Feedbacks: Cloud, water vapor, ice albedo, other

12.340 Global Warming Science
April 12, 2012
Dan Cziczo

Reading: IPCC 2007 2.4
(www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-4.html)

Hansen et al. 2005, Dessler et al. 2008 (posted)

Today's Class

- Forcing vs. Feedback
- Recap aerosols / The indirect effects
- Water vapor / surface evaporation
- Other feedbacks (biogeochemical)
- Aside: Cosmic rays and climate

Forcing vs. Feeback

Climate Forcing : Intergovernmental Panel on Climate Change: influence that a climatic factor (e.g. increase in CO_2) has in altering the balance energy in the Earth system.

Generally the balance is at the surface of the troposphere/stratosphere boundary.

Positive forcing tends to warm the surface while *negative forcing* tends to cool it. Forcing values are expressed in watts per square meter (W / m^2).

IPCC and <http://www.eoearth.org/article/Radiative_forcing?topic=49491>

Examples of Forcing:

- Changing solar constant
- Orbital forcing
- Changing concentrations of non-interactive greenhouse gases
- Volcanic aerosols
- Manmade aerosols
- Land use changes

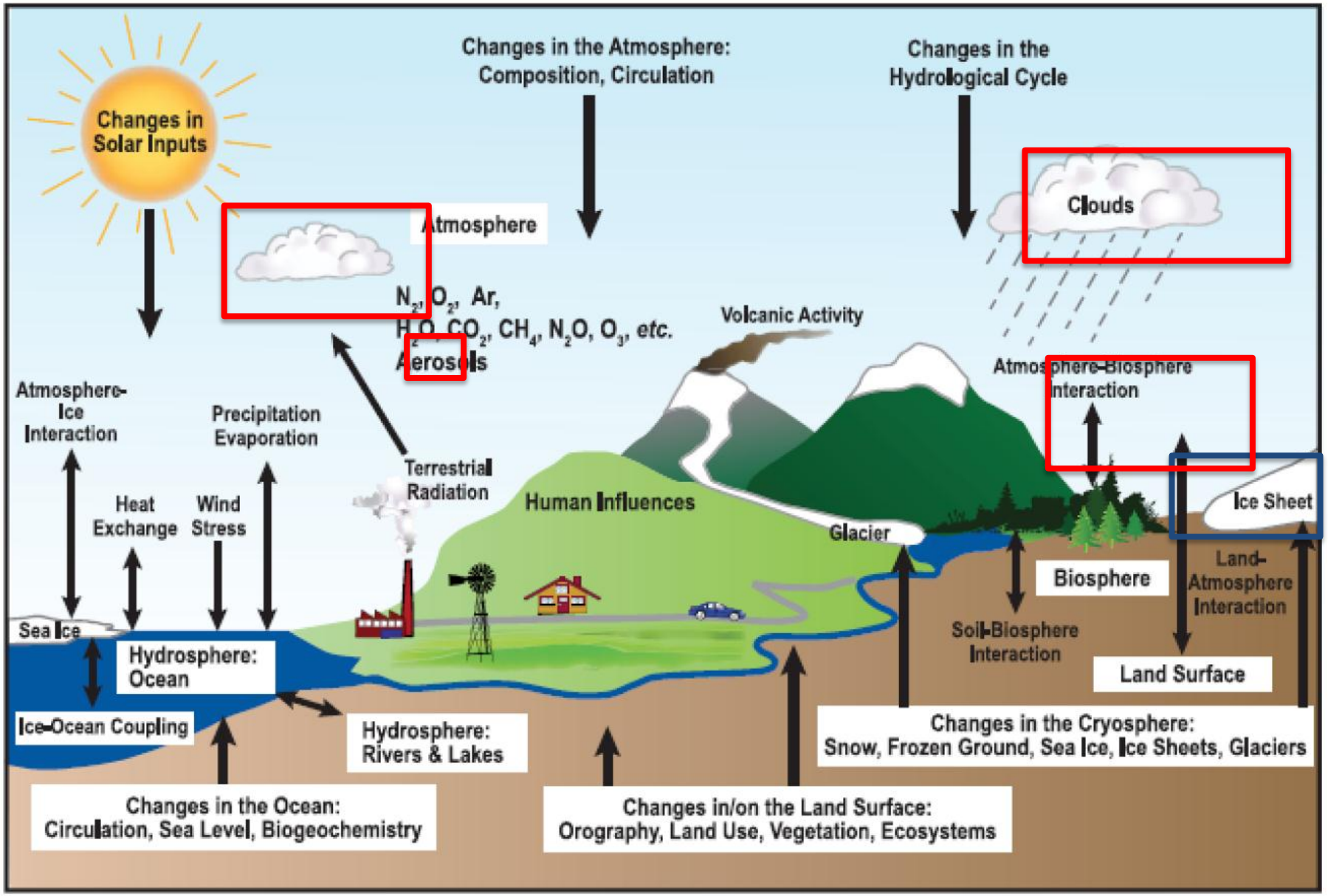
Forcing vs. Feeback

Climate Feedback (aka indirect effects, aka non-initial effects): An atmospheric, oceanic, terrestrial, or other process that is initiated by direct climate change. Climate feedbacks may increase (positive feedback) or diminish (negative feedback) the magnitude of the direct climate change.

