Geo-engineering a new Copernican Revolution.

An ultimate solution for Reducing Global Warming?

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   - Mitigation, Adaptation, Climate Engineering
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1. Introduction

The IPCC concluded that (Third Assessment Report, TAR, 2003) :

an increasing body of observations gives a collective picture of a warming world' **with** ***'new and stronger evidence that most of the warming observed in the past 50 years is attributable to human Activities'.***

Human Intervention : in Litho-, Bio- and Atmosphere (Gaia)

- FOSSILE ENERGY RESOURCE

- BUILT ENVIRONEMNT : CITIES, INFRASTRUCTURE, ...

- Techno-science & Industrialization

- Demographic Expansion

HOLOCENE ⇒ ANTHROPOCENE (Paul Crutzen)

WHICH HUMAN INTERVENTION?

- **Mitigation : Al Gore**

- **Adaptation : EEA Technical Report 2005**

- **Engineering :**

  Earth System : IESP
  Geo-Engineering
  Climate Engineering

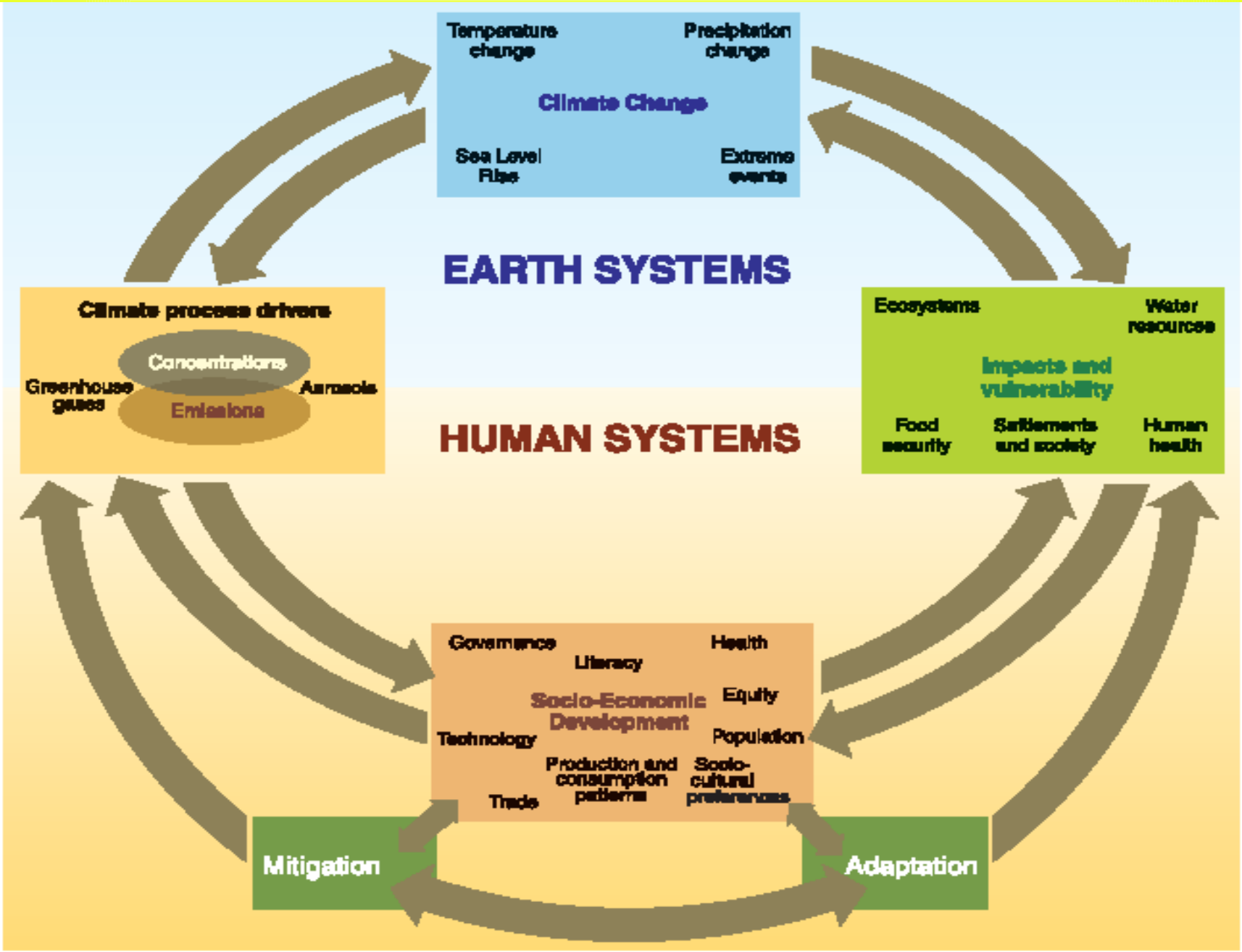


Figure I.1. Schematic framework representing anthropogenic drivers, impacts of and responses to climate change, and their linkages.

Definitions

1. Mitigation :

The IPCC defines mitigation as: “An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.” Climate Mitigation and Adaptation.

2. Adaptation

The *EEA and IPCC* define adaptation in baout the same terms: adaptation refers to policies, practices and projects which can either moderate damage and/or realise opportunities associated with climate change. (Technical Report 2005)

