# A quantitative outlook at the future of energy

## World energy consumption and resources: an outlook for the rest of the 21st century

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**Unit of energy for this talk: the "toe" (ton of oil equivalent)**

**= the average heating value of 1 metric ton of oil (1000 kg = 7.33 barrels)**

**1 toe = 10 Gcal = 41.87 GJ = 11,630 kWh**

- 1 toe at $95/bbl costs about $700;
- 1 toe of oil used in a 52% efficient oil-fired power plant yields 6,050 kWh of electricity;

**Global yearly consumption of primary energy in 2013: 14 Gtoe**

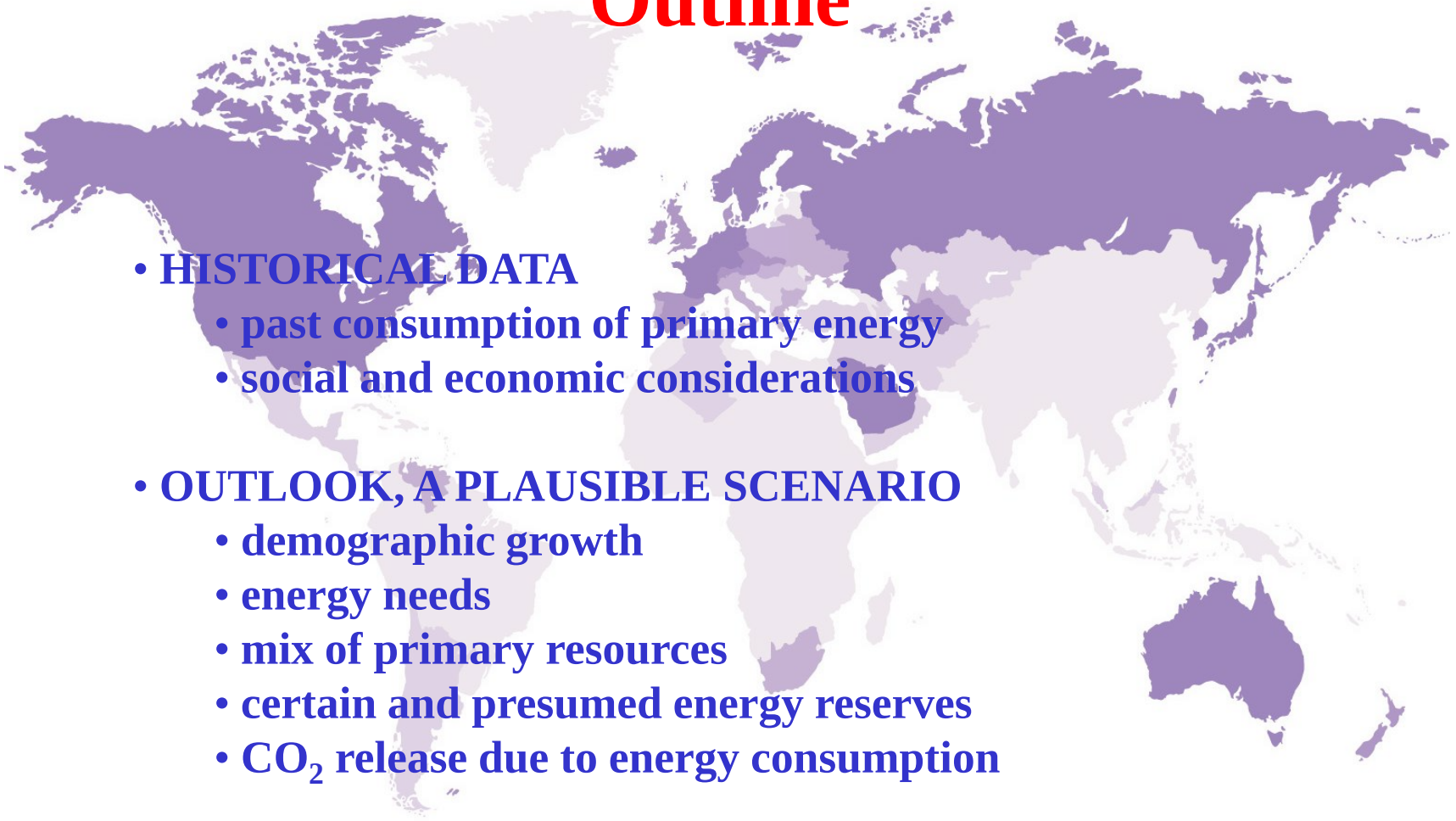
**Average per-capita consumption of primary energy in 2007:**

North America: 7.2 toe/yr
Europe : 3.8 toe/yr
World average: 1.9 toe/yr

**Average retail price of 6,050 kWh of electricity in 2013**

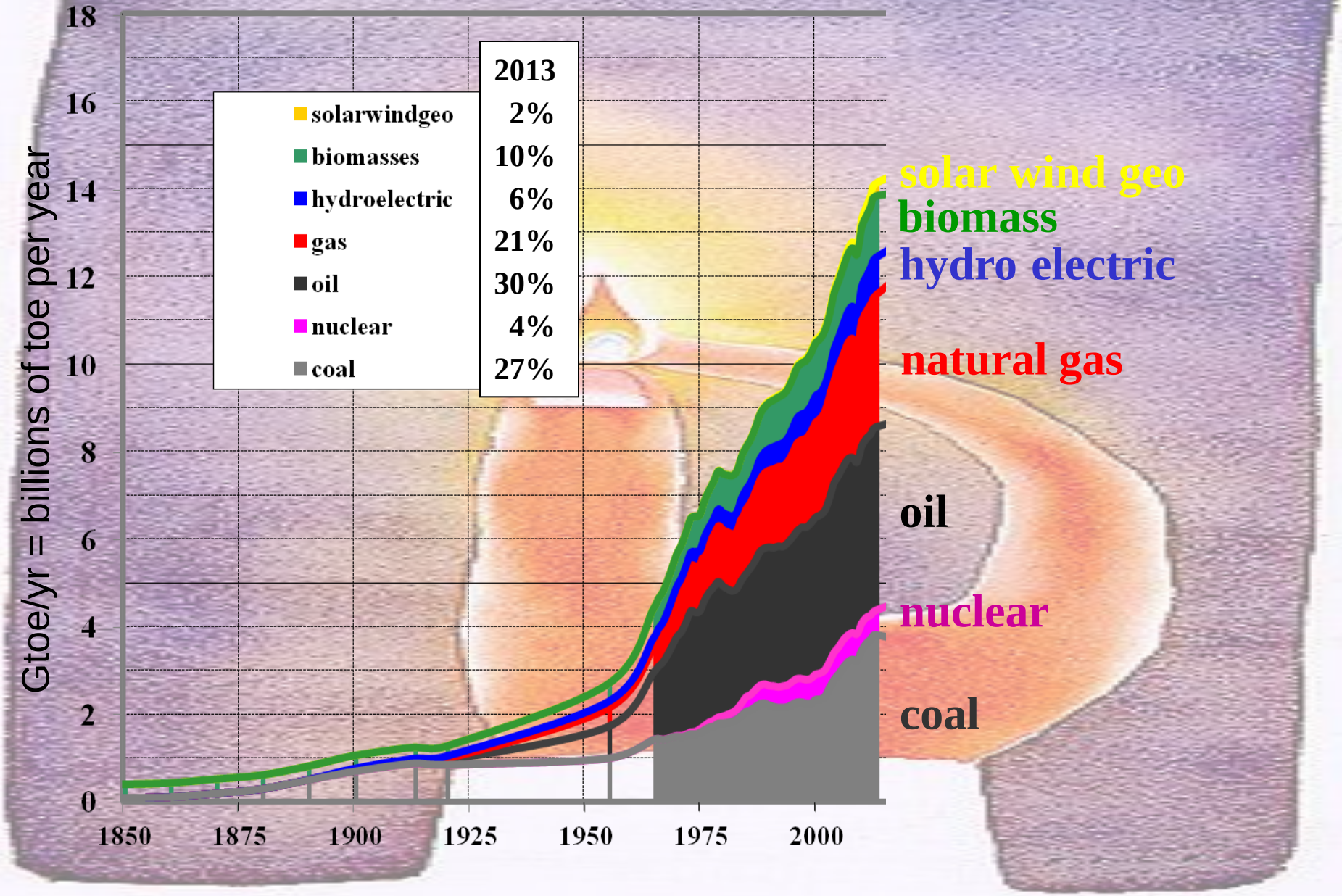
Europe: $1700 (0.28 $/kWh)
Mass.: $ 900 (0.15 $/kWh)
US average: $ 670 (0.11 $/kWh)

# Outline

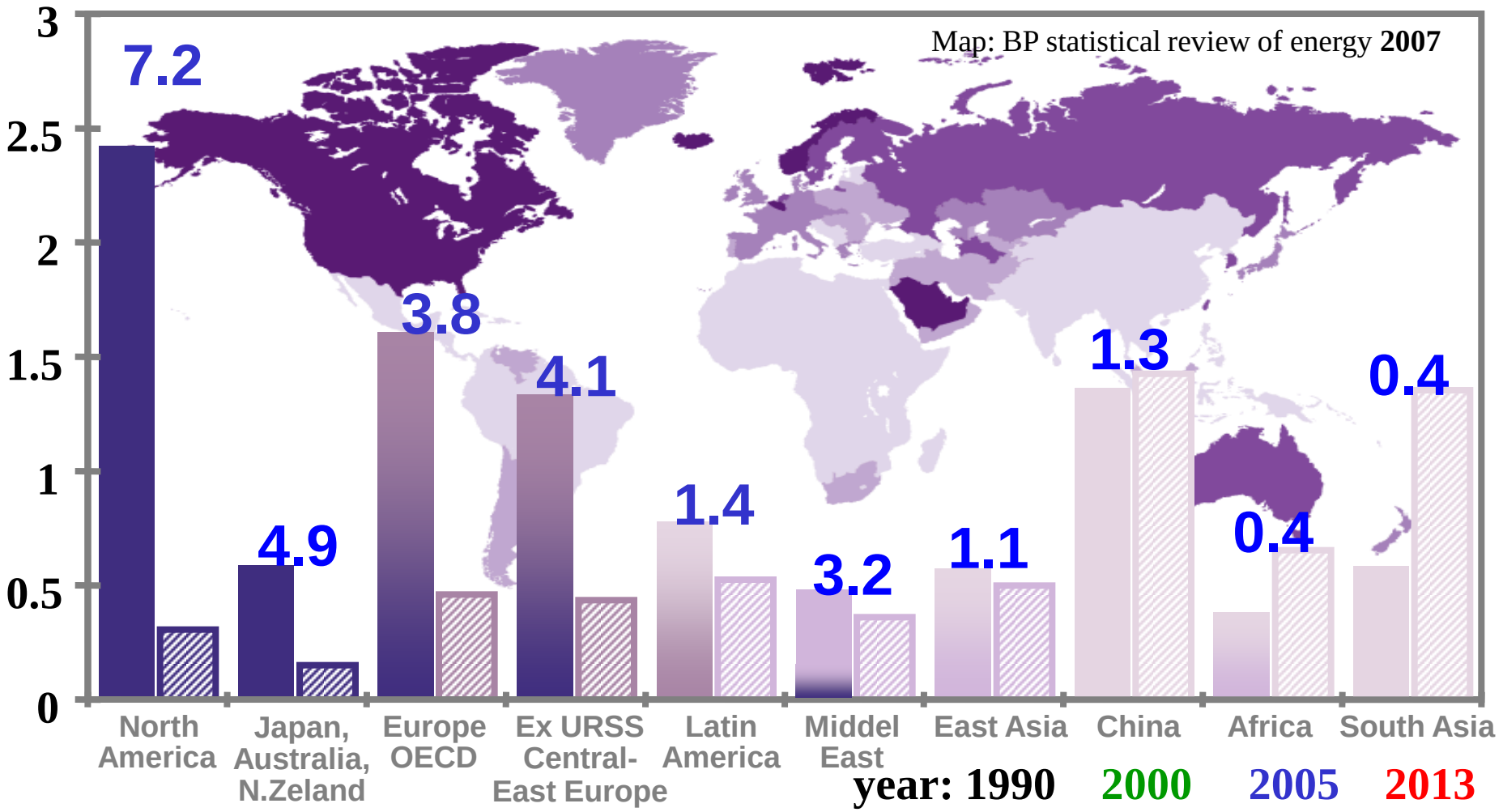


- HISTORICAL DATA
  - past consumption of primary energy
  - social and economic considerations
- OUTLOOK, A PLAUSIBLE SCENARIO
  - demographic growth
  - energy needs
  - mix of primary resources
  - certain and presumed energy reserves
  - $CO_2$ release due to energy consumption
- WHAT CAUSES CLIMATIC CHANGES?
  - global warming versus $CO_2$ concentrations
  - the role of solar activity

# Global consumption and mix of primary energy in the last 150 years



# Uneven spread of per-capita energy consumption




| year: | 1990 | 2000 | 2005 | 2013 |
|---|---|---|---|---|
| Energy consumption (Gtoe/yr) | 9.2 | 10.3 | 12.0 | 14.2 |
| Pupulation (billions) | 5.3 | 6.1 | 6.5 | 7.1 |
| toe/yr per capita | 1.74 | 1.73 | 1.85 | 1.99 |

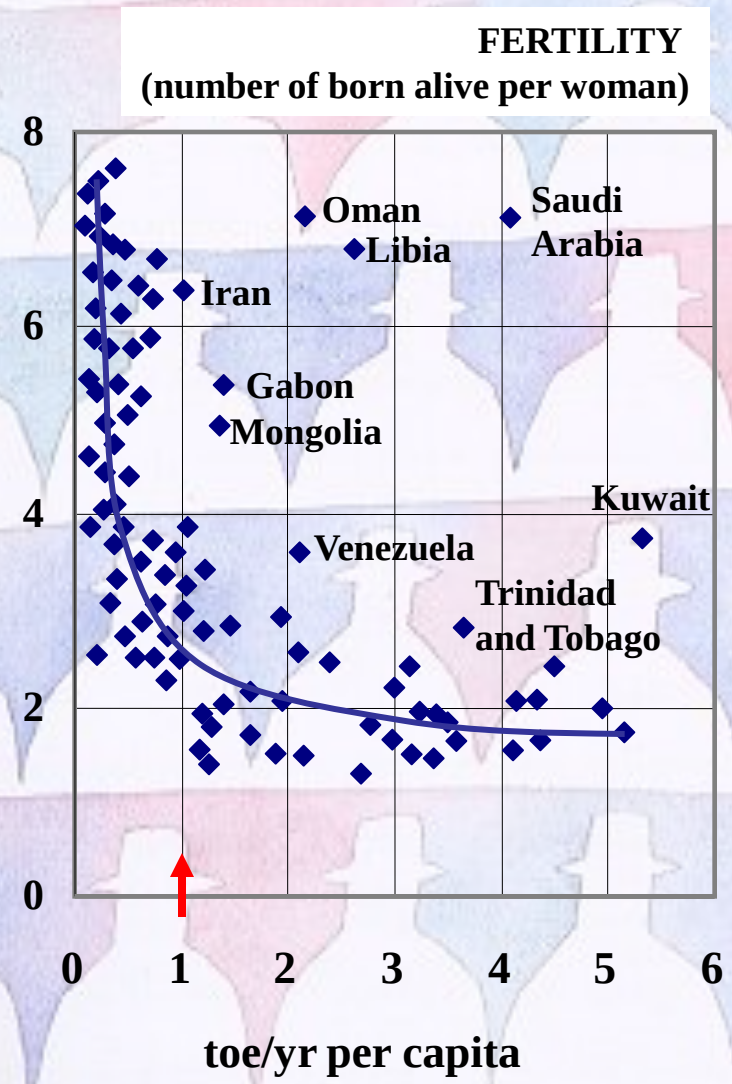
# History of per-capita energy consumption

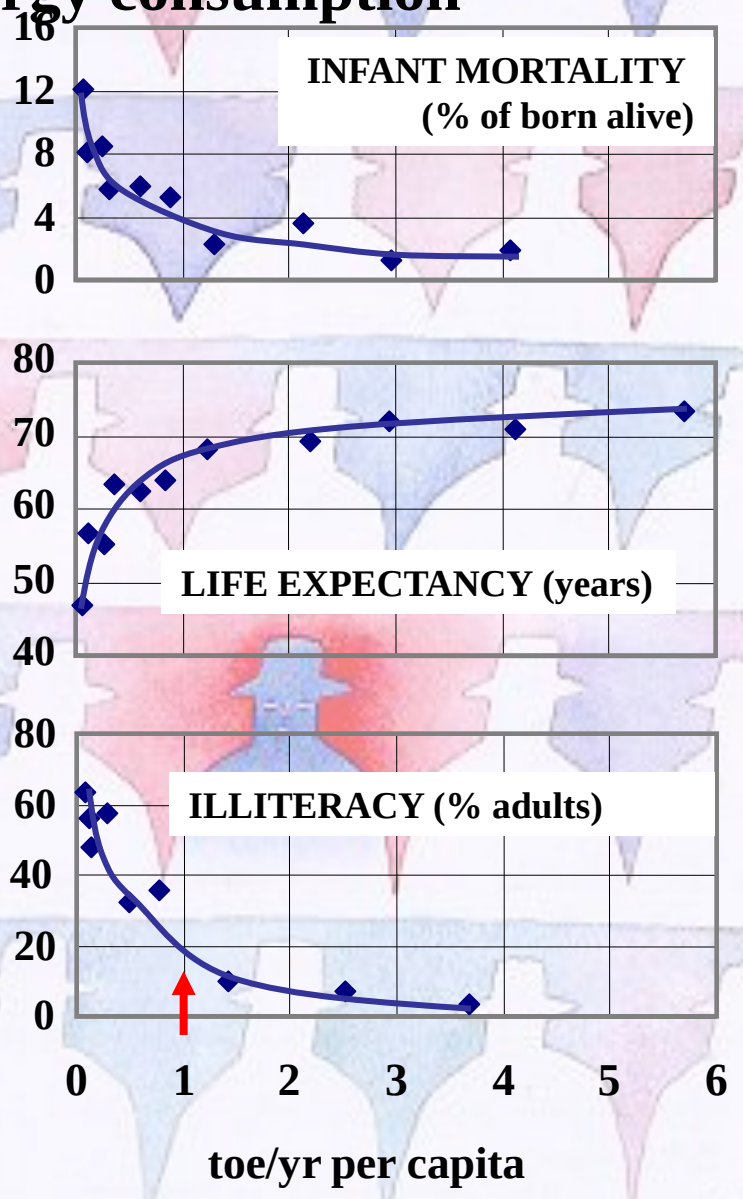
| | | |
|---|---|---|
| food for survival (3000 kcal/day) | | 0,11 toe/yr |
| after discovery of fire (500.000 years ago) | | 0,22 toe/yr |
| neolithic age, bronze age, iron age | | 0,45 toe/yr |
| greek-roman rural-artisan middle-age economy | | 0,50 toe/yr |
| 1800 - England | ⟷ | 0,55 toe/yr |
| 1900 - England | industrialization ⟷ | 2,8 toe/yr |
| 2000 - England | | 3,5 toe/yr |

| | agricoltural fraction of gross national product | | |
|---|---|---|---|
| <1900 - Italy | 66 % | | 0,50 toe/yr |
| 1900 - Italy | 50 % | | 0,50 toe/yr |
| 1913 - Italy | 42 % | ⟷ | 0,55 toe/yr |
| 1939 - Italy | 28 % | industrialization | 1,0 toe/yr |
| 1981 - Italy | 6,4 % | ⟷ | 2,5 toe/yr |
| 2000 - Italy | 3,3 % | | 3,0 toe/yr |

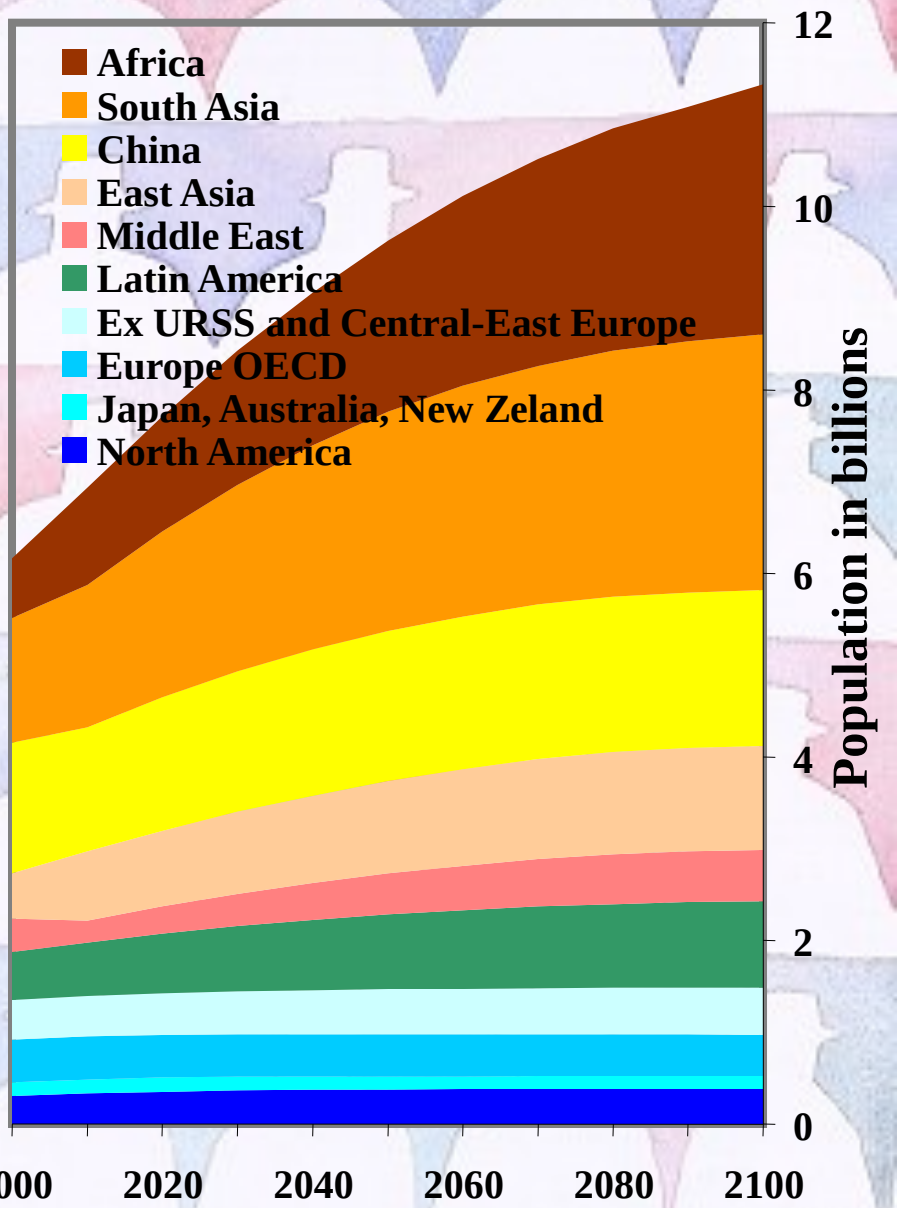
| | global consumption | population | average per capita |
|---|---|---|---|
| greek-roman age | 0,15 Gtep/yr | 0.3 billion | 0,5 toe/yr |
| year 2000 | 10,3 Gtep/yr | 6.2 billion | 1,7 toe/yr |