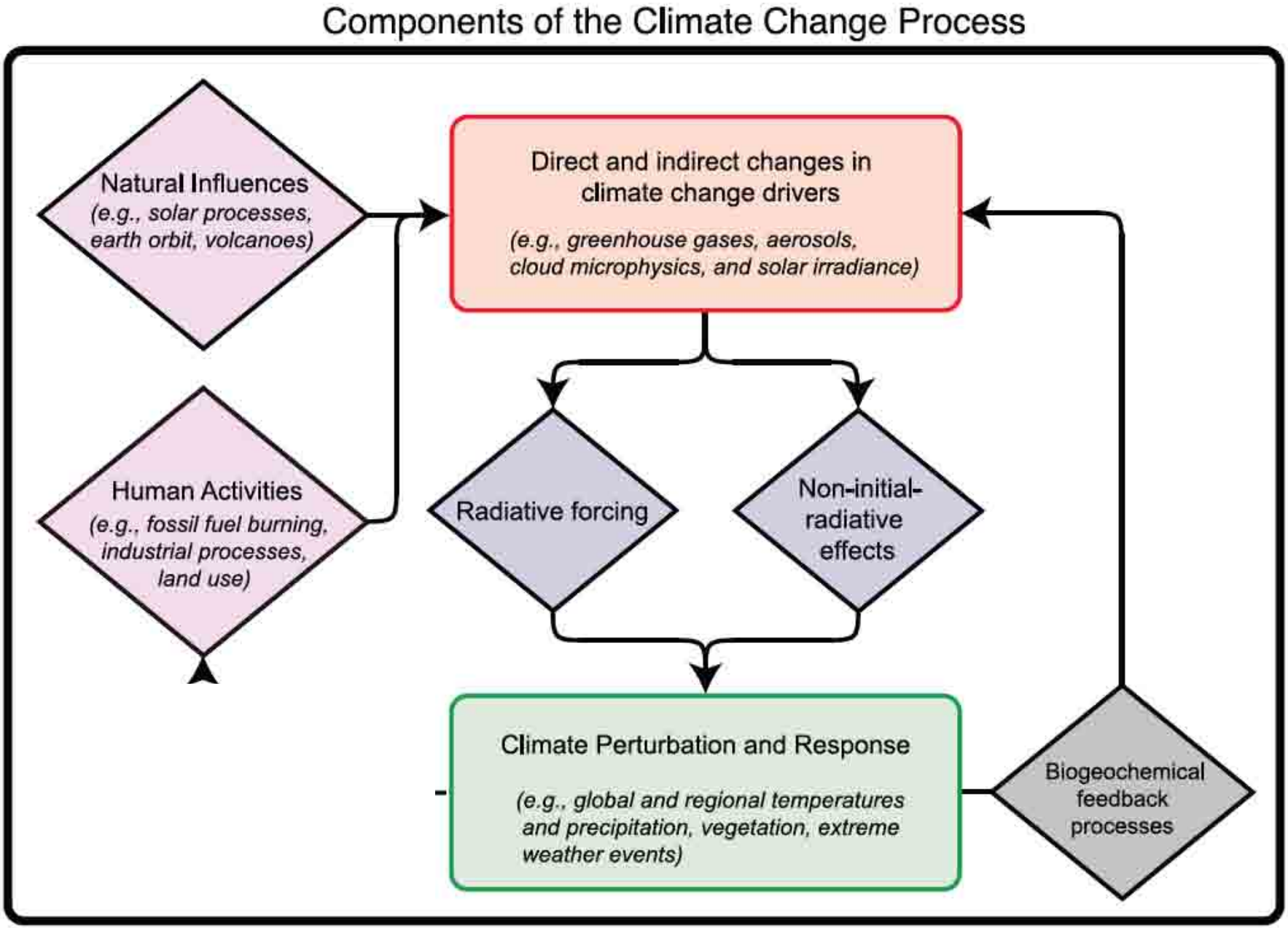
Examples of Feedbacks:

- Water vapor
- Ice-albedo
- Clouds
- Surface evaporation
- Biogeochemical feedbacks

Forcings and Feedbacks in the Climate System



Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, FAQ 1.2, Figure 1. Cambridge University Press. Used with permission.



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IPCC 2007

Aerosol Recap

Natural	Estimated Flux Tg/Yr
Biological debris	50
Mineral Dust	1500
Organic aerosol from biogenic VOC	11.2
Seasalt	10,000
Sulfates from DMS	12.4
Sulfates from Volcanic SO_2	20
Volcanic Dust	30

Aerosol Recap

Anthropgenic	Estimated Flux Tg/Yr
Black carbon	12
Industrial dust (except black carbon)	100
Nitrates from NOx	21
Organic aerosol	81
Sulfates from SO_2	49

Image by MIT OpenCourseWare.

This is the FORCING – the "DIRECT Effect"

