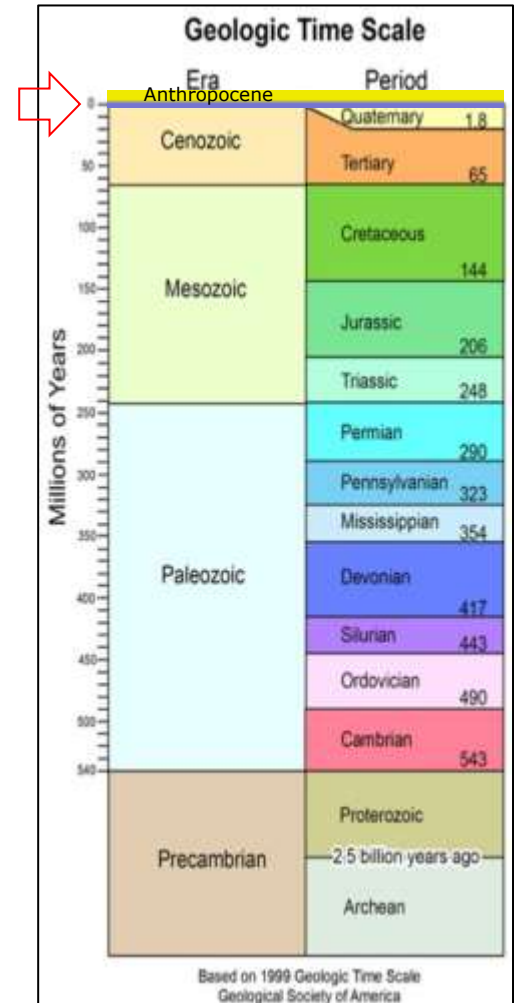


Agenda for Section (Sustainability @ "Anthropocene")

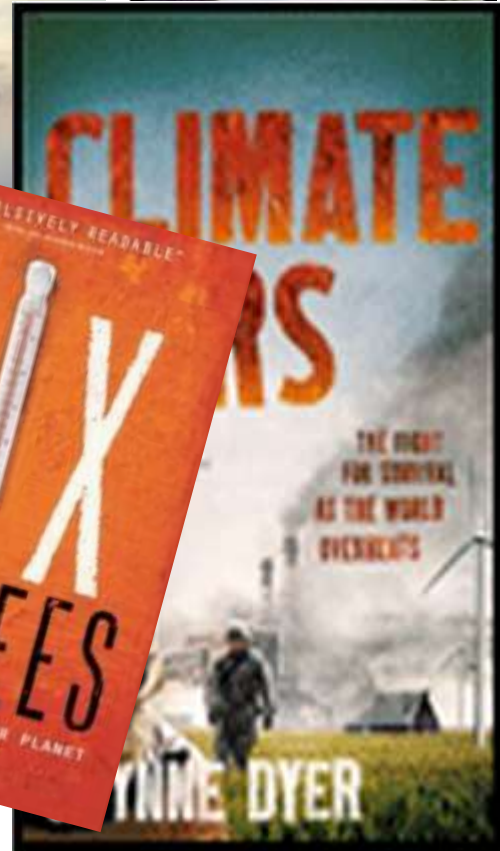
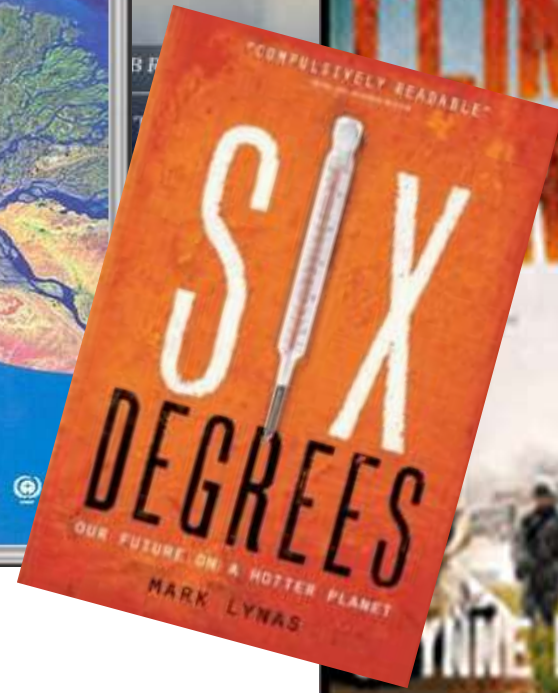
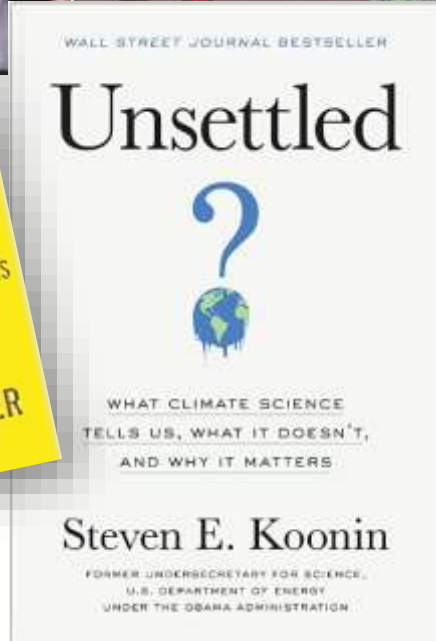
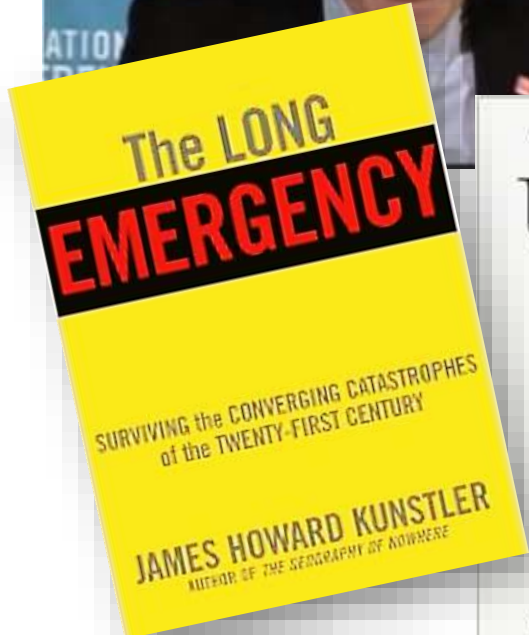
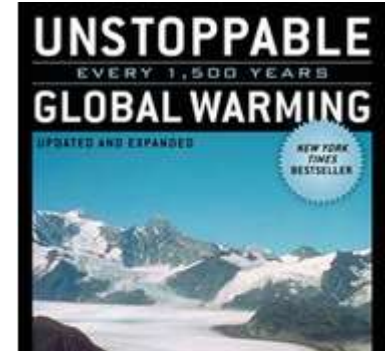
Grand picture Habitat and resource utilization

- Energy concept, human utilization of Energy
- Tools and fuels in human history
- Sustainability of Future Human Activity & Life on Earth
 - Limit to growth, Club of Rome, Socio-economic/ecological network.
- Finite resources: arable land and water for food production, materials for fabrication & construction, fuels for machinery & transportation,
 - Human eco-footprint, choices, and dilemmas,
- Energy utilization and environment,
 - Energy consumption and human development
 - External costs of energy consumption,
 - Correlations energy use with planetary climate, greenhouse effect.

