An Energethical Solution for Avoiding Climate Change and Peak-Oil.

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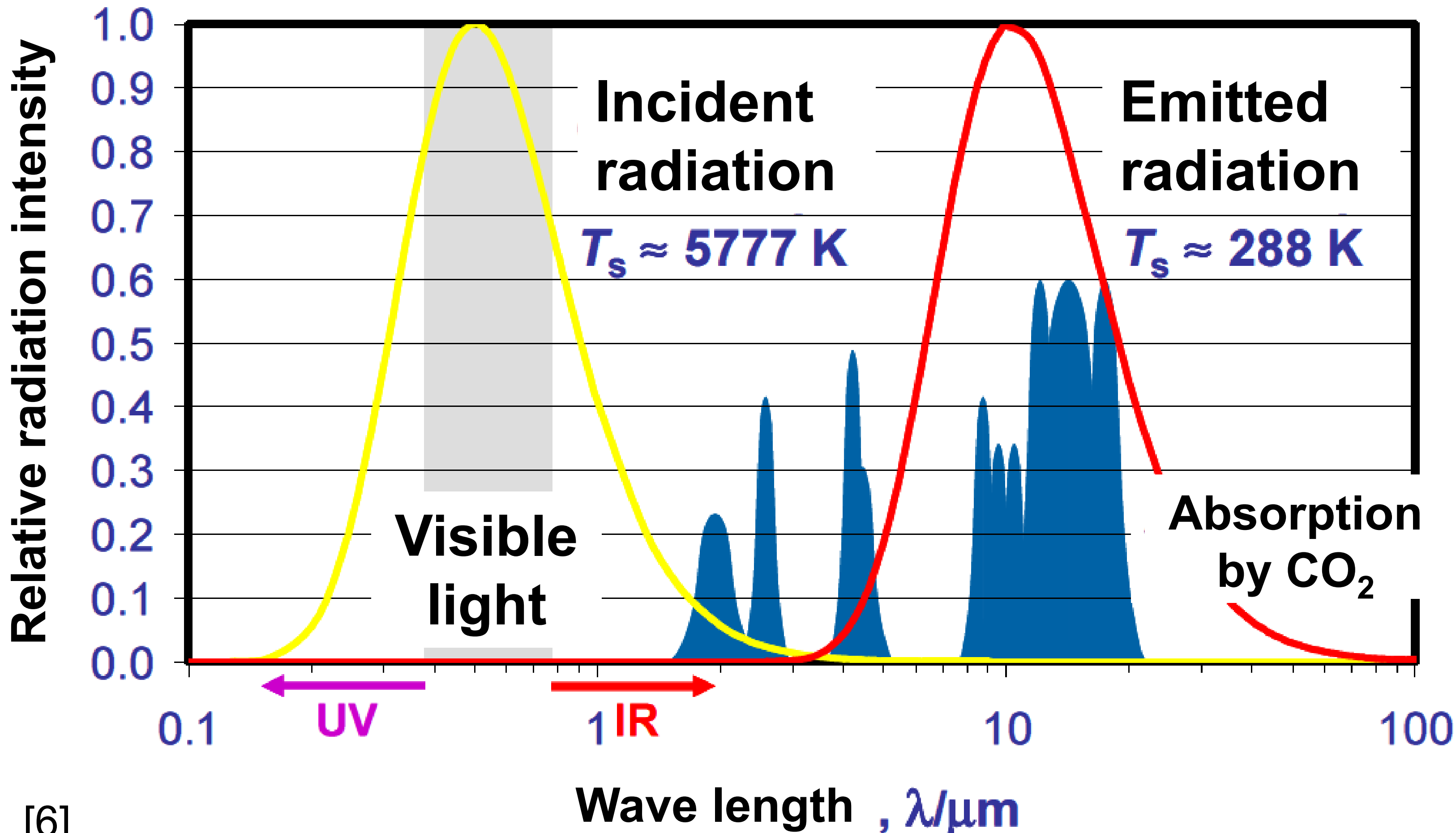
Presentation at the 2. PhD-Seminar of the Darmstadt Graduate School of Excellence, Energy Science and Engineering
2014, October 14

Agenda

- CO_2 absorption of infrared radiation
- Radiation balance of the earth
- Temperature rise in atmosphere and oceans
- Oceans get more acidic
- Correlation of carbon dioxide emission and temperature
- Crude oil production since 1850, Peak-Oil
- Further problems
- Ostensible Solutions for climate
- Replacement of fossil oil by ethanol, plant oil, electricity, H_2
- Growing oil plants on bad soil
- Long time fixation of carbon in the soil as Terra Preta, Reduction of CO_2 in air and water
- Simulation of the replacement of fossil oil and coal by plant oil and solar thermal power plants
- Résumé

Absorption spectrum of CO_2

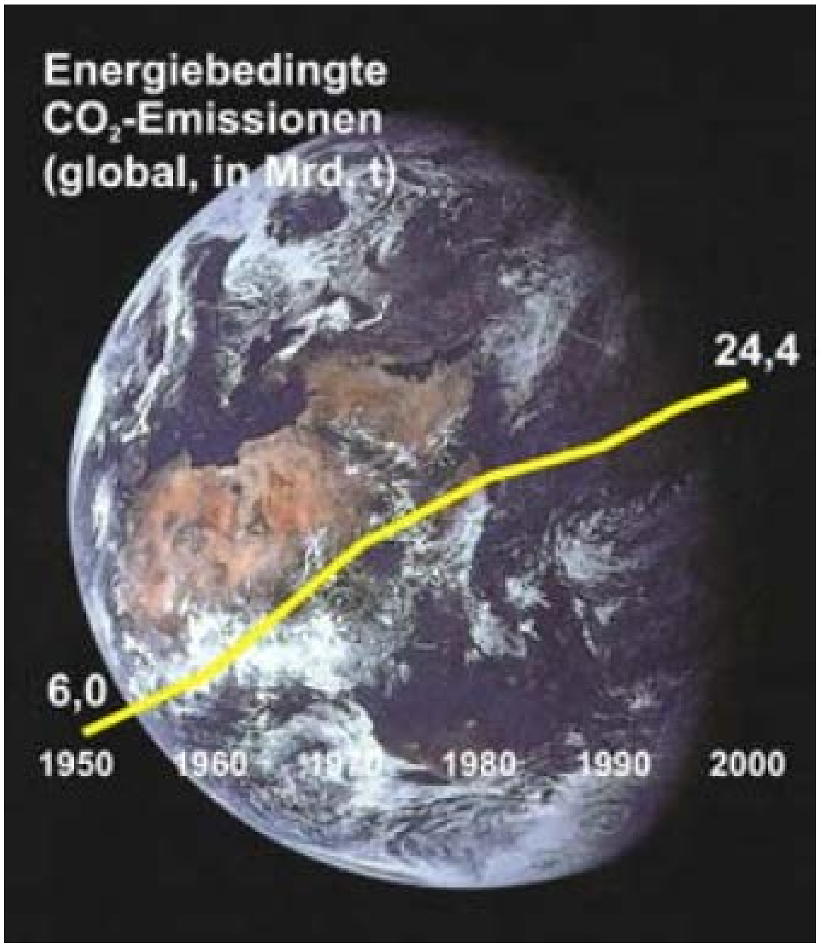


[6]

Radiation balance of the earth

- The earth receives about 1360 W/m^2 radiation from the sun on the projection area of $\pi * R^2 = 127.5 * 10^6$ km^2. So the heat input is $\dot{Q} = 173.4 * 10^{15}$ W
  Only about 1000 W/m^2 reaches the surface of the earth caused by absorption in the atmosphere and reflection, reducing the input to: $\dot{Q} = 127.5 * 10^{15}$ W
- To emit this heat as radiation the equation holds: $\dot{Q} = A * \varepsilon \cdot \sigma_B \cdot \left(T^4 - T_\infty^4\right)$
- For the outward radiation the area is $A = 4 \cdot \pi \cdot R^2 = 509.904 \cdot 10^6 km^2$
- The mean radiation temperature would be $T = \left(\dot{Q}/A * \varepsilon \cdot \sigma_B + T_\infty^4\right)^{0.25} = 257.69\ K$
- Until 1850 the CO_2-content of the atmosphere had been about 285 ppm.
  This caused an average temperature of nearly T = 13.5 °C = 286.65 K
- With this mean temperature the earth can emit 53% more radiation with only 285 ppm in the air.
- If only 1% more radiation is emitted back from the carbon dioxide molecules to the earth surface this will increase the mean temperature by 0.25%. This is 0.72 K.
- We have just 400 ppm in the air. This will rise the temperature much more than 2K.

Global CO_2-Emissions



- In 2013 we globally emitted 32.6 billion tons CO_2
- 38.6% goes to ocean sink
- The CO_2-content increased in July 2014 to 400 ppm.
- The actual increase is 3 ppm per year.

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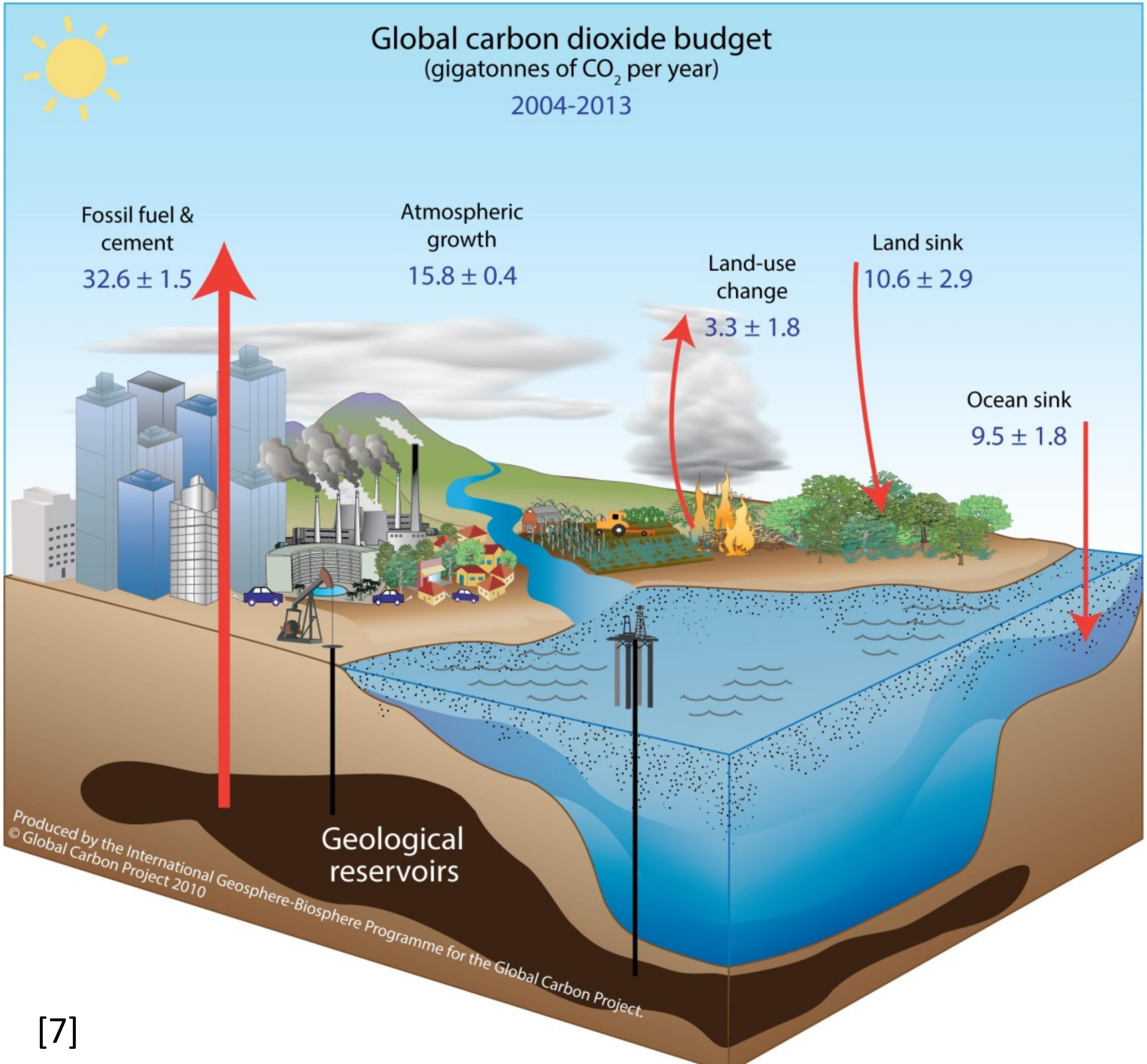
Global carbon dioxide budget
(gigatonnes of CO2 per year)
2004-2013
Fossil fuel & cement
32.6 ± 1.5
Atmospheric growth
15.8 ± 0.4
Land-use change
3.3 ± 1.8
Land sink
10.6 ± 2.9
Ocean sink
9.5 ± 1.8
Geological reservoirs
Produced by the International Geosphere-Biosphere Programme for the Global Carbon Project.
© Global Carbon Project 2010

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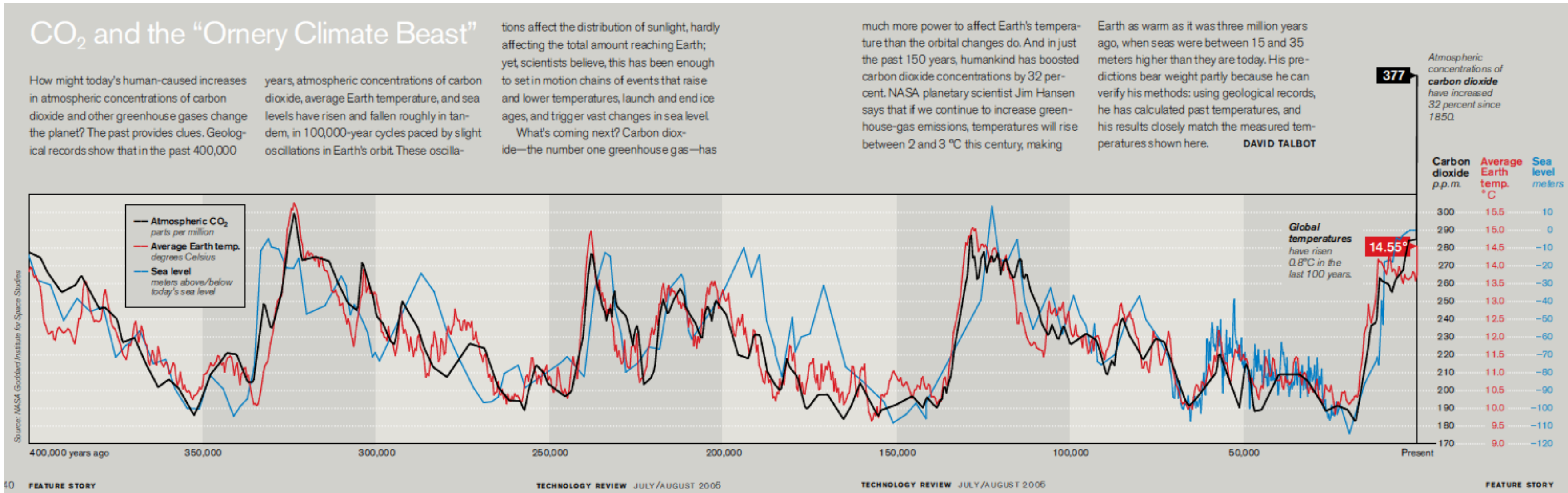
CO_2, temperature and Sealevel