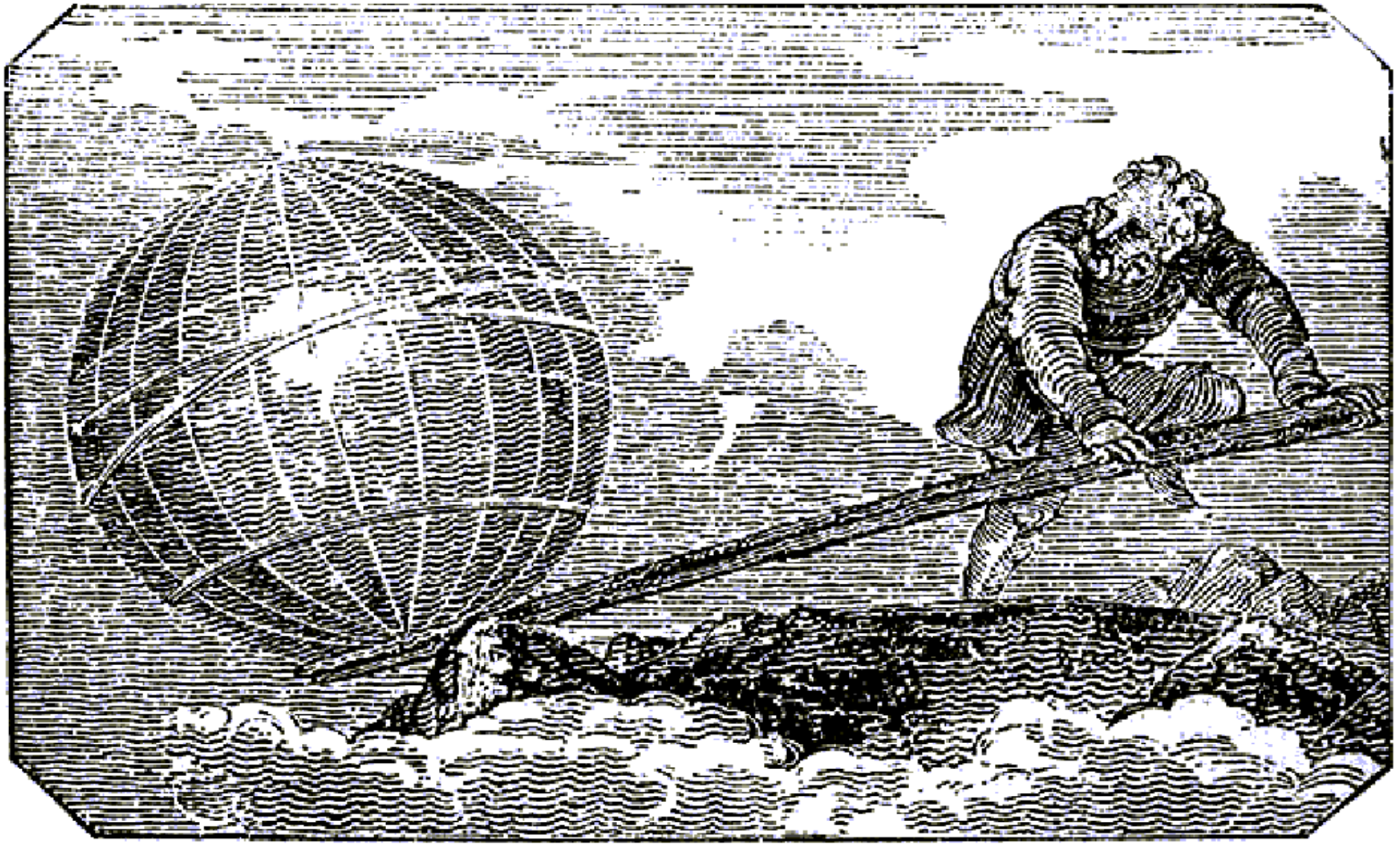
3. Climate / Geo -engineering / Earth System Engineering

Intentional, large-scale manipulation of the earth-system (environment) by humans to bring about environmental change, particularly to counteract the undesired side effects of other human activities. (David W. Keith)

large scale : objective is to addresses threats at **planetary** level. Strictly changing local weather conditions do not fall under this definition.

manipulation : technical solutions designed with **scientific methodologies**

environment : earth-system inclusive **extra-terrestrial** domains space &sun



David W. Keith, 2007

(MIT-Technology Review .2009)

2. Some numbers about our planet (IPCC)

2.1 GHG concentration

2.2 Average Tempearture rise

Sea level rise

2. 3Radiation data

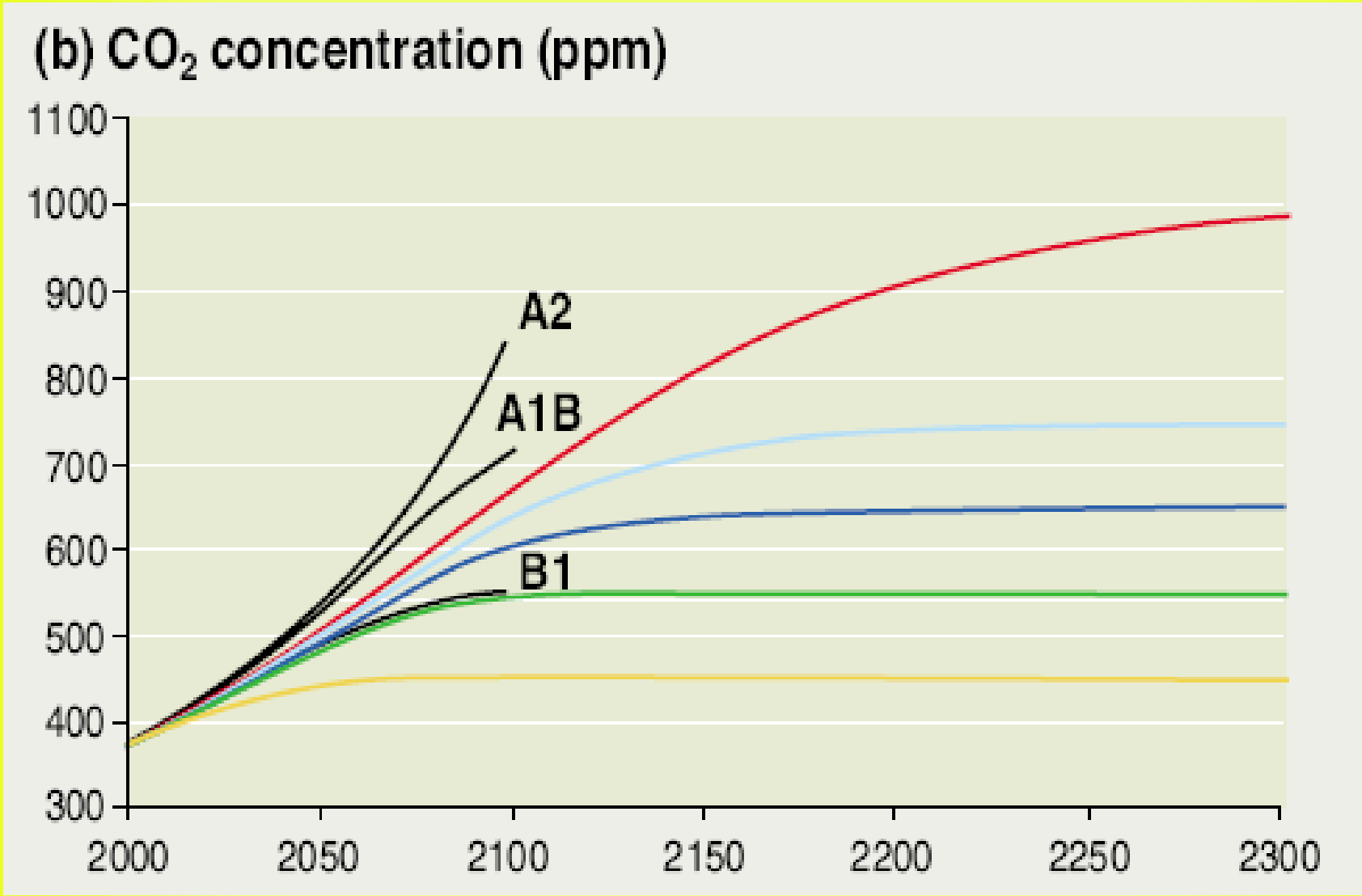
2.1 Atmospheric Concentrations and their Increase