Archer Fig. 11.6

Cloud Changes – The Indirect Effect

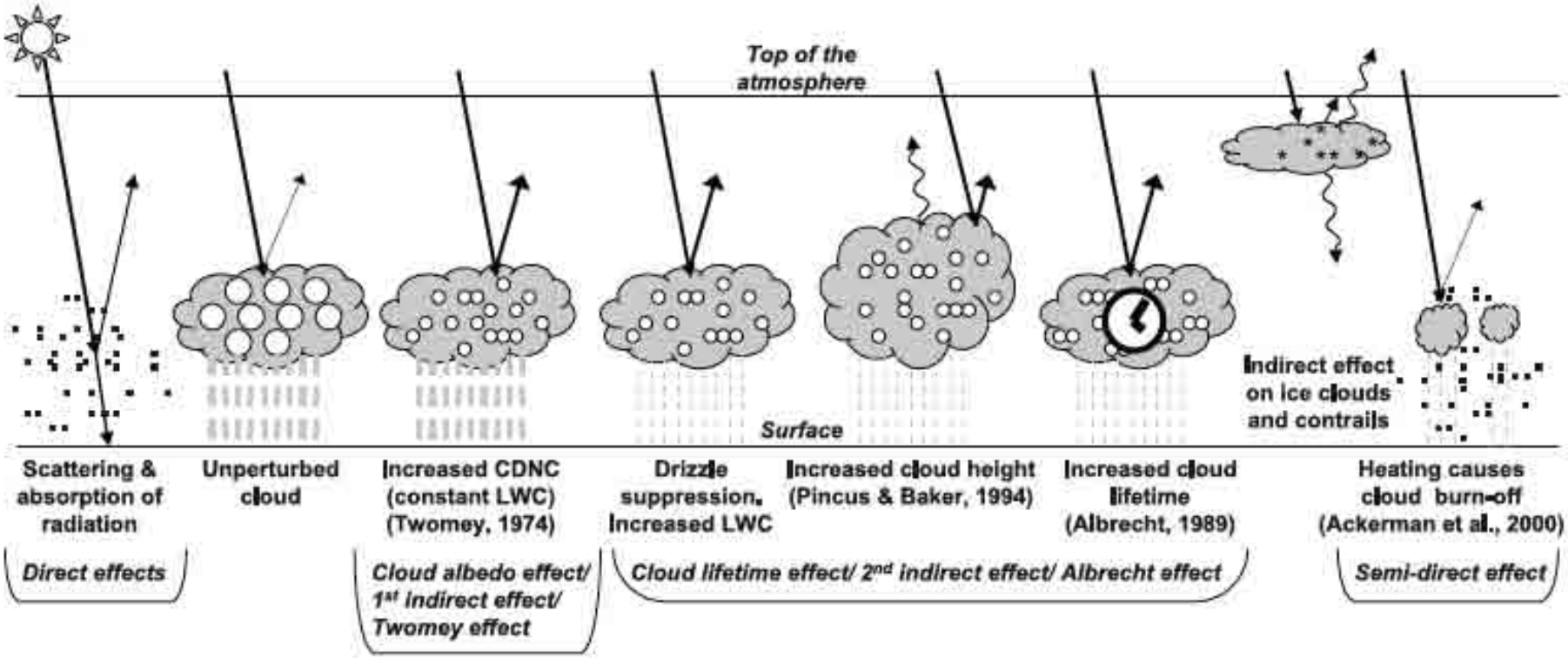

Figure 2.10. *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

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IPCC 2007

More on Warm Clouds

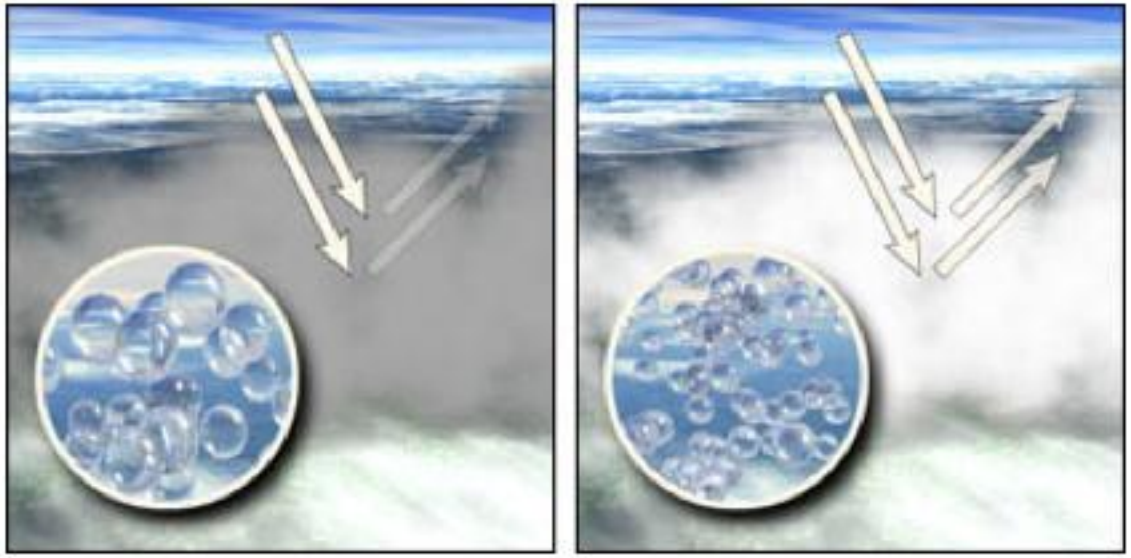


Image courtesy of NASA.

Figure 2a. (left) Clouds with low aerosol concentration and a few large droplets do not scatter light well, and allow much of the Sun's light to pass through and reach the surface.
Figure 2b. (right) The high aerosol concentrations in these clouds provide the nucleation points necessary for the formation of many small liquid water droplets. Up to 90% of visible radiation (light) is reflected back to space by such clouds without reaching Earth's surface.

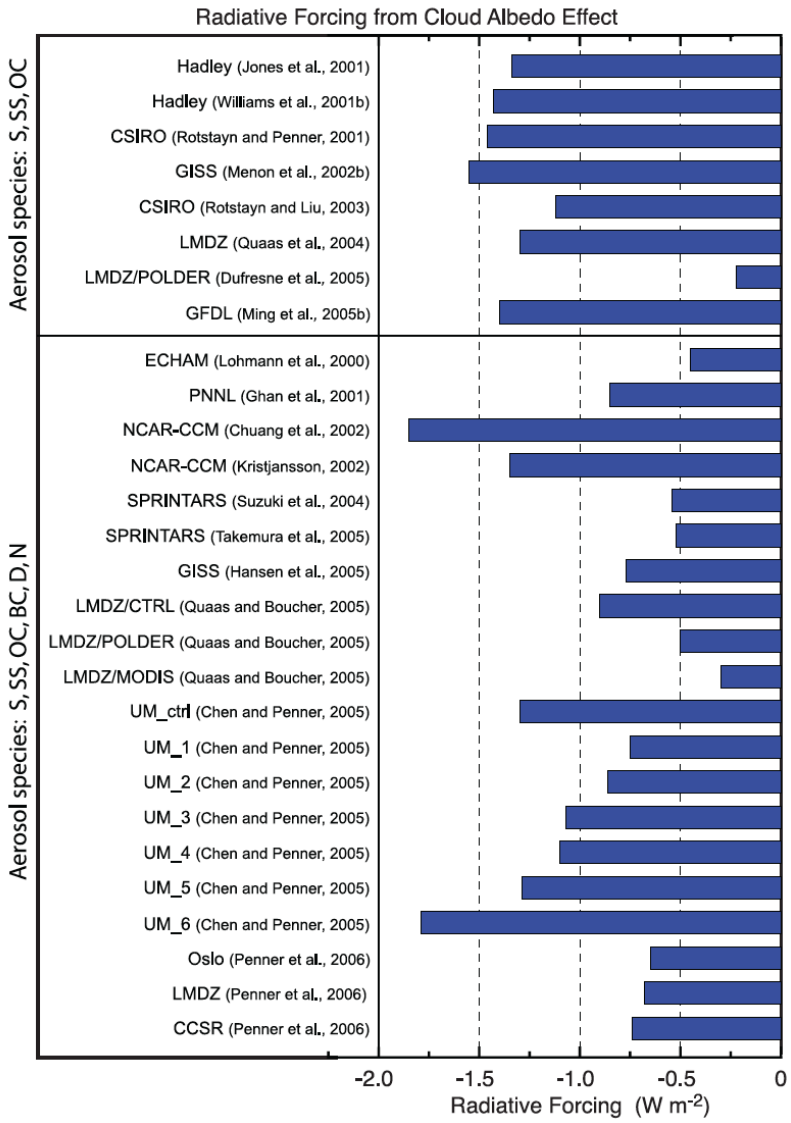
http://earthobservatory.nasa.gov/Features/Aerosols/

More on Cold Clouds

This image has been removed due to copyright restrictions. Please see the figure in Lohmann, G. *Geophysical Research Letters* (2002).