CO_2 and the "Ornery Climate Beast"

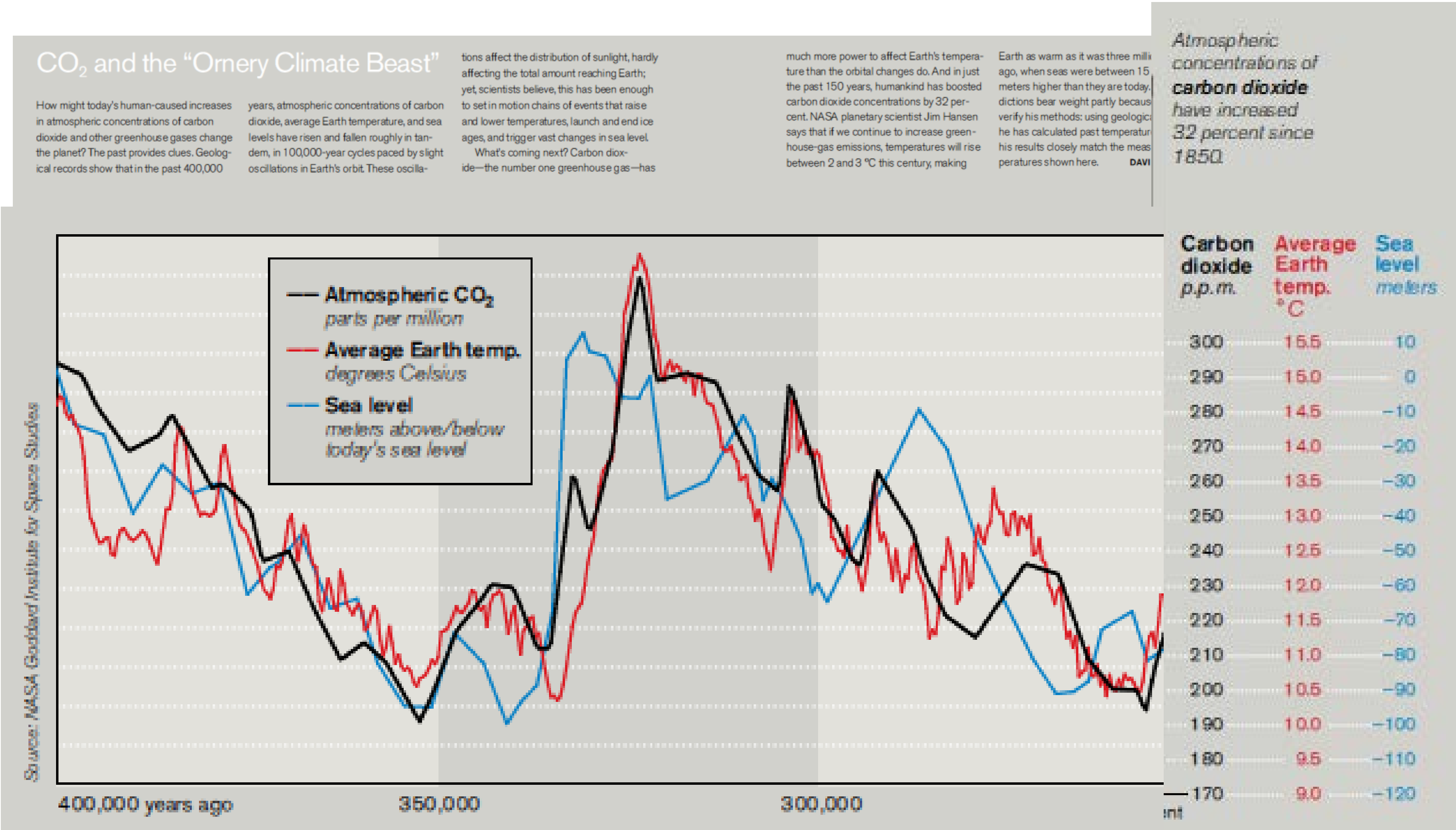
How might today's human-caused increases in atmospheric concentrations of carbon dioxide and other greenhouse gases change the planet? The past provides clues. Geological records show that in the past 400,000 years, atmospheric concentrations of carbon dioxide, average Earth temperature, and sea levels have risen and fallen roughly in tandem, in 100,000-year cycles paced by slight oscillations in Earth's orbit. These oscillations affect the distribution of sunlight, hardly affecting the total amount reaching Earth; yet, scientists believe, this has been enough to set in motion chains of events that raise and lower temperatures, launch and end ice ages, and trigger vast changes in sea level.

What's coming next? Carbon dioxide—the number one greenhouse gas—has much more power to affect Earth's temperature than the orbital changes do. And in just the past 150 years, humankind has boosted carbon dioxide concentrations by 32 percent. NASA planetary scientist Jim Hansen says that if we continue to increase greenhouse-gas emissions, temperatures will rise between 2 and 3 °C this century, making Earth as warm as it was three million years ago, when seas were between 15 and 35 meters higher than they are today. His predictions bear weight partly because he can verify his methods: using geological records, he has calculated past temperatures, and his results closely match the measured temperatures shown here. DAVID TALBOT

40 FEATURE STORY TECHNOLOGY REVIEW JULY/AUGUST 2006 TECHNOLOGY REVIEW JULY/AUGUST 2006 FEATURE STORY

[8]

CO_2, temperature and Sealevel



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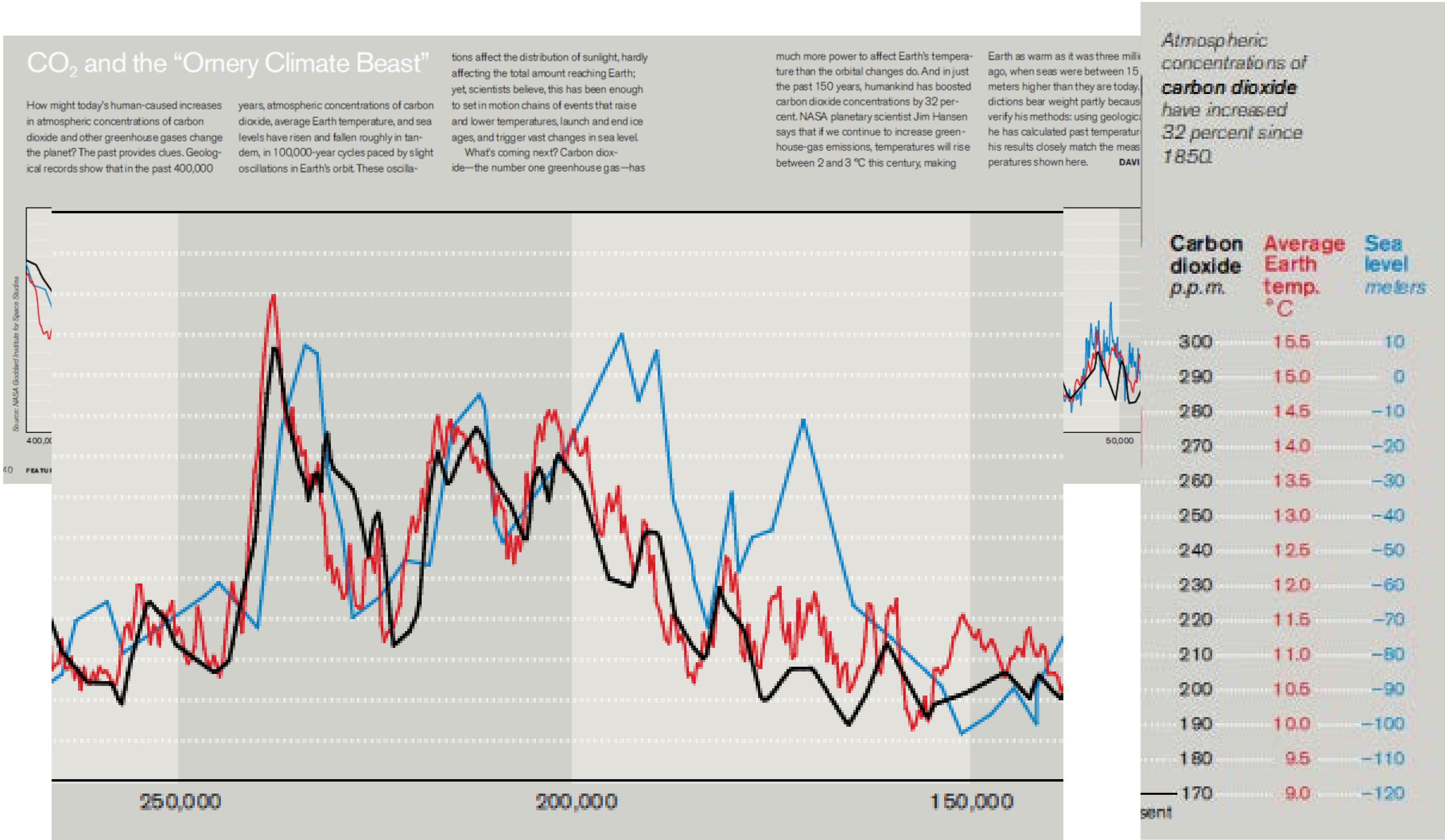

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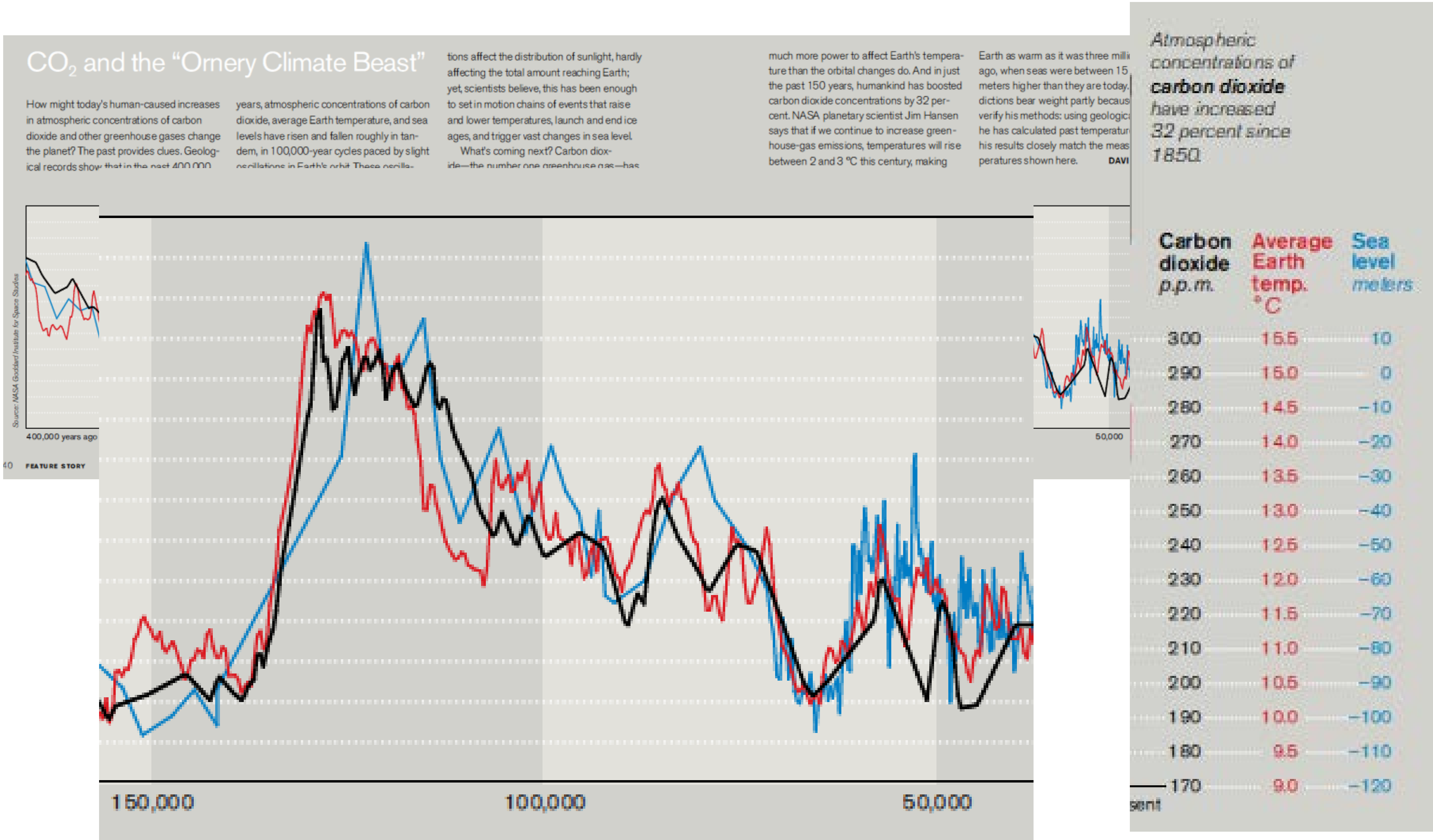

