CLIMATE CONSIDERATIONS: Earth forcings and feedbacks

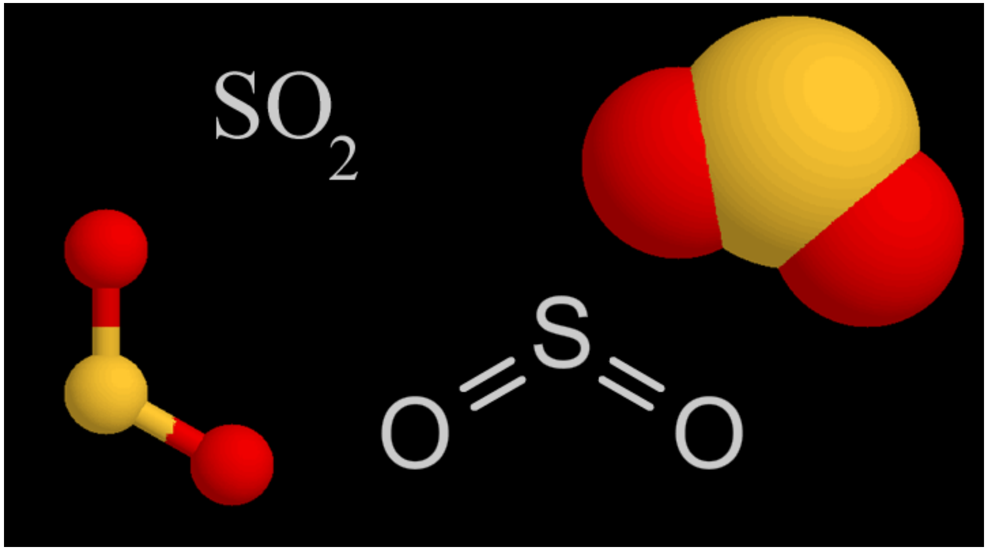
'A man should keep his little brain attic stocked with all the furniture that he is likely to use, and the rest he can put away in the lumber-room of his library where he can get it if he wants.'

Sherlock Holmes

–The Five Orange Pips

What about SO_2?

- It meets the vibration criteria, why not a GHG?



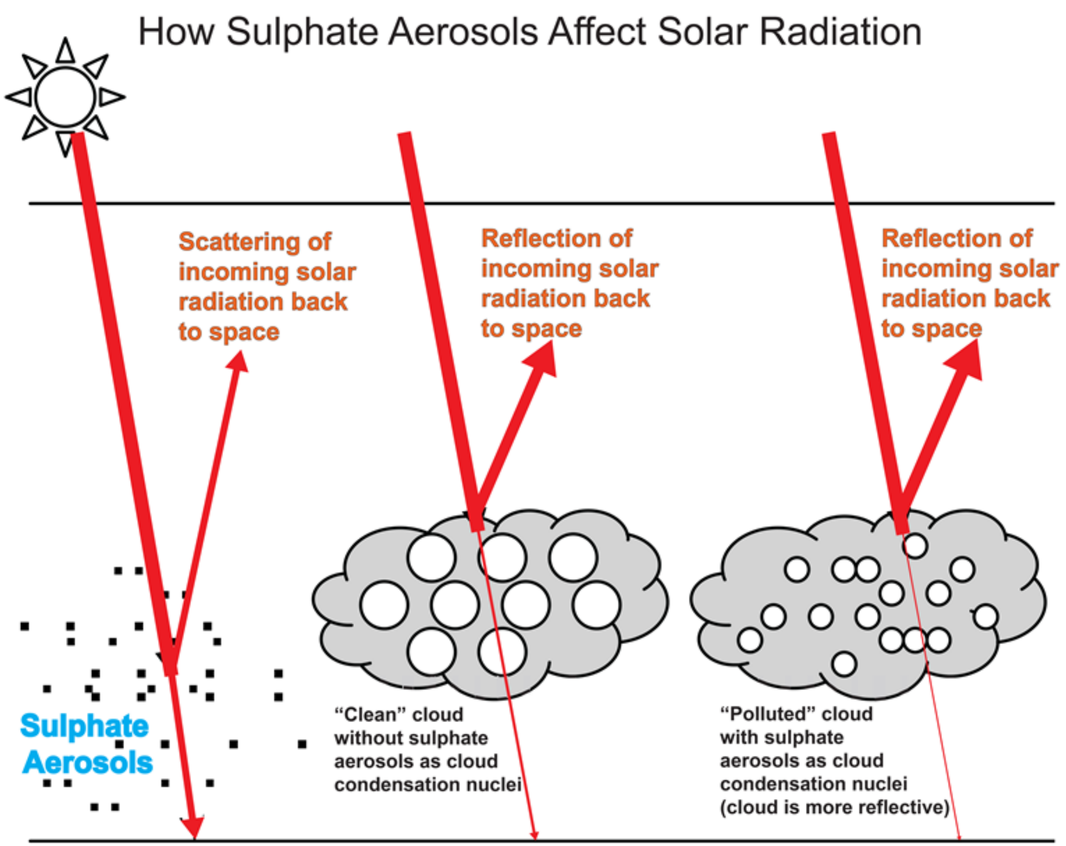
'I ought to know by this time that when a fact appears to be opposed to a long train of deductions it invariably proves to be capable of bearing some other interpretation.'

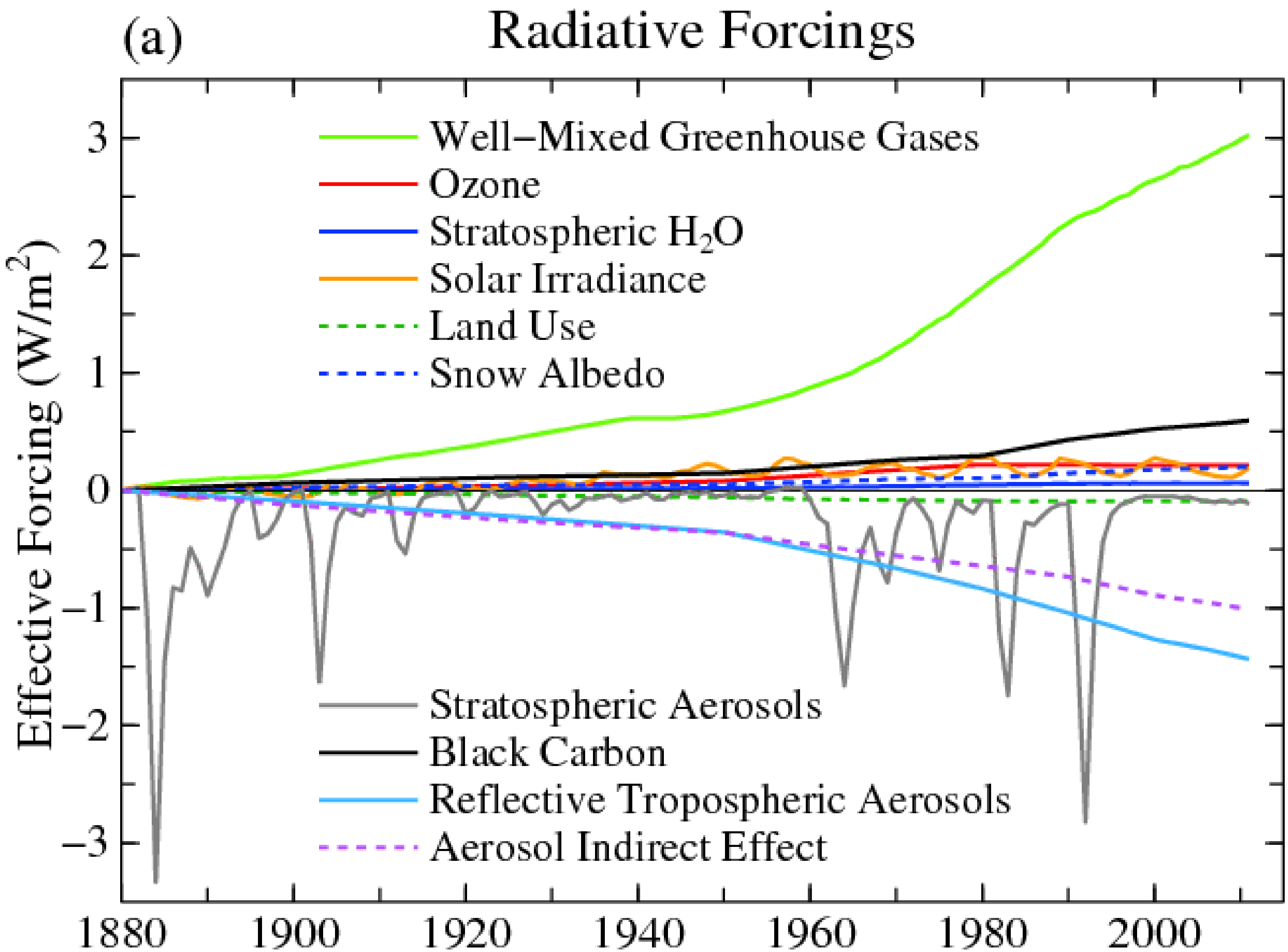
Sherlock Holmes

-*A Study in Scarlet*

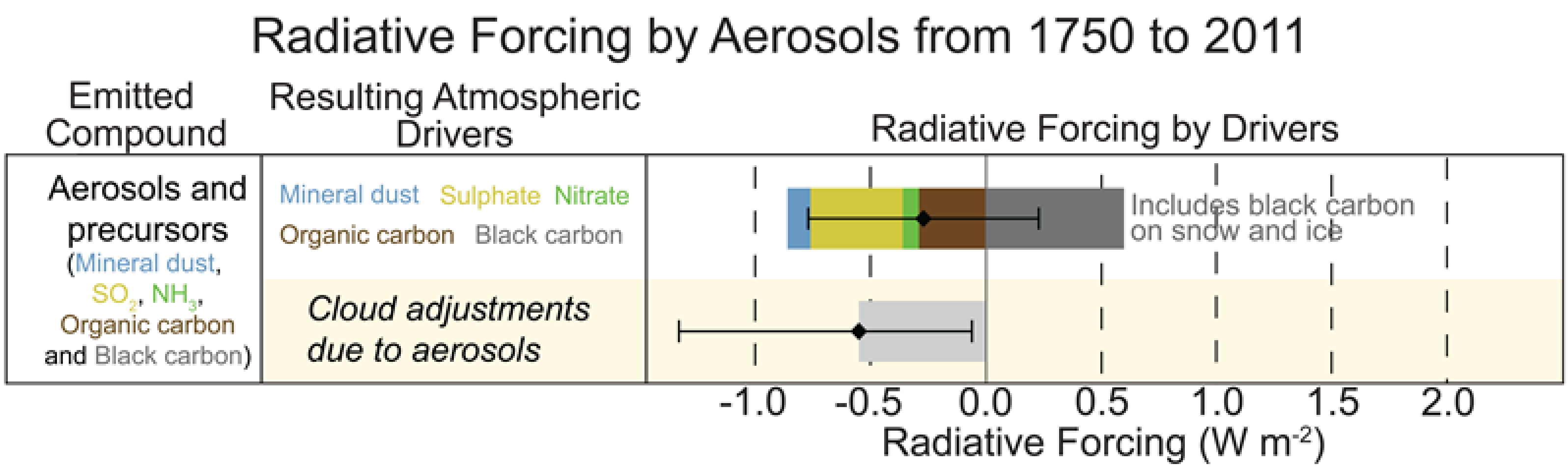
SO_2 that is emitted from fossil fuel combustion, volcanoes, and other sources creates H_2SO_4 in the atmosphere.

H_2SO_4 has a low vapor pressure and condenses under all atmospheric conditions to form aqueous sulfate particles referred to as **aerosols**.