Lohmann, GRL, 2002

Cloud Changes



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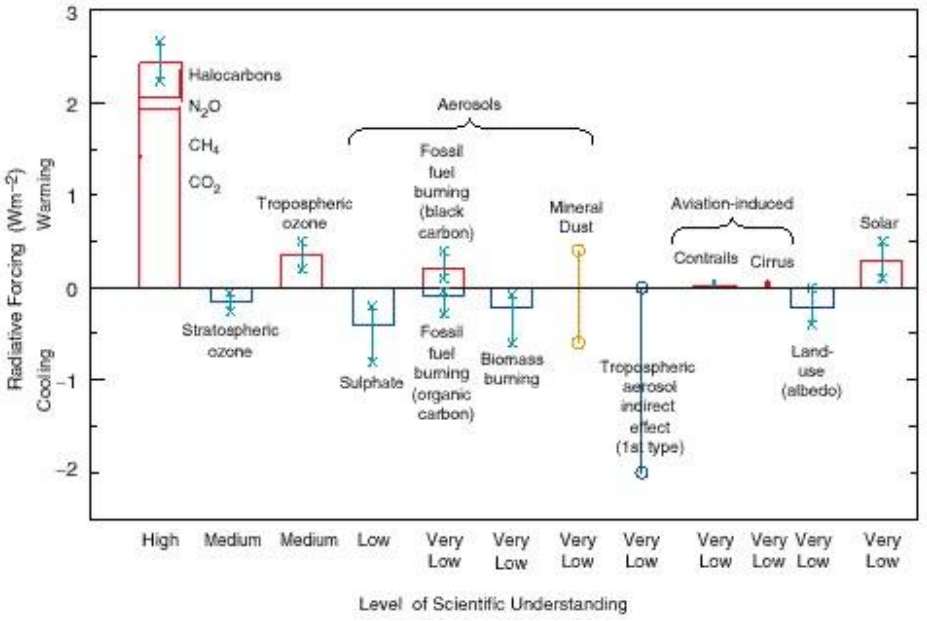
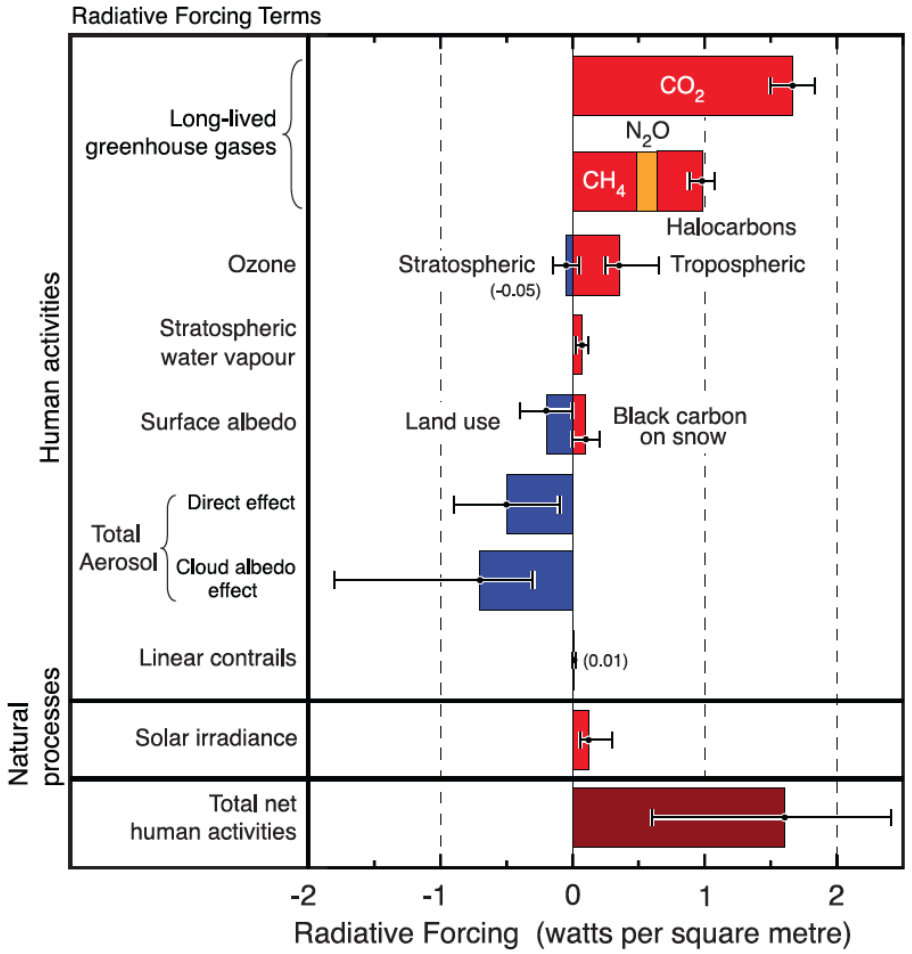
IPCC

Better Estimates?





Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Figure 6.6 and FAQ 2.1, Figure 2. Cambridge University Press. Used with permission.

IPCC 2001

IPCC 2007

Snow/Ice Feedbacks

Typically thought of as : Higher T → higher melt rate, more rain than snow → lower albedo

