Climate Modelling

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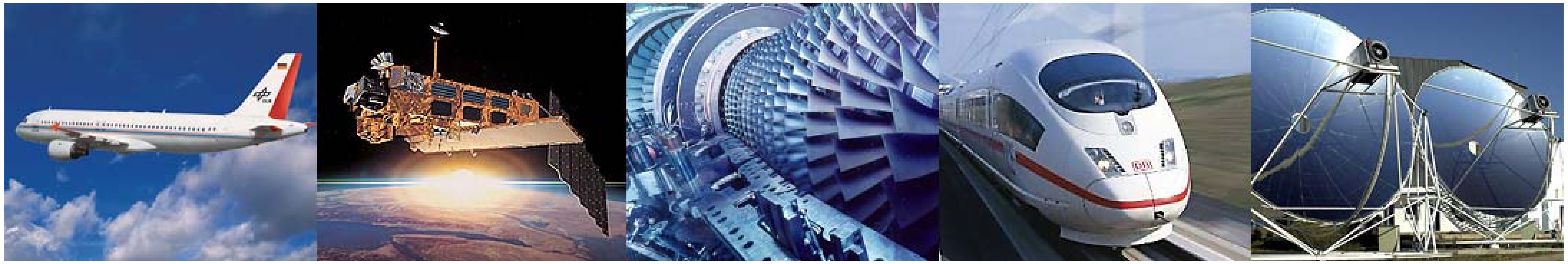
ESPACE-Seminar *Earth System Dynamics*
Institut für Astronomische und Physikalische Geodäsie
Technische Universität München
11. Januar 2010

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

German Aerospace Center

Das Deutsche Zentrum für Luft- und Raumfahrt

DLR
German Aerospace Center



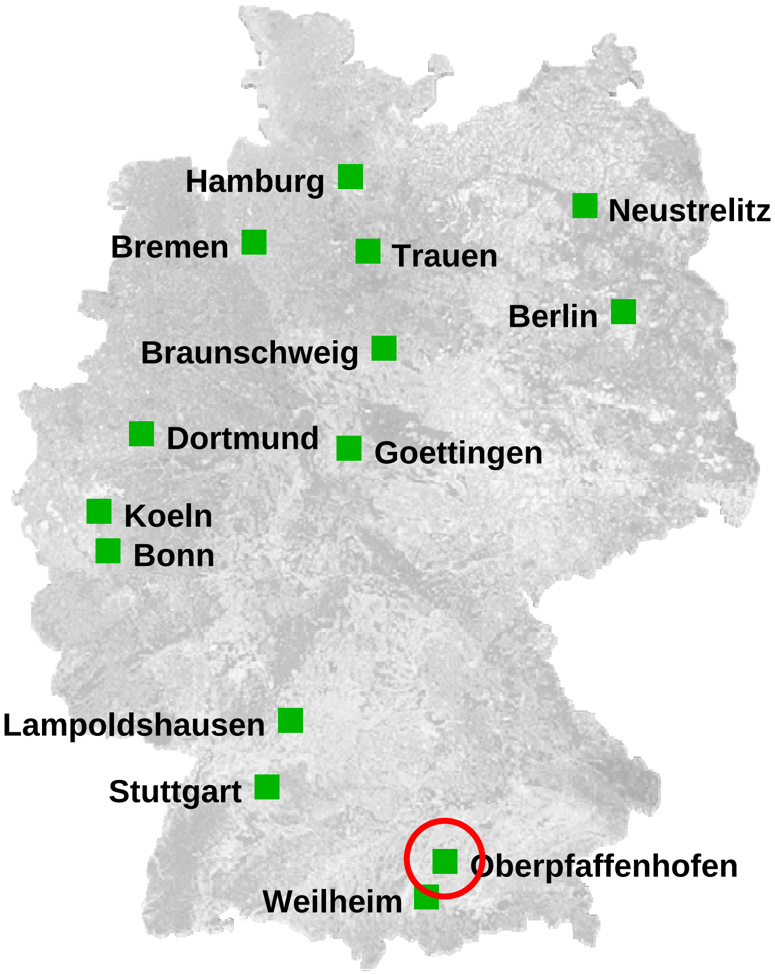
- Research Institution
- Space Agency
- Project Management Agency

Locations and employees

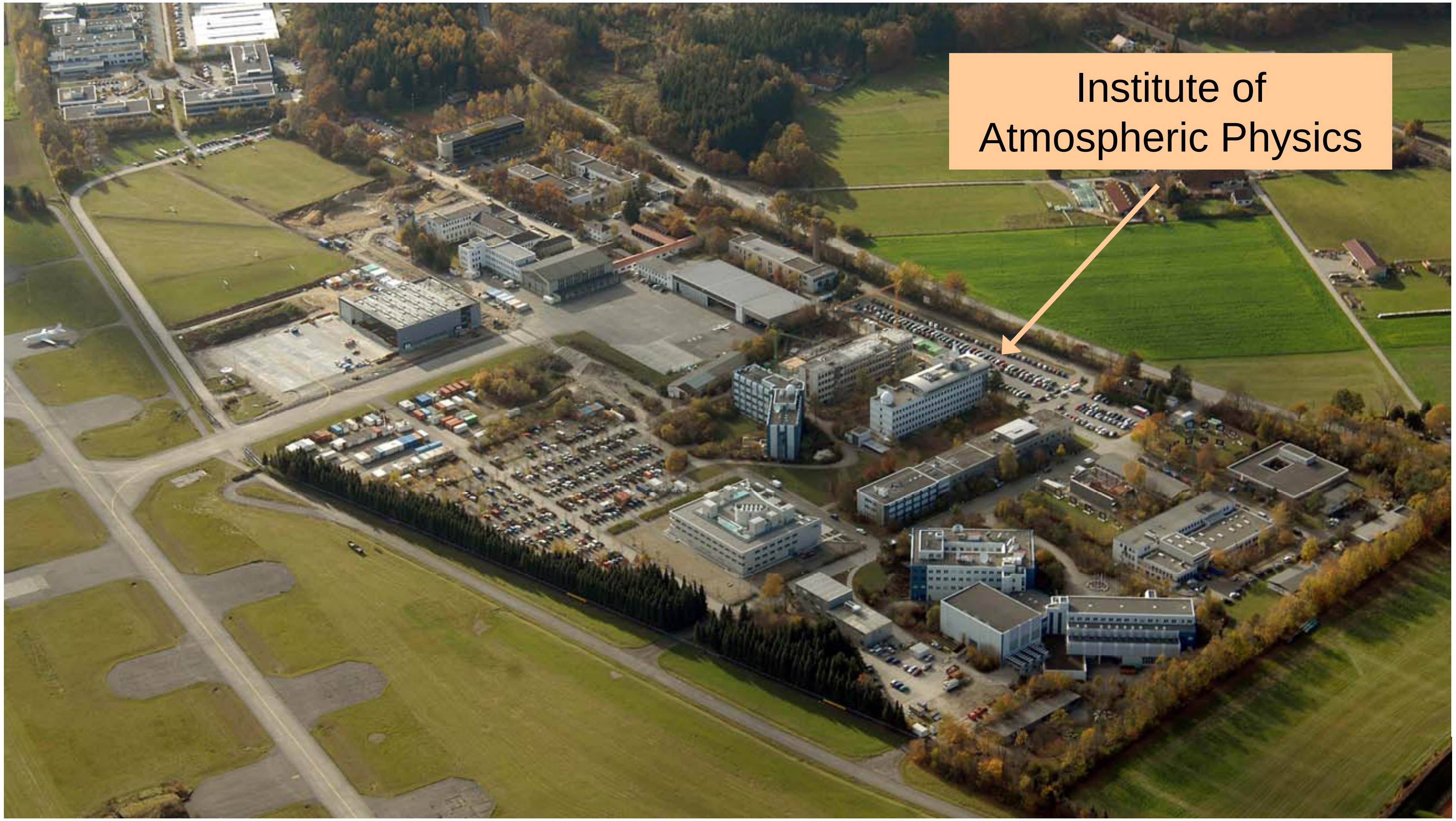
6500 employees across
29 research institutes and
facilities at

- 13 sites.

Offices in Brussels,
Paris and Washington.

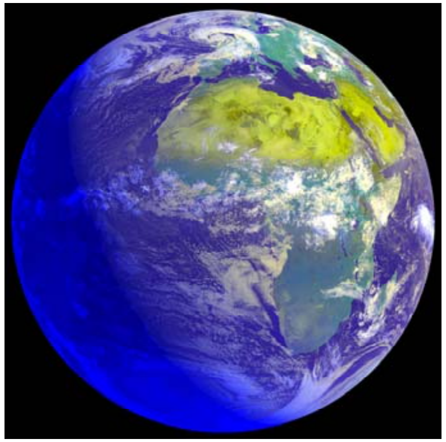


DLR site at Oberpfaffenhofen



The Institute of Atmospheric Physics

Das Institut für Physik der Atmosphäre (IPA)



Research on Atmospheric Physics:

Atmospheric Research: dynamics, composition, radiative transfer, cloud physics

Climate: the recent and the current century

Meteorology: observation and prediction methods

Research for weather-efficient and climate compatible **Aviation**

Development and application of **Earth Observation** methods

Research for sustainable **Transport** and Mobility

Development of the required **Methods**

Application und **Exploitation** of results

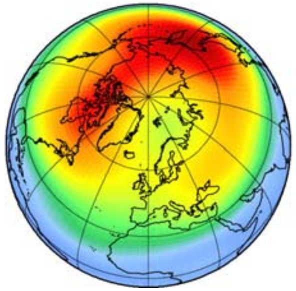
Training of young researchers and students

10.01.2010

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Institute of Atmospheric Physics
Prof. U. Schumann

Atmospheric Dynamics
Prof. R. Sausen



Coupled climate-chemistry models

Models of sound propagation

Extreme events

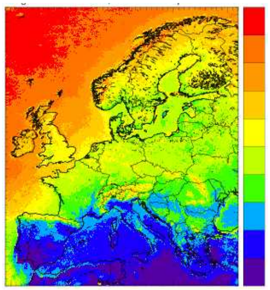
Atmospheric Trace Species
Dr. H. Schlager

Instruments for NOx, CO, CO_2, H_2O, SO_2, HNO_3, O_3, Aerosole, ...

Falcon, HALO

Process models: aerosols and clouds

Remote Sensing of the Atmosphere
Dr. R. Meerkötter
Prof. B. Mayer (LMU)



Remote sensing of clouds

3D radiative transport models

Weather and Aviation
Dr. T. Gerz
Prof. G. Craig (LMU)

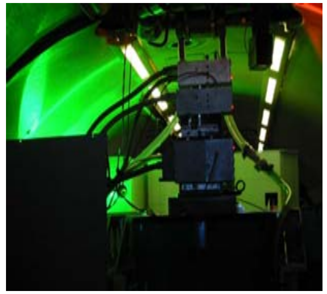
Cloud Radar

Detection of lightning

Models for wake vortices and weather prediction

Cloud physics models

Lidar
Dr. G. Ehret



Tuneable lasers

Lidars for trace gases and wind

Lidar to space

Climate Modelling

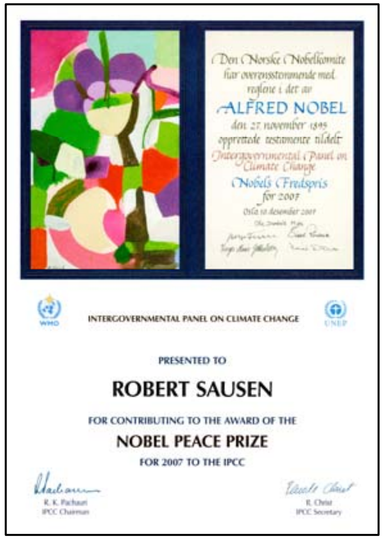
How is climate changing ?

What is the impact of transport on climate change ?

How is climate changing ?

Reports by the
Intergovernmental Panel on Climate Change

www.ipcc.ch



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How is climate changing ?

Has there been a climate change ?

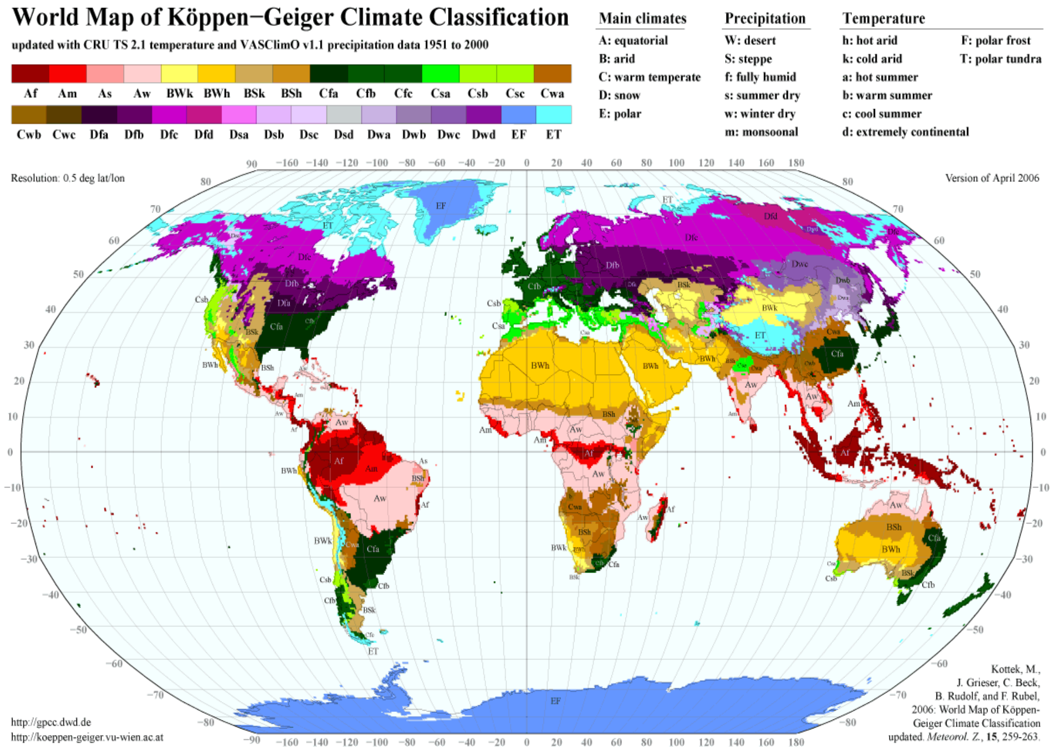
What is the impact of man ?

How will the climate develop in the future ?

What is "climate" ?

- Climate is the *statistical entity* of the mean atmospheric states and processes in a given region for a longer time period (30 years).

- Variables often considered: temperature, precipitation, near surface wind



Climates of the Earth

Kottek et al. (2006), Meterol. Z.

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Example: Retreat of Alpine glaciers

Pictures of Pasterzenzunge at Großglockner in Austria (3798 m)

about 1900	2000

Gesellschaft für ökologische Forschung, Wolfgang Zängl, http://www.gletscherarchiv.de

Bild
MÜNCHEN

3:0! Club schießt Hitzfeld ab

SCHOCKIERENDER WELTKLIMA-BERICHT

UNSER PLANET STIRBT!

● Jetzt amtlich: Erde immer heißer! ● Schlimmste Kohlendioxid-Konzentration seit 650 000 Jahren ● Immer häufiger Hitze-Wellen und Katastrophen-Wetter ● Meeresspiegel steigt dramatisch! ● Kiel, Hamburg und Rostock in Gefahr ● UND AN ALLEM IST NUR DER MENSCH SCHULD!