Gas	Pre-industrial Period 1000-1750	Current 2000	Change %
CO_2	ca. 280 ppmv	368 ppmv	ca. 31%
CH_4	700 ppbv	1750 ppbv	151%
N_2O	270 ppbv	316 ppbv	17%

Pre-industrial CO2 (<1750) : 280 ppmv
Today CO2 (Average 2007-2008) : 384 ppmv

Contribution of GHG to anthropogenic Climate Change

Gas	Contribution to Radiative Forcing	Share of GHG emissions in Industrialized countries early-1990
CO_2	70-72%	ca. 82%
CH_4	21-22%	ca. 12%
N_2O	6-7 %	ca. 4%
HFCs	<1%	ca. 2%


(b) CO_2 concentration (ppm)
1100
1000
900
800
700
600
500
400
300
2000
2050
2100
2150
2200
2250
2300
A2
A1B
B1

2.2 Global Earth Surface Temperature (since 1850)

1906-2005 linear trend temperature rise	**0.74°C (0.56-0.92°C)**
Last 50 years T rise :	**0.13°C/decade**
From 1850-1899 to 2001-2005	**0.76°C (0.57-0.95°C)**
Urban heat island effects are negligible	**0.006°C.**

Sea level rise

20th century rise	**0.17 [0.12 to 0.22] m.**
1961-2003	**1.8 [1.3 to 2.3] mm/ year**
1993-2003	**3.1 [2.4 to 3.8] mm/year**

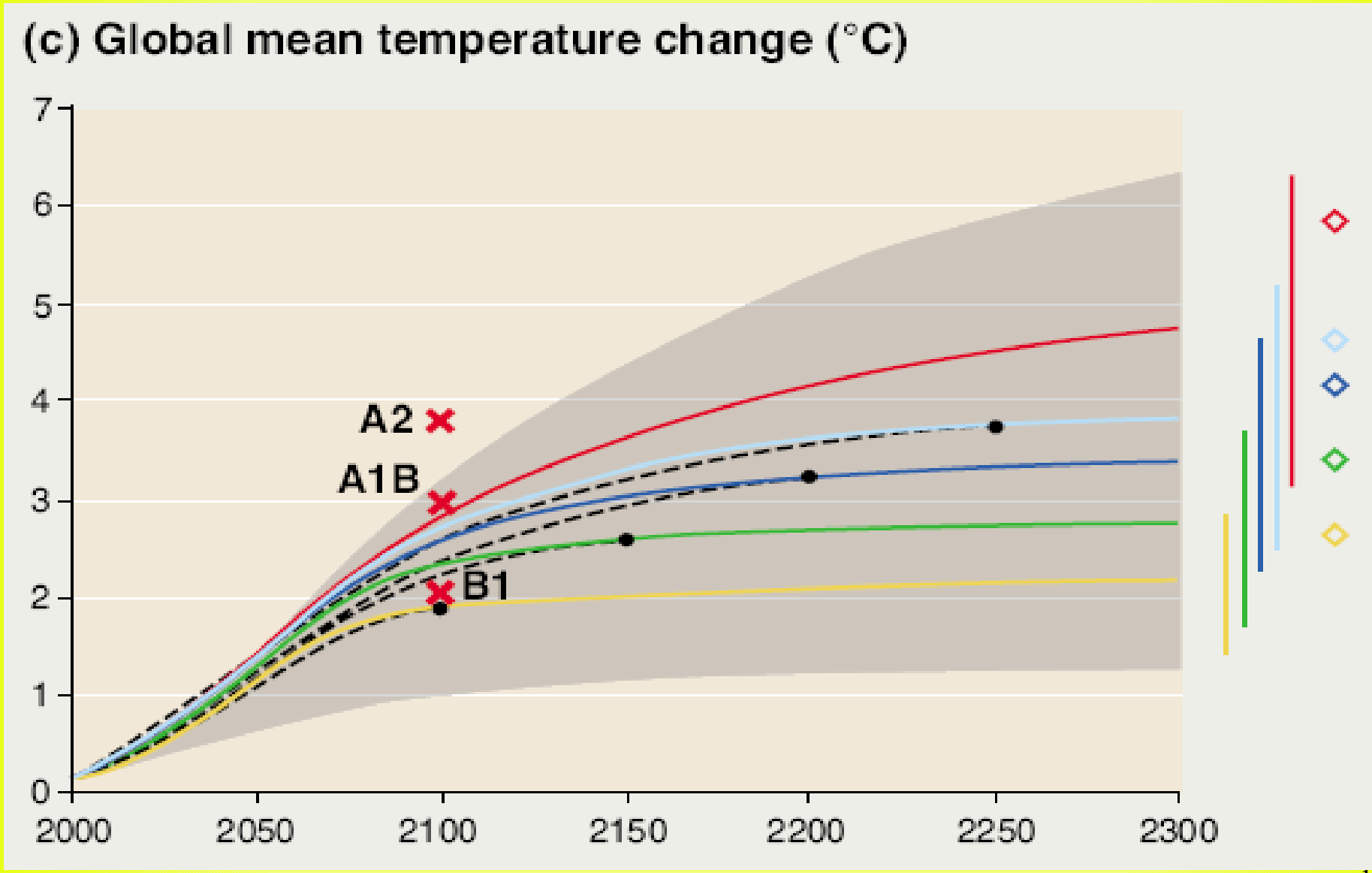
Arctic Sea Ice extent shrunk (satellite: since 1978)