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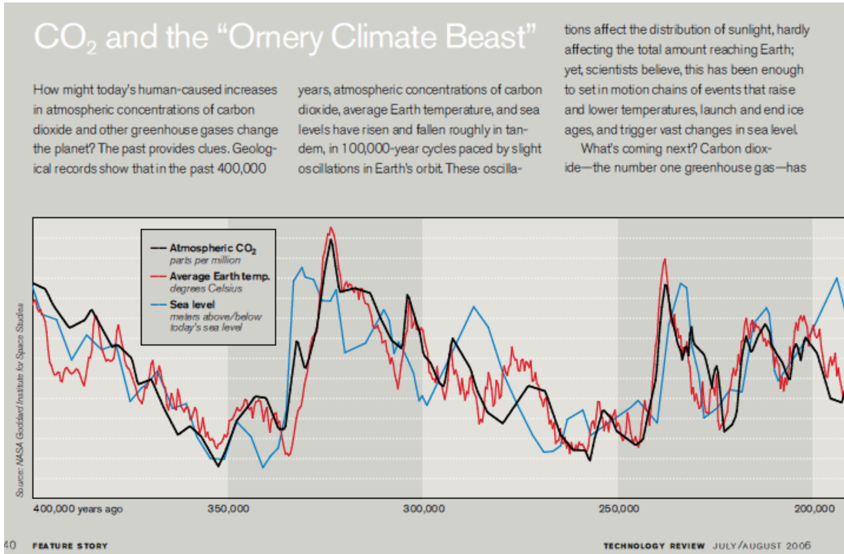

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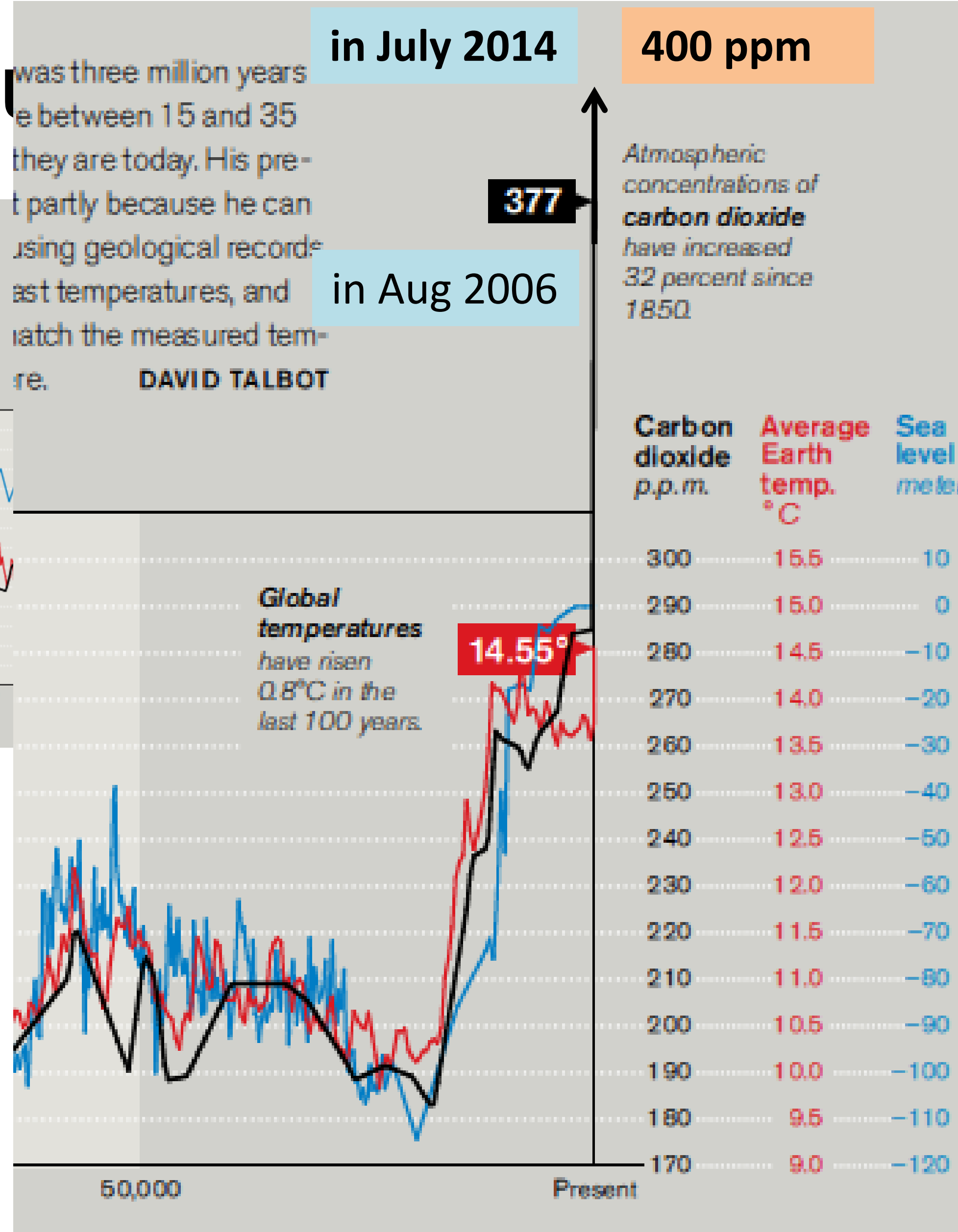

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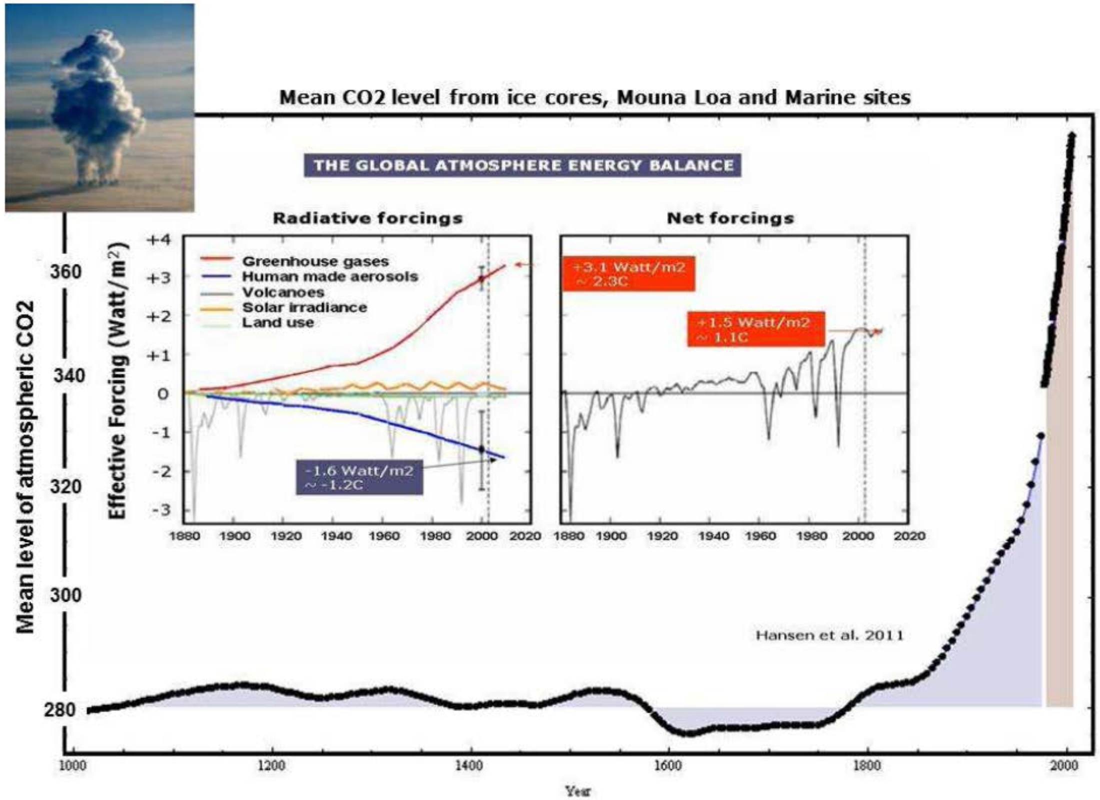
Mean CO_2-level from ice cores, Mouna Loa and Marine sites



Inset (Hansen et al., 2011). Left: Radiative forcings 2000 – 2011, including greenhouse gases (red), human-emitted aerosols (blue), volcanic eruptions (grey), solar radiance (yellow) and land use (green). Right: net of the various forcings. [5], [2]

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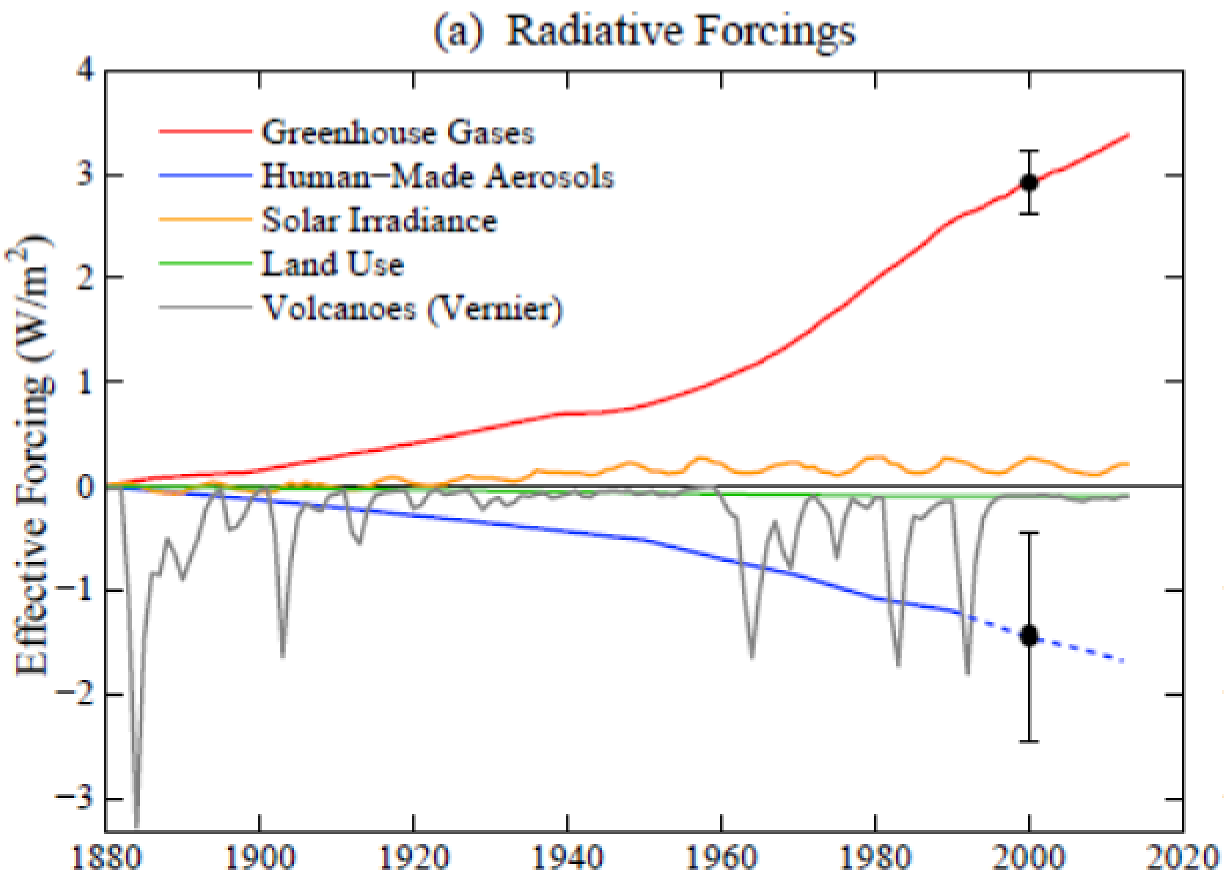

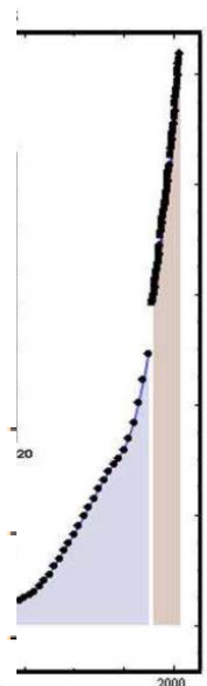

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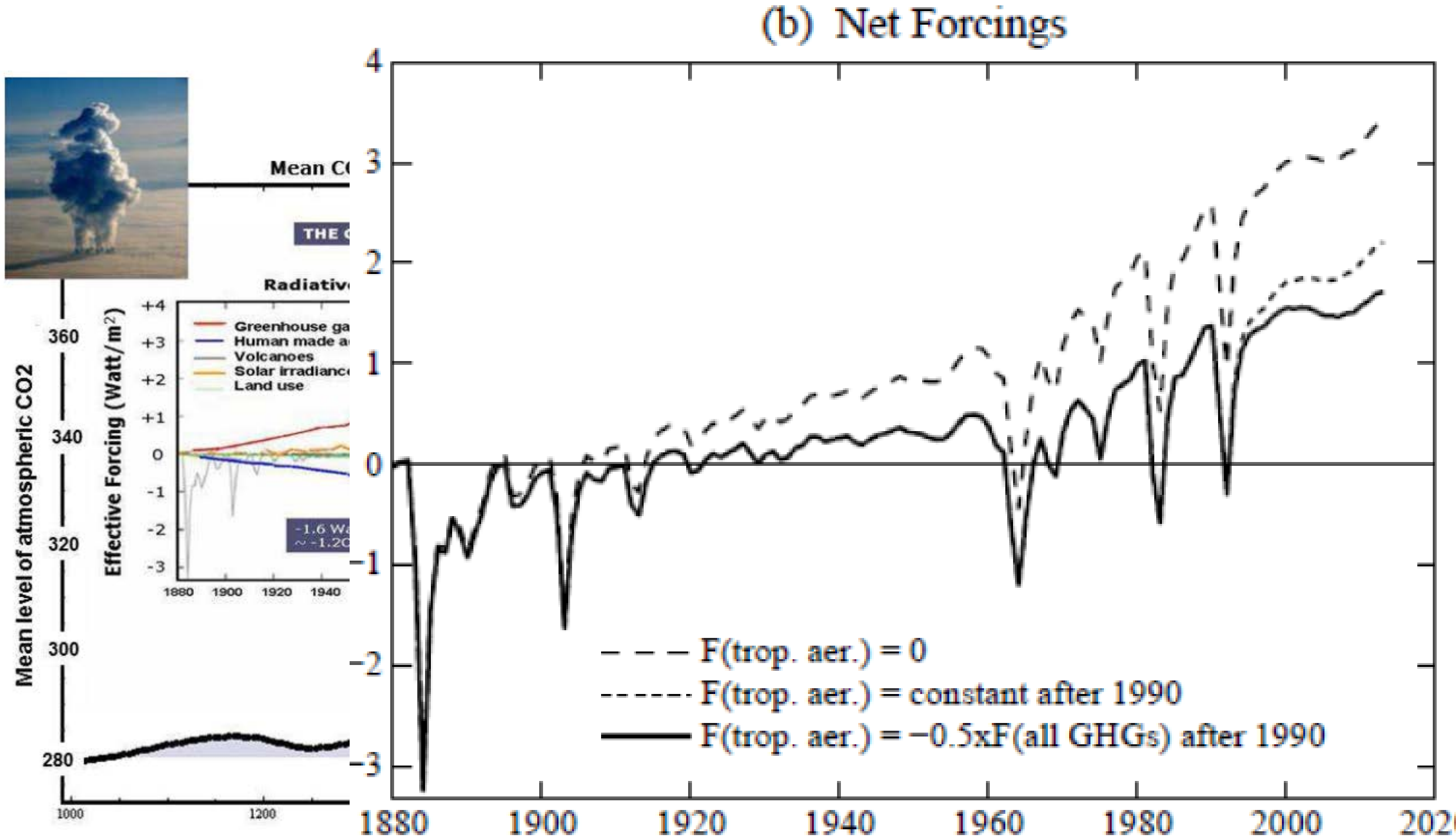