Live ARD
Super Bowl

NACHRICHTEN

Gesundheits-Murks-Reform beschlossen

Dreh dich mal um, Sarah Jayne

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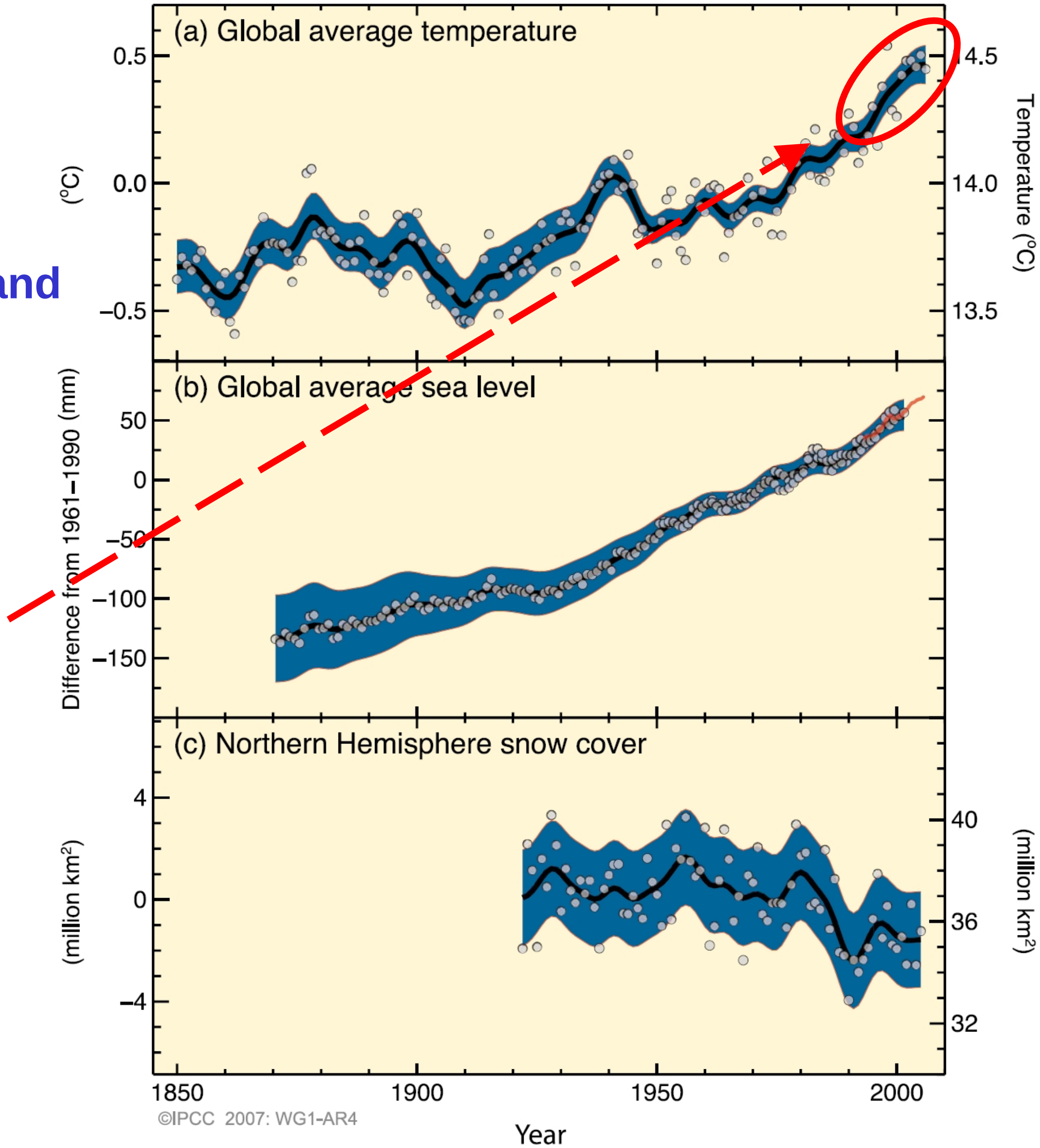
Observed changes of temperature, sea level and Northern Hemisphere snow cover

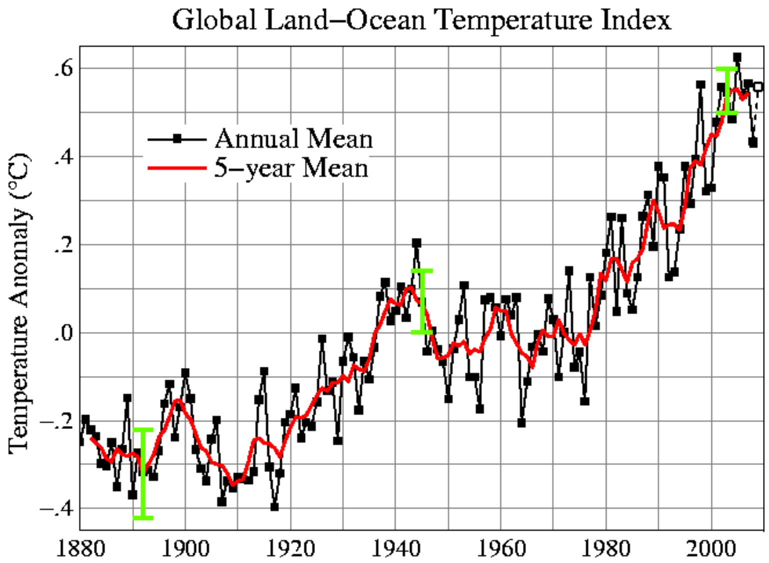


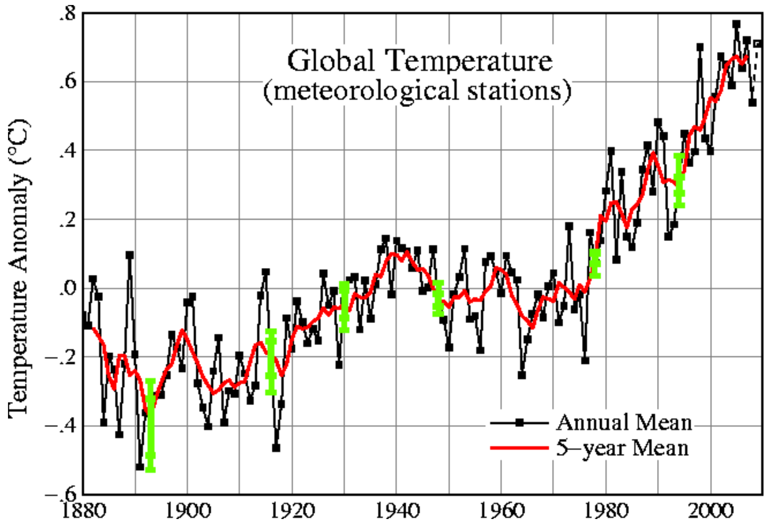
The 12 warmest years of the instrumental period (until 2006):

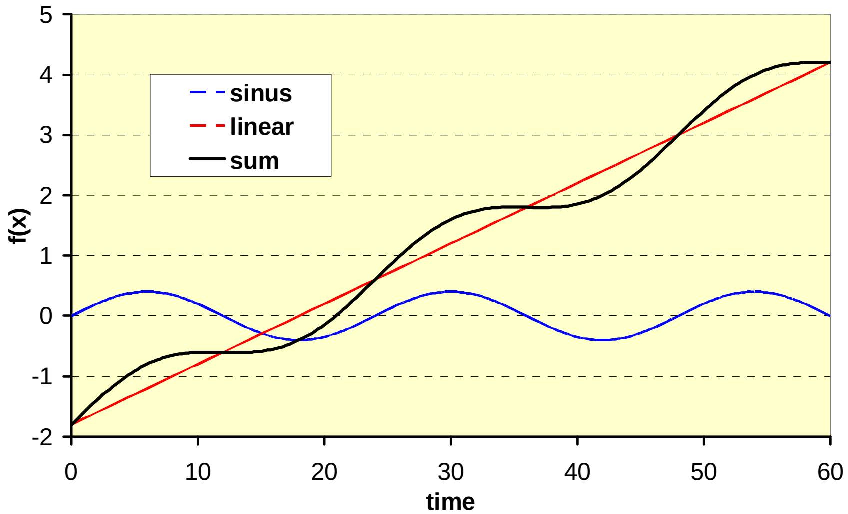
1998, 2005, 2003, 2002, 2004, 2006, 2001, 1997, 1995, 1999, 1990, 2000

IPCC, 2007, SPM

Observed temperature anomaly from 1880 until 2008 relative to mean 1951 - 1980, NASA GISS data







http://data.giss.nasa.gov/gistemp

superposition of linear curve and sinus function

Reconstructions of the Northern Hemisphere temperature during the recent 1300 years

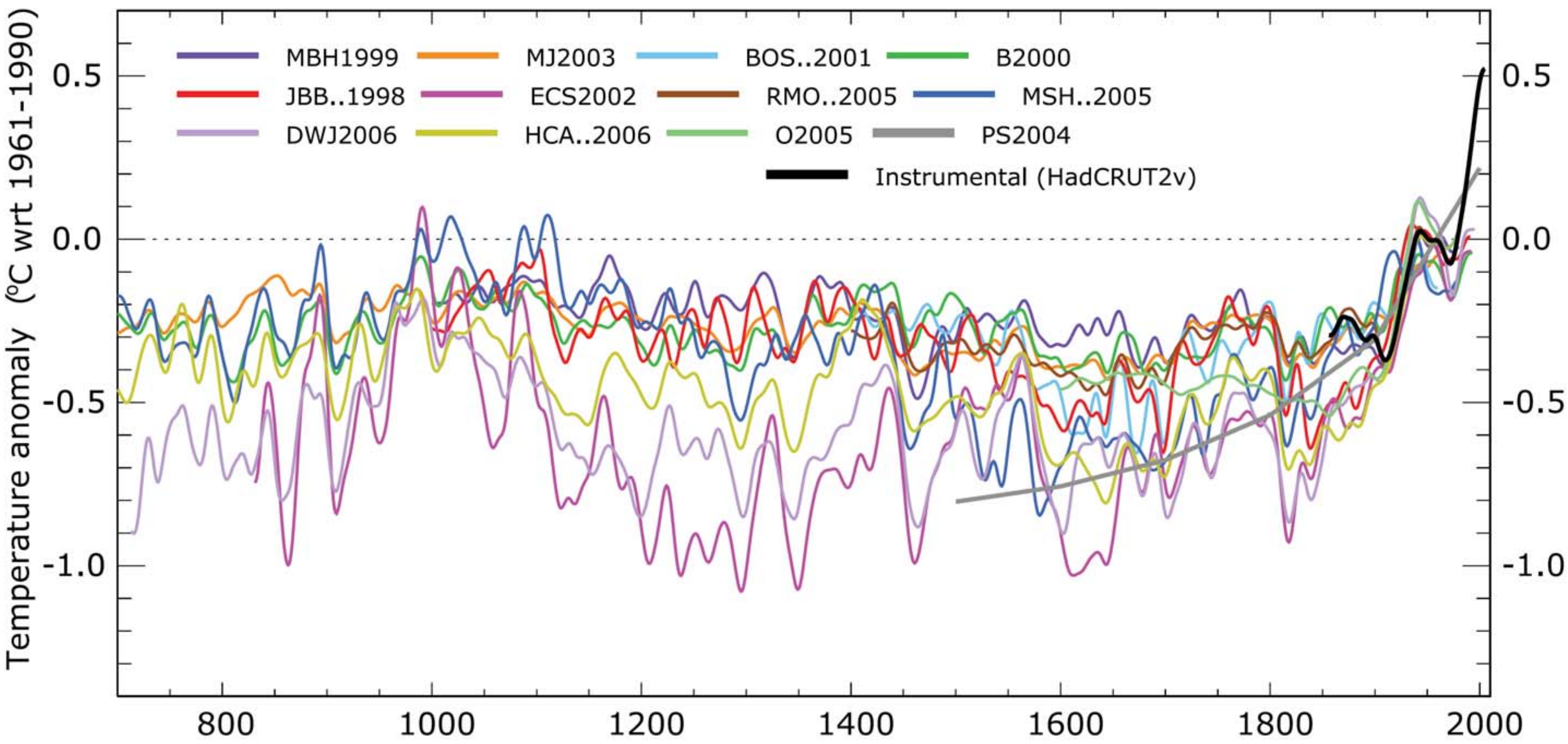


Figure TS.20. *(Top) Records of Northern Hemisphere temperature variation during the last 1300 years with 12 reconstructions using multiple climate proxy records shown in colour and instrumental records shown in black.*

IPCC, 2007

How is climate changing ?

Has there been a climate change ?

What is the impact of man ?

How will the climate develop in the future ?

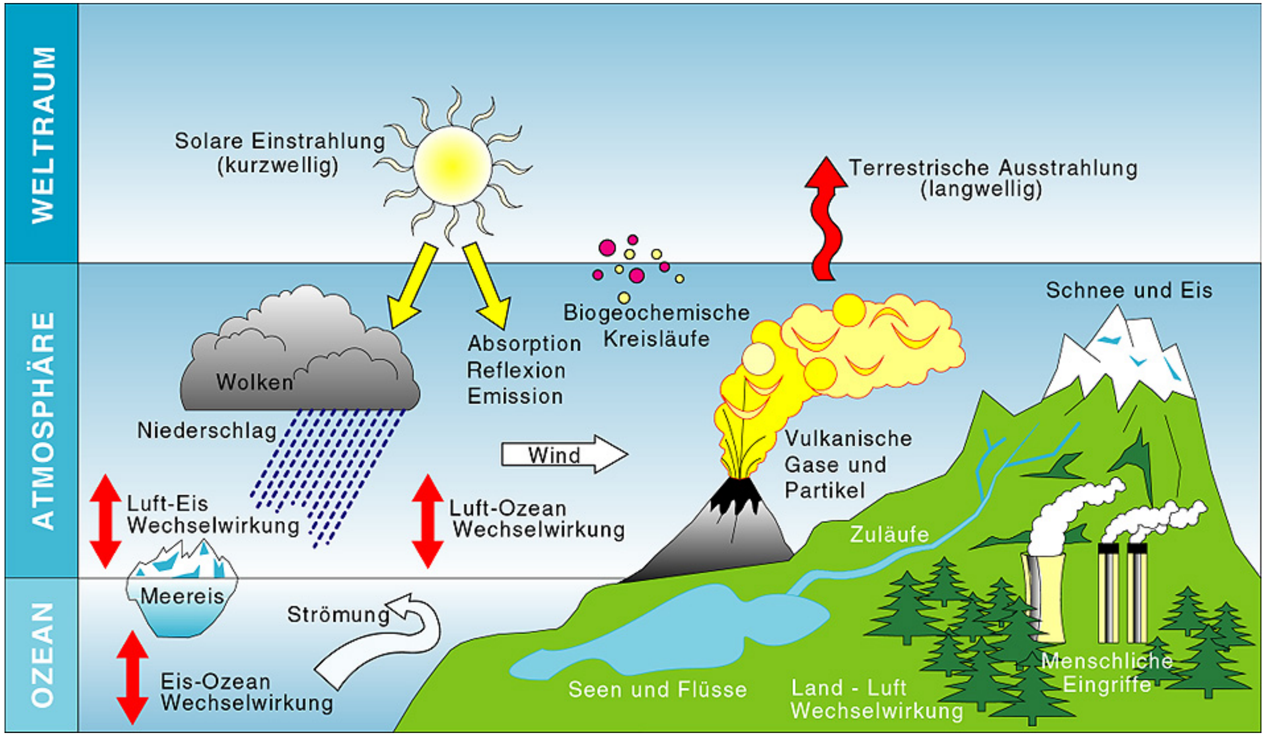
What determines our climate ?

- Solar irradiation

- Concentrations of greenhouse gases (natural and anthropogenic) and of other radiatively actives species

- Orography, land-see distribtion, soil paparameters

- . . .



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Radiative budget of the Earth: without atmosphere

equilibrium

$$\frac{S_0}{4}(1-A) = \varepsilon\sigma T_B^4$$

equilibrium of in-coming and out-going radiation

S_0 = solar constant (1368 W/m^2)

A = albedo (0.3)

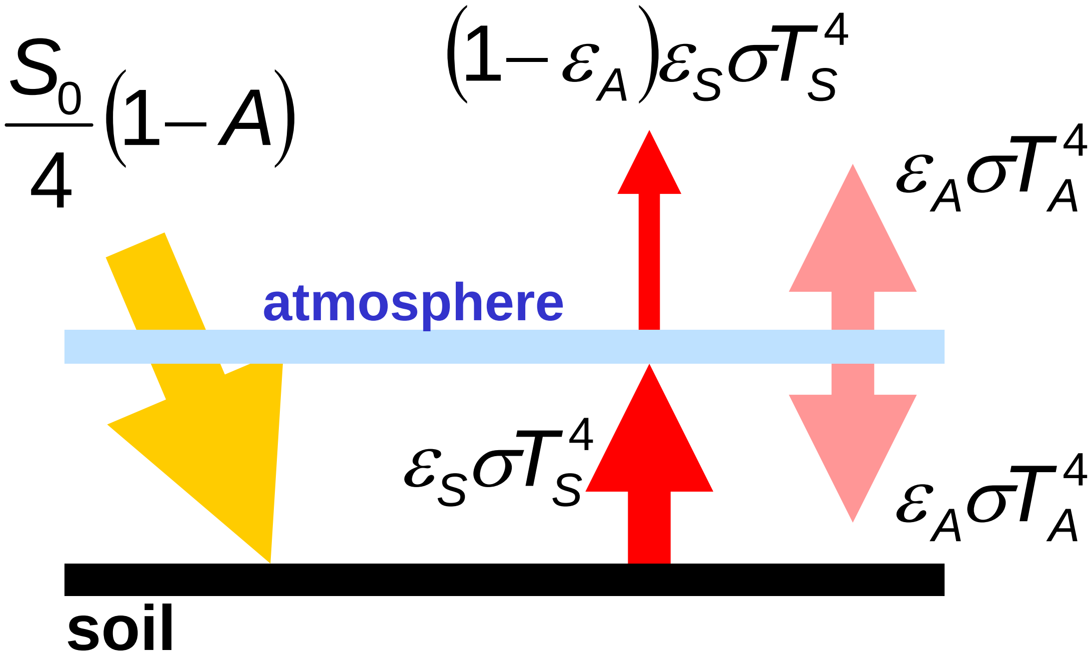
ε = emissivity of the soil (0.95)

σ = Boltzmann constant

T_S = surface temperature

$$\Rightarrow \quad T_S = \left(\frac{S_0(1-A)}{4\varepsilon\sigma}\right)^{\frac{1}{4}} = -15°C$$

Radiative budget of the Earth: with atmosphere



equilibrium of in-coming and out-going radiation

S_0 = solar constant (1368 W/m^2)

A = albedo (0.3)

ε = emissivity of the soil (0.95)

σ = Boltzmann constant

T_S = surface temperature

T_A = atmospheric temperature

$$T_S = \left(\frac{S_0(1-A)}{2\varepsilon_S\sigma(2-\varepsilon_A)}\right)^{\frac{1}{4}} = 15°C; \quad T_A = \left(\frac{S_0(1-A)}{4\sigma(2-\varepsilon_A)}\right)^{\frac{1}{4}} = -34°C$$

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Recent CO_2 concentrations and emissions