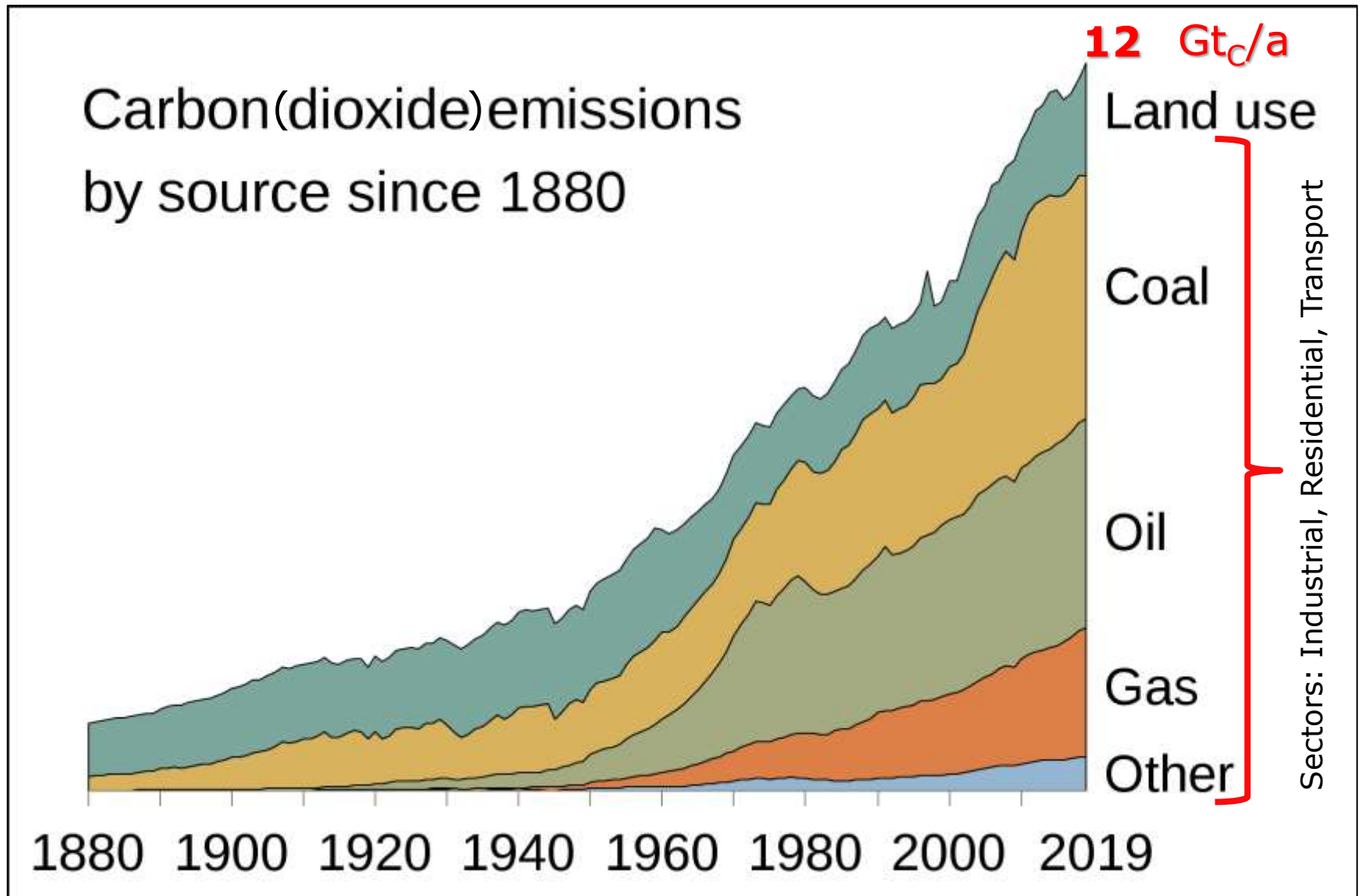


Climate Wars: Apocalypse Soon ?

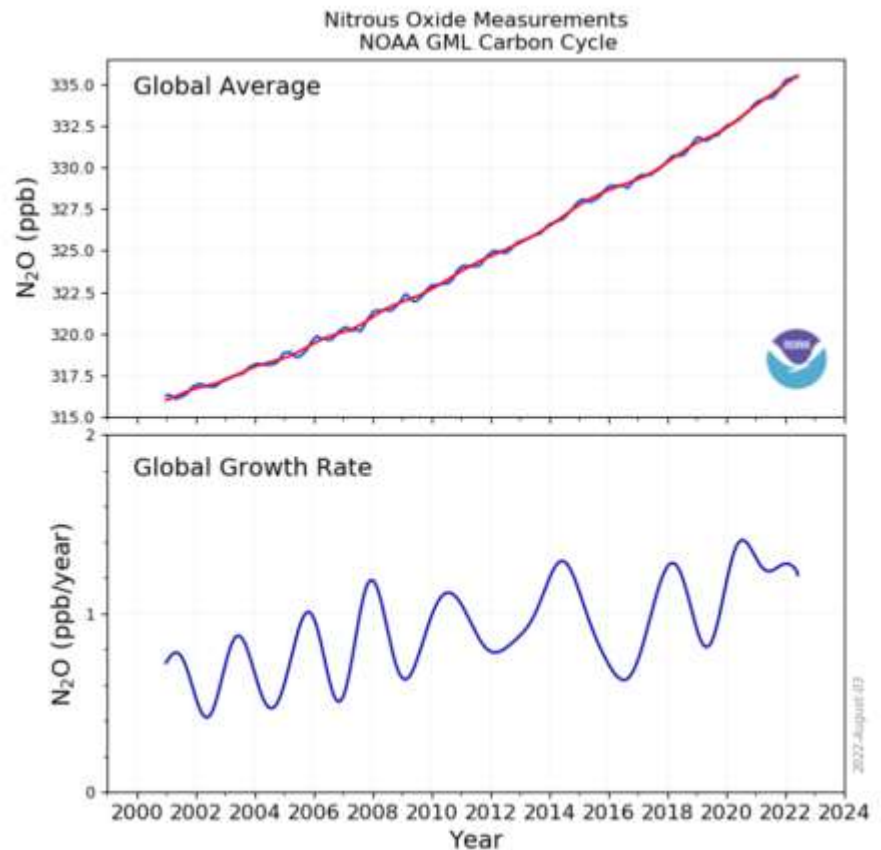
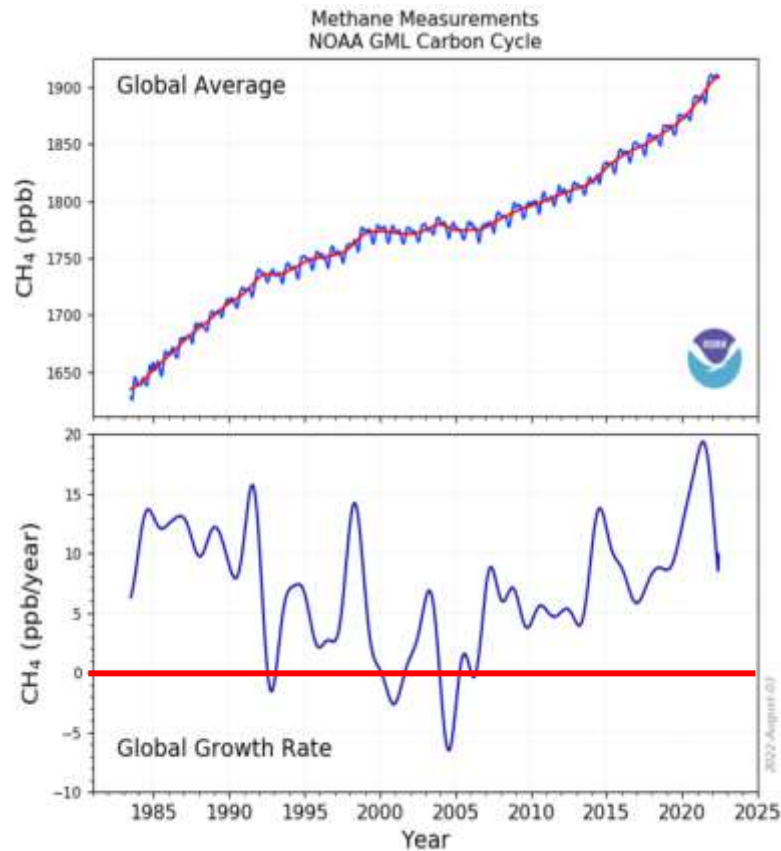
Energy External Cost & Climate 2



Anthropogenic Carbon Emissions 1880-2019 (Est.)

