The Economics of Climate Change

C 175 - Christian Traeger

Part 1: Introduction to Climate Change

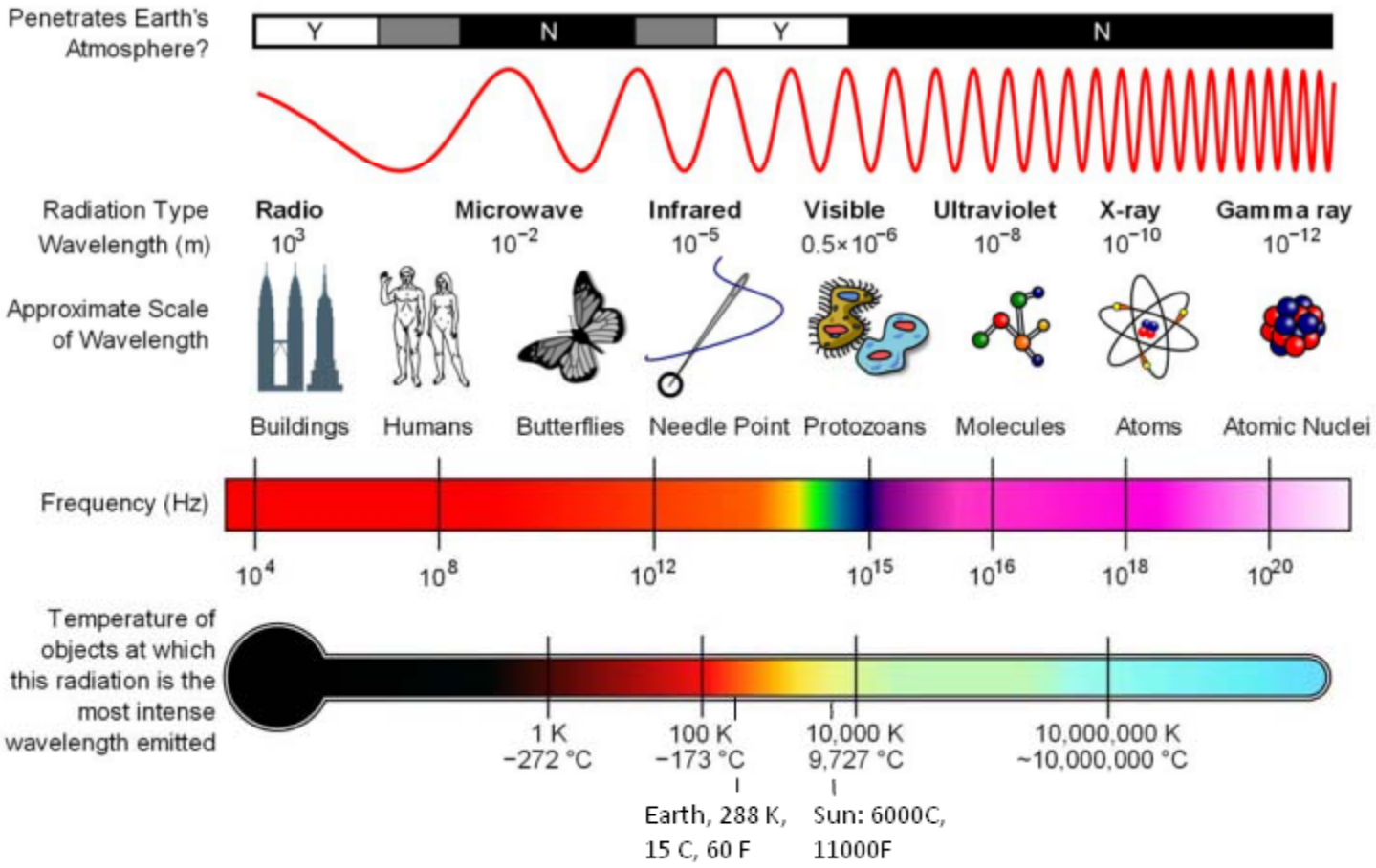
Suggested Reading:

IPCC (2007), "Climate Change 2007: The Physical Science Basis". Summary for Policymakers".

Congressional Budget Office (2003), "The Economics of Climate Change: A Primer", Chapter 2: "The Scientific and Historic Content".

Greenhouse Effect
&
Related Stuff

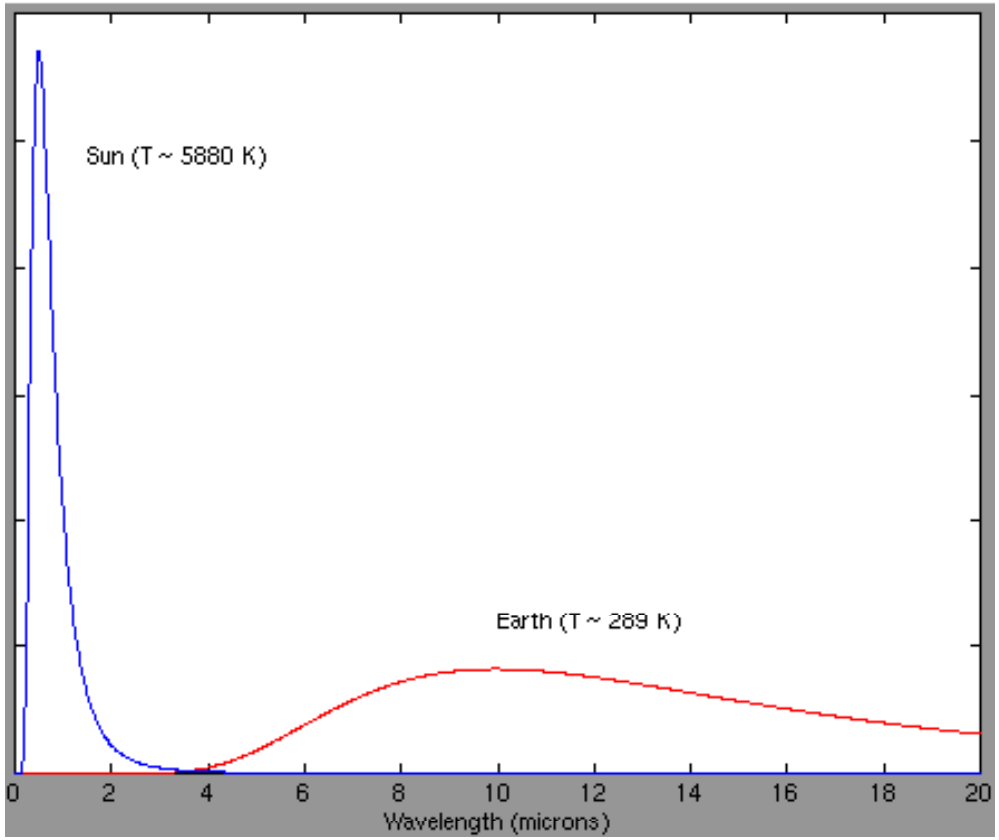
Electromagnetic Waves



Source: http://en.wikipedia.org/wiki/Electromagnetic_spectrum#Microwaves, adapted

Temperature Conversion: See section or e.g. http://www.unit-conversion.info/temperature.html