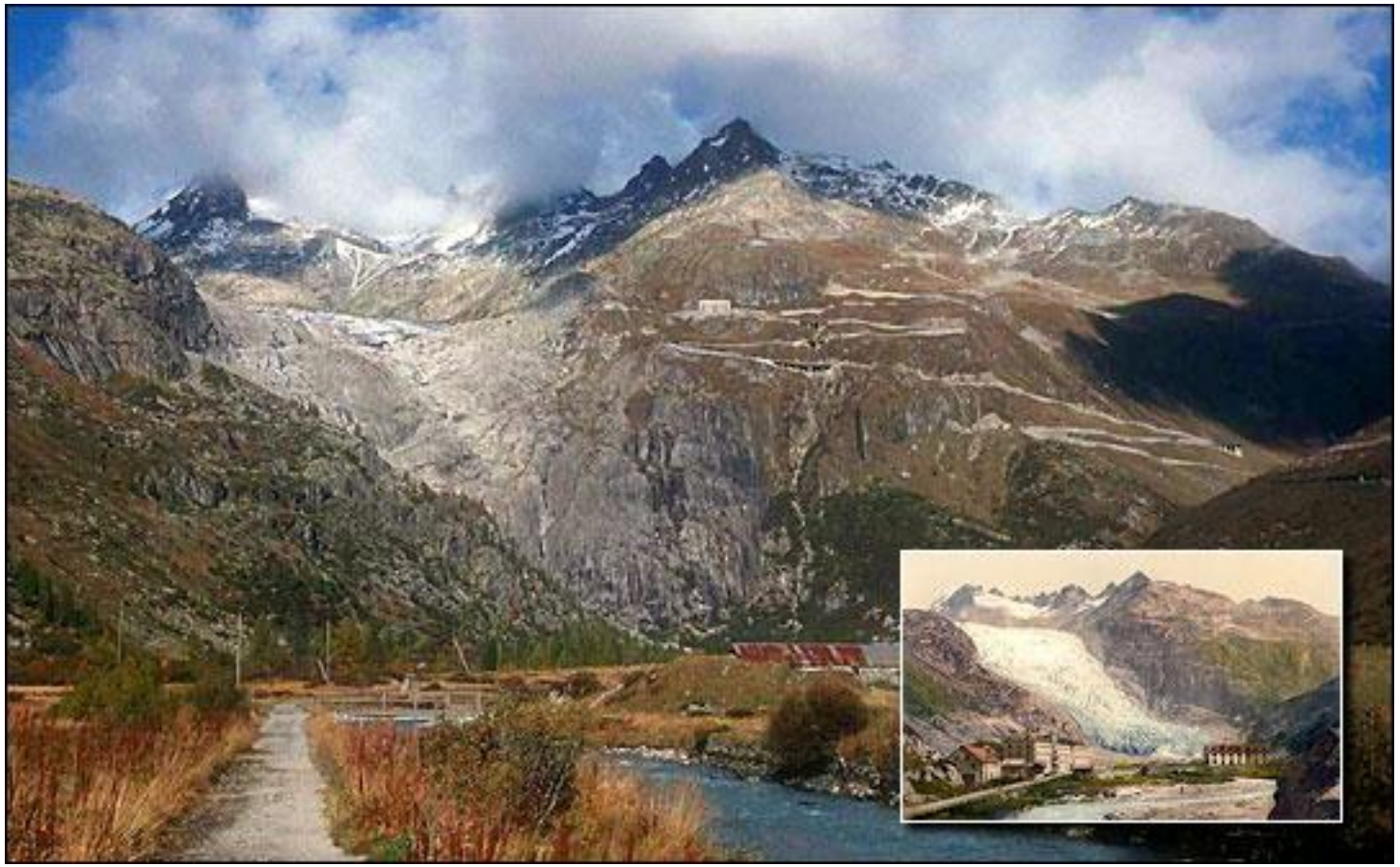


Image courtesy of NASA.

IPCC : +0.25 W m^{-2} feedback due to 1° C T rise (recall : 2x CO_2 = *4* Wm^{-2} = 1° C)

http://earthobservatory.nasa.gov

Snow/Ice Feedbacks

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But also via 'dirtying' of snow and ice by aerosol:

IPCC report best estimate for the BC on snow RF of +0.10 (± 0.10) W m^{-2}, with a *low level* of scientific understanding

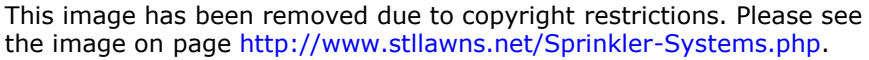
This image has been removed due to copyright restrictions. Please see the image on page http://www.treehugger.com/clean-technology/dirty-snow-just-as-bad-as-greenhouse-gases.html.

Water Vapor

• Anthropogenic water : ~1% of natural sources of water vapor (~3/4 agriculture)

• IPCC: change in the water vapor in The troposphere of 1% is +0.03 W m^{-2}.

• At surface temperature change was negative due to evaporative cooling.



Water Vapor / Evaporation

- The larger issue is the higher amount of water vapor in the atmosphere due to the higher temperature.

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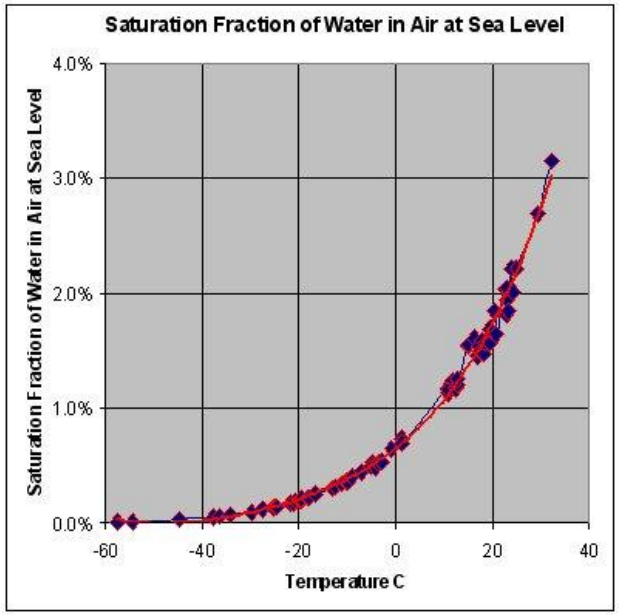

Image courtesy of NOAA.

+1° C = +2 W m^{-2} *high* estimate (Dessler et al. 2008) → no cloud effect

GEOPHYSICAL RESEARCH LETTERS, VOL. 35, L20704, doi:10.1029/2008GL035333, 2008

Click Here Full Article

Water-vapor climate feedback inferred from climate fluctuations, 2003–2008

A. E. Dessler,[1] Z. Zhang,[1] and P. Yang[1]

"Understanding Our Atmospheric Environment", Neiburger et al.
"Meteorology Today", Ahrens
http://epsc.wustl.edu/courses/epsc105a/, W. H. Smith

and NOAA database

Other Feedbacks

- Increased surface albedo in winter and spring (cooling) and evaporation in summer and in the tropics (warming) net - 0.01°C (Zhao et al., 2001) to -0.25°C (Govindasamy et al., 2001a; Brovkin et al., 2006) (paraphrased from IPCC)

- "Increasing concentrations of atmospheric CO_2 can perturb the climate system through direct effects on plant physiology."

- "Increased CO_2 concentrations can also 'fertilize' plants by stimulating photosynthesis, which models suggest has contributed to increased vegetation cover and leaf area over the 20th century (Cramer et al., 2001)." – various sources estimate a 20-40% increase in growth rate (species dependent at 2x CO_2

"The RF due to this (these) process(es) has (have) not been evaluated and there is a very low scientific understanding of these effects."

Other FOOD for Thought…

The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Blodiversity

Agriculture

Lead Author: J.L. HatfieId, USDA ARS

Contributing Authors:
Cropland Respose; K.J. Boote, B.A. Kimball, D.W. Wolfe, D.R. Ort
Postureland: R.C. Izaurralde, A.M. Thomson
Rangeland: J.A. Morgan, H.W. Polley P.A. Fay
Animal Management: T.L. Mader, G.L. Hahn

Grain Yield

Crop	Temperature (12°C)	CO_2 (380 to 440 ppm)	Temp/ CO_2 Combined Irrigated
	% Change		
Corn - Midwest (22.5°C)	-4.0	+1.0	-3.0
Corn - South (26.7°C)	-4.0	+1.0	-3.0
Soybean - Midwest (22.5°C)	+2.5	+7.4	+9.9
Soybean - South (26.7°C)	-3.5	+7.4	+3.9
Wheat - plains (19.5°C)	-6.7	+6.8	+0.1
Rice - South (26.7°C)	-12.0	+6.4	-5.6
Sorghum (full range)	-9.4	+1.0	-8.4
Cotton - South (26.7°C)	-5.7	+9.2	+3.5
Peanut - South (26.7°C)	-5.4	+6.7	+1.3
Bean - relative to 23°C	-8.6	+6.1	-2.5

Image by MIT OpenCourseWare.