# Correlations between social and economic development and per-capita primary energy consumption



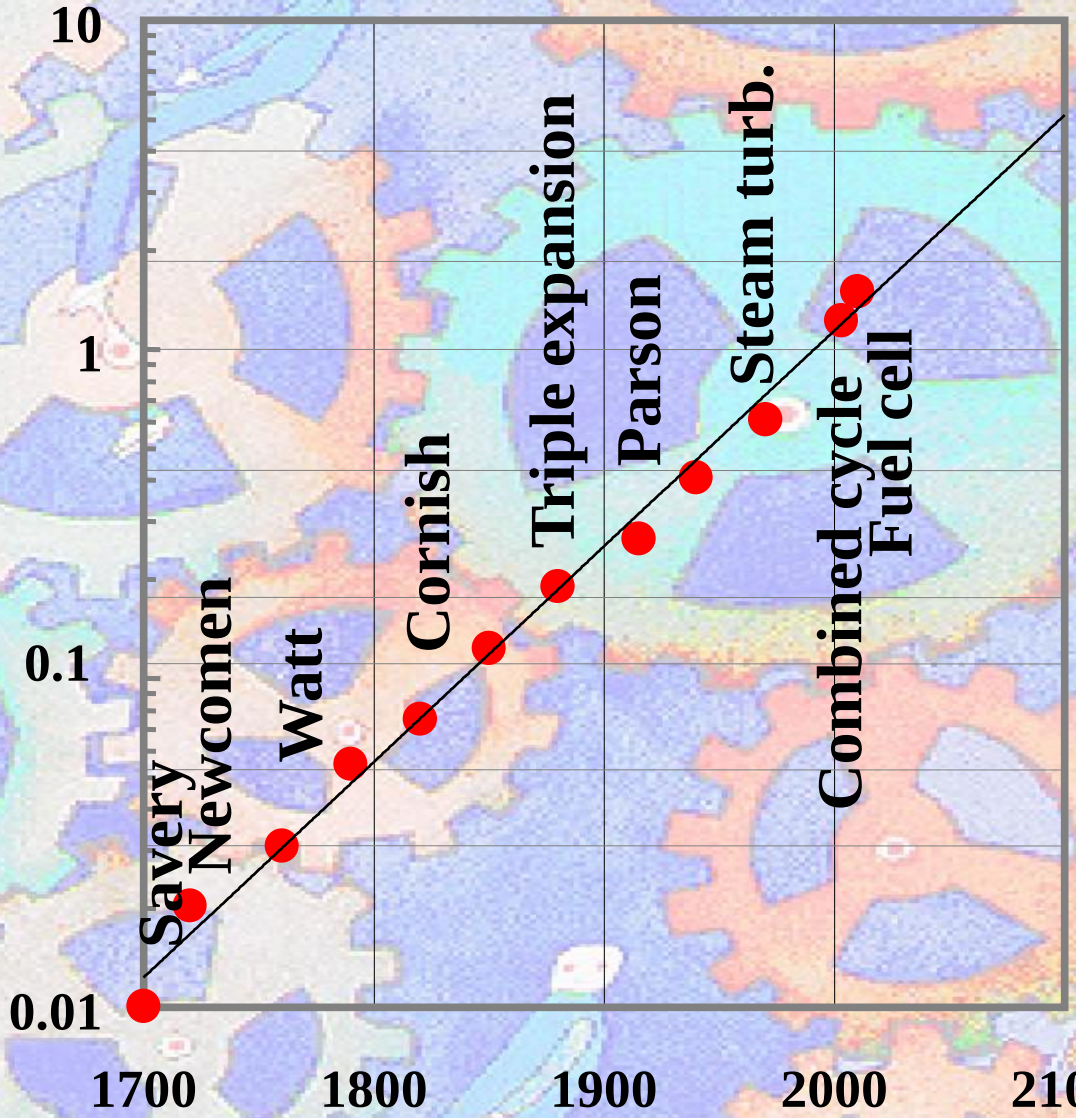
# Demographic growth outlook



# Role of scientific and technological research

$$\frac{\eta_{II}}{1-\eta_{II}}$$

**logistic scale (linearity is typical of a learning process)**




$\eta_{II}$

**Thermodynamic efficiency of the best-available mature technology for primary energy conversion to work or electricity**

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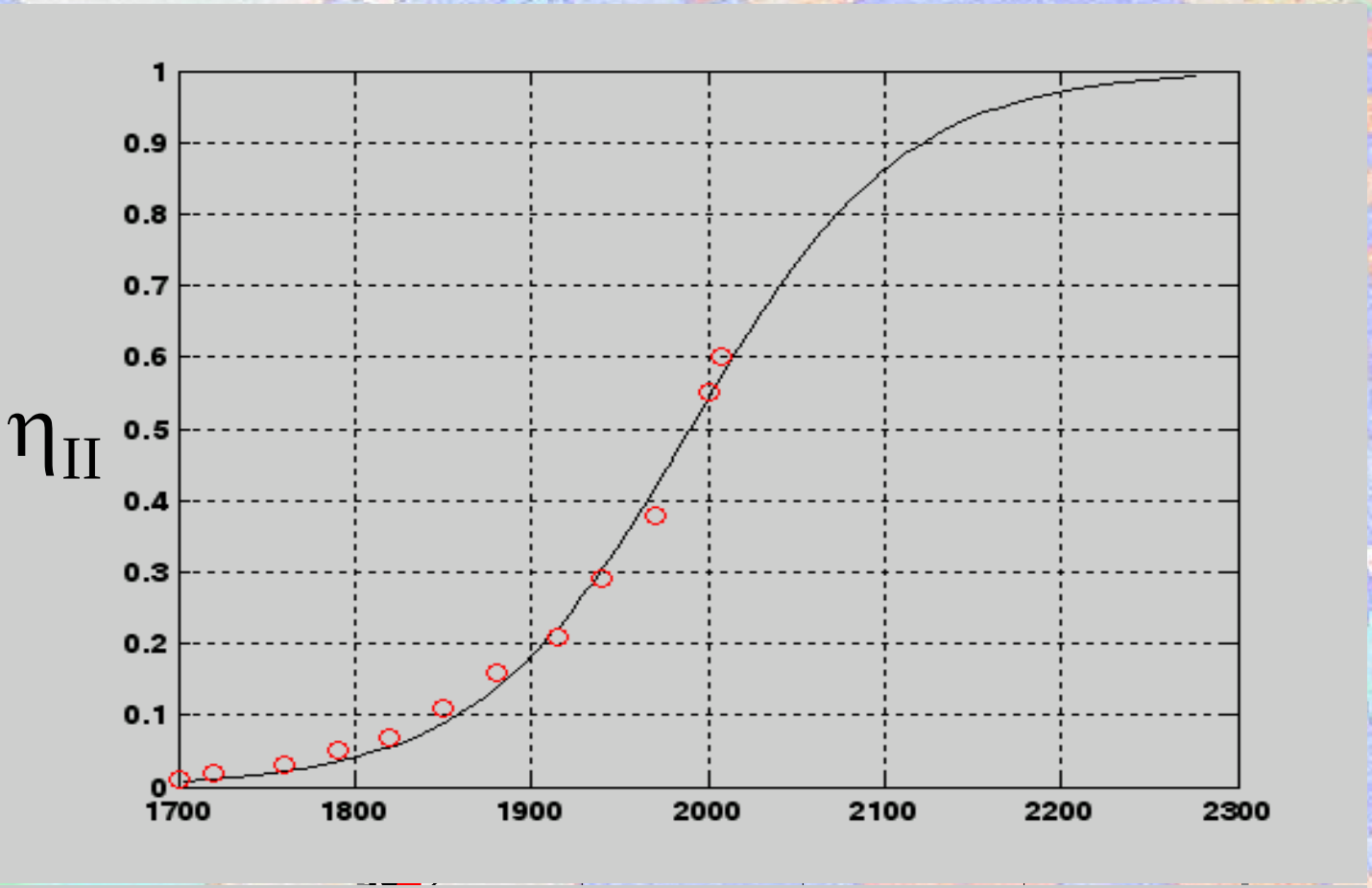
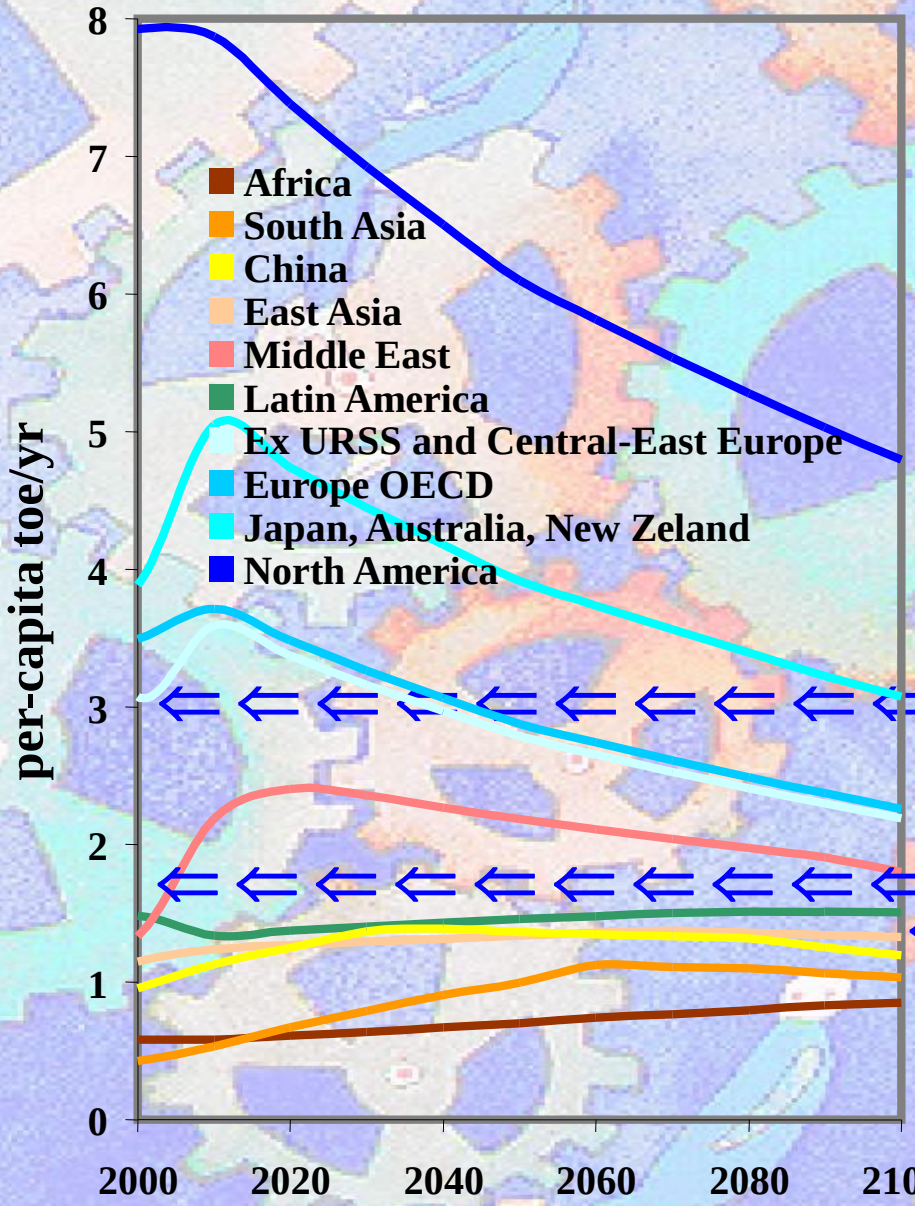



$$\frac{d\eta_{II}}{dt} = \frac{1}{\tau}\eta_{II}(1-\eta_{II}) \quad \text{with} \quad \tau \approx 60\,\text{yr}$$

$\eta_{II}$

**Thermodynamic efficiency of the best-available mature technology for primary energy conversion to work or electricity**

# Per-capita consumption (forecast)




**Net effect of :**

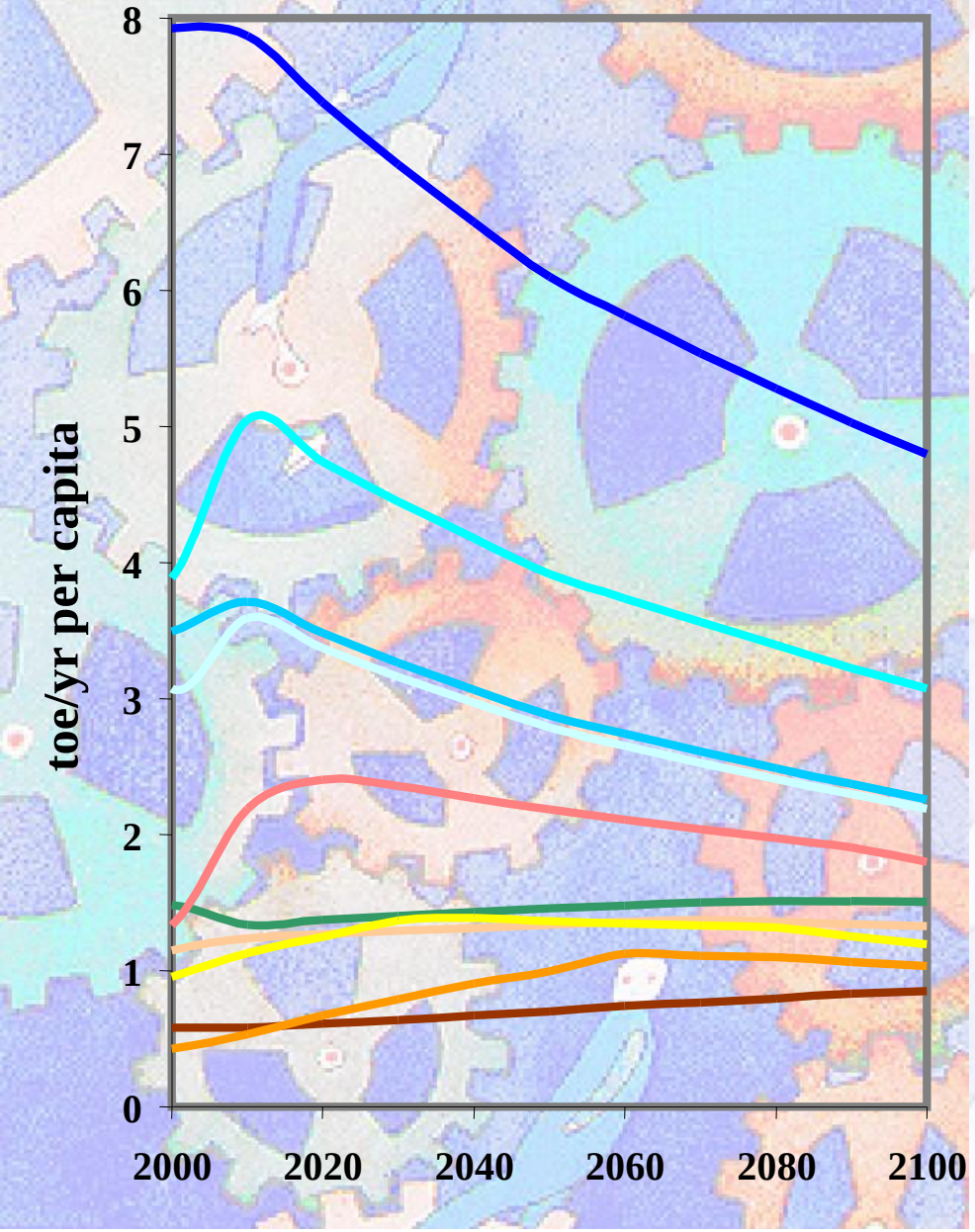
+ **industrialization of least developed countries**
− **social and technological improvements in "from well to final use" efficiency**

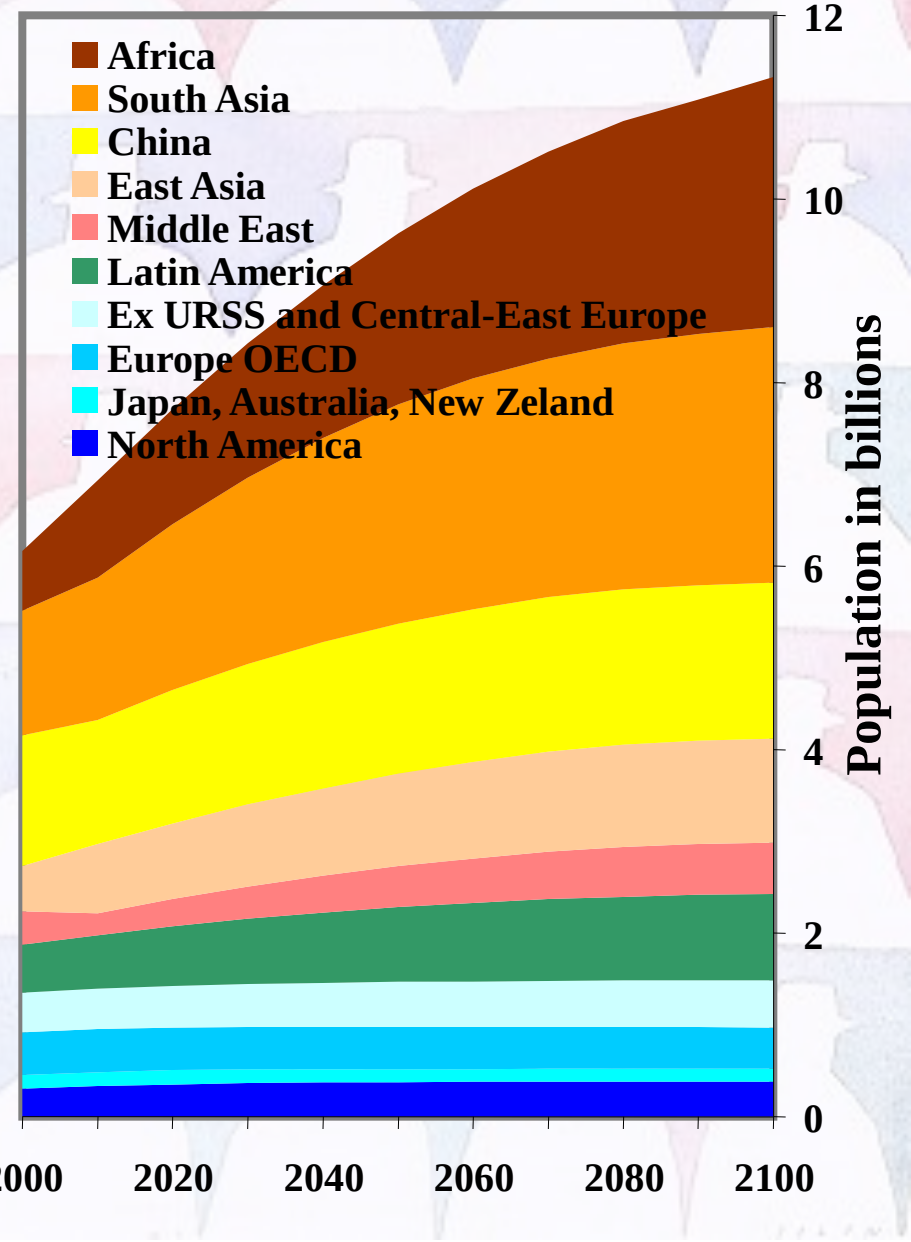
**Current average standard for industrialized countries**