`Electromagnetic Spectrum ('Light') of Sun and Earth



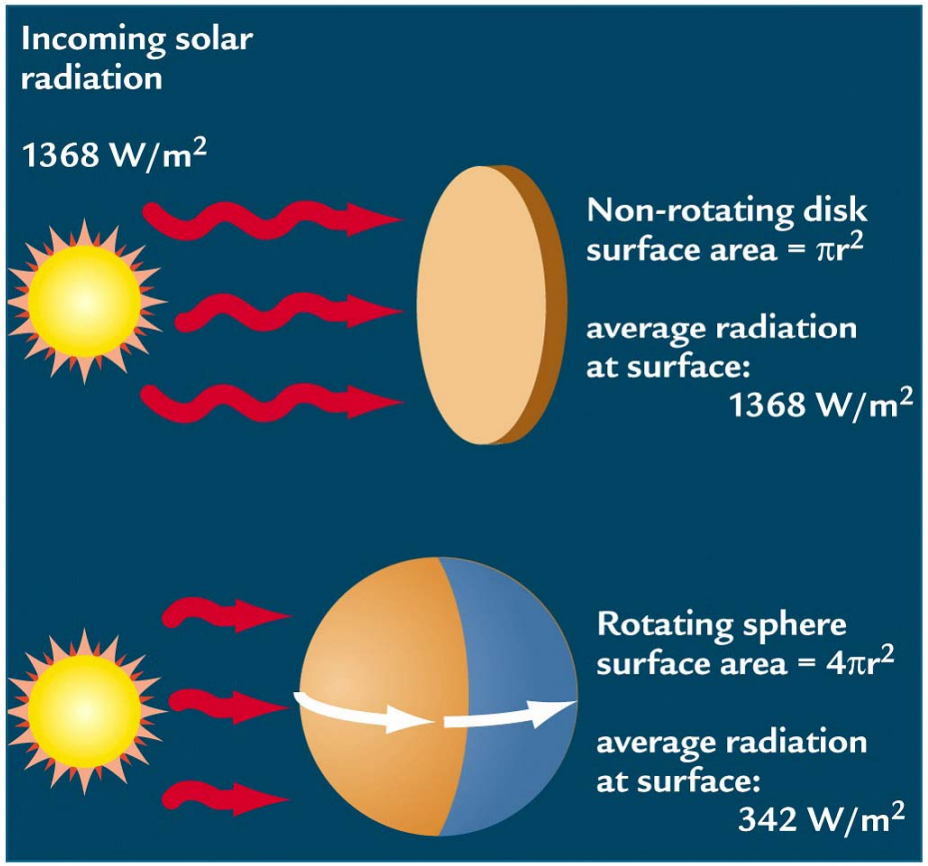
Source: http://marine.rutgers.edu/mrs/education/class/josh/black_body.html.

Electromagnetic wave spectrum for Sun (max~500nm=.5 micrometer) and Earth (max ~10 micrometer)

By Planck's law a 'black body' emits electromagnetic waves as a function of its temperature.

The magnitude of the Earth curve has been magnified 500,000 times.

Energy Flow from the Sun



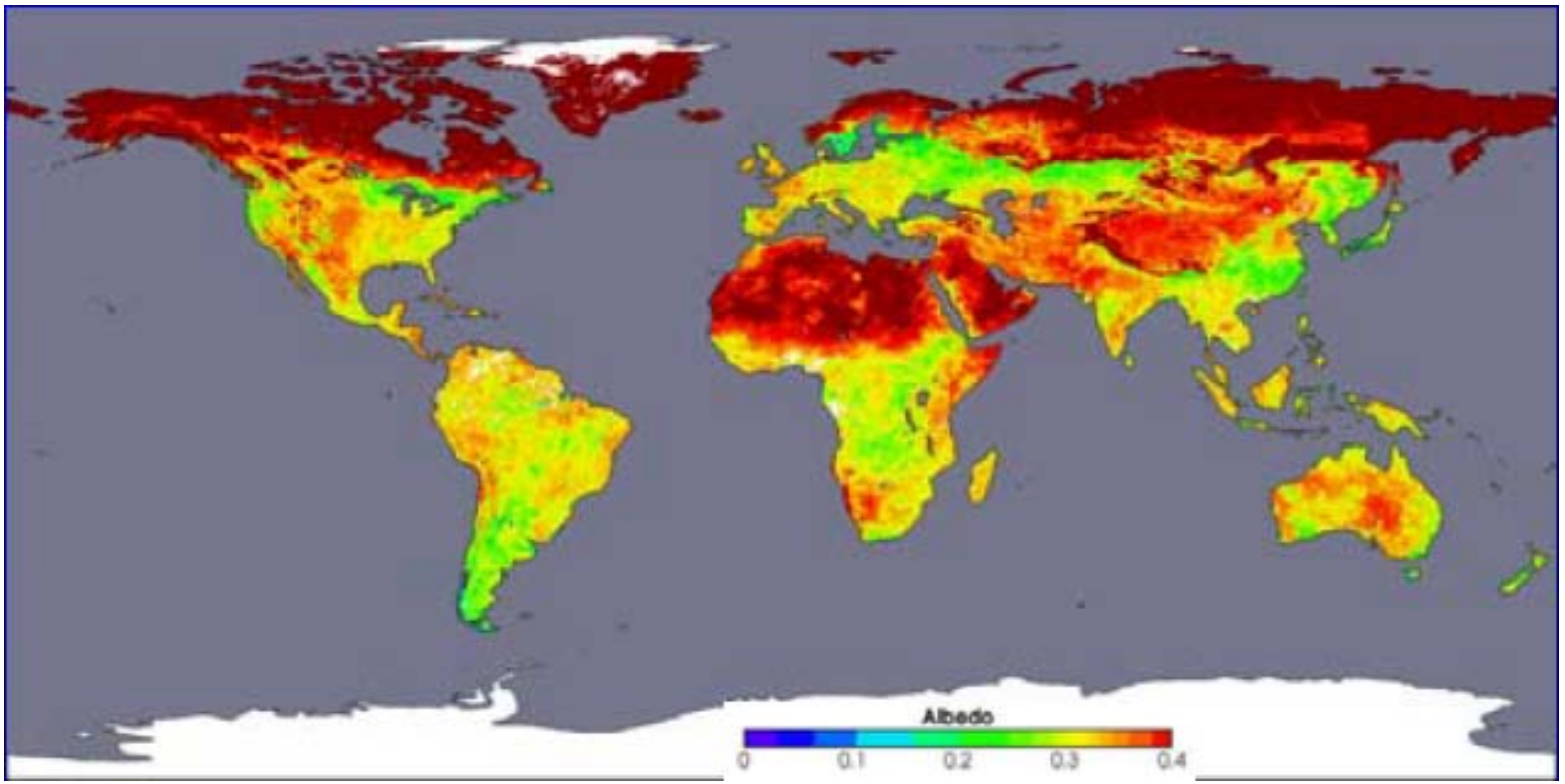
W=Watts
=Energy per time unit(=J/s)

← Solar constant

← Energy per time unit (J/s) that would fall on an 'average' solar panel (or on crop) per square meter, if there would be neither clouds nor atmosphere.

More on Blackboard.