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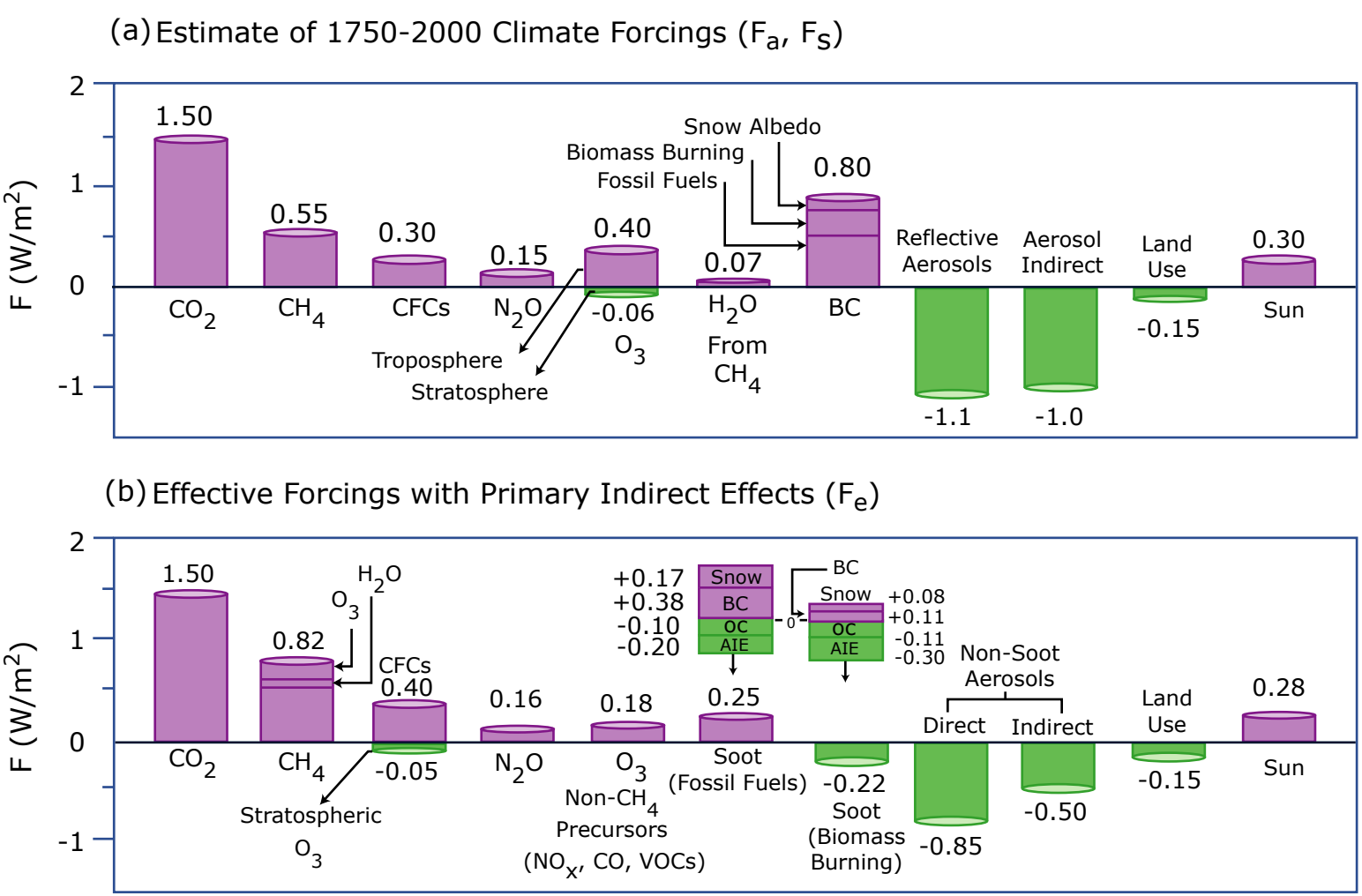
Logan et al. JGR 2009 (similar work by Solomon et al., others) : Increase in area burned of +50% in 2050 in US, +75-175% in the Pacific Northwest and Rocky Mountains.

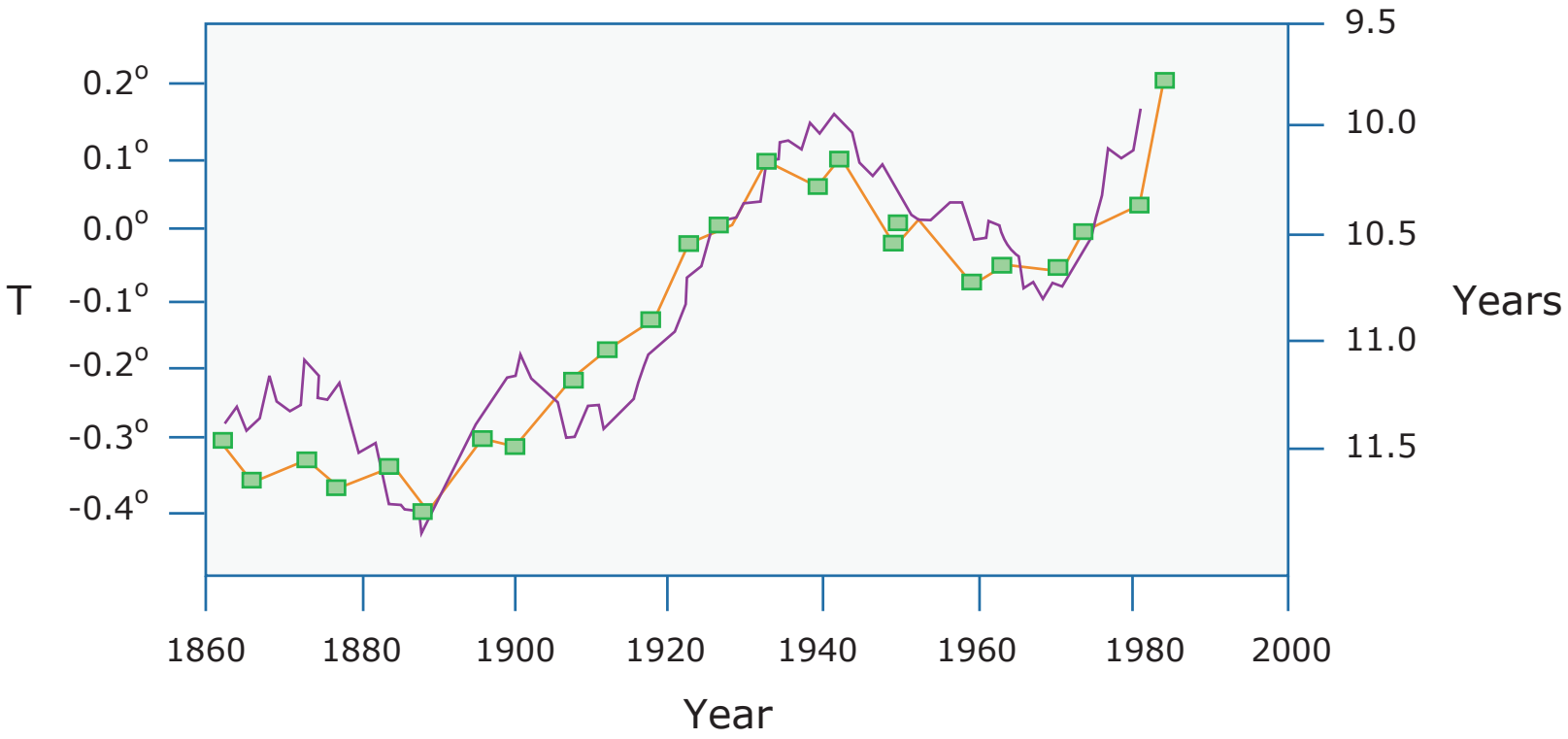
Recap



(a) A specific estimate of climate forcings for 1750-2000. (b) Same as (a), but with the effective forcing partially sorted by sources.