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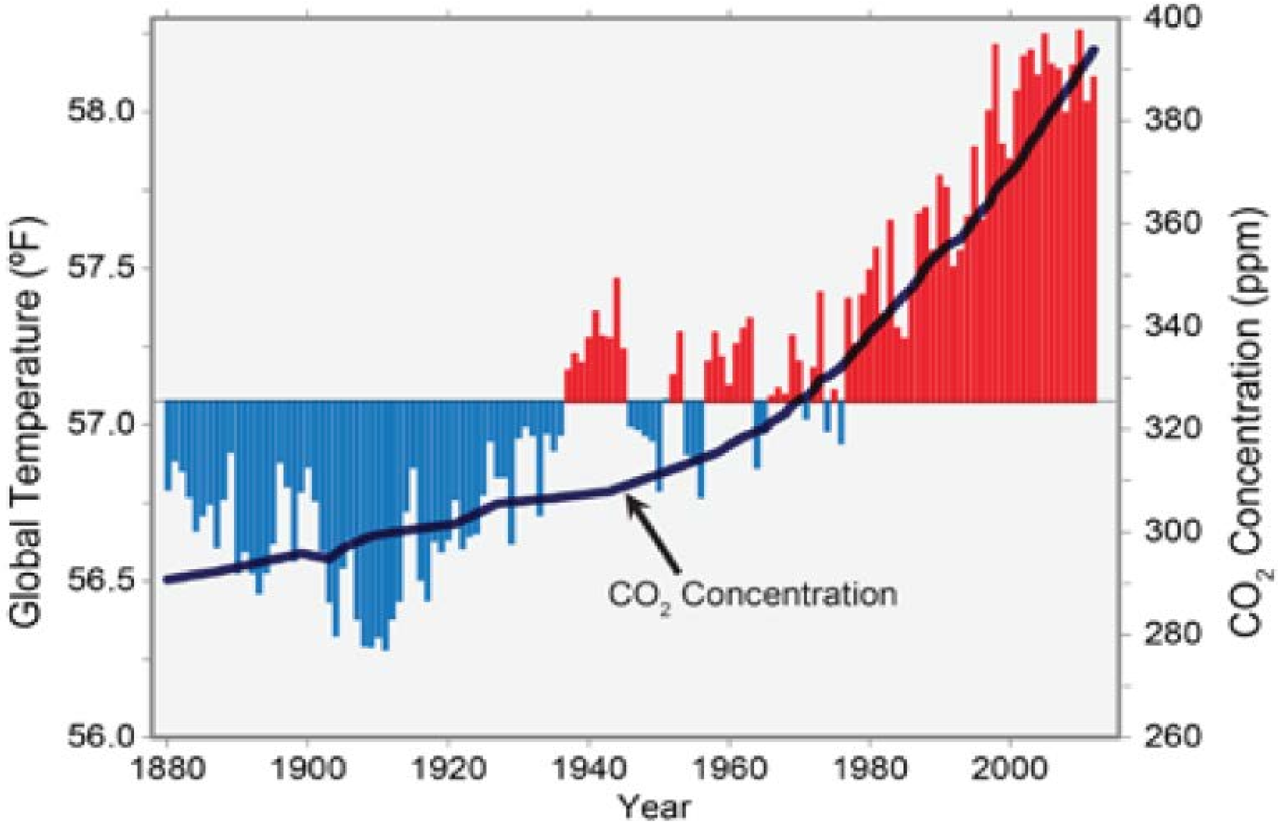
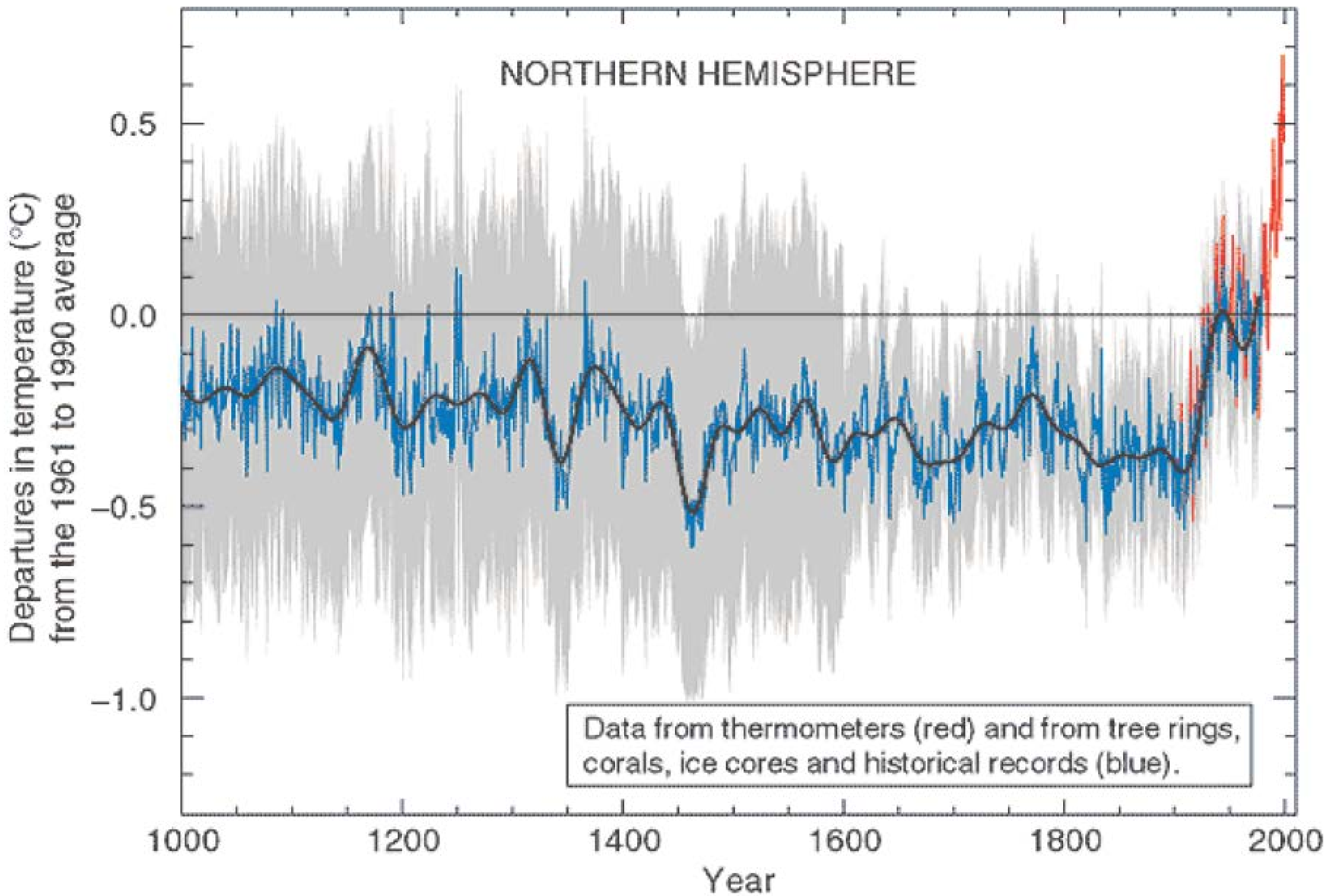
Global annual average temperature



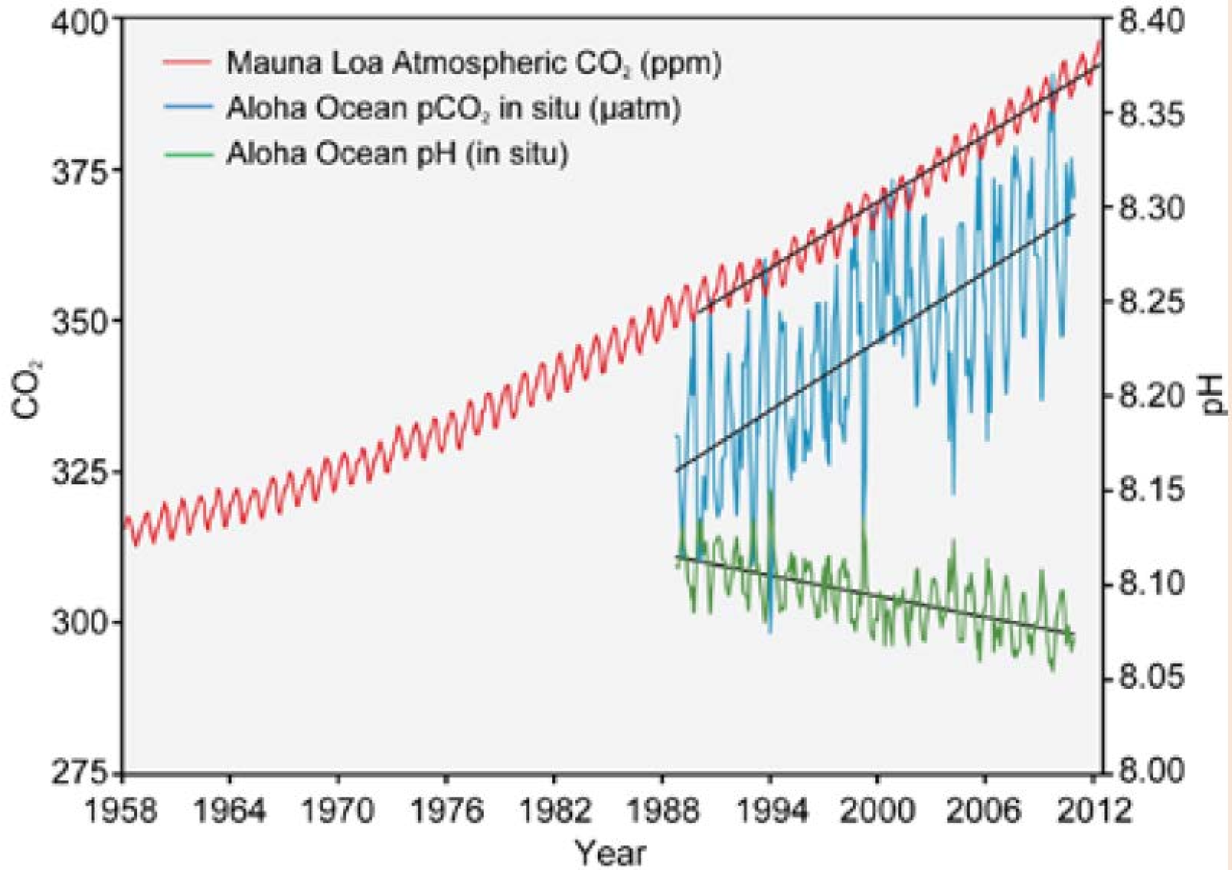
Global annual average temperature (as measured over both land and oceans) has increased by more than 1.5°F (0.8°C) since 1880 (through 2012). [5]

Departures in temperatures (°C) from the 1961 to 1990 average



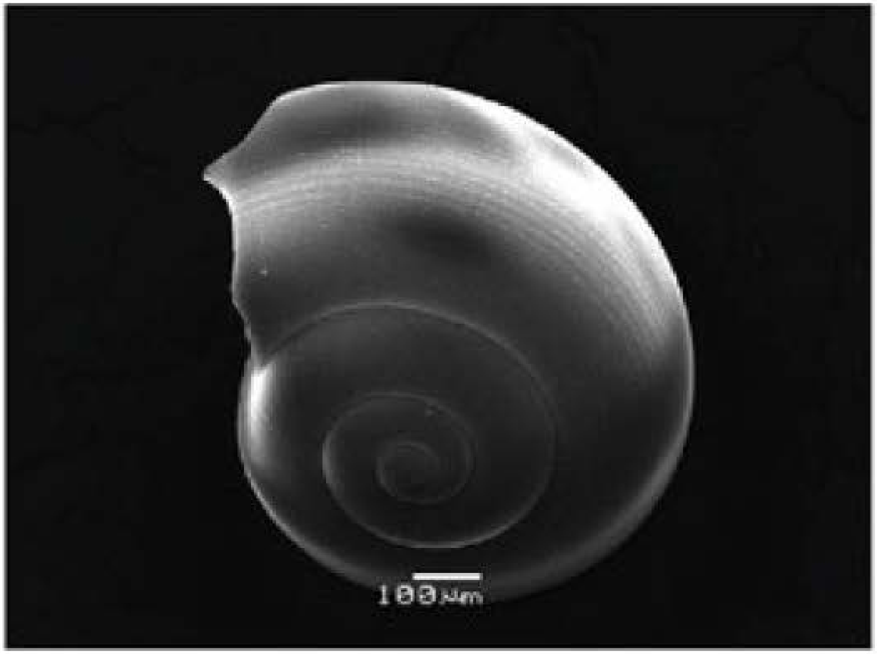
To avoid an increase in temperature of more than 2°C against 1850 the WBGU suggests to reduce the world wide emissions by 45-60% until 2050.

