Lecture 8: Extra Subjects

Learners: *Ice Ages and Climate*

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A few miscellaneous topics

- Aerosols
- Methane
- Internal variability
- Sea level rise
- Geoengineering

Aerosols

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- Methane
- Internal variability
- Sea level rise
- Geoengineering

Making aerosols

Airborne Aerosols

Understanding anthropogenic (human caused) effects on climate change means understanding aerosols.

Aerosols are micron scale particles consisting at least in part of solid material.

Density of an aerosol particle: 1.0 g/cm^3 (for soot) to 2.6 g/cm^3 (for minerals).

Natural aerosols:

salt (from seawater), natural terrestrial biomass burning, volcanic eruptions, windblown dust

Man-made aerosols:

pollution from industrial production, engine exhaust, burning trash, etc.

Density of aerosol particles varies a lot:

continent 2,300/cm^3 (windless desert), 3,000/cm^3 (clean air), 50,000/cm^3 (polluted), 160,000/cm^3 (urban)

sea 1,000/cm^3 (clean), 300-600/cm^3 (cleanest)

Arctic 6,600/cm^3 (mostly soot); Antarctic desert 43/cm^3 (sulfate)

Airborne Aerosols

Where are they found?

In the air over oceans, deserts, mountains, forests, ice, and every ecosystem in between

A billion tons of dust from the Sahara each year.

Small light particles stay in the atmosphere up to two weeks.

Volcanic ashes (small aerosols) rise in the atmosphere and can stay for 2 years.

Some aerosols block sunlight & cause cooling (by decreasing surface sunlight)