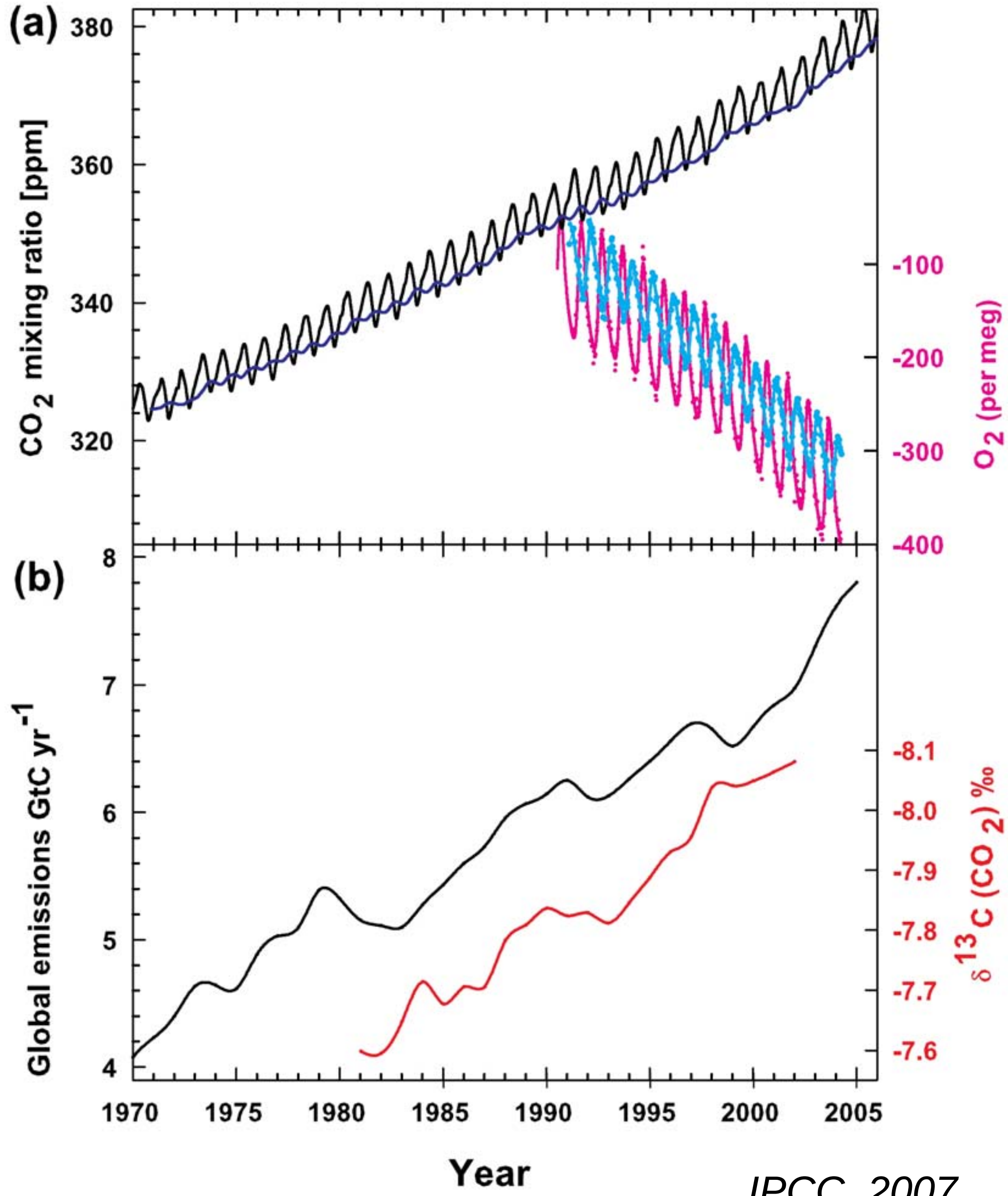


Figure 2.3. *Recent CO_2 concentrations and emissions. (a) CO_2 concentrations (monthly averages) measured by continuous analysers over the period 1970 to 2005 from Mauna Loa, Hawaii (19°N, black; Keeling and Whorf, 2005) and Baring Head, New Zealand (41°S, blue; following techniques by Manning et al., 1997). Due to the larger amount of terrestrial biosphere in the NH, seasonal cycles in CO_2 are larger there than in the SH. In the lower right of the panel, atmospheric oxygen (O_2) measurements from flask samples are shown from Alert, Canada (82°N, pink) and Cape Grim, Australia (41°S, cyan) (Manning and Keeling, 2006). The O_2 concentration is measured as 'per meg' deviations in the O_2/N_2 ratio from an arbitrary reference, analogous to the 'per mil' unit typically used in stable isotope work, but where the ratio is multiplied by 10^6 instead of 10^3 because much smaller changes are measured. (b) Annual global CO_2 emissions from fossil fuel burning and cement manufacture in GtC yr^{-1} (black) through 2005, using data from the CDIAC website (Marland et al, 2006) to 2003. Emissions data for 2004 and 2005 are extrapolated from CDIAC using data from the BP Statistical Review of World Energy (BP, 2006). Land use emissions are not shown; these are estimated to be between 0.5 and 2.7 GtC yr^{-1} for the 1990s (Table 7.2). Annual averages of the $^{13}C/^{12}C$ ratio measured in atmospheric CO_2 at Mauna Loa from 1981 to 2002 (red) are also shown (Keeling et al, 2005). The isotope data are expressed as $\delta^{13}C(CO_2)$ ‰ (per mil) deviation from a calibration standard. Note that this scale is inverted to improve clarity.*

IPCC, 2007

Results from Antarctic ice cores: C_2O, CO_2, CH_4 and deuterium (δD)

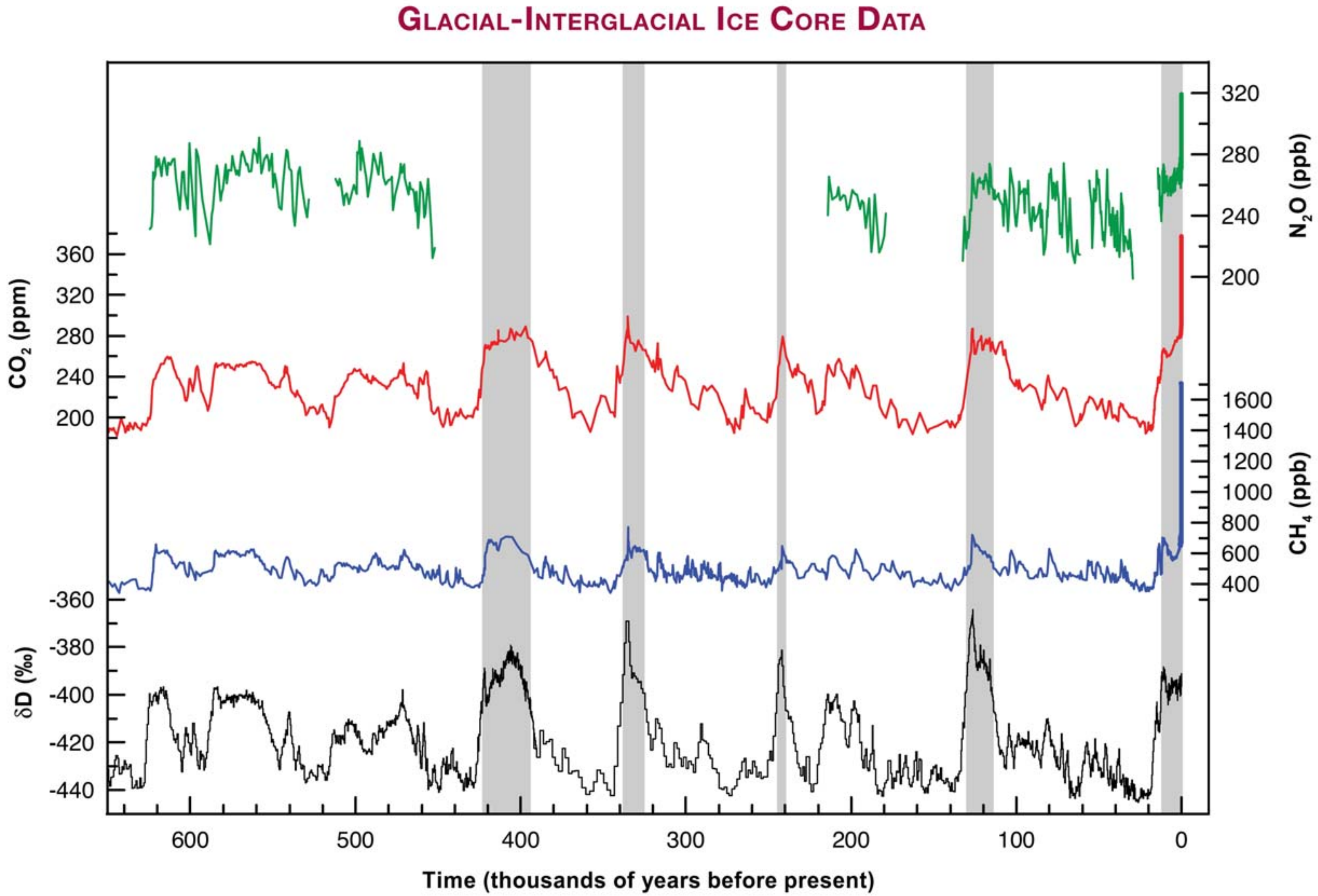


Figure TS.1. *Variations of deuterium (δD) in antarctic ice, which is a proxy for local temperature, and the atmospheric concentrations of the greenhouse gases carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in air trapped within the ice cores and from recent atmospheric measurements. Data cover 650,000 years and the shaded bands indicate current and previous interglacial warm periods. {Adapted from Figure 6.3}*

IPCC, 2007

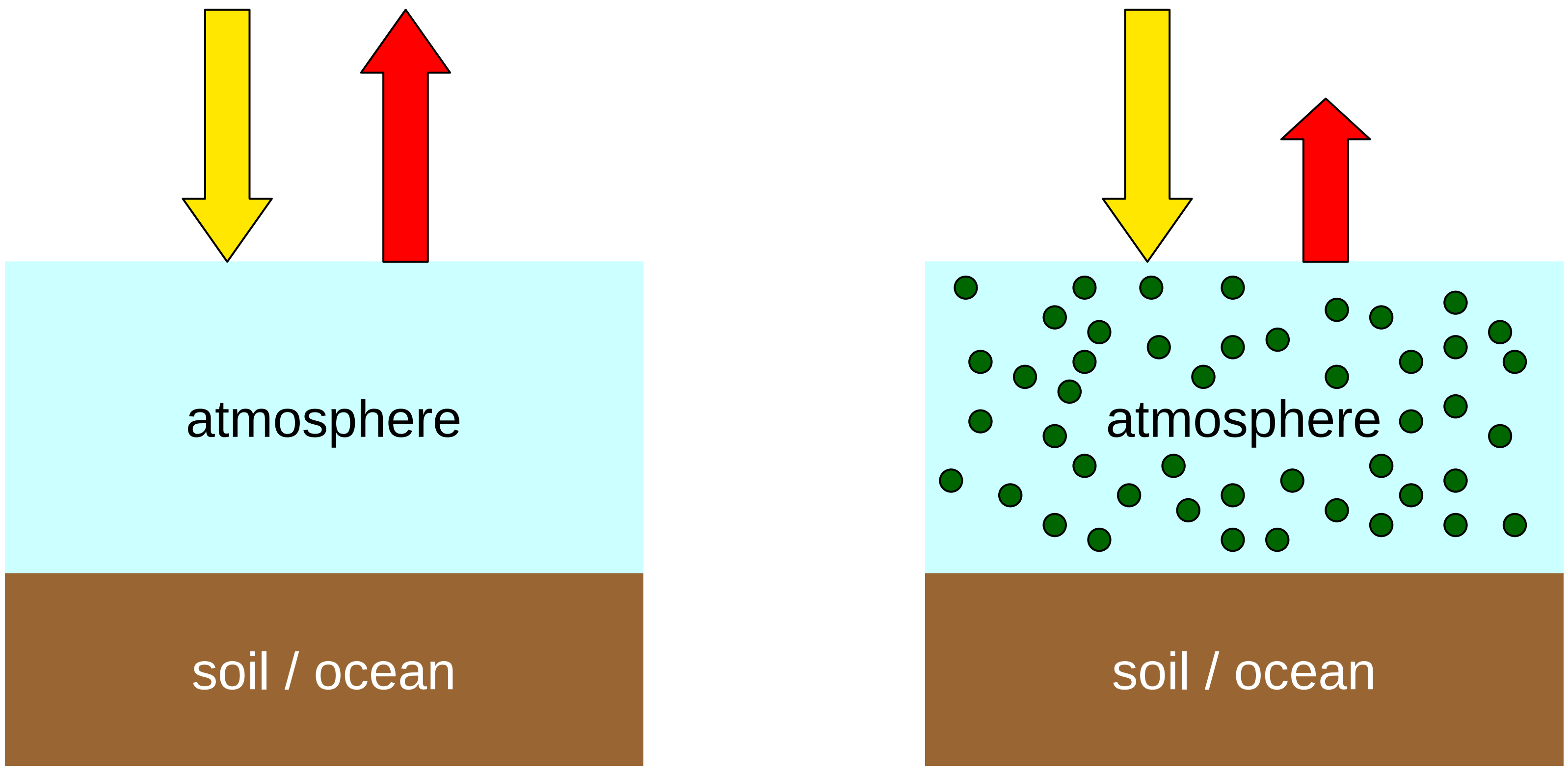
What is radiative forcing ?
(simplified)

equilibrium

$RF = 0$

perturbed situation

$RF > 0 \rightarrow \Delta T \nearrow$



What does radiative forcing tell us ?

(at first order)

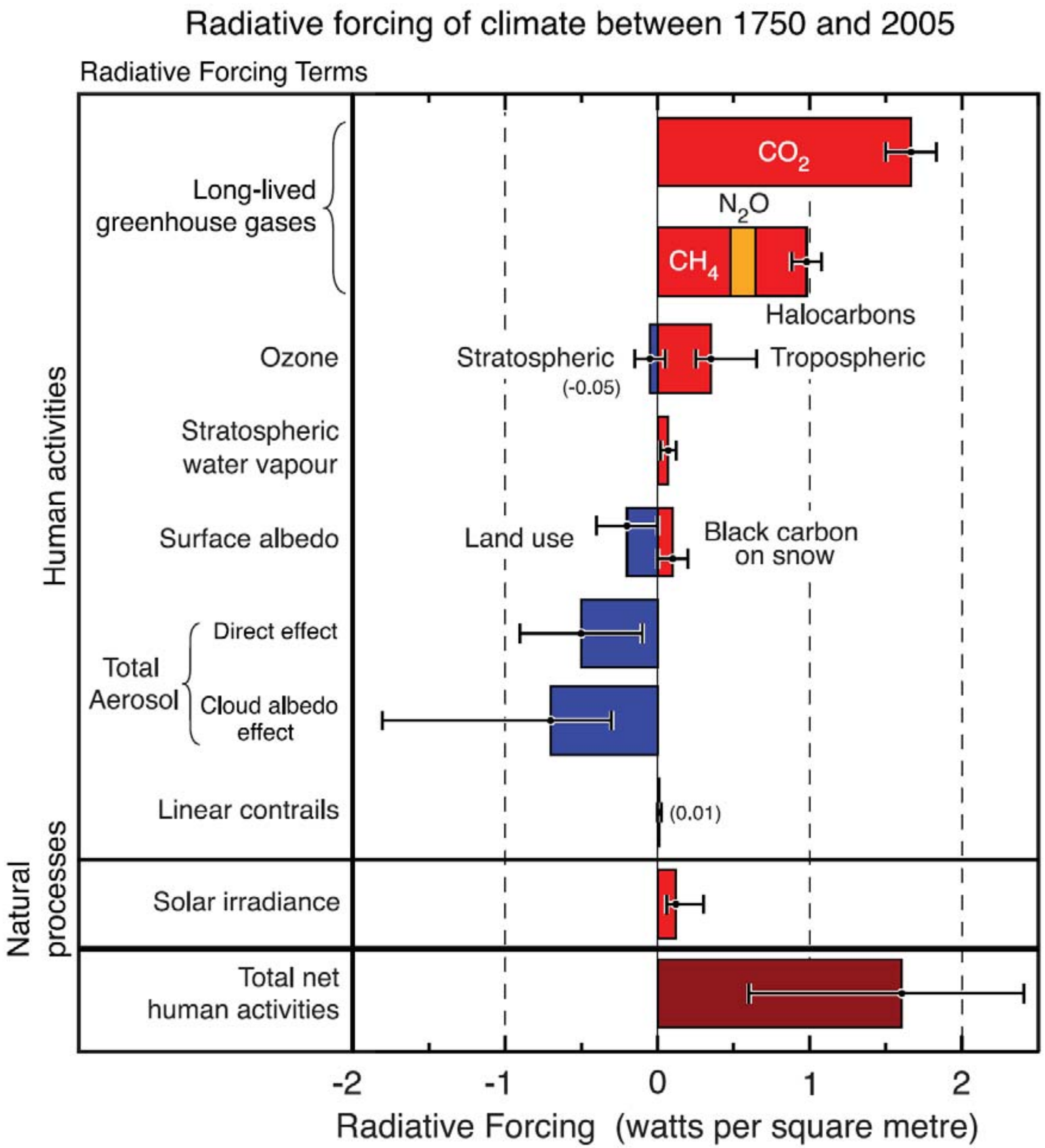
$$\Delta T_{\mathbf{surf}} = \lambda \cdot RF$$

global mean temperature (equilibrium)

radiative forcing

climate sensitivity parameter

Radiative forcing, *RF*



$$\Delta T_{surf} = \lambda \cdot RF$$

IPCC, 2007

Studying climate by means of models

What is a climate model ?

How good are climate models ?

What can they tell us about the future development of the climate ?

Studying climate by means of models

What is a climate model ?

Mapping the climate system on a system of coupled partial differential equations, which are numerically solved.

How good are climate models ?

What can they tell us about the future development of the climate ?

Studying climate by means of models

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Mapping the climate system on a system of coupled partial differential equations, which are numerically solved.

How good are climate models ?

Evaluation using many observational data

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Mapping the climate system on a system of coupled partial differential equations, which are numerically solved.

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Evaluation using many observational data

What can they tell us about the future development of the climate ?