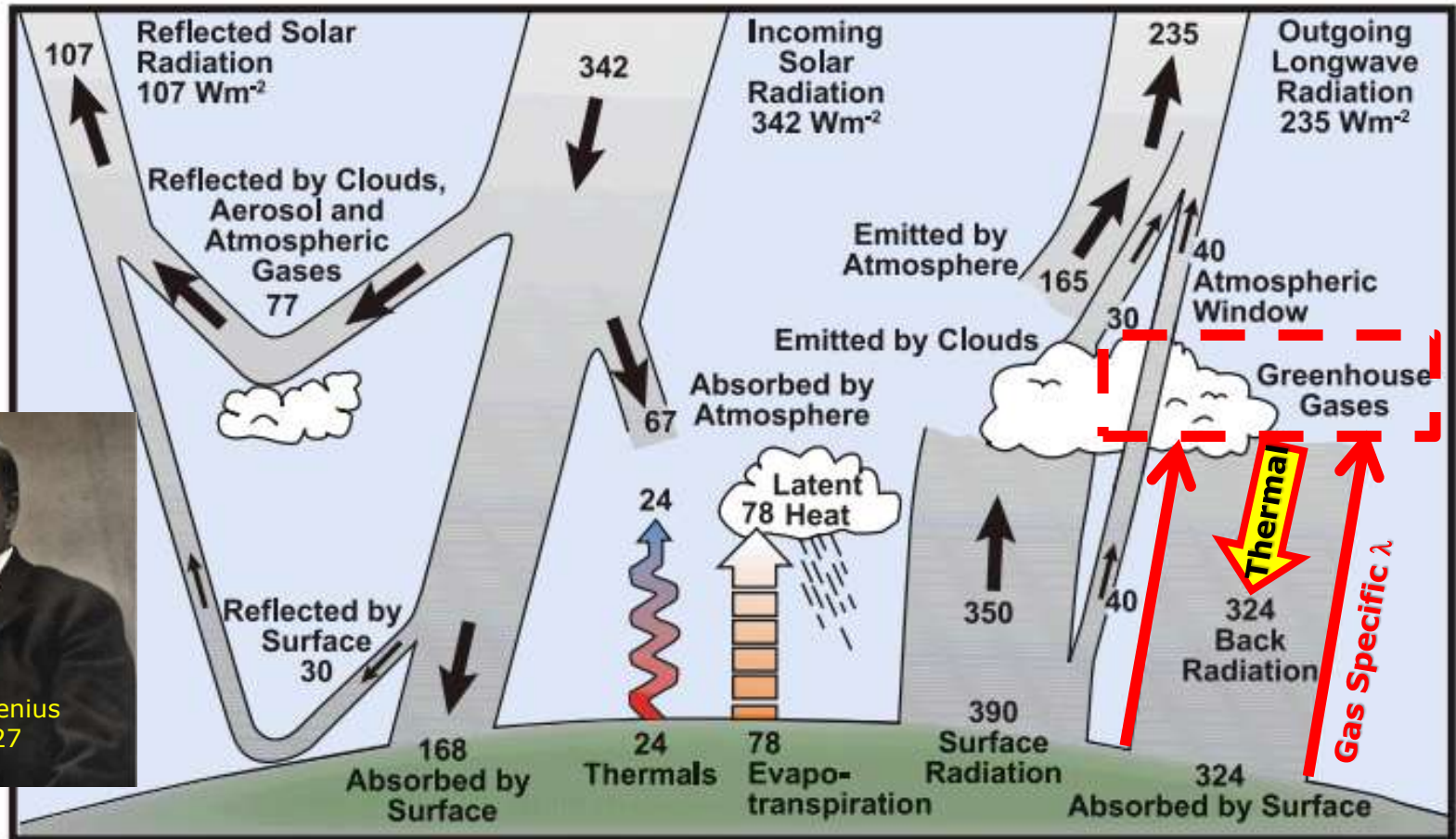


Growth of Other Atmospheric GHG Concentrations



Source: NOAA Carbon Cycle Cooperative Air Sampling Network.

Earth's Radiation Balance (incl. GH Effect)

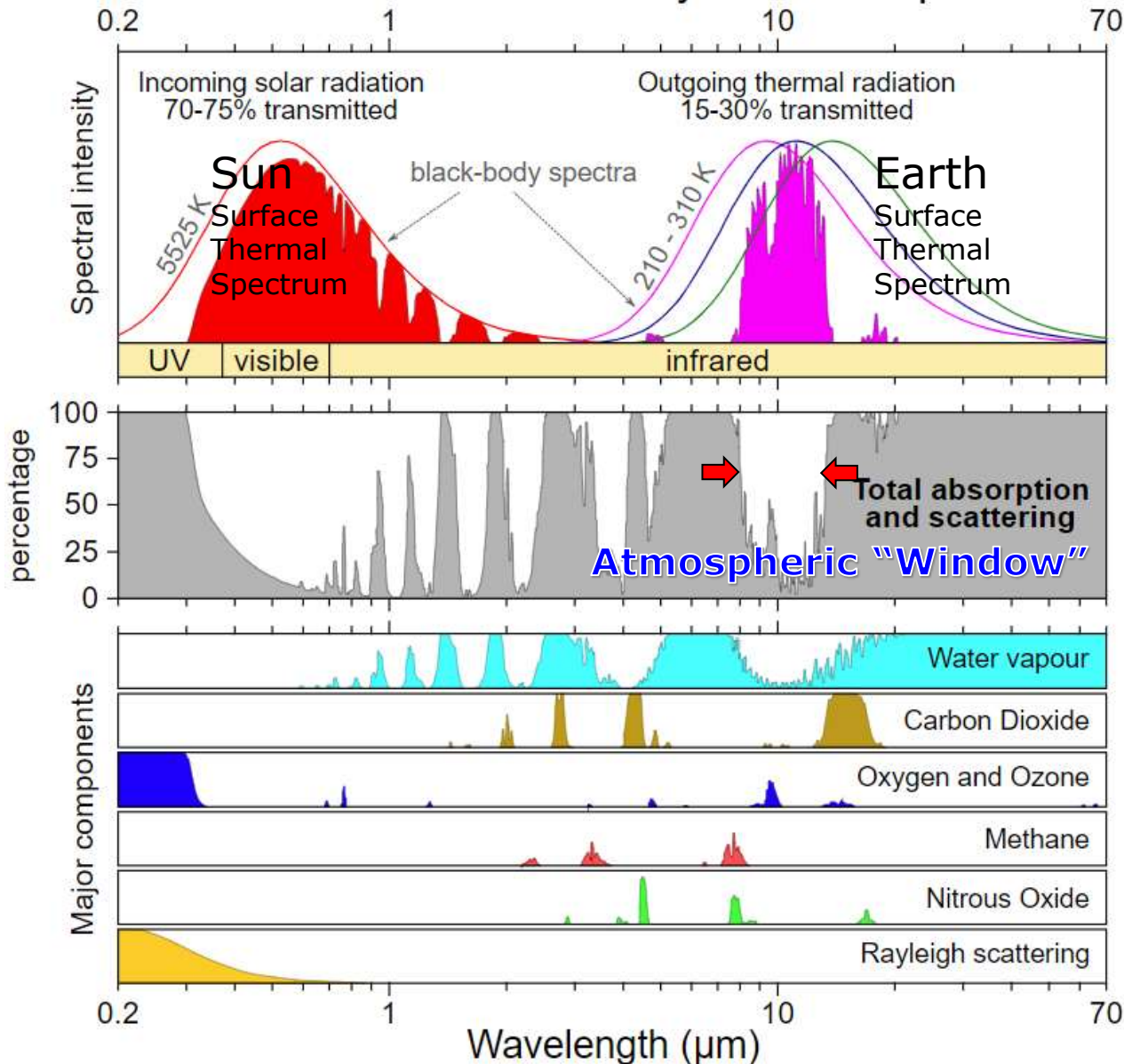


Svante Arrhenius
1859-1927

Modified after IPCC AR4 Report:

<http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter1.pdf>

Radiation Absorbed or Transmitted by Atmosphere



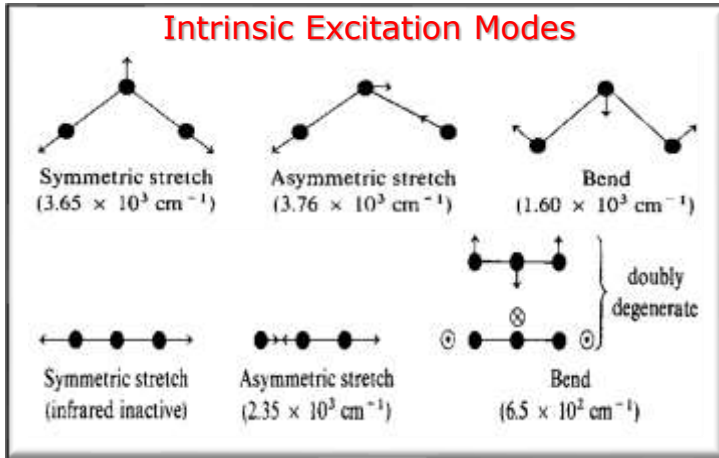
Thermal spectrum of Earth surface peaks around 10-15 μm

Molecules of different atmospheric components have characteristic "fingerprint" quantal absorption patterns.

Surface radiation in **Atmospheric Window** escapes into space and cools Earth.