As Oceans Absorb CO_2, They Become More Acidic



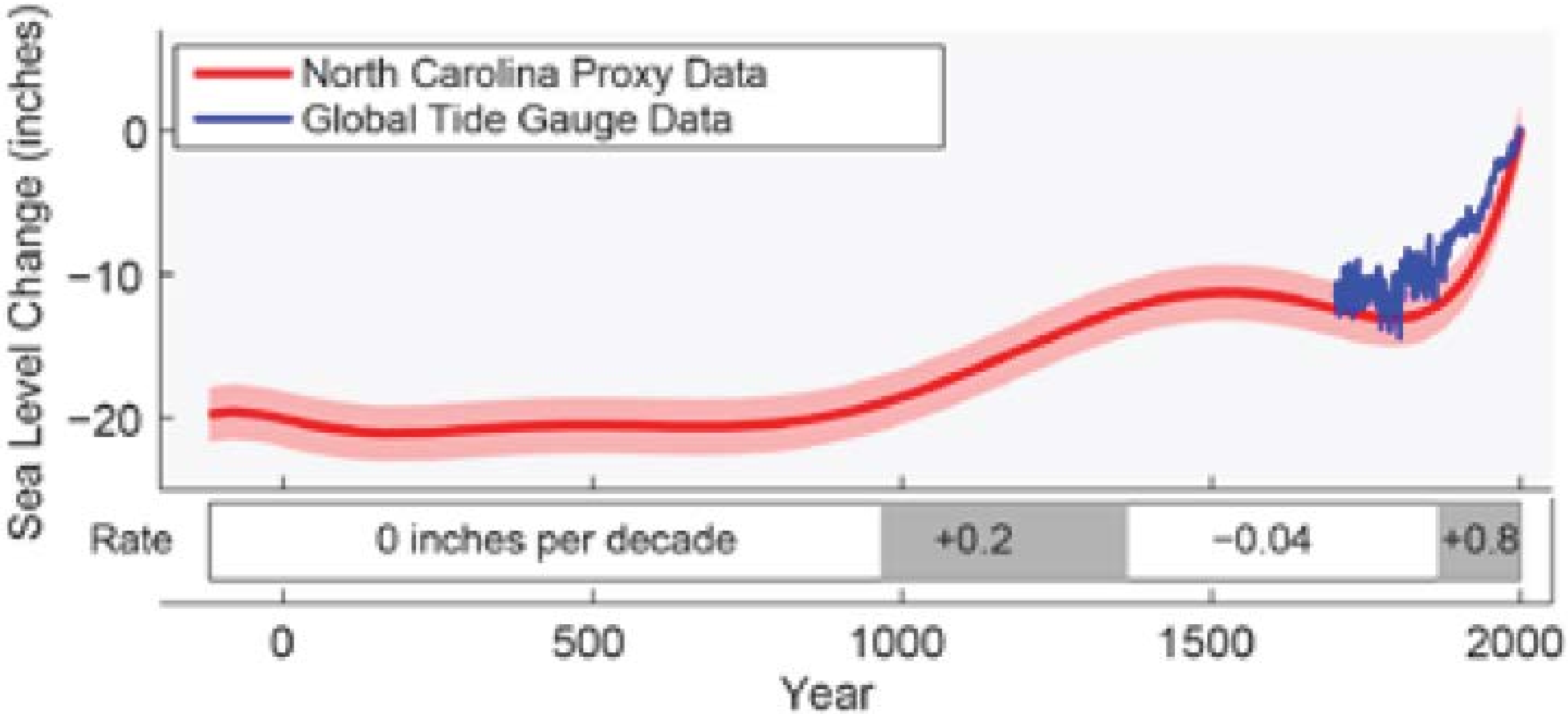
The correlation between rising levels of CO_2 in the atmosphere (red) at Mauna Loa and rising CO_2 levels (blue) and falling pH (green) in the nearby ocean at Station Aloha. As CO_2 accumulates in the ocean, the water becomes more acidic (the pH declines). [5]

Shells Dissolve in Acidified Ocean Water



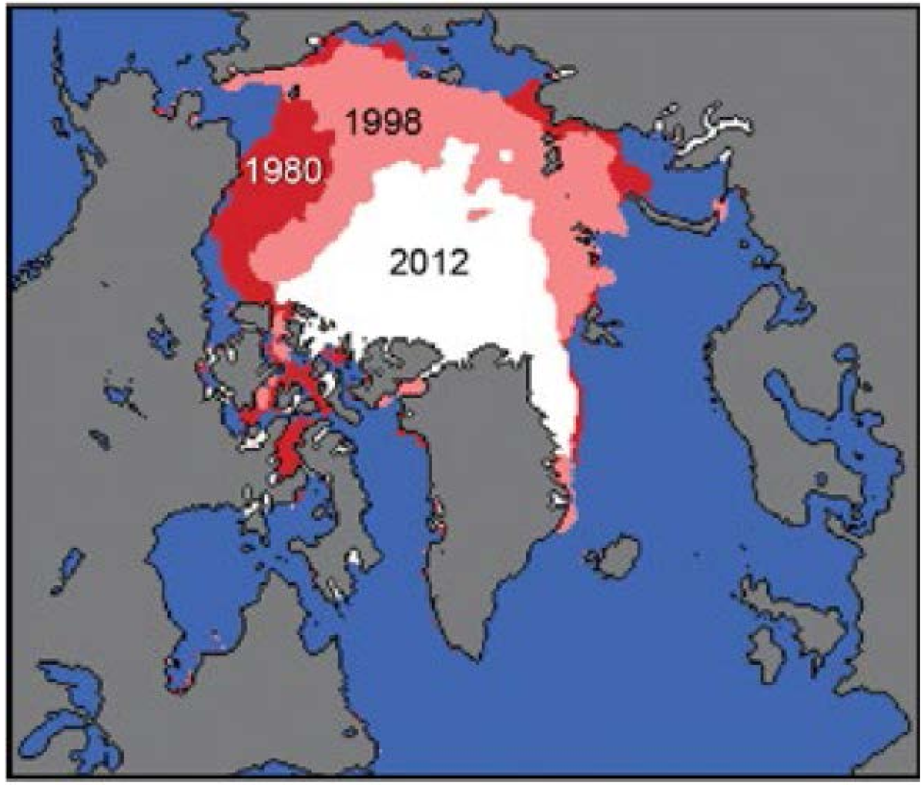
Pteropods, or “sea butterflies,” are free-swimming sea snails about the size of a small pea. Pteropods are eaten by marine species ranging in size from tiny krill to whales and are an important source of food for North Pacific juvenile salmon. The photos above show what happens to a pteropod’s shell in seawater that is too acidic. The left panel shows a shell collected from a live pteropod from a region in the Southern Ocean where acidity is not too high. The shell on the right is from a pteropod collected in a region where the water is more acidic. [5]

North Atlantic Sea Level Change



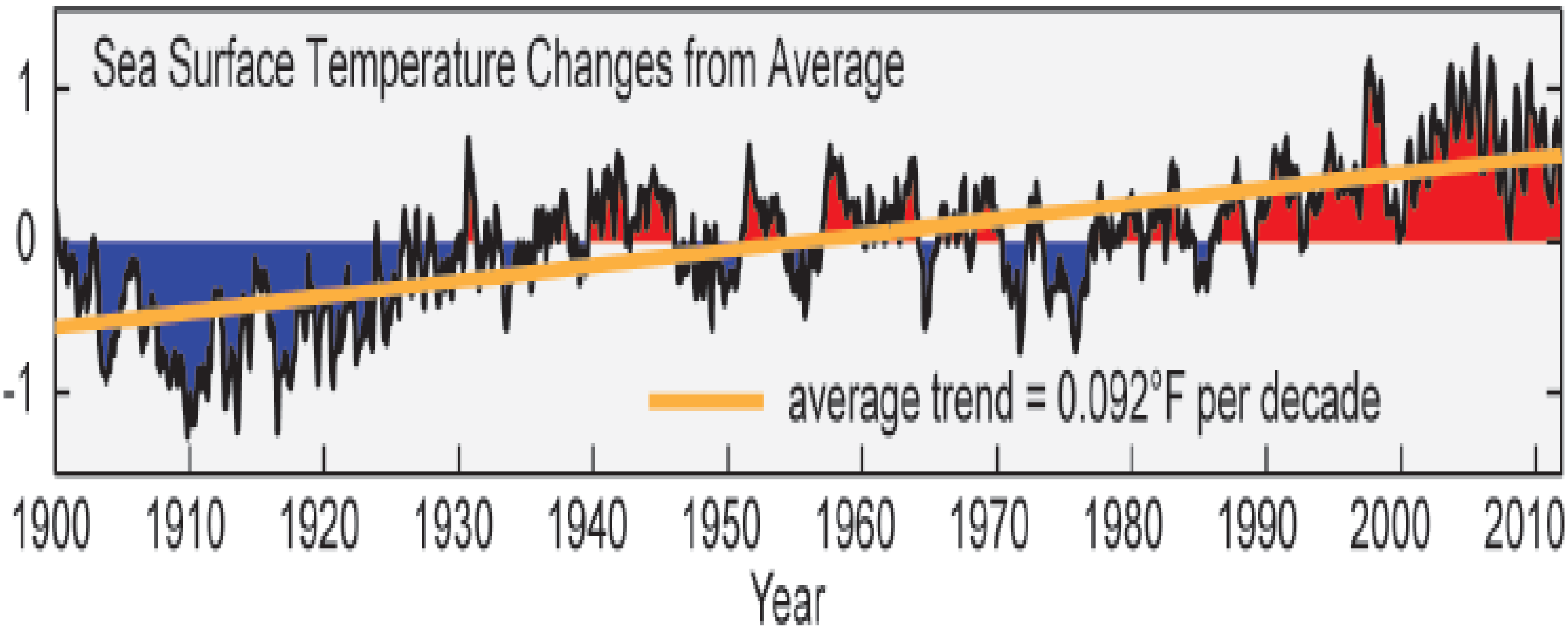
Sea level change in the North Atlantic Ocean relative to the year 2000 based on data collected from North Carolina (red line, pink band shows the uncertainty range) compared with a reconstruction of global sea level rise based on tide gauge data from 1750 to present (blue line).
(Figure source: NASA Jet Propulsion Laboratory). [5]

Decline in Arctic Sea Ice Extent



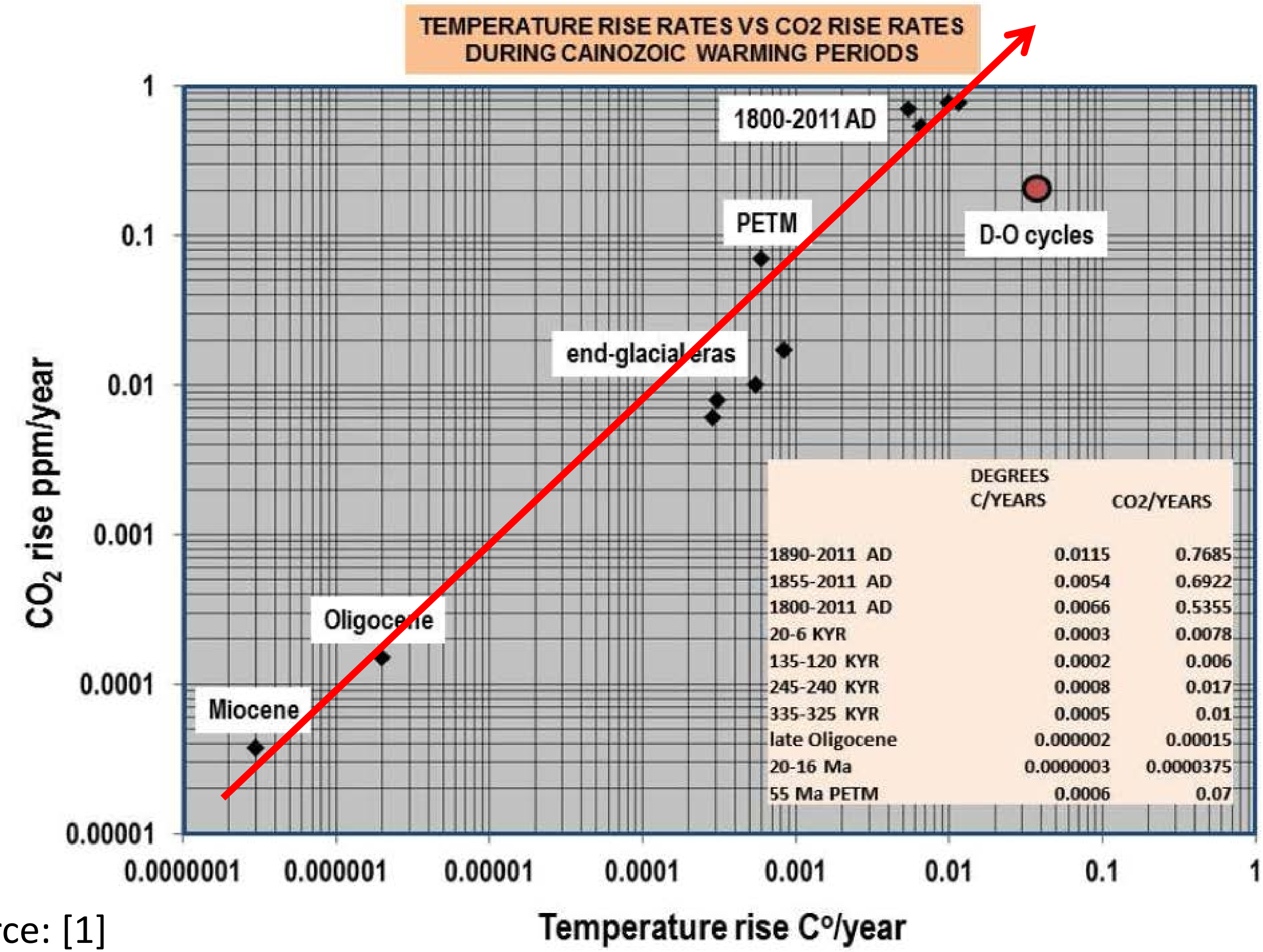
Summer Arctic sea ice has declined dramatically since satellites began measuring it in 1979. The extent of sea ice in September 2012, shown in white in the top figure, was more than 40% below the median for 1979-2000. [5]