Simulations for different scenarios of anthropogenic emissions

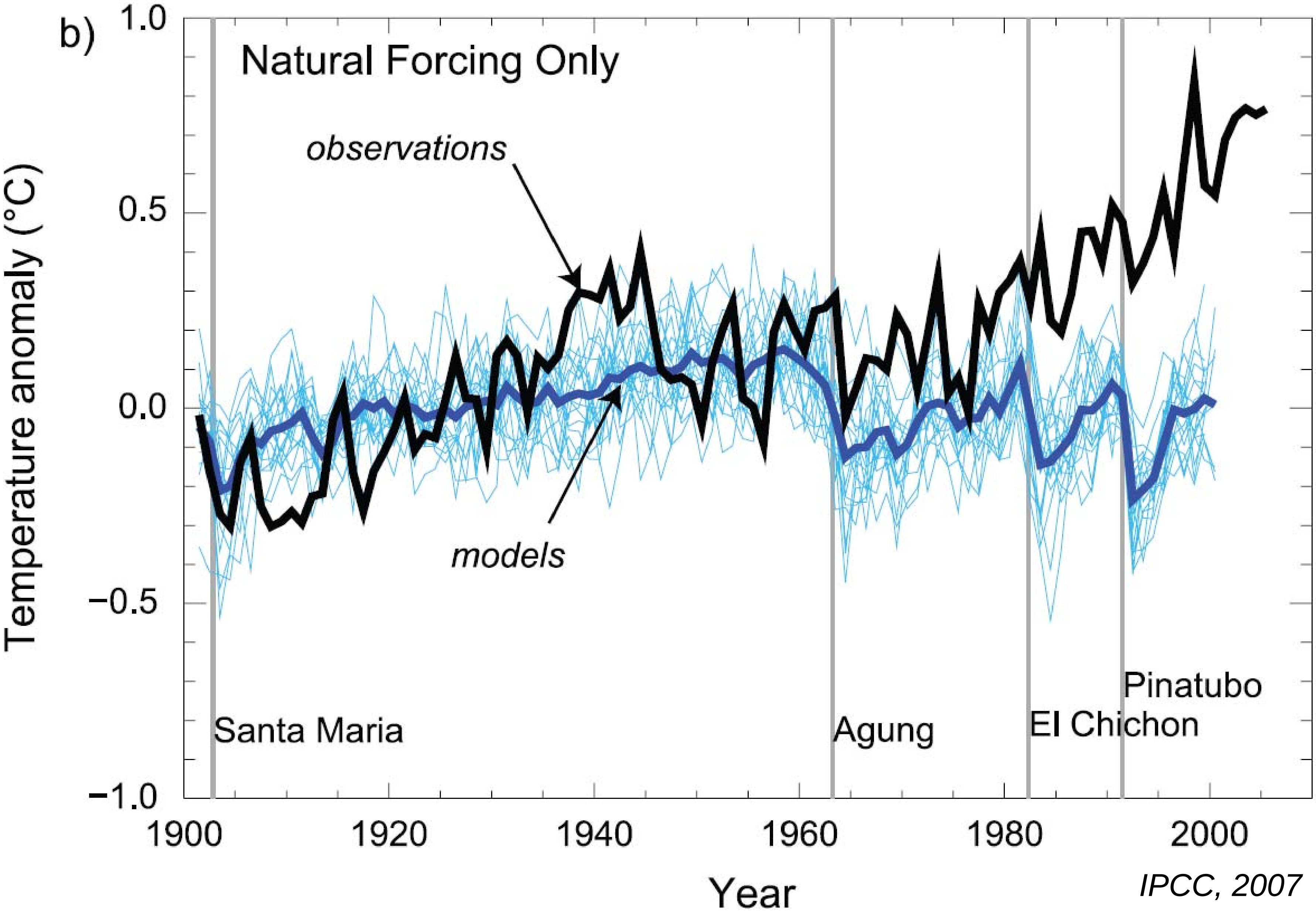
How is climate changing ?

Has there been a climate change ?

What is the impact of man ?

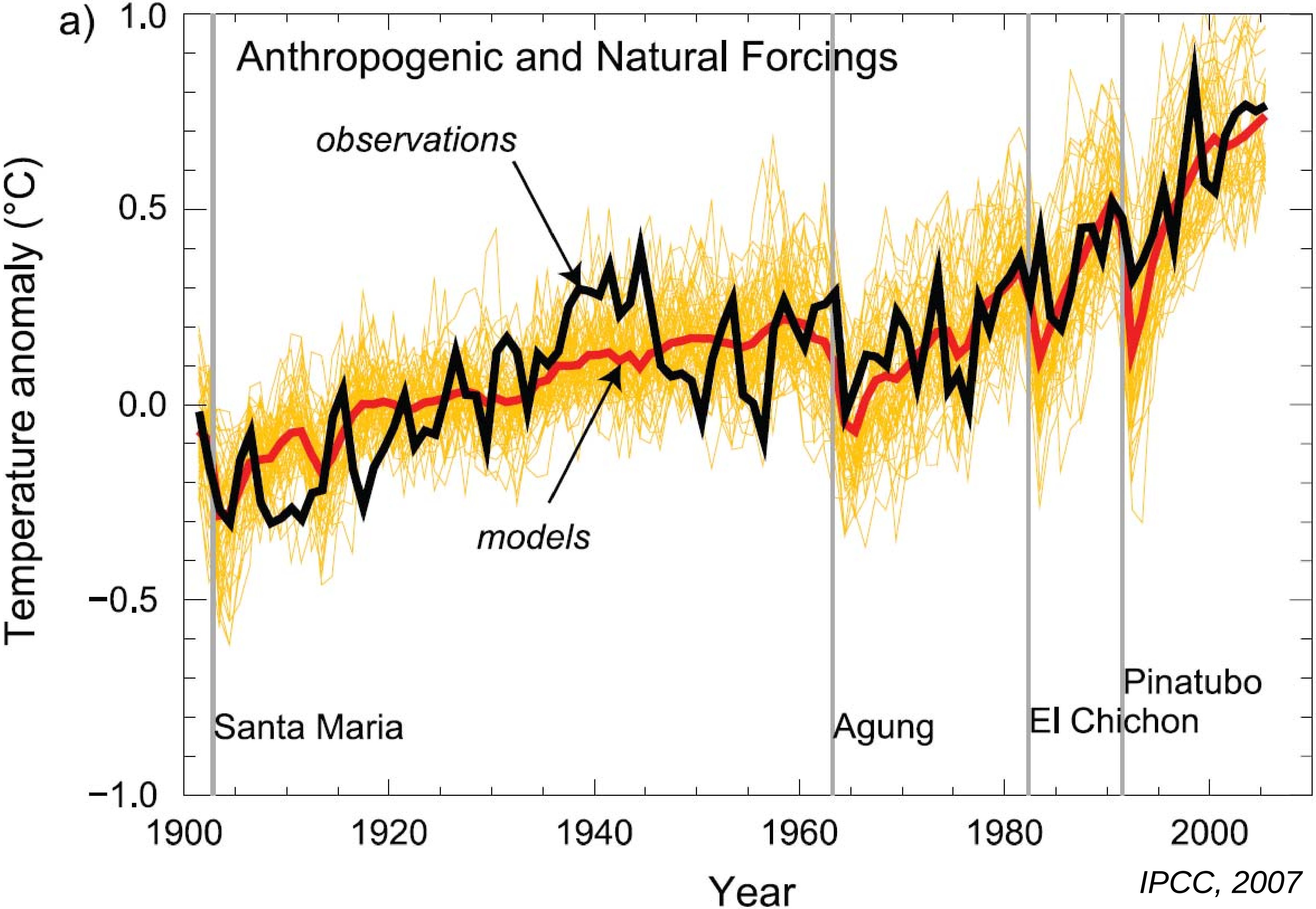
How will the climate develop in the future ?

Observed and simulated global mean temperature



IPCC, 2007

Observed and simulated global mean temperature



IPCC, 2007

How is climate changing ?

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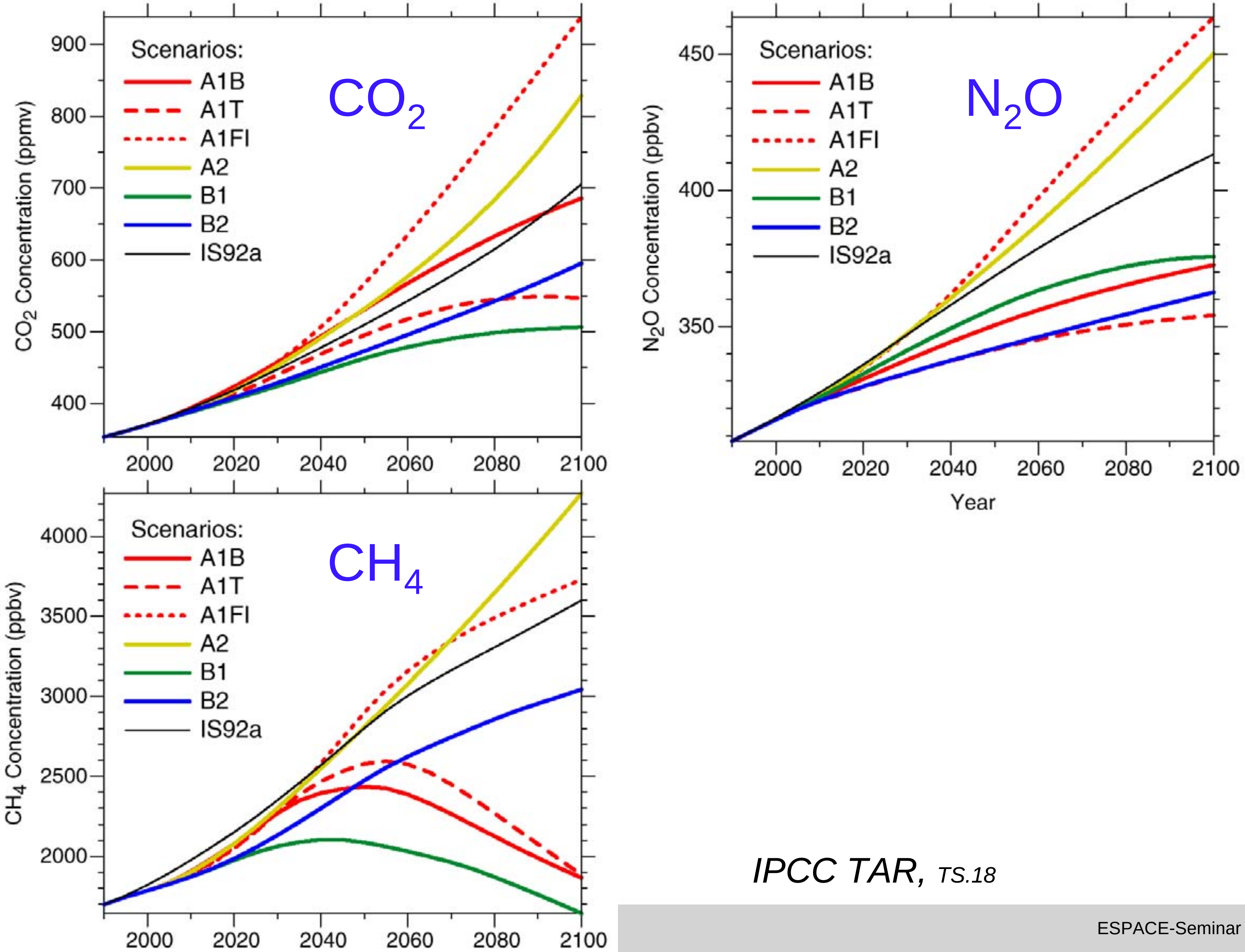
How will the climate develop in the future ?

Concentrations of well-mixed greenhouse gases for different emission scenarios



IPCC TAR, TS.18

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Temperature changes for different emission scenarios

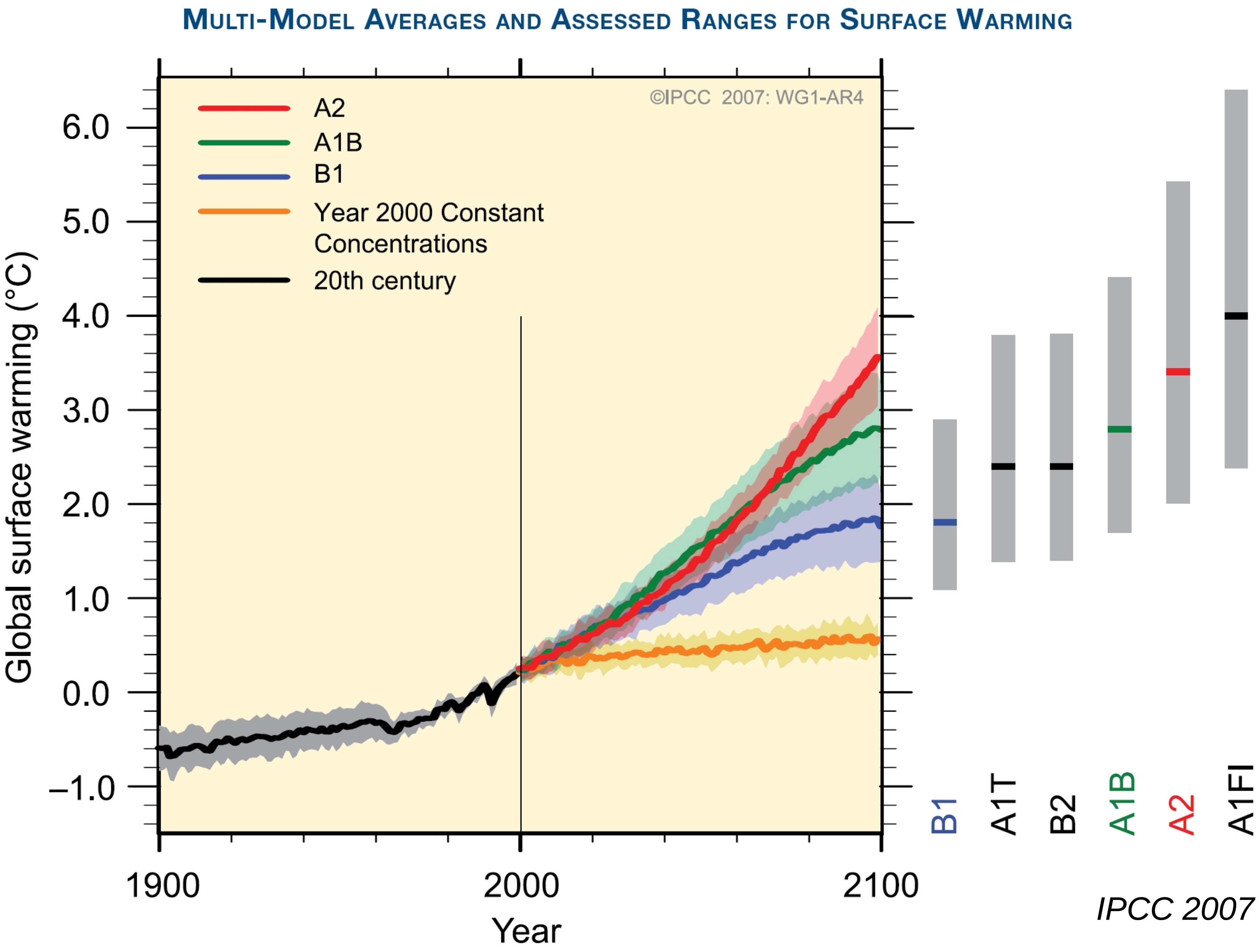
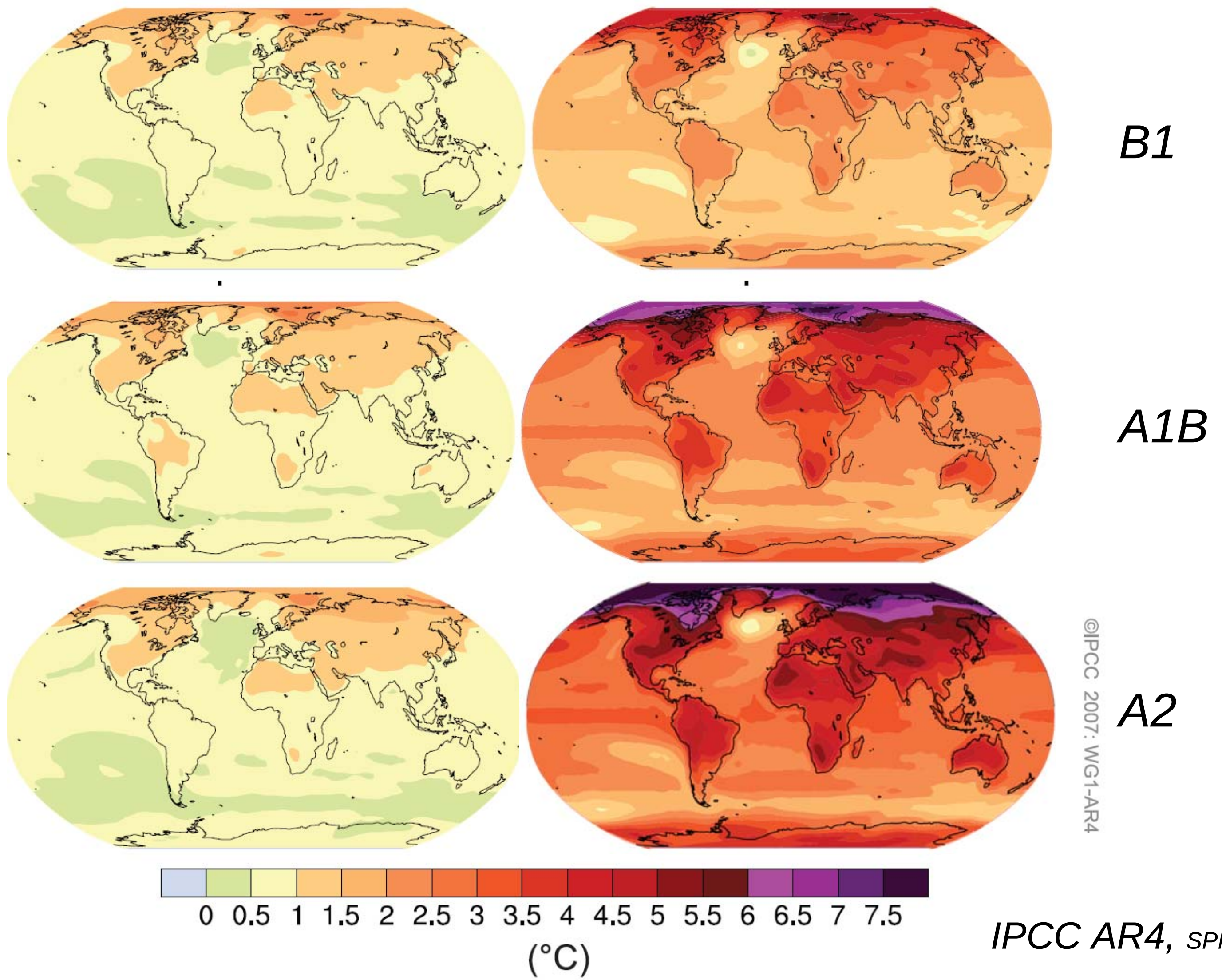


Figure SPM.5. *Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the* ***likely*** *range assessed for the six SRES marker scenarios. The assessment of the best estimate and* ***likely*** *ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. {Figures 10.4 and 10.29}*

Projected changes of the near surface temperature in relation to the mean of 1980-1999

Regional pattern for the *SRES scenarios*



IPCC AR4, SPM 6

Anthropogenic impact on extreme weather events

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]	*Likely*[i]

IPCC, 2007

What can we do ?

