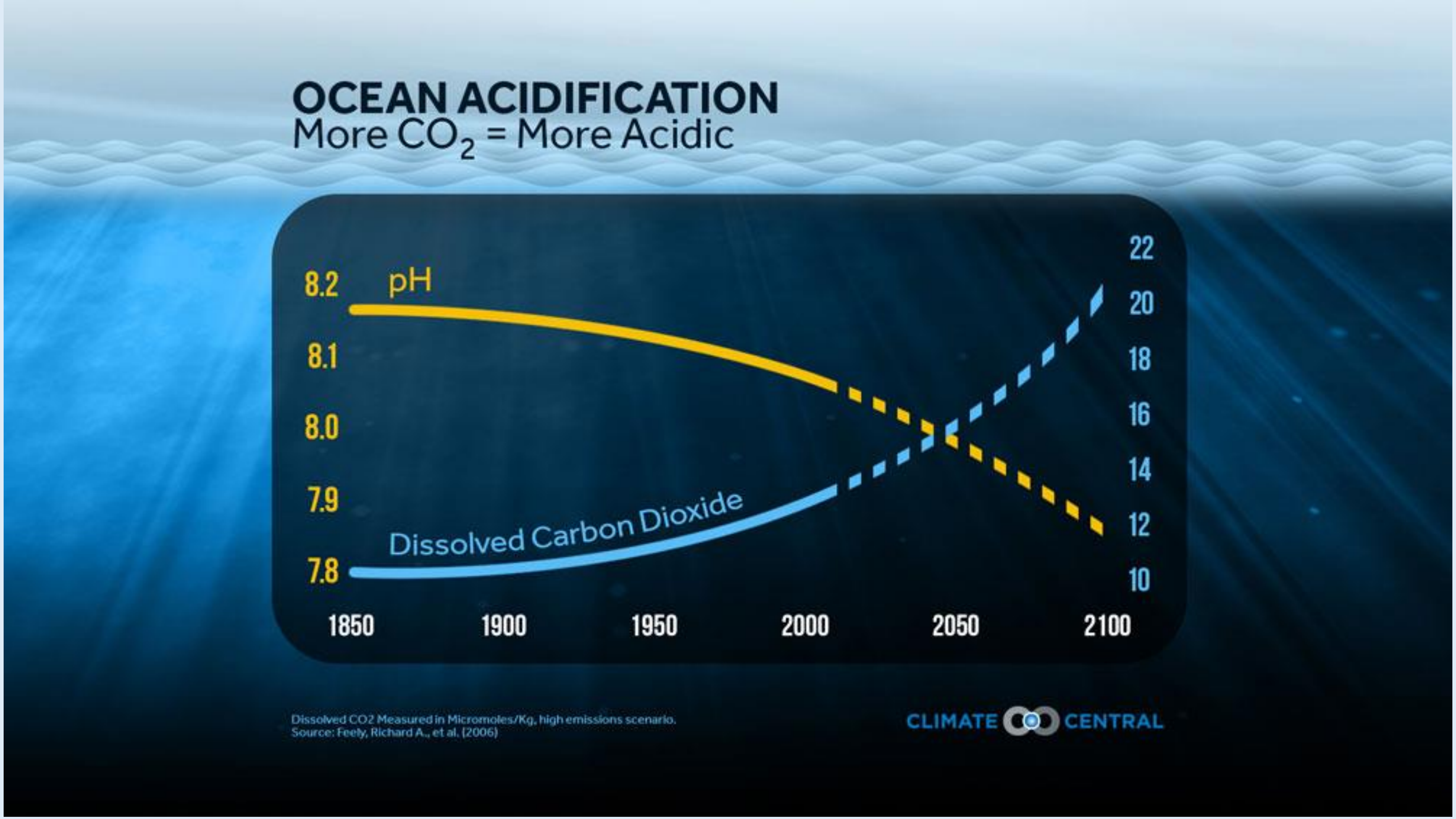


TOPEX
Jason-1
Jason-2
60-day smoothed
Trend: 3.4 ± 0.4 mm/yr
University of Colorado 2016_rel4
Δ MSL (mm)
Year
100
80
60
40
20
0
−20
1995
2000
2005
2010
2015