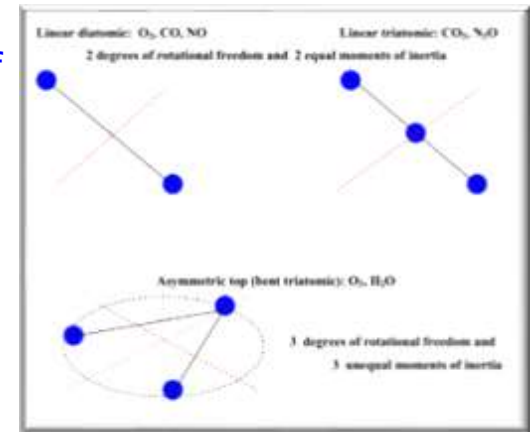
Global temporal Effects? 
 Predicted 1896 Arrhenius

Molecular Emission/Absorption Spectroscopy



Independent degrees of freedom of motion of a 3-atomic molecule:

- 1) translational as whole,
- 2) rotational (diff. axes)
- 3) vibrational (diff. modes)
- 4) Electronic.



$$E = E_{\text{trans}}(\nu) + E_{\text{rot}}(J_i) + E_{\text{vib}}(n) + E_{\text{el}}(\dots)$$

Translation energy E_{trans} has continuous "thermal" spectrum, generated by multiple collisions.

Mean energy about $kT \approx 400 \text{ cm}^{-1}$ ($T = 300 \text{ K}$), infrared (IR)

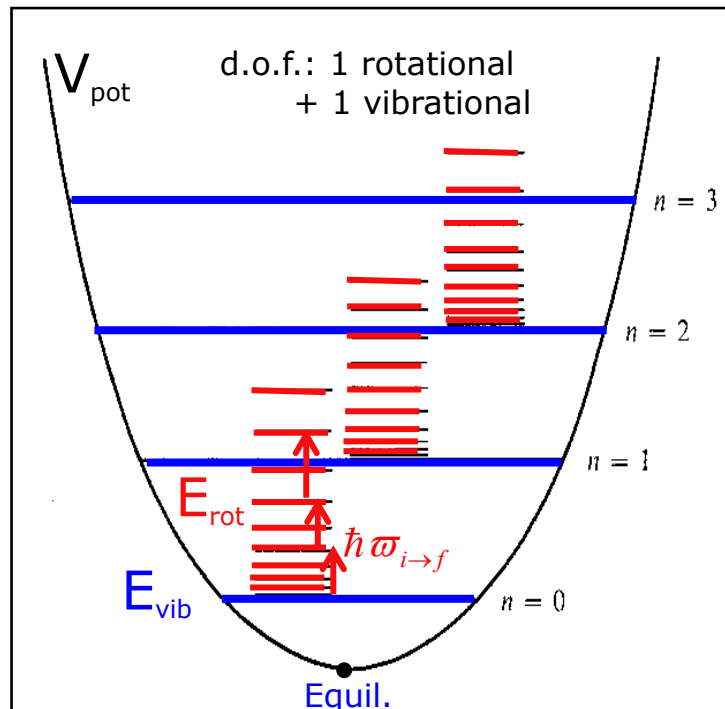
Can absorb or emit any energy amount (E conserved).

Quantized degrees of freedom absorb/emit discrete energy packages $\hbar \omega_{i \rightarrow f} = \pm(E_f - E_i)$

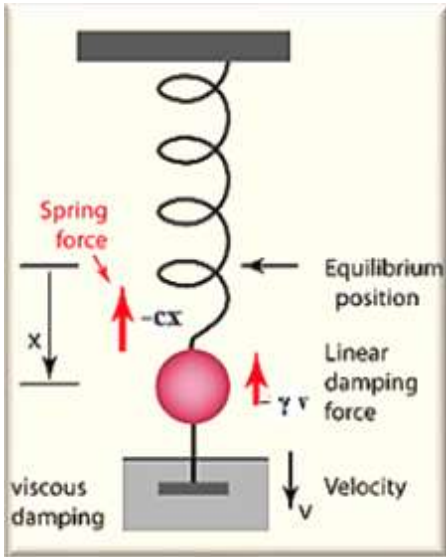
Rotational energy E_{rot} is quantized (line spectrum), typical Energies = $(1-500) \text{ cm}^{-1}$ (far-IR to microwave)

Vibrational energy E_{vib} is quantized (line spectrum): energy of vibrating nuclei about their equilibrium positions; $E \sim (500 \text{ to } 10^4) \text{ cm}^{-1}$ (near-IR to far-IR)

Electronic energy E_{el} is quantized (line spectrum), typical energies $(10^4-10^5) \text{ cm}^{-1}$ (UV and visible).



Energy Transfer via Collisional Relaxation



Internally rot-vib excited di/poly-atomic molecules in atmosphere suffer multiple collisions with other particles in random (thermal) motion, which act as a "viscous heat bath."

Energy is transferred back and forth between all (f) degrees of freedom, until equi-partition

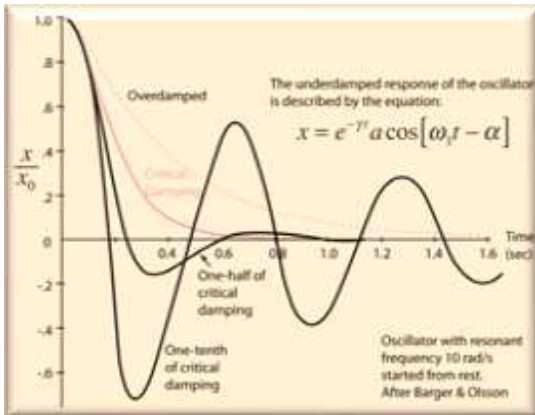
$$\langle E_i \rangle_{eq} = \frac{1}{2} k \cdot T \quad (i=1,2,\dots,f)$$

3D translational motion $\langle E \rangle_{eq} = \langle E_x \rangle_{eq} + \langle E_y \rangle_{eq} + \langle E_z \rangle_{eq} = 3 \cdot \frac{1}{2} k \cdot T$

Consequently: for damped oscillation of mass m on a spring

Undamped: $x_{free}(t) = x(t=0) \cdot \cos(\omega \cdot t) \quad \omega = \sqrt{c/m}$

Damping coefficient $\gamma \rightarrow x_{damped}(t) = x(t=0) \cdot e^{-\gamma t} \cdot \cos(\omega \cdot t)$



Energy ($E(t) \sim x(t)^2$) transfer to bath particles and back until equilibrium is attained (bath heats up).

$$\frac{d}{dt} \langle E_{damped} \rangle = [\langle E_{damped} \rangle - E] / \tau_{relax} \quad , \text{ with } \tau_{relax} \propto \tau_{coll}$$

collision time $\tau_{coll} = \text{function}(\text{density}, T)$

$$\tau_{coll} = \frac{\text{mean free path } \lambda}{\text{mean thermal speed}} \approx \left(\frac{5 \cdot 10^{-3} \text{ cm}}{p / \text{Torr}} \right) \sqrt{\frac{m}{8\pi kT}} \sim 10^{-10} \text{ s}$$

Fast relaxation/attainment of equilibrium

Internal molecular energy dissipated quickly and heats surrounding gas @ equilibrium



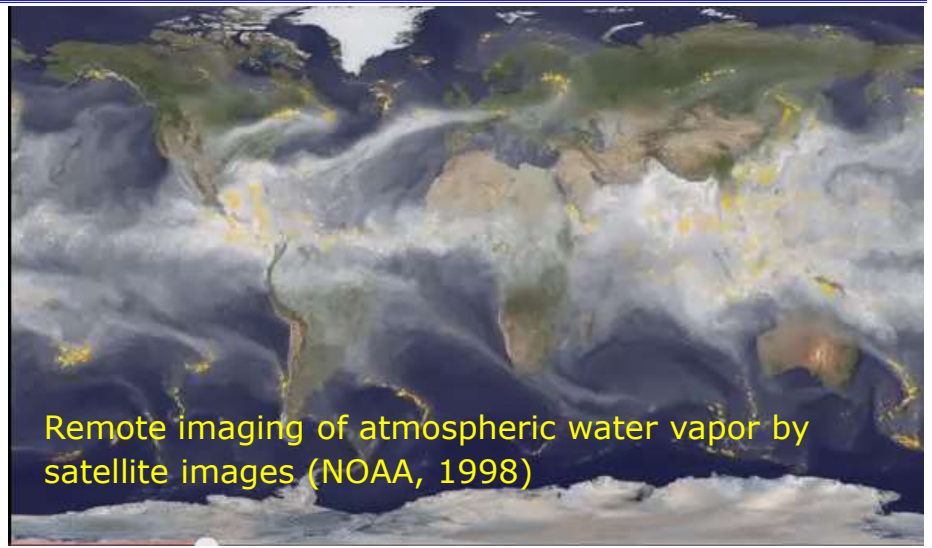
Big Data: Weather & Climate Information Sources

9

ESTS E & Climate



One of many weather stations (Albany) of US Network.