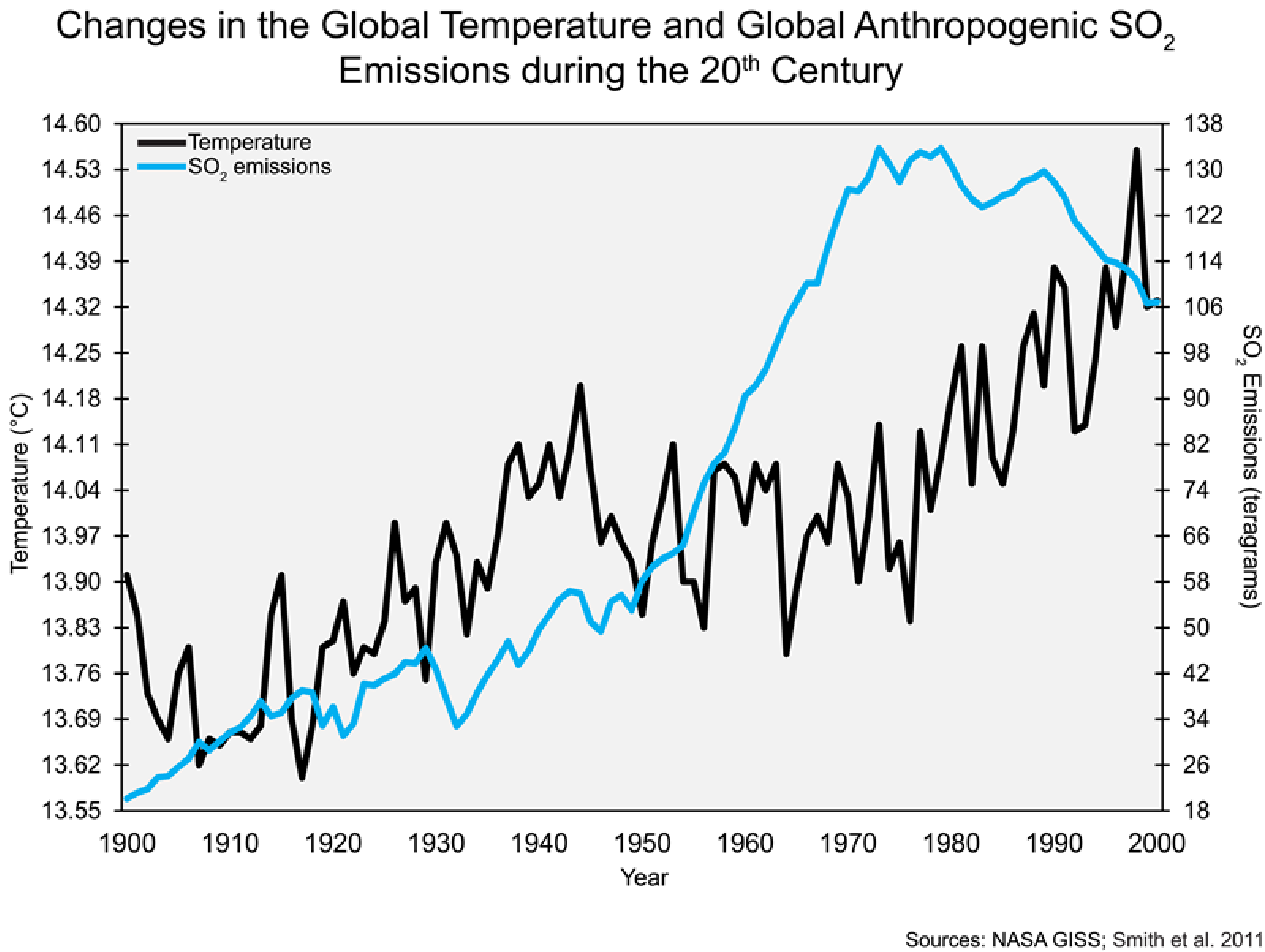




http://data.giss.nasa.gov/modelforce/



Source: IPCC 2014


Changes in the Global Temperature and Global Anthropogenic SO2 Emissions during the 20th Century
Temperature
SO2 emissions
Temperature (°C)
SO2 Emissions (teragrams)
Year
14.60
14.53
14.46
14.39
14.32
14.25
14.18
14.11
14.04
13.97
13.90
13.83
13.76
13.69
13.62
13.55
138
130
122
114
106
98
90
82
74
66
58
50
42
34
26
18
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Sources: NASA GISS; Smith et al. 2011

Let's explore the relationship between large eruptions and climate fluctuations

Table 1: Ave. Global temp in °C and °F from 1880 – 2005, The Climate System, Columbia Univ. http://eesc.ldeo.columbia.edu/courses/ees/climate/labs/globaltemp

Year	Ave. Global Temp. (°C)	Ave. Global Temp. (°F)	Year	Ave. Global Temp. (°C)	Ave. Global Temp. (°F)	Year	Ave. Global Temp. (°C)	Ave. Global Temp. (°F)
1880	13.75	56.75	1922	13.76	56.77	1964	13.79	56.82
1881	13.8	56.84	1923	13.8	56.84	1965	13.89	57.00
1882	13.77	56.79	1924	13.79	56.82	1966	13.97	57.15
1883	13.76	56.77	1925	13.84	56.91	1967	14	57.20
1884	13.7	56.66	1926	13.99	57.18	1968	13.96	57.13
1885	13.7	56.66	1927	13.87	56.97	1969	14.08	57.34
1886	13.75	56.75	1928	13.89	57.00	1970	14.03	57.25
1887	13.65	56.57	1929	13.75	56.75	1971	13.9	57.02
1888	13.74	56.73	1930	13.93	57.07	1972	14	57.20
1889	13.85	56.93	1931	13.99	57.18	1973	14.14	57.45
1890	13.63	56.53	1932	13.94	57.09	1974	13.92	57.06
1891	13.72	56.70	1933	13.83	56.89	1975	13.95	57.11
1892	13.68	56.62	1934	13.95	57.11	1976	13.84	56.91
1893	13.68	56.62	1935	13.89	57.00	1977	14.13	57.43
1894	13.67	56.61	1936	13.96	57.13	1978	14.02	57.24
1895	13.73	56.71	1937	14.08	57.34	1979	14.09	57.36
1896	13.83	56.89	1938	14.11	57.40	1980	14.18	57.52
1897	13.88	56.98	1939	14.03	57.25	1981	14.27	57.69
1898	13.75	56.75	1940	14.05	57.29	1982	14.05	57.29
1899	13.83	56.89	1941	14.11	57.40	1983	14.26	57.67
1900	13.9	57.02	1942	14.03	57.25	1984	14.09	57.36
1901	13.84	56.91	1943	14.1	57.38	1985	14.06	57.31
1902	13.73	56.71	1944	14.2	57.56	1986	14.13	57.43
1903	13.69	56.64	1945	14.07	57.33	1987	14.27	57.69
1904	13.66	56.59	1946	13.96	57.13	1988	14.31	57.76
1905	13.75	56.75	1947	14.01	57.22	1989	14.19	57.54
1906	13.8	56.84	1948	13.96	57.13	1990	14.38	57.88
1907	13.61	56.50	1949	13.94	57.09	1991	14.35	57.83
1908	13.66	56.59	1950	13.85	56.93	1992	14.13	57.43
1909	13.65	56.57	1951	13.96	57.13	1993	14.14	57.45
1910	13.67	56.61	1952	14.03	57.25	1994	14.24	57.63
1911	13.66	56.59	1953	14.11	57.40	1995	14.38	57.88
1912	13.66	56.59	1954	13.9	57.02	1996	14.3	57.74
1913	13.68	56.62	1955	13.9	57.02	1997	14.4	57.92
1914	13.85	56.93	1956	13.83	56.89	1998	14.57	58.23
1915	13.91	57.04	1957	14.08	57.34	1999	14.33	57.79
1916	13.7	56.66	1958	14.08	57.34	2000	14.33	57.79
1917	13.6	56.48	1959	14.06	57.31	2001	14.48	58.06
1918	13.68	56.62	1960	13.99	57.18	2002	14.56	58.21
1919	13.8	56.84	1961	14.08	57.34	2003	14.55	58.19
1920	13.81	56.86	1962	14.04	57.27	2004	14.49	58.08
1921	13.87	56.97	1963	14.08	57.34	2005	14.63	58.33

TERC EarthLabs

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Climate and the Cryosphere

- 2A: **Ocean Circulation**
- 4C: **Ice Swings**

Climate and the Biosphere

- 1C: **Weather vs Climate**
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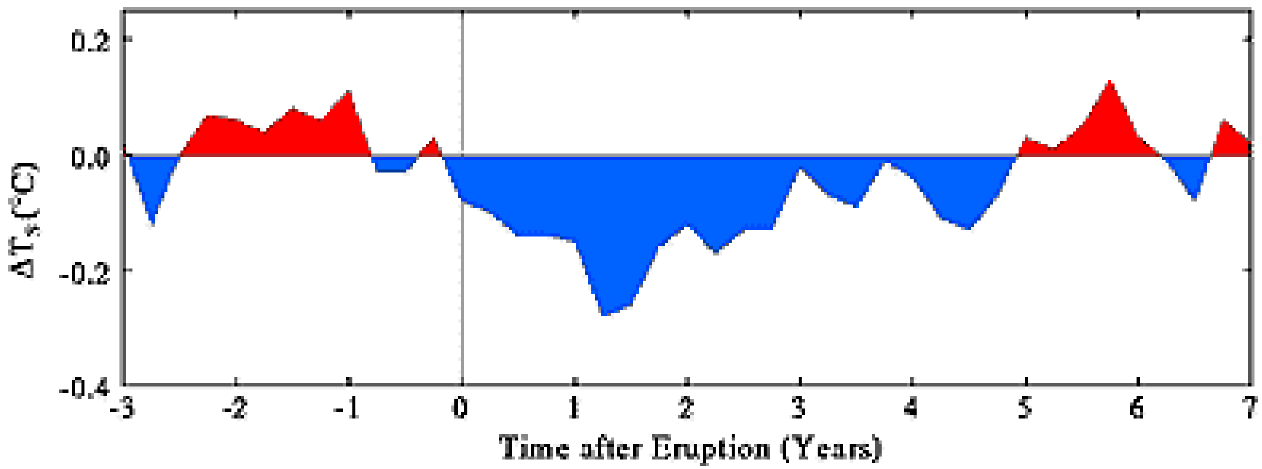
- 2B: **The Carbon Cycle**
- 6A: **Oceanic Biological Pump**
- 6B: **Trichodesmium**
- 6B: **Nitrogen Cycle**
- 7B: **Shell Building**

Climate Detectives

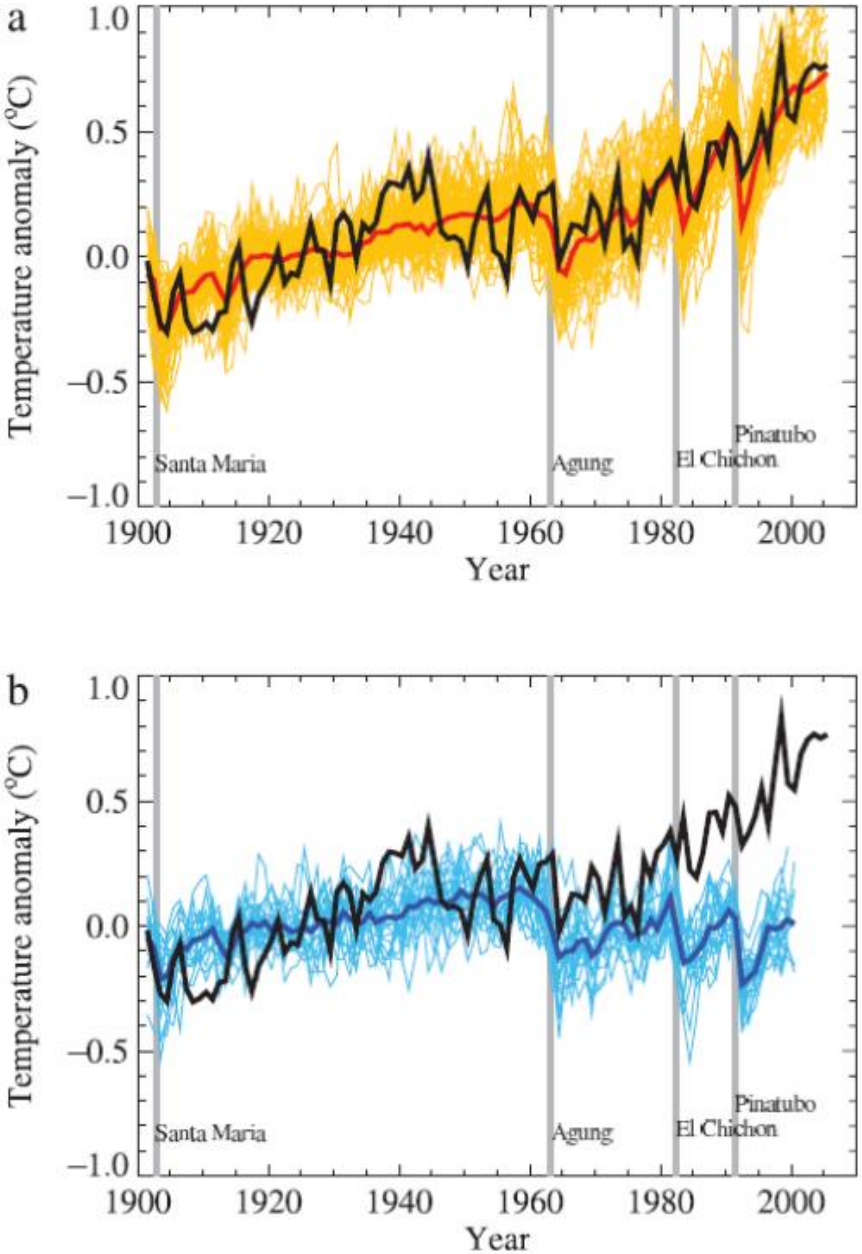
- 6B & 6D: **The Core Lab**

EarthLabs App icon image credit: NASA



Composite global surface temperature change near the time of the five volcanoes producing the greatest optical depths since 1880: Krakatau (1883), Santa Maria (1902), Agung (1963), El Chichon (1982) and Pinatubo (1991).