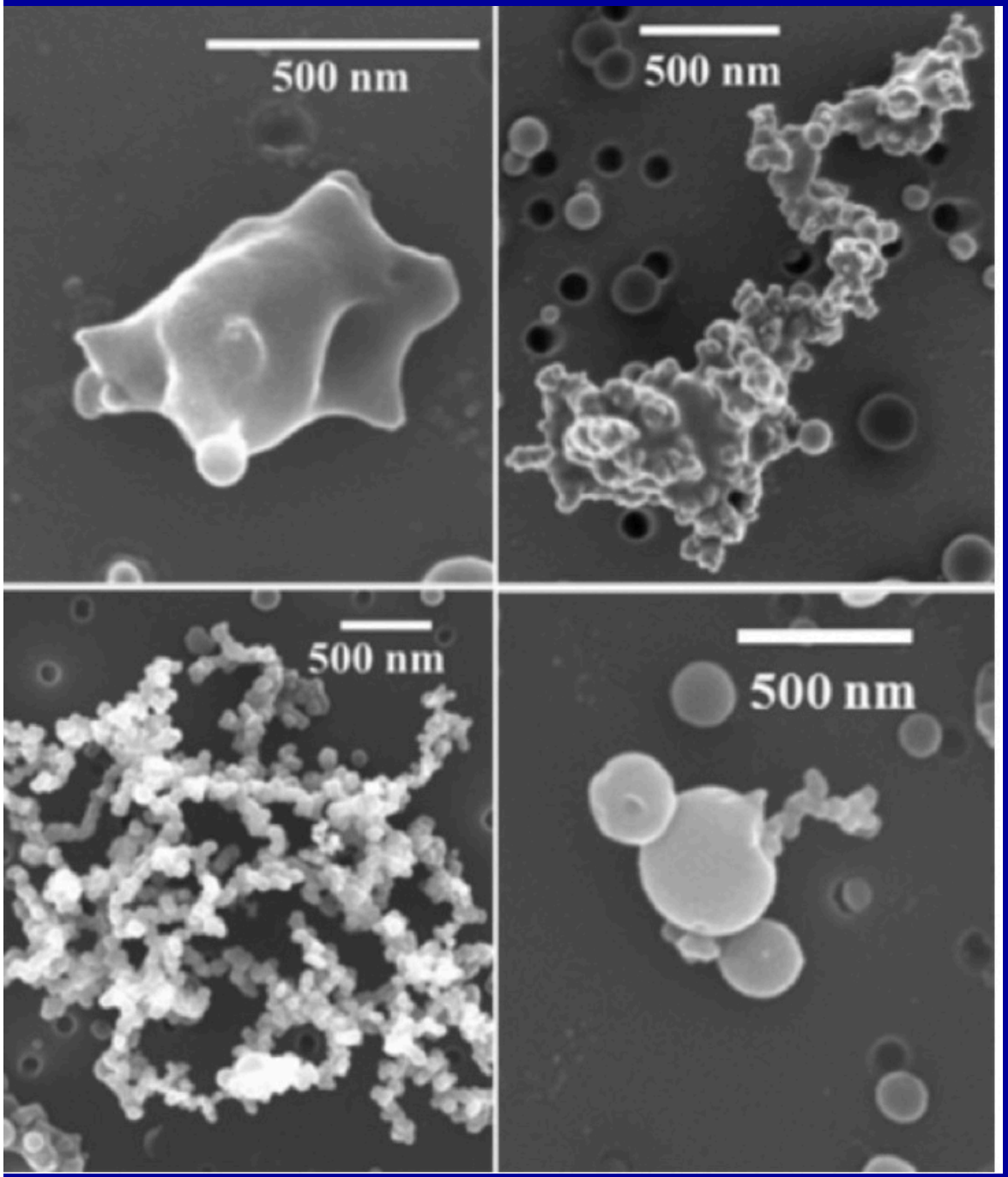
Volcanic emissions

Black soot absorbs solar radiation causing warming

Anthropogenic sources now overwhelm natural sources over much of the globe

Some aerosols are important in nucleating raindrops

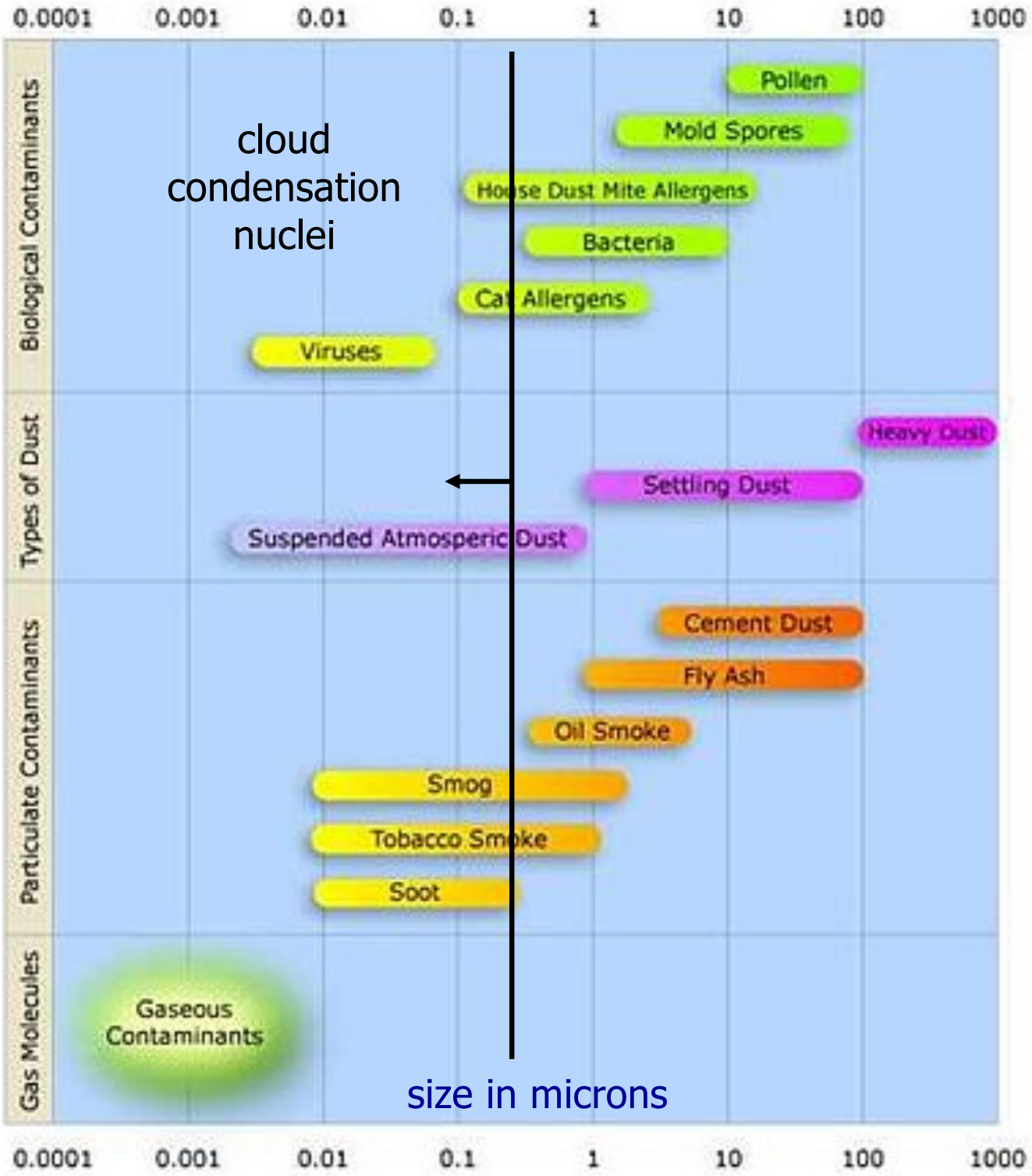
Other aerosols nucleate water droplets causing thin clouds or haze.



The enormous variety of aerosol shapes and chemical compositions is maddening to modelers

These are soot particles, tarballs, etc. from a 2011 New Mexico fire

Credit Warren Wiscombe: NASA, GSFC 2014



Aerosols

sea salt, dust, soot and, yes, viruses

Cloud condensation nuclei <0.2 microns -> rain

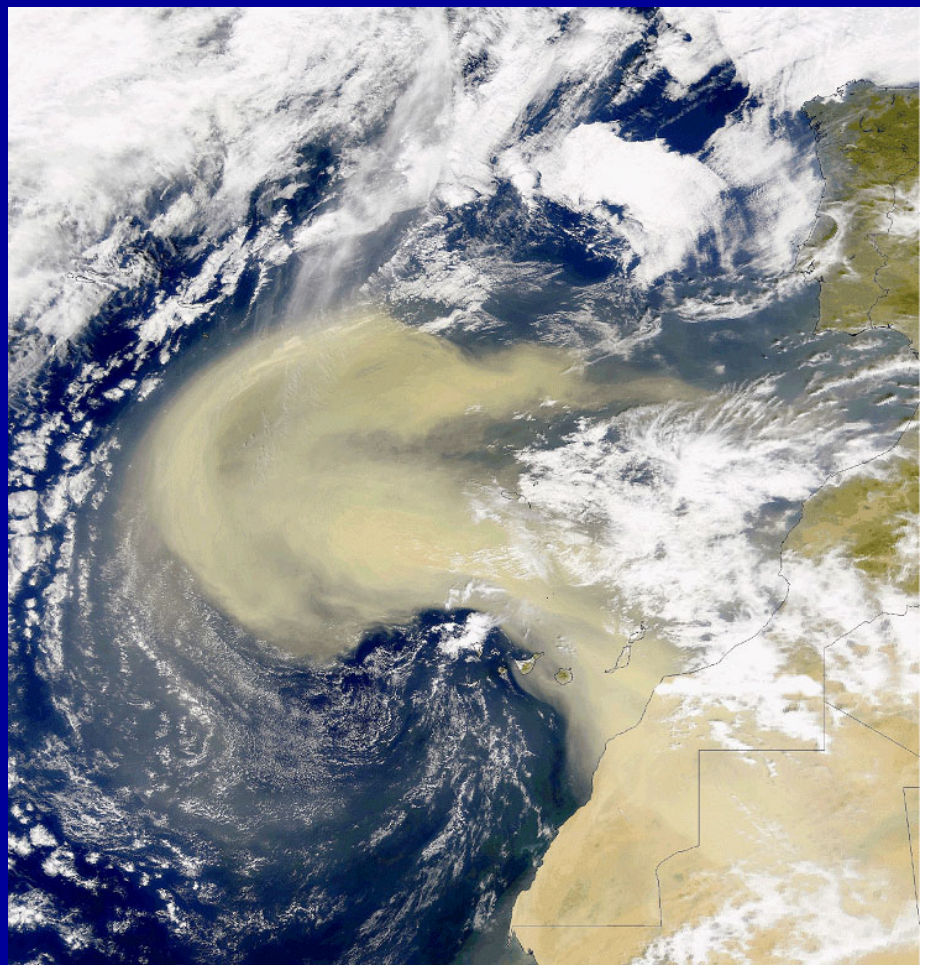
Anthropogenic sources now overwhelm natural sources over much of the globe

Some cool (T down), some warm (T up); not well understood

Saharan dust feeds the Amazon rain forest

A single, very dusty, location in the Sahara Desert literally supplies half of the amount of the critical mineral dust needed by the Amazon rainforest to survive.

NASA movie



Volcanos

Volcanic ash, dust and SO_2 all block the incoming sun and have a cooling effect.