**2000 world average**

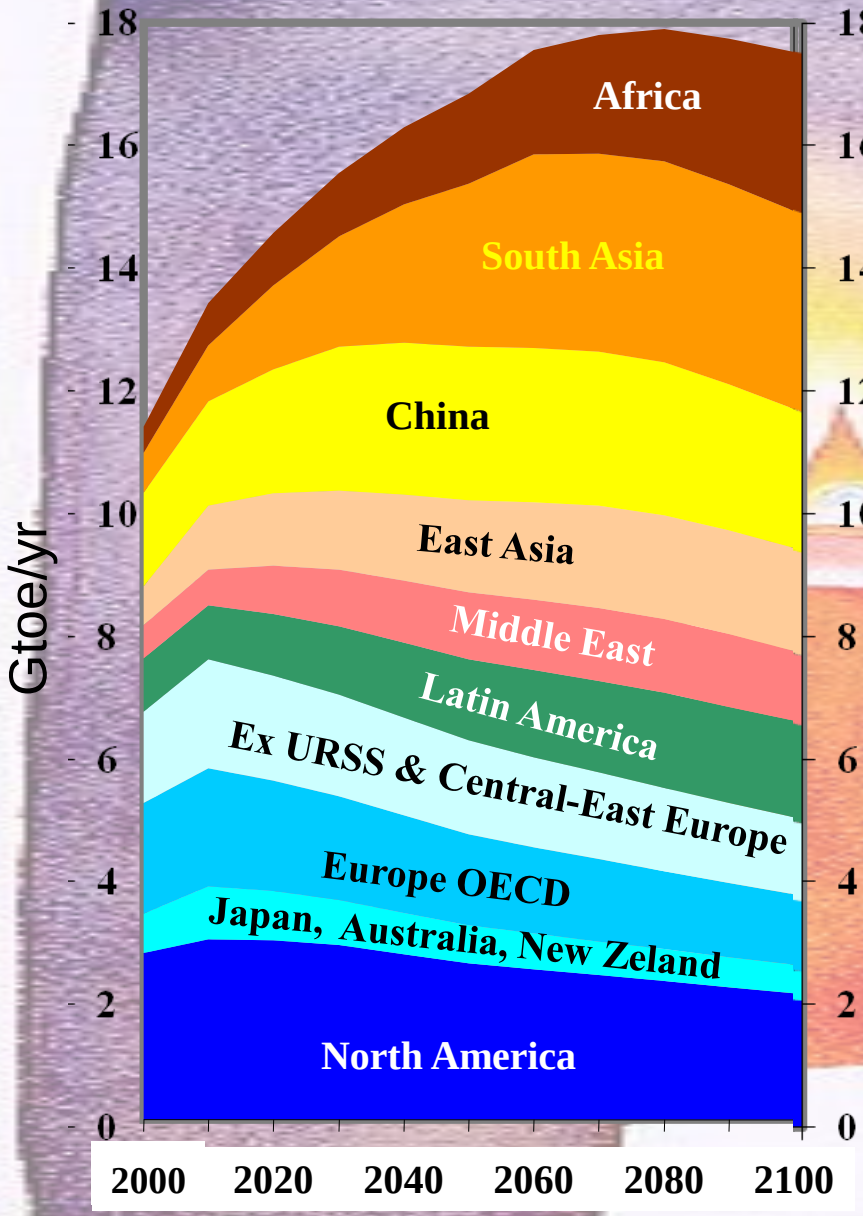
**2100 world average**

# Per-capita consumption x population = ...

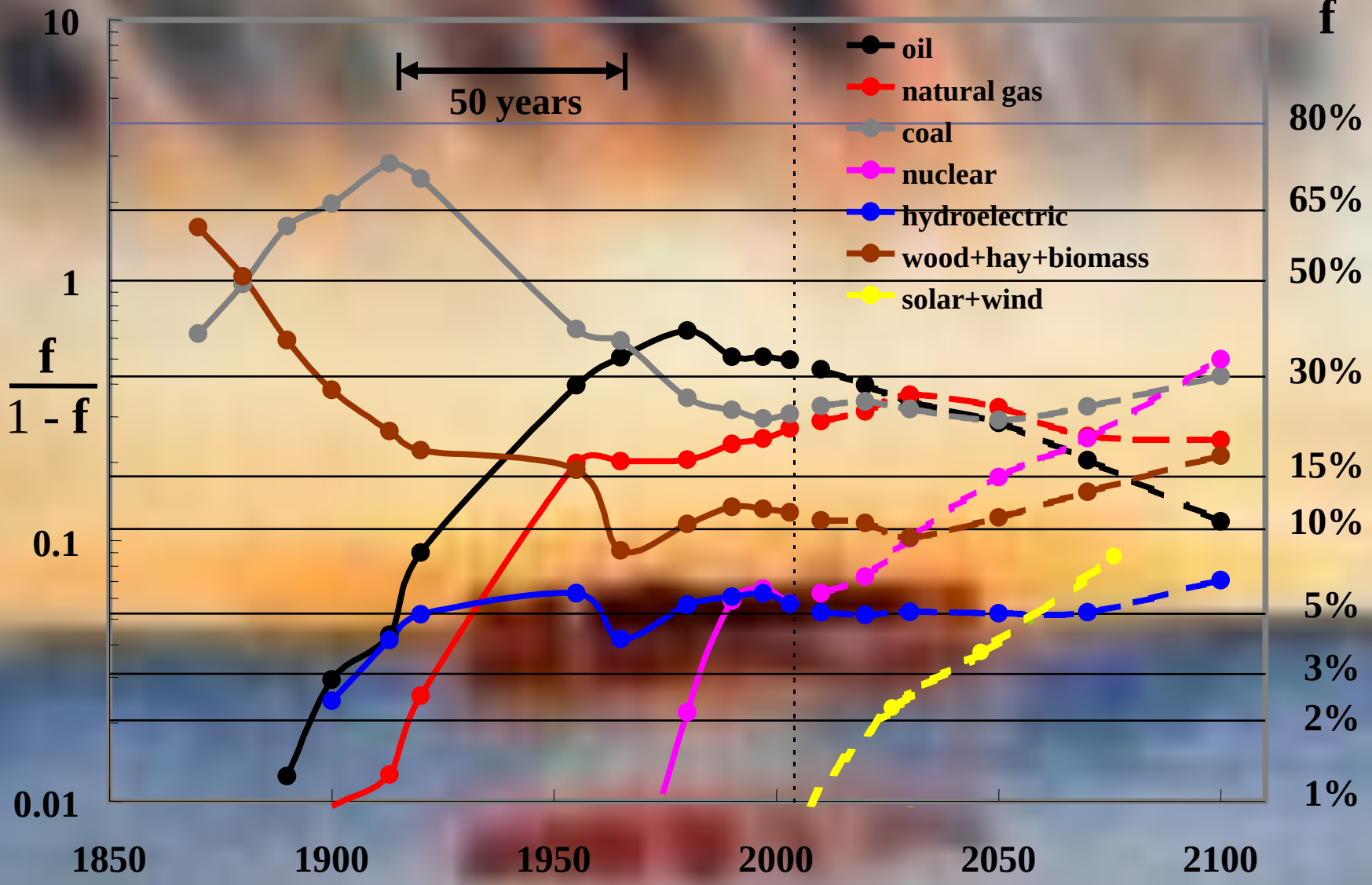


# … = global primary energy consumption (outlook)



# System's inertia: history and outlook of market shares



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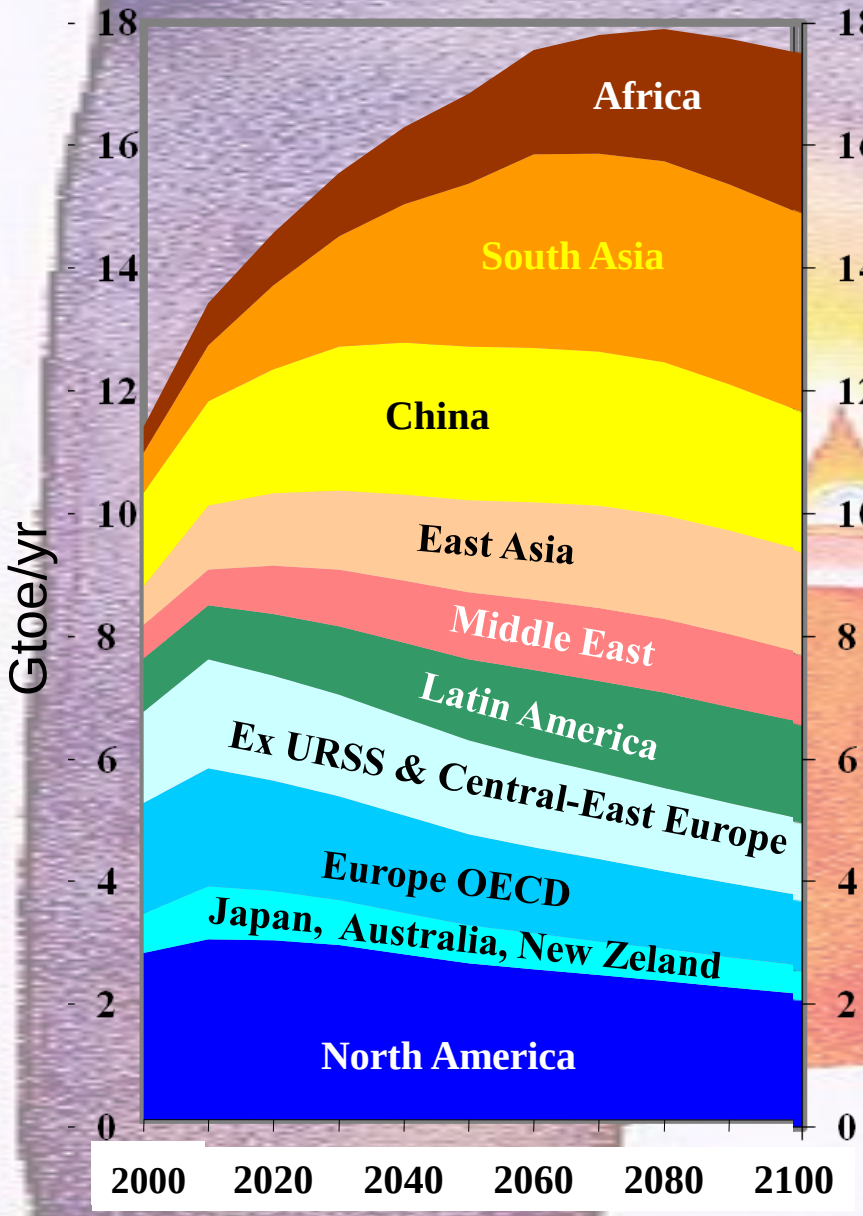

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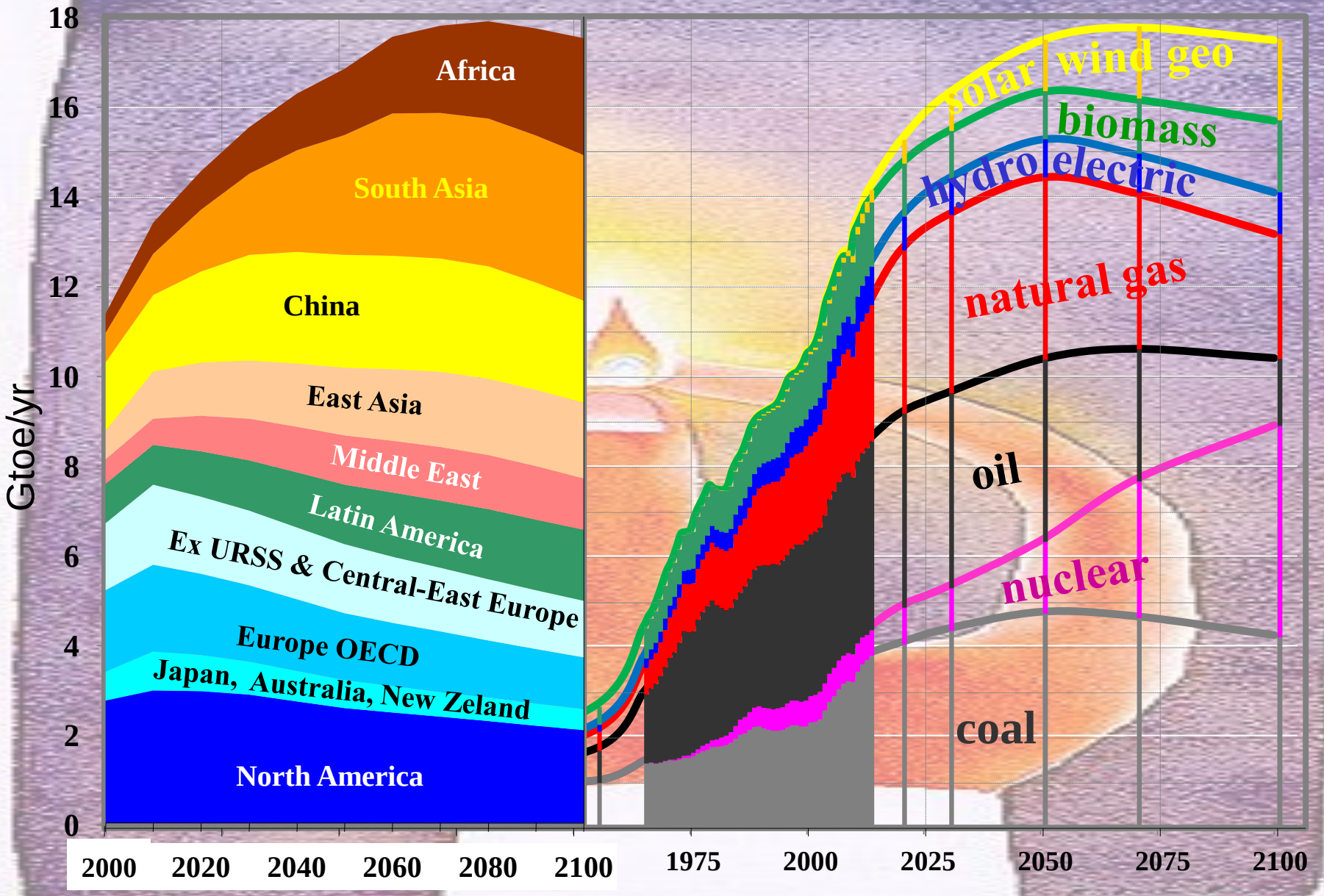

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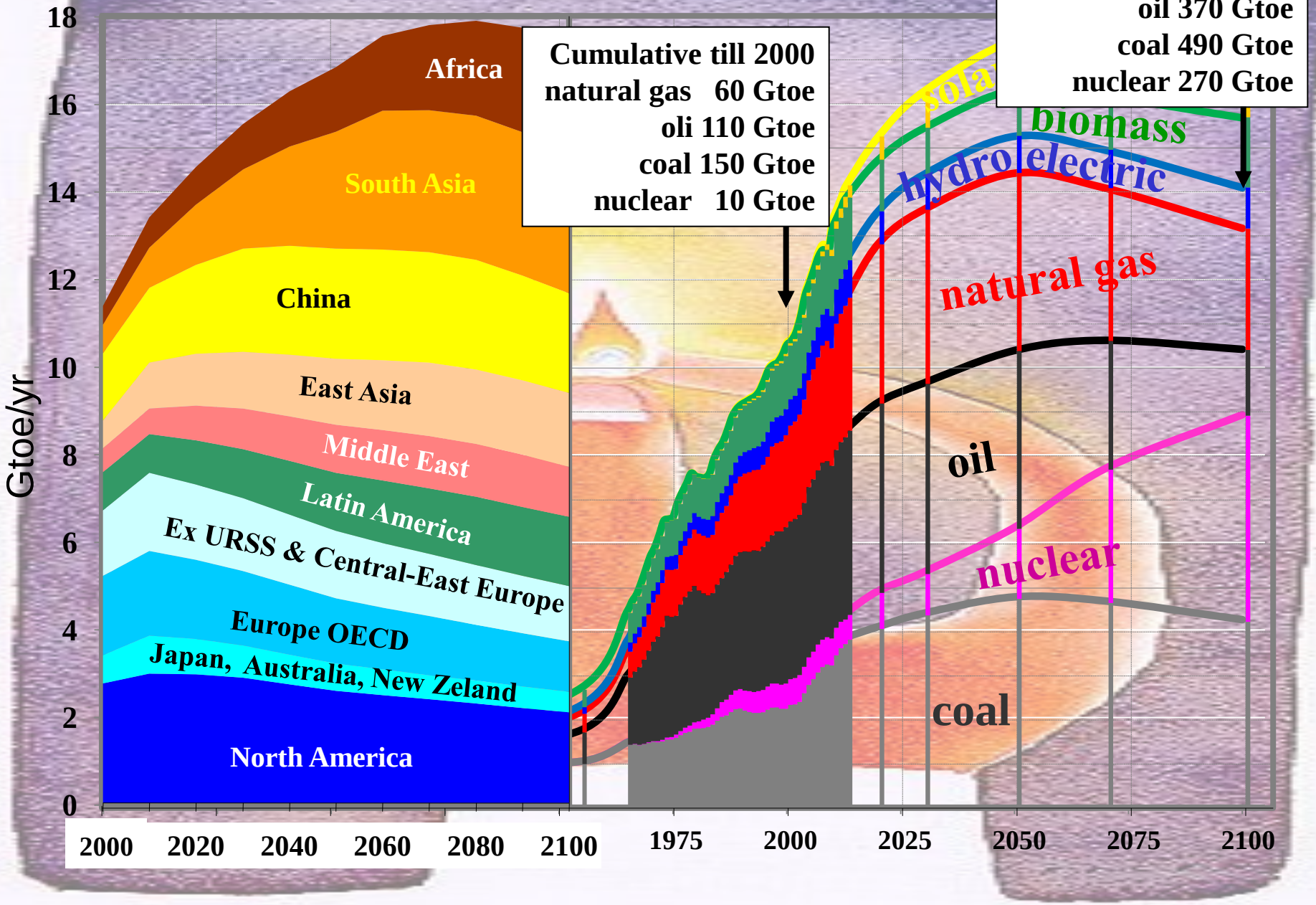

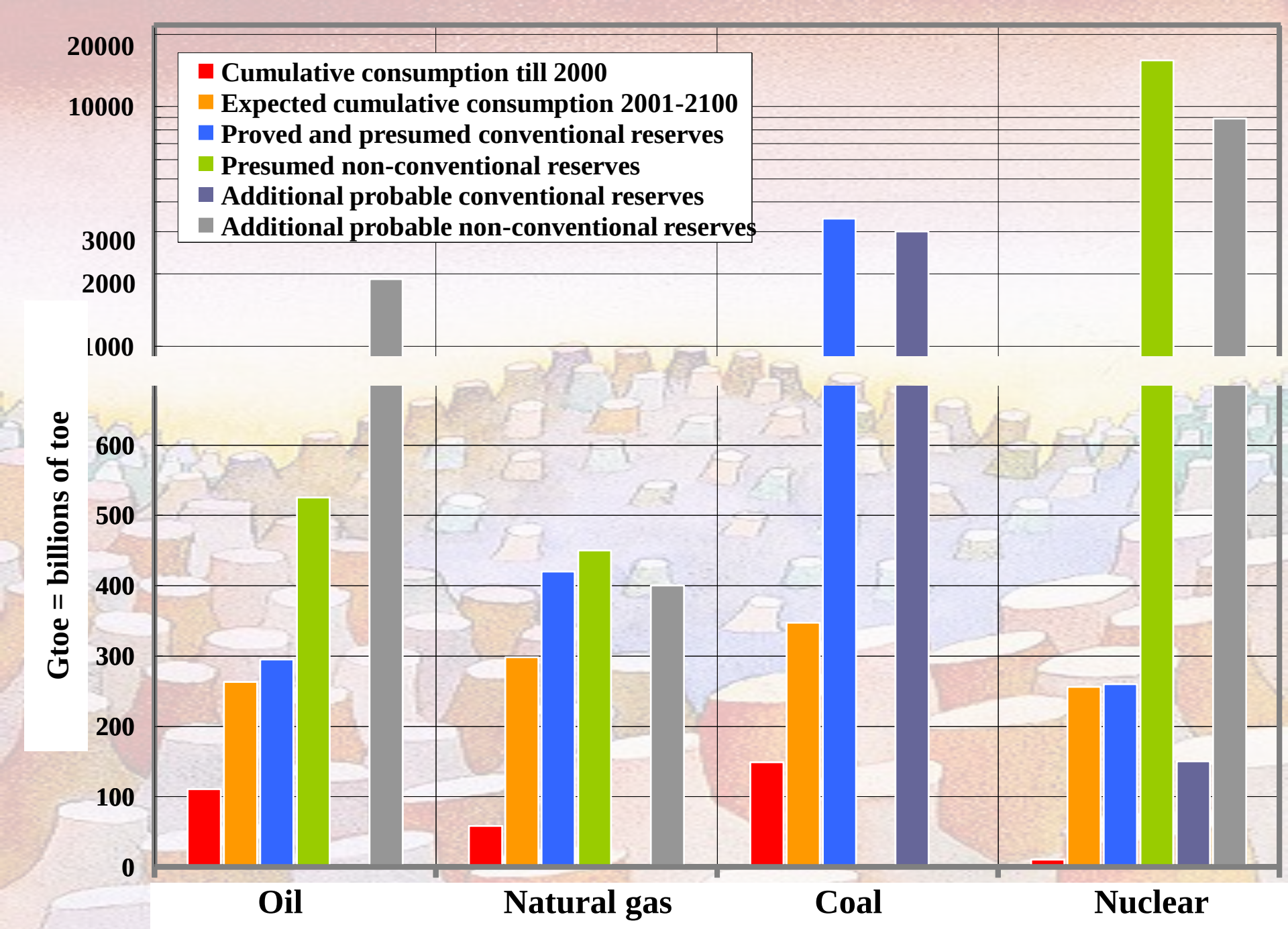

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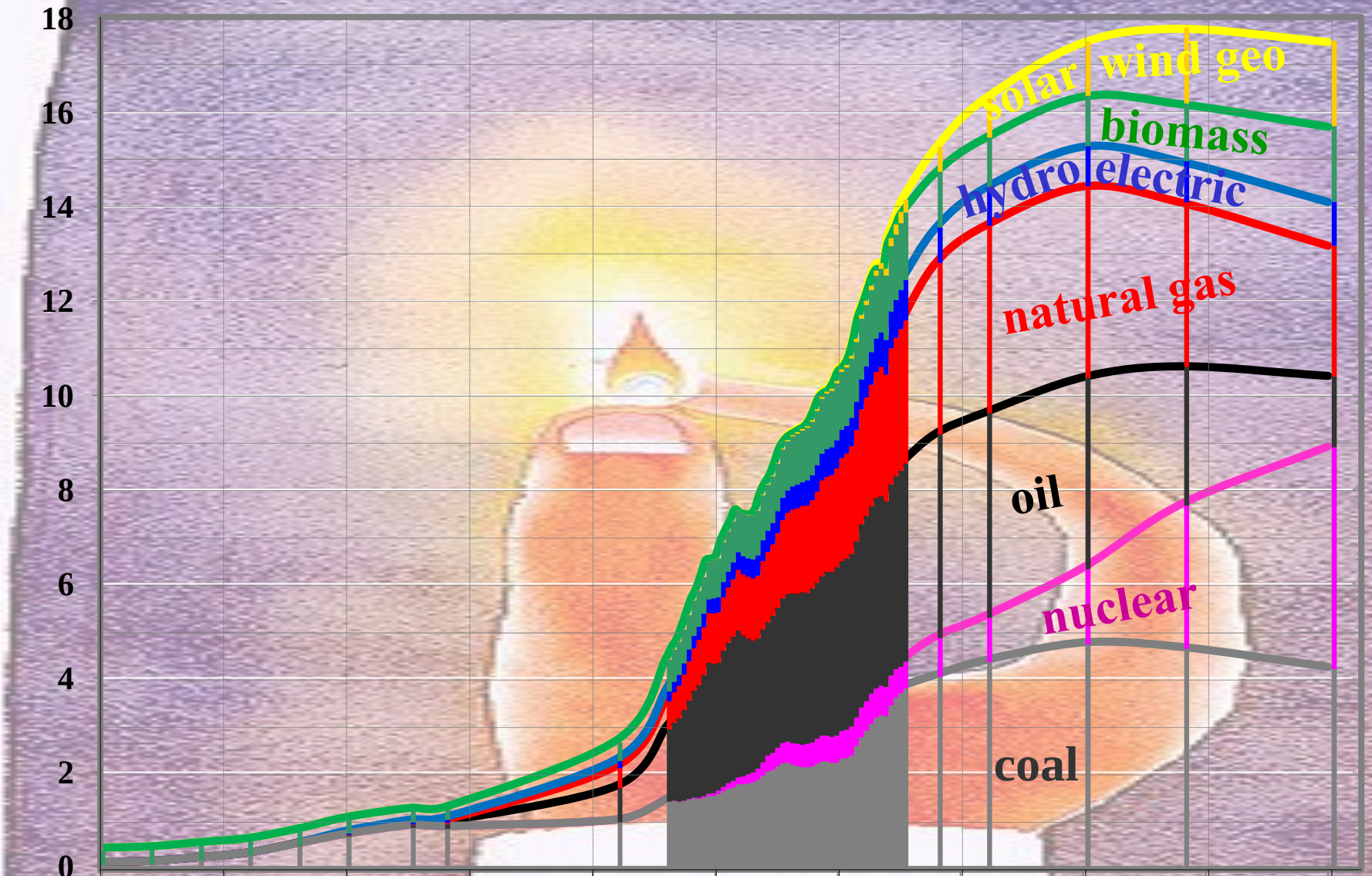