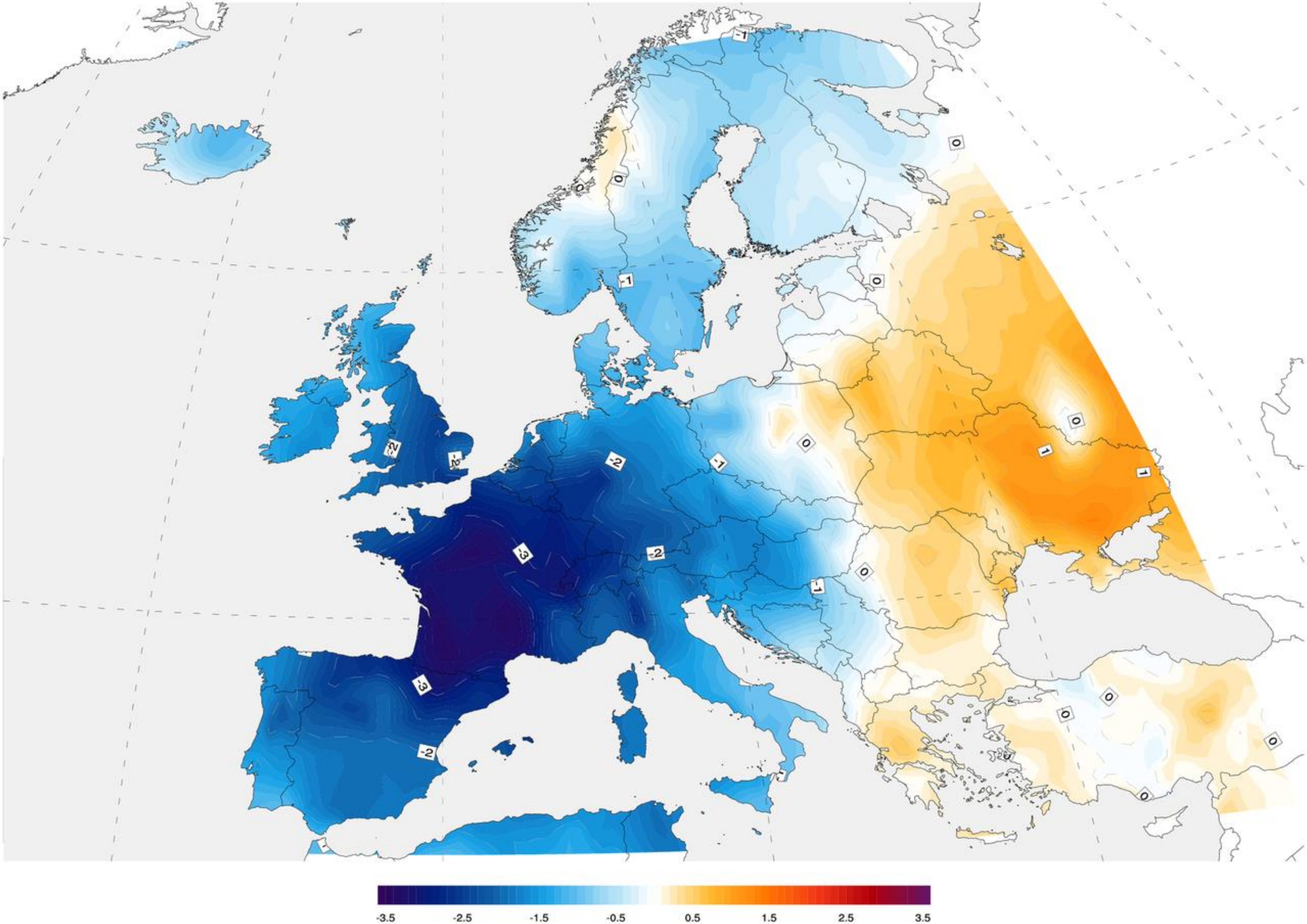
http://www.giss.nasa.gov/research/briefs/hansen_02/



Comparison between global mean surface temperature anomalies (°C) from observations (black) and simulations (computer model outputs) forced with (a) anthropogenic and natural forcings (solar and volcanogenic) and (b) natural forcings only.

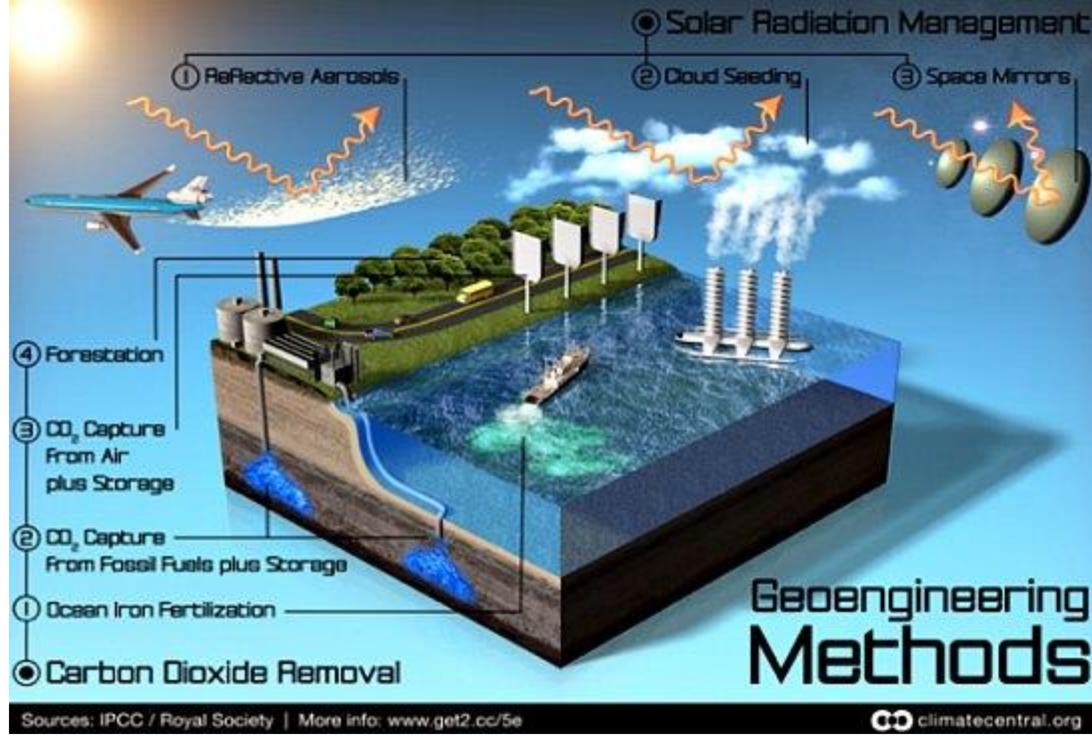
IPCC AR4

1816 Summer Temperature Anomaly



http://www.npr.org/player/v2/mediaPlayer.html?action=1&t=1&islist=false&id=12688403&m=12697259

The gloomy summer weather also inspired writers. During that summer-less summer, Mary Shelley, her husband, the poet Percy Bysshe Shelley, and poet Lord Byron were on vacation at Lake Geneva. While trapped indoors for days by constant rain and gloomy skies, the writers described the bleak, dark environment of the time in their own ways. Mary Shelley wrote *Frankenstein*, a horror novel set in an often stormy environment. Lord Byron wrote the poem *Darkness,* which begins, "**I had a dream, which was not all a dream. The bright sun was extinguish'd**."

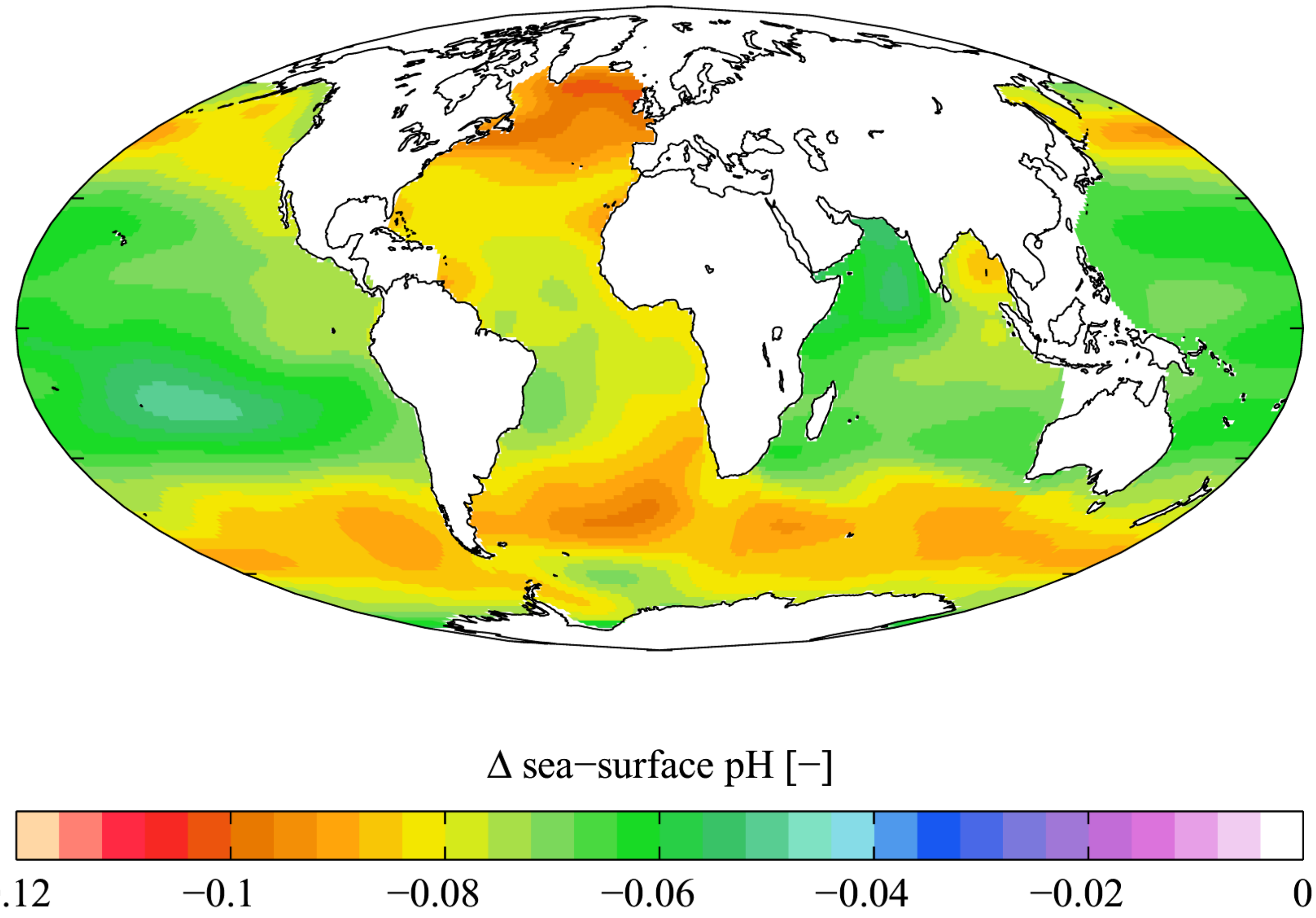


IT IS BETTER TO LEARN WISDOM LATE, THAN NEVER TO LEARN IT AT ALL.

THE ADVENTURES OF SHERLOCK HOLMES
BY SIR ARTHUR CONAN DOYLE

WWW.BOOKQUOTESHUB.COM

OCEAN ACIDIFICATION



Oceans can absorb CO2 from the atmosphere…hooray!

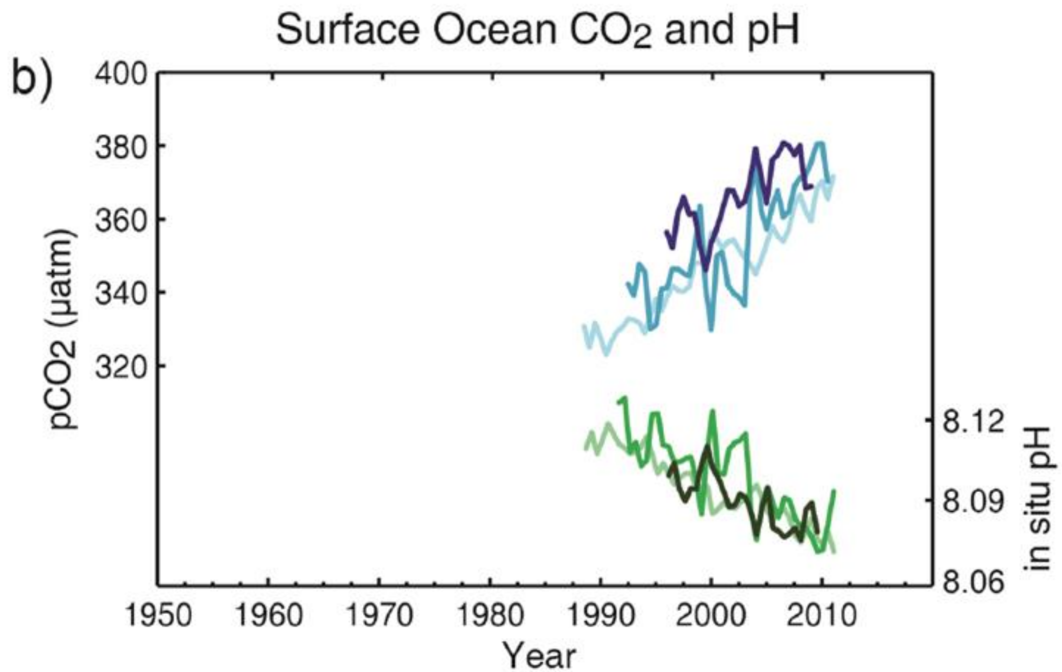
But won't that alter its chemistry?