Remote imaging of atmospheric water vapor by satellite images (NOAA, 1998)

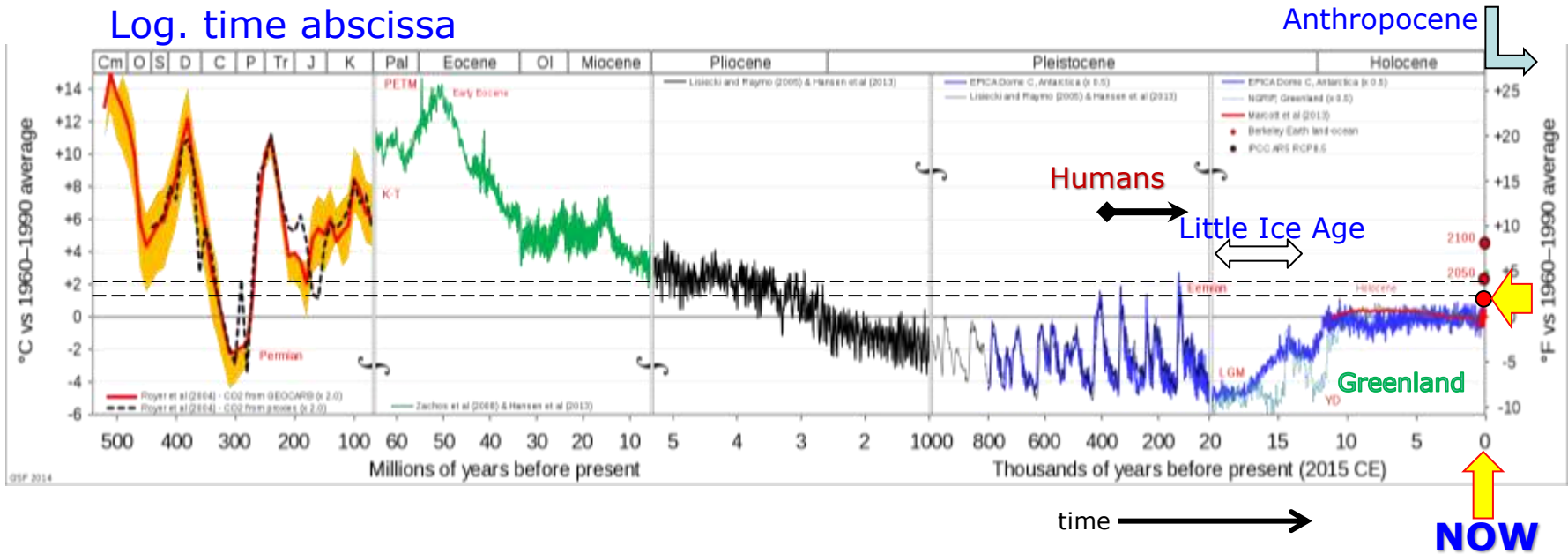


Ice cores stored in the U.S. Geological Survey National Ice Core Lab (NAS 2010)

Accurate current observations and systematic studies and modeling global historic climate trends are provided by:
Excellent weather/climate information provided by several national/international agencies (NOAA) + Research efforts in Nat'l Labs/Univ. → systematic climate evaluation and projection →

1. U.S. *Historical Climatology Network* (USHCN): 1221 US stations .
2. NOAA/NASA/ESA/EUMETSAT satellites.
3. National ice core lab for paleo climatology: air bubbles in Greenland or Antarctic ice cores, tree rings, coral reefs, historical records → atmospheric composition, isotope ratios, → temperature
4. Sediments, geological labs.

Context Paleo-Climature: Global Surface Temps



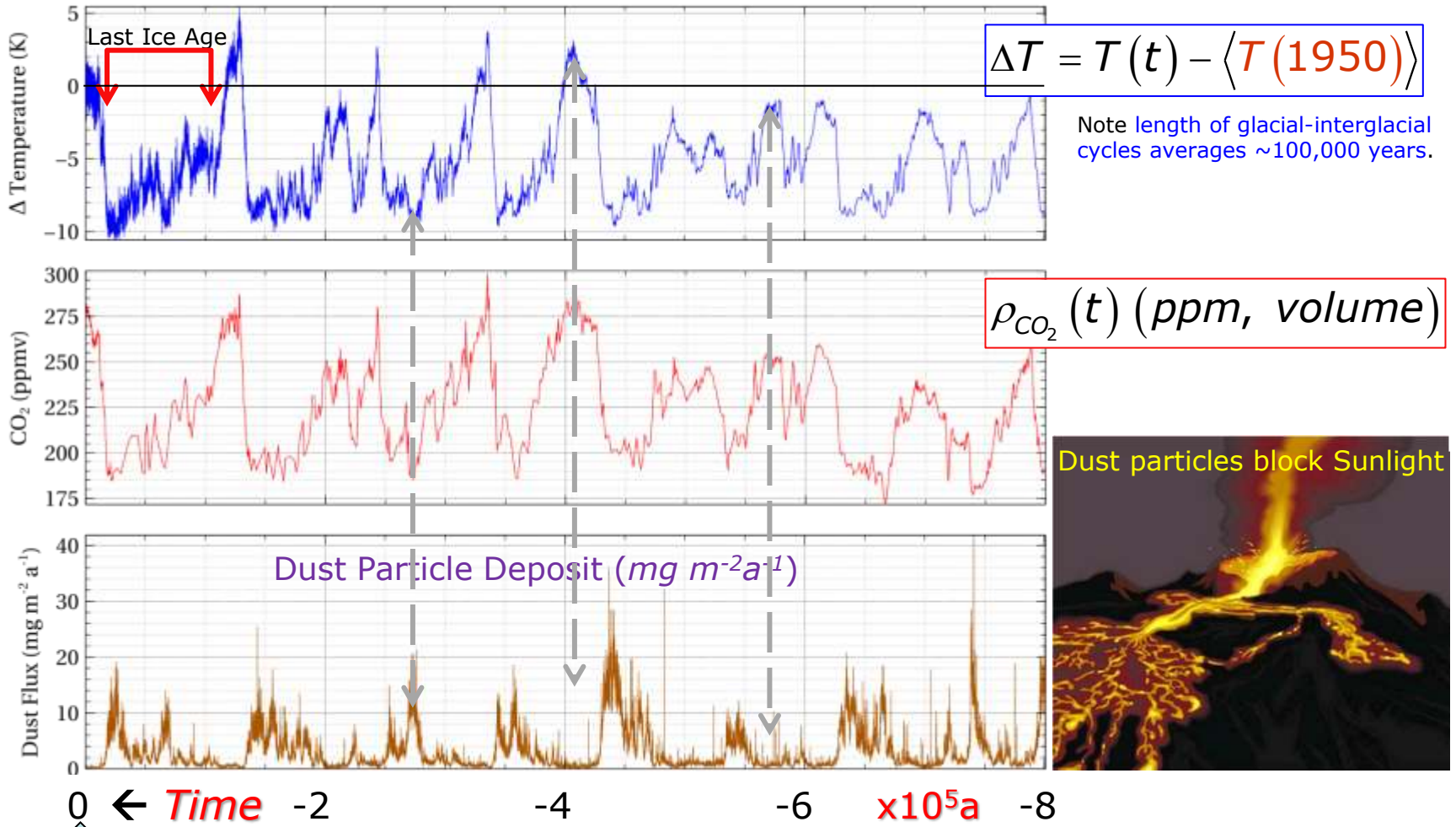
Holocene epoch = unusably and consistently stable, warm period following the last Ice Age in which we live today. Current temps like those of 100,000 years ago (or 3-5 M years ago).

Recent uptick in Mean Global temperatures → for $\Delta T > 5^{\circ}\text{C}$ maybe we are leaving the stable **T** regime → back to $< -4\text{Ma}$?