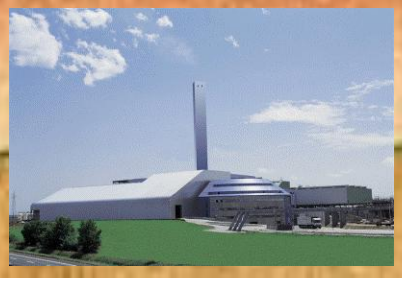
# CO2 immissions due to primary energy consumption

| The combustion of | produces* |
|---|---|
| 1 toe of coal | 4,0 ton of CO2 |
| 1 toe of oil | 3,1 ton of CO2 |
| 1 toe of natural gas | 2,3 ton of CO2 |
| 1 toe of urban waste (~6 ton) | – 10 ton of CO2(eq) |

*these are rough estimates based on stoichiometry; accurate estimates would require full life-cycle well-to-final-use analyses

**The waste-to-energy conversion of ~6 ton of solid urban waste saves 1 toe of primary energy and, with respect to landfilling, saves overall greenhouse gas emissions by:**

| | |
|---|---|
| Best technology, controlled landfill | – 2,4 ton of CO2(eq) |
| Worse technology landfill (uncontrolled) | – 17 ton of CO2(eq) |



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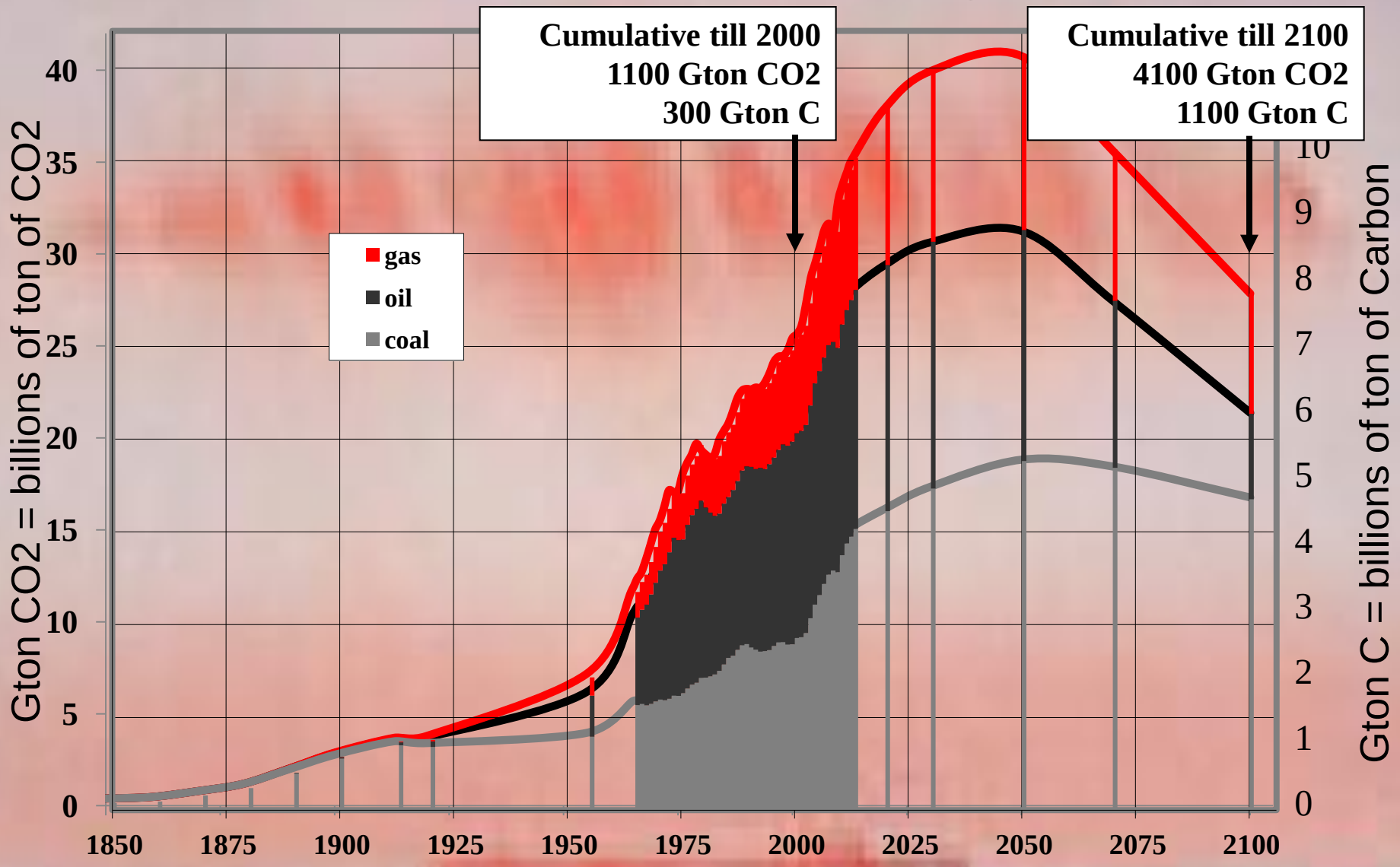

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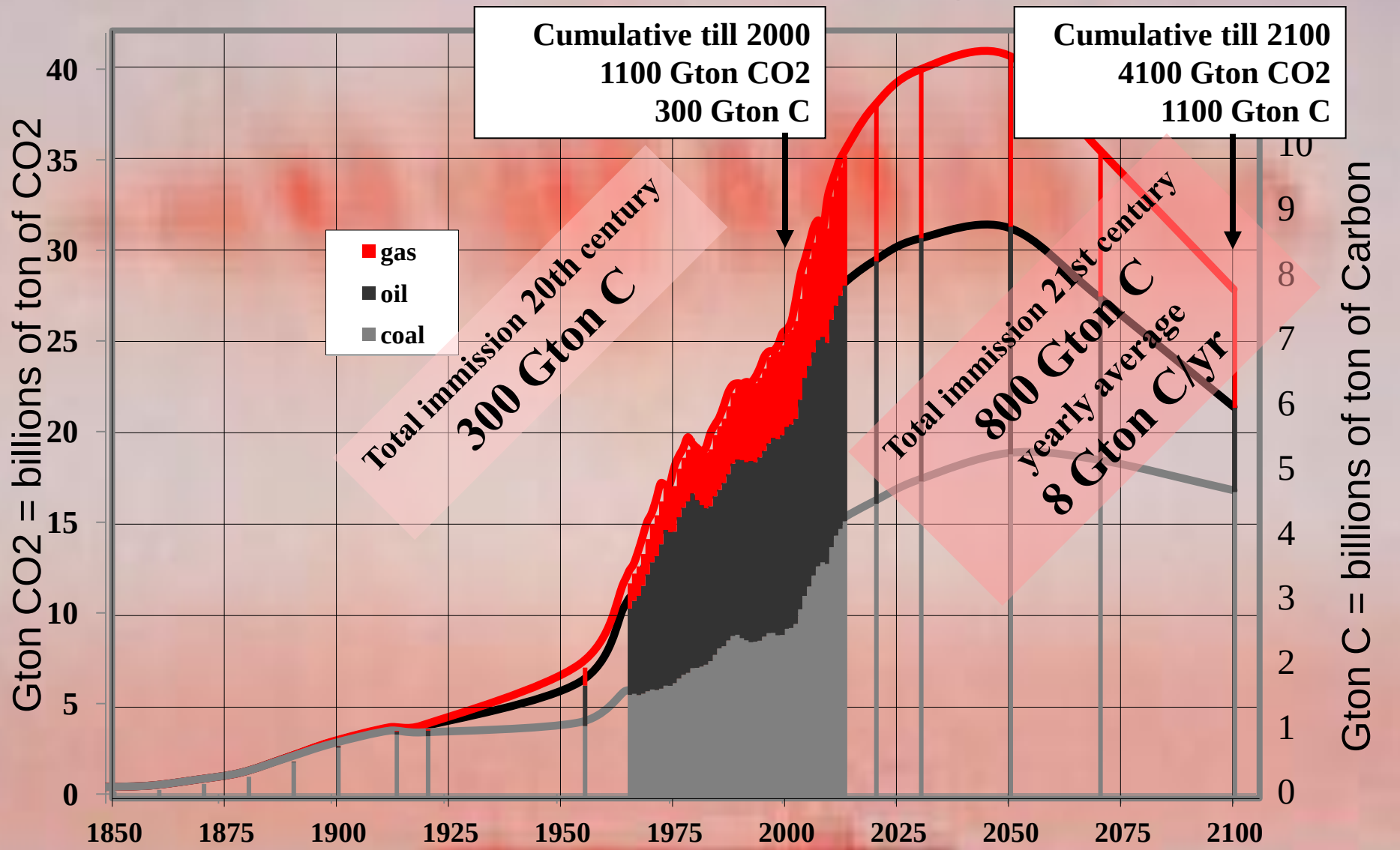
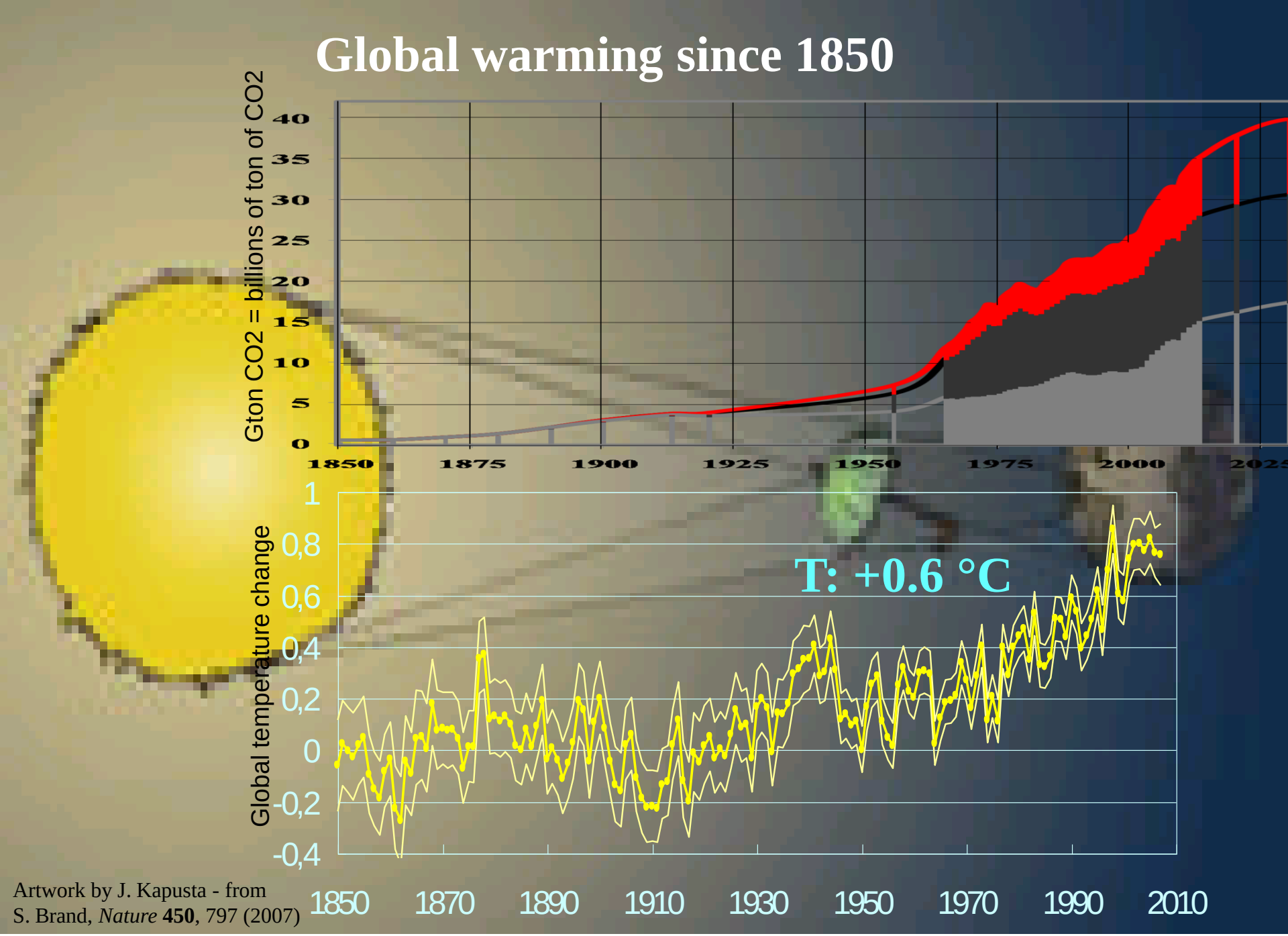
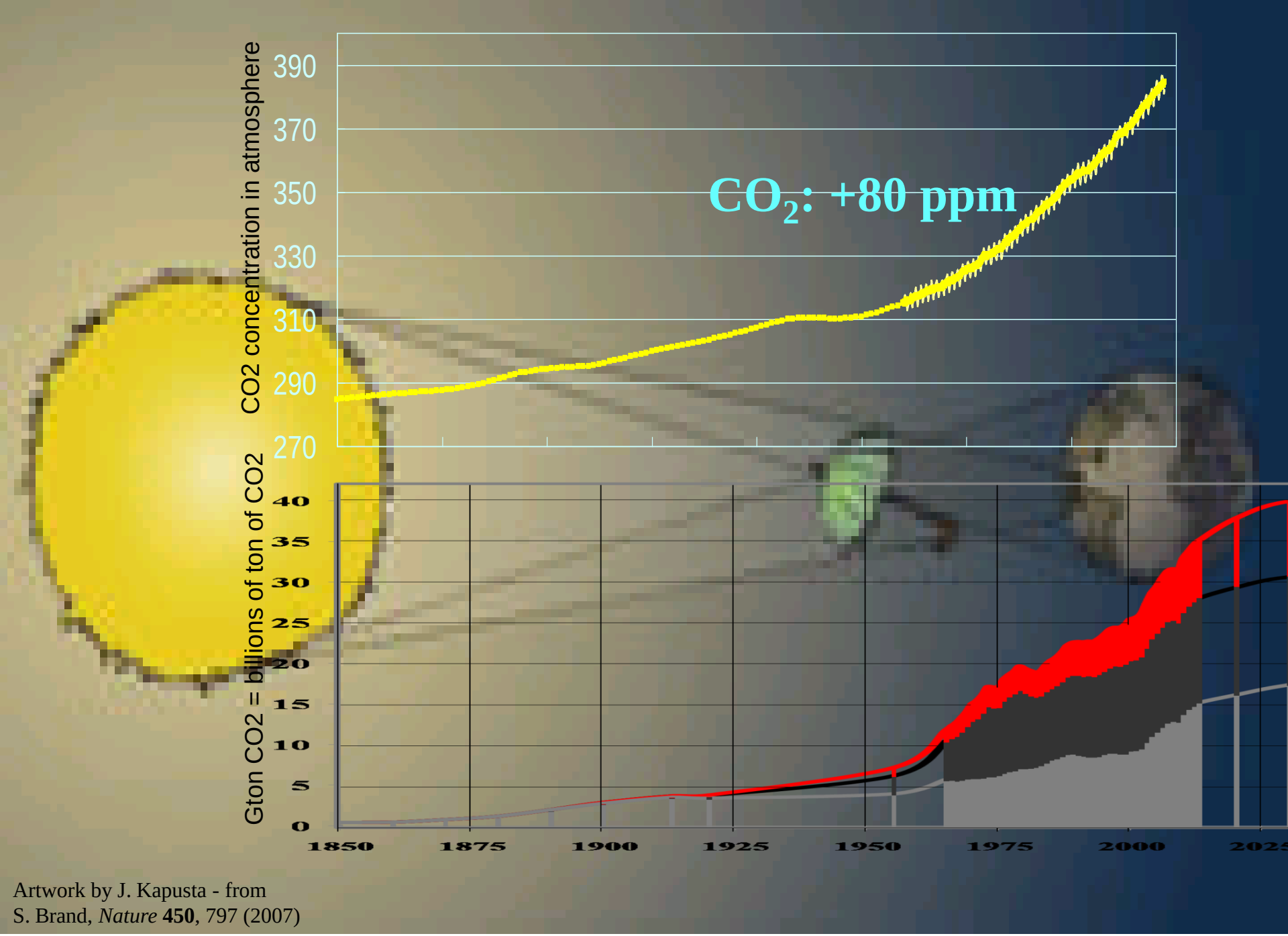


# Global warming since 1850




Artwork by J. Kapusta - from
S. Brand, *Nature* **450**, 797 (2007)

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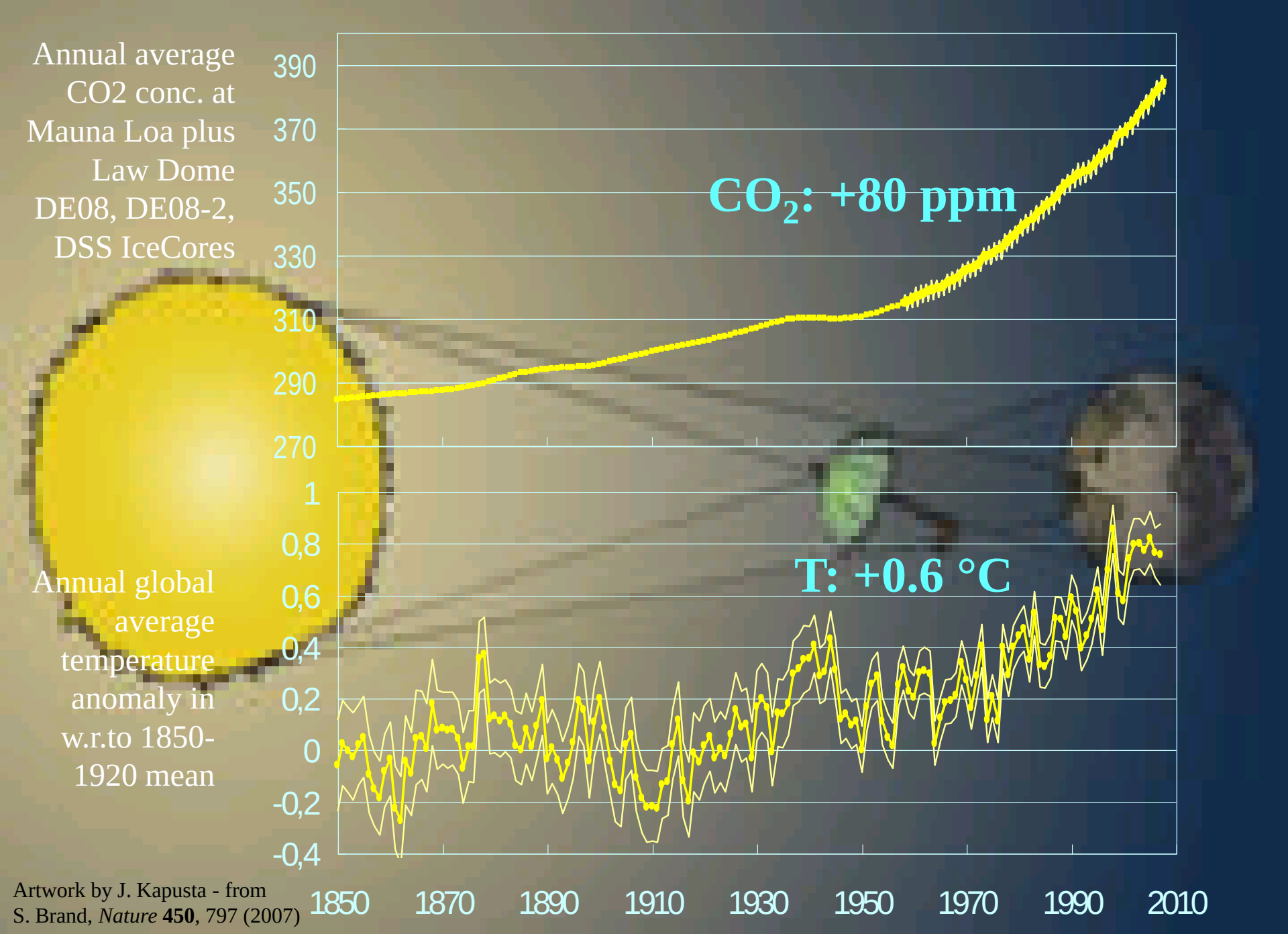