Observed Ocean Warming



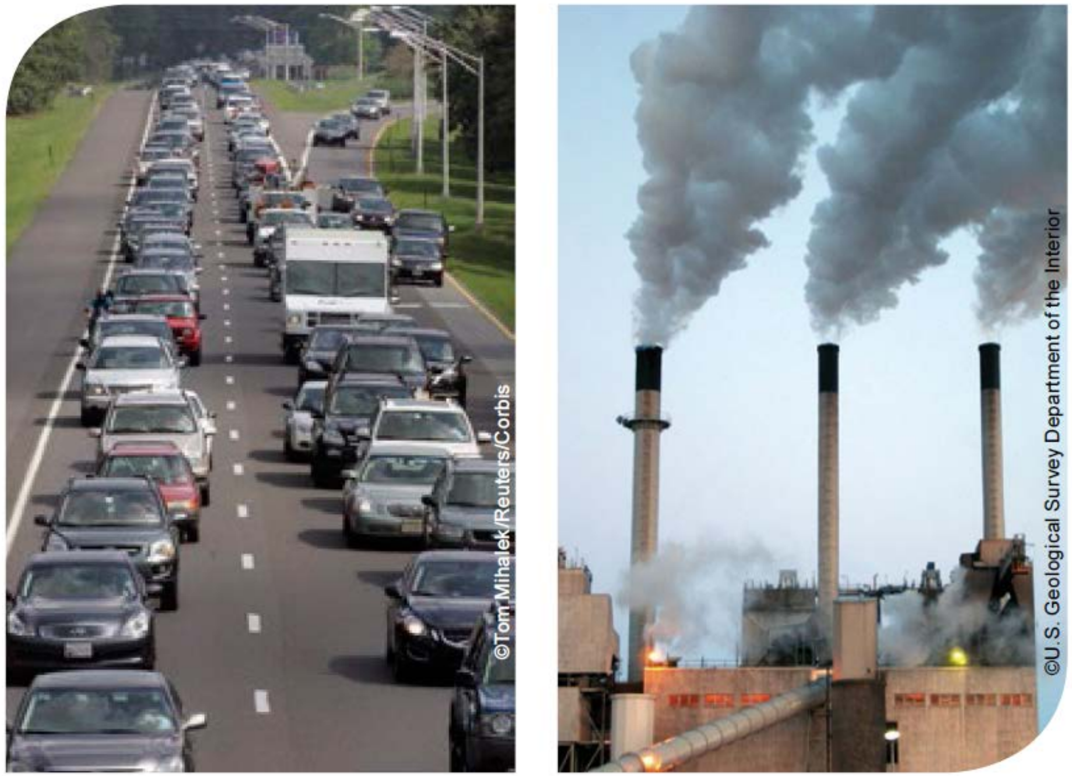
Sea surface temperatures for the ocean surrounding the U.S. and its territories have risen by more than 0,9°F over the past century. [5]

There is a strong correlation of the mean rise of the temperature and the rise of CO_2-content in air.



Source: [1]

The world economy is strongly dependent on fossil energies.



Oil used for transportation and coal used for electricity generation are the largest contributors to the rise in carbon dioxide that is the primary driver of observed changes in climate over decades. [5]

Further problems on our planet

- Nearly 800 million people worldwide are starving, mostly in developing countries.
- More than 2 billion people have no access to pure fresh water.
- Because of melting Himalaya glaciers this will soon be much more.
- Every year huge areas of arable land are destroyed caused by wrong treatment, too much cattle, deep ploughing, wrong irrigation, etc.
- Tropical rainforest is destroyed to grow sugar cane (in Brazil) or palm oil (in Malaysia, Indonesia) for the production of biofuels.

Ostensible Solutions for climate change

- Adaption and mitigation are discussed.
  - Reduce solar input by SO_2 release in the high atmosphere.
  - Paint roofs white to reflect more sunlight.
  - Carbon Capture and Storage.
  - Breed plants, which can survive hotter climate.
  - CO_2 absorption by marine life and deposition on the sea floor.
  - CO_2 washing with amine or $NaHCO_3$.
  - Plant billions of trees (good, but they will release CO_2 after cutting them down).
- All this will not reduce CO_2 fast enough if ever and emission will continue.
- Reduction of emission by 3%/year is necessary.
  → That has never be realized and CO_2-content will rise.

An Energethical Solution for Avoiding Climate Change and Peak-Oil.

- We need something that **replaces fossil oil** and coal.
- It should **reduce the carbon dioxide** in the air.
- It may not use land, which is now used for food production.
- It should not destroy rainforests.
- It should restore the degraded soil and give additional food.

If a project can reduce hunger and scarcity of water, it is favorable to other concepts.

How much oil is needed?

- World production of crude oil in Sept. 2014:

  93.8 million barrel /day = 14.91 billion litre/day

  = 5.44 * 10^{12} litre/year

- Oil yield: Palm oil, Jatropha curcas : 5,000 – 10,000 $\frac{litre}{hectare}$

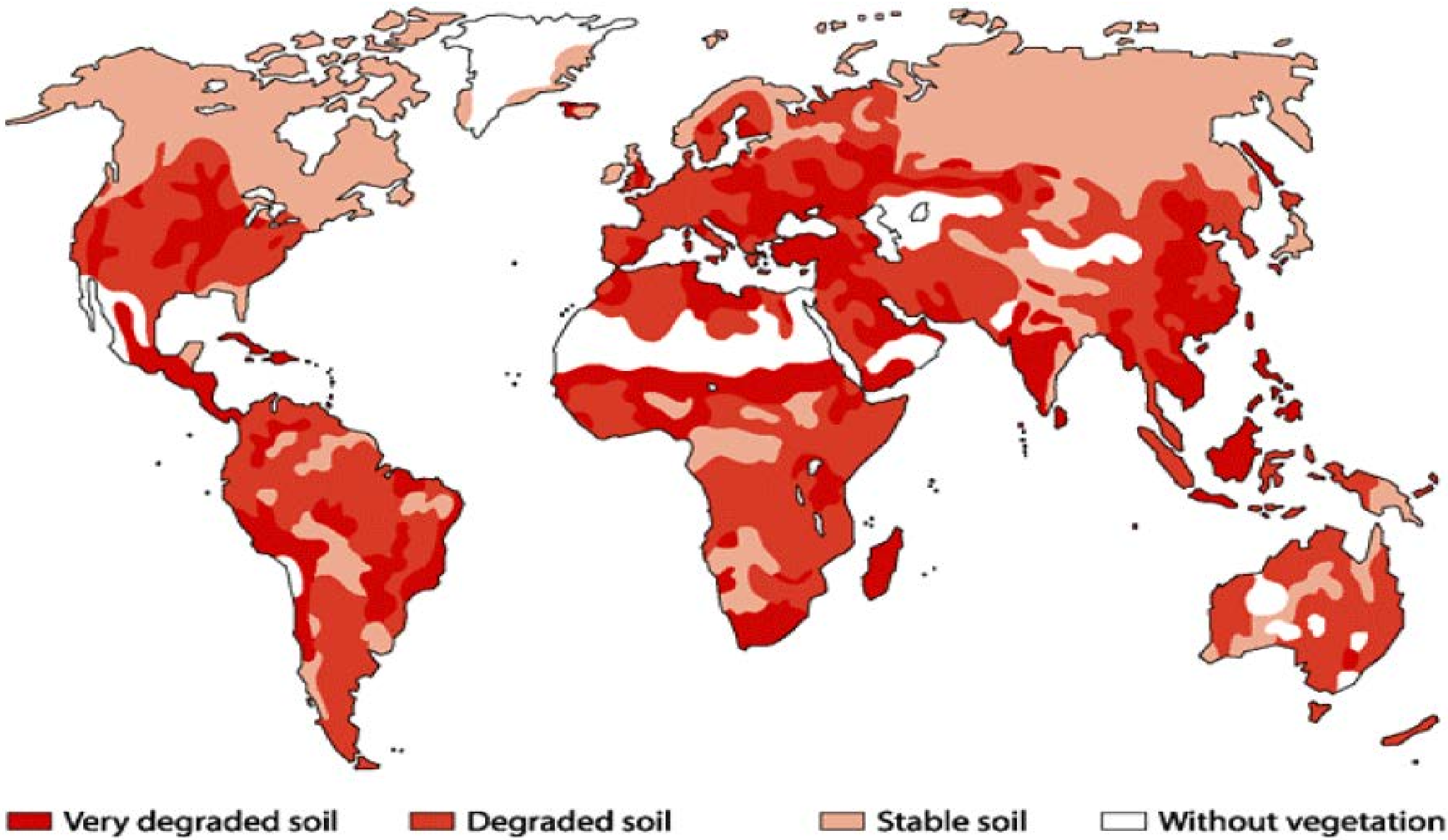
- Production area :

$$\frac{5.44 \cdot 10^{12}\ litre}{5000\ liter/ha} = 1{,}09 \cdot 10^{9} ha = 11\ million\ km^2$$

- For comparison: Worldwide we have made

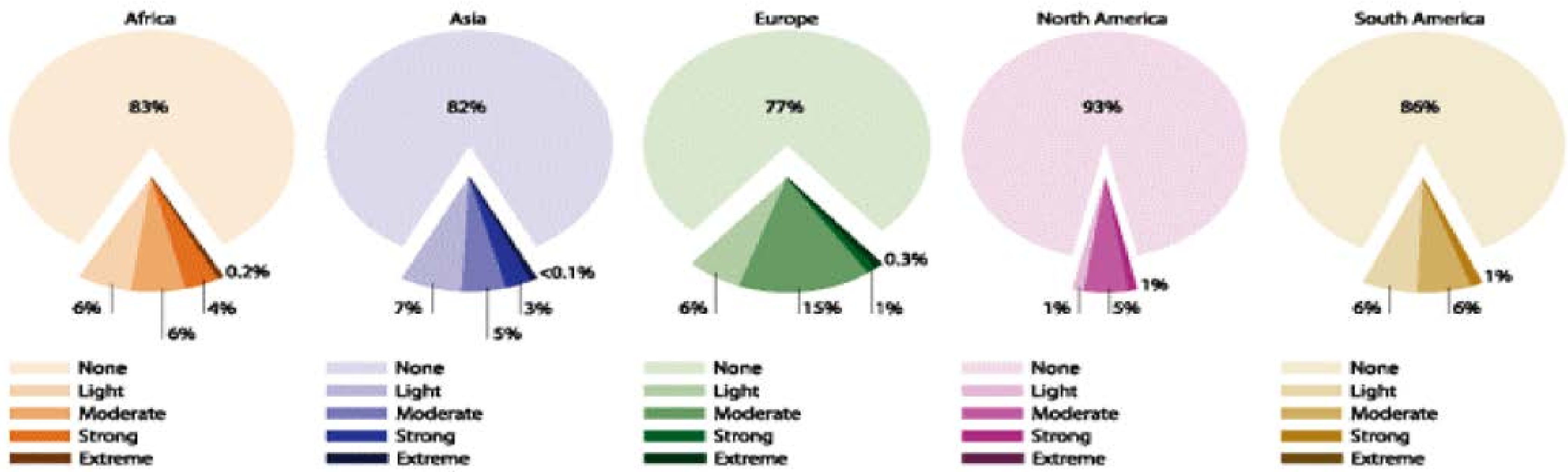
  20 million km^2 degraded land and 36 million km^2 deserts.

Bio-diesel from Jatropha plantations on degraded land
Prof. Dr. K. Becker and Dr. G. Francis

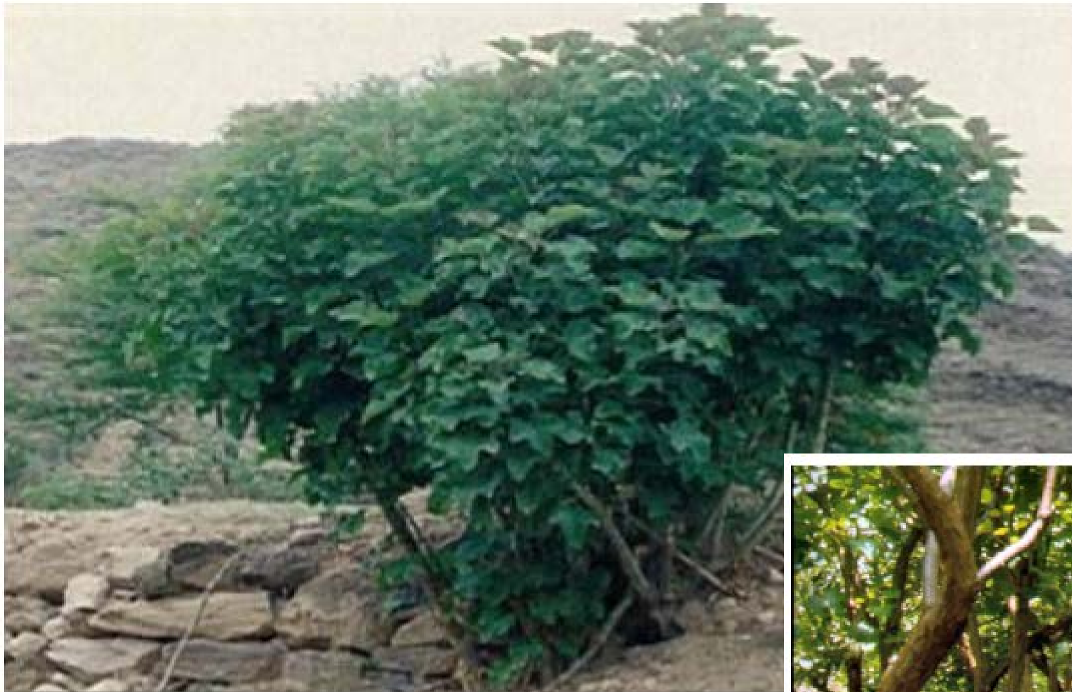


Distribution of degraded land in the different continents (Source UNEP)

2000 million ha is degraded land, that is 15% of the earth land area



Jatropha curcas



Vigorously growing Jatropha plant on rocky substrate

Vegetables intercropped between rows of Jatropha plants (Photo: K. Becker)

How many workers are needed?