Cited by S.E. Koonin, Glen Fergus: data sources are cited below, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=31736468>
https://en.wikipedia.org/wiki/Paleoclimatology#/media/File:All_palaeotemps.svg/

Paleo-Climate Correlated Trends: Global Surface Temps

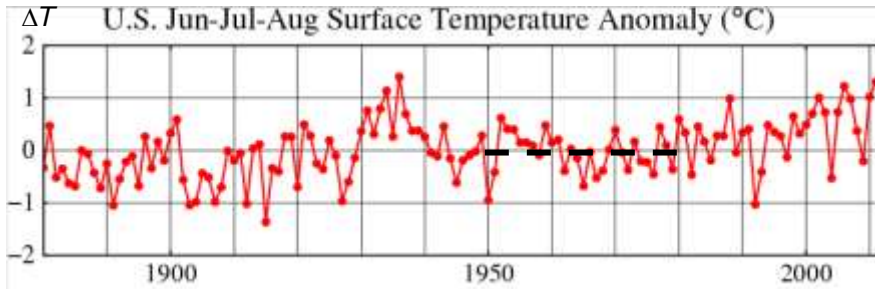
Ice core data for past 800,000 years (x-axis values represent age before 1950)



ΔT correlates with $[CO_2]$ & anticorrelates with atmospheric dust.
Independent corroborating data on T-dependent C, O isotopic ratios.

Current Evidence: Systematically Changing Climate

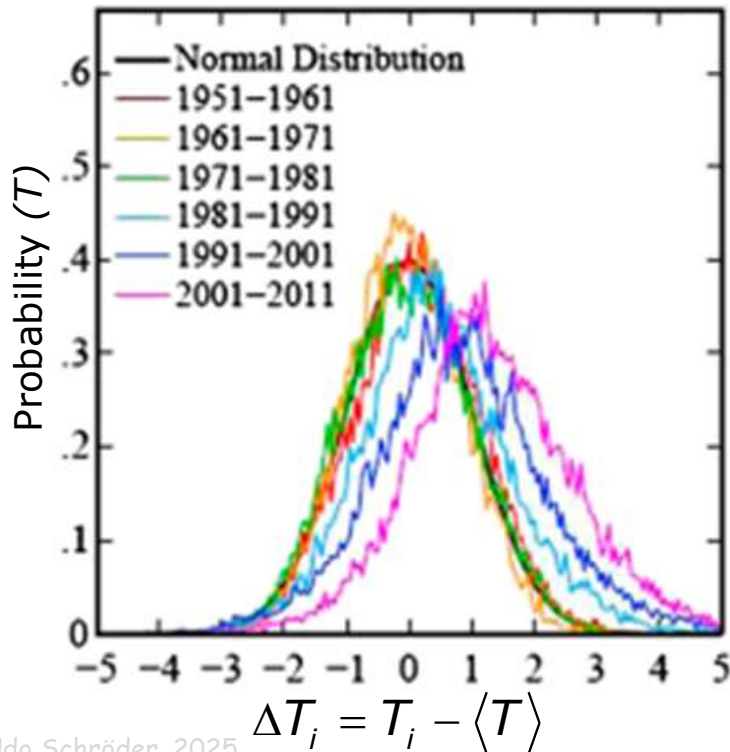
NH Land Surface Temperatures Jun-Aug



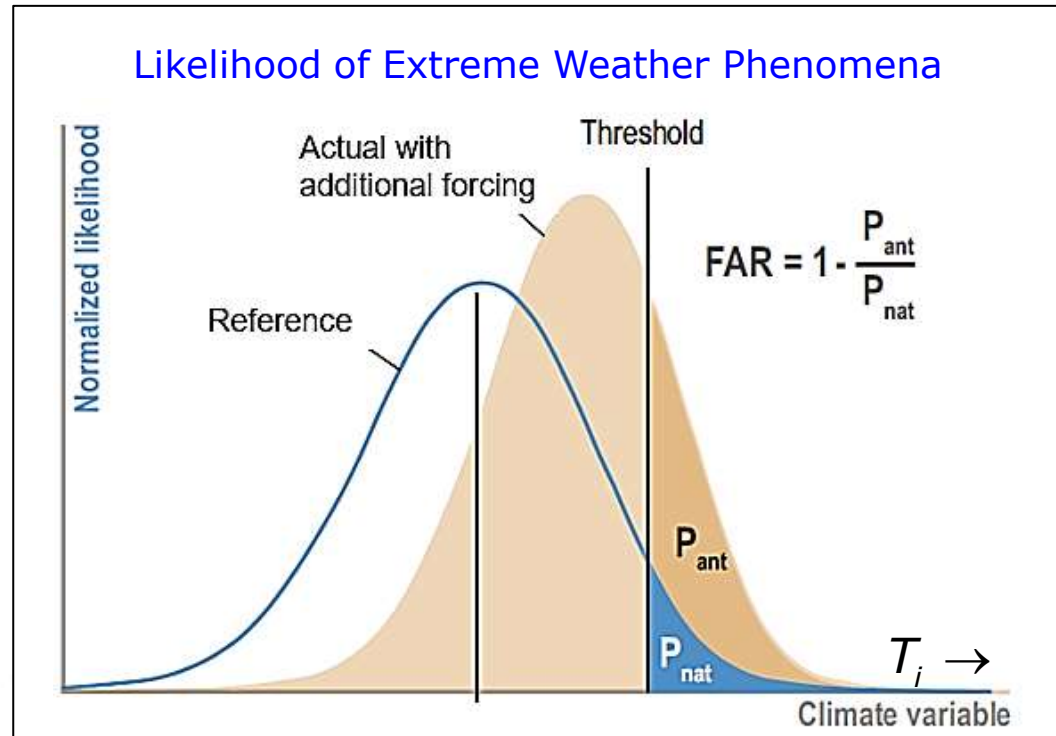
US: World's most extensive weather and climate records publicly available.

2012 statistical study of changing temperature patterns: Report *Perception of climate change* by James Hansen et al., (NASA Goddard Institute for Space Studies & Columbia University Earth Institute)