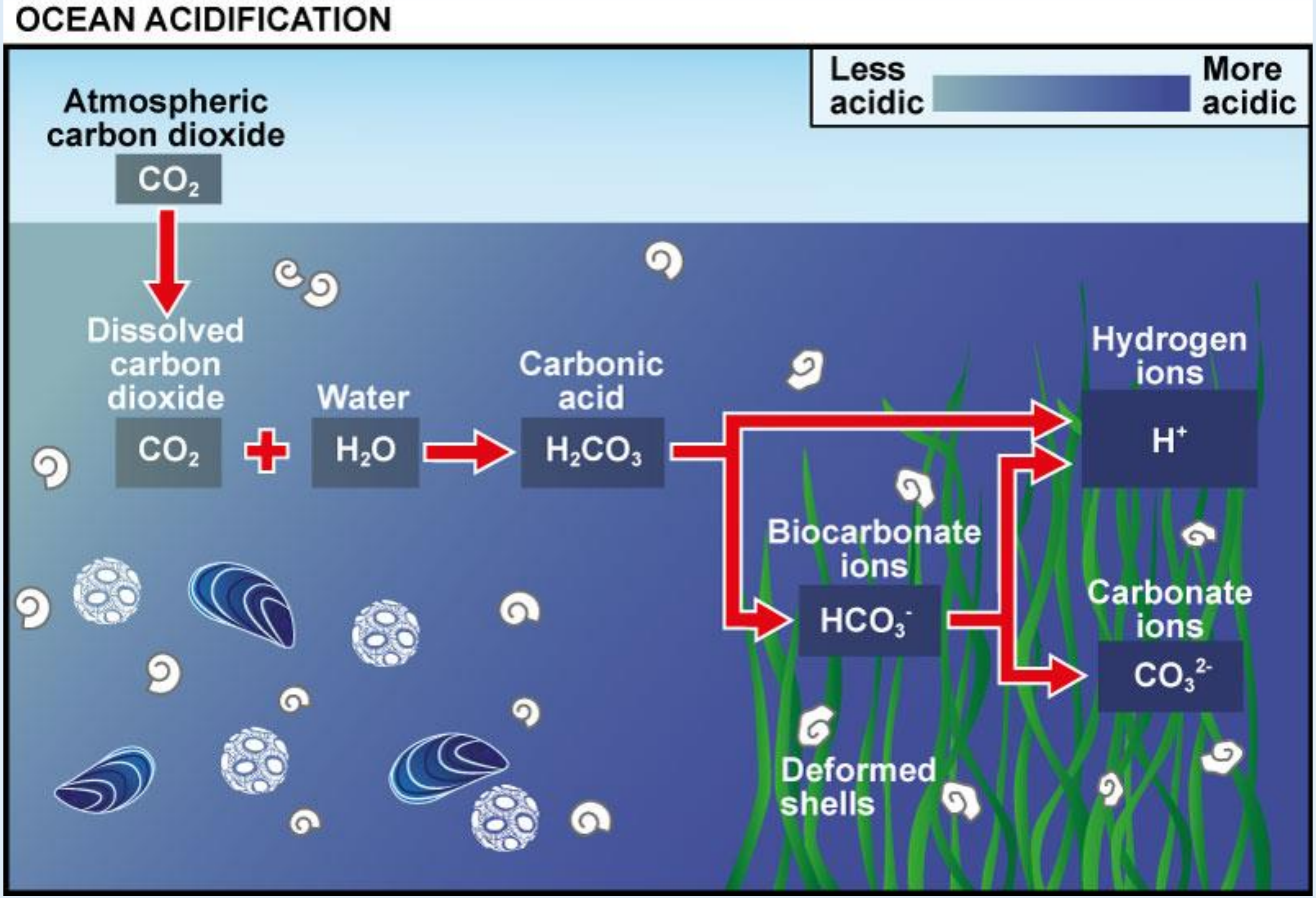
Sea Level Rise

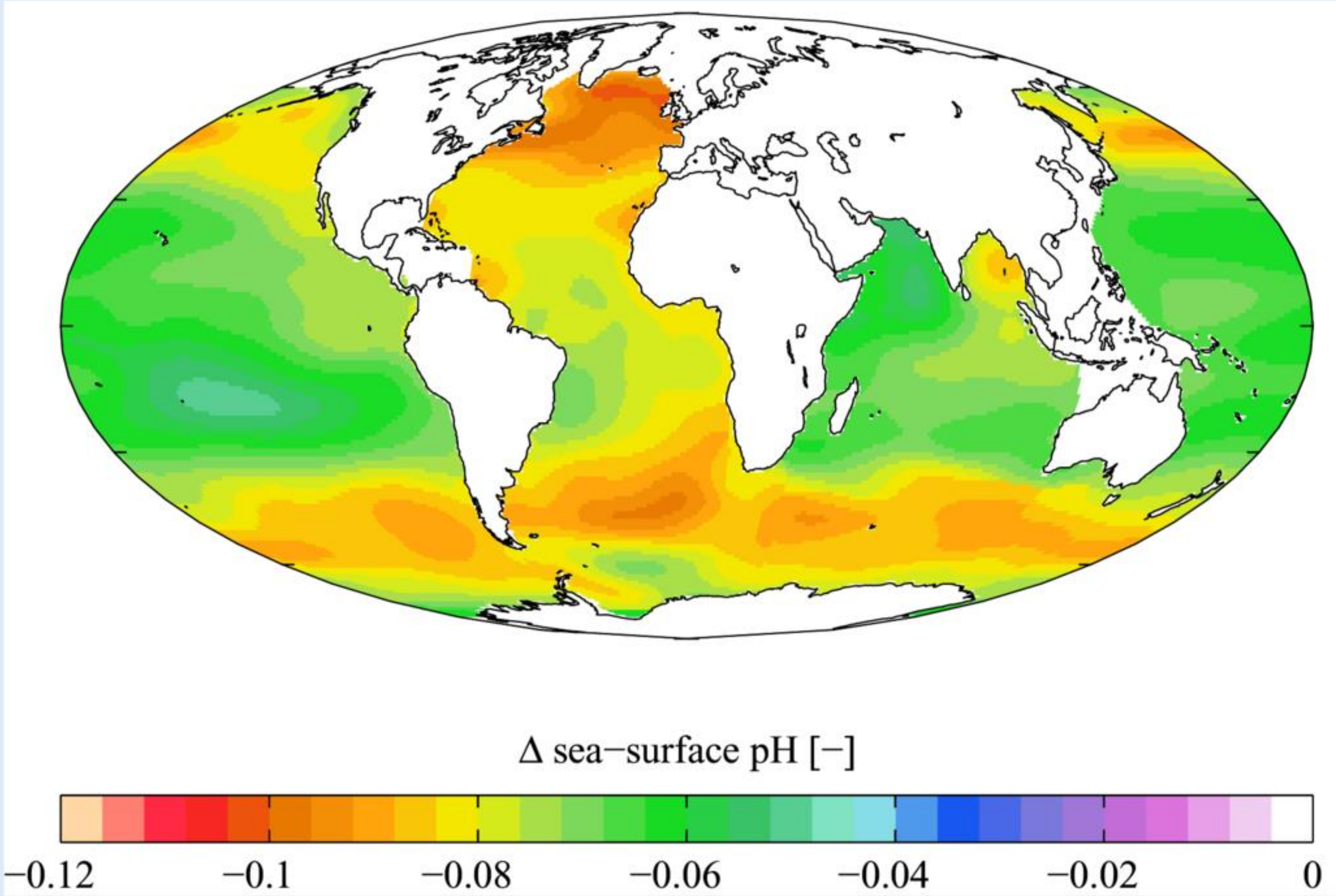


Ocean acidification



OCEAN ACIDIFICATION
More CO_2 = More Acidic
pH
Dissolved Carbon Dioxide
8.2
8.1
8.0
7.9
7.8
22
20
18
16
14
12
10
1850
1900
1950
2000
2050
2100
Dissolved CO2 Measured in Micromoles/Kg, high emissions scenario.
Source: Feely, Richard A., et al. (2006)
CLIMATE CENTRAL

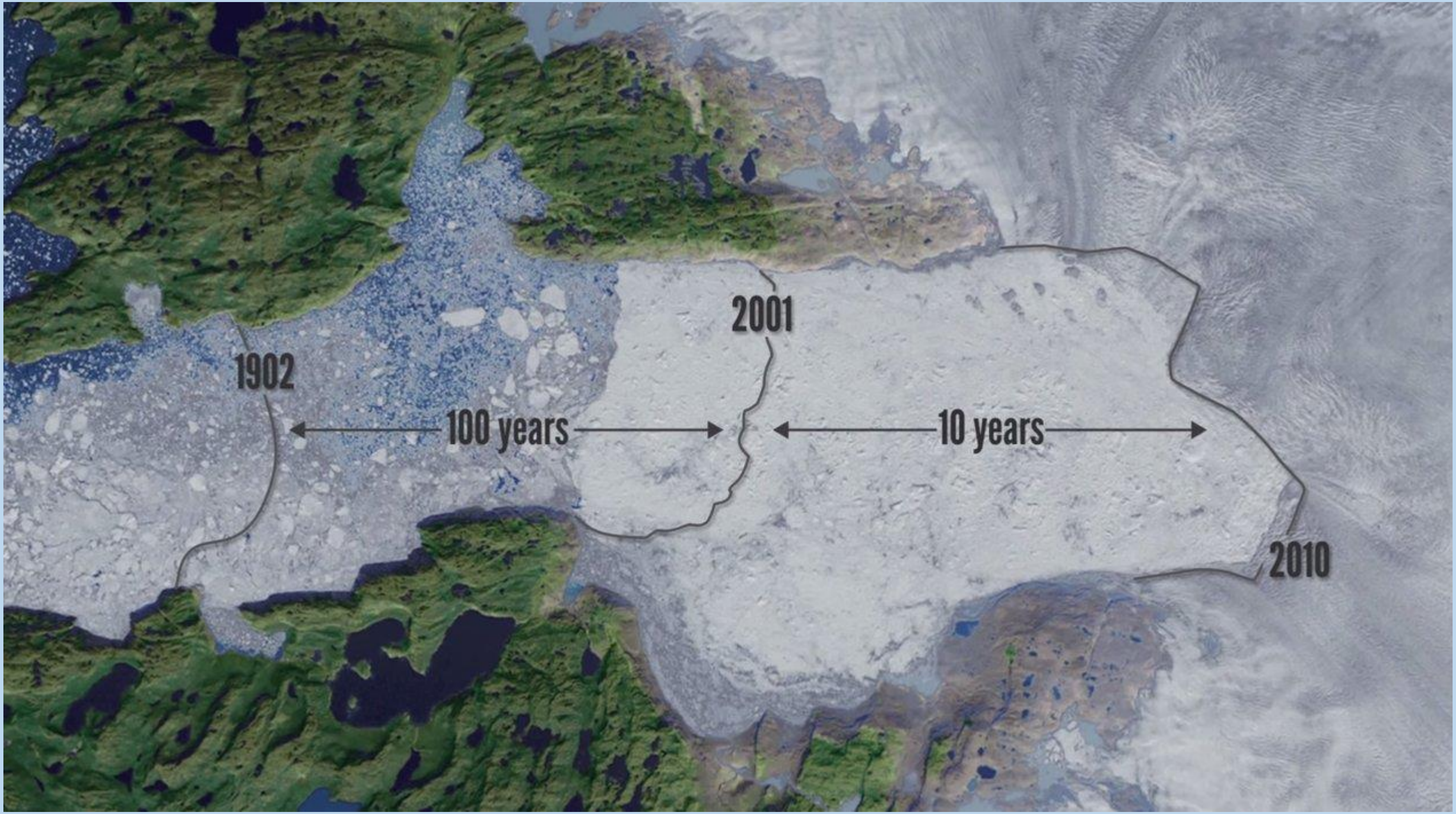

OCEAN ACIDIFICATION
Less acidic
More acidic
Atmospheric carbon dioxide
CO_2
Dissolved carbon dioxide
CO_2
Water
H_2O
Carbonic acid
H_2CO_3
Hydrogen ions
H^+
Biocarbonate ions
HCO_3^-
Carbonate ions
CO_3^{2-}
Deformed shells