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (1992)

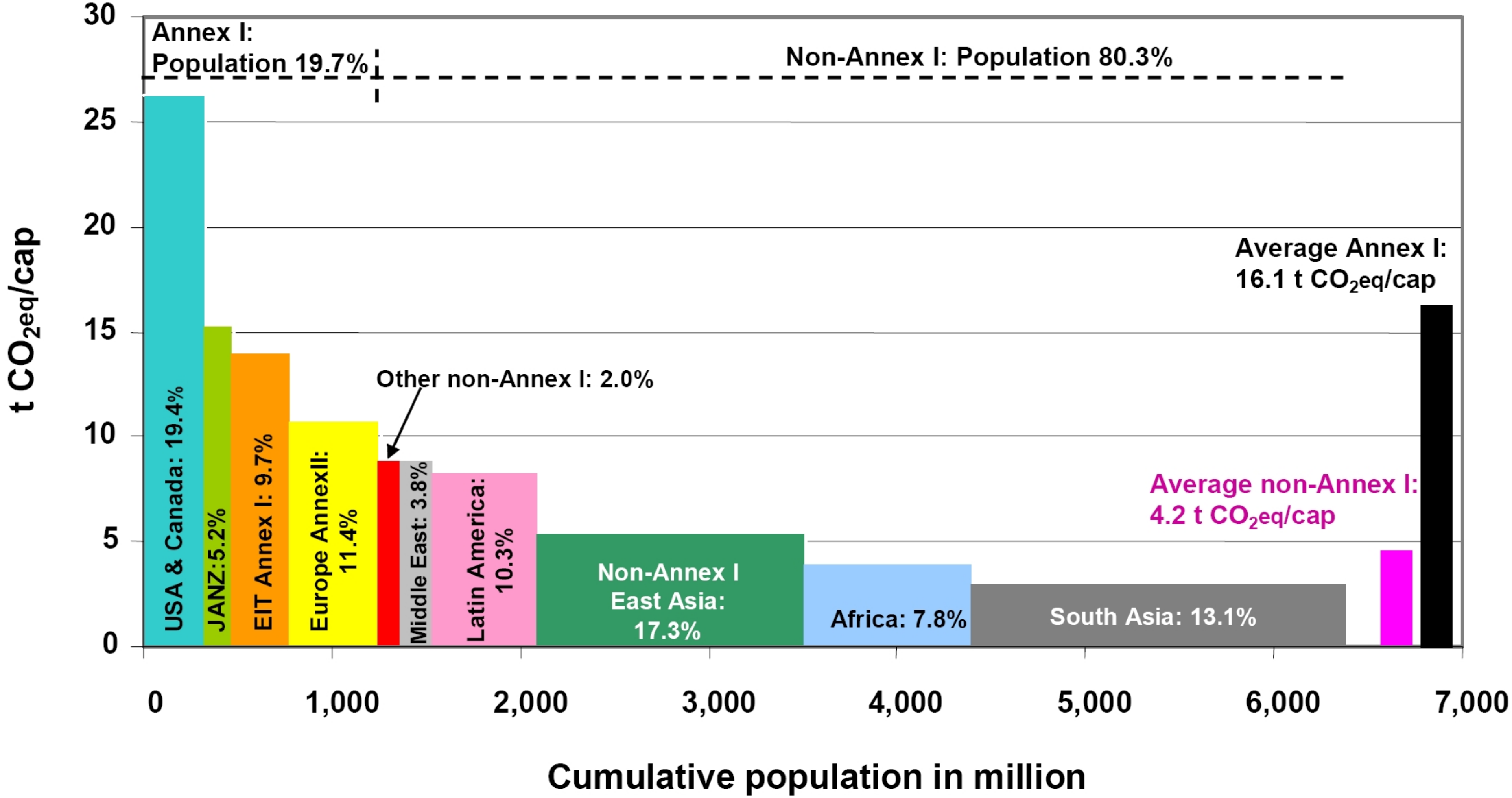
Article 2

OBJECTIVE

The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

UNITED NATIONS
1992

2004 distribution of regional per capita GHG emissions

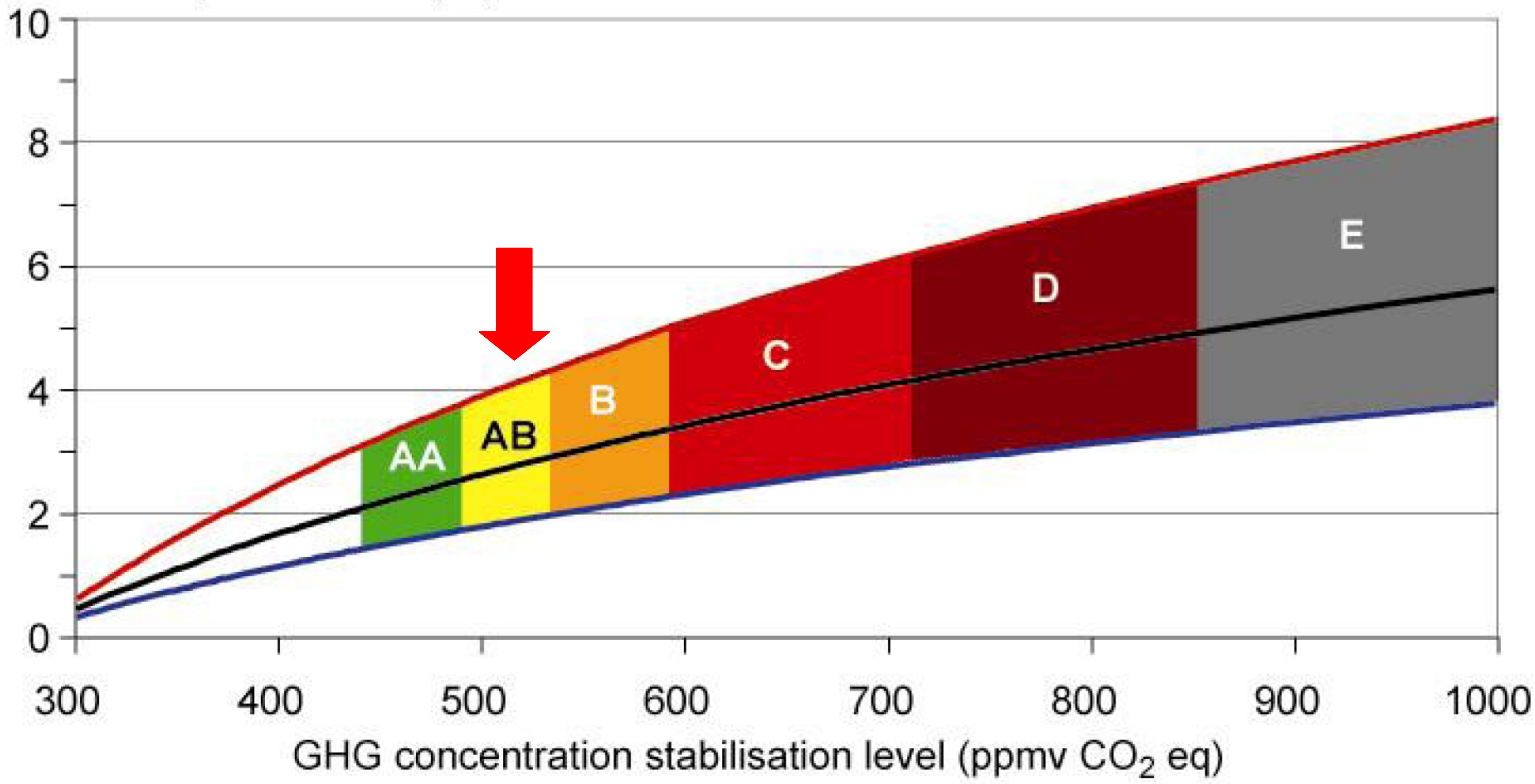


IPCC, 2007

Temperature rise as function of the CO_2 equivalent concentration

change in CO_2 emissions until 2050: -30% to -60% relative to 2000

annual change in GDP: less than 0.12 percent points



IPCC, 2007

KYOTO PROTOCOL TO THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (1997 / 2005)

Article 3

1. The Parties included in Annex I shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases listed in Annex A do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments inscribed in Annex B and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012.

Annex A

Greenhouse gases

Carbon dioxide (CO_2)
Methane (CH_4)
Nitrous oxide (N_2O)
Hydrofluorocarbons (HFCs)
Perfluorocarbons (PFCs)
Sulphur hexafluoride (SF_6)

International aviation and shipping (bunker fuels) are **not** included in the Kyoto Protocol.

European targets

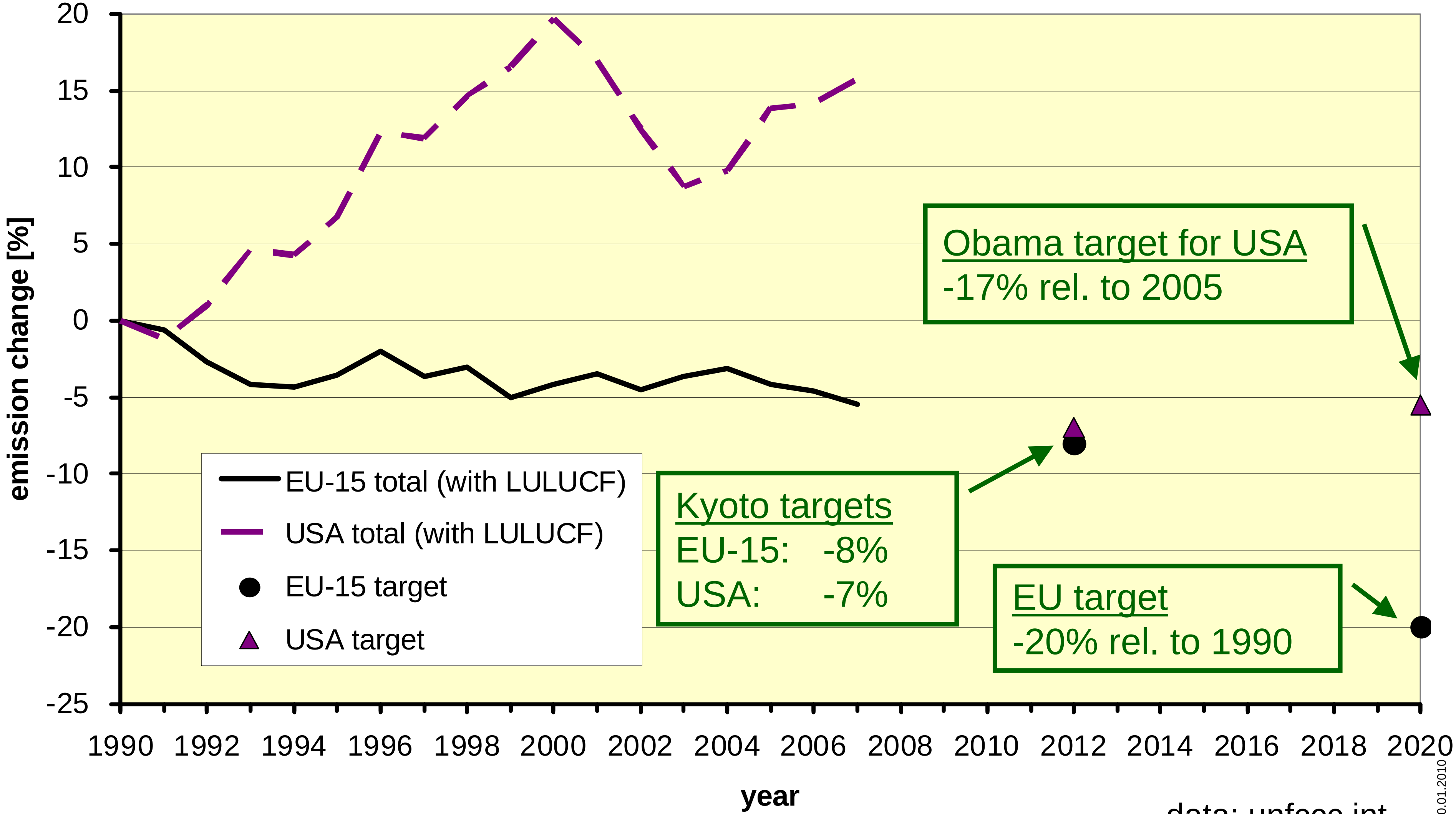
Kyoto Protocol: Reducing equivalent CO_2 emissions relative to 1990:

- EU-15: - 8 % until 2012.

Further EU targets:

- limiting the anthropogenic rise of the global mean surface temperature to + 2 °C;
- reduction of the equivalent CO_2 emissions relative to 1990 by 20 - 30 % until 2020.

CO_2 equivalent emissions of EU-15 and USA
Change since 1990 and targets for 2012 and 2020



data: unfccc.int

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Climate Modelling

How is climate changing ?

What is the impact of transport on climate change ?

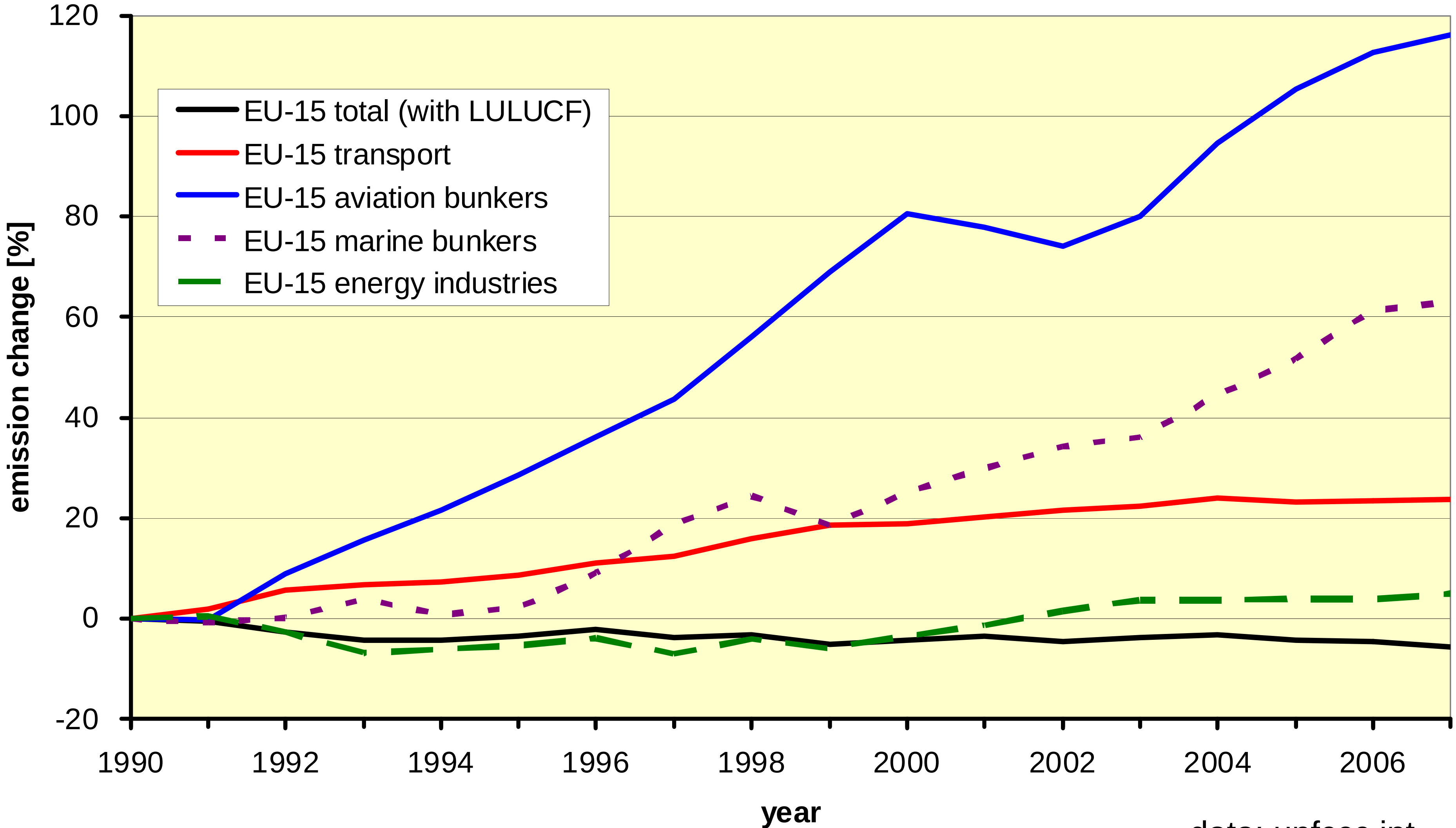
How can transport impact climate ?