Hansen et al. 2005

Aside : Cosmic Rays and Climate



Eleven-year running mean of the annual average northern hemisphere land-air temperature relative to the average temperature 1951-1980 and the filtered length of the sunspot cycle.

Aside : Cosmic Rays and Climate

Letter

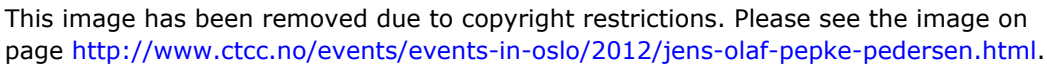
doi: 10.1038/nature10343

Role of sulphuric acid, ammonia and galactic cosmic rays in atmospheric aerosol nucleation

Jasper Kirkby, et al

However, the fraction of these freshly nucleated particles that grow to sufficient sizes to seed cloud droplets, as well as the role of organic vapours in the nucleation and growth processes, remain open questions experimentally. These are important findings for the potential link between galactic cosmic rays and clouds.

How Might This Work ?



Eigil Friis-Christensen & Knud Lassen (correlation); Henrik Svensmark (theory), Jeff Pierce (process understanding)

1. How much does ion formation in the atmosphere change due to changes in the cosmic-ray flux to the atmosphere (e.g. due to the solar cycle)?

The best understood. With current information about the Earth's magnetic field and solar activity, we have fairly robust predictions of the ion formation rate from cosmic rays.
Ion formation rate from cosmic rays varies by 0-20% throughout the region of the atmosphere where clouds form.

http://cr0.izmiran.rssi.ru/clmx/main.htm

2. How much do aerosol nucleation rates change due to changes in ion formation rates?

This is the ONLY part of the theory actually tackled in the CLOUD paper.
Figure 2 shows that a doubling of ion concentration leads to less than a doubling in nucleation rate.
Therefore, a 0-20% change in ion formation rates from cosmic-ray changes will lead to ~0-15% change in nucleation rates.

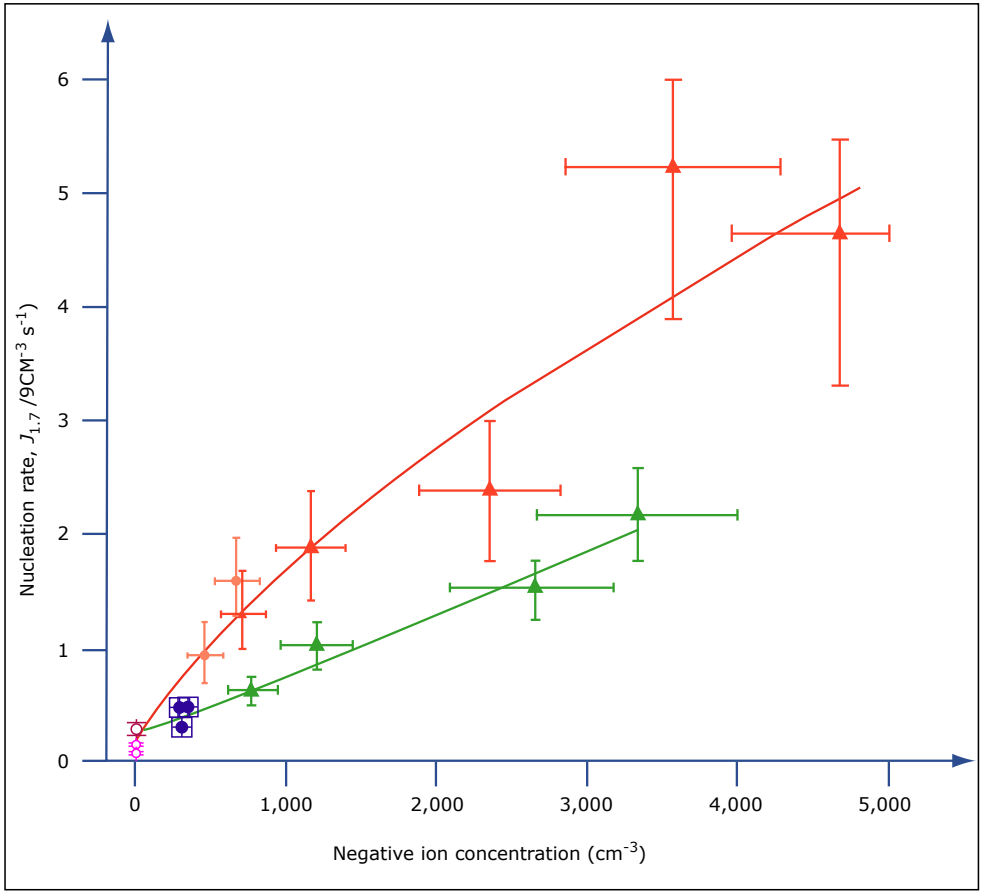


Image by MIT OpenCourseWare.

Nucleation rate as a function of ion concentration for two different conditions (the two colored lines).

3. How much do CCN concentrations change due to changes in newly formed aerosol nucleation rates?

The impact of changing aerosol nucleation rates on CCN concentrations in all studied cases is *much smaller* than the change in nucleation rates. Pierce and Adams, 2009 and Snow-Kropla et al., 2011, have specifically looked at this question in the context of cosmic-ray changes, and found that even though nucleation rates are changing by up to 5% throughout much of the troposphere (and up to 20% in locations), the changes in CCN are generally around 0.1-0.2% throughout much of the globe. The reason for this strong dampening is shown in the figure below (note 10^4 or MORE volume change!)

4. How much do clouds change due to changes in CCN concentrations?

CCN concentrations have more than doubled in many polluted regions due to human-generated emissions.

From 1-3 a change in CCN due to cosmic rays of <1% is reasonably expected.