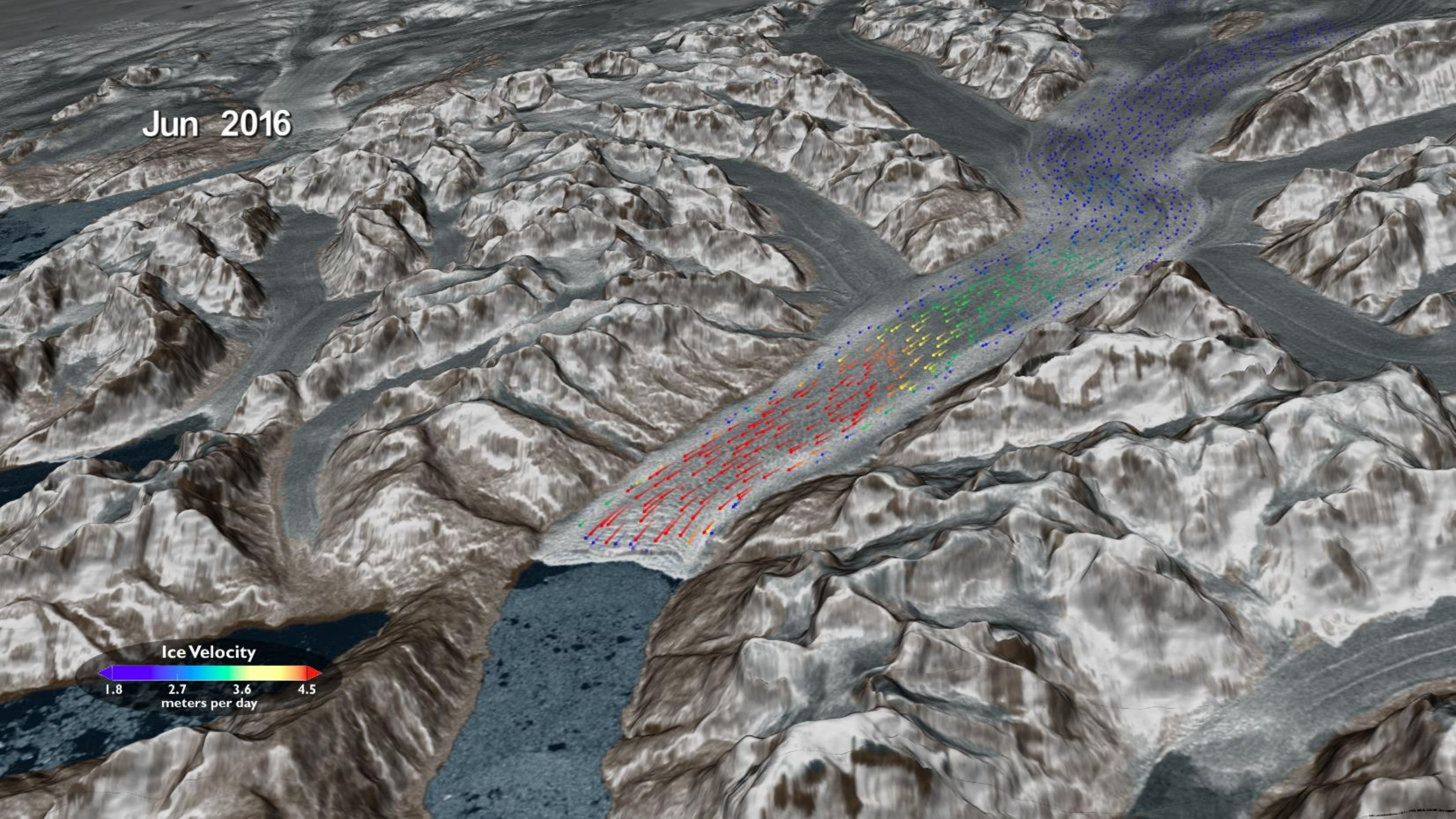


Estimated change in sea water pH caused by human created CO_2 between the **1700s and the 1990s,** from the Global Ocean Data Analysis Project(GLODAP) and the World Ocean Atlas