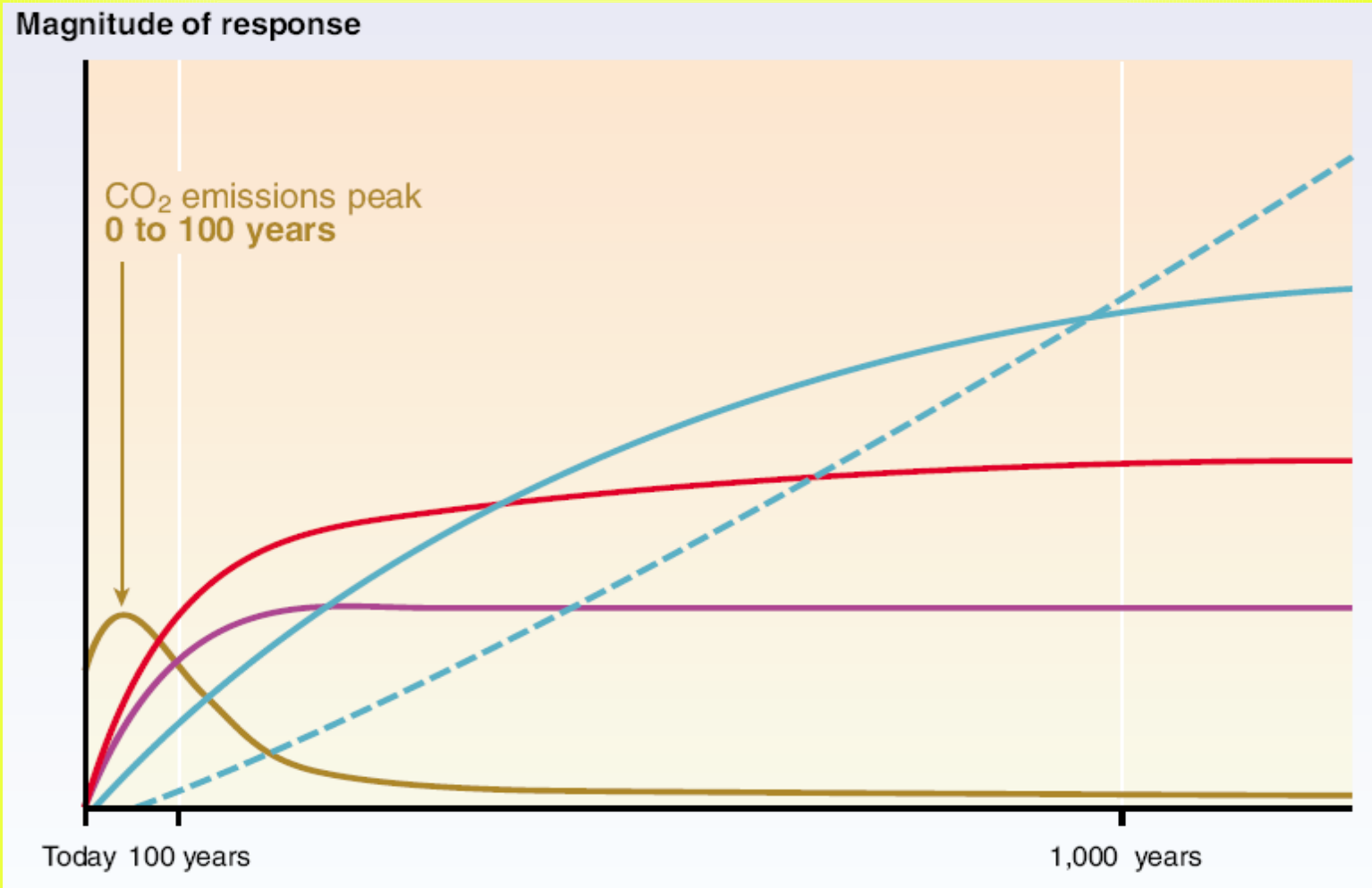
2.7 (2.1-3.3) %/ decade

Permafrost

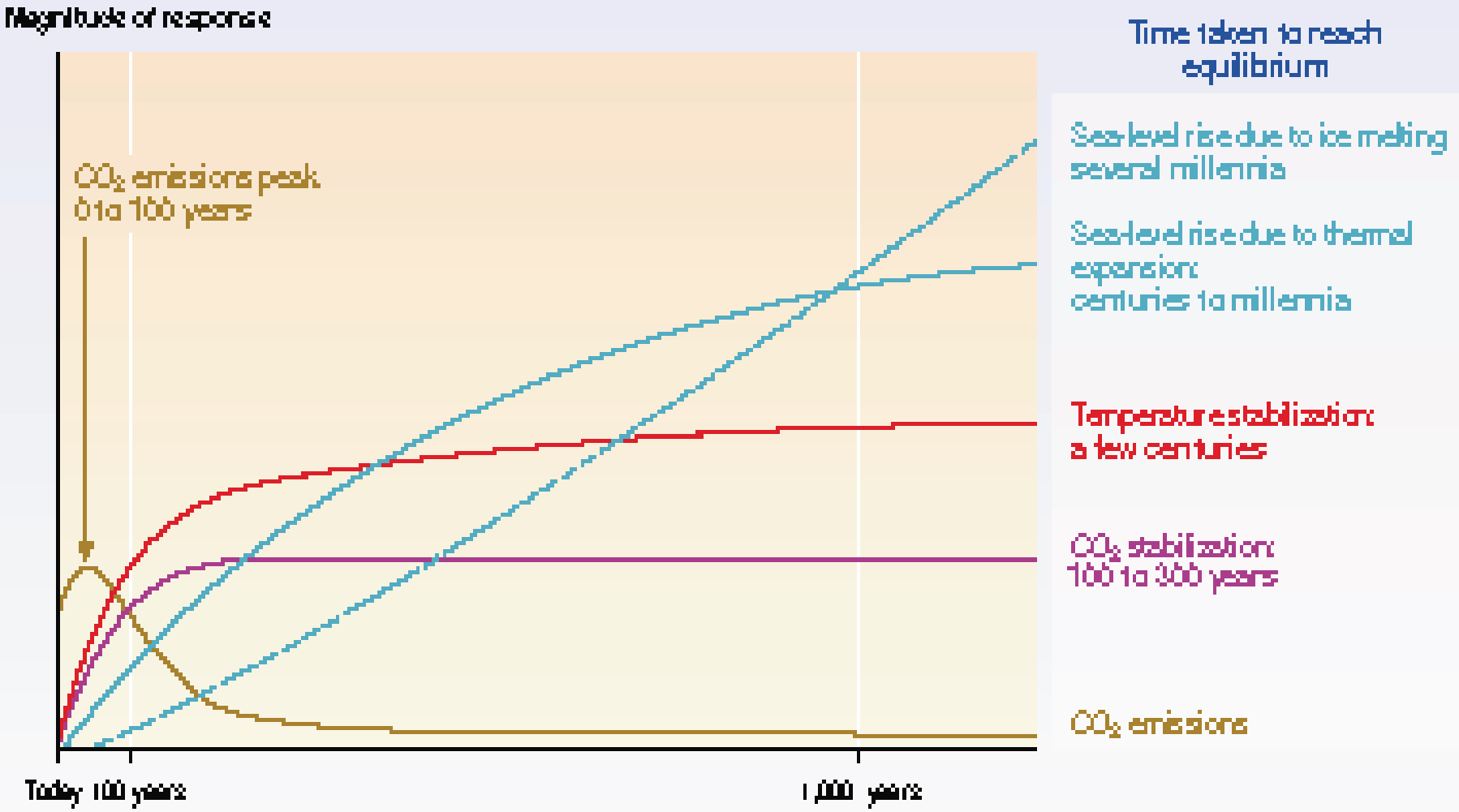
Temperature at top since 1980s rose by up to 3%

Area seasonally frozen ground decreased by about 7% since 1900.