Studies (field and model) show cloud reflectivity, precipitation and cloud lifetime change by less than the change in CCN for most clouds (e.g. we know that cloud droplet number and cover has not more than doubled due to human-generated emissions; lifetime has not doubled). Cloud changes are therefor <<1% for cosmic rays and 10^2 less than local anthropogenic changes.

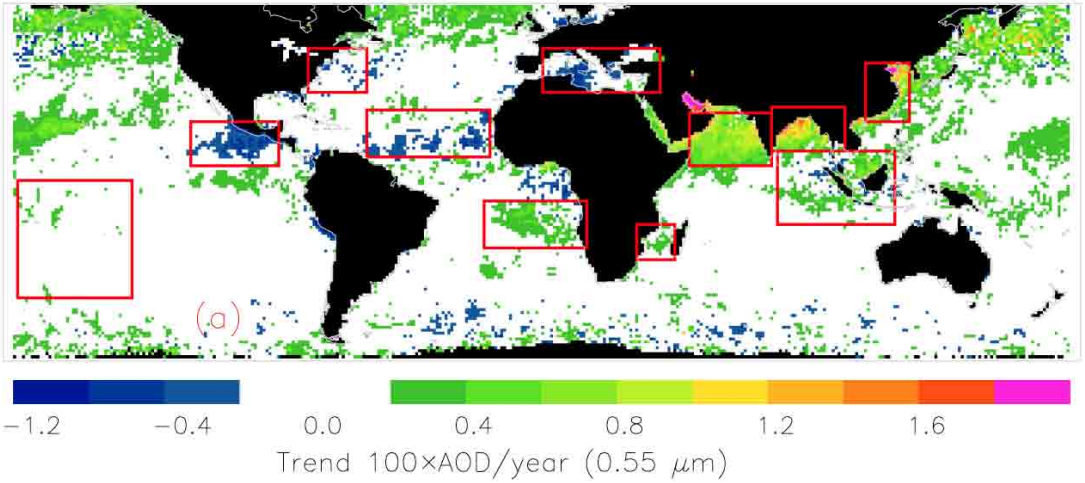
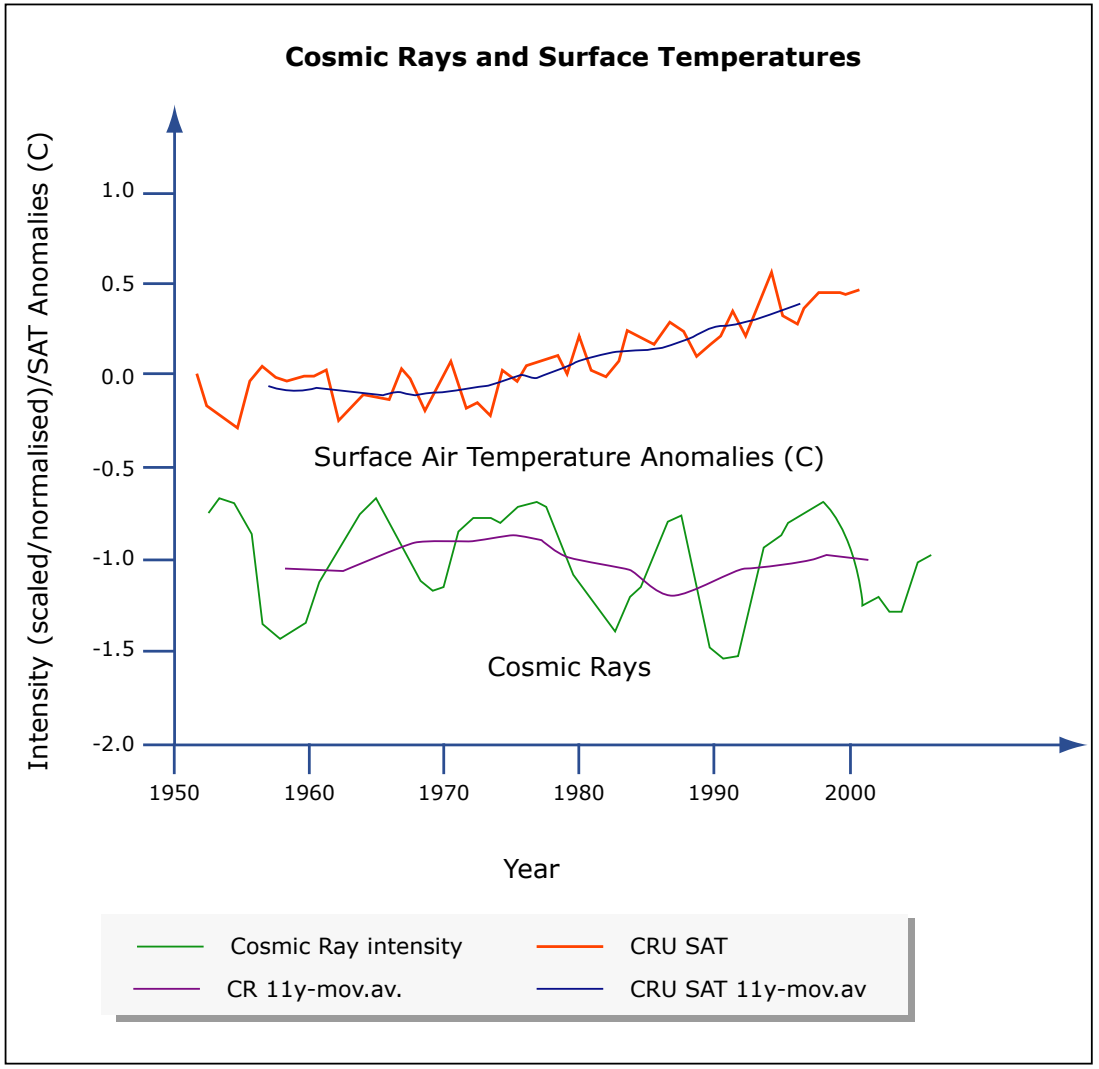


Image courtesy of the European Geosciences Union.

5. Have Cosmic Rays Changed in the Manner That Climate Has?



So, that's the end of it, right?

The Other Climate Theory – Anne Jolis, The Wall Street Journal, September 7, 2011

--- my clarification --- my emphasis

"Al Gore won't hear it, but heavenly bodies (def: planet or planetoid; likely means cosmic ray) might be driving long-term weather trends. (weather is local, global T is climate; likely means later)"

"These shifts might significantly impact the type and quantity of clouds covering the earth, providing a clue to one of the least-understood but most important questions about climate. Heavenly bodies might be driving long-term weather trends. "

"Last month's findings don't herald the end of a debate, but the resumption of one. That is, if the politicians purporting to legislate based on science will allow it."

"Disinformation travels with the click of a button, information has to be peer reviewed" – Susan Solomon

12.340 Global Warming Science

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