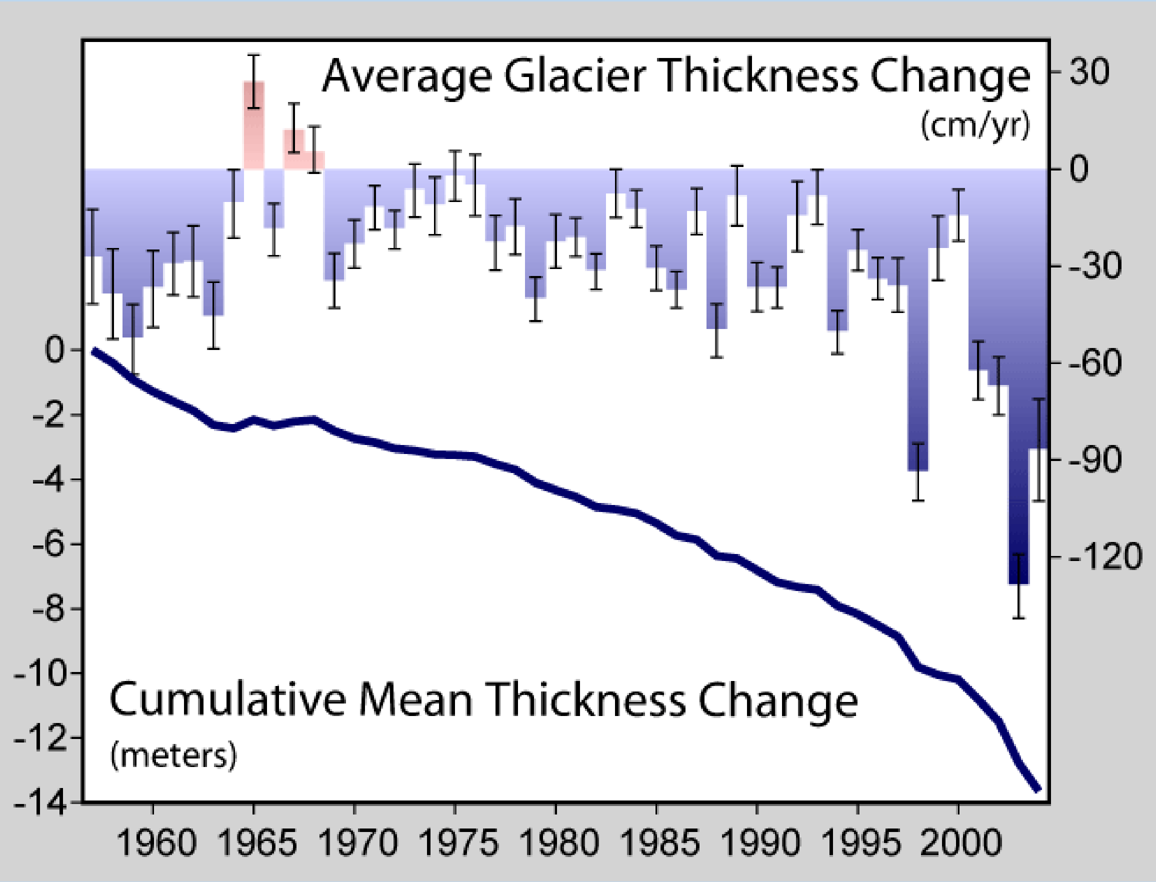
Glaciers

Greenland calving fronts

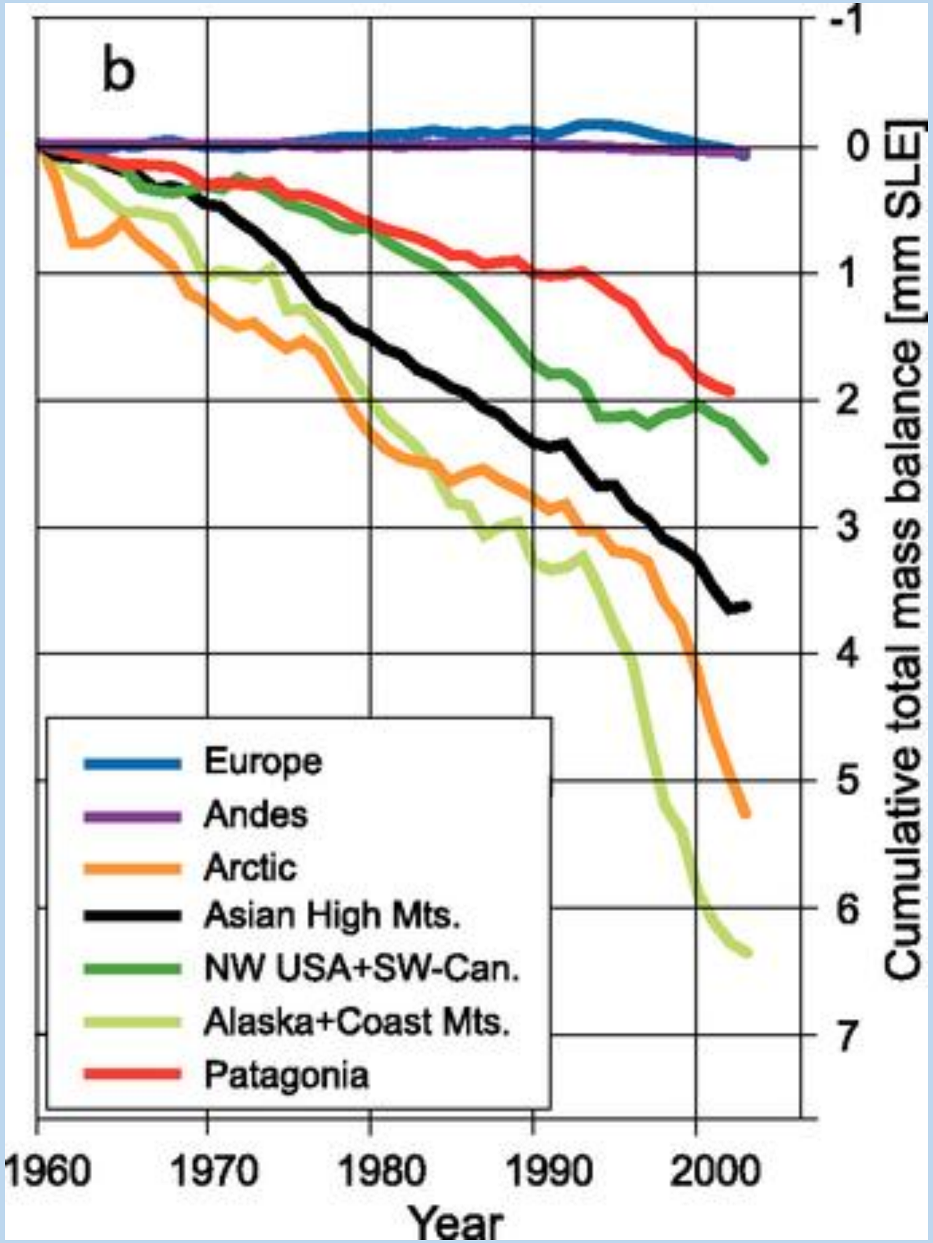


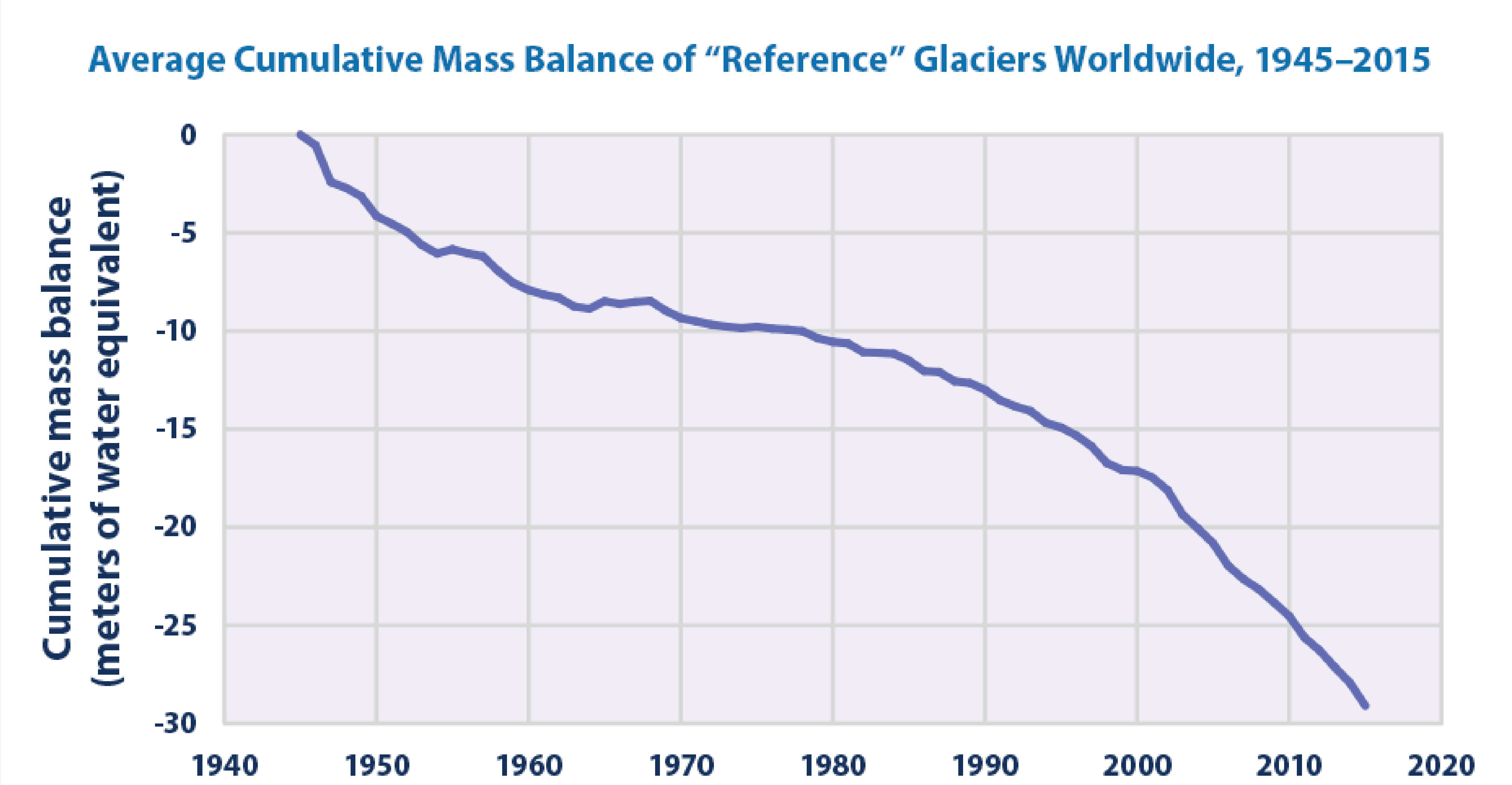

Jun 2016
Ice Velocity
1.8
2.7
3.6
4.5
meters per day

Glaciers



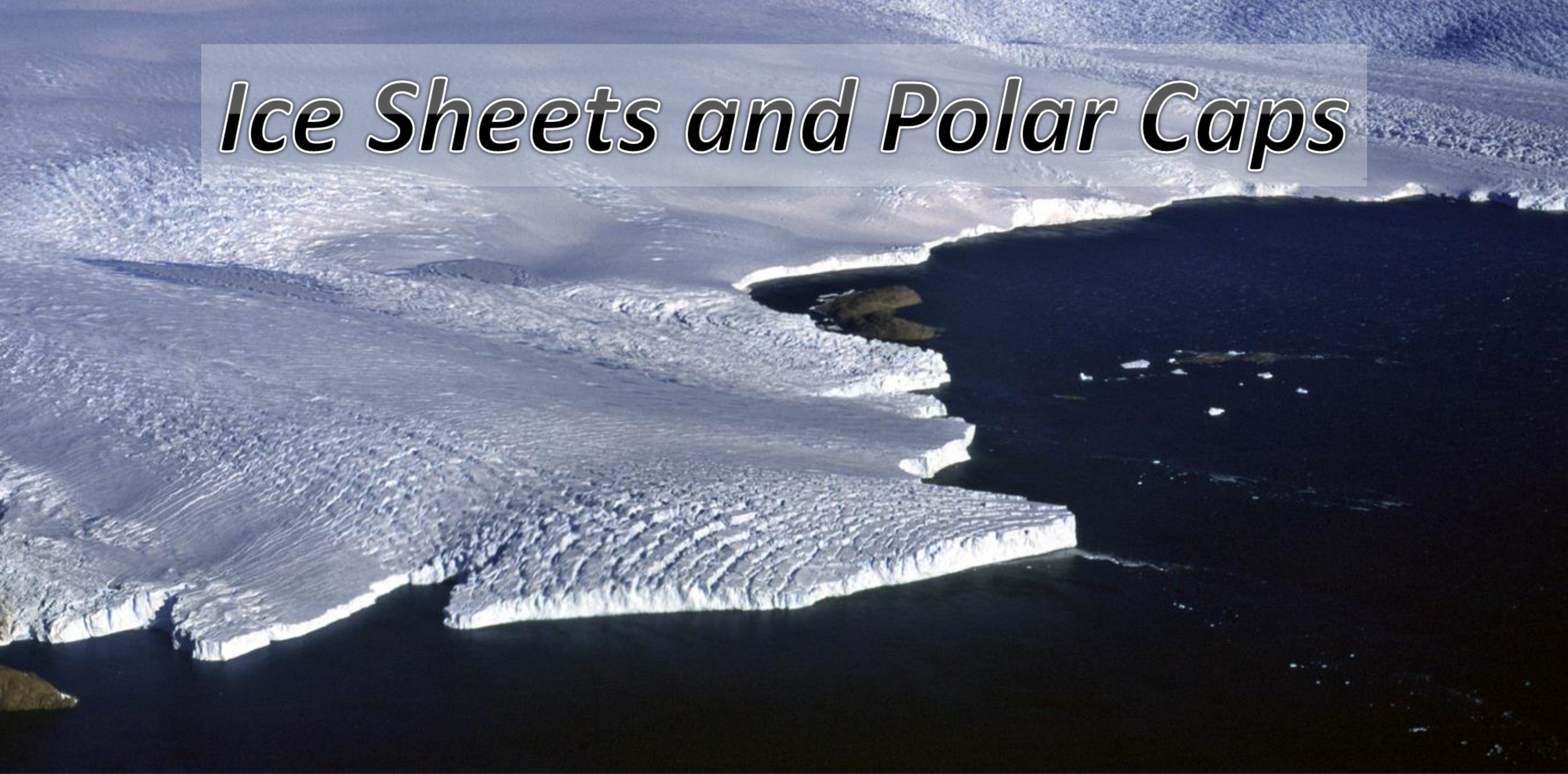
Mountain glaciers

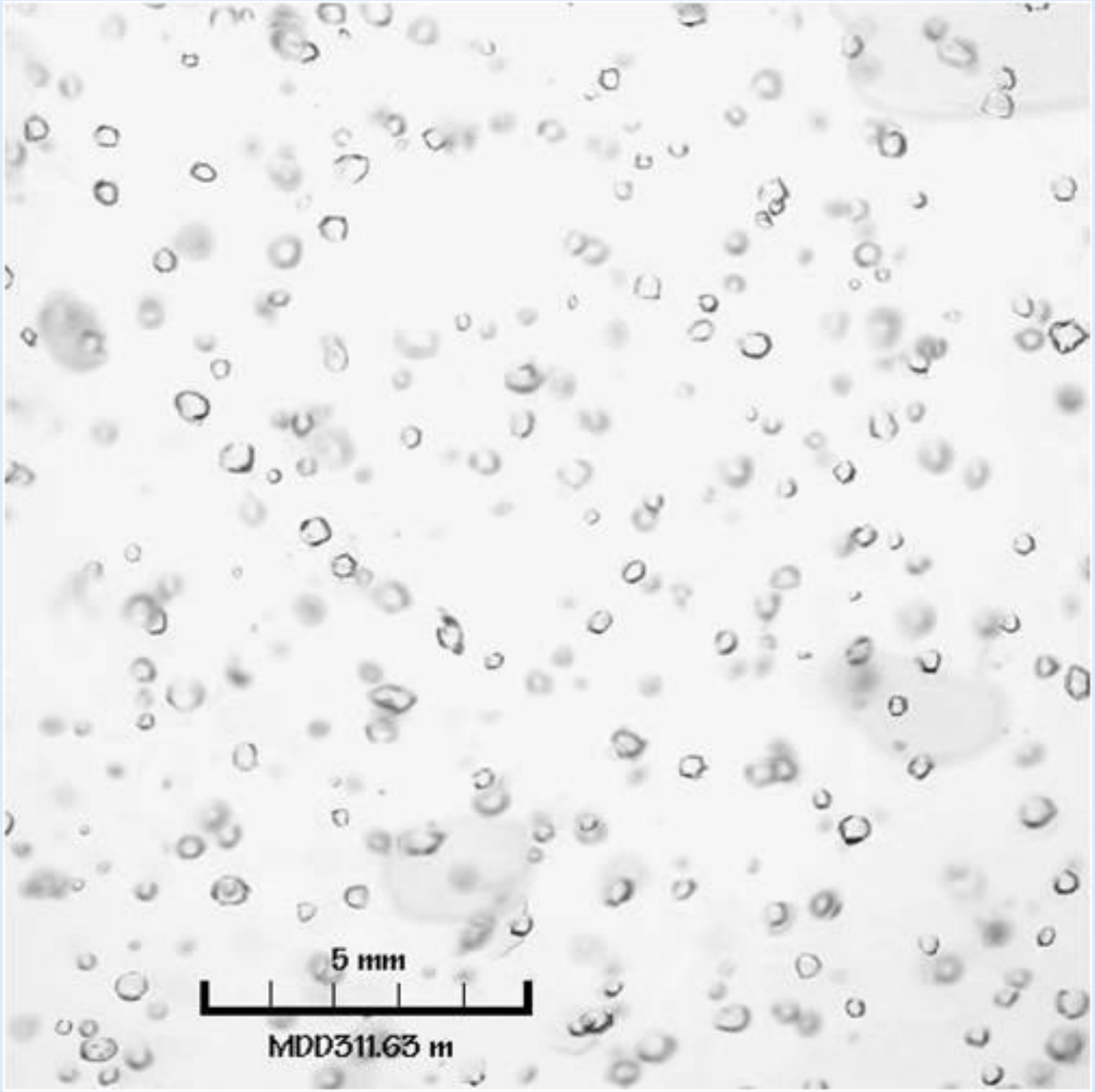




https://www.epa.gov/climate-indicators/climate-change-indicators-glaciers

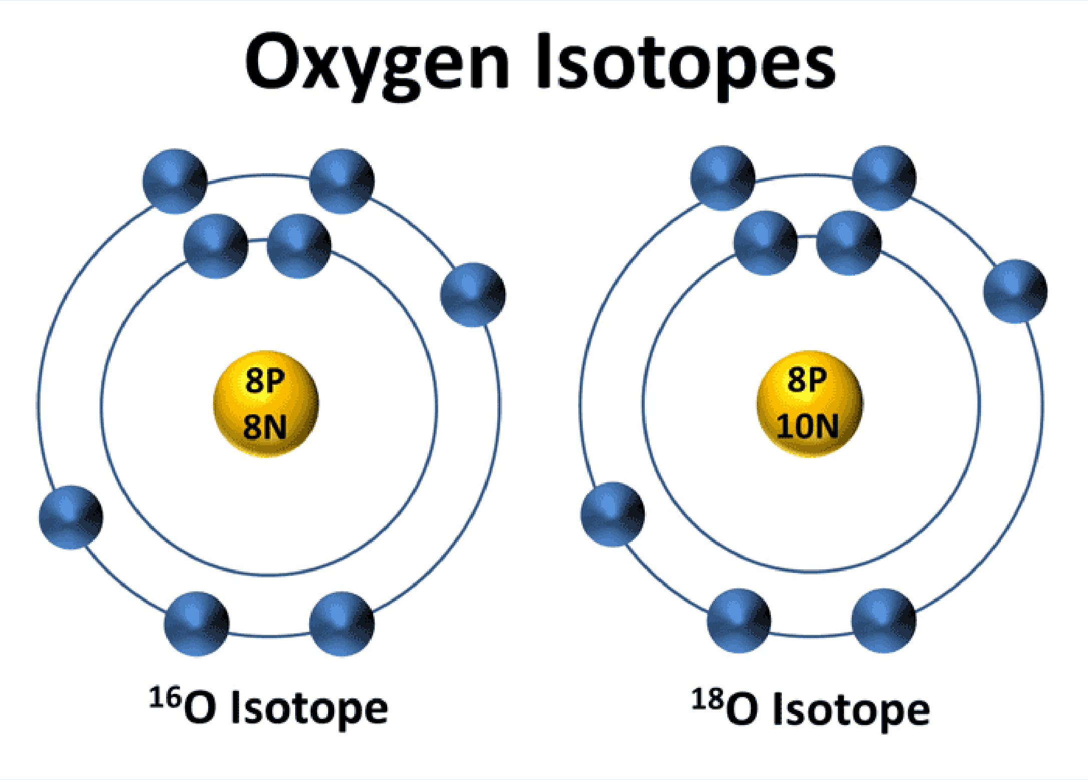
Ice Sheets and Polar Caps