Surface Albedo Earth, 7th to 22nd of April 2002

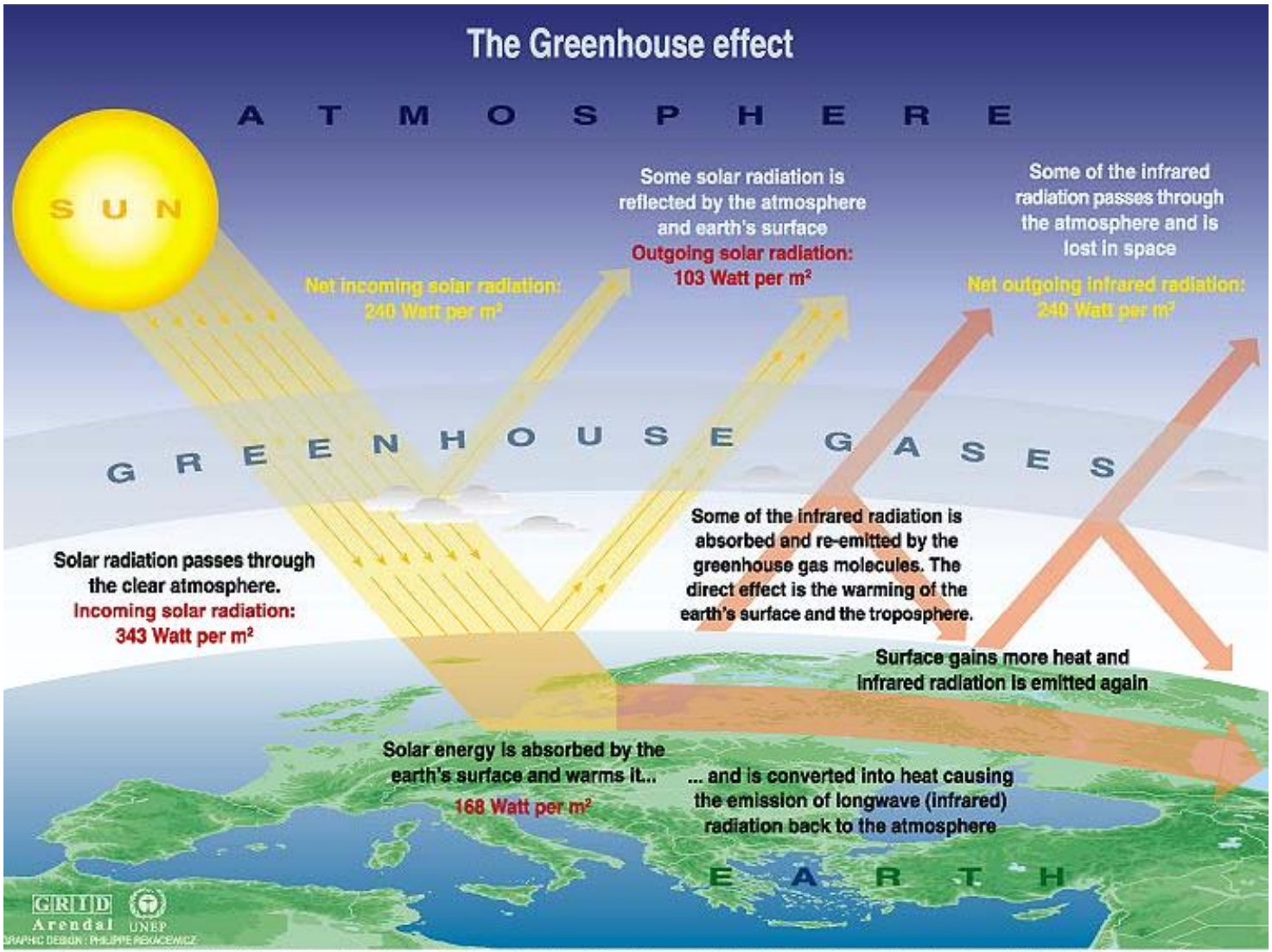


NASAs Terra satellite Moderate Resolution Imaging Spectroradiometer (MODIS, http://modis.gsfc.nasa.gov)

Average Surface Albedo (=reflectivity) or Earth: 13%
Planetary Albedo Earth (Surface + Atmosphere): 30%

Surface Albedo, examples

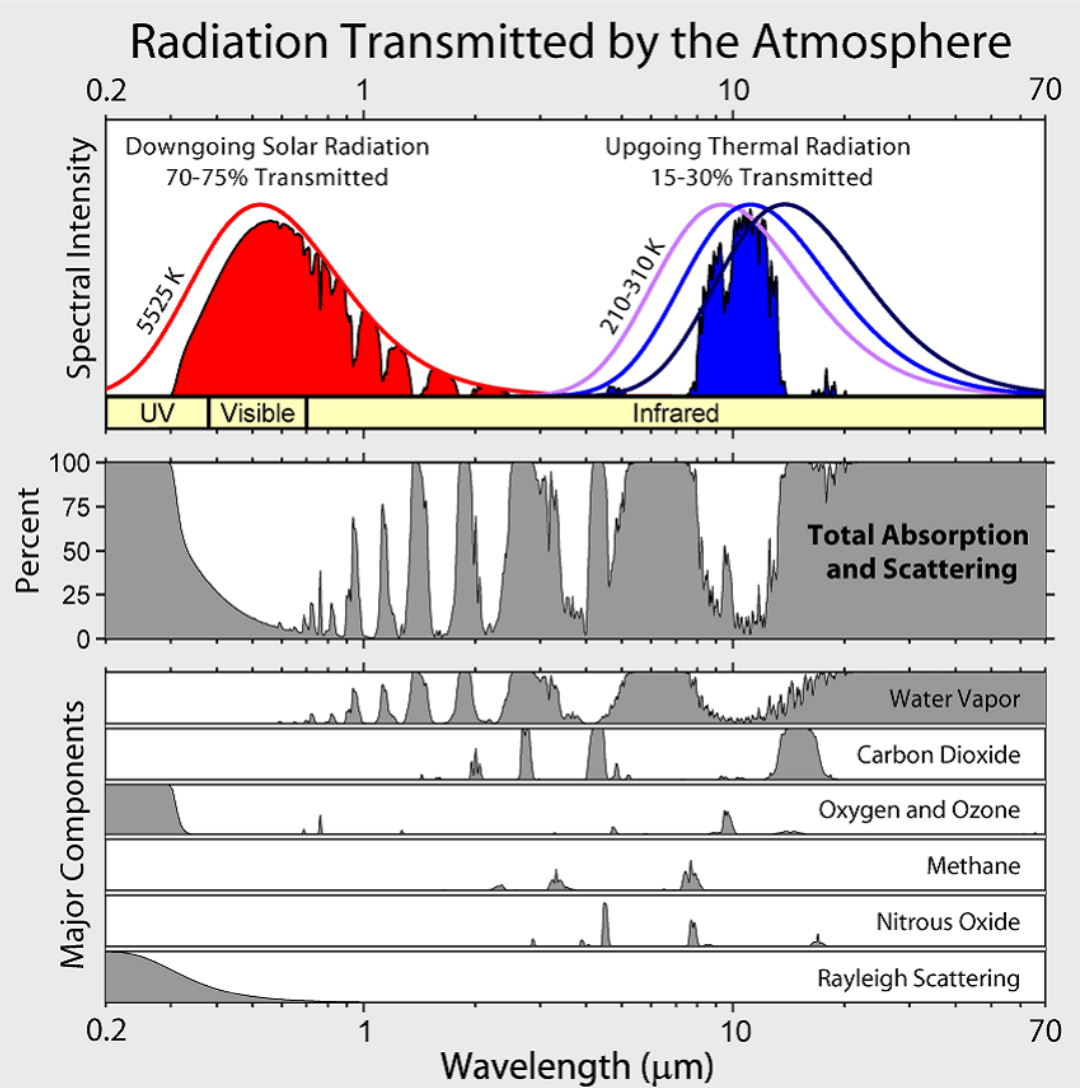
- Fresh Snow 75 – 95 %
- Old Snow 40 – 70 %
- Sea Ice A 30 – 40 %
- Dry Sand Dune 35 – 45 %
- Wet Sand Dune 20 – 30 %
- Forest (Needle Trees) 5 - 15 %
- Water (steep incidence) 7 – 10 %
- Wasser (flat incidence) 20 – 25 %



Sources: Okanagan university college in Canada, Department of geography, University of Oxford, school of geography; United States Environmental Protection Agency (EPA), Washington; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge university press, 1996.