No problem, rock weathering results in buffering agents being transported to the oceans by rivers, so all is good.

But is rock weathering happening fast enough?

Well, actually, NO. Which means the CO2 is also building up in the oceans!

What happens when we dissolve CO2 in water?



“The world is full of obvious things which nobody by any chance ever observes.”

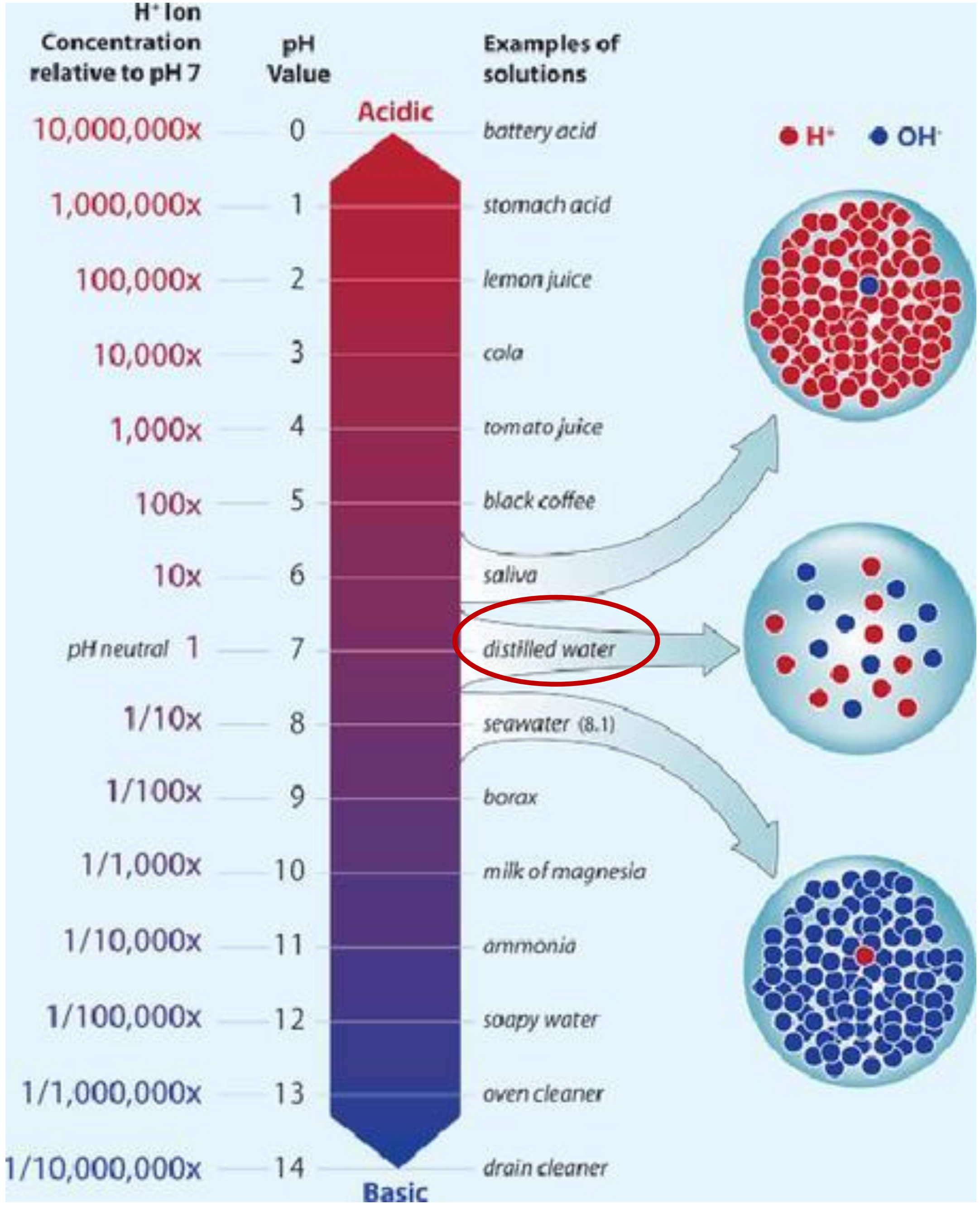
— Sherlock Holmes, *The Hound of the Baskervilles*

Distilled water with a pH of 7?

Only in a world with no atmosphere…

It is quite easy to demonstrate the effect of dissolved gases (CO_2) in water.

Woods Hole Oceanographic Institute should know better…



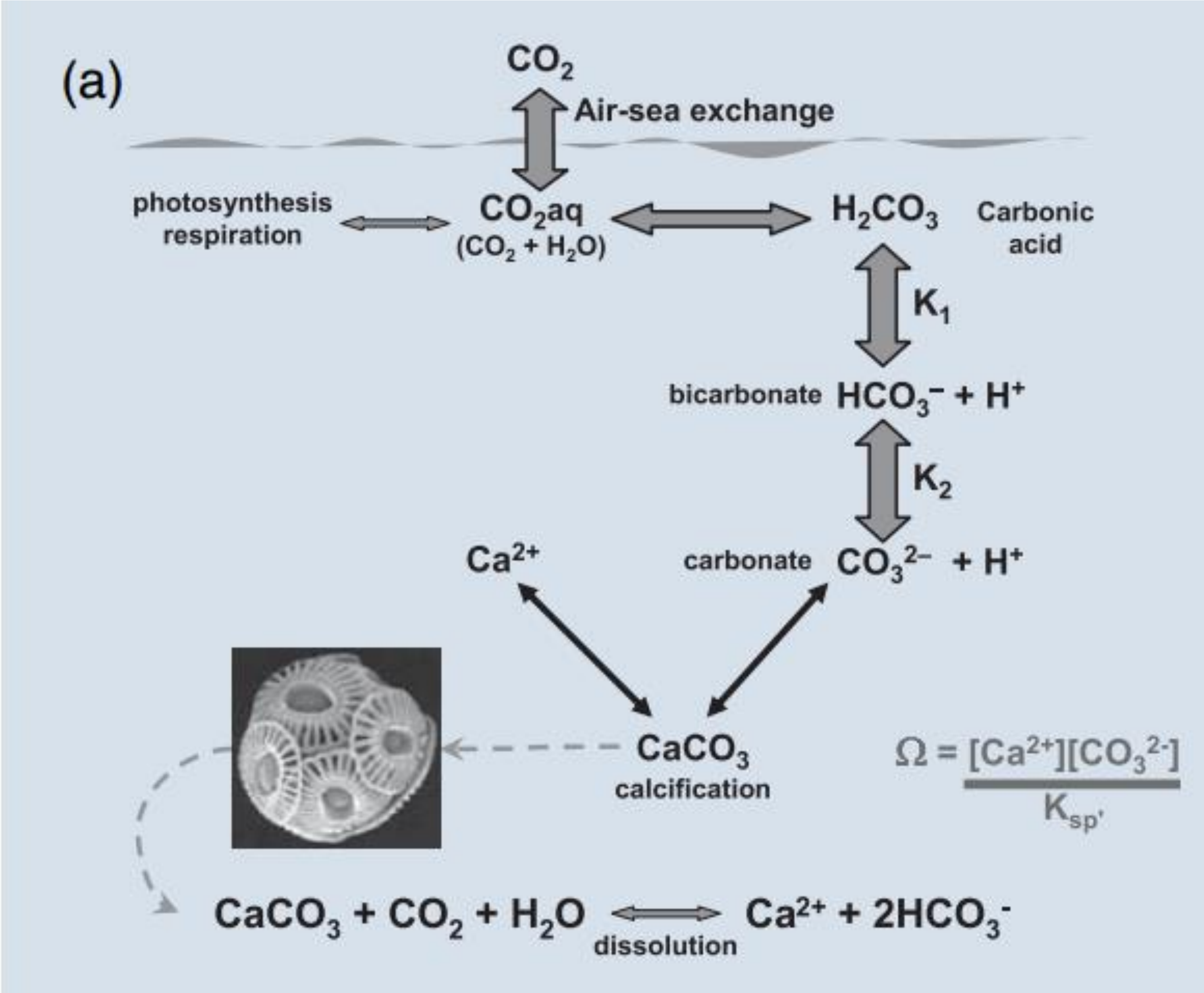
http://www.whoi.edu/oceanus/feature/small-drop-in-ph-means-big-change-in-acidity

The relationship between H^+, OH^- and pH

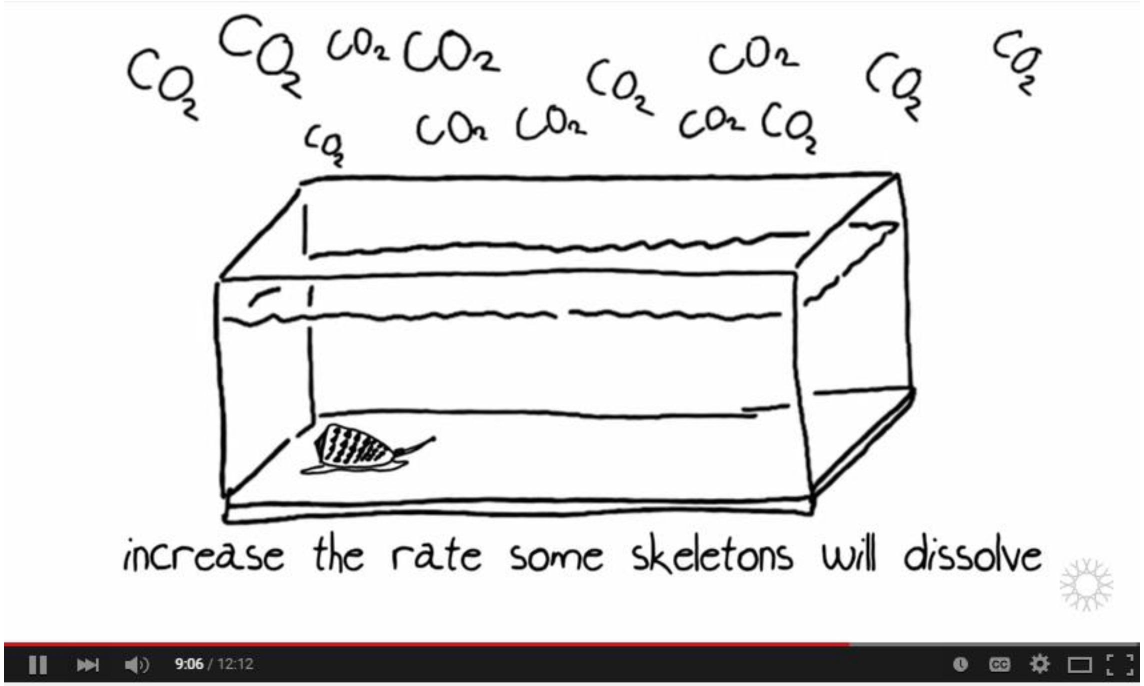
OH^- concentration(mol/l)		pH	H^+ concentration(mol/l)	
1×10^{-14}	0.00000000000001	**0**	1	1 x 100
1×10^{-13}	0.0000000000001	**1**	0.1	1×10^{-1}
1×10^{-12}	0.000000000001	**2**	0.01	1×10^{-2}
1×10^{-11}	0.00000000001	**3**	0.001	1×10^{-3}
1×10^{-10}	0.0000000001	**4**	0.0001	1×10^{-4}
1×10^{-9}	0.000000001	**5**	0.00001	1×10^{-5}
1×10^{-8}	0.00000001	**6**	0.000001	1×10^{-6}
1×10^{-7}	0.0000001	**7**	0.0000001	1×10^{-8}
1×10^{-5}	0.00001	**9**	0.000000001	1×10^{-9}
1×10^{-4}	0.0001	**10**	0.0000000001	1×10^{-10}
1×10^{-3}	0.001	**11**	0.00000000001	1×10^{-11}
1×10^{-2}	0.01	**12**	0.000000000001	1×10^{-12}
1×10^{-1}	0.1	**13**	0.0000000000001	1×10^{-13}
1 x 100	1	**14**	0.00000000000001	1×10^{-14}