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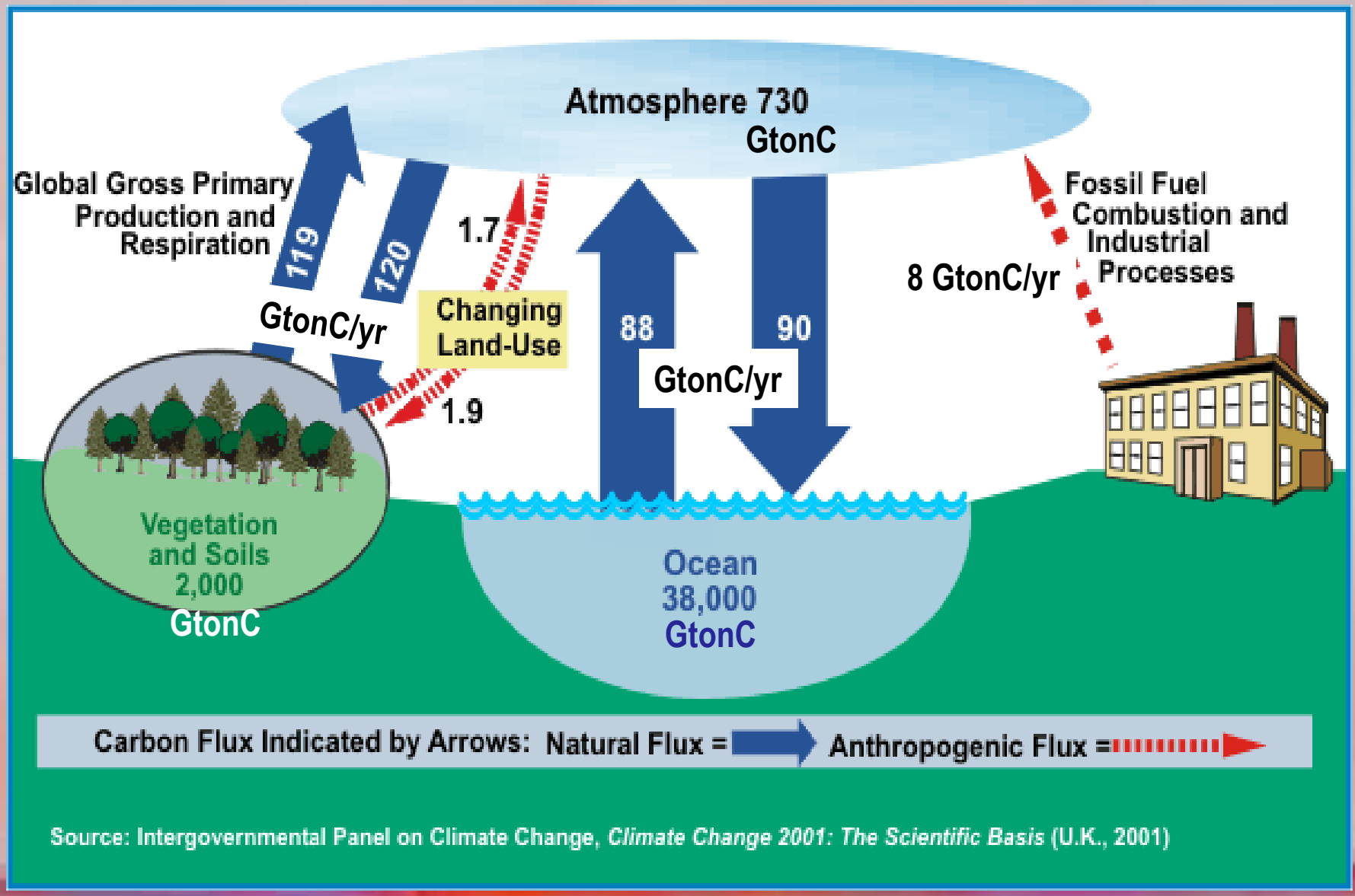
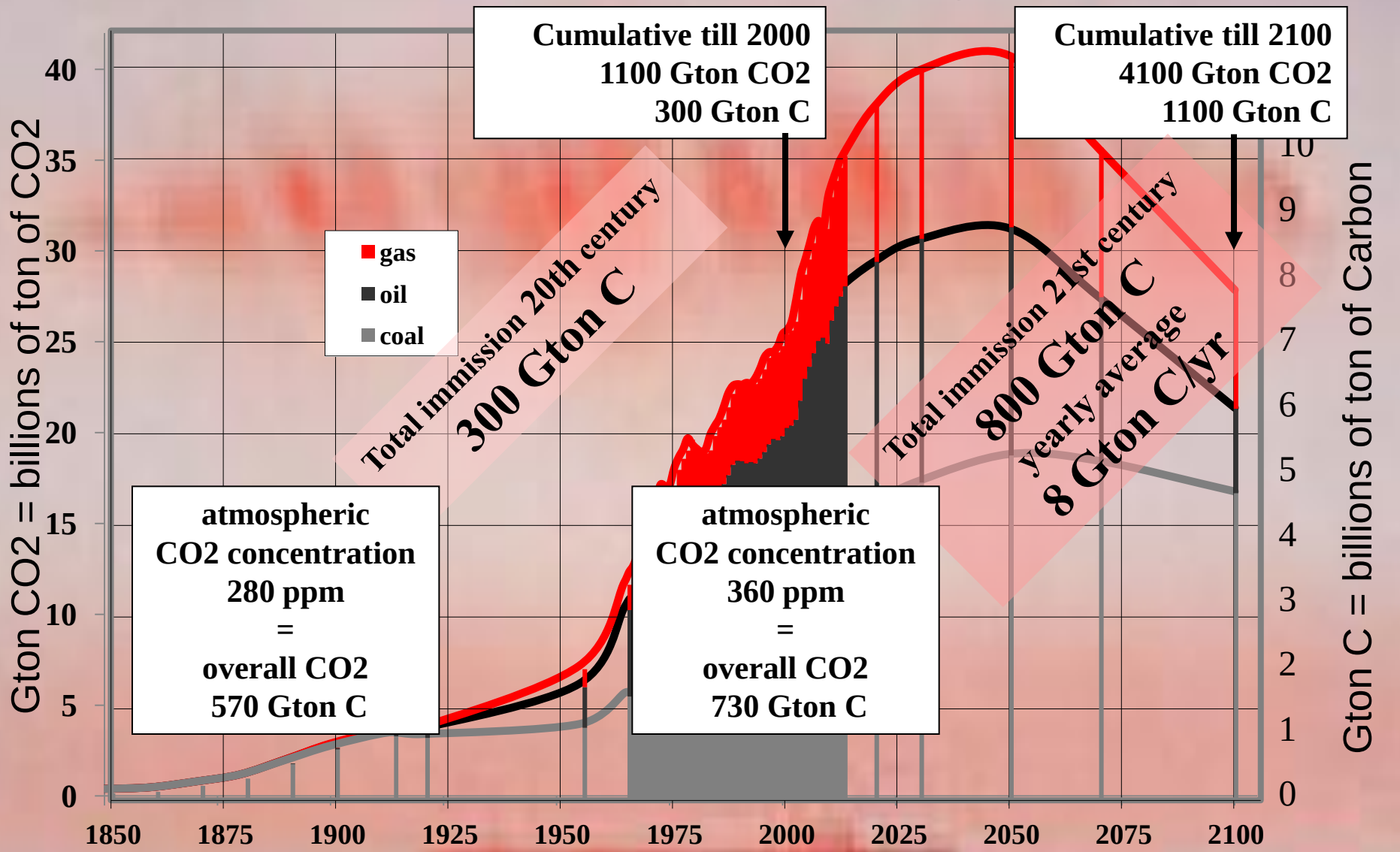
# Energy related anthropic immissions are relatively small compared to the natural carbon exchanges and reserves of CO2 on Earth




Source: Intergovernmental Panel on Climate Change, *Climate Change 2001: The Scientific Basis* (U.K., 2001)

# CO2 immissions due to primary energy consumption



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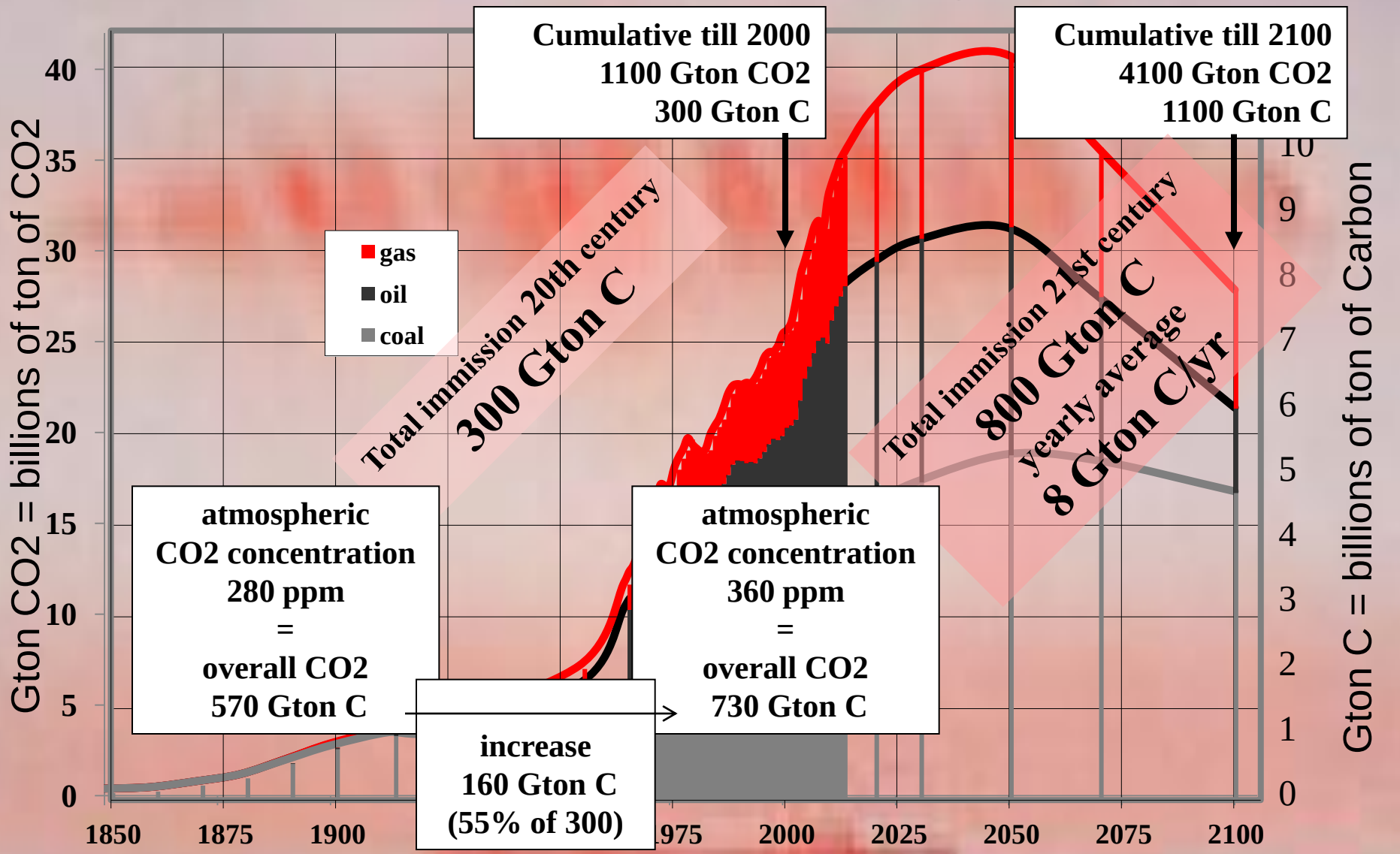

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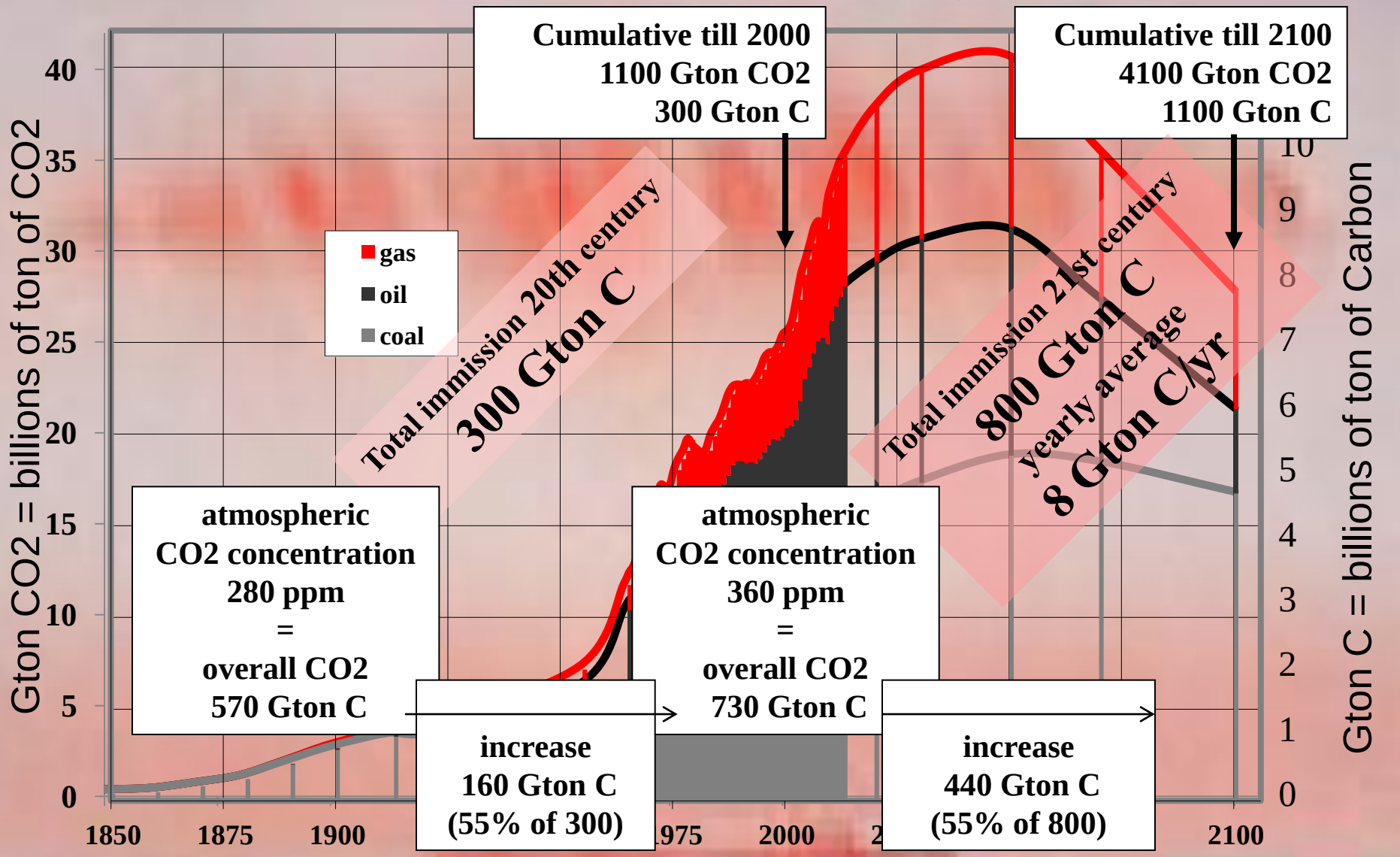

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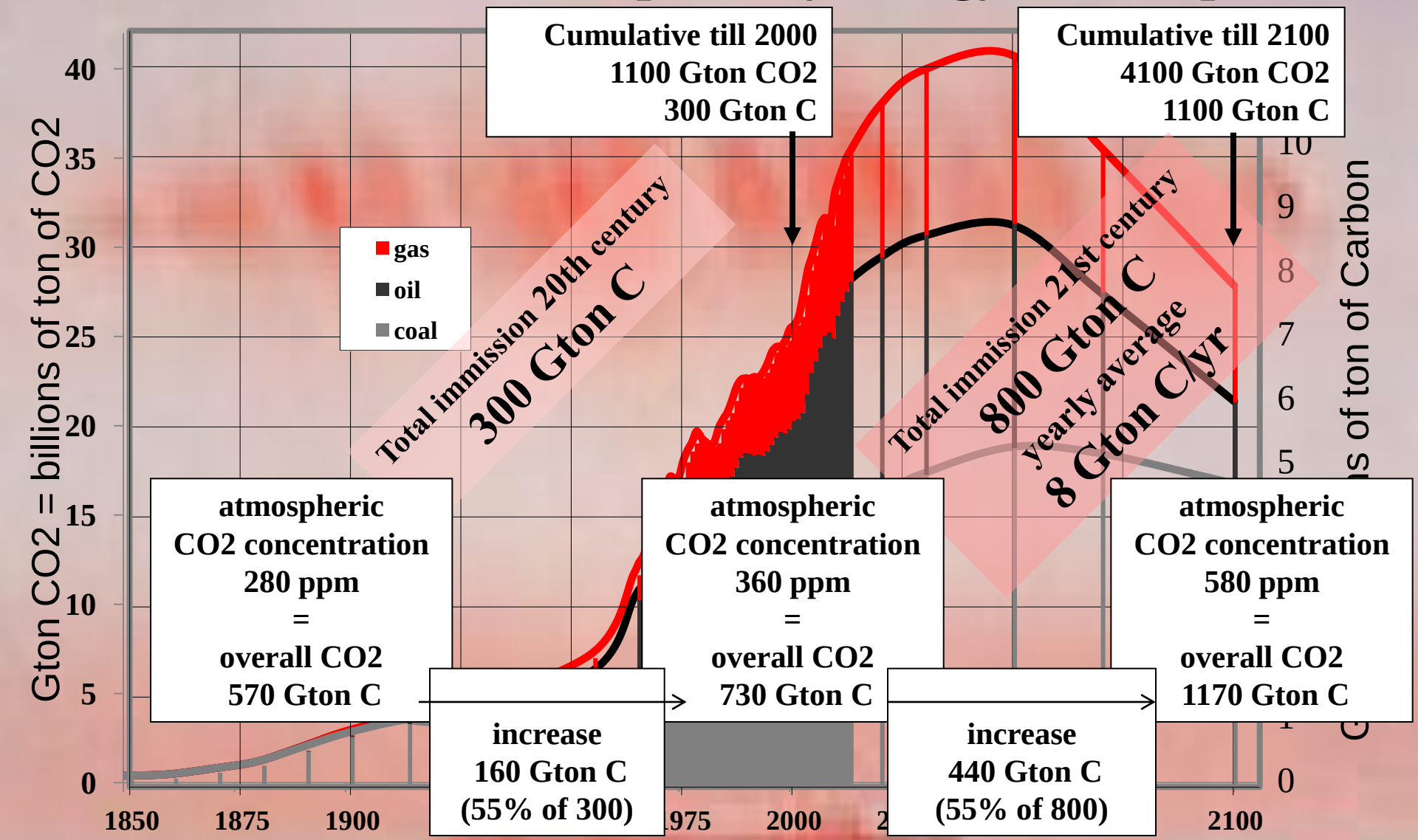