Source: http://www.grida.no/climate/vital/03.htm

Absorption and Transmission in the Atmosphere



Greenhouse Effect

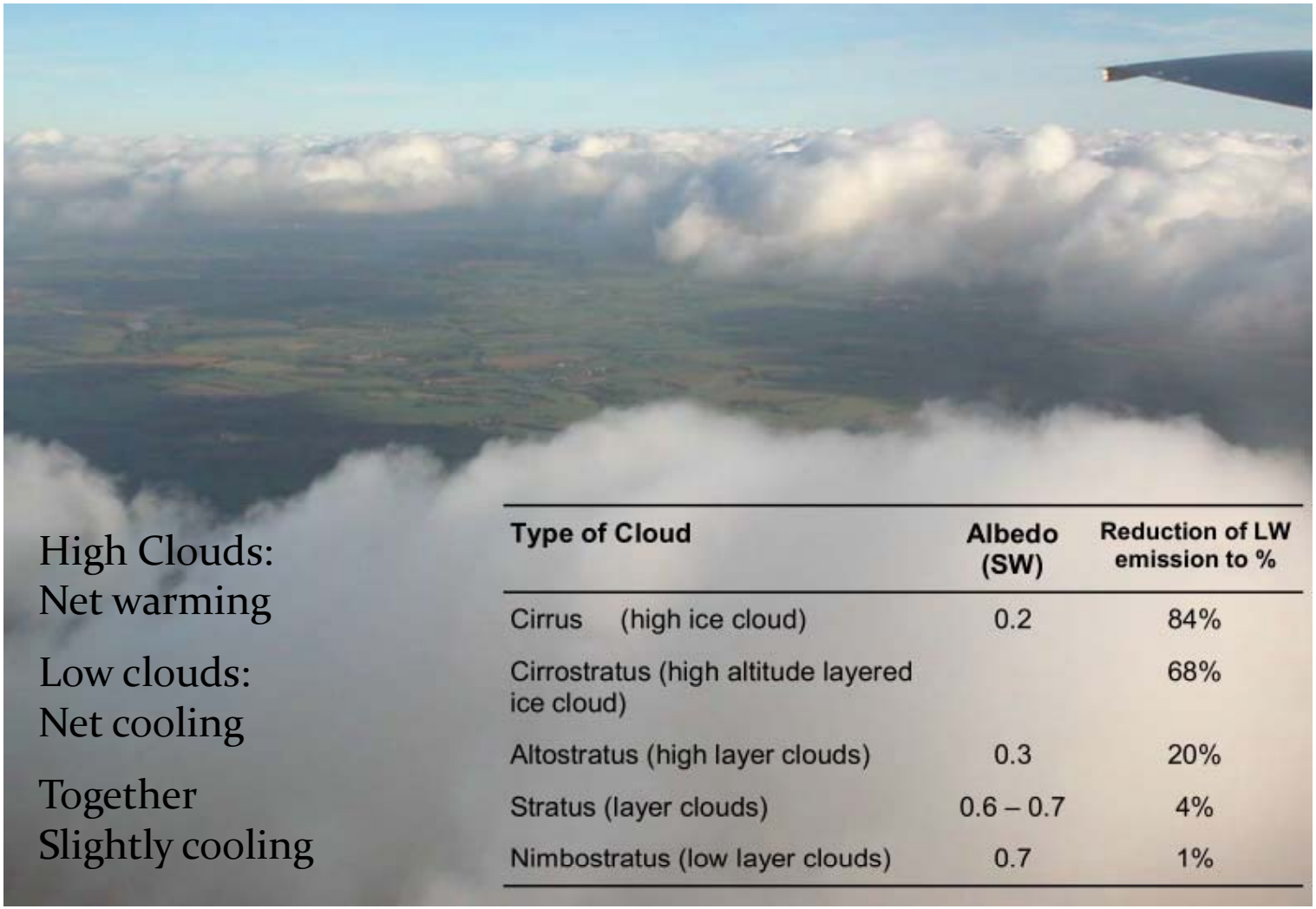
Gas	Current Amount	Increase	Radiative forcing ($W\ m^{-2}$)	
			< 1750	1750-2007
H_2O			94	-
CO_2	383 ppm	105 ppm (38%)	50	1.71
CH_4	1745 ppb	1045 ppb(150%)	1.1	0.48
N_2O	314 ppb	44 ppb (16%)	1.25	0.16
CFCs	< 1 ppb			0.31
(CFC-11, CFC-12, CFC-113, Other CFCs, HCFC-22)				
Preindustrial Greenhouse Forcing			**146**	
Anthropogenic Greenhouse Forcing				**2.66**

Source: Presentation by Peter Köhler @ AWI Bremerhaven.

Radiative forcing measures the additional energy captured in the climate system without feedback effects.

In the IPCC reports, radiative forcing is always measured as difference with respect to 1750 values.