Sample from the Taylor Dome core in Antarctica. The depths are indicated, and scale is shown.

Credit: Alley, R.B. and J.J. Fitzpatrick. Conditions for bubble elongation in cold ice-sheet ice. Journal of Glaciology 45(149), 147-154 (1999).



Stable

Stable
0.2%

Stable Isotope Notation

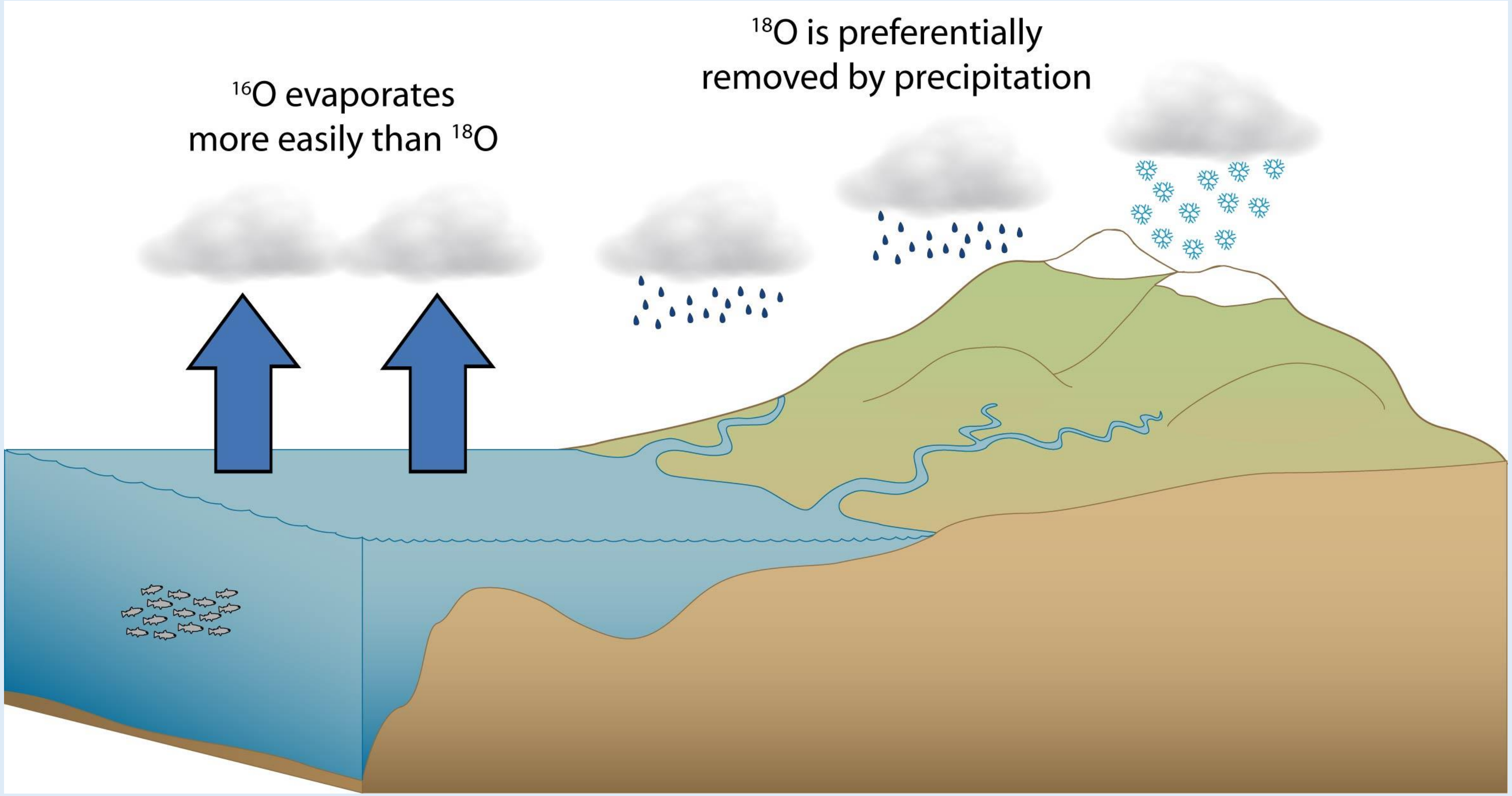
$$\delta^{18}O = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{standard}}{(^{18}O/^{16}O)_{standard}} \times 1000$$