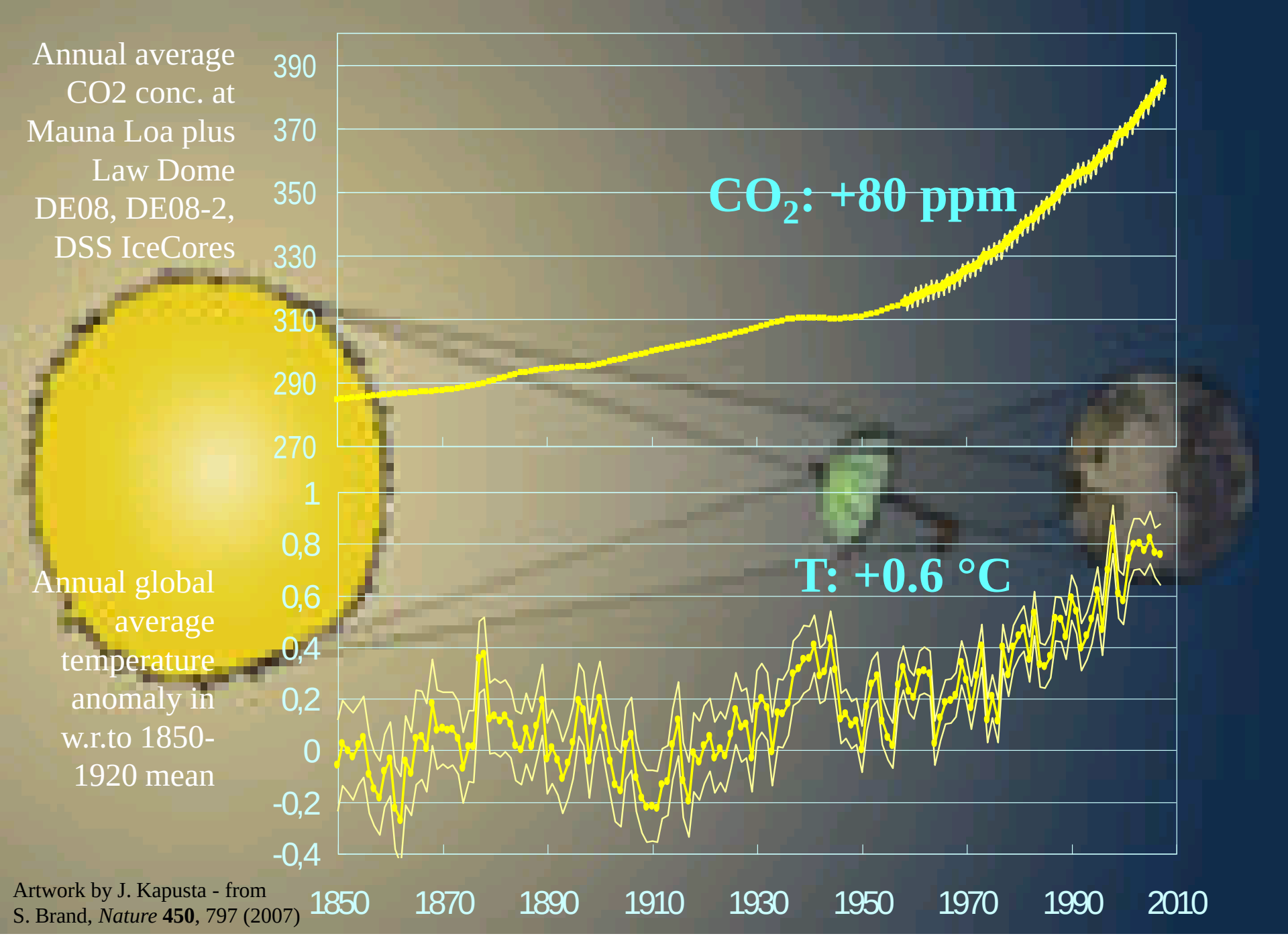


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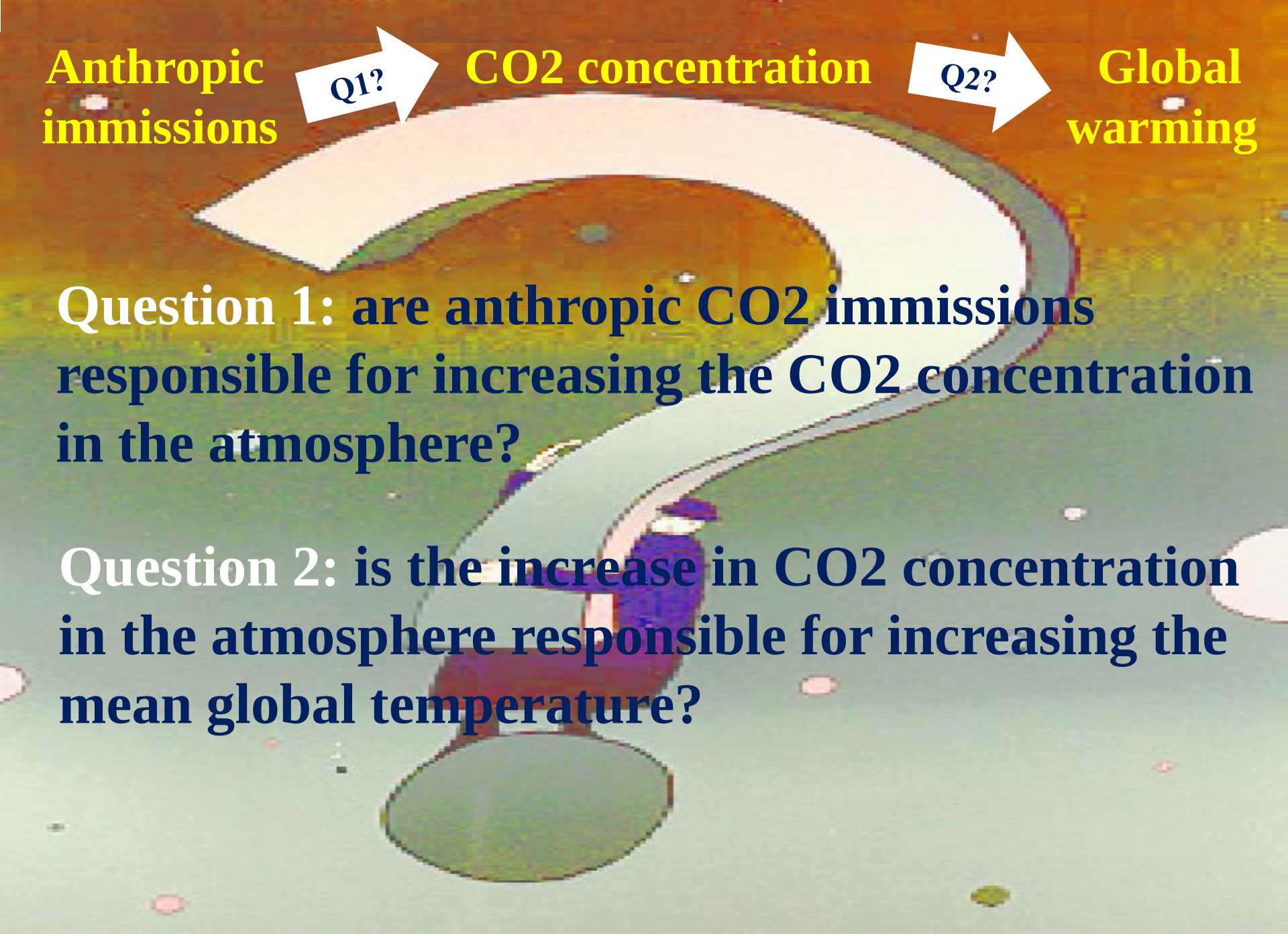
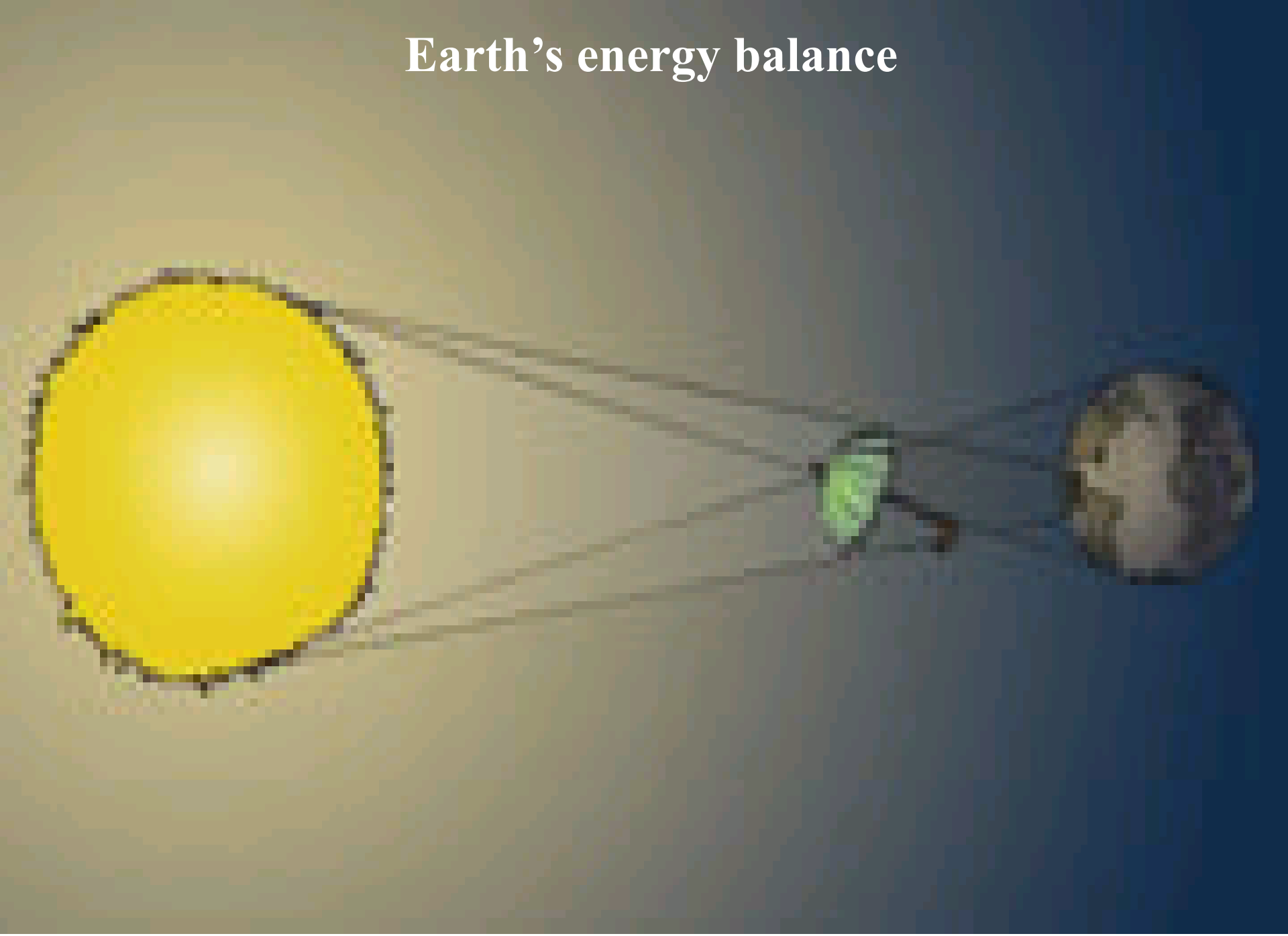



**Question 1: are anthropic CO2 immissions responsible for increasing the CO2 concentration in the atmosphere?**

**Question 2: is the increase in CO2 concentration in the atmosphere responsible for increasing the mean global temperature?**

# Earth's energy balance



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- Solar radiation — $I_0 = 1367\ W/m^2$
- Albedo (about 32% gets reflected away) — $I_{eff} = 930\ W/m^2$

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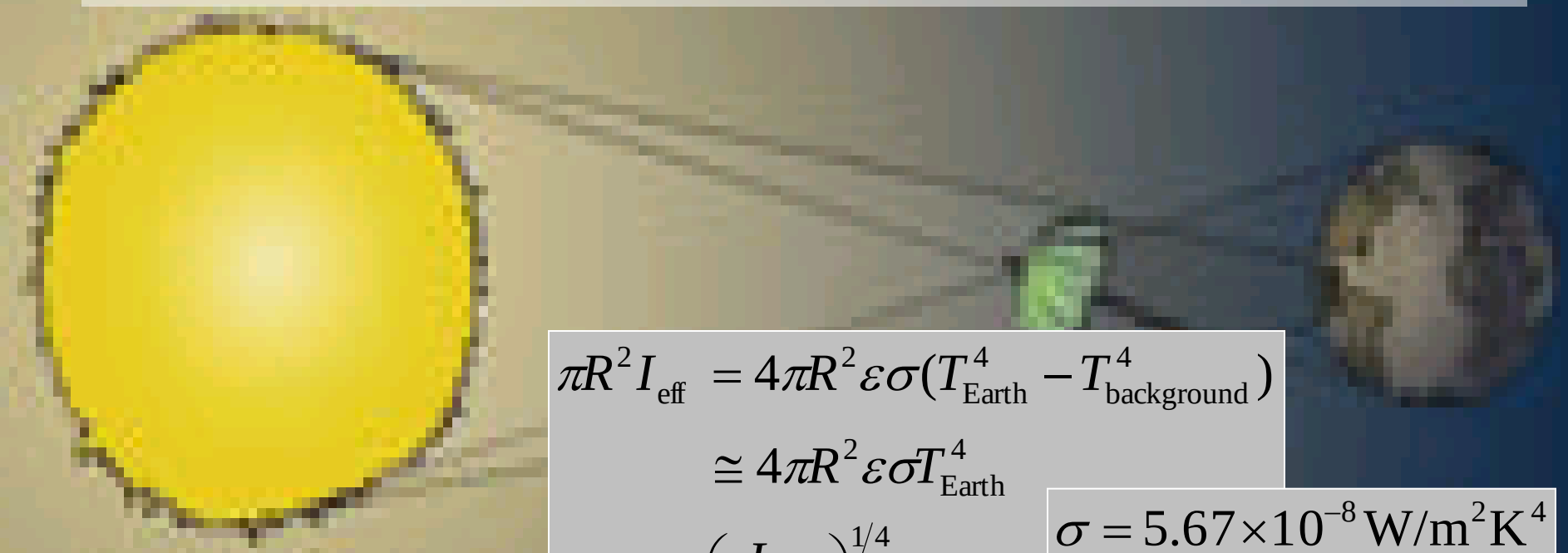

$$\pi R^2 I_{\text{eff}} = 4\pi R^2 \varepsilon\sigma (T_{\text{Earth}}^4 - T_{\text{background}}^4)$$

$$\cong 4\pi R^2 \varepsilon\sigma T_{\text{Earth}}^4$$

$$T_{\text{Earth}} = \left( \frac{I_{\text{eff}}}{4\varepsilon\sigma} \right)^{1/4}$$

$$\sigma = 5.67 \times 10^{-8}\ \text{W/m}^2\text{K}^4$$

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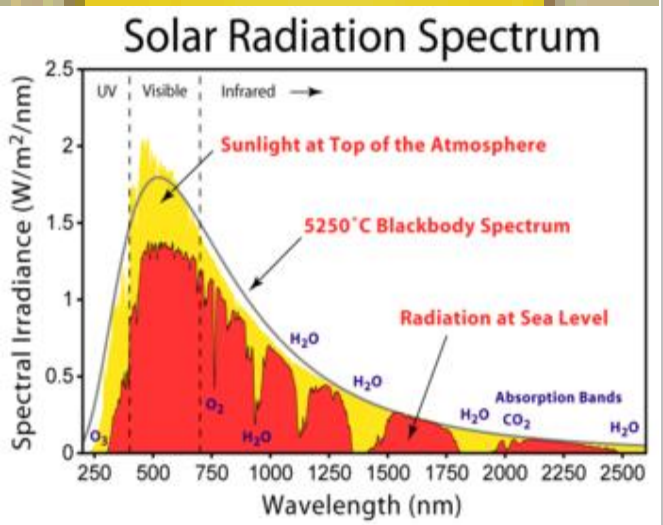


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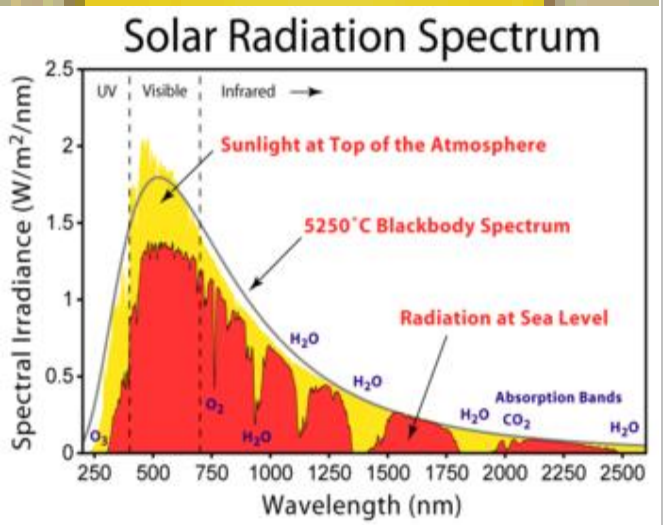


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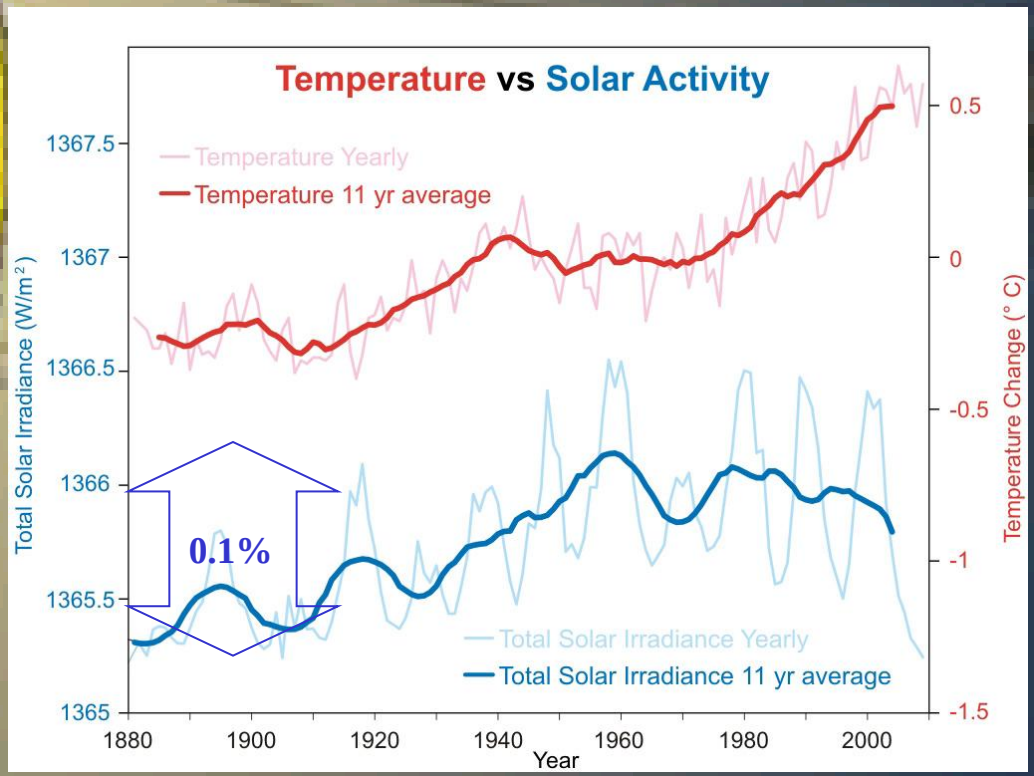
- Measured variations in $I_0$ are less than 0.1%



# CO2 effect as a greenhouse gas

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- Temperature with no greenhouse gases — $T_0 = 255\ K\ (-18°C)$
- With pre-industrial greenhouse gases (1750) — $T_1 = 288\ K\ (+15°C) = T_0 + 33°C$
- Corresponds to an additional radiation — $I = I_0 + F = 1367 + 144\ W/m^2$
- F, called radiative Forcing, — $F = 144\ W/m^2$ $T_1 - T_0 = 33°C$

can be split between the main greenhouse gases

| | | | |
|---|---|---|---|
| 64% | due to water vapor | 92 W/m$^2$ | 21°C |
| 21% | due to $CO_2$ | 30 W/m$^2$ | 7°C |
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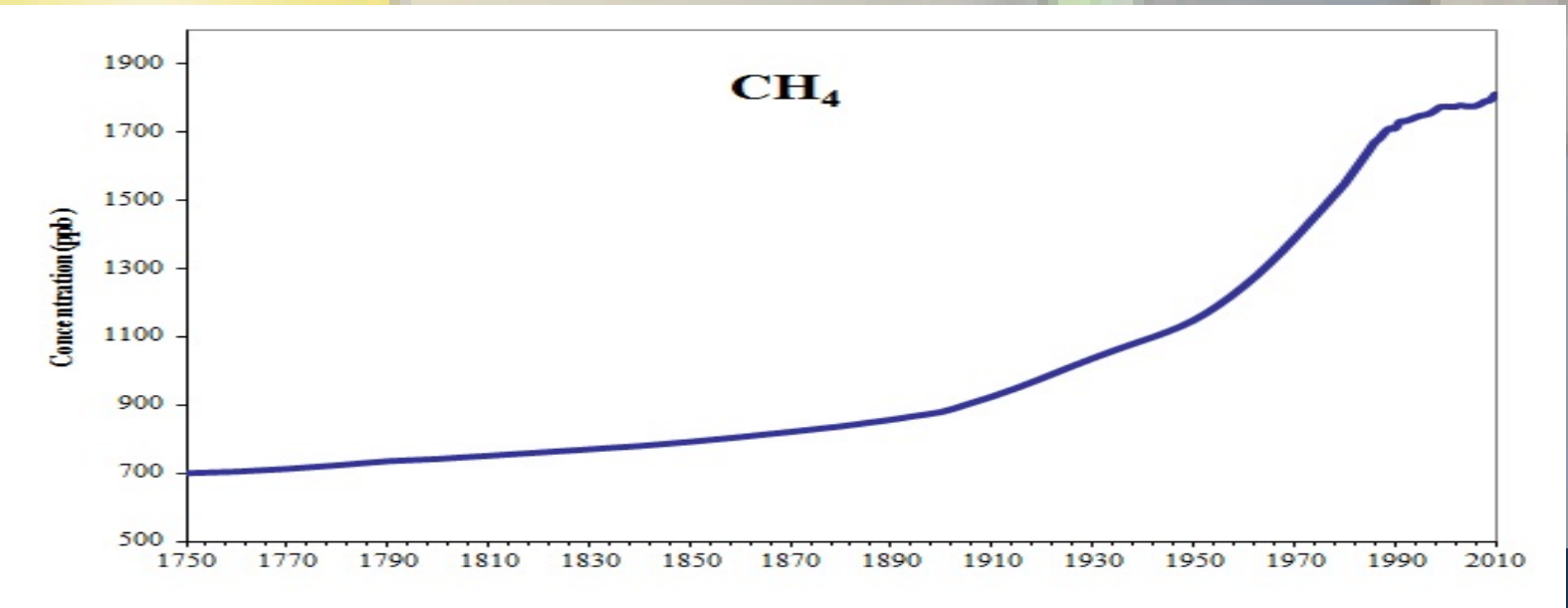

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- Corresponds to an additional radiation — $I = I_0 + F = 1367 + 144\ W/m^2$
- F, called radiative Forcing, — $F = 144\ W/m^2$ $T_1 - T_0 = 33°C$

can be split between the main greenhouse gases

| | | | |
|---|---|---|---|
| 64% | due to water vapor | 92 W/m² | 21°C |
| 21% | due to $CO_2$ | 30 W/m² | 7°C |
| 15% | due to CH4, N2O, other | 22 W/m² | 5°C |