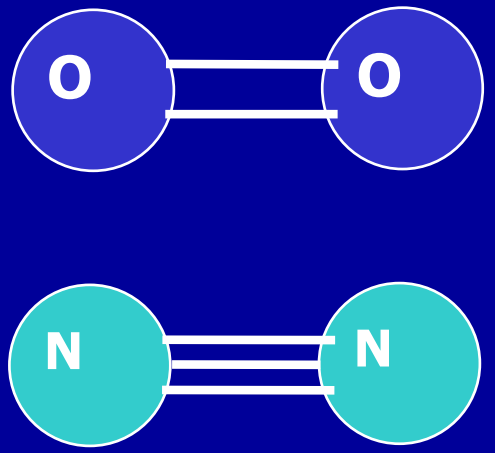
Methane

- Aerosols
- Methane
- Internal variability
- Sea level rise
- Geoengineering

Dancing Molecules and Heat Rays!

- Nearly all of the air is made of nitrogen (N_2) and oxygen (O_2) in which two atoms of the same element share electrons

- Infrared (heat) energy radiated up from the surface can be absorbed by these molecules, but not very well.

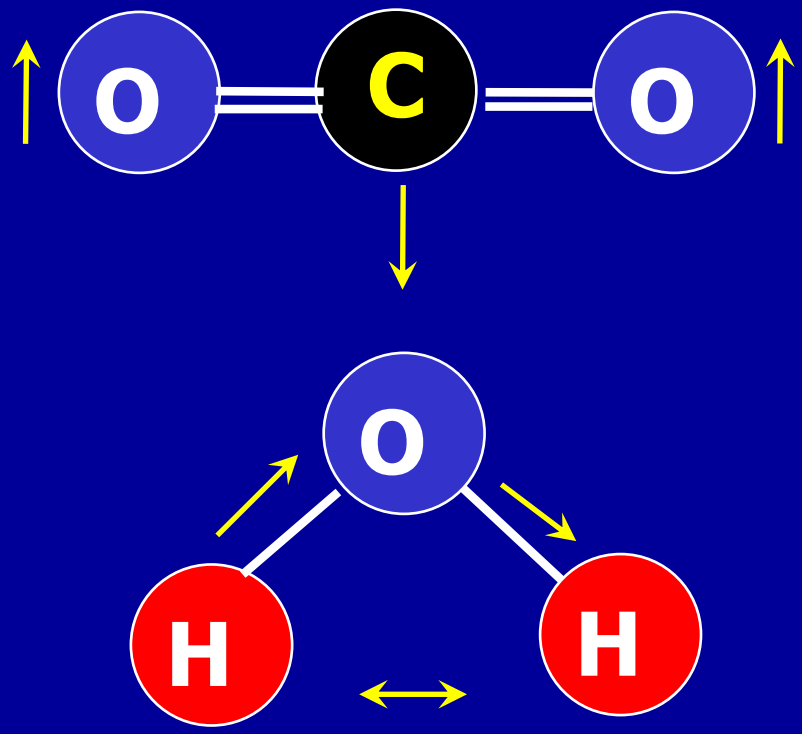


Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical, so there is only one mode of motion.

Dancing Molecules and Heat Rays!

- Carbon dioxide (CO_2) and water vapor (H_2O) are different!

- They have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation

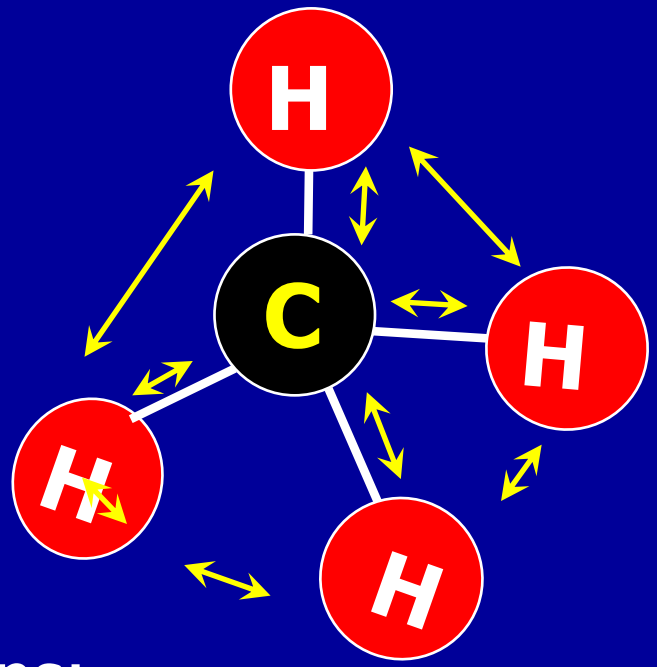


Molecules that have many ways to wiggle are called "Greenhouse" molecules

The absorption spectrum of CO_2 was measured by John Tyndall in 1863.

Methane is even nastier.

- Methane (CH_4) has even more ways to vibrate and rotate, so is even better at absorbing and emitting infrared (heat) radiation



Net of several reactions:

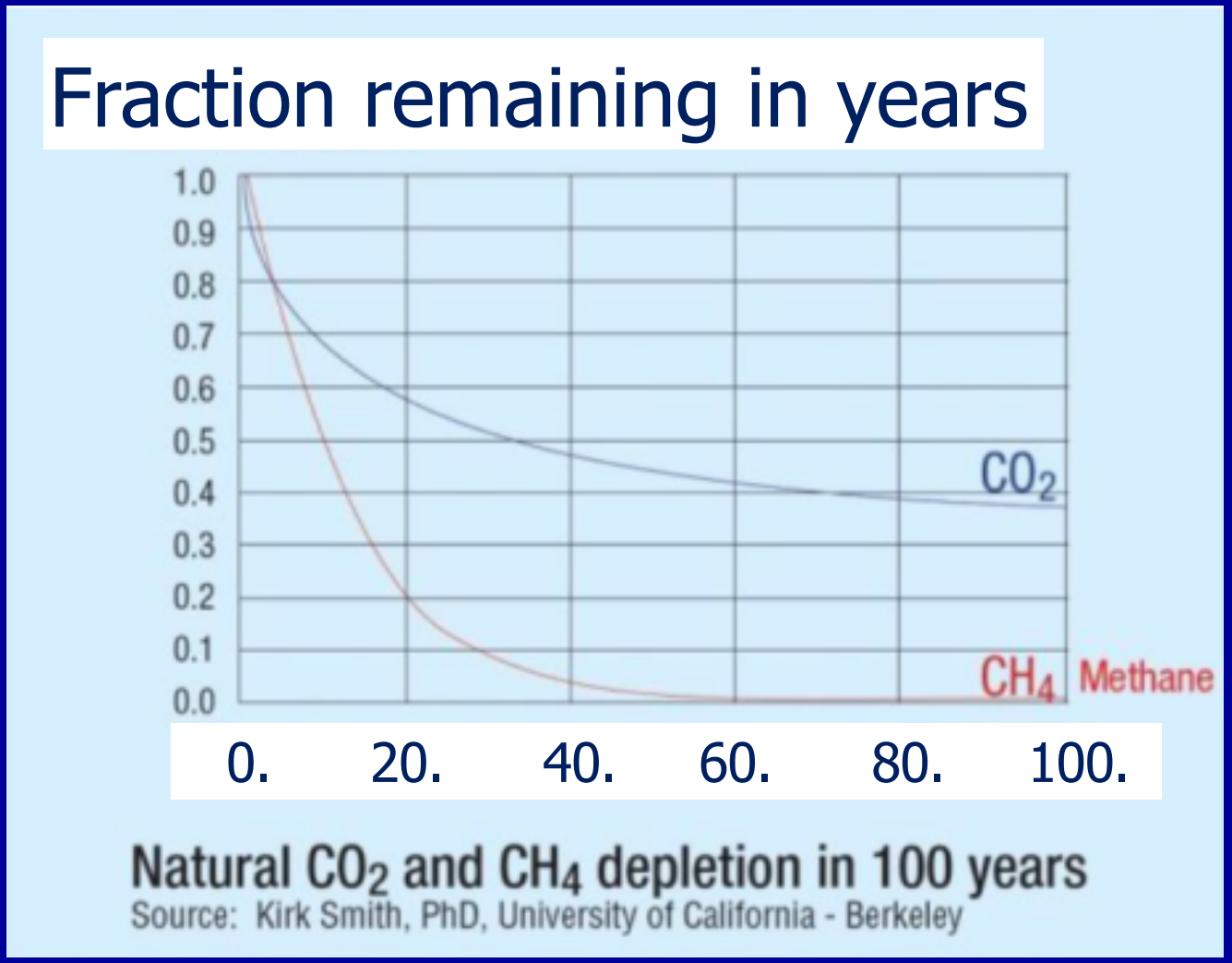
$CH_4 + OH^- \rightarrow CO_2 + H_2O$

10-12 year lifetime

vicious cycle, positive feedback

Once in the atmosphere CH_4 finds an OH radical and becomes a CO_2 molecule.

CO_2 and CH_4 lifetimes

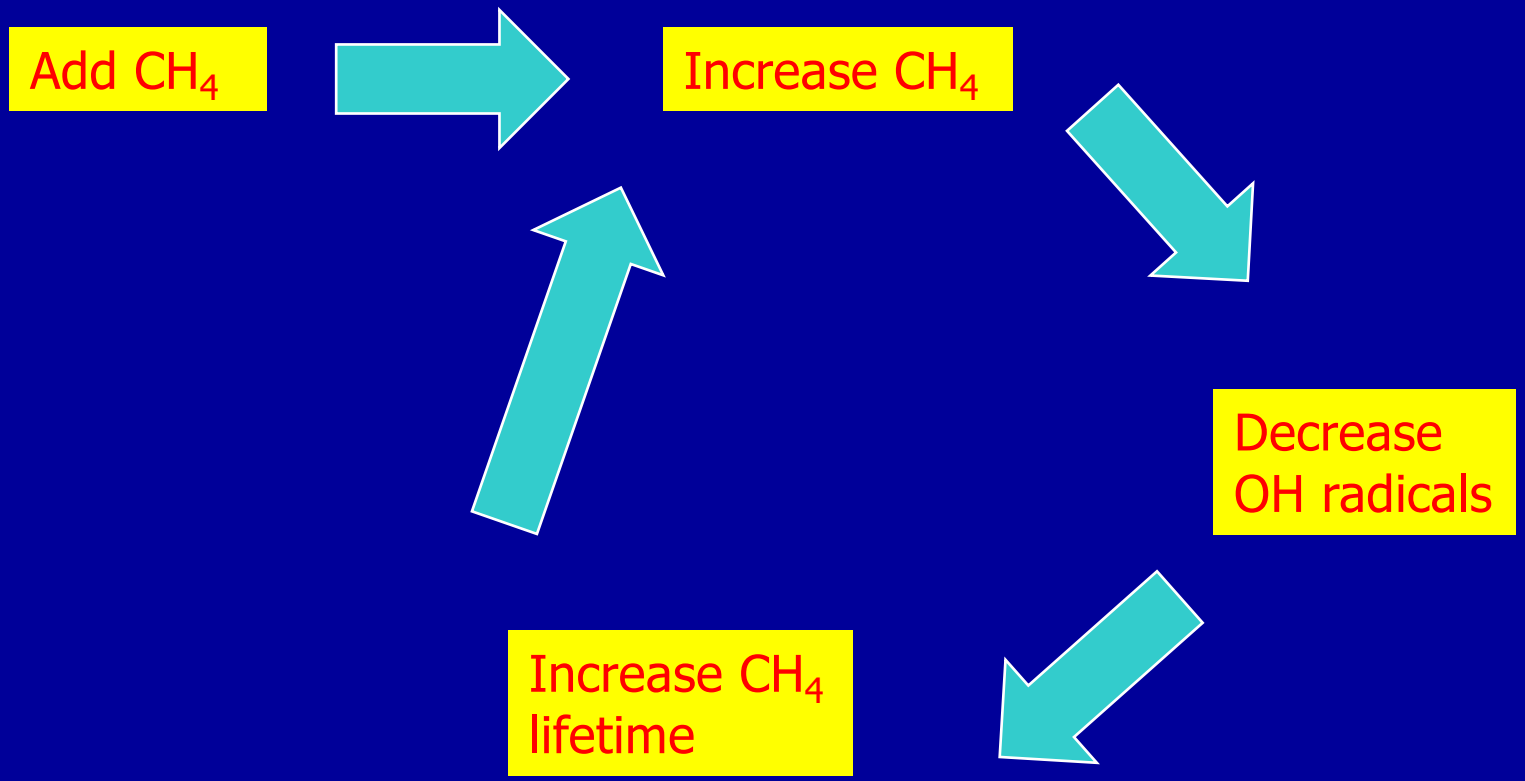


Methane lifetime

- Net of several reactions:
  - $CH_4 + OH^- \rightarrow CO_2 + H_2O$
  - ~~8-10~~ 12.5 year lifetime
  - vicious cycle, positive feedback

- E.g. 1% increase in CH_4 -> 0.32% decrease in OH –> effective lifetime – 12-15 years

Positive Feedback methane



Global warming potential

Comparison by equal mass

Note: CO_2 = 12+2*16 = 44; CH_4 = 12+4 = 16; 44/16=2.75

IPCC 2007	Lifetime (years)	GWP time horizon	
		20 years	100 years
Carbon dioxide	Variable	1	1
Methane	12	100	30
Nitrous oxide	114	289	298
HFC-23 (hydrofluorocarbon)	270	12,000	14,800
HFC-134a (hydrofluorocarbon)	14	3,830	1,430
Sulfur hexafluoride	3200	16,300	22,800

Biological formation of methane

Anaerobic (no O_2) decomposition of organic material by methane producing (methanogenic) bacteria (flooded soils, wetlands, landfills, digestive tracts).