- One worker can plant, cut and harvest 5- 8 ha .
- So he will get 25,000 – 40,000 litre /year.
- Number of workers: $\frac{1{,}1 \cdot 10^9 \, ha}{5 \, ha/worker} = 220$ million .
- If a family has 3 children, there are 550 million people.
- They need food, which is produced on additional 0.5 ha/person, so 275 million ha arable land is added.
- 1090 + 275 million ha = 1365 million ha are to be planted.

Jatropha curcas for Example

- Jatropha curcas plantation in Madagascar, unripe, ripe and peeled nuts

Source: Reinhard K. Henning, The Jatropha System, An integrated approach of rural development

DaimlerChrysler jatropha biodiesel project in India

At the beginning

First plantings

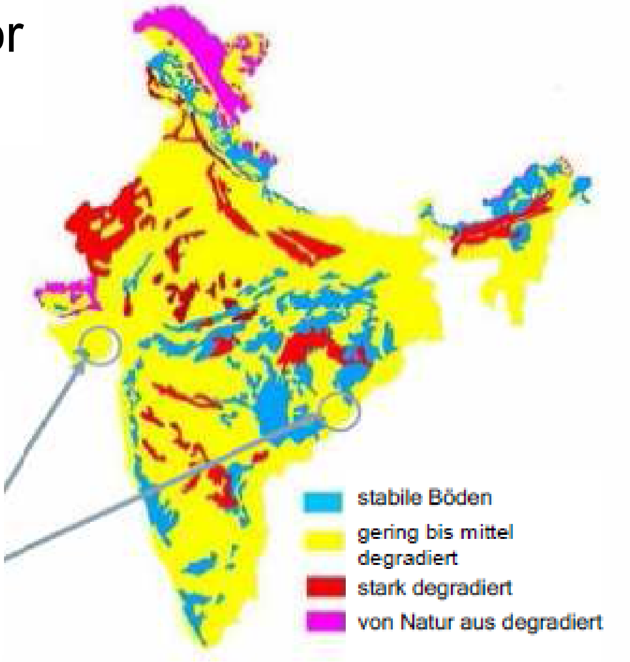
After some years

Driving with biodiesel

Quelle: DaimlerChrysler, Jatropha – Biodiesel from Eroded Soils, A Concept for Sustainable Mobility in Developing Countries, RBP/CF July 17, 2006

Degraded soils in India

- In India are 130 million hectare degraded land
- 33 million hectare are available for planting Jatropha curcas
- Political programs for recultivation are at work



Plantation in Gujarat (10 ha)

Plantation and tree nursery in Orissa (20 ha)

Quelle: *DaimlerChrysler, Jatropha – Biodiesel from Eroded Soils, A Concept for Sustainable Mobility in Developing Countries, RBP/CF July 17, 2006*

How much water is needed?

- Example: Jatropha curcas
- Jatropha curcas grows with rainfall of at least 300 - 1000 mm on bad, but good drained soils. Survives 6 month without rain.
- No competition with food.
- Yield: 2500 to 5000 kg/ha (sometimes 10000 kg/ha) dried black seeds
- Oil content: 30% - 35% (up to 46% reported)
- Oil yield: 875 – 1500 Litre/ha on dry land
  (10000 Litre/ha reported from Jatrophacurcas-plantations.com
  5520 Litre/ha, dry Land, irrigated
  3600 Litre/ha, arid, irrigated from Biodieseltechnocrats.com)

$$600\,\frac{dm^3 water}{m^2}\cdot 10000\,\frac{m^2}{ha}\Big/1500\,\frac{dm^3}{ha}oil = \frac{4m^3 water}{dm^3 oil}$$

- Water must be cheap!

How to get enough water?

- Seawater desalination is possible in industrial scale.
- The remaining salt content for irrigation may not be higher than 25 mg salt/kg water (FAO).
- Energy demand for thermal desalination:

  ~50 kWh_{heat}/m^3 water and 2-3 $kWh_{el.}$ Energy /m^3 water

  or

- Reverse Osmosis 4-5 $kWh_{el.}$ Energy /m^3 water

Desalination types, properties, energy demand

- Seawater desalination methods:
  - Reverse Osmosis (RO) needs high pressures

    pumps 4-5 $kWh_{el.}/m^3$,

    Membranes have to be replaced every 18 month

    salt content: > 50 mg salt/kg water. (good for drinking, not for irrigation)
  - Multi stage flash evaporation (MSF)

    ~45-50 kWh_{th}/m^3 heat at 120°C, 2-3 $kWh_{el.}/m^3$
  - Multi effect distillation (MED)

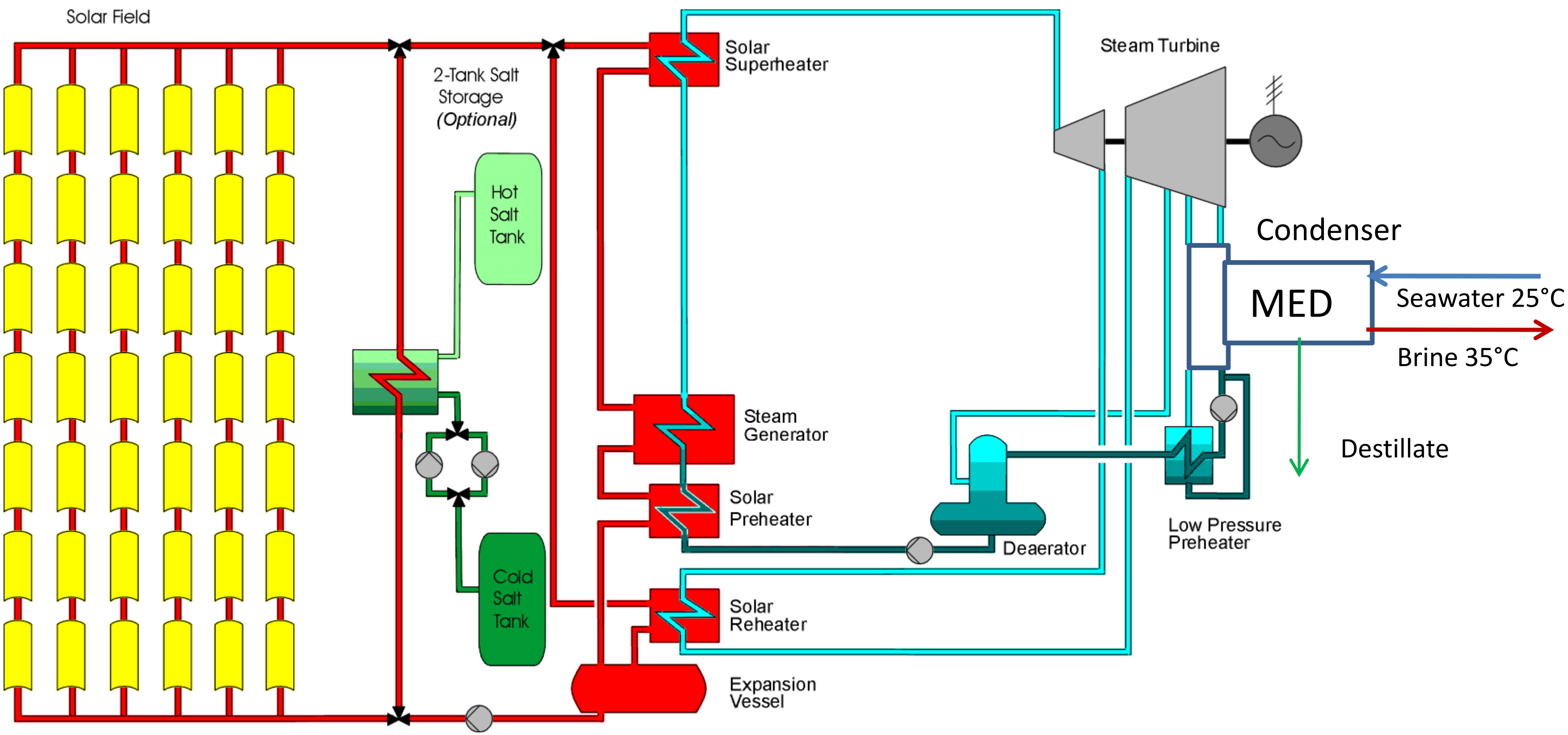
    ~45-50 kWh_{th}/m^3 heat at 80°C, 2-3 $kWh_{el.}/m^3$

    salt content : < 25 mg salt/kg water.

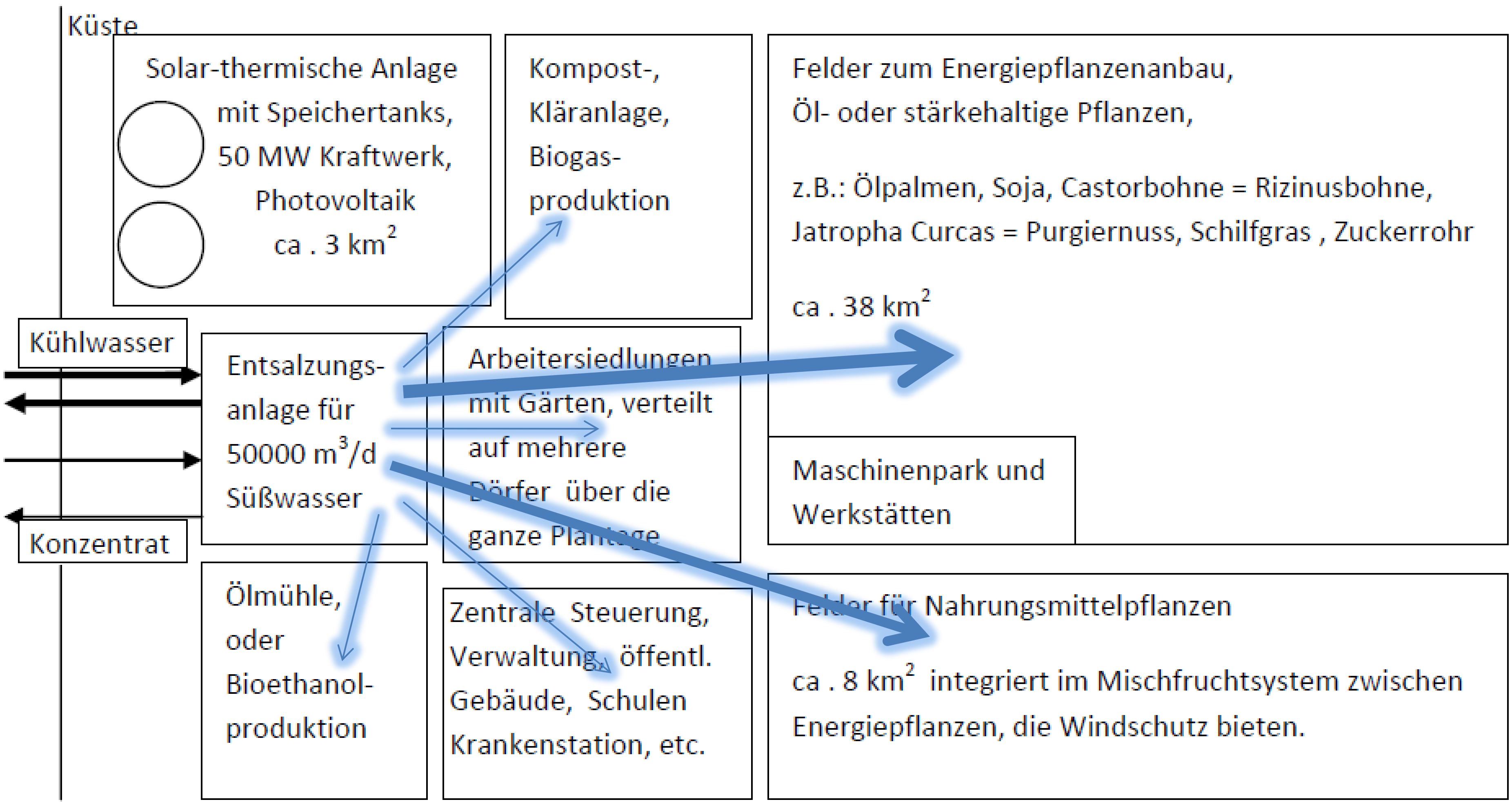
Energy supply

- Heat is abundant in deserts and tropical regions.
- Combination with solar thermal power plants.
- One 50 MW_{el} power plant (Andasol 1) has about 93 MW waste heat at 80°C
- With this it is possible to gain up to 50.000 m^3 per day fresh water (44,5 kWh/m^3).

Combined heat and power plant with thermal desalination



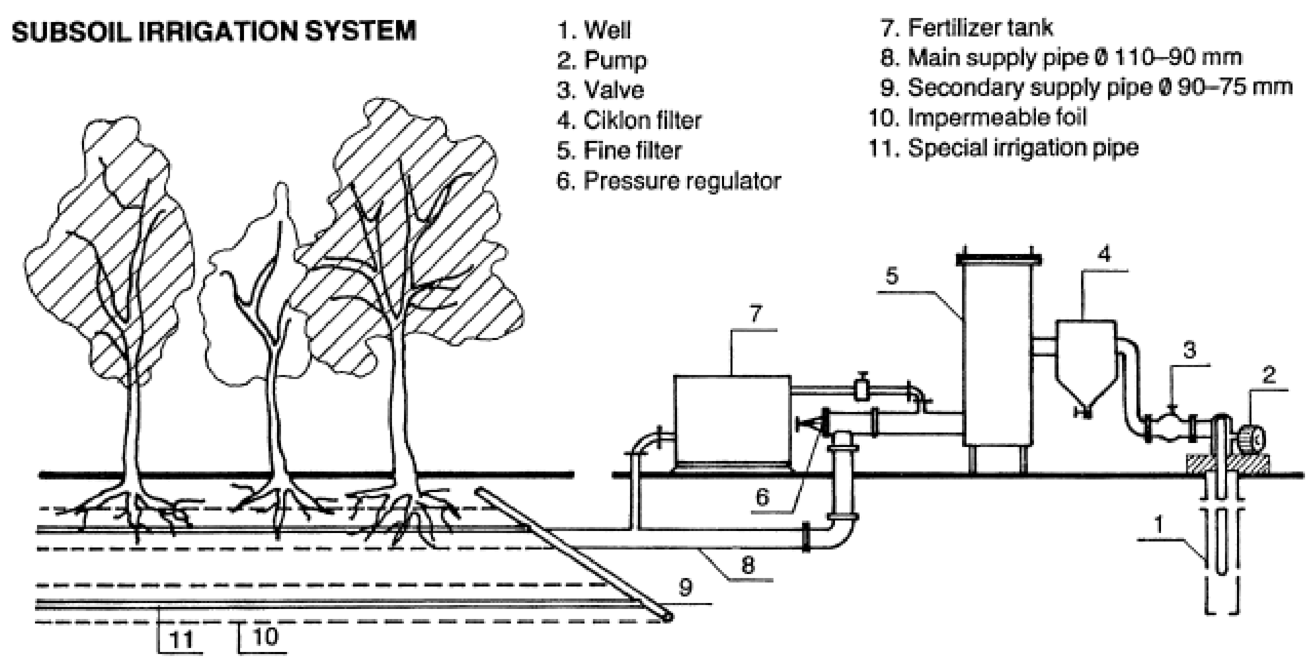
Concept of combined solar thermal power plant, desalination, irrigation and oil and food production



Efficient Irrigation

- Evaporation rates in tropic regions are very high. So efficient usage of water is necessary.
- Subsoil irrigation needs only 25% - 30% of the amount of water compared to sprinkler systems.
- For various crops up to 200 litre/($m^2{*}a$) are necessary.