(c) Global mean temperature change (°C)
7
6
5
4
3
2
1
0
2000
2050
2100
2150
2200
2250
2300
A2
A1B
B1


Magnitude of response
CO_2 emissions peak
0 to 100 years
Today
100 years
1,000 years

CO_2 concentration, temperature, and sea level continue to rise long after emissions are reduced



2.3 Radiation : Earth absorbs and radiates energy leaves it (W/m2)

Shortwave : warming through incoming solar energy (<3µm)
SWCE: shortwave climate engineering

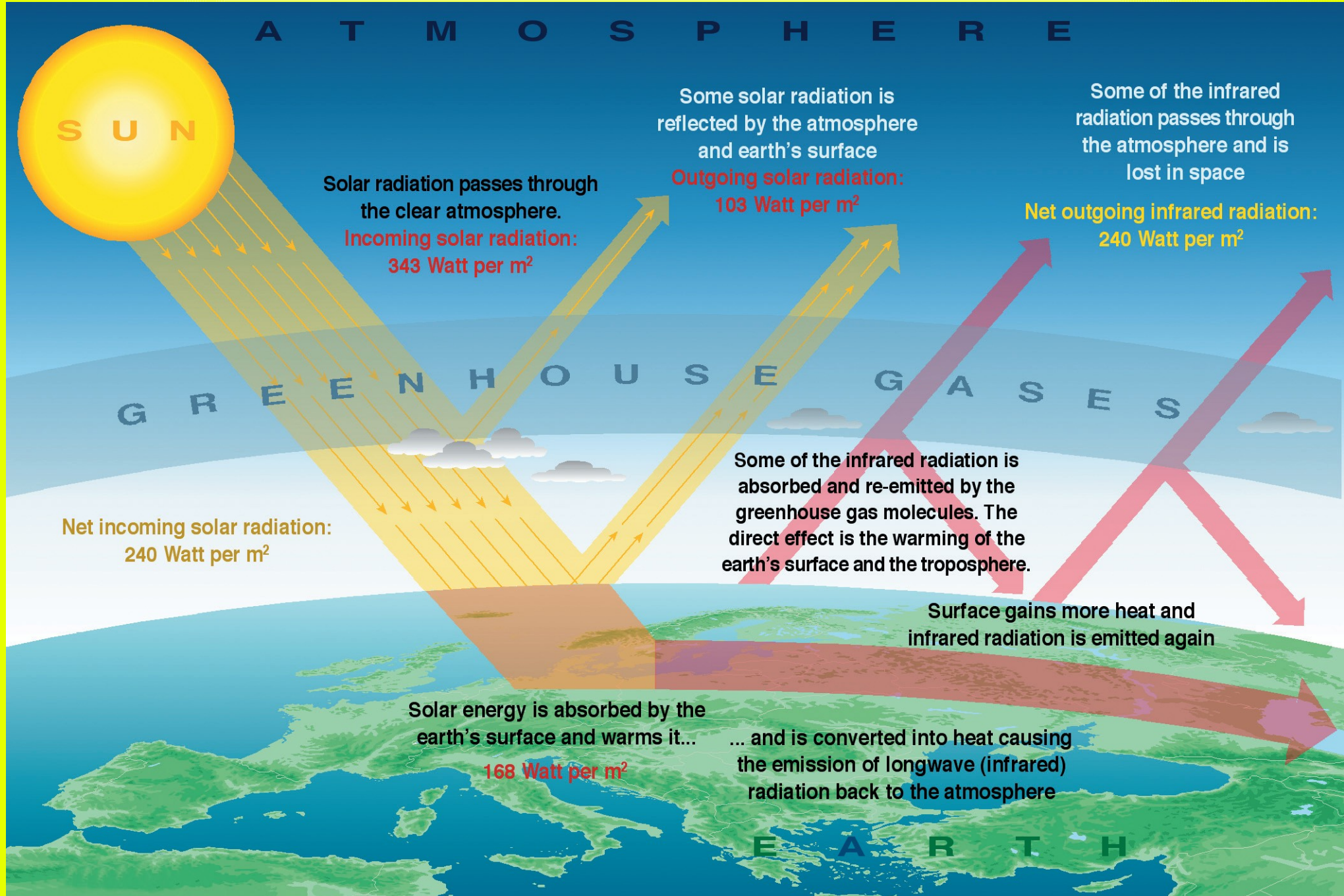
Longwave : cooling through longwave infrared (~8-14 µm) radiation into space

342W/m2 Shortwave solar reaching top of Atmosphere (TOA)
77 Reflected by Atmsophere clouds
67 Absorbed by atmosphere

198W/m2 reach the surface of earth

30 Reflected by earth surface : Longwave
168 Absorbed by earth surface

In total 107 W/m2 reflected by atmosphere + earth surface
235 W/m2 absorbed by atmosphere + earth surface


ATMOSPHERE
SUN
Solar radiation passes through the clear atmosphere.
Incoming solar radiation:
343 Watt per m²
Some solar radiation is reflected by the atmosphere and earth's surface
Outgoing solar radiation:
103 Watt per m²
Some of the infrared radiation passes through the atmosphere and is lost in space
Net outgoing infrared radiation:
240 Watt per m²
GREENHOUSE GASES
Some of the infrared radiation is absorbed and re-emitted by the greenhouse gas molecules. The direct effect is the warming of the earth's surface and the troposphere.
Net incoming solar radiation:
240 Watt per m²
Surface gains more heat and infrared radiation is emitted again
Solar energy is absorbed by the earth's surface and warms it...
168 Watt per m²
... and is converted into heat causing the emission of longwave (infrared) radiation back to the atmosphere
EARTH