Increasing acidity ↑

Increasing basicity ↓

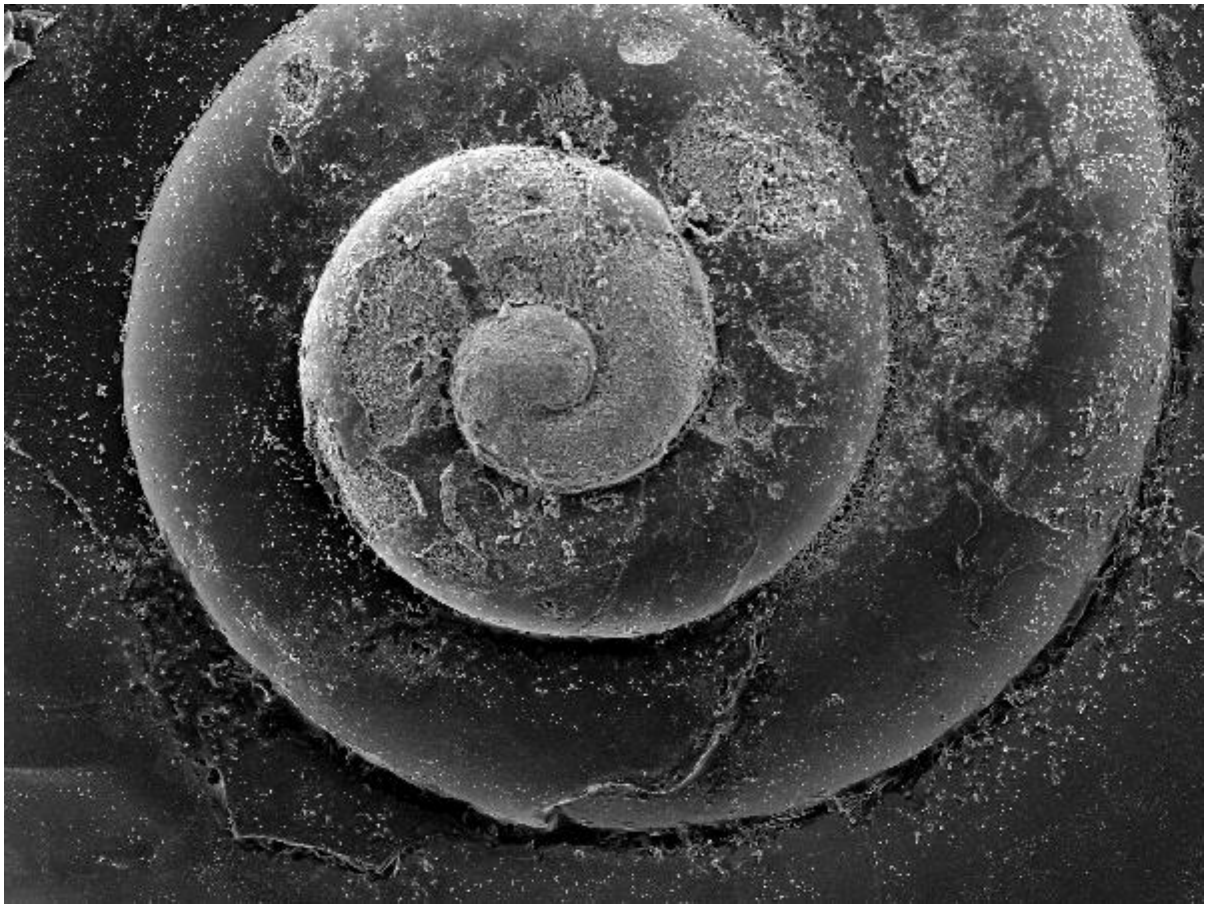


http://www.ucar.edu/communications/Final_acidification.pdf



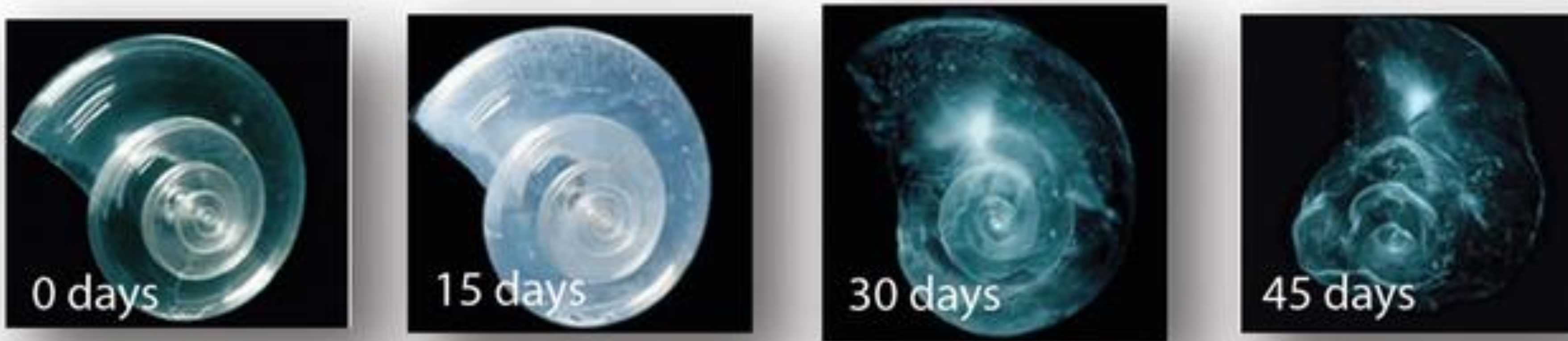
https://www.youtube.com/watch?v=GL7qJYKzcsk

Between 1751 and 1994 surface ocean pH is estimated to have decreased from approximately 8.25 to 8.14, representing an increase of almost 30% in H^+ ion concentration in the world's oceans.



Ocean acidification in the modern ocean is already affecting some marine life, as shown by the partly dissolved shell of this planktic snail, or pteropod, caught off the Pacific Northwest. (Nina Bednaršek/NOAA)

The photos below show what happens to a pteropod's shell when placed in sea water with pH and carbonate levels projected for the year 2100. The shell slowly dissolves after 45 days.

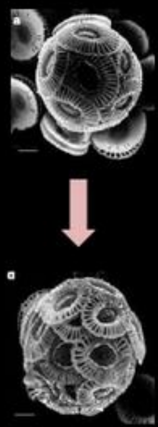
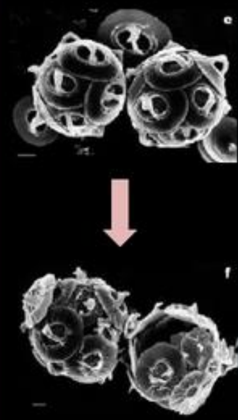


The pteropod, or "sea butterfly", is a tiny sea creature about the size of a small pea. Pteropods are eaten by organisms ranging in size from tiny krill to whales and are a major food source for North Pacific juvenile salmon.

Coccolithopores

Single-cell algae

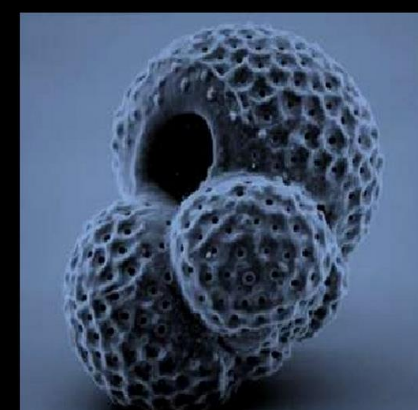
manipulation of CO_2 system by addition of HCl or NaOH

	Emiliania huxleyi	*Gephyrocapsa oceanica*
p**CO_2 280-380 ppmv**		
780-850 ppmv		
Calcification decreased	**- 9 to 18%**	**- 45%**

Riebesell et al.(2000); Zondervan et al.(2001)

Formanifera

single-celled protists



-4 to -8% decline in calcification at pCO_2= 560 ppm
-6 to -14% decline in calcification at pCO_2= 780 ppm

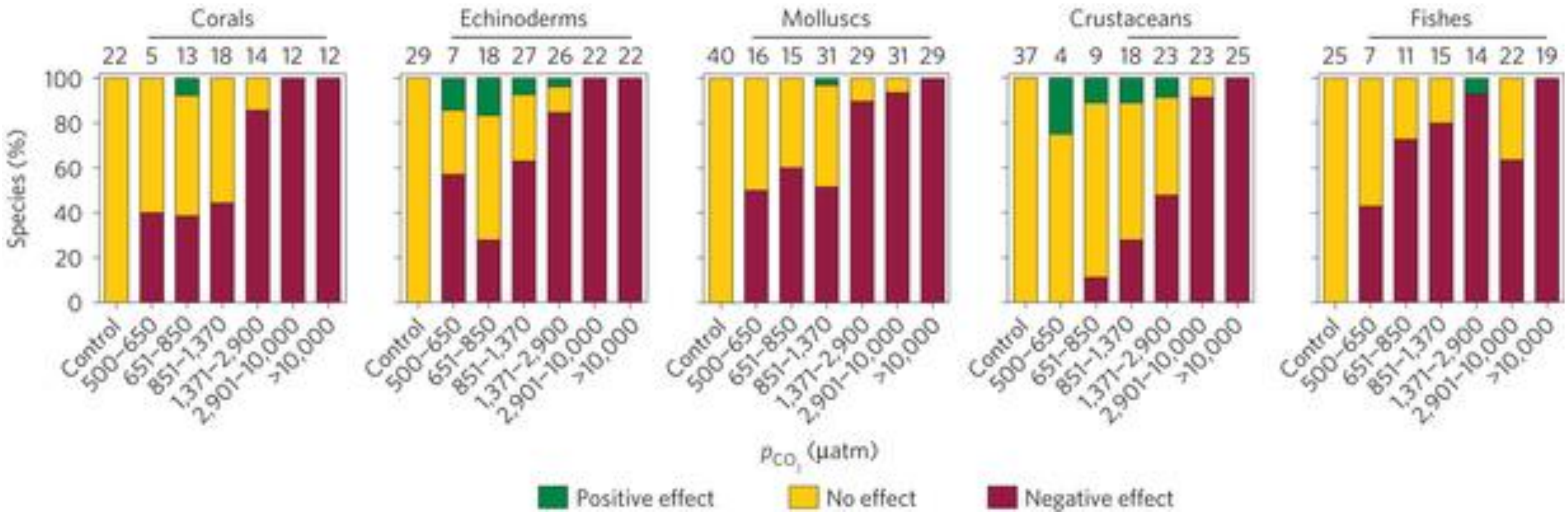
Bijma et al. (2002)

WINNERS AND LOSERS

Impacts Scorecard

		# species studied	Response to increasing CO_2: \	/	—	∩
calcification	coccolithophores	4	2	1	1	1
	planktonicformanifera	2	2	-	-	-
	mollusks	4	4	-	-	-
	echinoderms	2	2	-	-	-
	tropical corals	11	11	-	-	-
	corraline red algae	1	1	-	-	-
photo-synthesis	coccolithophores	2	-	2	2	-
	prokaryotes	2	-	1	1	-
	seagrass	5	-	5	-	-
nitrogen fixation	cyanobacteria	1	-	1	-	-
repro-duction	mollusks	4	4	-	-	-
	echinoderms	1	1	-	-	-

Marine animal sensitivities across variable CO2 concentrations



http://climateinterpreter.org/sites/default/files/resources/165_AragoniteSaturation.mp4

Sensitivities of extant animal taxa to ocean acidification

•Astrid C. Wittmann & Hans-O. Pörtner

Nature Climate Change **3**, 995–1001 (2013)

TERC EarthLabs

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EarthLabs App icon image credit: NASA

ON IPAD, you must do this activity in a browser such as PUFFIN, which allows flash:

In this activity, you will use the online carbonate simulation to investigate the impact of changes in dissolved CO_2 and water temperature on pH and carbonate concentrations over time.

1. Visit www.dataintheclassroom.org and click on the Ocean Acidification module link.

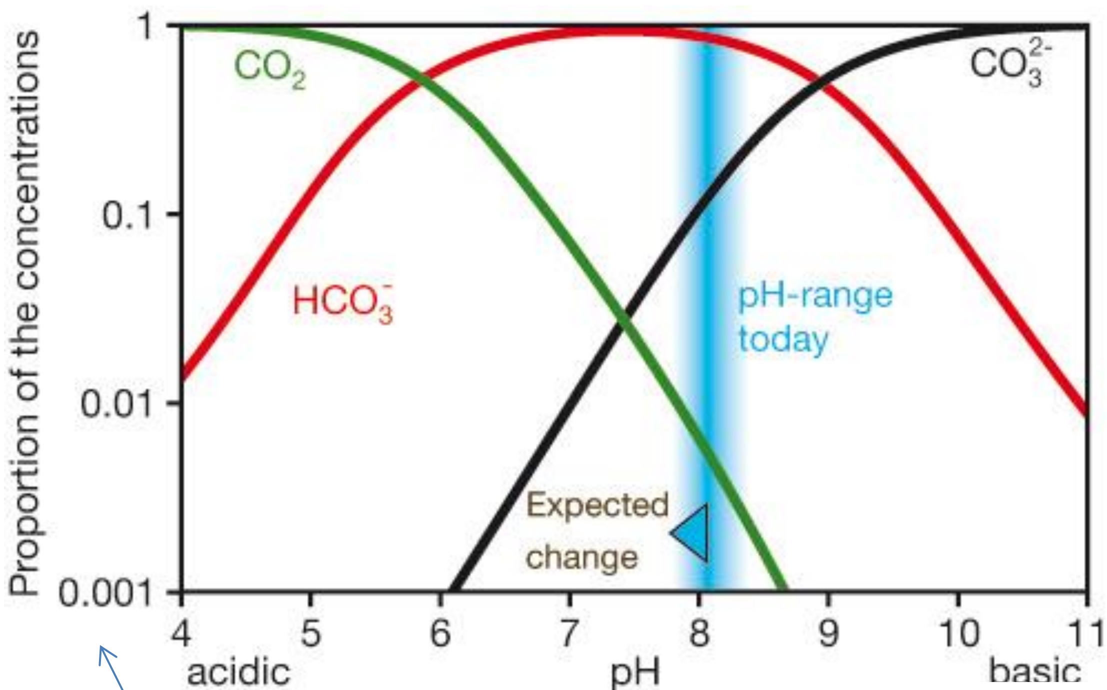
2. Follow the link to "Carbonate Simulation."