Clouds: Albedo (short wave) vs Reduction of IR (long wave) emission



High Clouds:
Net warming

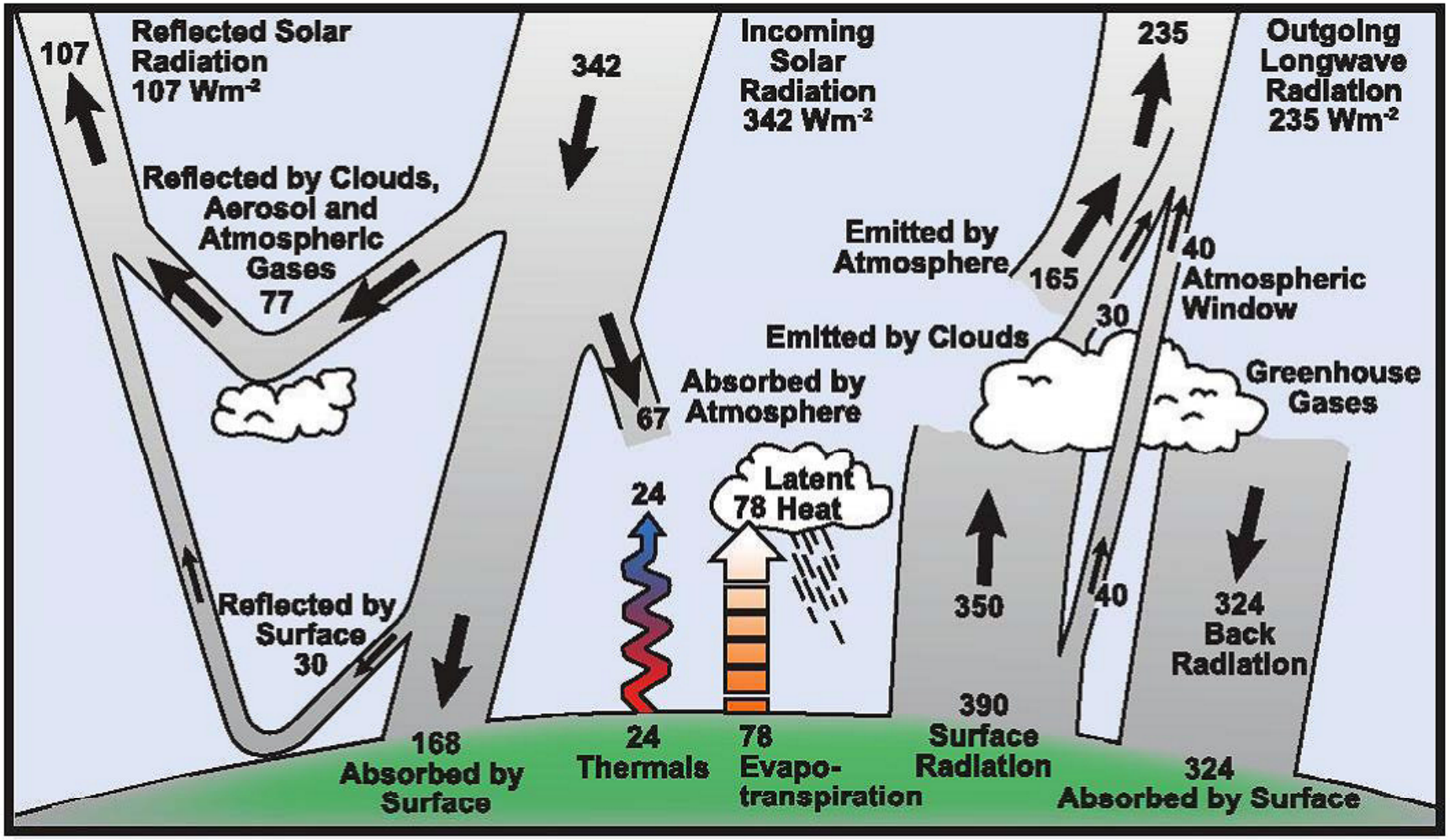
Low clouds:
Net cooling

Together
Slightly cooling

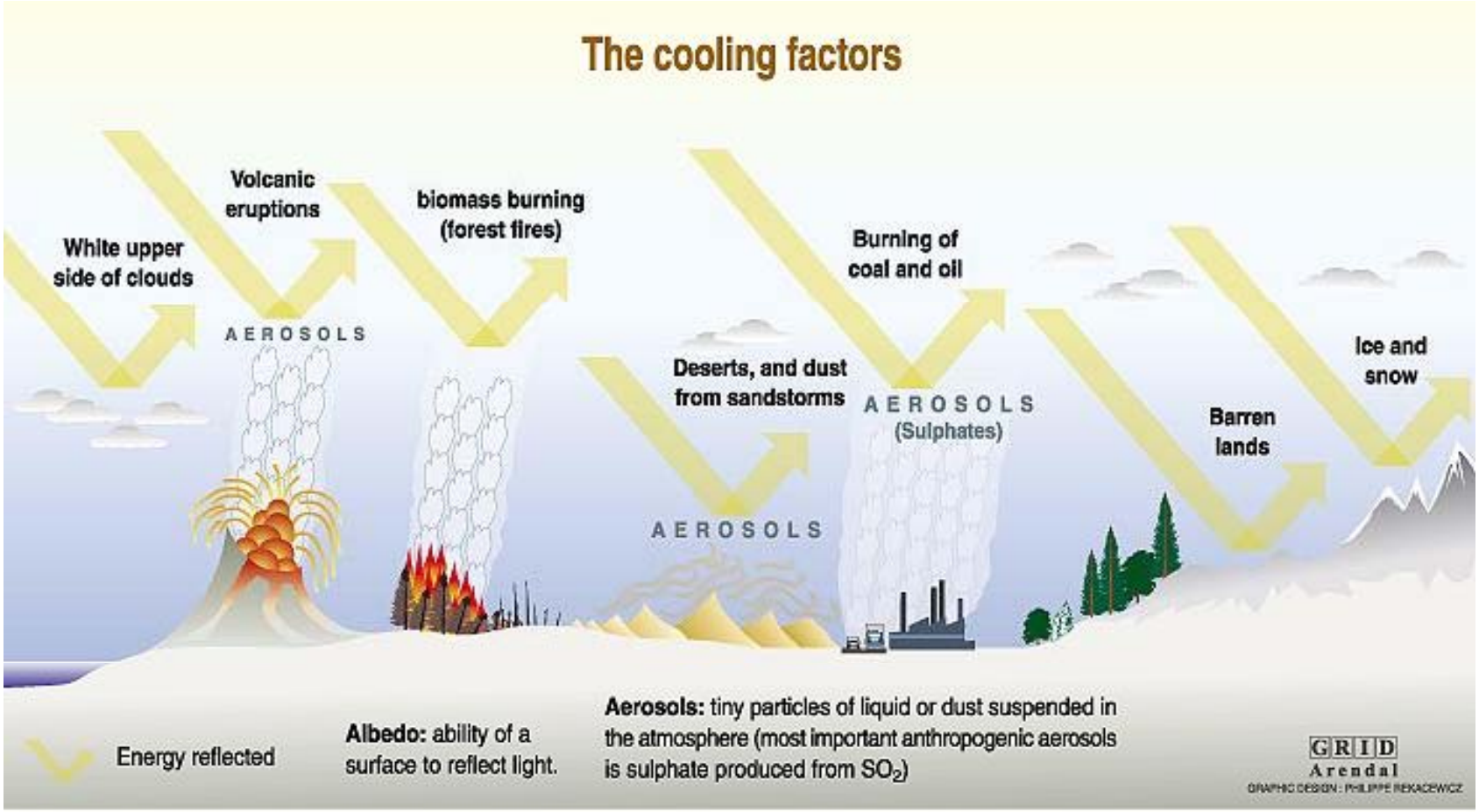
Type of Cloud	Albedo (SW)	Reduction of LW emission to %
Cirrus (high ice cloud)	0.2	84%
Cirrostratus (high altitude layered ice cloud)		68%
Altostratus (high layer clouds)	0.3	20%
Stratus (layer clouds)	0.6 – 0.7	4%
Nimbostratus (low layer clouds)	0.7	1%

Ulrich Platt, Lecture Material

The radiative balance in more detail



The cooling factors ……. Aerosols



Sources: Radiative forcing of climate change, the 1994 report of the scientific assessment working group of IPCC, summary for policymakers, WMO, UNEP; L.D. Danny Harvey, Climate and global environmental change, Prentice Hall, pearson Education, Harlow, United Kingdom, 2000.