3. Planetary Problems & Some 'engineering' proposals

3.1 Localizing Human Interventions

3.2 Threat of Irreversible 'Tipping points'?

Arctic - Antarctic - Greenland

3.3 Large Scale Impacts

Mountain Glaciers

Desertification

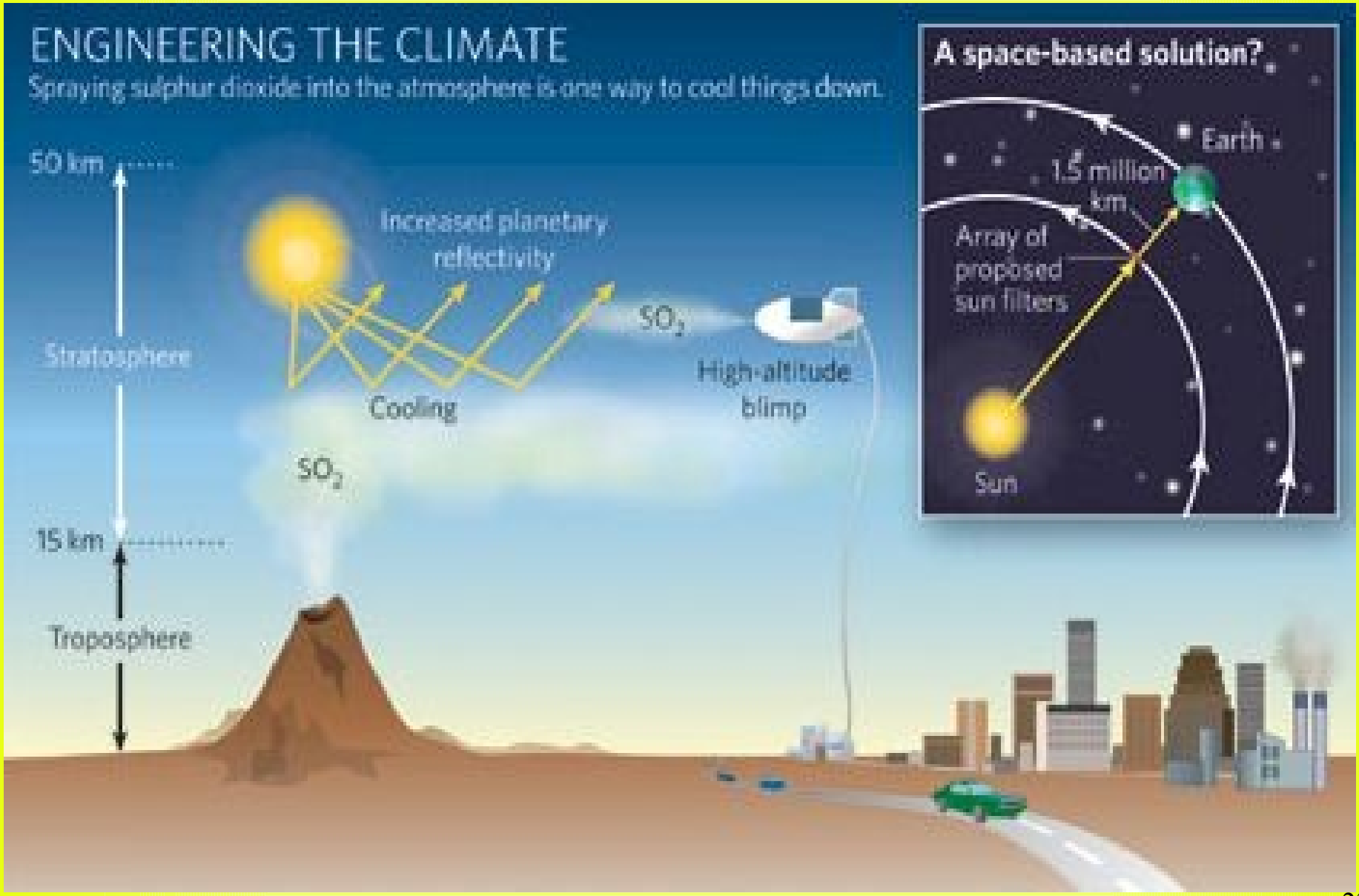
Bio-diversity

3.1 Human Intervention: Climate Engineering

Shortwave : reducing amount of absorbed solar radiation
GHG concentration reduction

Either : reducing solar radiation reaching at top of atmosphere
Or : increasing reflection of Albedo : atmosphere or surface

Longwave : increasing radiation emitted by the earth


ENGINEERING THE CLIMATE
Spraying sulphur dioxide into the atmosphere is one way to cool things down.
50 km
Stratosphere
15 km
Troposphere
Increased planetary reflectivity
Cooling
SO_2
SO_2
High-altitude blimp
A space-based solution?
Earth
1.5 million km
Array of proposed sun filters
Sun

Estimated radiative forcing potential to alter planetary albedo

Option	Area (m2)	Fraction of Earth *f*Earth	RF (Wm−2)
Increase atmospheric albedo			
Stratospheric aerosols	5.1×10+14	1	−3.71
Cloud albedo-mechanical	8.9×10+13	0.175	−3.71
Cloud albedo-biological	5.1×10+13	0.1	−0.016
Increase surface albedo			
Desert	1.0×10+13	0.02	−1.74
Grassland	3.85×10+13	0.075	- 0.64
Cropland	1.4×10+13	0.028	−0.44
Human settlement	3.25×10+12	0.0064	−0.19
Urban areas	2.6×10+11	0.00051	−0.010

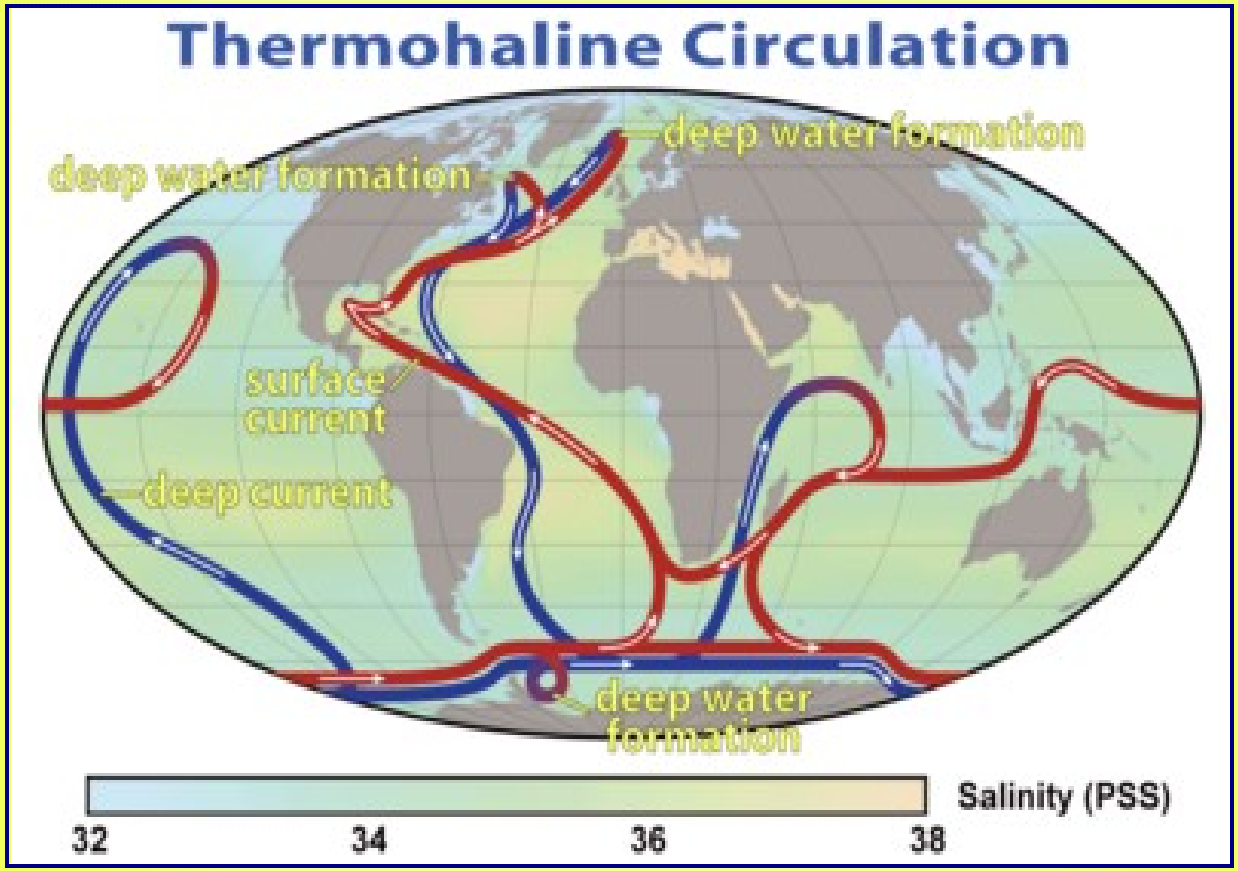
(T. Lenton, 2006)