Changes in radiative forcing can be caused by

- the emission of greenhouse gases, including long-lived species like CO_2 and N_2O, but also of water vapour

CO_2 equivalent emissions of EU-15

Change since 1990



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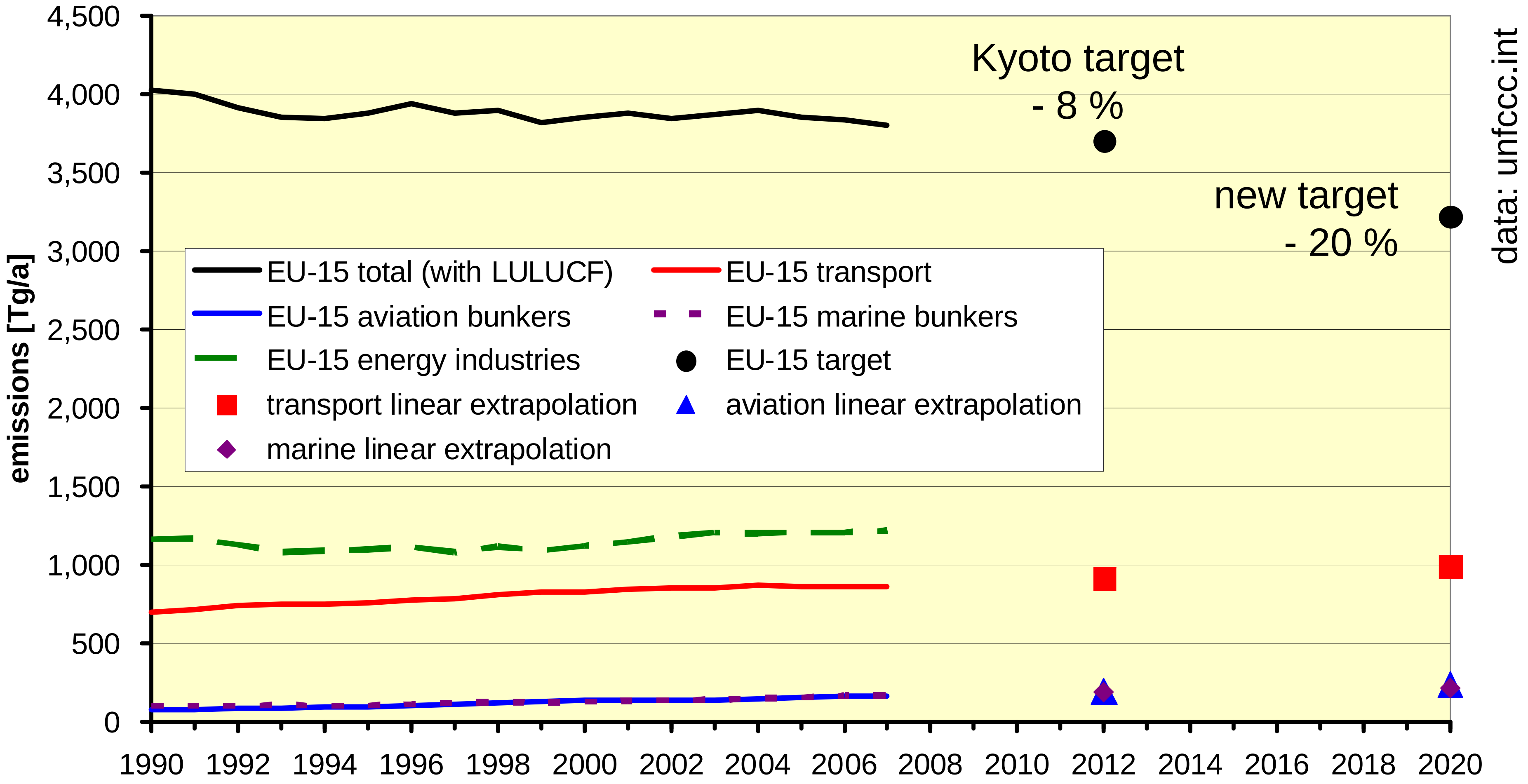
New EU target and consequences for transport:

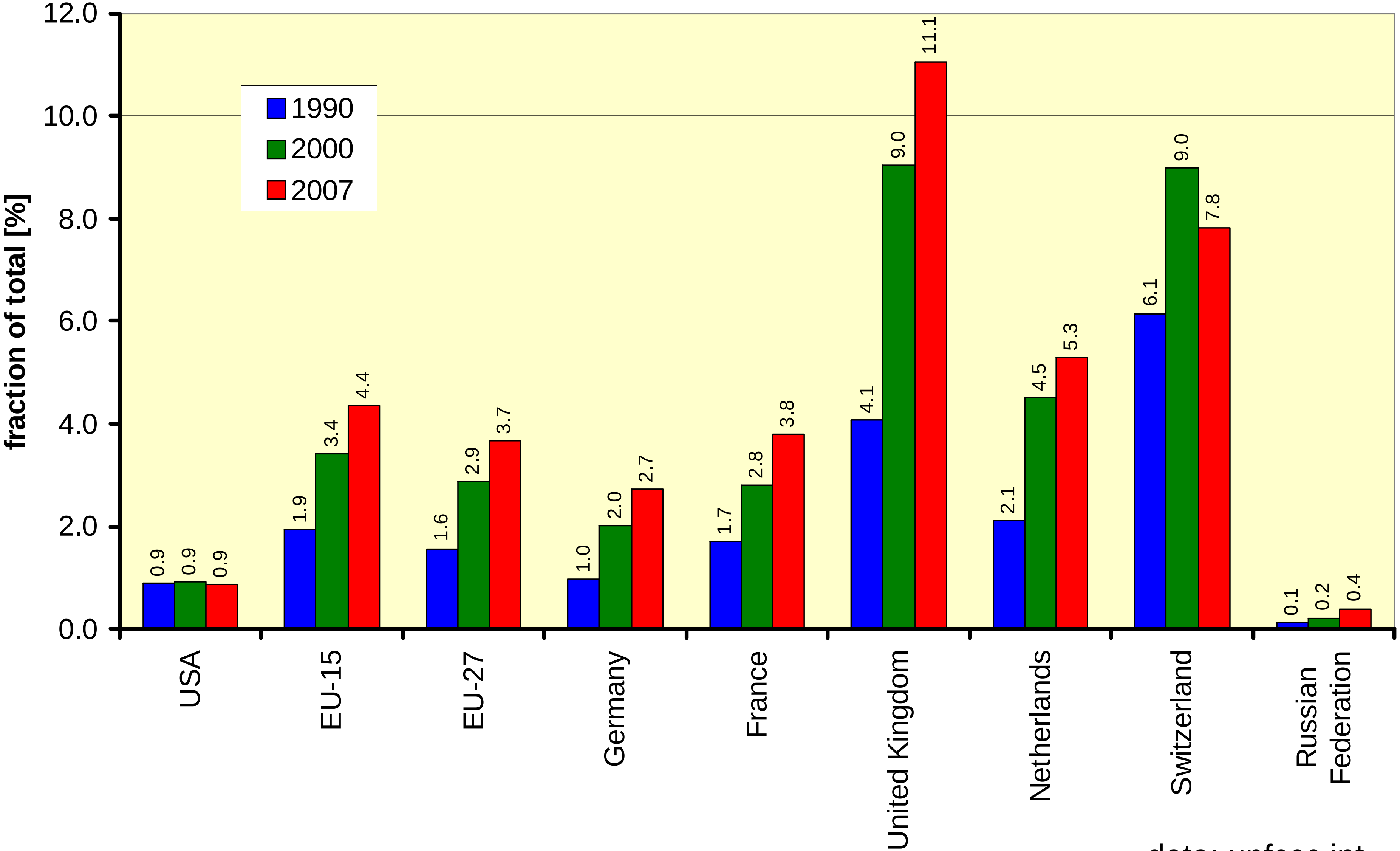
Reduction by 20 % relative to 1990



transport fractions (1990	**2007**	**2012**	**2020):**
national transport: 17.4 %	22.8 %	24.7 %	30.9%
aviation bunkers: 1.9 %	4.4 %	5.3 %	7.4 %
marine bunkers: 2.6 %	4.5 %	5.1 %	6.9 %

linear growth of transport emissions after 2007

Contribution of aviation to total equivalent CO_2 emissions [%]



data: unfccc.int

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CO_2 emissions per passenger for selected flights

(economy, incl. return)

München (MUC) - Paris (CDG)	0.19 t (CO_2) 131 g/Pkm 0.26 t (CO_2) [1]	A320, 150 seats, load factor 70%, FL 310, 105 passengers, 725 km
München (MUC) - Mallorca (PMI)	0.18 t (CO_2) 70 g/Pkm 0.33 t (CO_2) [1]	A737-800, 184 seats, load factor 95%, FL 350, 175 passengers, 1289 km
München (MUC) - Teneriffa (TFN)	0.52 t (CO_2) 77 g/Pkm 0.67 t (CO_2) [1]	A330-200, 323 seats, load factor 85%, FL 370, 274 passengers, 3365 km
Frankfurt (FRA) - New York (JFK)	1.20 t (CO_2) 94 g/Pkm 1.21 t (CO_2) [1]	B747-400, 390 seats, load factor 90%, FL 350 - 370, 351 passengers, 6391 km
Frankfurt (FRA) - Sydney (SYD) via Singapore (SIN)	4.46 t (CO_2) 131 g/Pkm 3.33 t (CO_2) [1]	A340-300, 259 seats, load factor 70%, FL 330 - 370, 181 passengers, 17071 km *Schäfer and Plohr, 2008*

For comparison:

mean annual CO_2 equivalent of a German resident: 12.2 t

passenger car (diesel, 6.5 l / 100 km, 175.5 g (CO_2) / km, 10000 km travelled): 1.8 t

[1] http://lufthansa.myclimate.org/calculate_flight

How can transport impact climate ?

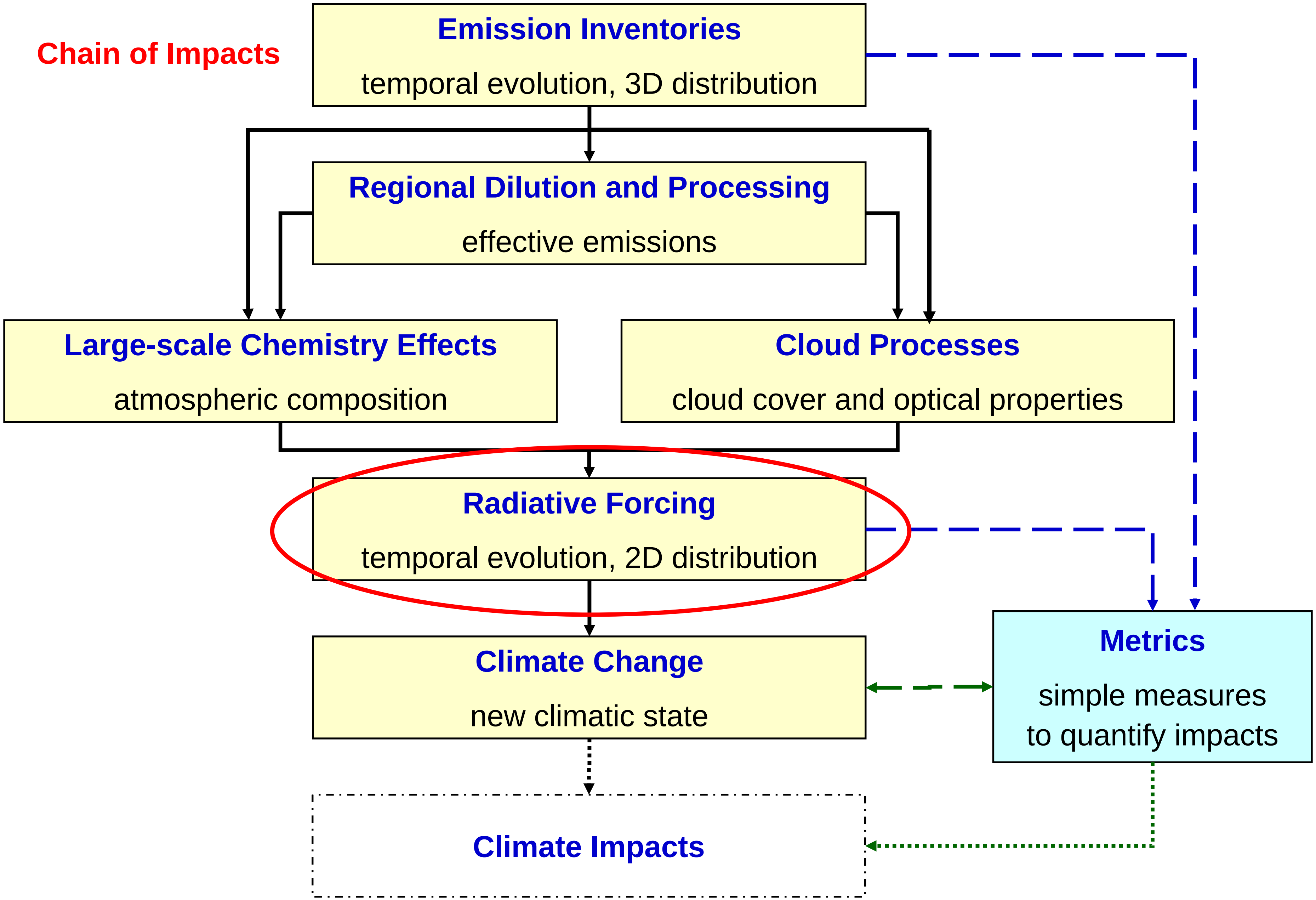
Changes in radiative forcing can be caused by

- the emission of greenhouse gases, including long-lived species like CO_2 and N_2O, but also of water vapour

- the emission of ozone precursors, like NO_x

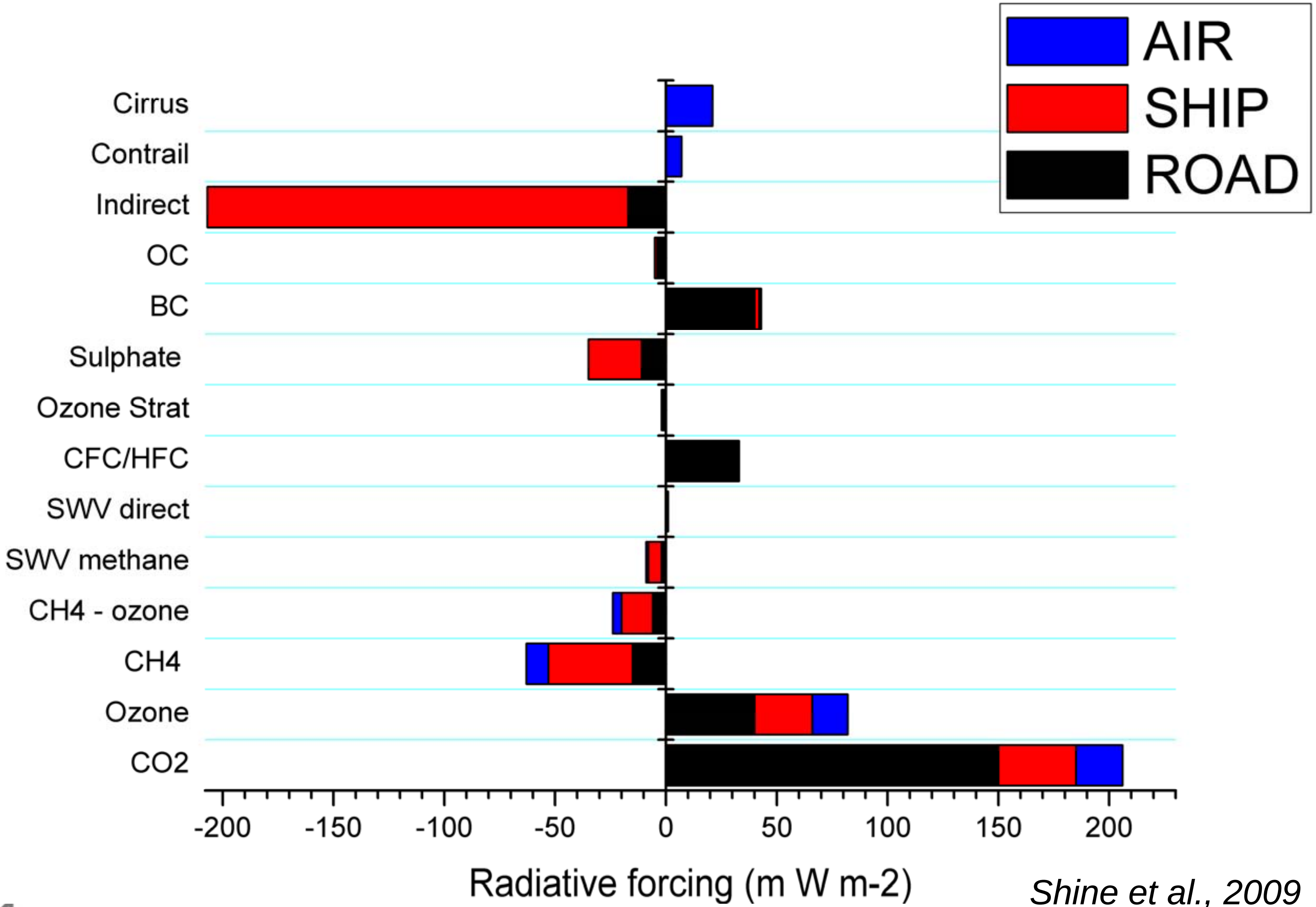
- the emission of particles and their precursors

- triggering additional clouds (e.g., contrails, contrail cirrus)
  and
  by modifying natural clouds (e.g., ship tracks)