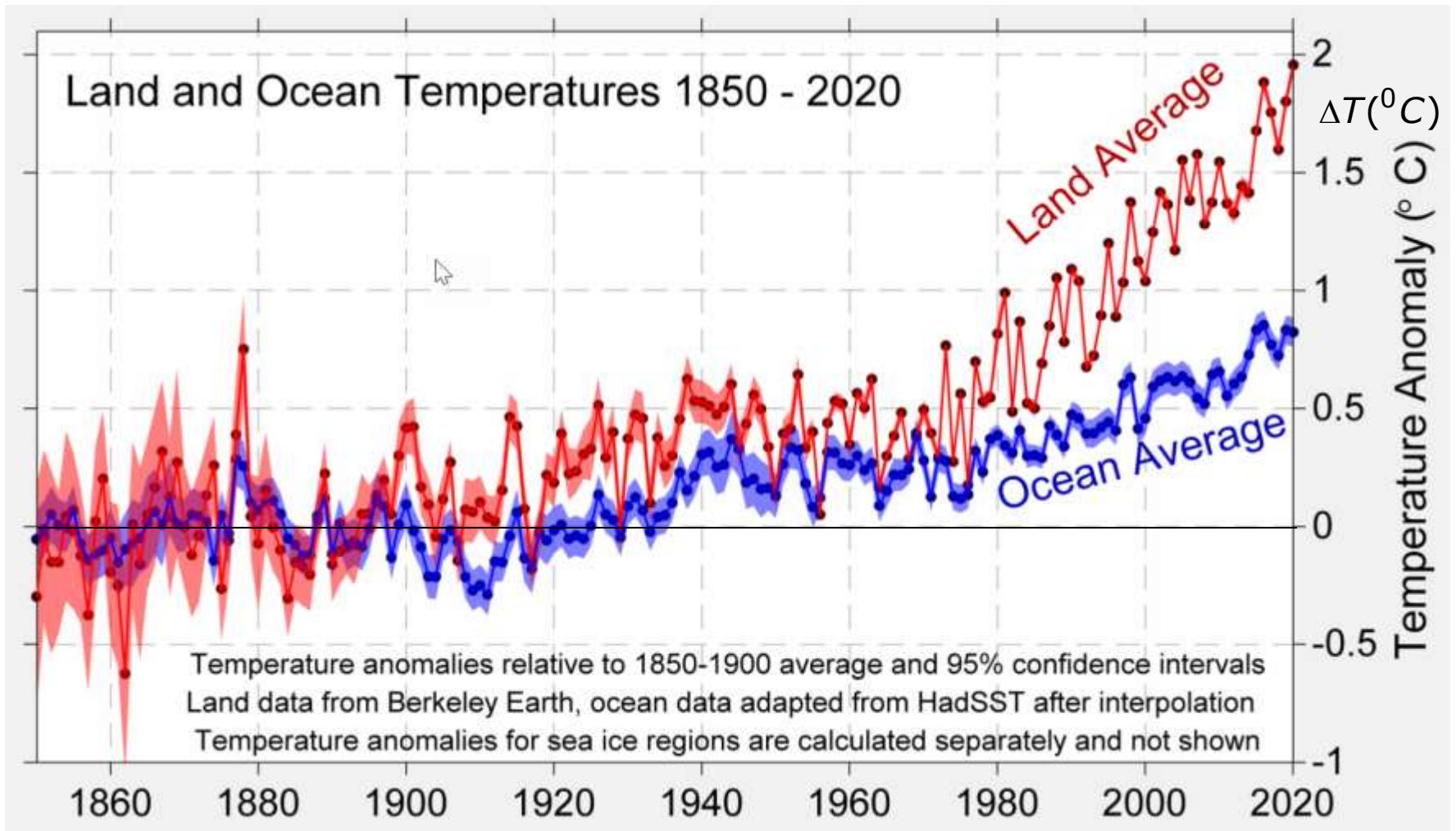
Reference 1951-1980



Likelihood of Extreme Weather Phenomena

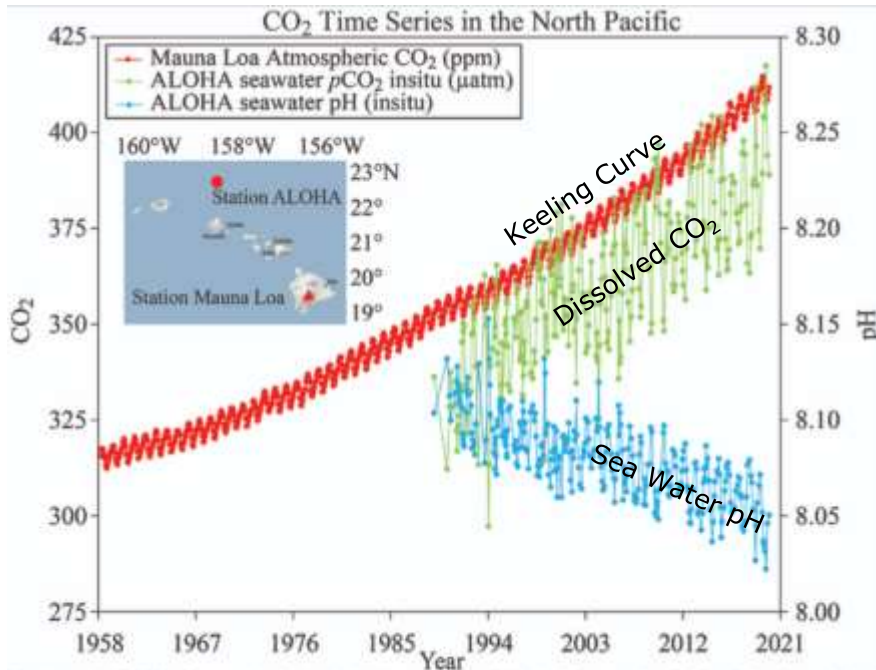
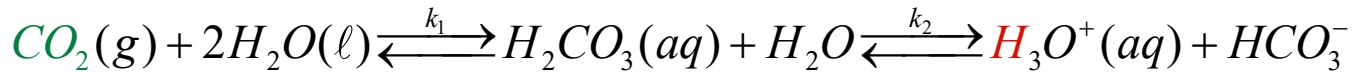


Mean Land and Ocean Temperature Trends



<http://berkeleyearth.org/global-temperature-report-for-2020/>

Atmospheric-Aqueous CO₂ Equilibrium and Consequences



<https://www.pmel.noaa.gov/co2/file/Hawaii+Carbon+Dioxide+Time-Series>

Shells Dissolve in Acidified Ocean Water



$$\text{Henry's Law } p_{CO_2} = k_H(T) \cdot [CO_2]$$

Increasing atmospheric concentration of CO₂ → increasing CO₂ solvation in sea water → decreasing pH value (increasing [H⁺]=[H₃O⁺], complex set of rxns)

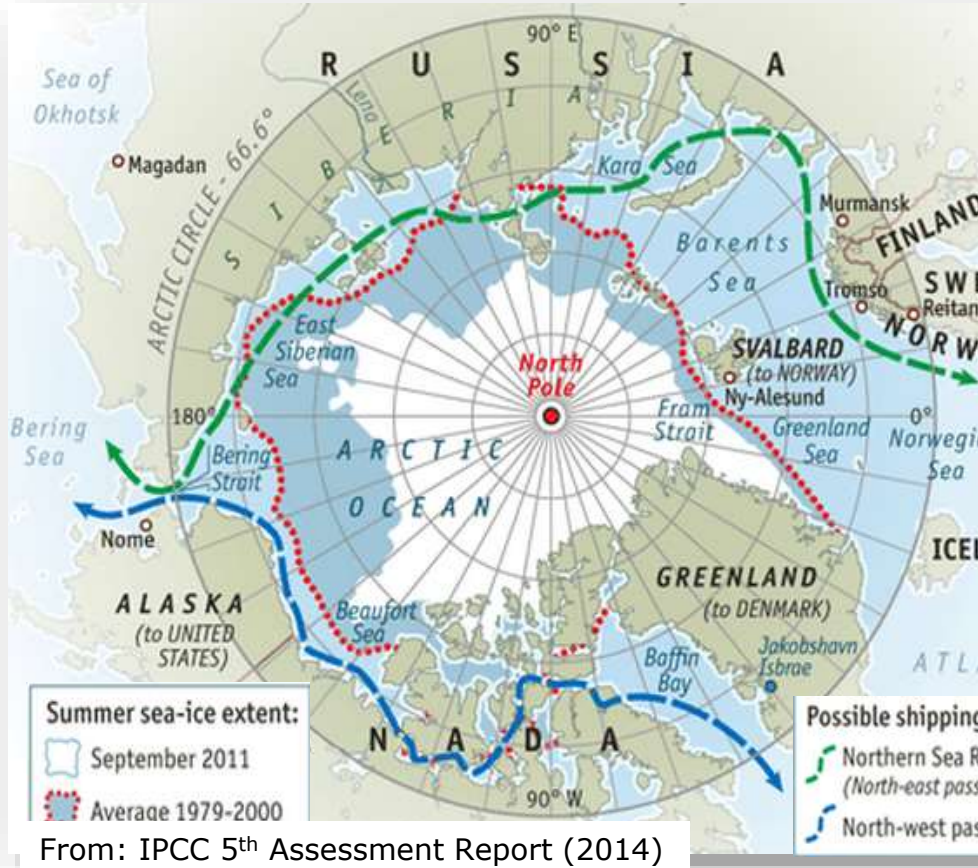
NCADAC Report 2013

Consequences of ocean acidity

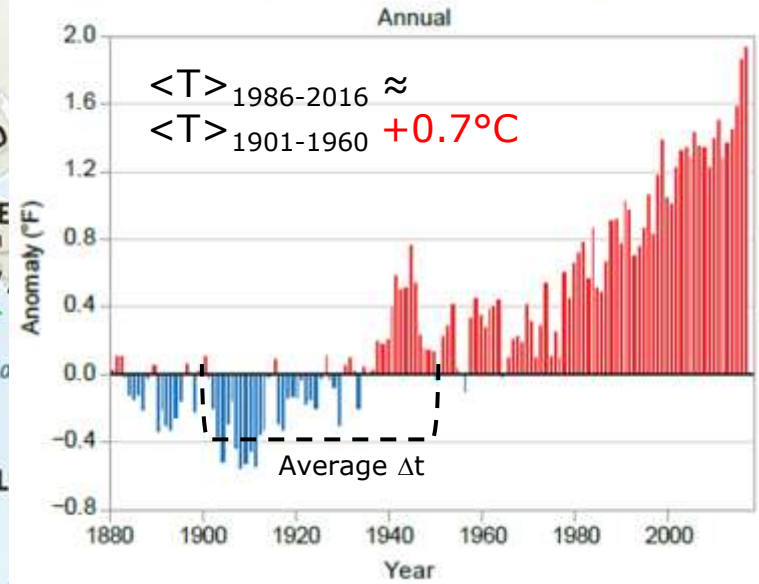
Bleaching of corals,
Dissolution of shells of marine animals
Example: Pteropod, "sea butterfly":
Tiny sea creature (size of pea).
Pteropods = food for marine species from krill to whales, major food for North Pacific salmon.
Shell slowly dissolves after 45 days.