3. This simulation is set up with inputs for time in years, change in surface water temperature, and change in CO_2 concentration just above the air/water contact. Set the time to 100 years and leave the other two inputs set to their default "0" values. Click Play. You should see that, if the CO_2 level remains at the default 368 ppm level, pH and dissolved carbonates (carbonate and aragonite) remain stable. The graphs "flat line."

4. Let us see if water temperature has an effect. Select 50 years for "Time."

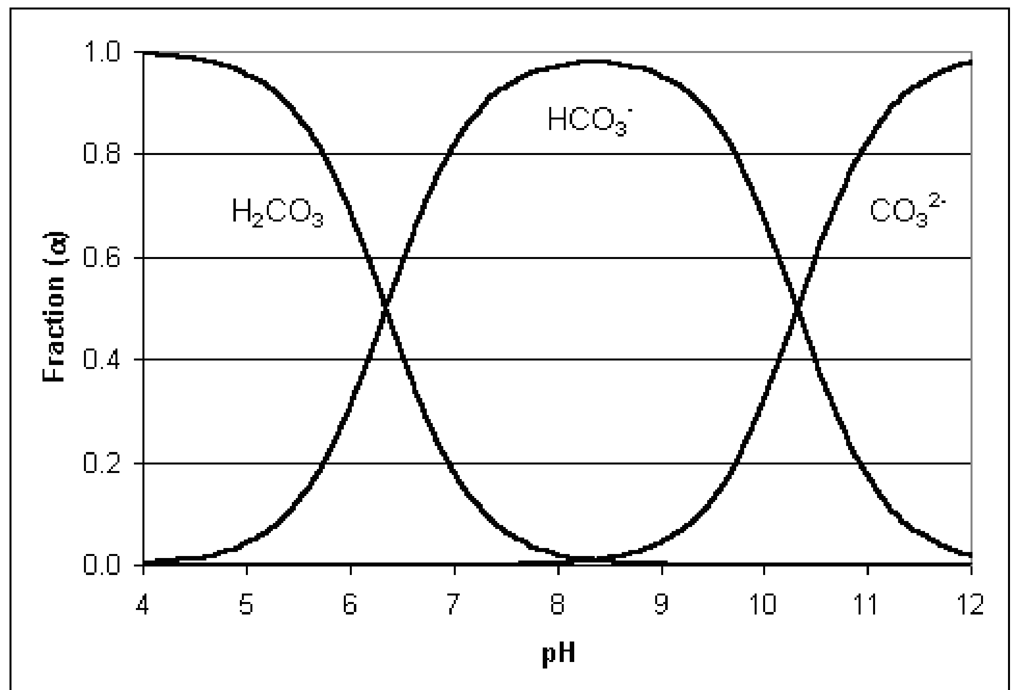
5. To isolate the variables, pick a number for ΔCO_2 and leave that constant while you vary the change in water temperature. For now, use "50" for the "ΔCO_2" input.

6. Now try different "Δ Temp" settings and run the simulation. Record the observed data in the table below.



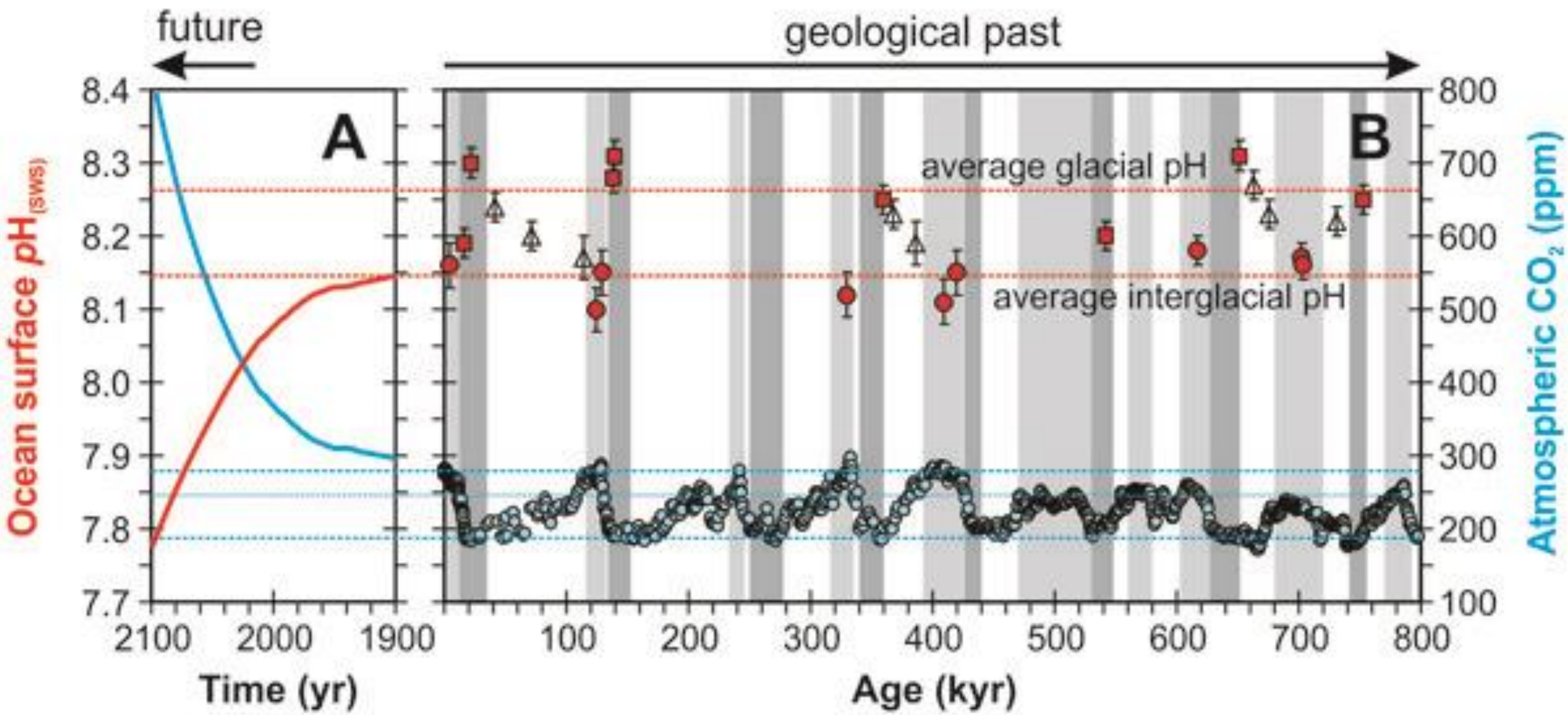
Proportion of the concentrations
1
0.1
0.01
0.001
CO_2
HCO_3^-
CO_3^{2-}
pH-range
today
Expected
change
4
5
6
7
8
9
10
11
acidic
pH
basic

Note scales

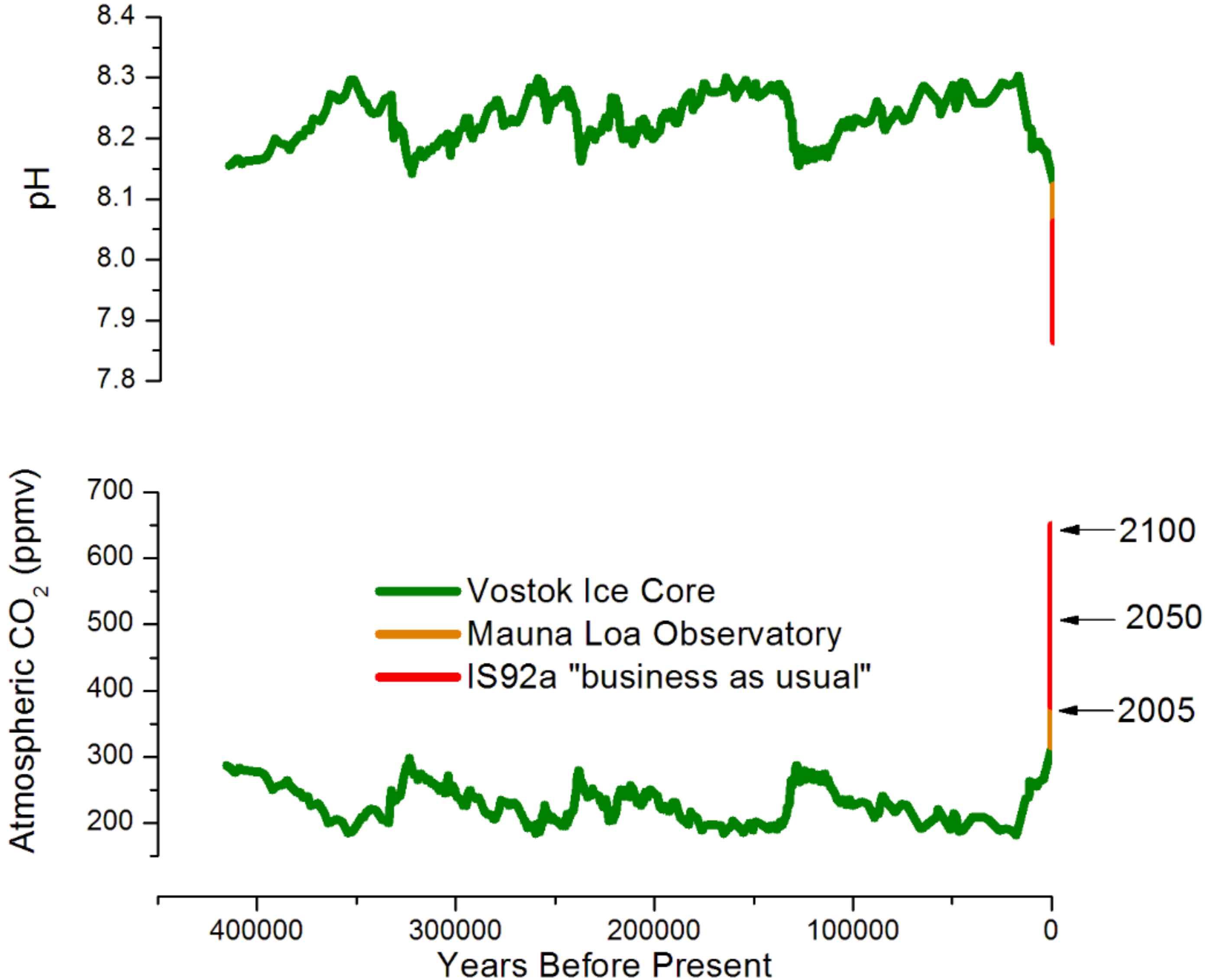


1.0
0.8
0.6
0.4
0.2
0.0
Fraction (α)
H_2CO_3
HCO_3^-
CO_3^{2-}
4
5
6
7
8
9
10
11
12
pH

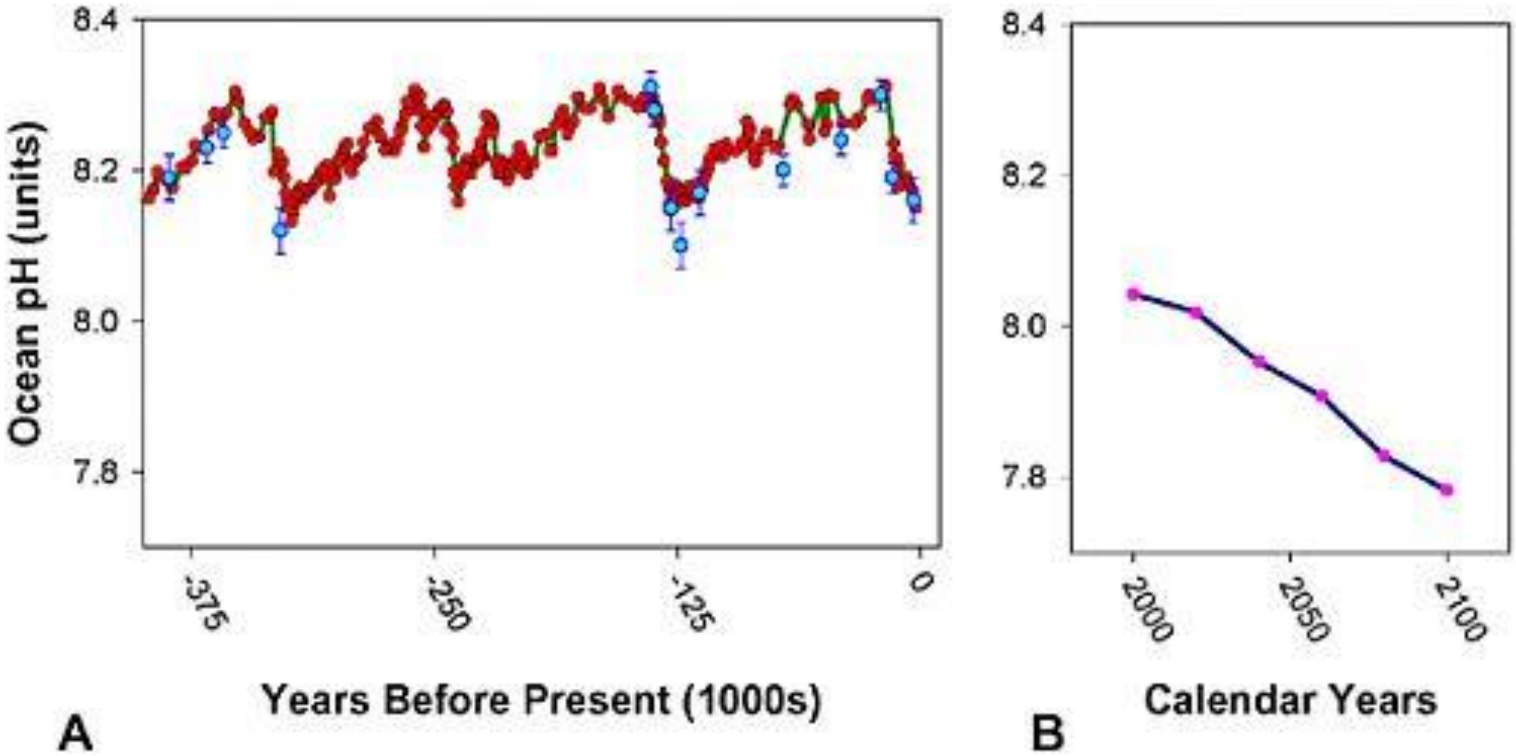
What is the average ocean pH today?
What is the current globally average CO_2 value?



http://www.nature.com/scitable/knowledge/library/ocean-acidification-25822734



http://coralreefwatch.noaa.gov/satellite/oa/description/figures/PAGE_3_CO2pH_animation.gif



The RATE of pH change is unprecedented in earth's recent history (400,000 years or more).