$2CH_2O$ (formaldehyde)
-> CH_4 (methane) + CO_2 (carbon dioxide)

Formaldehyde is ubiquitous in living organisms.

Methane production is temperature dependent, with a maximum reaction rate between 37 and 45 ^oC (98.6 & 113 ^oF).

Origin CH_4 Emission
Mass (M metric tons/yr)

Sources

Natural Emissions	
Wetlands (incl. rice agriculture)	225
Termites	20
Ocean	15
Hydrates	10
Natural Total	270

Anthropogenic Emissions	
Energy	110
Landfills	40
Ruminates (Livestock)	115
Waste treatment	25
Biomass burning	40
Anthropogenic Total	330

Sinks

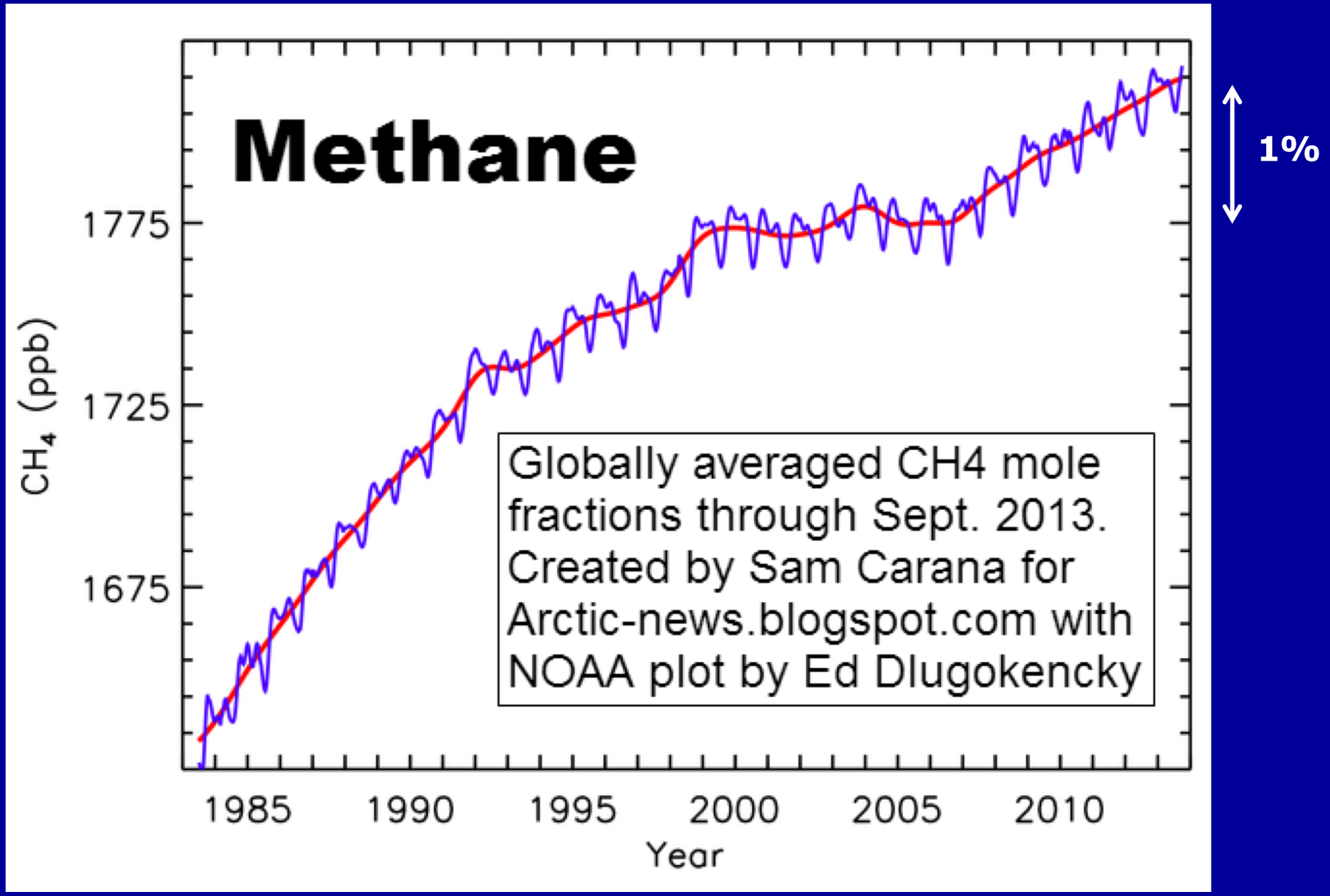
Soils	-30
Tropospheric OH	-510
Stratospheric loss	-40
Sink Total	-580