Standard = Standard Mean Ocean Water

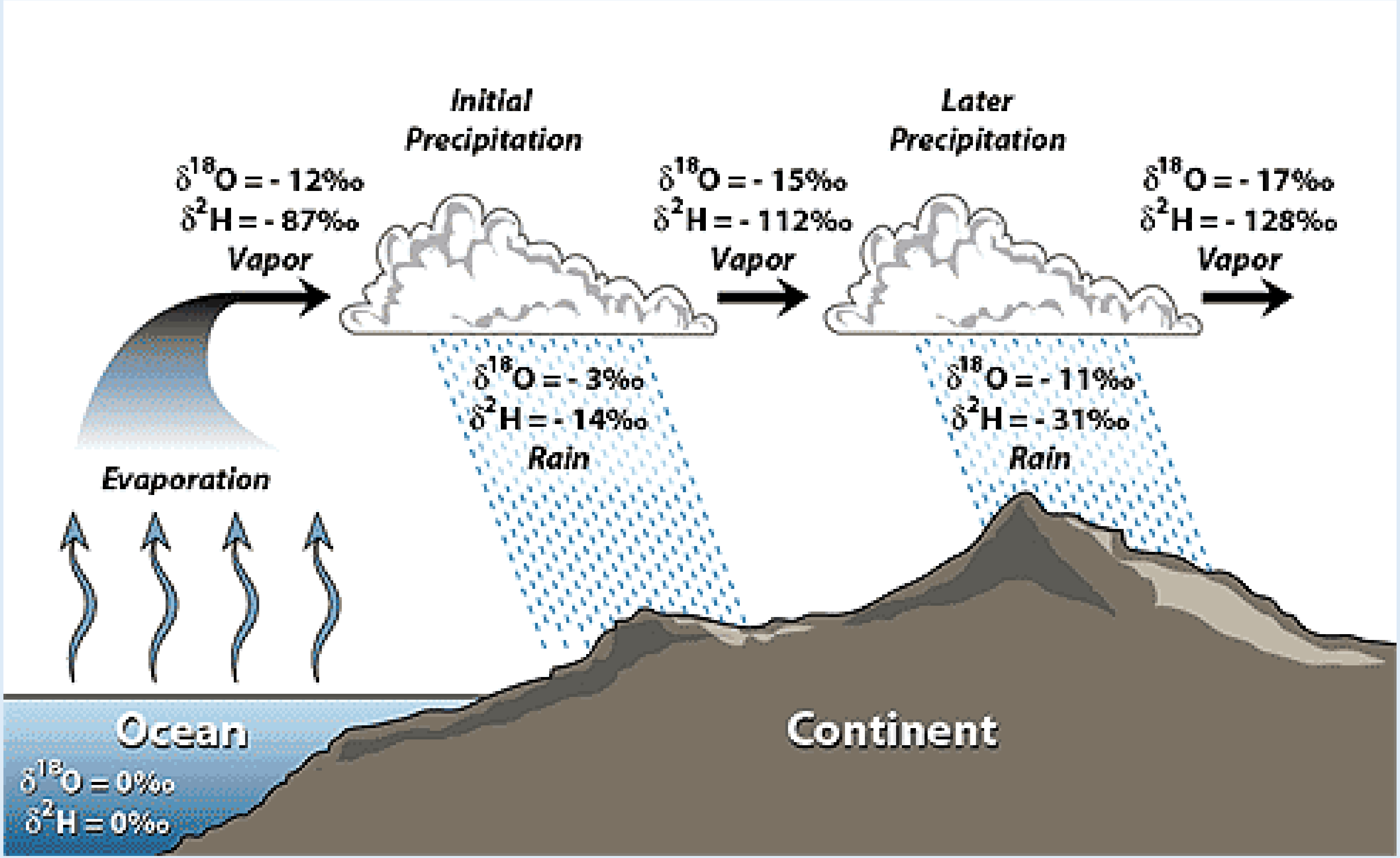
Standard = SMOW ≡ 0 permille

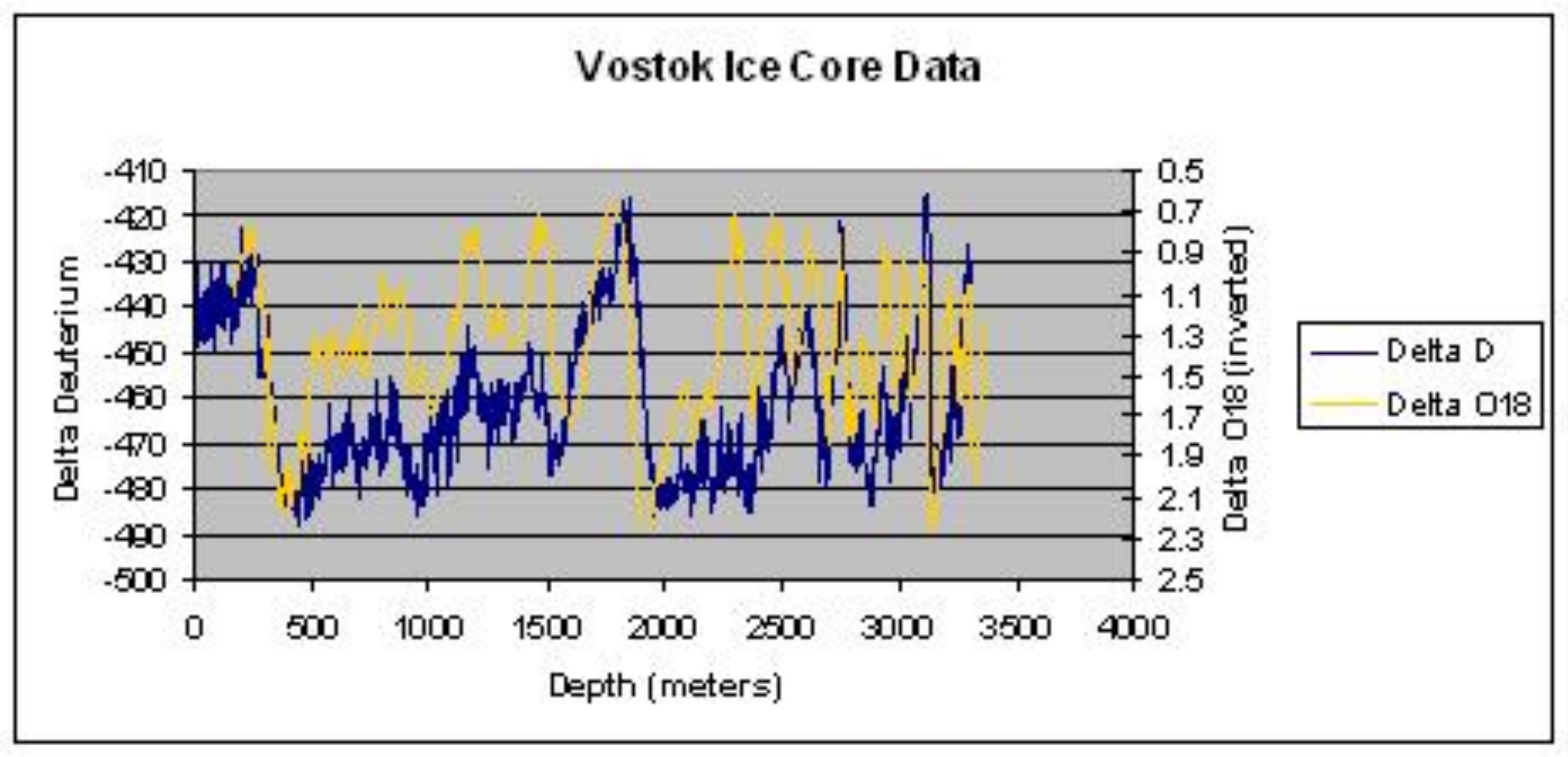
typical precipitation $\delta^{18}O$ values

tropical rain:	0 to −2 permille
mid-latitude rain:	−8 to −12 permille
polar snows:	−20 to −40 permille