At high sustained CO_2 concentrations the changes in ocean chemistry will take thousands of years to be buffered by the natural dissolution of $CaCO_3$ from sediments and tens to hundreds of thousands of years to be eliminated completely by the weathering of rocks on land (Archer et al., 2009).

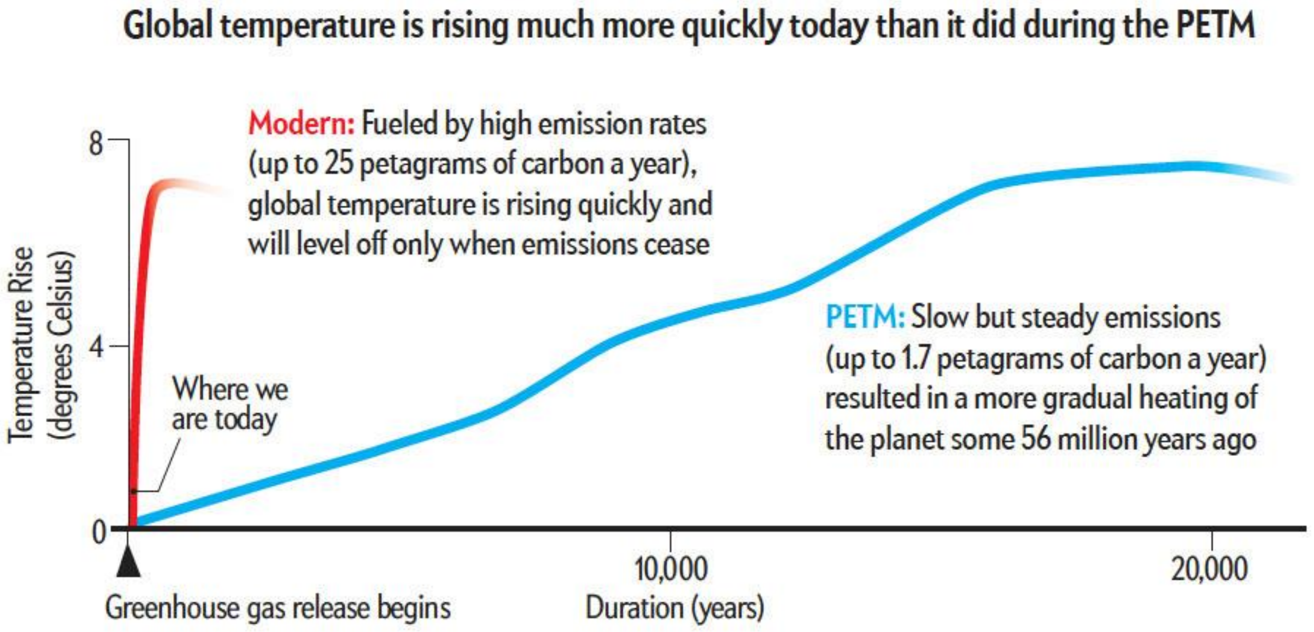
By the end of the century, ocean pH is projected to fall another 0.3 pH units, to 7.8. While the researchers found a comparable pH drop during the PETM--0.3 – but the *PETM shift happened over a few thousand years*

*The pH is not unprecedented, the **rate** of change is what has scientists concerned.*

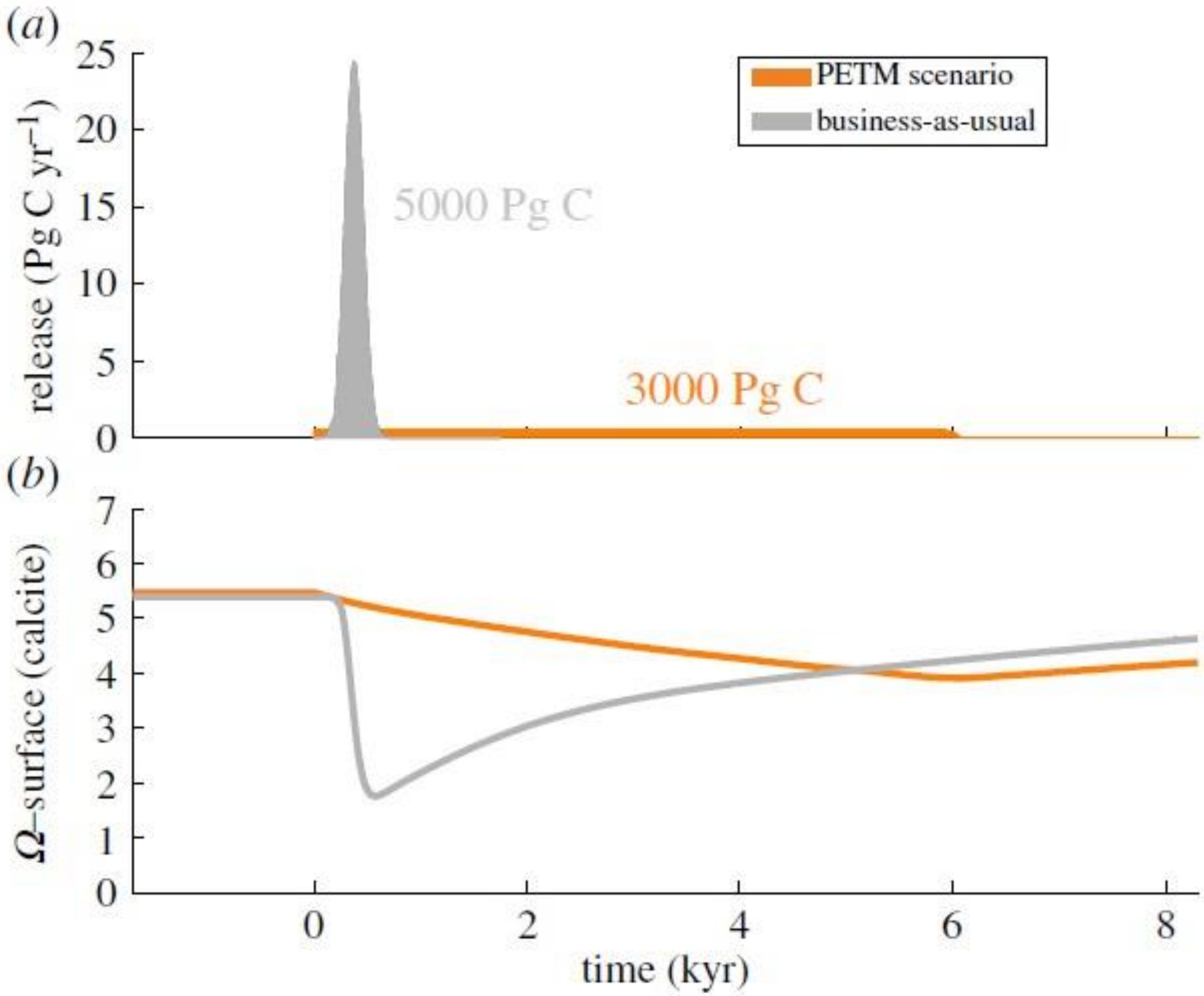
http://www.earth.columbia.edu/articles/view/3172units--the shift happened over a few thousand years.

Paleocene-Eocene Thermal Maximum (PETM)

The PETM was a short-lived (~ 200,000 years) global warming event when temperatures increased by 5-9°C. It was marked by the largest deep-sea mass extinction among calcareous benthic foraminifera in the last 93 million years.



Rate of temperature change today (red) and in the PETM (blue). Temperature rose steadily in the PETM due to the slow release of greenhouse gas (around 2 billion tons per year). Today, fossil fuel burning is leading to 30 billion tons of carbon released into the atmosphere every year.



Comparison of the effects of anthropogenic emissions (total of 5000 Pg C over 500 years) and PETM carbon release (3000 Pg C over 6 kyr) on the surface ocean saturation state of calcite. From Zeebe, 2013

ALBEDO


Earth pictured from the moon.
Planetary albedo of the earth is about 0.3
Certain regions are typically much more reflective than others.

Positive Feedback = change from equilibrium condition

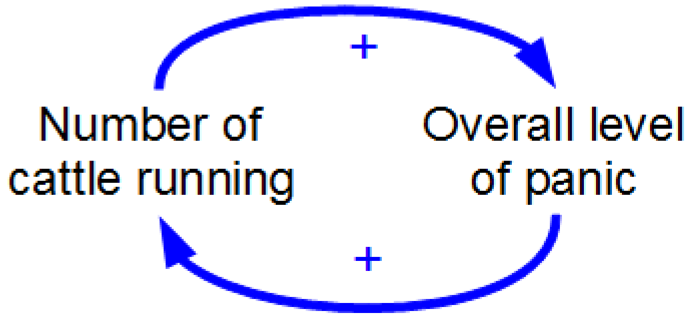
Negative Feedback = return to equilibrium condition