Emissions + Sinks Imbalance (trend) +20 M tons/year

Recall C mass from CO_2 was 10 billion tons/yr

Importance per unit mass (20yr): $CO_2/CH_4 = 500/100 = 5$

Methane trend

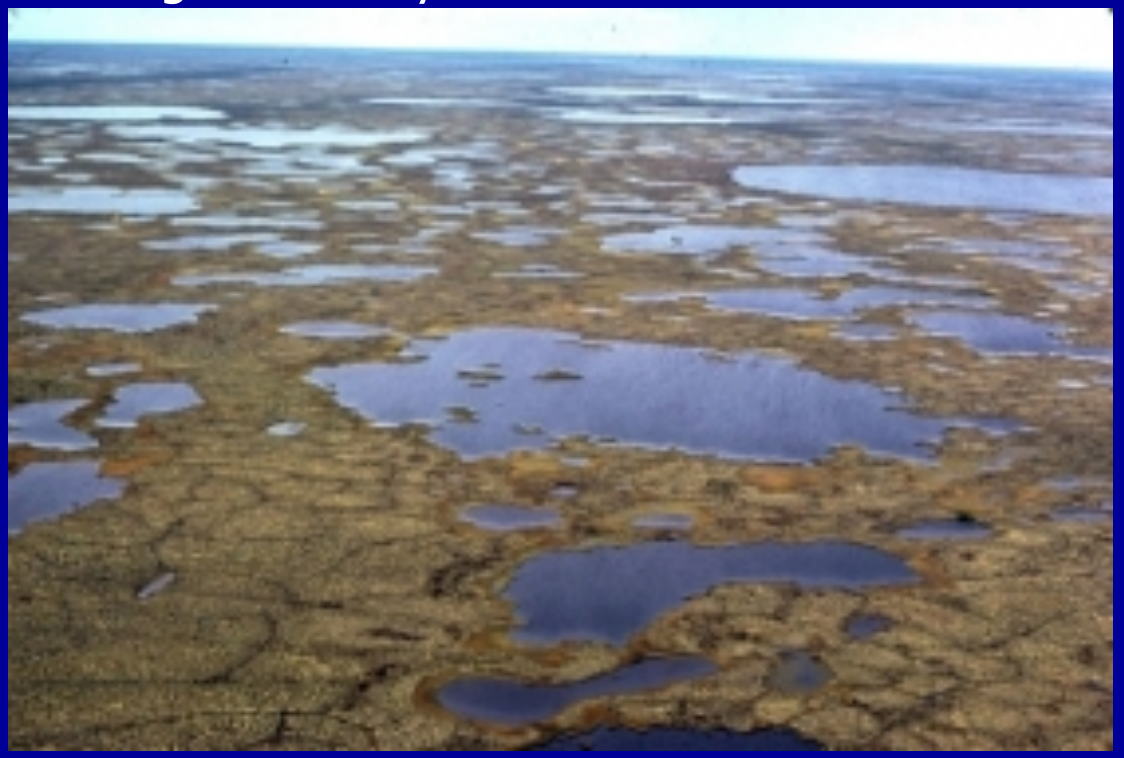


Natural gas well CH_4 losses 4% in CO; 9% in Utah.

Permafrost melt releases CH_4 and CO_2.

Near term: *Changes in peat chemistry associated with permafrost thaw increase greenhouse gas production*,
Hodgkins et al. 2014, doi: 10.1073/pnas.1314641111

On longer time scales, ~1000 years, the lakes formed, called thermokarst lakes, may absorb more carbon than is released. This absorption of CO_2 is the result of the slow development of biological activity in the lakes.
Anthony et al., Nature, 2014



Natural gas: Better than coal?

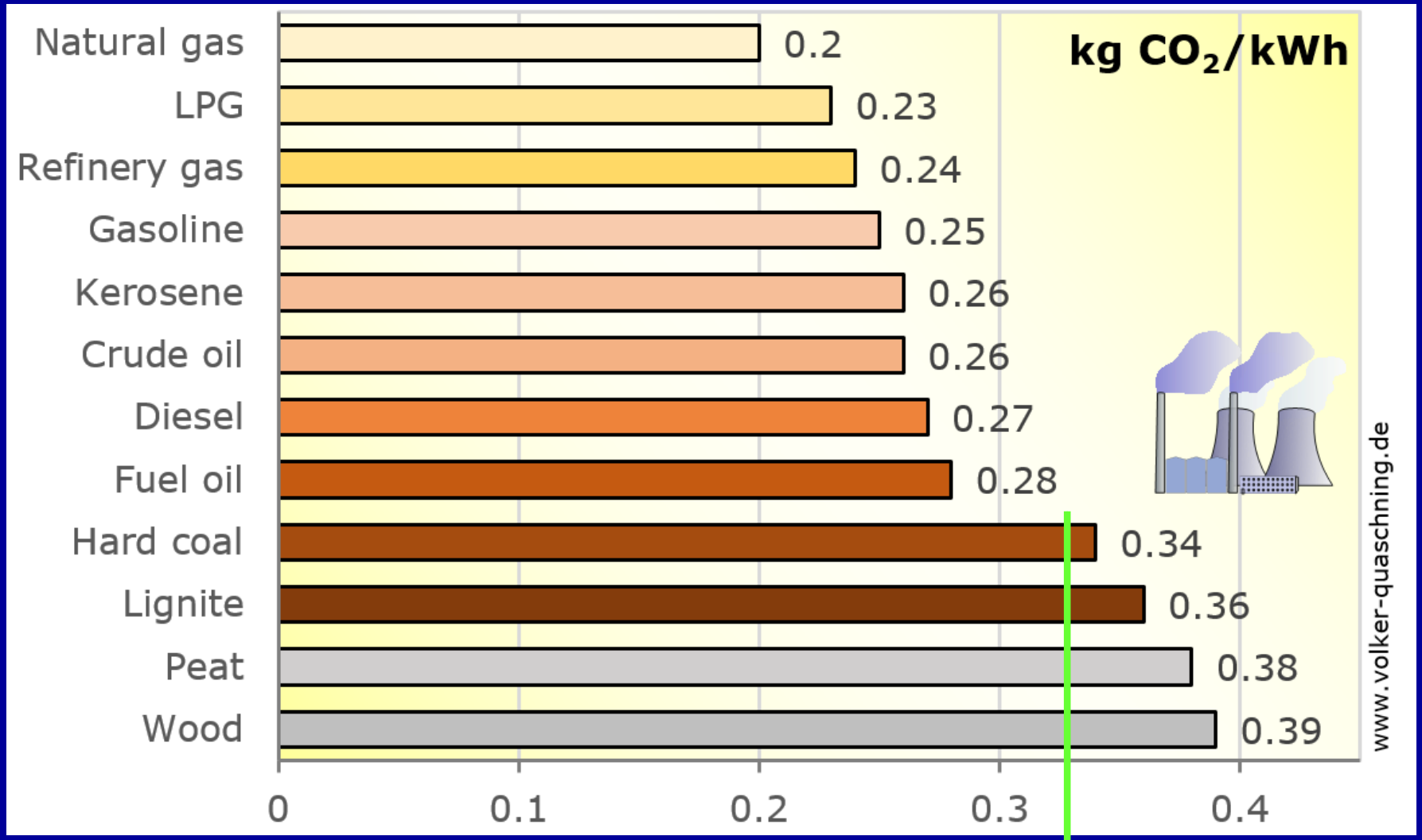
Natural gas (mostly CH_4) emits about half as much CO_2 as coal per unit of energy when burned, but the 4-8% losses of CH_4 to the atmosphere offsets most of the gain.

(See "Methane and the greenhouse-gas footprint of natural gas from shale formations", Howarth, Santoro, and Ingraffea, 2011, Climatic Change, **106**, p 679)

CH_4 is not much better than coal unless this lost gas can be recaptured.

- loss is more than double the official inventory
- roughly in line with estimates made in 2011
- challenged by industry

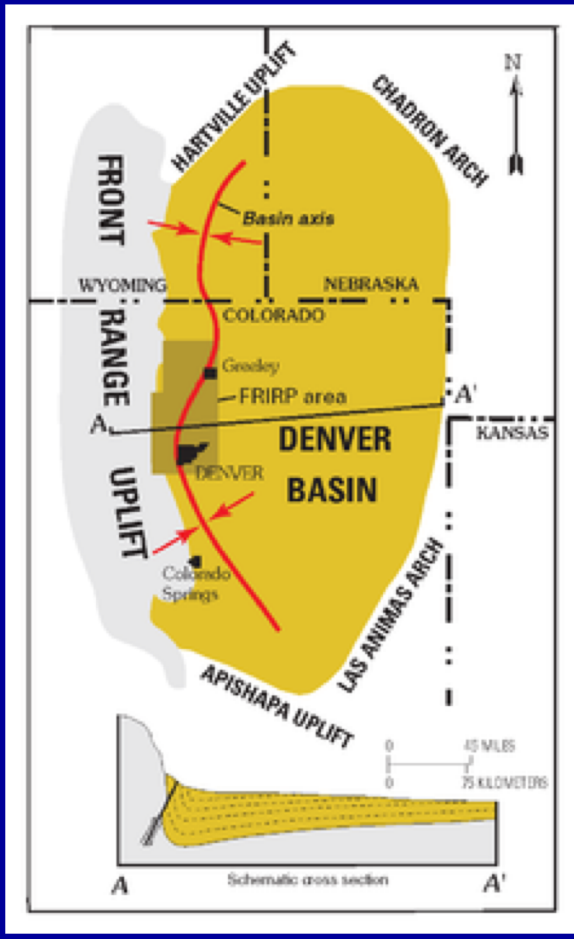
Not all fossil fuels are created equal



Tar sands use huge amounts of water, forest destruction.