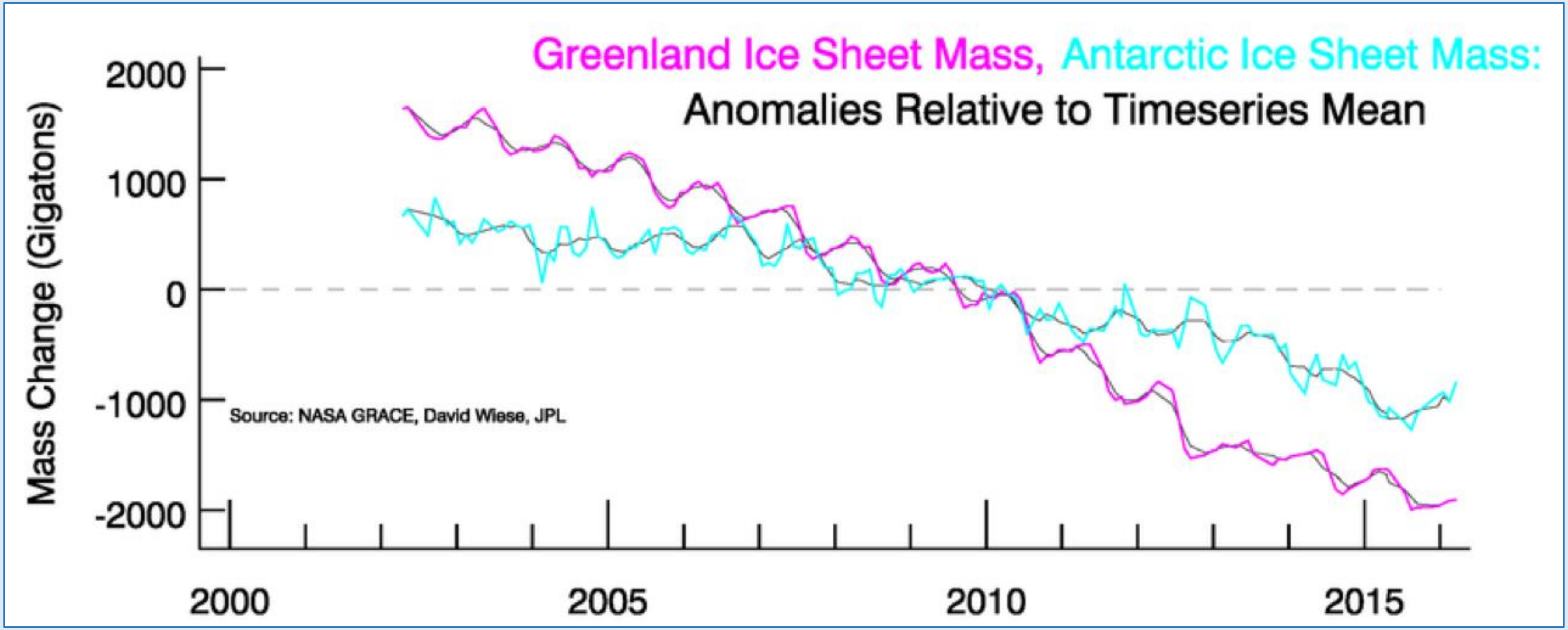
^{18}O is preferentially removed by precipitation
^{16}O evaporates more easily than ^{18}O


Initial Precipitation
Later Precipitation
$\delta^{18}O$ = - 12‰
$\delta^{2}H$ = - 87‰
Vapor
$\delta^{18}O$ = - 15‰
$\delta^{2}H$ = - 112‰
Vapor
$\delta^{18}O$ = - 17‰
$\delta^{2}H$ = - 128‰
Vapor
$\delta^{18}O$ = - 3‰
$\delta^{2}H$ = - 14‰
Rain
$\delta^{18}O$ = - 11‰
$\delta^{2}H$ = - 31‰
Rain
Evaporation
Ocean
$\delta^{18}O$ = 0‰
$\delta^{2}H$ = 0‰
Continent

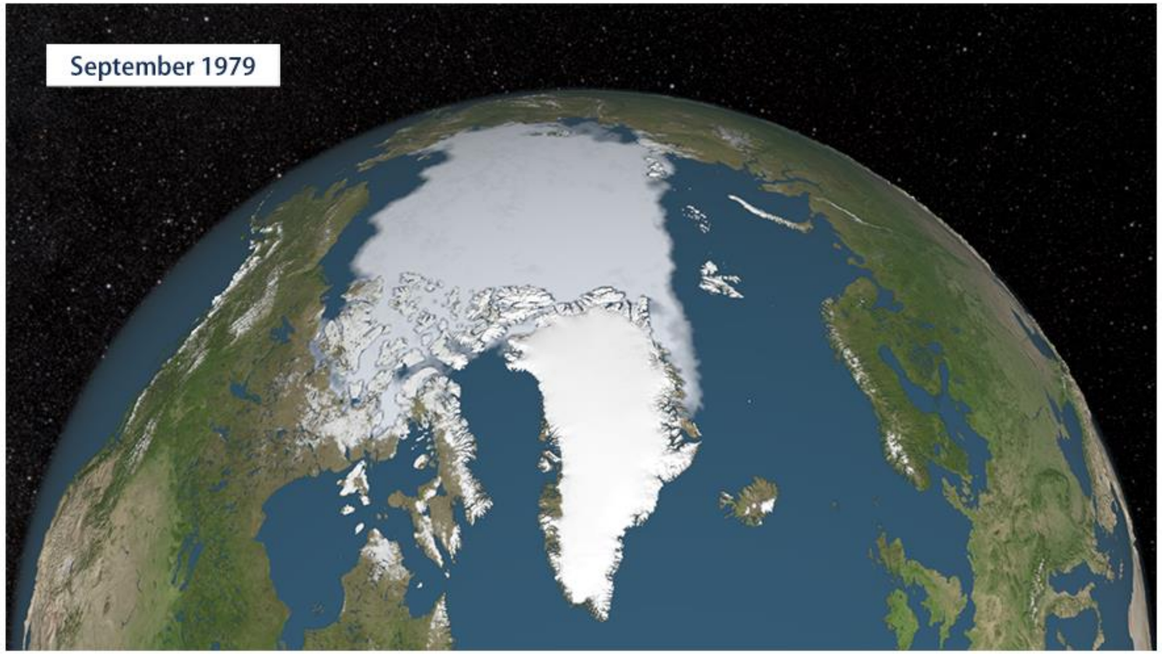


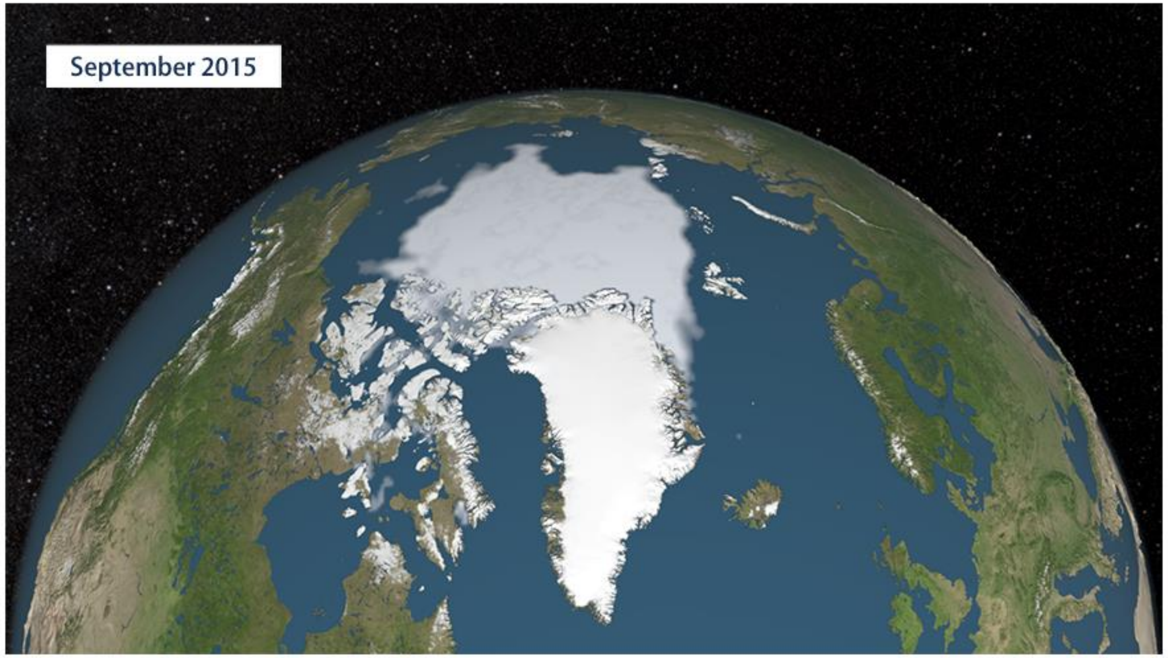
Vostok Ice Core Data
-410
-420
-430
-440
-450
-460
-470
-480
-490
-500
Delta Deuterium
0.5
0.7
0.9
1.1
1.3
1.5
1.7
1.9
2.1
2.3
2.5
Delta O18 (inverted)
0
500
1000
1500
2000
2500
3000
3500
4000
Depth (meters)
Delta D
Delta O18