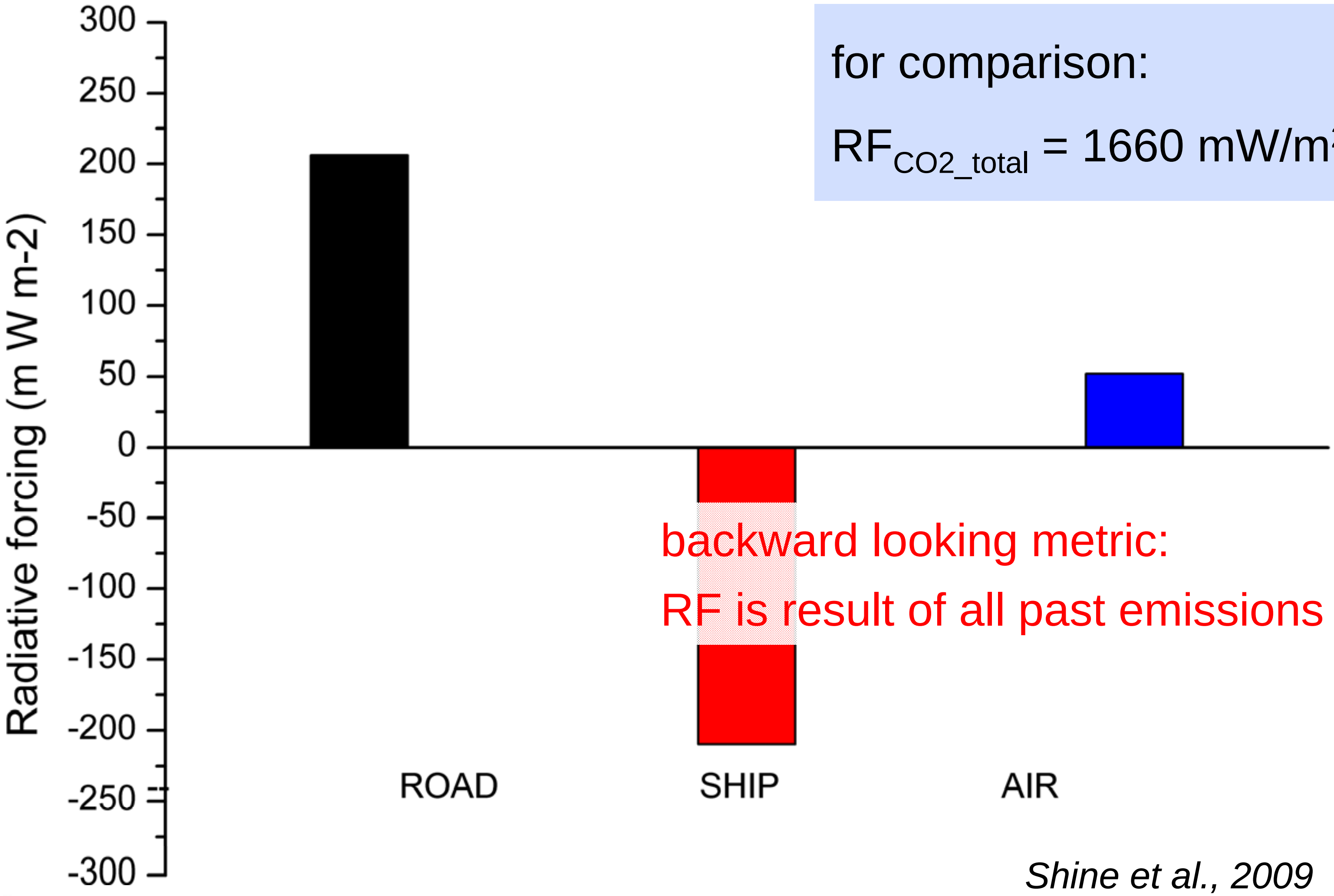
Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

Radiative forcing from transport
(preliminary)



Shine et al., 2009

Radiative forcing from transport (totals)
(preliminary)



for comparison:

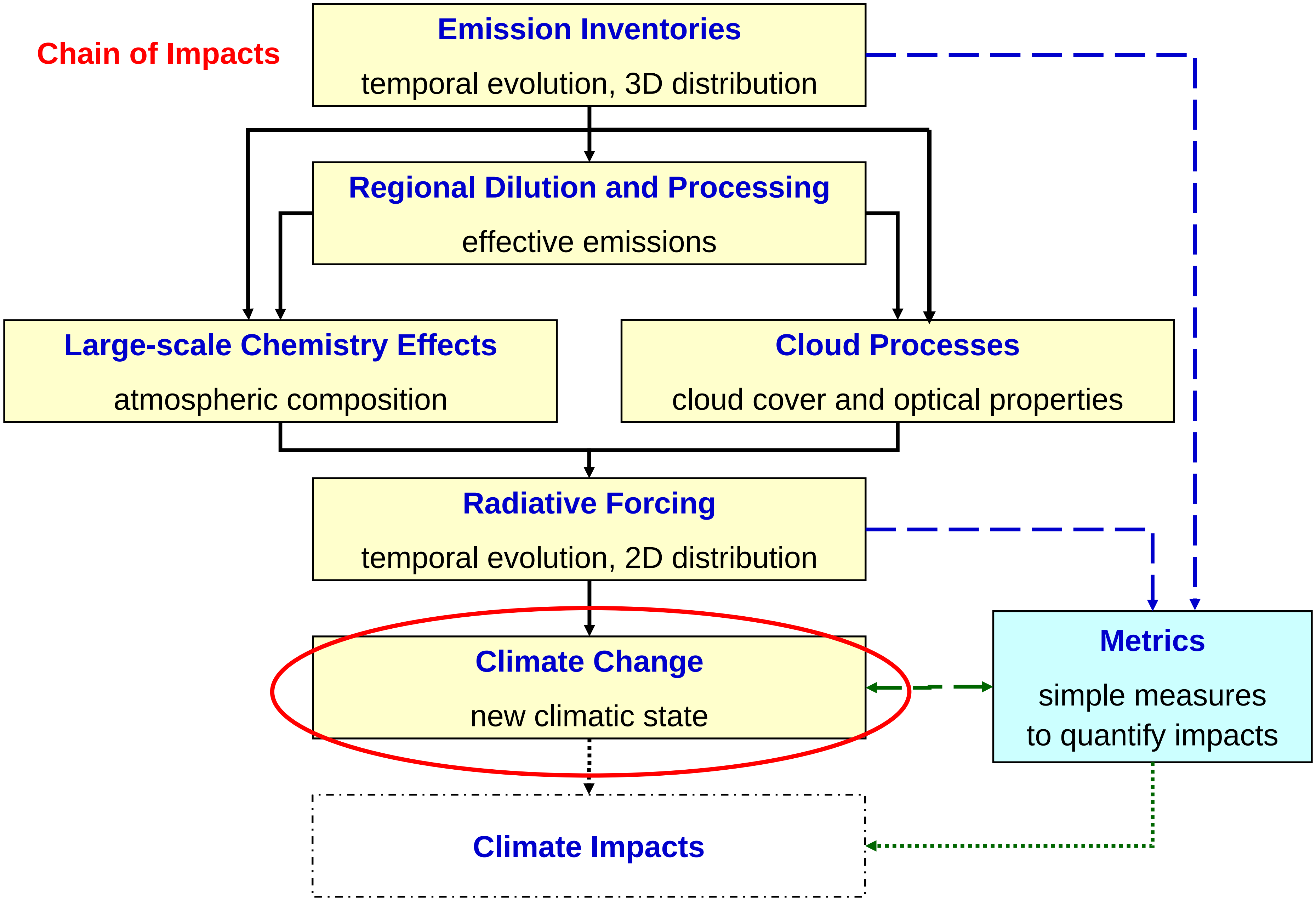
RF_{CO2_total} = 1660 mW/m²

backward looking metric:

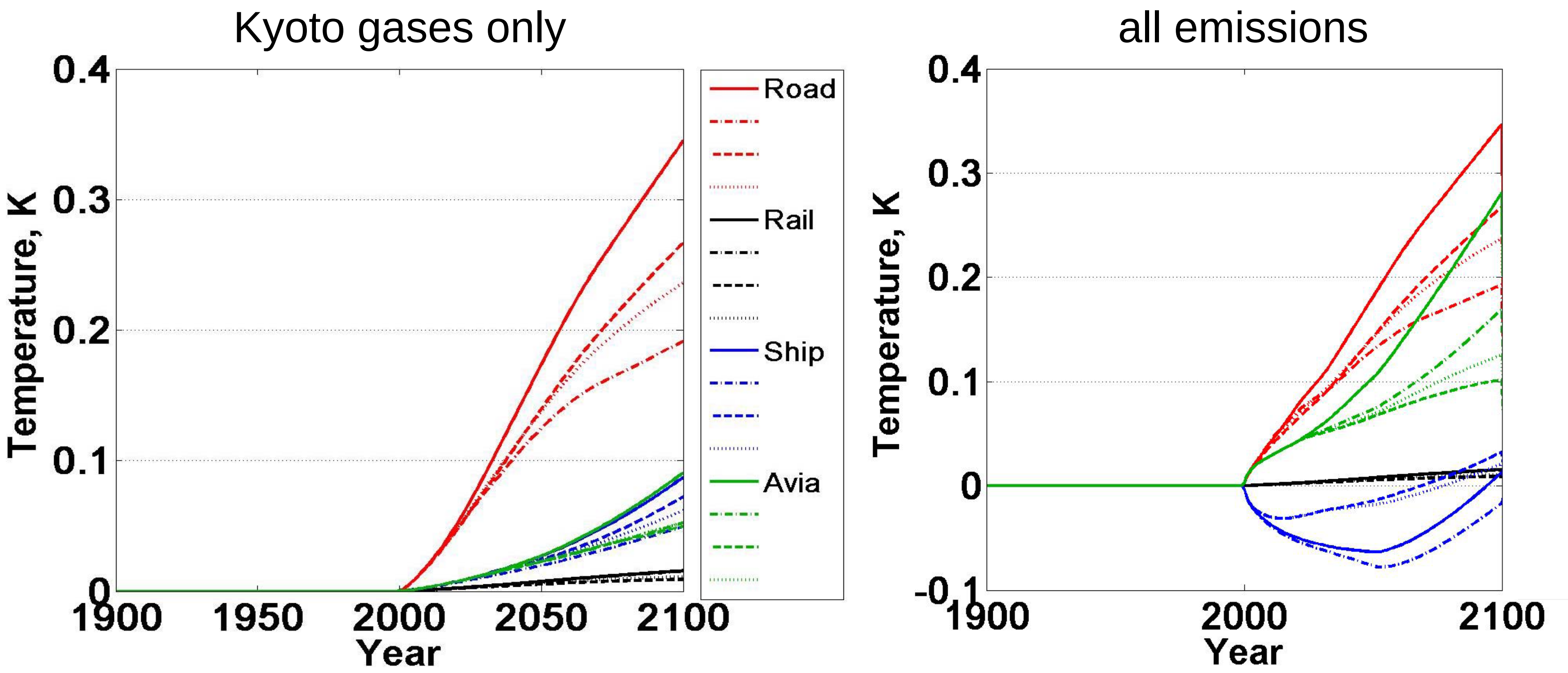
RF is result of all past emissions

Shine et al., 2009

Chain of Impacts



Temperature change due to transport emissions size 2000
(QUANTIFY emission scenarios, start from equilibrium)



"Kyoto gases only" relative to "all emissions"

Road:	Similar
Aviation:	Smaller warming
Shipping:	No cooling

Skeie et alii, 2009

10.01.2010

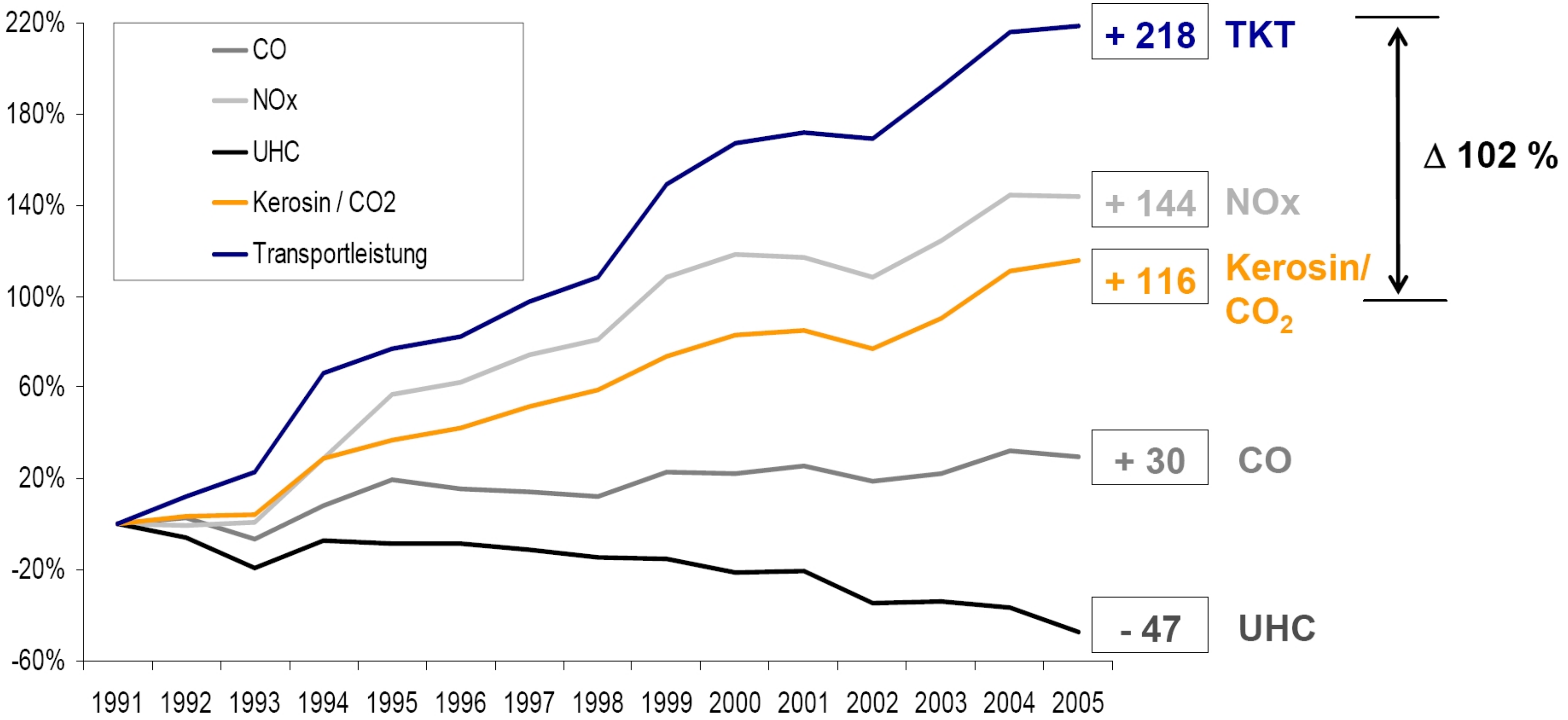
How to reduce the climate impact of aviation ?

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Reducing the climate impact of aviation

- Fly less
  - reduce demand
- Reduce specific emissions
  - ACARE goals (CO_2: -50%, NOx: -80%) by
    technological means
    higher load factors
    better operation

Entkopplung von Wachstum und Emissionen



... durch kontinuierliches Investment in neue Technologie und operative Maßnahmen.

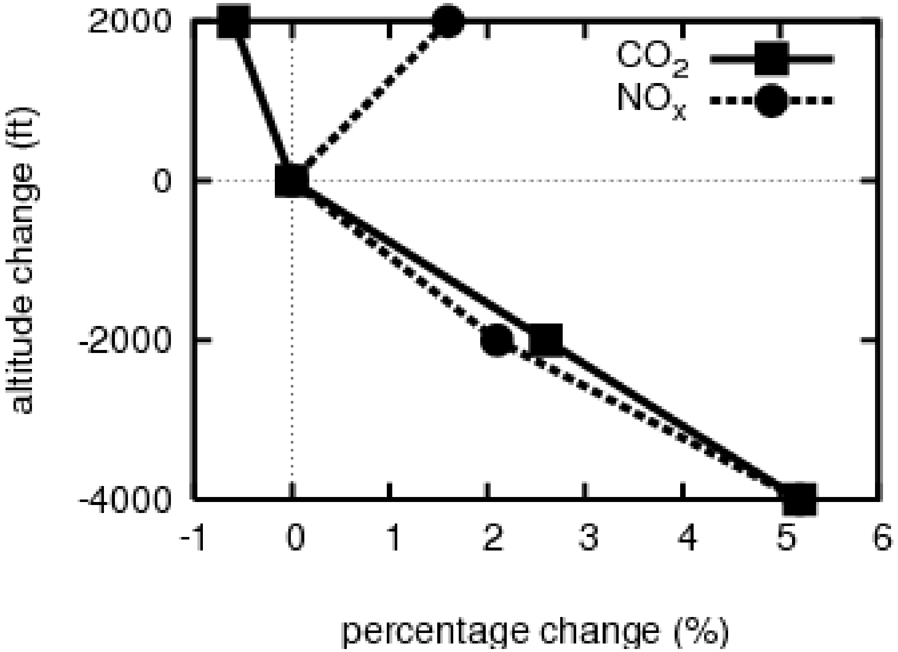
Reducing the climate impact of aviation

- ✈ Fly less
  - reduce demand
- ✈ Reduce specific emissions
  - ACARE goals (CO2: -50%, NOx: -80%) by
    technological means
    higher load factors
    better operation
- ✈ Environmentally friendly flight planning
  - preferably fly at locations and altitudes with smaller climate impact