Natural gas: Gain lost via fracking?

Samples of air from a tower north of Denver, Colorado, showed that natural-gas producers in the Denver-Julesburg Basin are losing about 4% of their gas to the atmosphere — not including additional losses in the pipeline and distribution system.
(See Tollefson, 2012, Nature, **482**, and Pétron et al., 2014, J. Geophysical Res, in press)



FRIRP: Front Range Infrastructure Resources Project

Methane

Study found sources of methane in southwestern Pennsylvania in June 2012 with emissions rates 1,000 times higher than those estimated by the EPA. (Caulton et al., 2014, Proc. NAS, doi: 10.1073/pnas.1316546111)

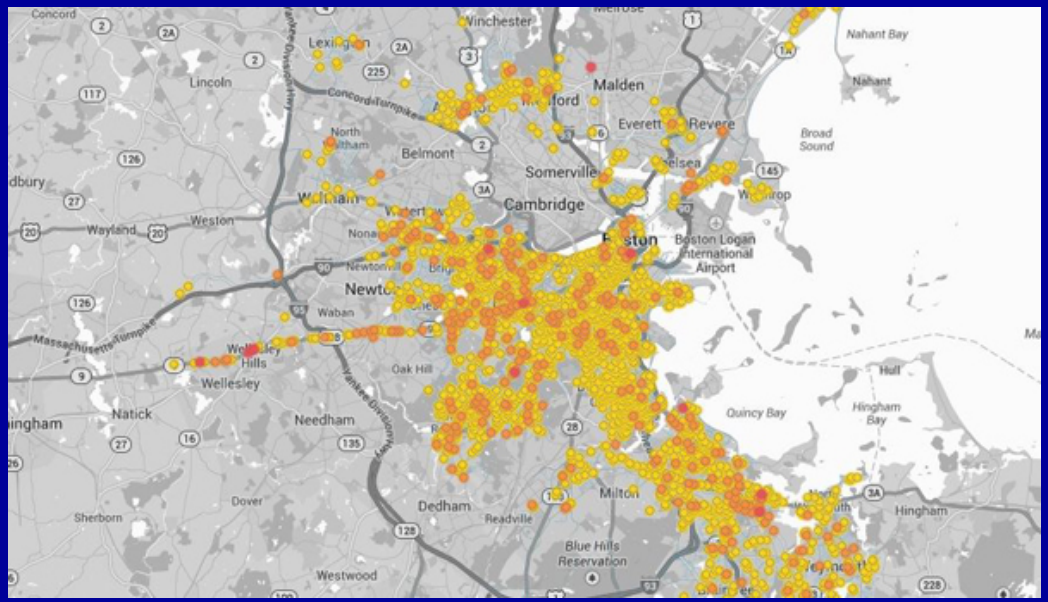
White House ordered the EPA to identify ways to cut methane from oil & gas production, with any new rules to be in place by the end of 2016.

Fighting over this ever since!

Google car detecting methane leaks

red dots indicate places where methane was leaking at a rate of more than 60,000 liters per day (sewer pipes)