Estimated maximum radiative forcing potential of carbon cycle geo-engineering options.

Option	2050		2100			3000	
	ΔCO2 (ppm)	RF (Wm−2)	ΔCO2 (ppm)	RF (Wm−2)	∑*C*seq (PgC)	ΔCO2 (ppm)	RFfinal (Wm−2)
Enhance land carbon sink							
Afforestation	−41	−0.49	−34	−0.37	183	−16	−0.27
Bio-char production	−10	−0.12	−37	−0.40	399	−34	−0.52
Air capture and storage	−58	−0.69	-186	−1.99	>1000	>|−85|	>|−1.43|
Enhance ocean carbon sink							
Phosphorus addition	−6.5	−0.077	−14	−0.15	574	−52	−0.83
Nitrogen fertilisation	−4.5	−0.054	−9.3	−0.10	299	−25	−0.38
Iron fertilisation	−9.0	−0.11	-19	−0.20	227	−19	−0.29
Enhance upwelling	−0.1	−0.0017	−0.3	−0.0032	16	−1.9	−0.028
Enhance downwelling	−0.08	−0.00095	−0.18	−0.0019	9	−1.1	−0.016
Carbonate addition	−0.4	−0.0048	−2.3	−0.025	251	−30	−0.46

3.2 Tipping points. Some policy-relevant points

Tipping element	Feature of system, F (direction of change)	Global warming	Key impacts & timescale, T
Arctic summer sea-ice	Areal extent (-)	+0.5–2°C	amplified warming, ecosystem change ~10yr
Greenland ice sheet (GIS)	Ice volume (-)	+1–2°C	Sea level +2–7 m 300yr
West Antarctic ice sheet (WAIS)	Ice volume (-)	+3–5°C	Sea level + 5 m 300yr
Atlantic thermohaline circulation (THC)	Overturning (-)	+3–5°C	Regional cooling, Sea level ~100yr
El Niño–Southern SE Oscillation (ENSO)	Amplitude (+)	+3–6°C	Drought in Asia and elsewhere ~100yr


Thermohaline Circulation
deep water formation
deep water formation
surface current
deep current
deep water formation
Salinity (PSS)
32
34
36
38

(NASA)

3.3 Large Scale Impacts

Himalayas

Seven of Asia's great river systems : the Brahmaputra, the Ganges, the Huang He, the Indus, the Mekong, the Salween and the Yangtze—will be affected.
These river systems provide water and sustain food supplies for over **2 bio people**.

China

At current rates 2/3 of China's glaciers -including Tien Shan- will disappear by 2060, with total melting by 2100. The Gangotri glacier, one of the main water reservoirs for **500 million** people living in the Ganges basin, is shrinking by 23 meters a year.

China-Tibet plateau

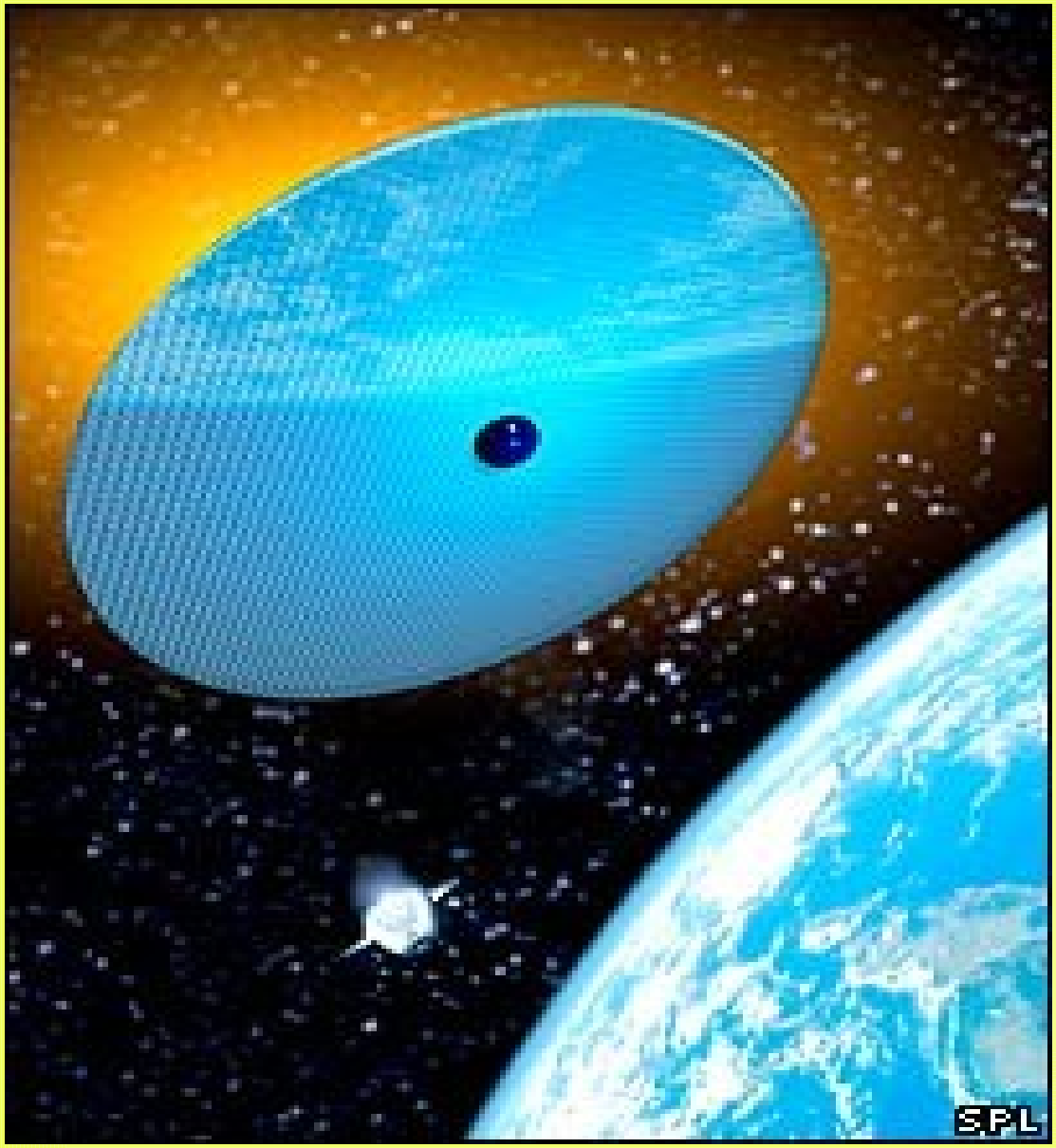
Glaciers on the Qinghai-Tibet plateau, a barometer of world Climate conditions and the source of the Yellow and Yangtze rivers, have been melting by 7 % a year.