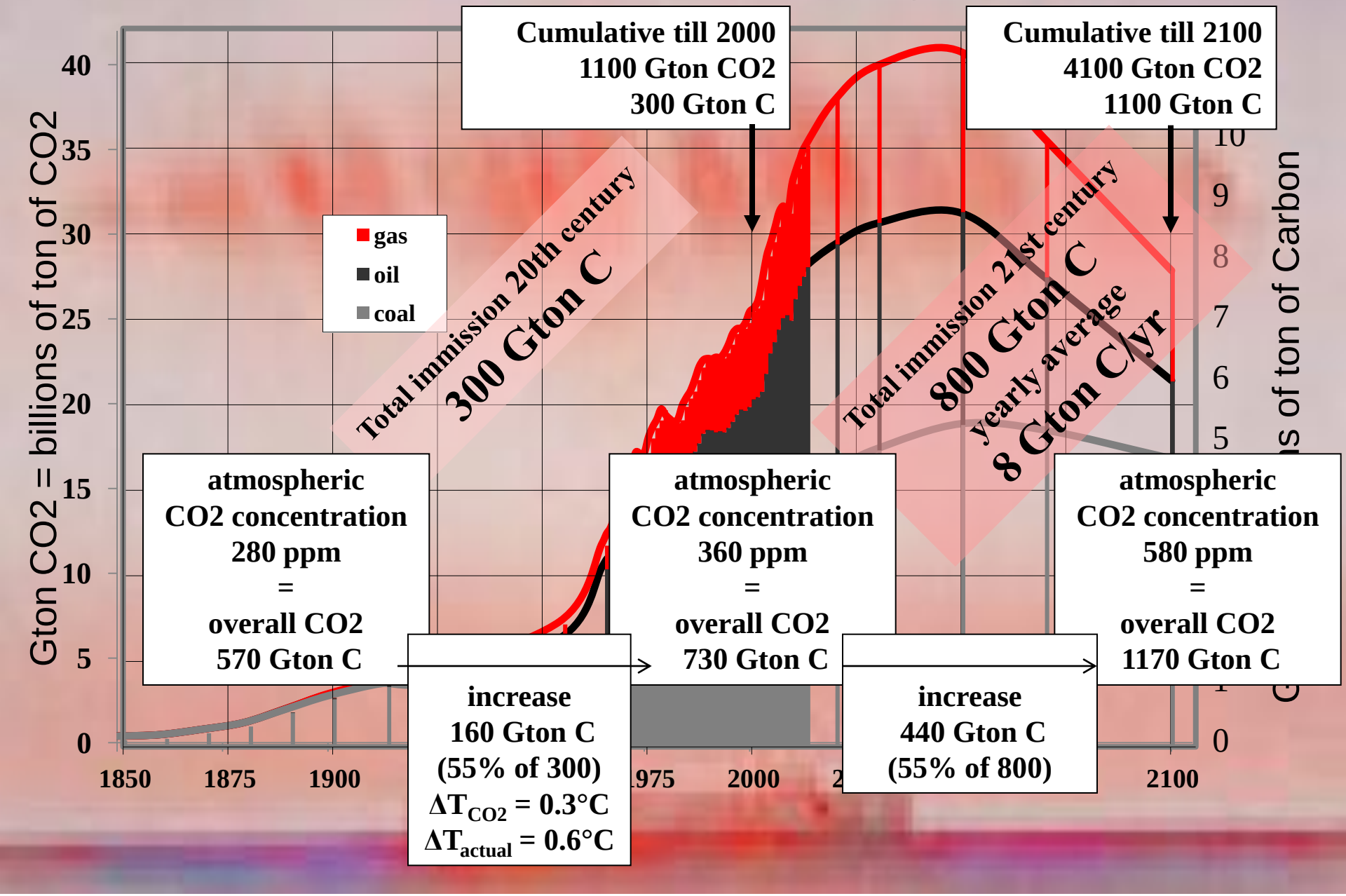
- IPCC formula

$$F - F_0 = 5.35 \ln(C/C_0)$$

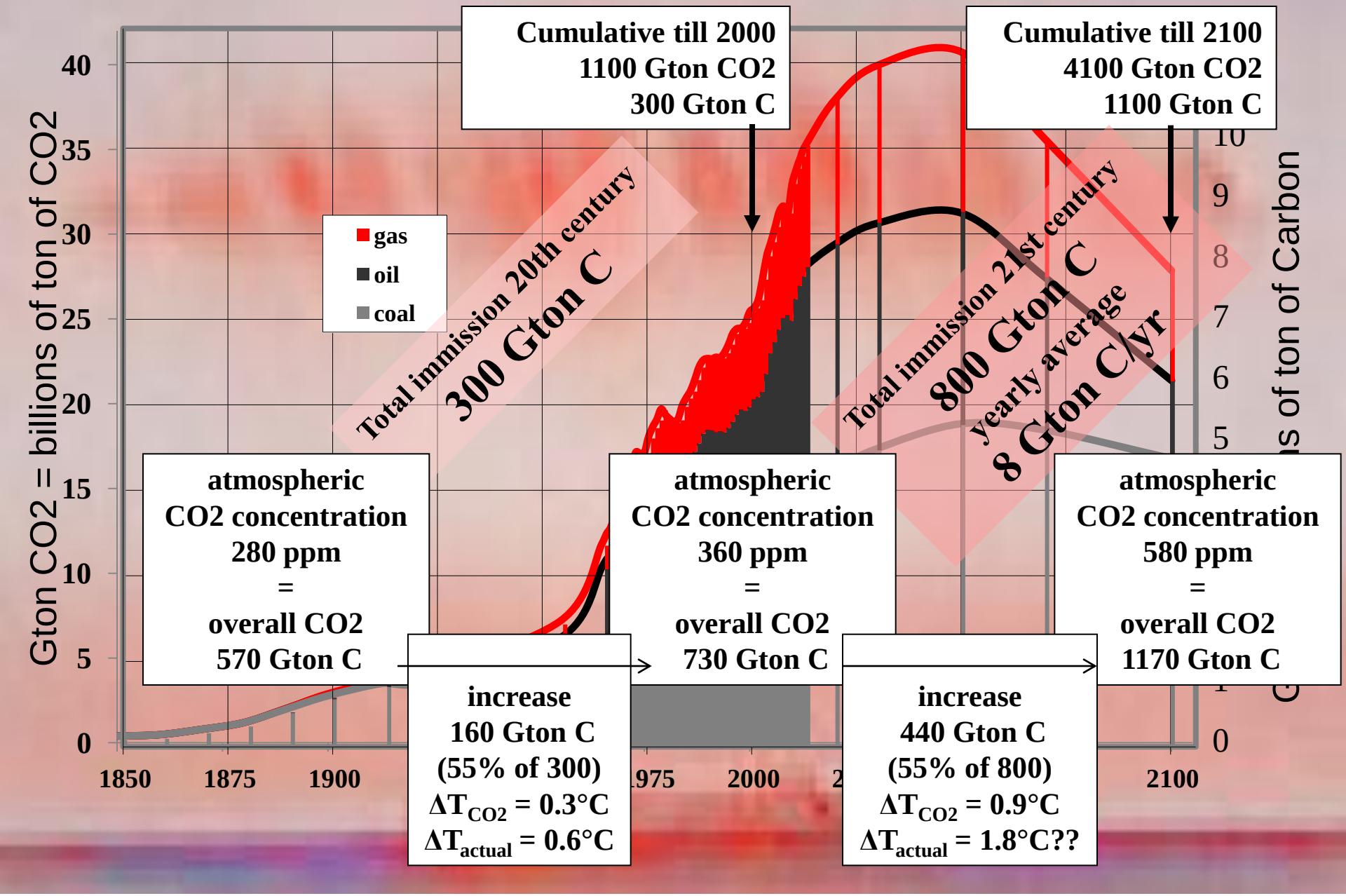
- $F_{2000} - F_{1850} = 5.35 \ln(360/280) = 1.35$ for CO2 during 20th century
- $1.35 * 33/144 =$ <u>0.3°C</u> therefore CO2 accounts for <u>only half of the 0.6°C</u> increase

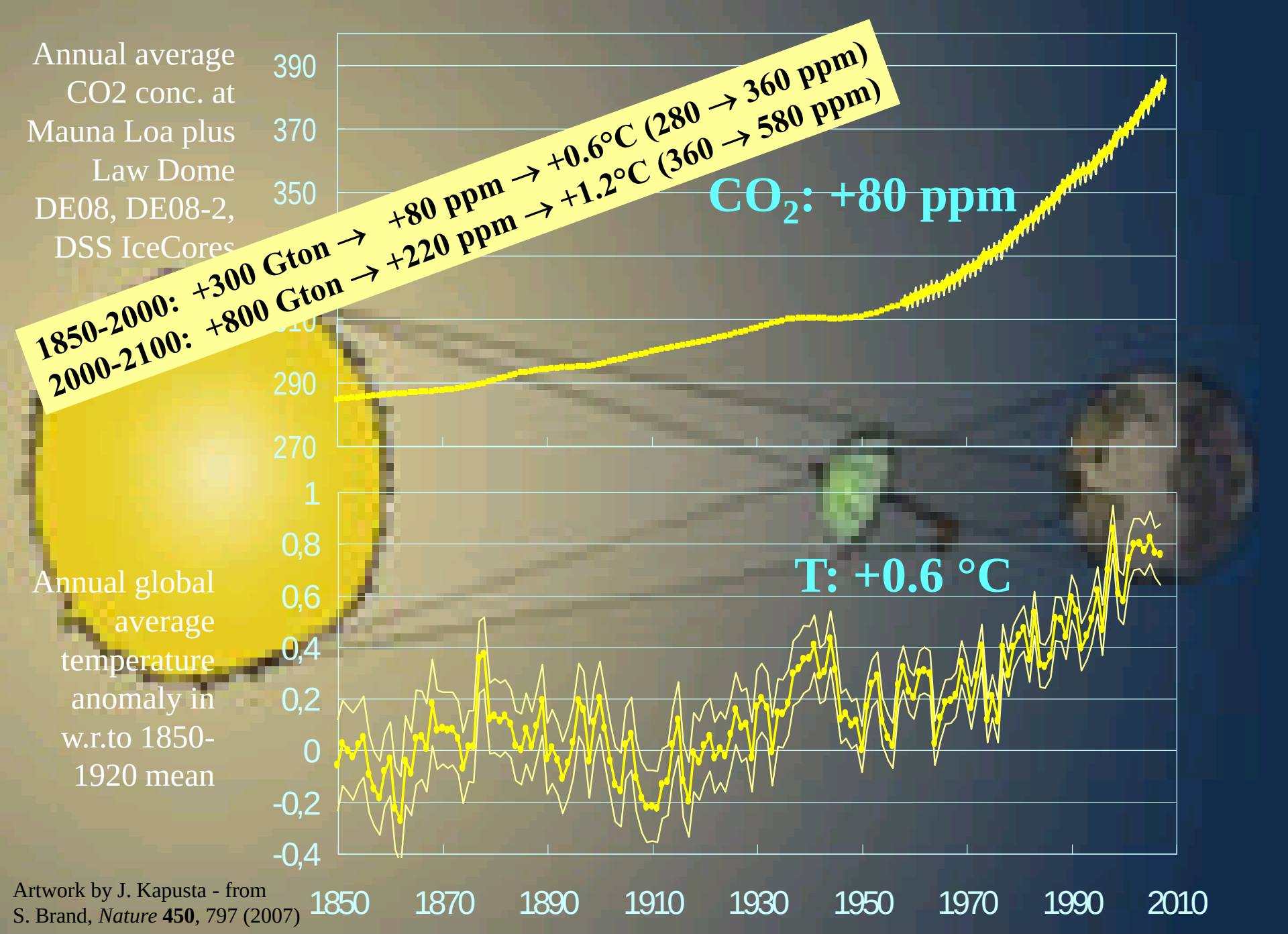
- $F_{2100} - F_{1850} = 5.35 \ln(580/280) = 3.89$ for CO2 during 20th+21th century
- $3.89 * 33/144 =$ <u>0.9°C</u> is the estimate of $T_{2100} - T_{1850}$ due to CO2 immissions

# CO2 immissions due to primary energy consumption

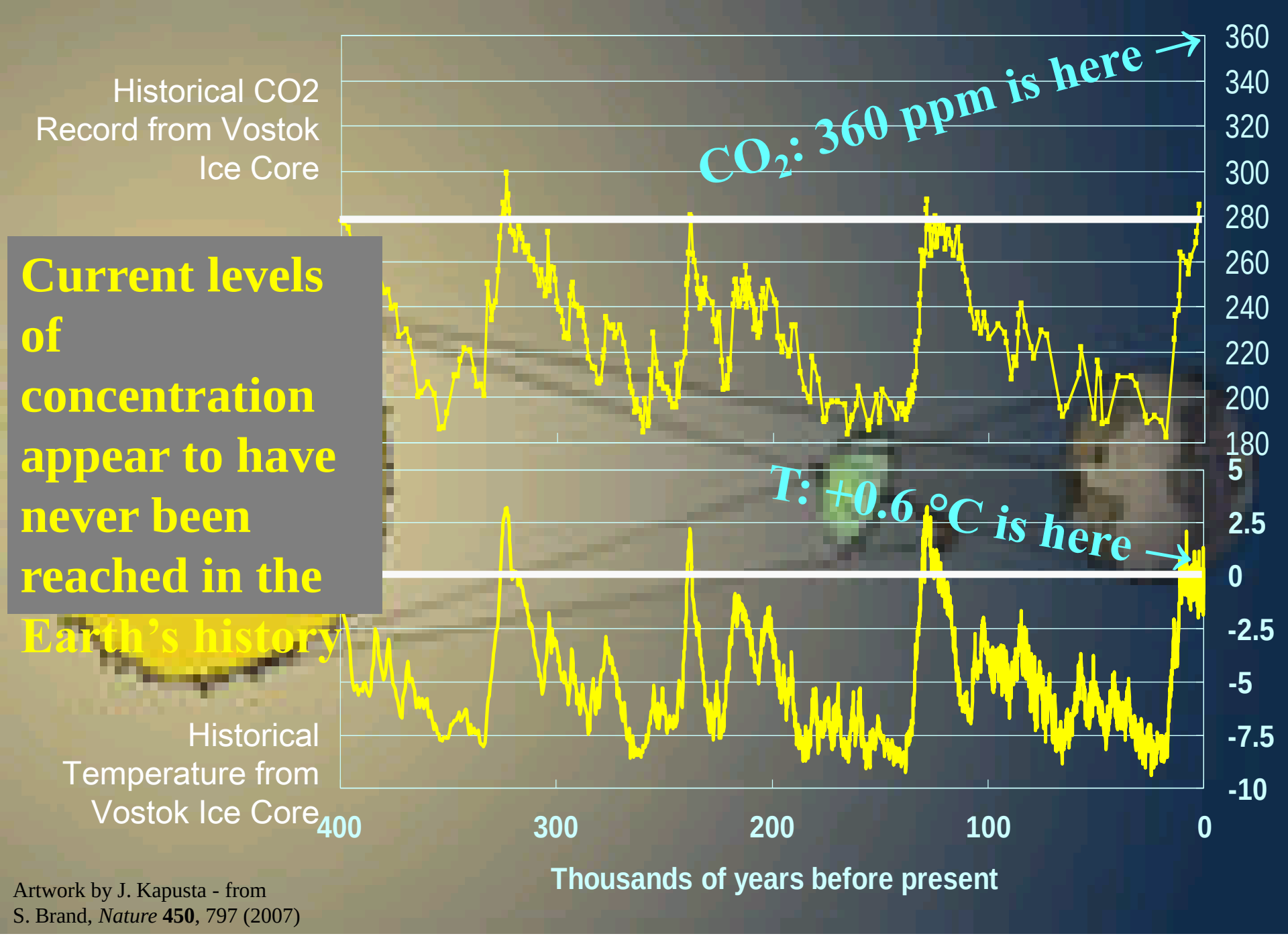


# CO2 immissions due to primary energy consumption






Artwork by J. Kapusta - from S. Brand, *Nature* **450**, 797 (2007)

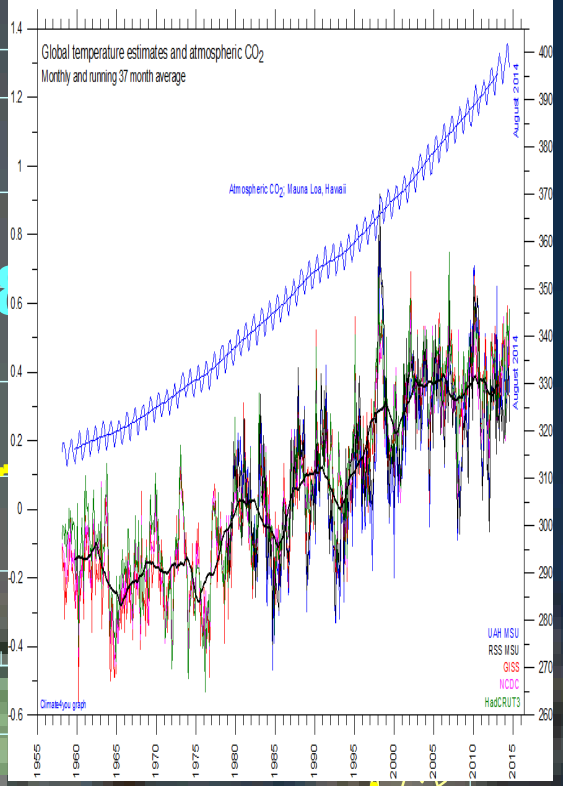



Artwork by J. Kapusta - from S. Brand, *Nature* **450**, 797 (2007)

Annual average CO2 conc. at Mauna Loa plus Law Dome DE08, DE08-2,

**However… correlation appears weaker in the last two decades**

Annual global average temperature anomaly in w.r.to 1850-1920 mean




$CO_2$: +8

T: +0.6 °C

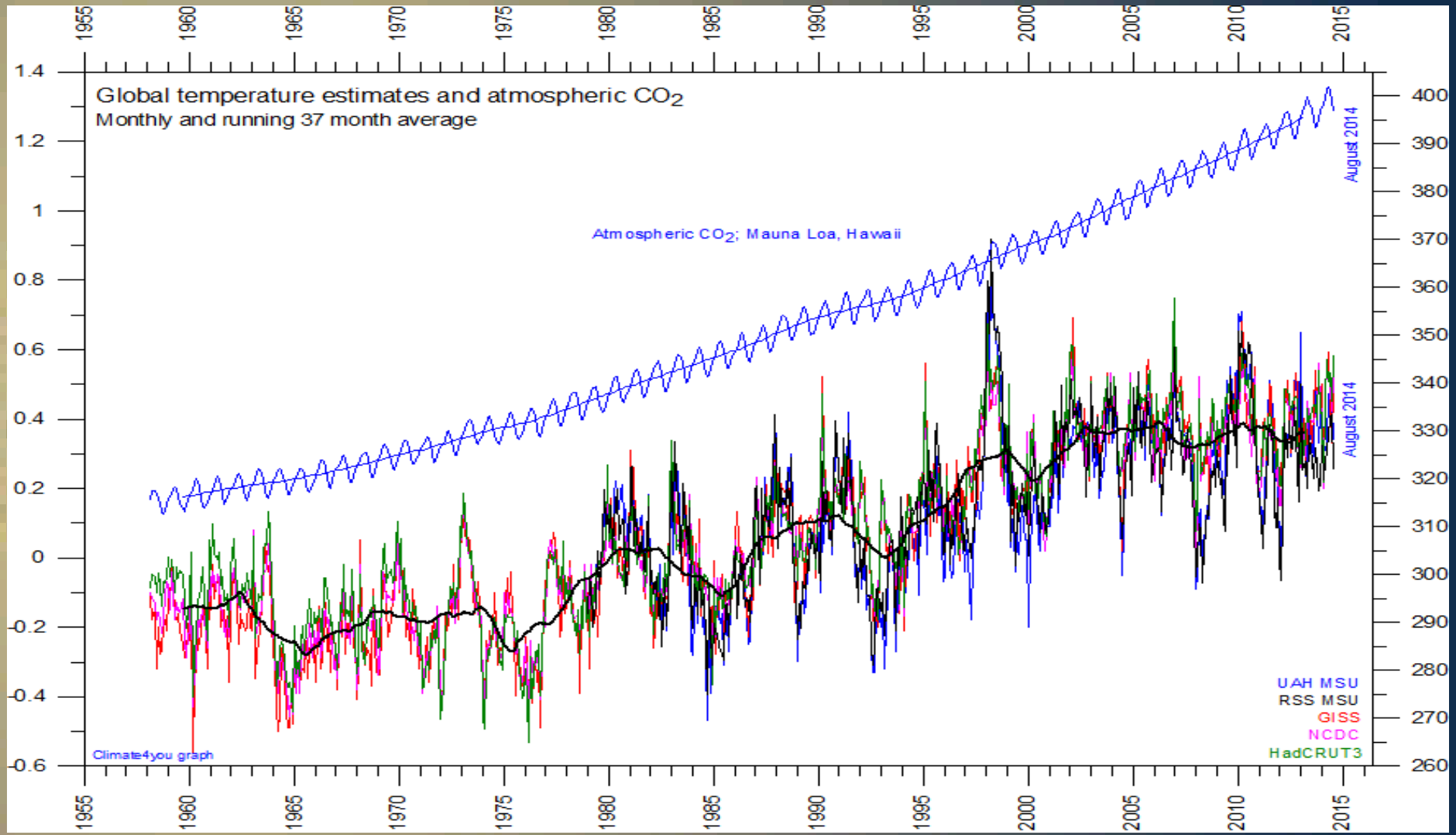
390 370 350

0,6 0,4 0,2 0 -0,2 -0,4

1850 1870 1890 1910 1930 1950 1970 1990 2010

Artwork by J. Kapusta - from S. Brand, *Nature* **450**, 797 (2007)

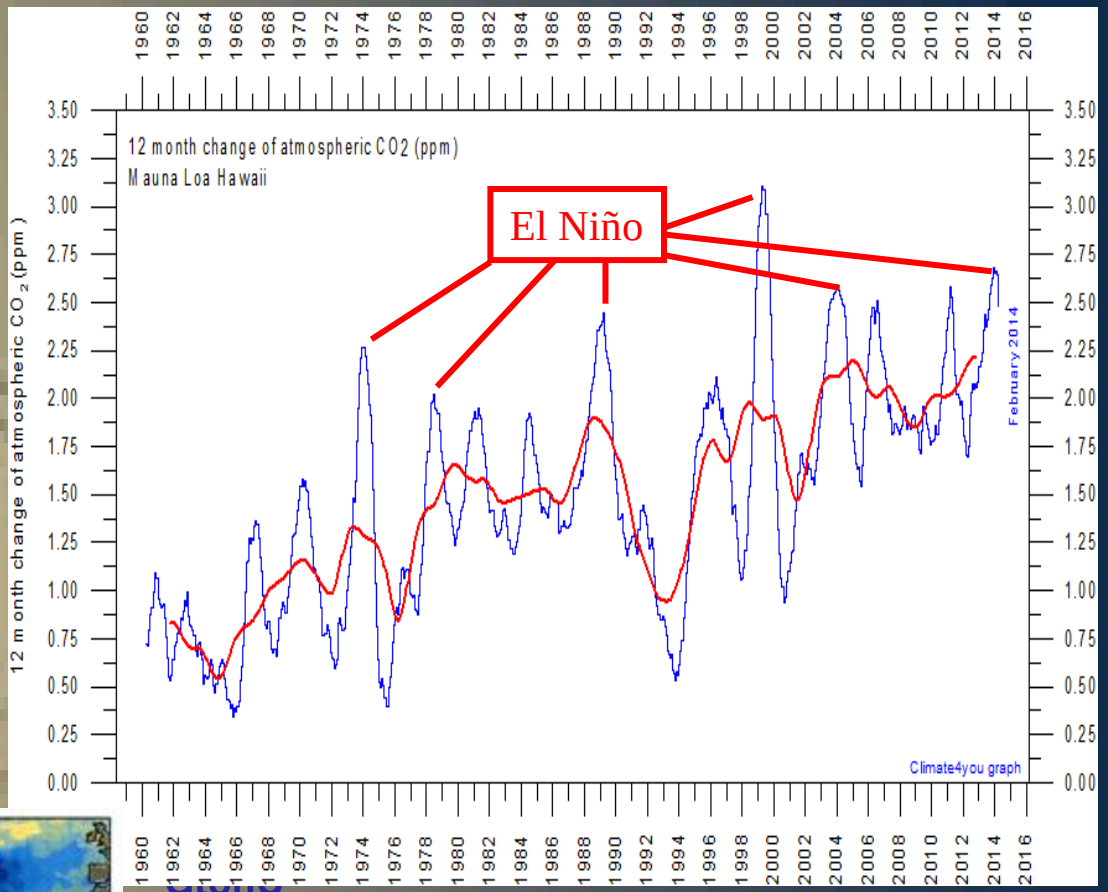
# Correlation appears weaker in last two decades