Source: http://www.grida.no/climate/vital/14.htm

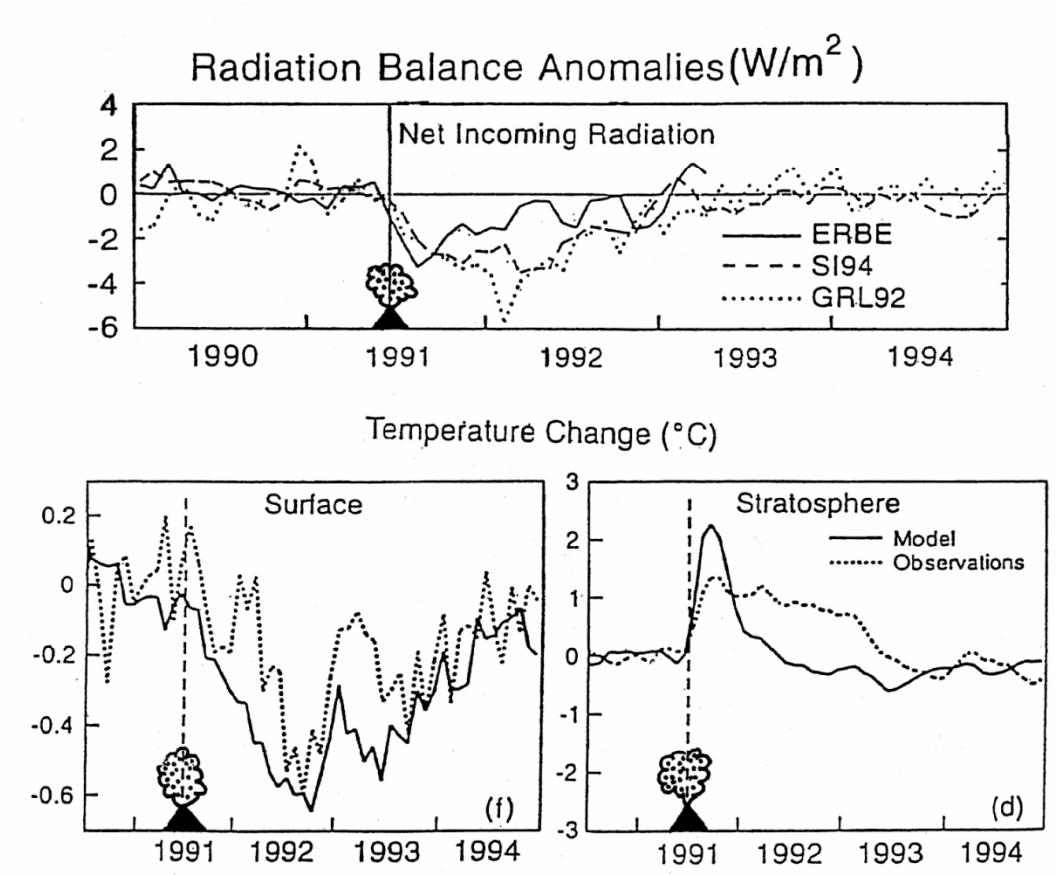
Aerosols:

- Direct Effect: aerosols reflect or absorb sunlight
- Indirect Effects: aerosols create more and smaller cloud droplets which
  - increases reflection, and
  - suppresses rainfall
- Semi-direct effect: absorbing aerosols heat air and cool surface suppressing convection and condensation

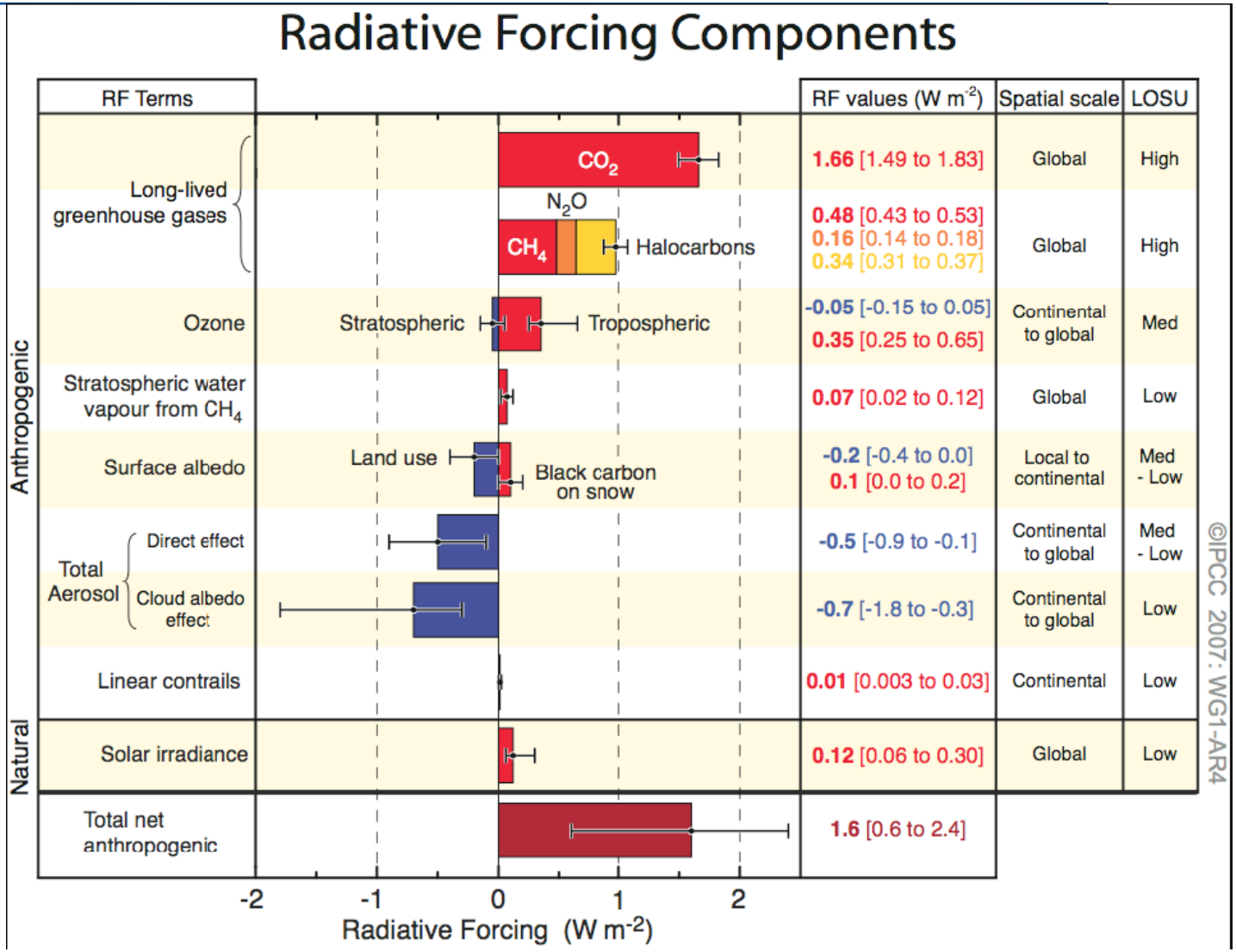
Volcanic Eruption, Mount Pinatubo, Philippines

Source: http://en.wikipedia.org/wiki/Mount_Pinatubo

Volcanic Eruption, Mount Pinatubo, Aerosol Effect



Hansen, J., R. Ruedy, M. Sato, and R. Reynolds. "Global surface air temperature in 1995: Return to pre-Pinatubo level." *Geophys. Res. Lett. 23, no. 13 (1996): 1665-1668.*
Adapted by and taken from MIT open coursework.