- Yields are ca. 30% higher.
- Here we calculate with 400 litre/($m^2{*}a$).



H.K. Barth, Sustainable and effective irrigation through a new subsoil irrigation system (SIS), Agricultural Water Management 40 (1999) 283-290

What will this plant oil cost?

- Efficient usage of water and higher yield give 400% efficiency compared to sprinkler systems
- Water needed for 1 liter oil ~ 1.6 m^3
- Only 4/5 of the area will produce plant oil, 1/5 is needed for food production and water supply of the workers and their families.

Costs of waste heat (0,95€/GJ) 0,00174 €/kWh * 50 kWh/m^3=	0,087 €
Electricity for pumps 3 kWh/m^3 * 0,05 €/kWh =	0,150 €
Costs for desalination installment /m^3 water	0,102 €
Costs for irrigation system /m^3 water	0,020 €
Maintenance and Personal /m^3 water	0,050 €
Total costs for water /m^3 without interest	0,409 €
Total costs for water /m^3 with interest (8%/a for 28 a)	0,95 €

What will this plant oil cost?

- Costs for water in plant oil: 5/4*1,6*0,409€ = 0,818 €/dm^3 oil

  for 2500 litre oil/ha. May be lower if yields are higher.

- Working costs:
  - One worker can harvest 30 kg/h, with 10-12,5 Liter oil
  - 10€ for 8h wage → 10€/80 litre -10€/100 litre → 0,1 -0,125€/ litre oil
  - In 50 weeks with 5 days a worker gains 2500 €
    for comparison : wage of a teacher in Ghana: 2500 €/a

Working costs per Litre oil=	0,100 €
Water costs per Litre oil=	0,818 €
Total costs per Litre oil without interest	0,918€
Water costs per Litre oil with interest =	1,899€
Total costs per Litre oil with interest =	2,00 €

FED and EZB just give money for only 0,25%, but only to banks, not to planters and for energy sustainability.

Carbon capture and storage **in biomass**

- The oil will be burned instead of fossil oil.
- Burning coal can be reduced (solar thermal power plant).
- Additional CO_2 will be bound in the biomass.
- 50 – 70 t/ha pruning can be harvested every year.
- Nearly 50% is carbon, taking > 91,6 t/ha CO_2 from the air.
- Converting this dried pruning to bio char by pyrolysis will release 1/3 of the carbon again.
- 16,6 t/ha bio char will be left to store it in the soil.
- This bio char can not be digested by microbes or oxidized.
- Thus it stays in the soil for at least 2000 years.
- This Terra Preta makes soil more fertile and stores water.

Compensation for CO_2 releasing of the atmosphere

- 60 t/ha CO_2 are at least taken from the air.
- More is bound in the roots and the trunk.
- CO_2 bound in leaves will be reemitted after 2 years.
- If the planter gets 20 €/t CO_2, he receives 1200 €/ha
- EU only has to announce, that CO_2-certificates are reduced every year 3%.
- This reduces the costs for plant oil 1200 € / 2500 litre =0.48 €/litre
- The final costs are 0.92 €-0.48 € = 0.44 €/litre
- This is only necessary for startup. After some years yields/ha are growing
- For comparison:
  crude oil is just at $US 88.94/br (in Oct. 2014)
  =88.94/1.2659/159 €/litre = 0,442 €/litre

Long time results

- 20 years with 16.6 t/ha bio char will enhance the carbon content of the soil to 33.2 $kg/m^{2.}$
- Additional 16.6 kg/m^2 will be bound in the humus as microbes.
- 50 kg/m^2 carbon in 15 cm soil means 50/300 = 16,67%
- Thus restoring fertility and water storage capability.
- Yields can be expected to rise at least 100%

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Long time results

Left: compost,
had to be irrigated in
the dry summer

Right: compost with 15% bio char,
no irrigation necessary
Source: Dr. Bruno Glaser,
University Halle/Saale

How much CO_2 is taken from the air?

- 50 kg/m^2 * 11 million km^2= $550*10^{12}$ kg C
- $550*10^{12}$ *44/12 kg CO_2 =$2016,7*10^{12}$ kg CO_2 will be bound in the soil in 20 years.
- Since 1850 we released

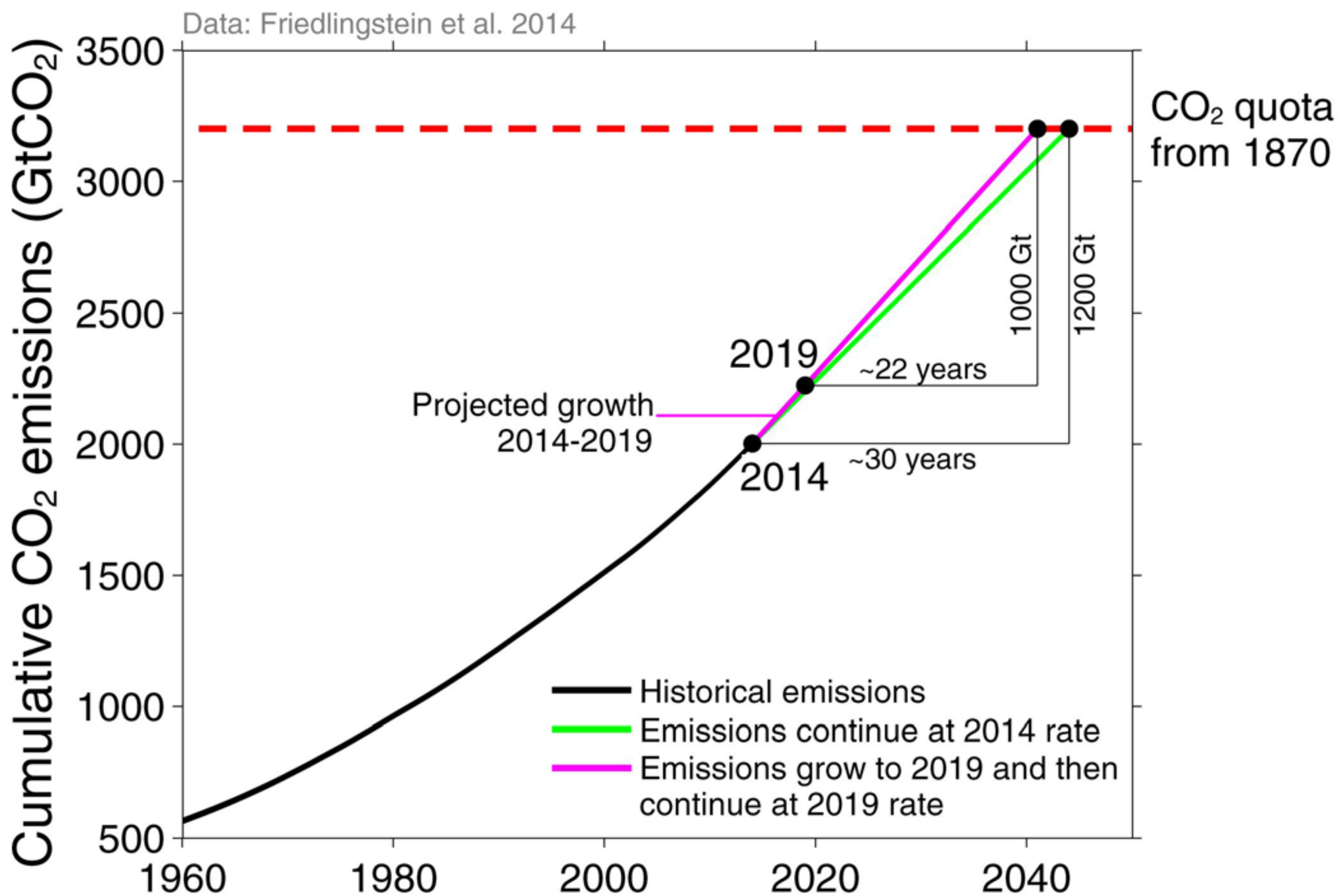
2000 billion t CO_2=$2*10^{15}$ kg CO_2

This implies no additional CO_2 is released.

All burning of fossil fuel is stopped immediately.

This is not possible, but we should start soon and replace every coal and nuclear power plant by a solar thermal power plant.

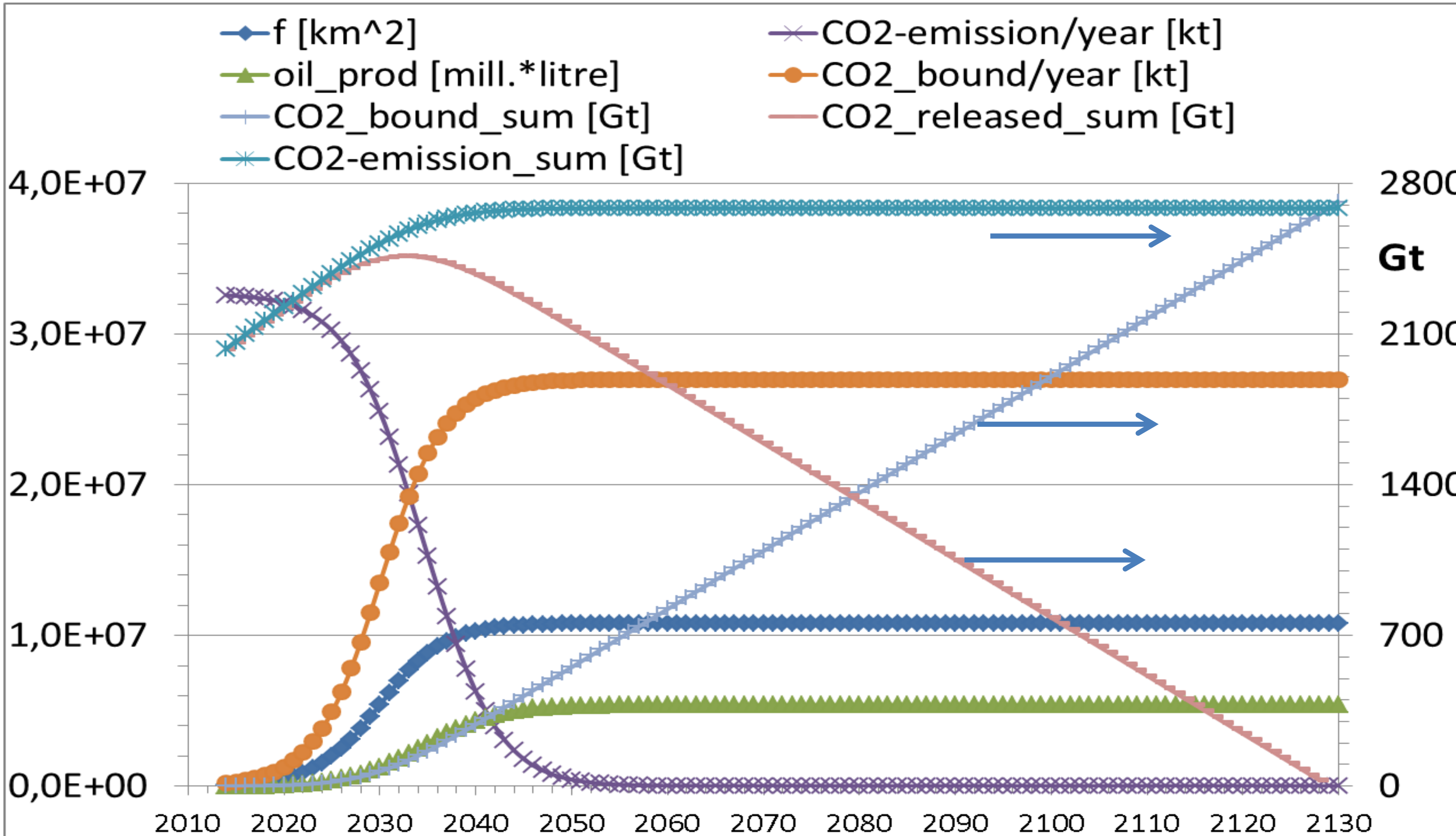
How much CO_2 is taken from the air?



If we can not reduce the emissions we will reach the allowable limit in 30 years.

How long will the replacement last?

- If a natural growth is assumed, the area for plant oil production will look like this:



How long will the replacement last?

- The plantation area will increase in about 40 years to maximum .
- In this time the CO_2-emissions of fossil CO_2 will decrease, but the amount of CO_2 in the air and the ocean will increase further to about 2800 Gt .
- From 2045 on the CO_2-content in the air will decrease.
- From 2060 on no fossil CO_2 will be emitted.
- At the end of the century we could reach a level like in the mid on the 20th century.
- At this time most of the energy will be provided by wind, water, photovoltaic and biomass.
- The plantations can than produce more food for 9 billion people.

Résumé

- These plantations can deliver plant oil to replace the dwindling fossil oil.
- The trees will bind much more CO_2 than is bound in the oil and set free in burning the oil.
- Converting this biomass to bio char and building Terra Preta will help to enhance water storage capability and fertility of the degraded soils.
- CO_2-content in air and water can be reduced to pre-industrial level
- Between the energy plants food for 550 million people can be produced. Water scarcity is reduced.
- Education possibilities for these people are possible.
- The solution is sustainable and ethical.

Thank You for Your attention

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