Examples of 'engineering' proposals :
[In search of a 'Benchmarking Methodology']

- Sunshade
- Reforestation: UNEP Billion Tree Campaign
- Iron Spray
- Heat Islands
- Bio-char
- CO2 capture: CCS

Benchmarking Proposals : Climate Engineering, Mitigation & Adaptation (RW 26.05.2009)

Proposed Solutions	Radiative GHG	Science Technology	Spatial Scale	Frequency Intervention	End of Pipe	Large Scale	New Tech. Innovative	Pilot/ Applied
1. Climate Engineering. Solar Radiation Management-SRM (Applicable and Financed by International Authoritiy)								
1.1 Space Mirror	Radiative	Physics	Outer Space	Once	Y	Planetary	Y	N
1.2 Space Multi. Mirror	Radiative	Physics	Outer Space	Once	Y	Planetary	Y	N
1.3 Aerosol Sulfur	Radiative	Chemist.	Stratosphere	~Yearly	Y	Planetary	Y	Simulation
1.4 Spray Seawater	Rad-Cloud	Chemist.	Lower Troposph.	~Yearly	Y	Ocean	Y	Pilot
1.5 Heat Island	Rad-Cloud	Aerodynamics	Lower Troposph.	continuous	Y	Local	Y	?
1.6 Surface Albedo	Radiative	Phys/Chem	Earth	?	Y	Local	Y	?
2. Mitigation (Applicable by Private Business & National Authority)								
2.1 Renewable/Carbon-Free	GHG	Energy	Earth	continuous	N	Distributed	N	Applied
2.2 Space Solar Power	GHG	Phyiscs	space	Once	N	Planetary	Y	N
2.3 Sequestration-CCS	GHG	Mechan.	Ocean-Earth	Project Based	N	Power PL	N	Applied
2.4 Bio-Char Sequestration	GHG	Pyrolysis	Soil	continuous	Y	Distributed	Y	Pilot?
2.5 Reforestation	GHG	Biology	Earth	continuous	Y	Distributed	N	Applied
2.6 Geochemical	GHG/CO2	Chemistry	Ocean	continuous	Y	Specific	N	N
2.7 Iron/Algae	GHG	Biology	Oceans	continuous	Y	Specific	N	Pilot
3. Adaptation (Applicable by Private Business & National Authority)								
3.1 Electro/Cloud	Wheather	Electro	Lower Troposph.	~Timely	Y	+/-	+/-	Pilot
3.2 Sea Level			Earth					
3.3								



(M. Bentley, 2006)

UNEP The Billion Tree Campaign. (Mrs. Wangari Maathai)

Worldwide deforestation continues about 13 million hectares per year, an area the size of Greece.

In Africa nearly half of the forest loss was due to removal of wood fuel. Forests in Europe are expanding.

Asia, which had a net loss in the 1990s, reported a net gain of forests in the past five years, primarily due to large-scale forestation in China.

Started	:	End 2006		
Planted	:	First billion in November 2007		
As of today	:	Planted	:	2,291,493,625
		Pledged	:	3,887,424,329
		Target end 2009	:	7,000,000,000

Iron spray in Oceans (ETC. Gambling with Gaia, 2007 p. 6)

1993	**IRONEX I**
1995	**IRONEX II**
1999	**SOIREE**
	CARUSO
2001	**SEEDS**
2002	**SOFeX**
	SERIES
2004	**SEEDS II**
	EIFEX

4. New World Visions

4.1 Gaia Hypothesis (James Lovelock)

The Earth system is a self-regulating system comprising the atmosphere, oceans and surface rocks and all the organisms, including humans. (Phil. Trans. R. Soc., 2008).

.... the Gaia hypothesis views the biosphere as an active, adaptive control system able to maintain the earth in homeostasis.

4.2 Anthropocene Prof. Paul Crutzen

On the Anthropocene. ..... we propose the latter part of the 18th century, although we are aware that alternative proposals can be made (some may even want to include the entire holocene).
..... Such a starting date also coincides with James Watt's invention of the steam engine in 1784. (IGBP Newsletter, 2000)

4.3 New Copernican Revolution (H. J. Schellnhuber)

Sophisticated information-compression techniques incl. simulation modeling are now ushering in a second 'Copernican' revolution.

...strives to understand the 'Earth System' as a whole and to develop, on this cognitive basis, concepts for global environmental management. (Nature, 1999)

5. Conclusions

- **Resilience of the GAIA System is threatened : Irreversible TIPPING points?**

- **The non-linear behavior of Climate systems requires : URGENCY of Action**

- **When 'politics' fails, 'engineering' as a LAST RESORT?**

James E. Hansen

Testimony to US Congress June 23 2008, twenty Years after the one on June 23 1988

CEOs of fossil energy companies know what they are doing and are aware of the long-term consequences of continued business as usual. In my opinion, these CEOs should be tried for high crimes against humanity and nature.

(In Guest Opinion: Global Warming Twenty Years Later 2008)

Al Gore

.....to accept this challenge – for America to be running on 100 percent zero-carbon electricity in 10 years. It's time for us to move beyond empty rhetoric. We need to act now.

Lester Brown

....BAU will not continue for much longer. Massive change is inevitable. Will the change come because we move quickly to restructure the economy, or because we fail to act and civilization begins to unravel. Saving civilization will take a massive mobilization, and at wartime speed. (Plan B3.0, 2008)