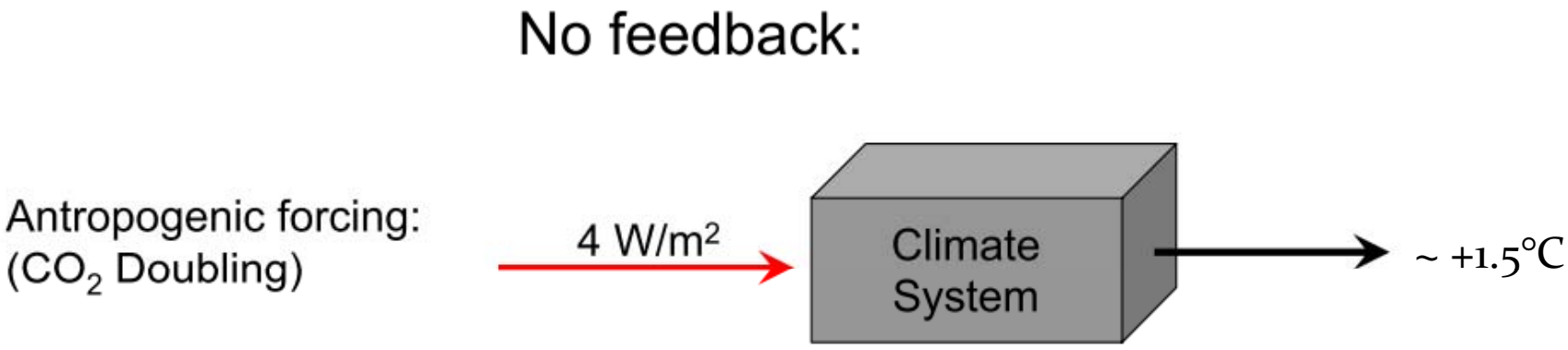
Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU).

Radiative Forcing

- I hope the meaning became clear in the meanwhile, but here you have a sentence spelled out:

- **Radiative Forcing** is a measure of the influence that a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system. It is an index of the importance of the factor as a potential climate change mechanism. Positive forcing tends to warm the surface while negative forcing tends to cool it. Usually expressed in watts per square metre (Wm^{-2}).

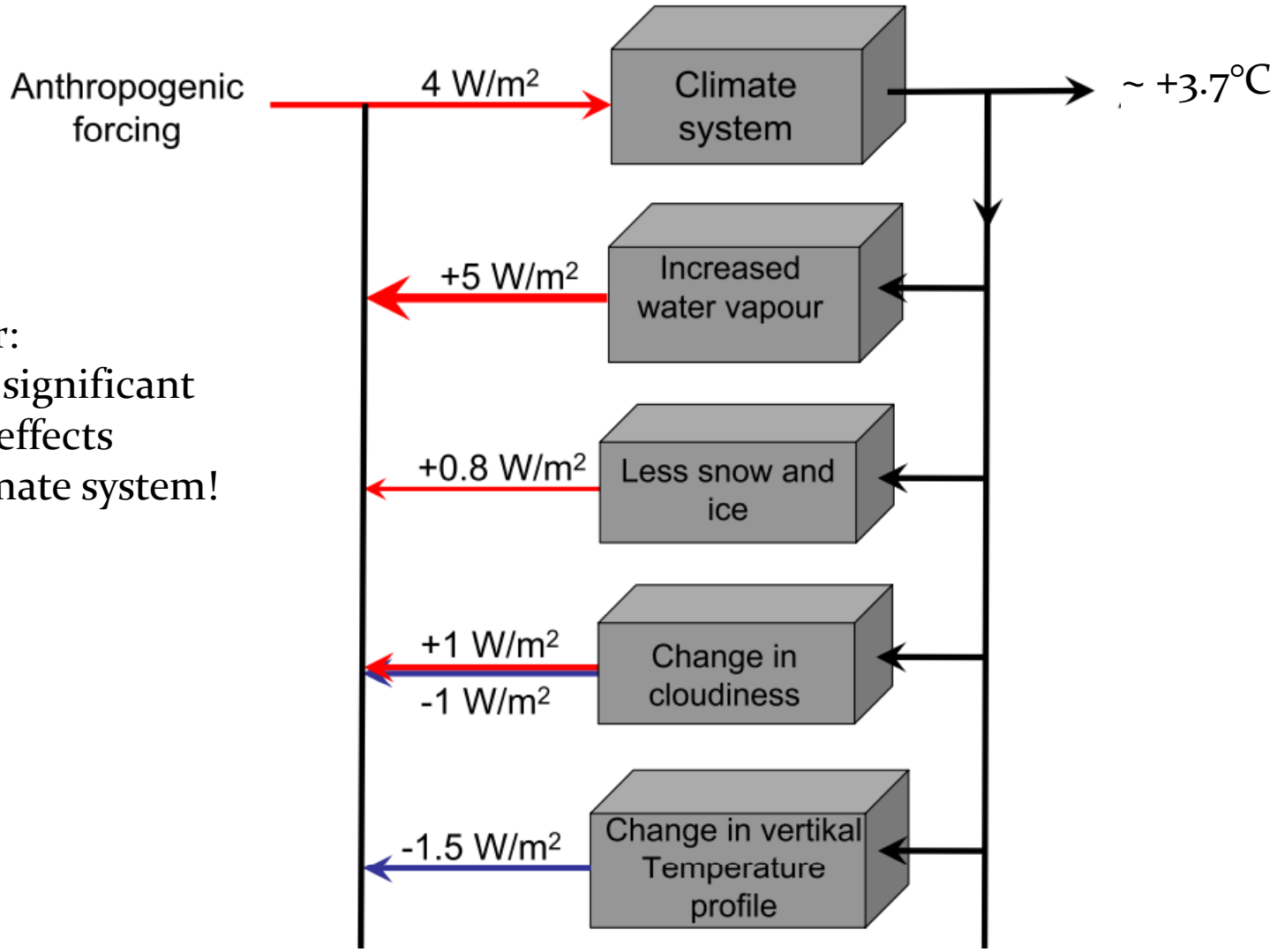
Feedbacks



It could be so easy…

Ulrich Platt, Lecture Material, based on
Schwartz, S. E. (2007), Heatcapacity, time constant, and sensitivity of Earth's climatesystem, J. Geophys. Res., 112.

Feedbacks



…however:
There are significant feedback effects in the climate system!

Climate Sensitivity

The temperature increase caused by a doubling of CO_2 concentration with respect to pre-industrial 1750 is called
"**Climate Sensitivity Parameter**"

The IPCC (2007) estimates it to be in the range of [2°C,4.5°C]
with a best estimate of 3°C =5.4 ˚F
(slightly differing from the one cited on the last slide).

Climate models support a linear relation between

- change in radiative forcing ΔF since 1750 and
- change in global average surface temperature ΔT

-> decent approximation relating radiative forcing and temperature change

$$\Delta T = \lambda \ \Delta F$$

If climate sensitivity is $\Delta T \approx 3$ ˚C and the forcing caused by a doubling of CO_2 is