also detects leaking natural gas vehicles



Katey Walter Antony, Univ. of Alaska, Fairbanks

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

Internal variability

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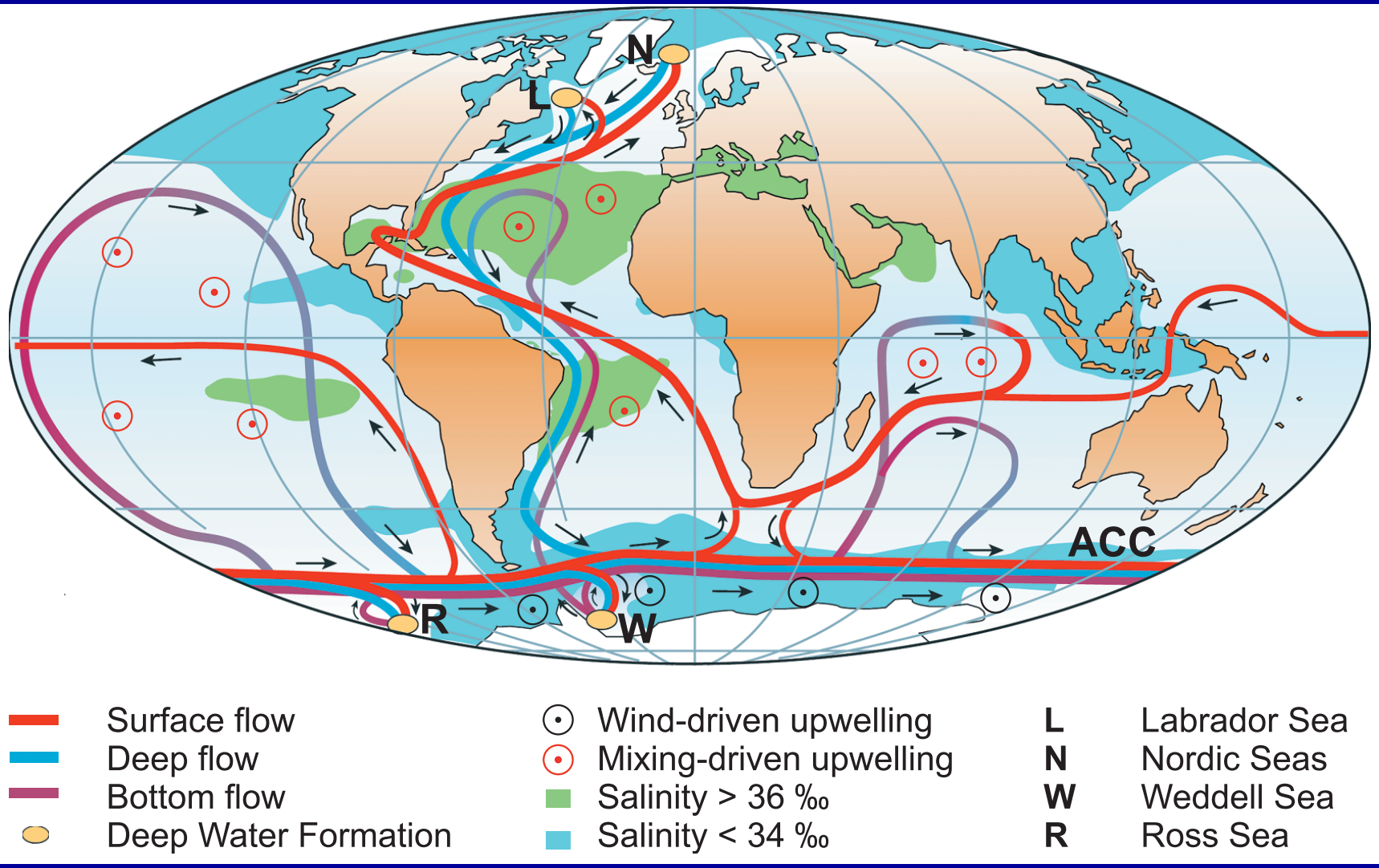
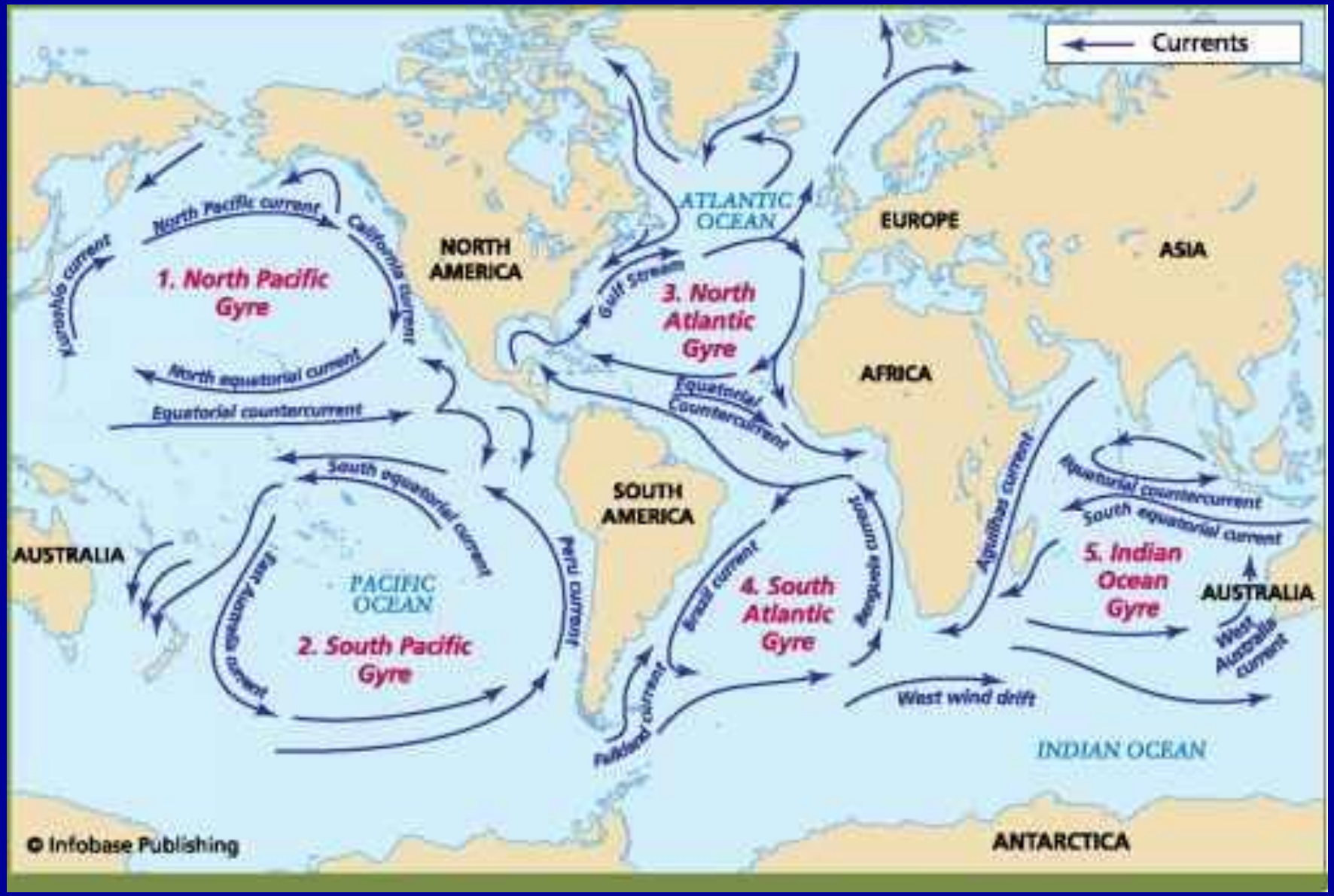
Thermohaline circulation



Global circulation gyres



North Pacific gyre and garbage patch

Result: an enormous trash buildup that's killing birds and sea life

Seiche

- Standing waves in a partially bounded body of water
- Waves stimulated by tidal surges, winds, earthquakes, or even children
- Natural frequency=1/T $T = \frac{2L}{\sqrt{gh}}$
  - T: period of oscillation, L: length, h: height, g: accel. of gravity
  - Swimming pool: $2*50m/\sqrt{(9.8m/s^2*3m)}=18$ s
  - Bay of Fundy: $2*235$ km$/\sqrt{(9.8m/s^2*10m)}=13$ hrs
  - Pacific Ocean: 2 days
- Known in freshman physics as a simple harmonic oscillator

About to go back and forth!

If she does, water everywhere!

Global Engine for heat

- Cold water, denser, falls
- Freezing water removes salt, salt water more dense
  - Antarctic winter!
- Water falls when it's cold and salt free
  - Arctic and Antarctic winters help drive ocean currents

Meltwater from Greenland (or Lake Agassiz and the Laurentide Ice sheet) can disrupt or modify this engine.

Gulf Stream

- Discovery credit goes to Anton de Alaminos, a pilot for Ponce de Leon (both sailed with Columbus) 1519
- Northern leg was charted by Benjamin Franklin and his cousin Folger in the 18^{th} century; Spanish treasure ships used the stream to return to Europe throughout the 16^{th} century.
- British Admiralty wanted to know why American ships sailed to England 2 weeks faster than theirs. Franklin was called to testify. They ignored his testimony.
- More than 20 times all the great land rivers and glacier melt combined.
- One hundred thousand million (10^{11}) tons of warm salt water flow between Florida and the Bahamas every hour. At 235 gallons per ton, we have 235 x 10^{11} gallons per hour flowing between two and five miles per hour northward.