(Photo credit: National Geographic Images)

Evidence for Current Large-Scale Changes



Global Land and Ocean Temperature Anomalies



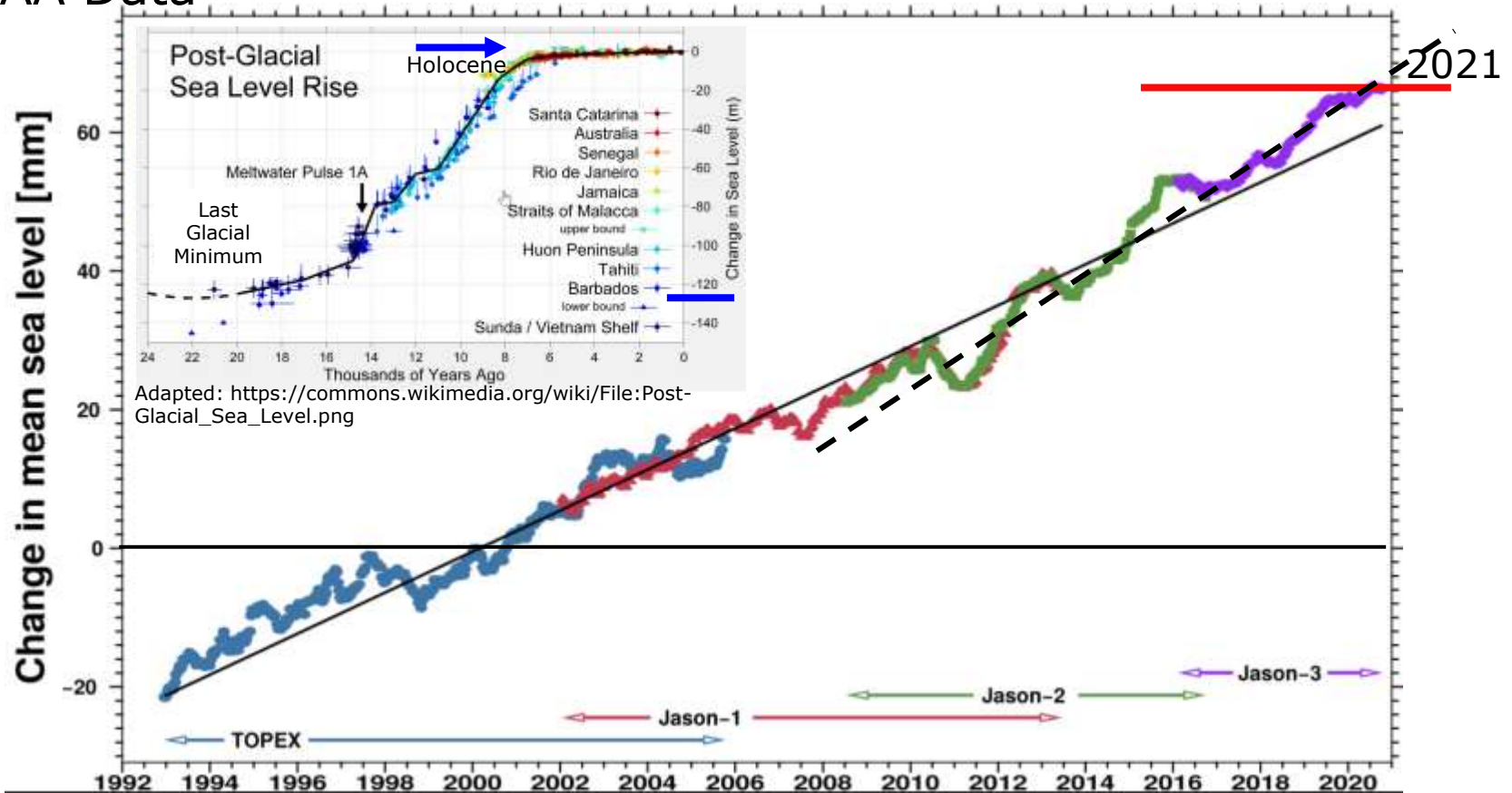
**Important Question:
 Natural vs. man-made
 →
 Economic Implications**

Greenland surface ice layer melts within 4 days: July 8–July 12, 2011
 NASA/NOAA satellite image.



Recent and Ancient Sea Level Trends

NOAA Data



2021: $\Delta h = +67$ mm since 1850, mean rate: (3.0 ± 0.4) mm/a, slightly increasing. Seasonal cycle ($\Delta H = \pm 7$ mm) is superimposed on general trend. Comparison (inset) sea levels since last glacial minimum (-125 m !), now probably in pre-glacial rise (uncertainty $\Delta H = \pm 10$ m), modified by anthropogenic influences.

Ominous Correlation: Temperature vs. Atmospheric CO₂



Dips in the observed historic temperature pattern **match in time of occurrence and amplitude** the emissions of known explosive volcanic eruptions.

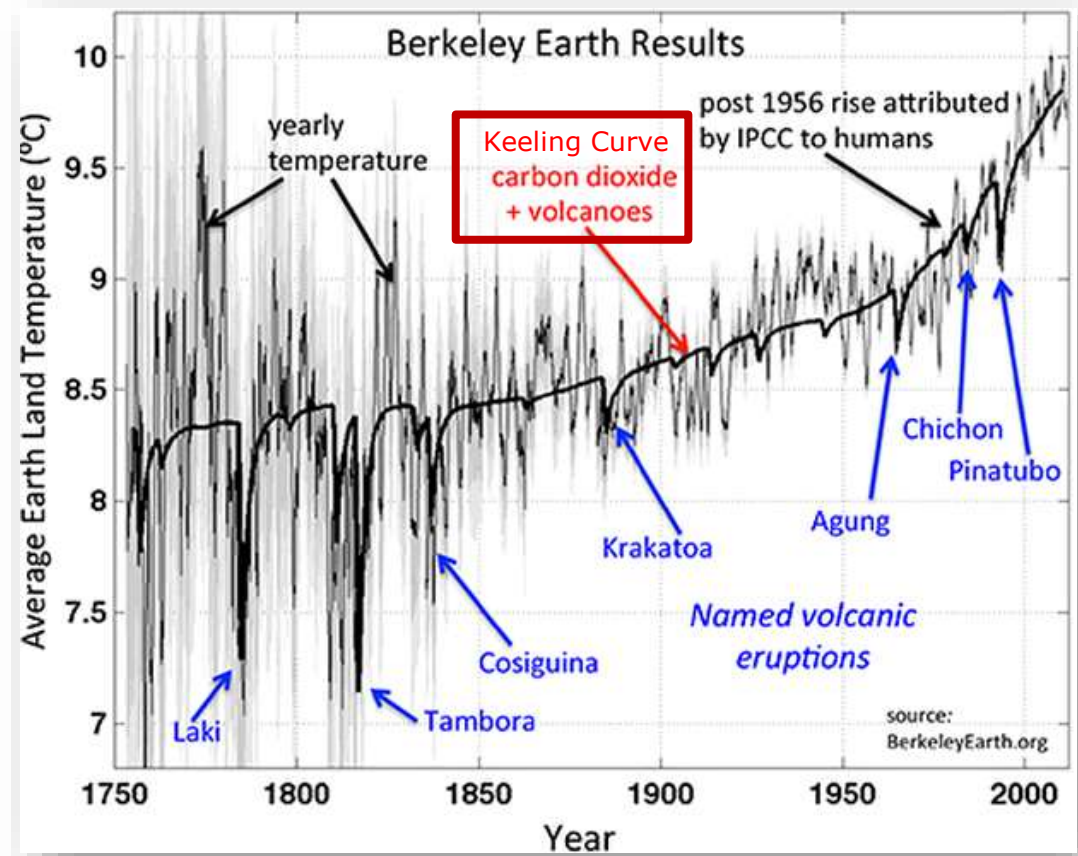
Particulate clouds from volcanic events reflect sunlight and cool the Earth's surface for a few years.

Small rapid variations are attributable to El Nino and other ocean currents such as the Gulf Stream.

(From [BerkeleyEarth Project](http://BerkeleyEarth.org).)

Systematic gradual rise of $\Delta T = 1.5^{\circ}\text{C}$ correlates with experimental record of atmospheric CO₂, as measured from atmospheric samples and air trapped in polar ice.

Solar variation does not seem to impact the mean temperature trend.
(Berkeley Earth Surface Temperature study, 2012)



What is Human role in T increase?