Antarctica and Greenland Ice Sheet Loss



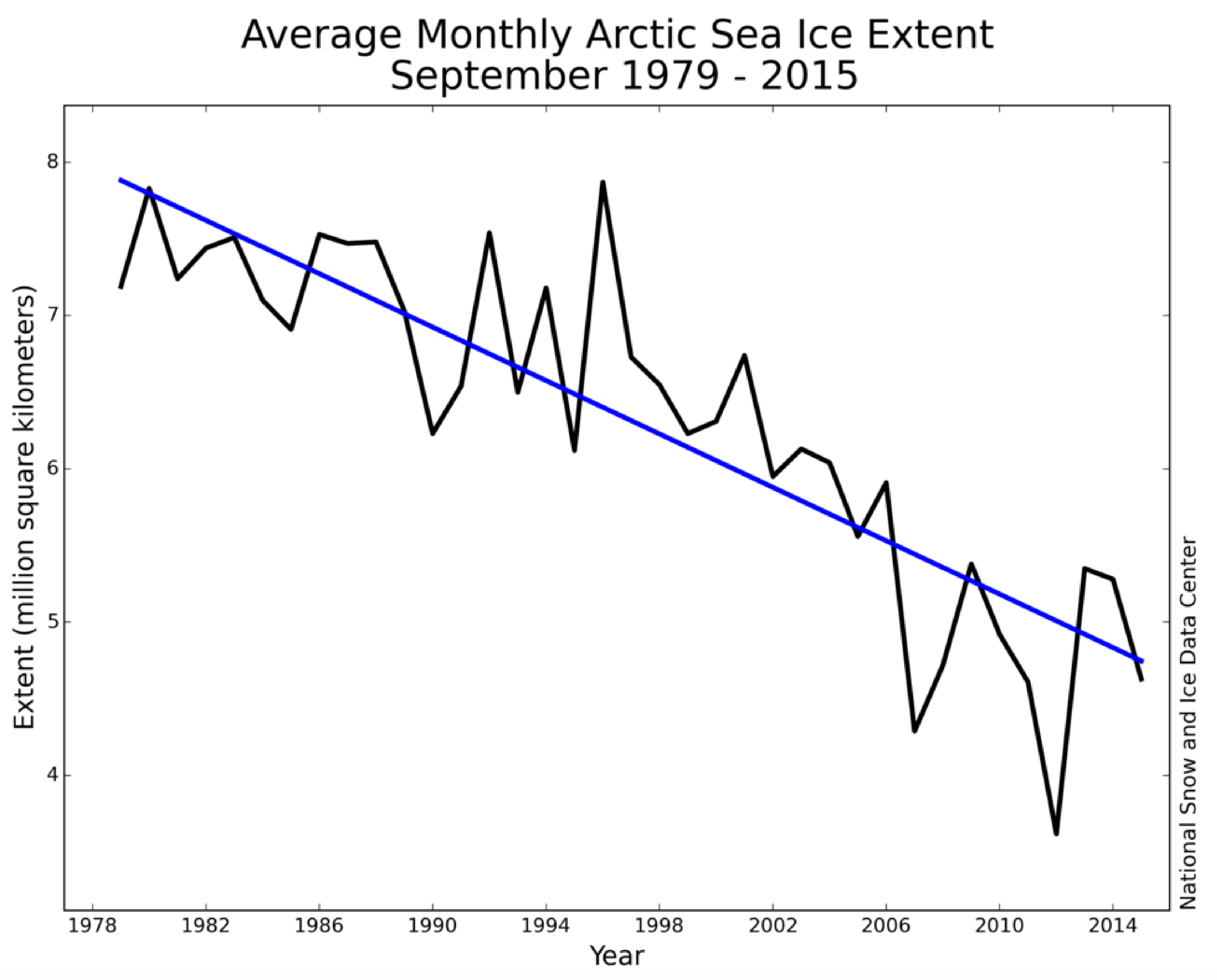
Dwindling Artic Sea Ice



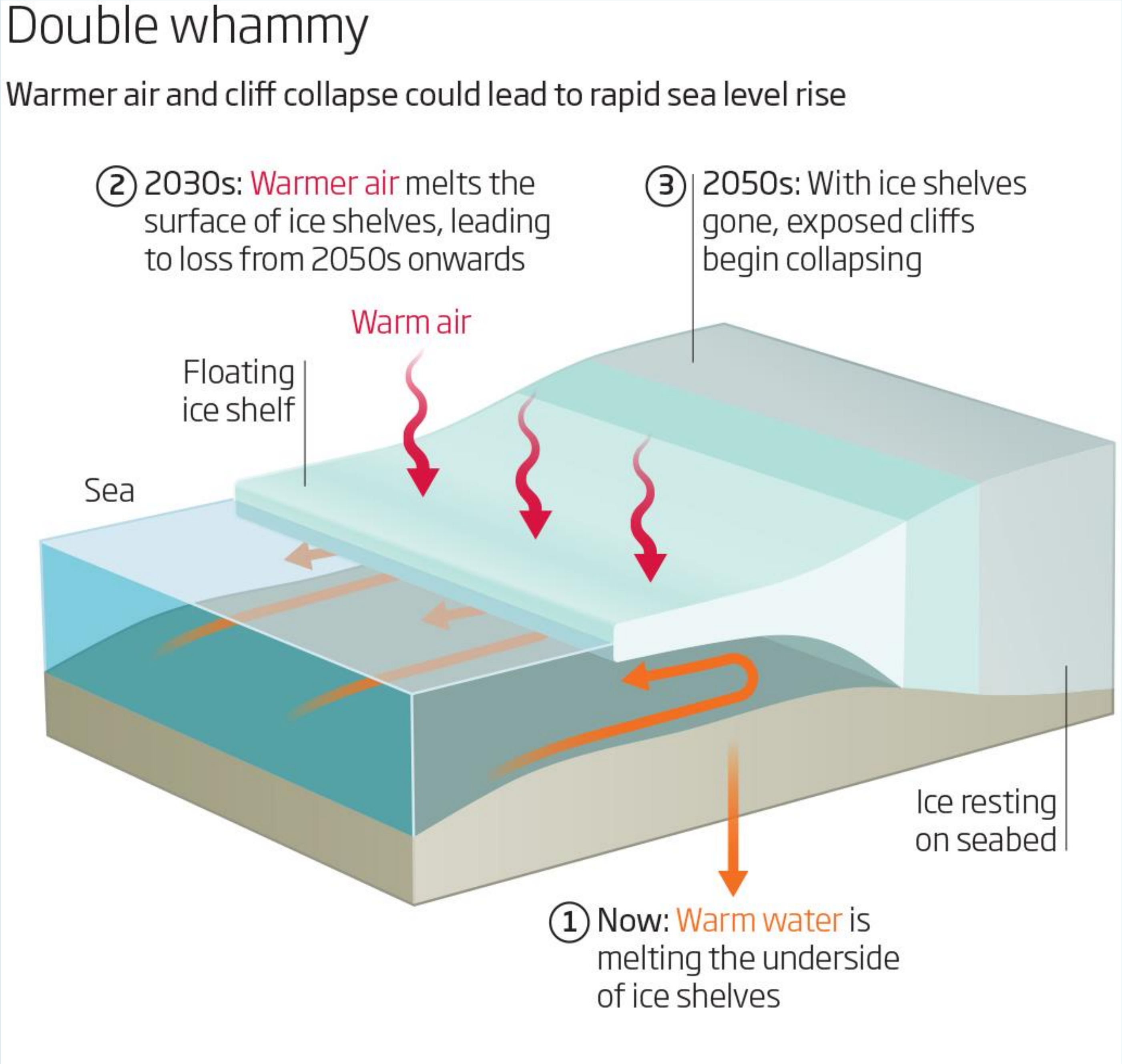


Source: NASA (National Aeronautics and Space Administration). 2016. NASA's Goddard Space Flight Center Scientific Visualization Studio. http://svs.gsfc.nasa.gov.

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at www.epa.gov/climate-indicators.



In November 2016, Arctic sea ice extent averaged 9.08 million square kilometers (3.51 million square miles). This is 800,000 square kilometers (309,000 square miles) below the previous record low in November 2006 – about the size of France and the United Kingdom combined.


Double whammy
Warmer air and cliff collapse could lead to rapid sea level rise
2 2030s: Warmer air melts the surface of ice shelves, leading to loss from 2050s onwards
3 2050s: With ice shelves gone, exposed cliffs begin collapsing
Warm air
Floating ice shelf
Sea
Ice resting on seabed
1 Now: Warm water is melting the underside of ice shelves