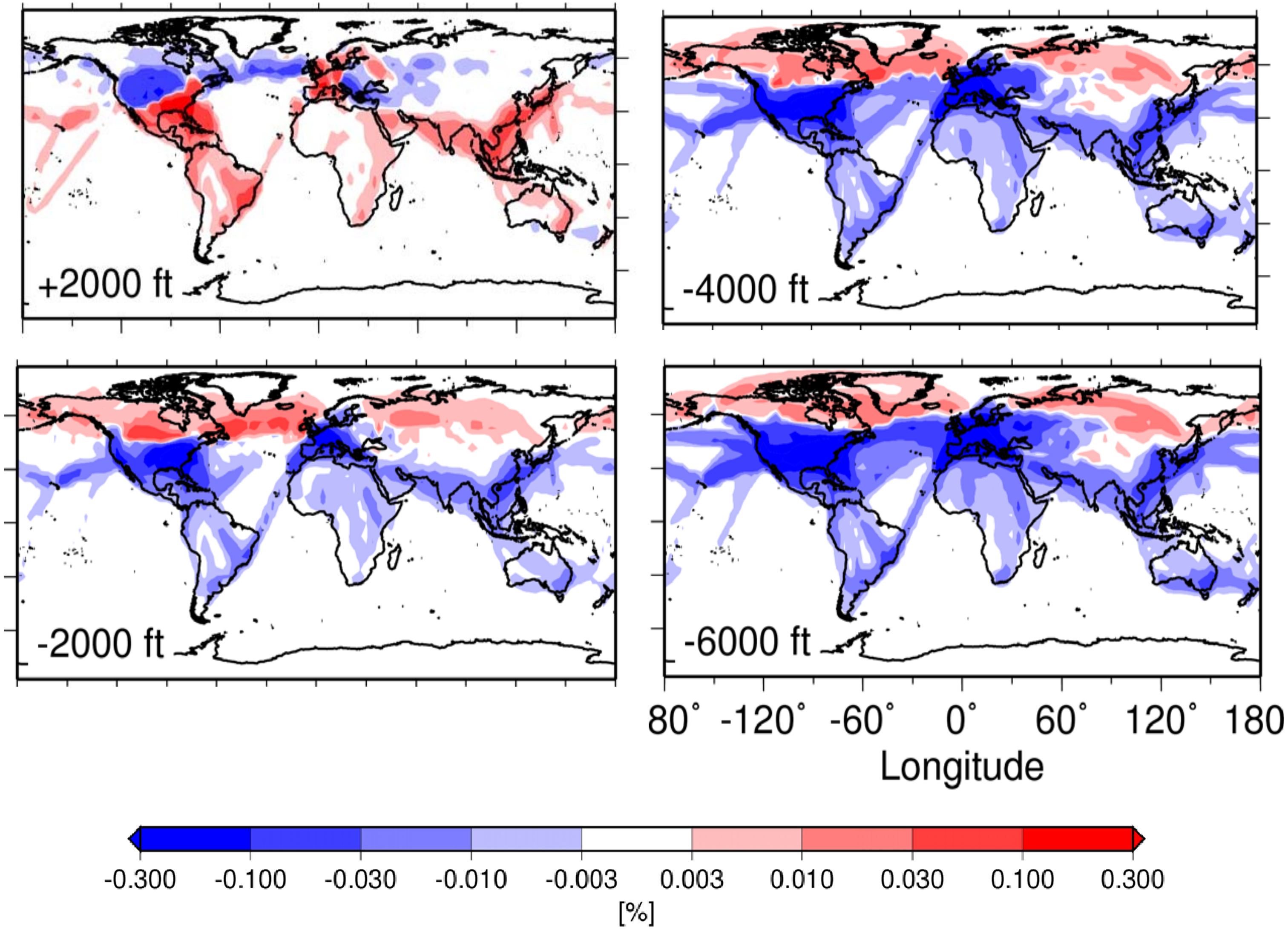
Impact of mean flight altitude on radiative forcing

Move cruise level of all flights up or down
and calculate associated emission inventory

relative change of emissions [%]

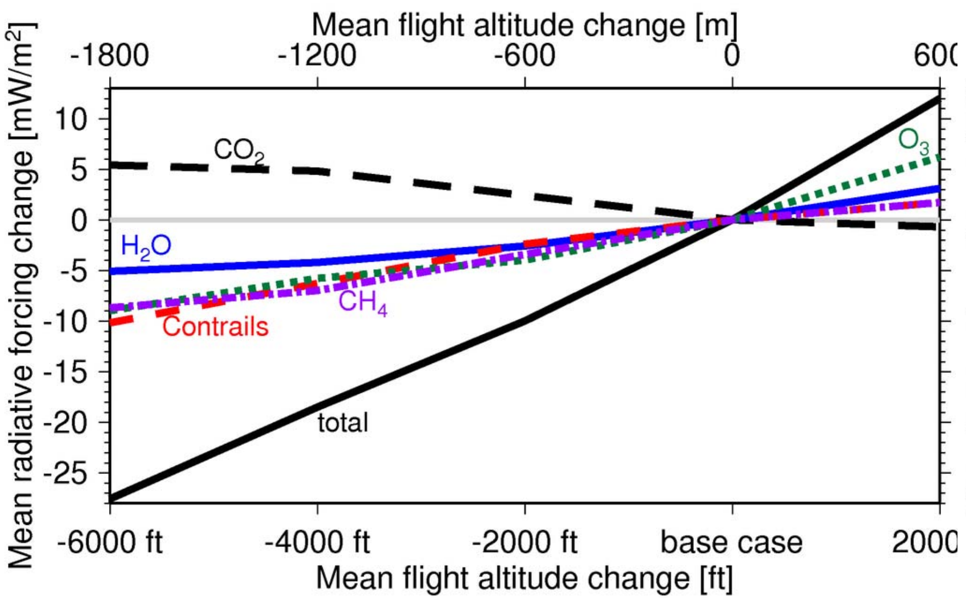


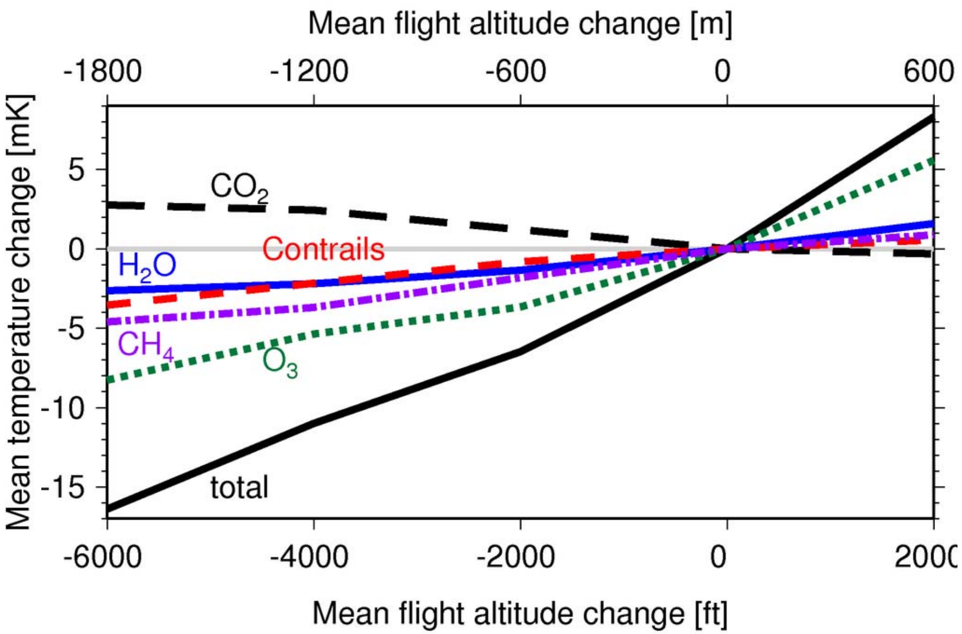
Impact of flight altitude on contrail cover



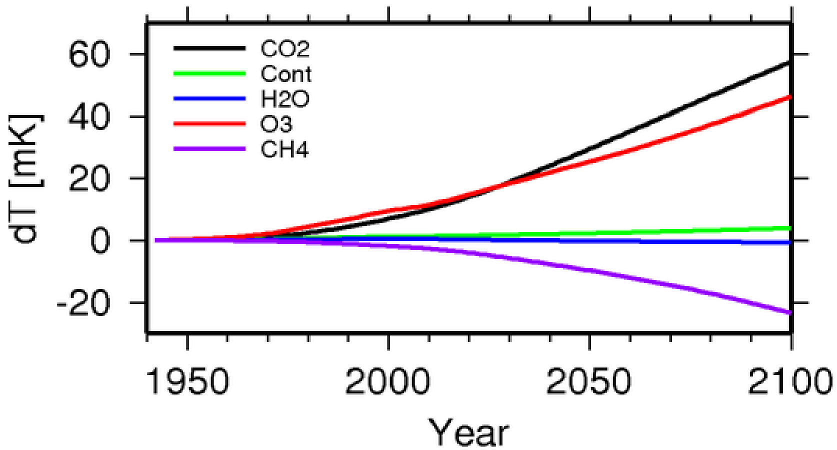
Fichter et al., 2005

Global RF and ΔT changes in 2100 for mean flight altitude changes



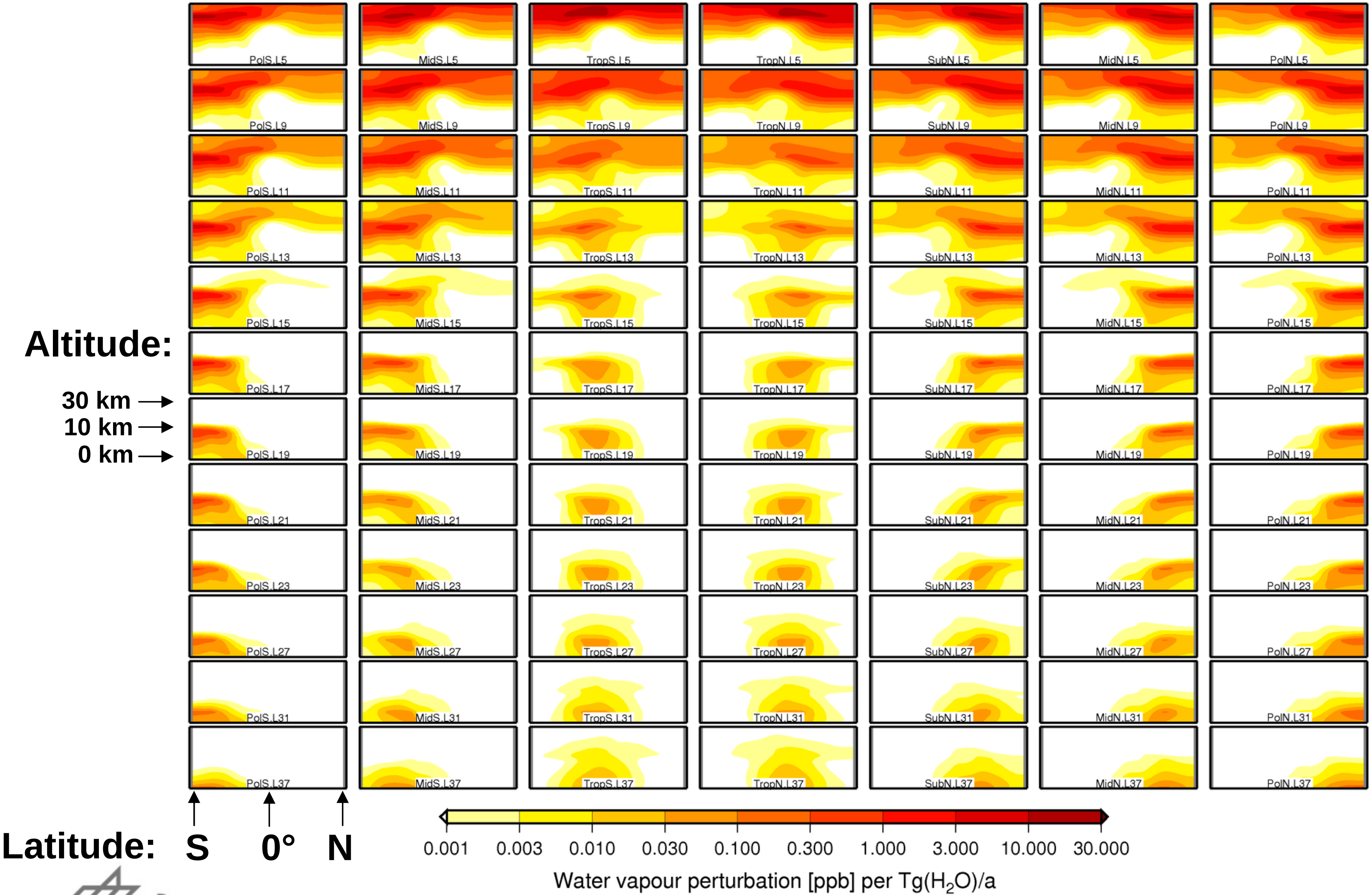


- ✈ Global vertical shift of cruise altitude
- ✈ Future air traffic development according to Fa1



Fichter et al., 2005

Effect of idealized H_2O emissions with respect to emission location and altitude (normalized to emission strength)



Fichter et al., 2009

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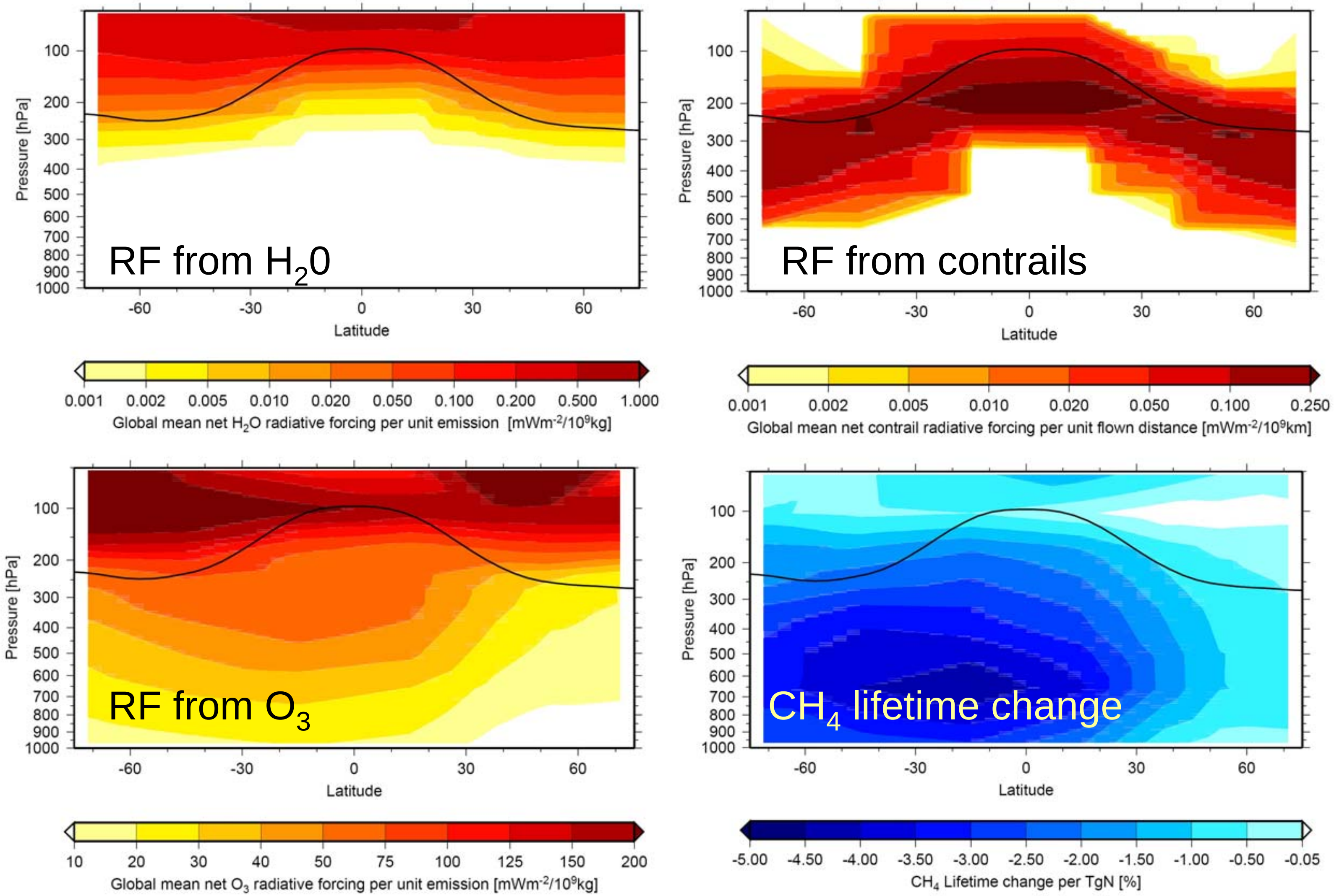
Impact of unit "emissions" as function of latitude and altitude of emission



Fichter et al., 2009

~ 50 000 CPUh NEC SX6

Concluding remarks (climate in general)

- Climate is changing.
- Climate models are good tools to study past and future climate changes.
- The major fraction of the observed climate change is anthropogenic.
- Even at constant greenhouse gas concentrations, the global mean surface temperature would rise by an additional 0.5 °C.
- Depending on scenario and model, the global mean surface temperature will rise between 1.1°C and 6.4°C until 2100.
- Regional climate changes substantially differ from the global mean.
- Regional changes, in particular extreme events, will impact mankind most severely.
- Limiting global warming to 2 - 3°C requires drastic reduction of greenhouse gas emissions during the next few decades to come.

Concluding remarks (transport)

- Transport significantly contributes to climate change, and its contribution is growing.
- Transport changes climate by many other effects beyond CO_2 (and other long-lived greenhouse gases), but great uncertainty exists with respect to the climate impact of short-lived non-CO_2 emissions.
- In general, radiative forcing at a certain time is <u>no good measure</u> for the expected climate change.
- Multiplying CO_2 emissions by any simple multiplication factor would weaken incentives to reduce the total climate impact beyond a reduction of the fuel consumption.
- Eventually, it might become possible to include non-CO_2 effects by their individual contributions to climate change.
- Often emissions have further effects beyond climate change, e.g., impact on air quality.

...and that concludes my federal report on the status of global warming. Now, special agent Coffield here will be placing you all under arrest for having classified information.

Further Information

Integrated Project: Quantifying the Climate Impact of Global and European Transport Systems

http://ip-quantify.eu

Text by German Bundesministerium für Umwelt:

http://www.bmu.de/klimaschutz/internationale_klimapolitik/ipcc/doc/39274.php

Assessment Reports by the Intergovernmental Panel on Climate Change

http://www.ipcc.ch

ICAO Environment Report 2007 (p 122)

http://www.icao.int/icao/en/env/pubs/Env_Report_07.pdf

CCG-Seminar "Verkehr und Umwelt"

http://www.ccg-ev.de/de/seminare/programme/se/se0312.html

This lecture

http://elib.dlr.de/ ➔ search for "Sausen" and "2010"