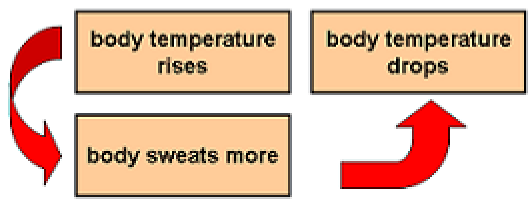
positive does not mean good

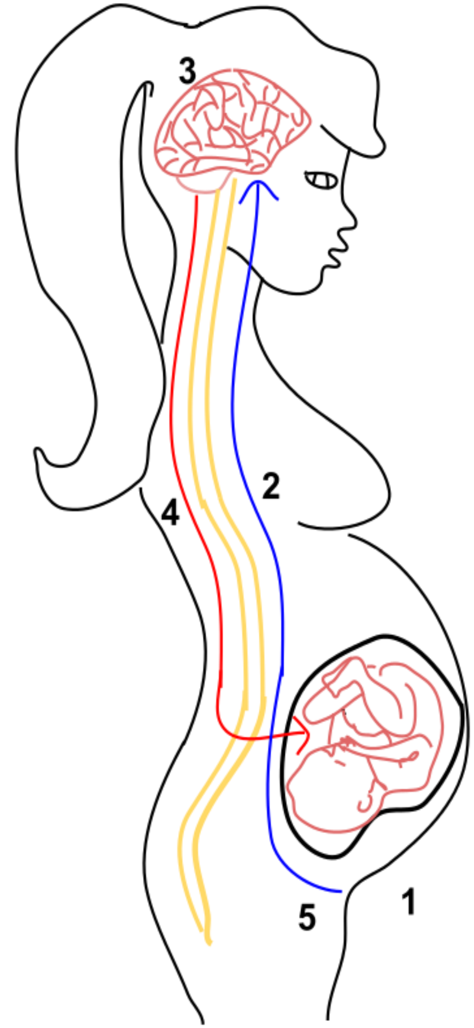
negative does not mean bad

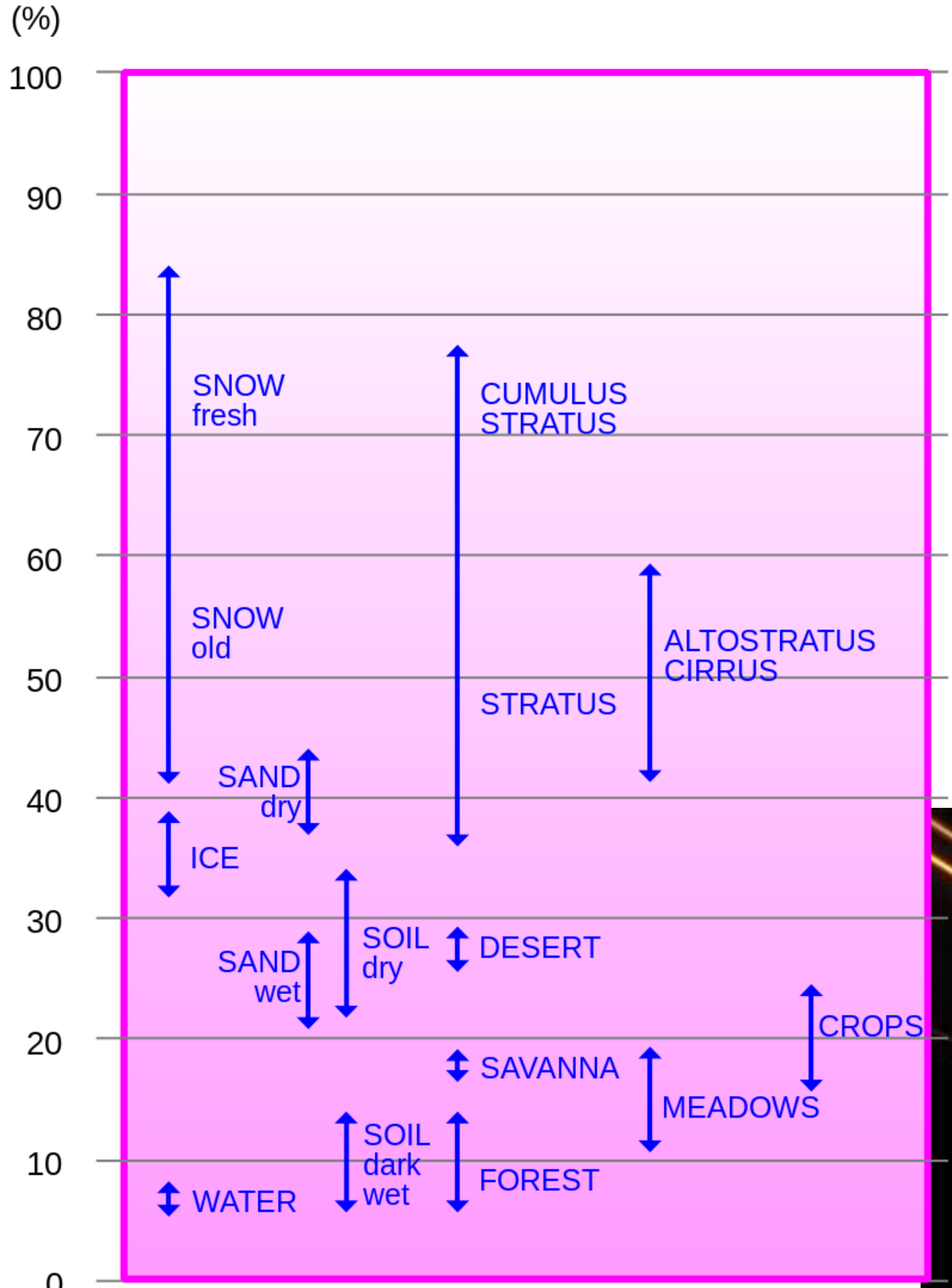
- A positive climate feedback increases the climate warming, while a negative climate feedback decreases that warming.

Examples of positive or negative feedback?





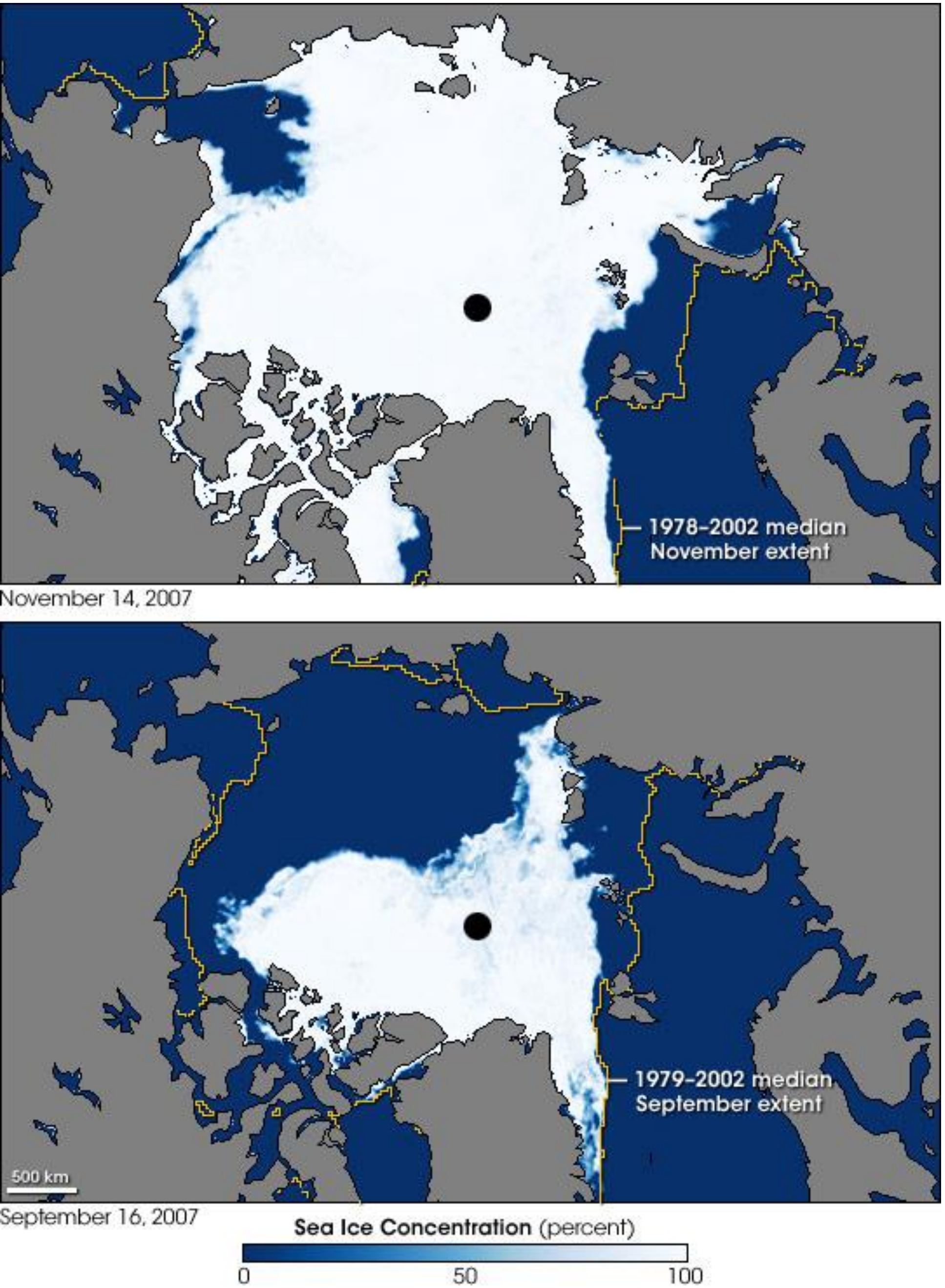




Albedo is the fraction of solar energy (shortwave radiation) reflected from the Earth back into space. It is a measure of the reflectivity of the earth's surface. Ice, especially with snow on top of it, has a high **albedo**: most sunlight hitting the surface bounces back towards space.

Pure white ice/snow reflects ~80% of sunlight

Open ocean reflects 7% of sunlight



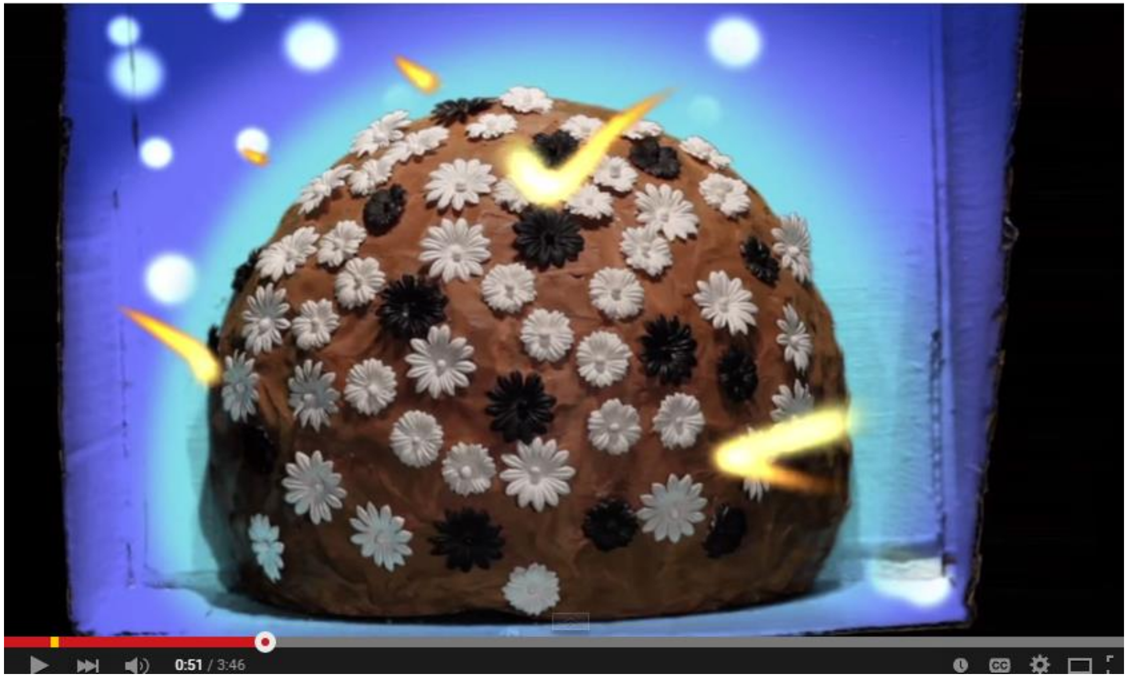
When sea ice melts, it exposes dark, heat-absorbent open ocean which, in turn,

- decreases net albedo,
- increases regional heat absorption,
- induces further melting,
- further decreases net albedo,
- further increases regional heat absorption,

and ultimately warms global climate.

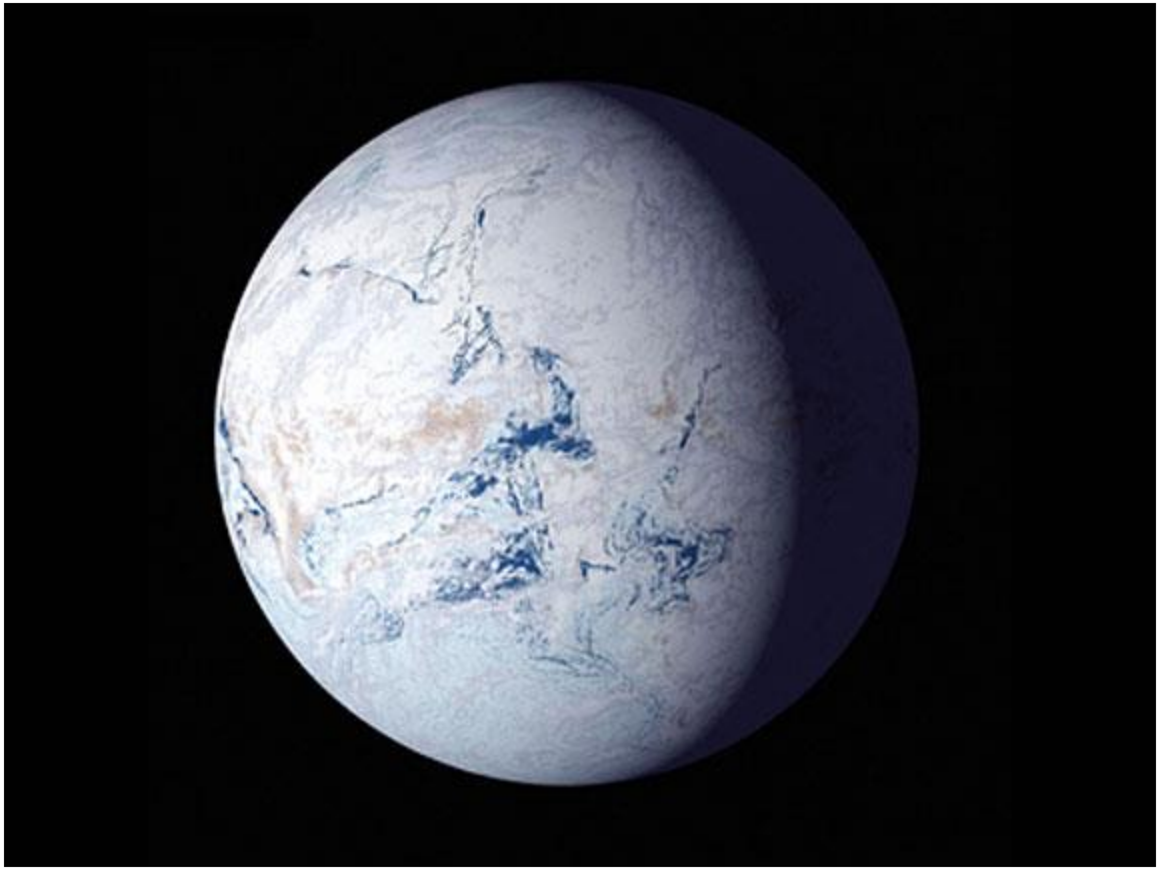
This is the sea ice-albedo positive feedback loop.

ALBEDO



https://www.youtube.com/watch?t=53&v=cW4JTHz1aRg

SNOWBALL EARTH and the ALBEDO FEEDBACK
(this can work in both directions)



http://article.wn.com/view/2003/07/18/Scientists_Test_Snowball_Earth_Hypothesis/