$$\Delta F \approx 3.7 \text{ W/m}^2$$

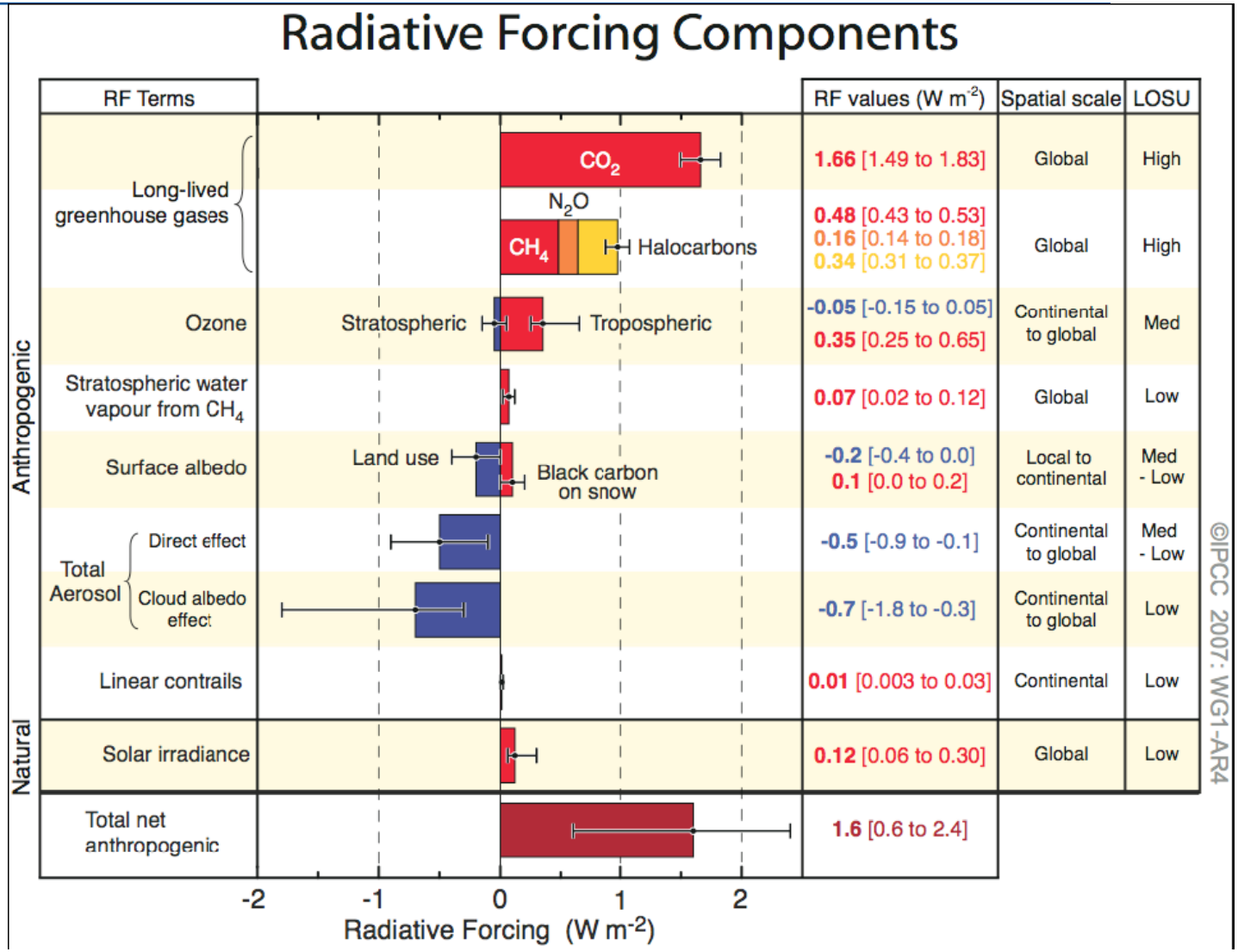
we find that $\lambda = \Delta T / \Delta F \approx .8$ ˚C / (W/m^2)

"2 Greenhouse Effects"

- *Natural* greenhouse effect makes sure earth has 'nice' temperature: on average 14°C=57°F instead of -18°C=0°F
- *Enhanced* greenhouse effect is anthropogenic: human-caused emissions of greenhouse gases (GHGs) cause additional greenhouse effect

Major GHGs for enhanced greenhouse effect are

- Carbon Dioxide CO_2
- Methane CH4
- Nitrous Oxide N2O
- Halocarbons/CFCs



Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU).

Radiative Forcing is a measure of the influence in altering the balance of incoming and outgoing energy in the Earth-atmosphere system. It measures the energy per time and surface unit (Wm^{-2}) that is added to the system (warming it up).

However, to translate radiative forcing into temperature changes we have to take into account **Feedback Mechanisms** like

- Change in albedo (reflectivity)
- Increase in water vapour (traps long wave radiation of the earth)
- Clouds formation (net effect depends on type/altitude of clouds)

Climate Sensitivity I

The temperature increase caused by a doubling of CO_2 concentration with respect to pre-industrial 1750 is called "**Climate Sensitivity** "

The IPCC (2007) estimates it to be in the range of [2°C,4.5°C] with a best estimate of 3°C =5.4 ˚F

Climate models support an approximately linear relation between

- change in radiative forcing ΔF since 1750 and
- change in global average surface temperature ΔT

-> Decent approximation to relate radiative forcing and temperature change is

$$\Delta T = \lambda \ \Delta F$$

If climate sensitivity is $\Delta T \approx 3$ ˚C and the forcing caused by a doubling of CO_2 is

$$\Delta F \approx 3.7 \text{ W/m}^2$$

we find that

$$\lambda = \Delta T / \Delta F \approx .8 \text{ ˚C / (W/m}^2)$$

Climate Sensitivity II

Climate sensitivity = Equilibrium change in global mean surface temperature following a doubling of the atmospheric (equivalent) CO_2 concentration.

IPCC Fourth Assessment Report estimates:

(slightly more precise than linear aproximation on previous slide)

Eq. CO_2-eq ppm	Temperature increase °C		
	Best estimate	Very likely above	Likely in the range
350	1.0	0.5	0.6-1.4
450	2.1	1.0	1.4-3.1
550	2.9	1.5	1.9-4.4
650	3.6	1.8	2.4-5.5
750	4.3	2.1	2.8-6.4
1,000	5.5	2.8	3.7-8.3
1,200	6.3	3.1	4.2-9.4

Source: IPCC (2008)

Flows, Stocks and Greenhouse Effect

It is important to distinguish between

- 1 unit of CO_2 emitted (flow) and
- 1 unit of CO_2 in the atmosphere (stock)

We will see that, fortunately, not every unit emitted stays up in the atmosphere (at least not for long).

Half life (or time up in the atmosphere) varies for different GHGs!

How can we compare different gases with respect to their greenhouse effect contribution?

Global Warming Potential

- **Global warming potential (GWP)**
  - Is defined as the ratio of the time-integrated radiative forcing from the instantaneous release of a kg of a trace substance relative to that of a kg of a reference gas

$$GWP(x) = \frac{\sum_{t=0}^{TH} a_x x(t)}{\sum_{t=0}^{TH} a_r r(t)}$$

where a_x is the radiative forcing due to a unit increase in atmospheric abundance of the substance (i.e., $Wm^{-2}\ kg^{-1}$) and x(t) is the time-dependent decay in abundance of the substance following an instantaneous release of it at time t=o.

- **Kyoto Protocol** uses CO_2 as the reference gas.

  Then GWP is an index for estimating relative global warming contribution due to atmospheric emission of a kg of a particular greenhouse gas compared to emission of a kg of carbon dioxide.

Beware:

GWP critically depends on the **time span** over which the potential is calculated:

GAS		Lifetime (years)	Global Warming Potential (Time Horizon in Years)		
			20 yrs	100 yrs	500 yrs
Carbon Dioxide	CO_2		1	1	1
Methane	CH4	12	72	25	8
Nitrous Oxide	N2O	114	289	298	153
CFC-11		45	6730	4750	1620

Source: IPCC (2007) WG1. Note: This is Direct Global Warming Potential without effects of degradation products or the radiative effects caused by changes in concentrations of greenhouse gases due to the presence of the emitted gas. Only the GWP for methane includes indirect effects from enhancements of ozone and stratospheric water vapour.

And what about the lifetime of CO_2 ? Not just a single lifetime, based on …