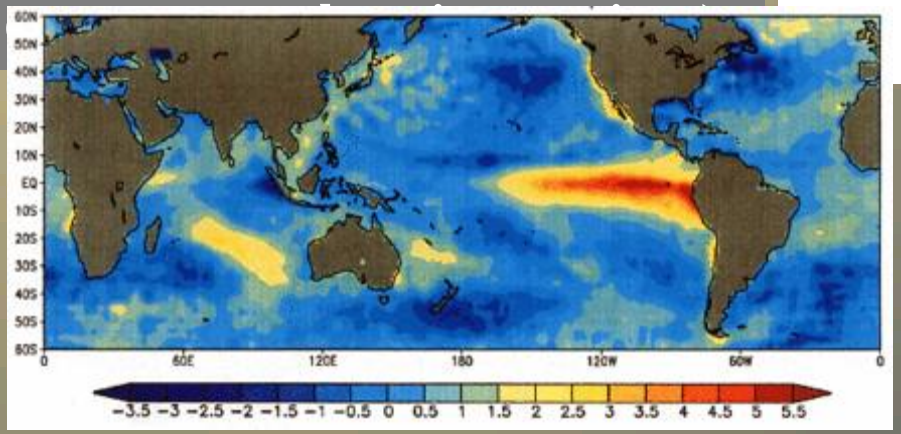


# Irregular fine variations in CO2 concentration

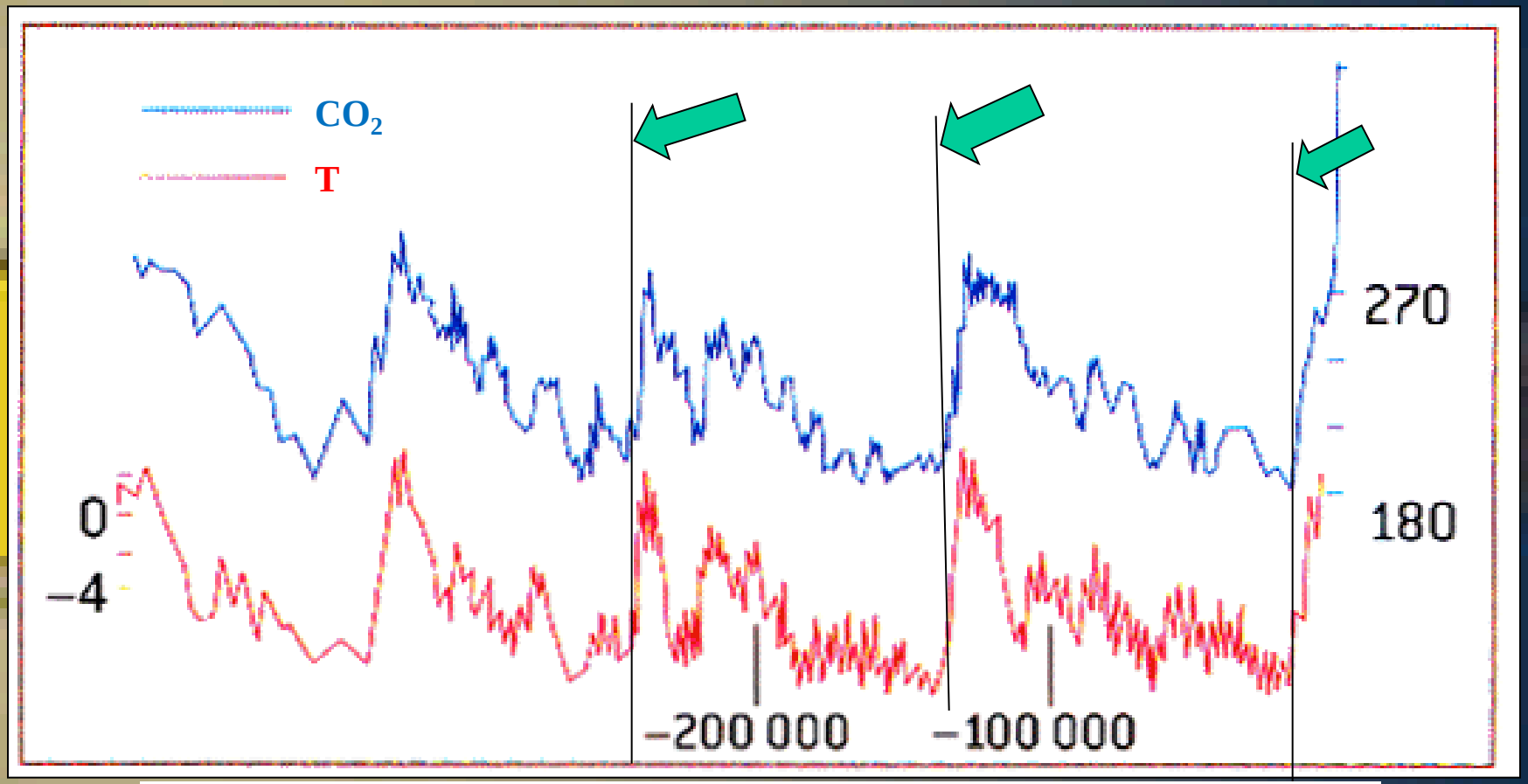
**Anthropic immissions are steady,**
**fine variations in concentration is not as regular.**

**Very much affected by the natural periodic phenomenon known as El Niño (involves**



# Long-time historical correlation is good but with CO2 lagging behind T, not viceversa




**At 240000 before present, temperature increase is before $CO_2$ increase by a 800 years.**

Artwork by J. Kapusta - from
S. Brand, *Nature* **450**, 797 (2007)

# The phase relation between atmospheric carbon dioxide and global temperature

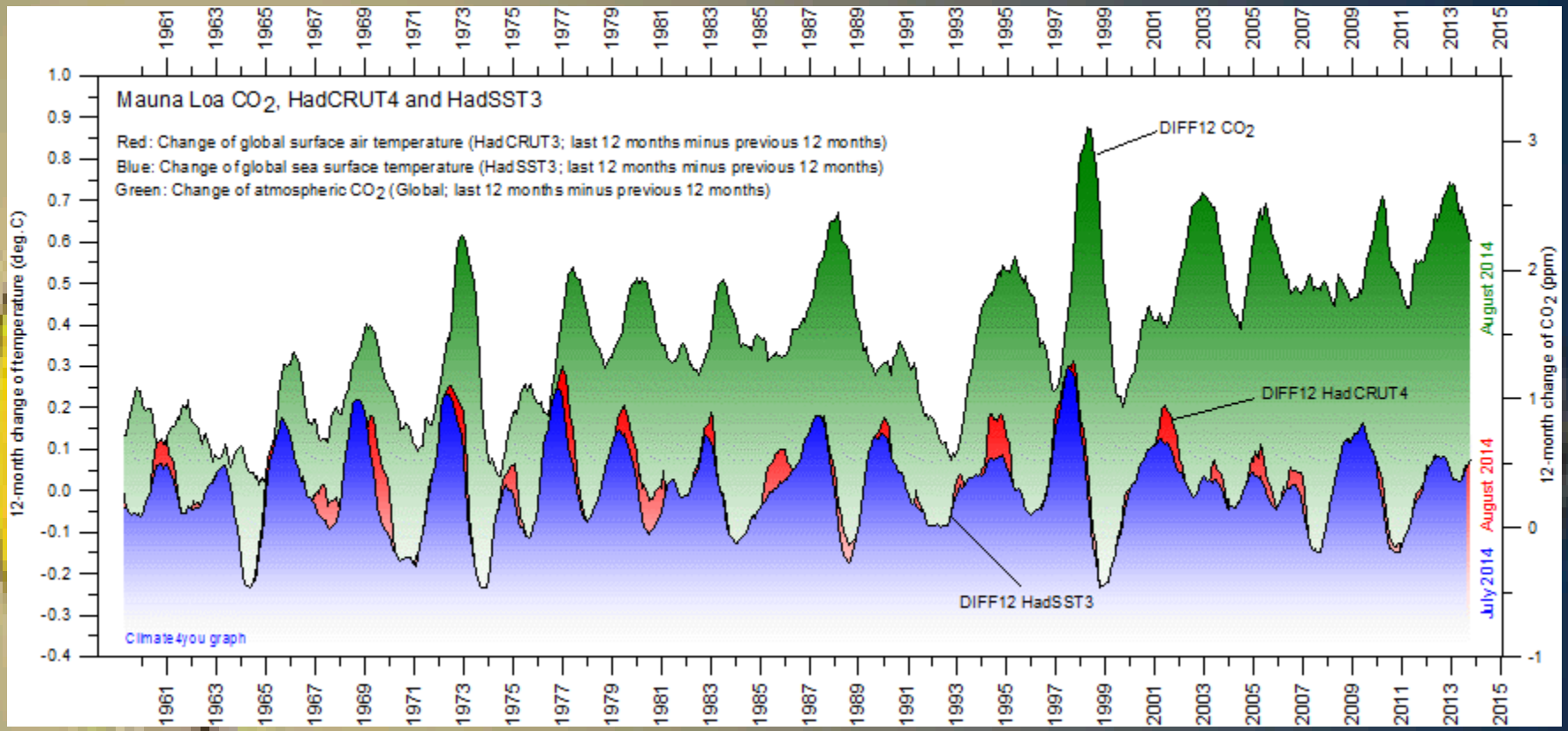
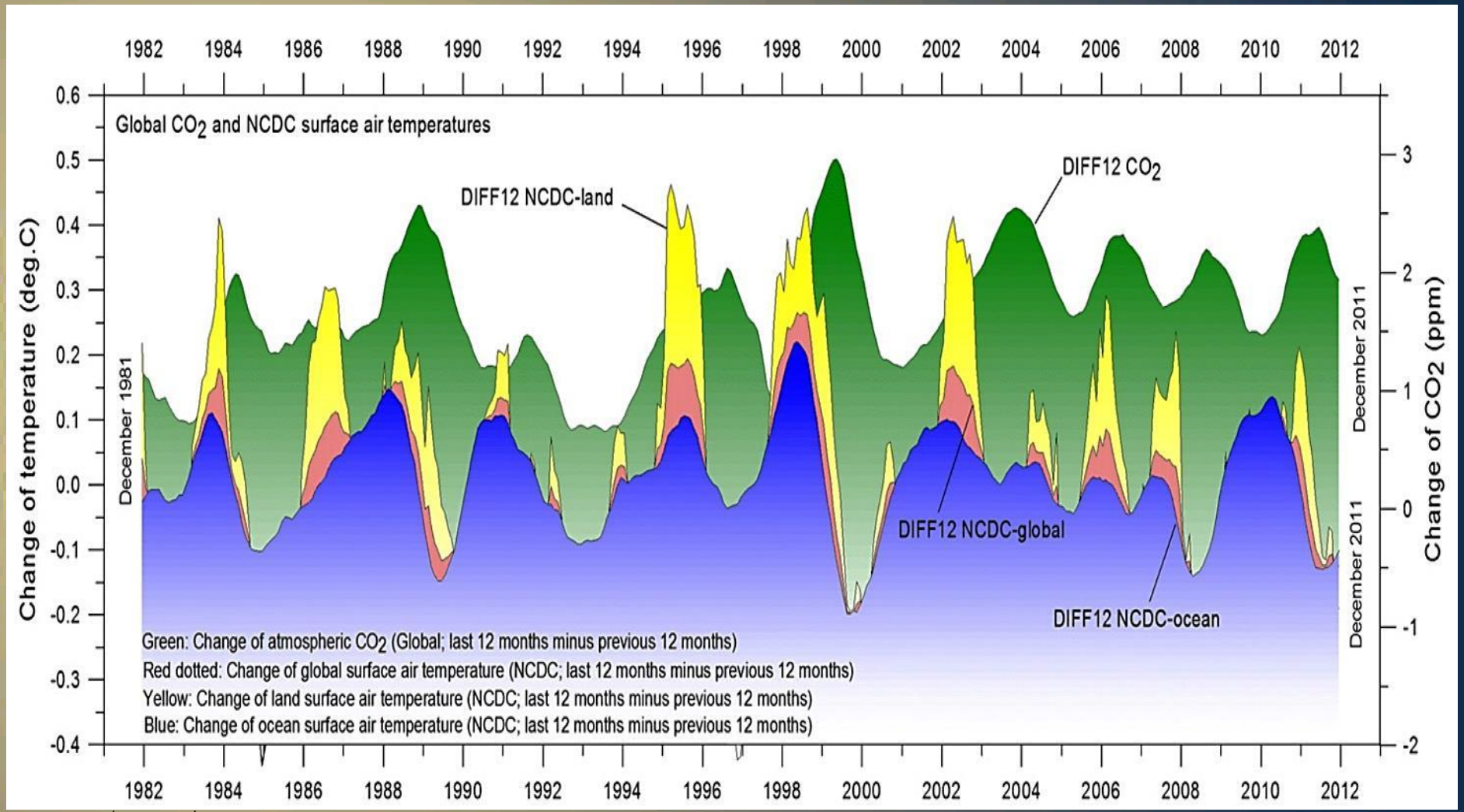



*Figure taken from http://www.climate4you.com/. Ice cores show atmospheric $CO_2$ variations to lag behind atmospheric temperature changes on a century to millennium scale, but modern temperature is expected to lag changes in atmospheric $CO_2$, as the atmospheric temperature increase since about 1975 generally is assumed to be caused by the modern increase in $CO_2$. The maximum positive correlation between $CO_2$ and temperature is found for* ***$CO_2$ lagging 11–12 months in relation to global sea surface temperature, 9.5–10 months to global surface air temperature****, and about 9 months to global lower troposphere temperature.*

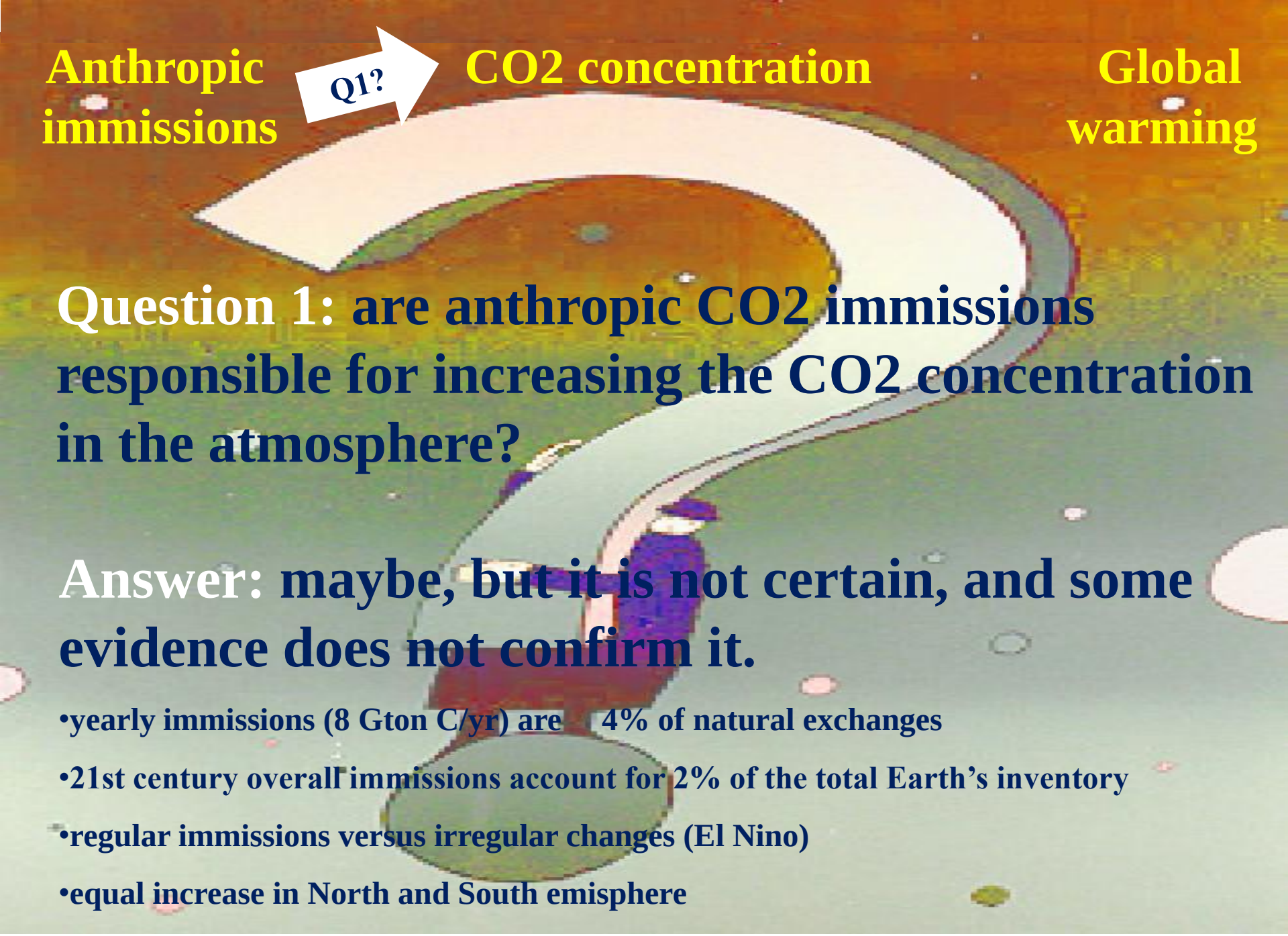
**(last 50 years)**

# The phase relation between atmospheric carbon dioxide and global temperature




*temperature.*

**(last 20 years)**




**Question 1: are anthropic CO2 immissions responsible for increasing the CO2 concentration in the atmosphere?**

**Answer: maybe, but it is not certain, and some evidence does not confirm it.**

- yearly immissions (8 Gton C/yr) are 4% of natural exchanges
- 21st century overall immissions account for 2% of the total Earth's inventory
- regular immissions versus irregular changes (El Nino)
- equal increase in North and South emisphere

Anthropic immissions → CO2 concentration —Q2?→ Global warming

**Question 2: is the increase in CO2 concentration in the atmosphere responsible for increasing the mean global temperature?**

**Answer: there are several doubts, and some experimental evidence does not confirm it.**

- no warming over last 20 years vs continued increase in concentration
- measured increases in CO2 seem to lag behind measured increases in T, not viceversa
  - large changes on a long time scale of 100000 years lag by about 800 years
  - small changes on a short time scale of 20-50 years lag by about 9-12 months

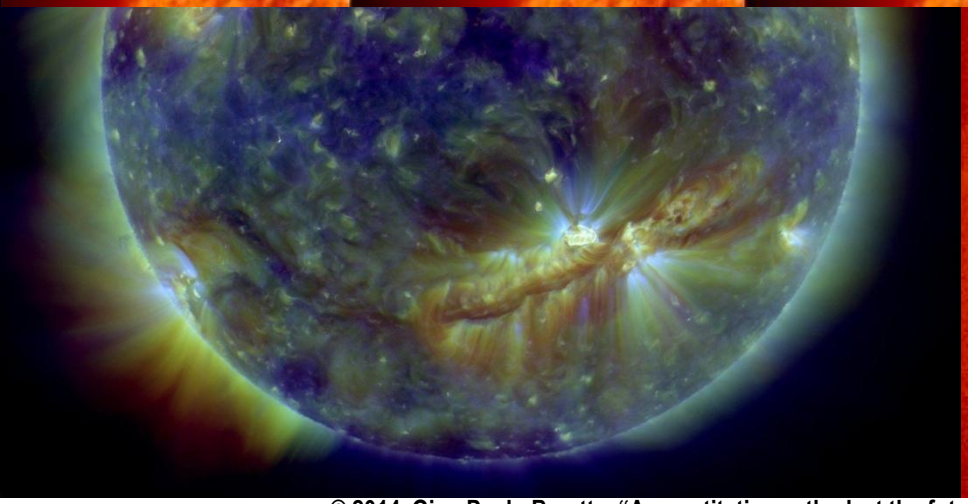

**Question 3: could climatic changes be caused by solar activity?**

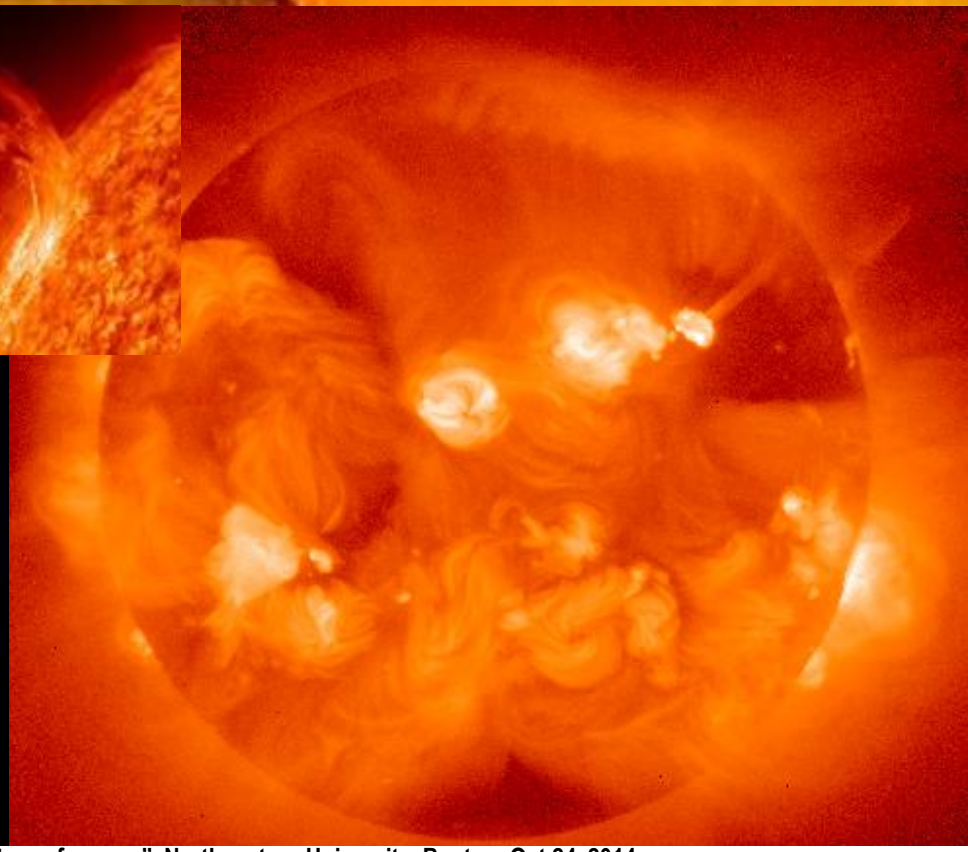
# Some preliminary observations:

- during the last few decades also other planets (Mars, Jupiter, Neptune and Pluto) and their satellites have shown clear signs of warming
  - Mars +0.65°C in the last 30 years
  - data seem well correlated with Earth's data
- measured variations in solar irradiance (0.1%) cannot explain such large changes
- changes have been attributed to albedo variations

# Solar activity: sunspots, flaring, and solar wind

Caused by cyclic magnetic phenomena in the photosphere, it increases brightness only of order 0.1%, but…





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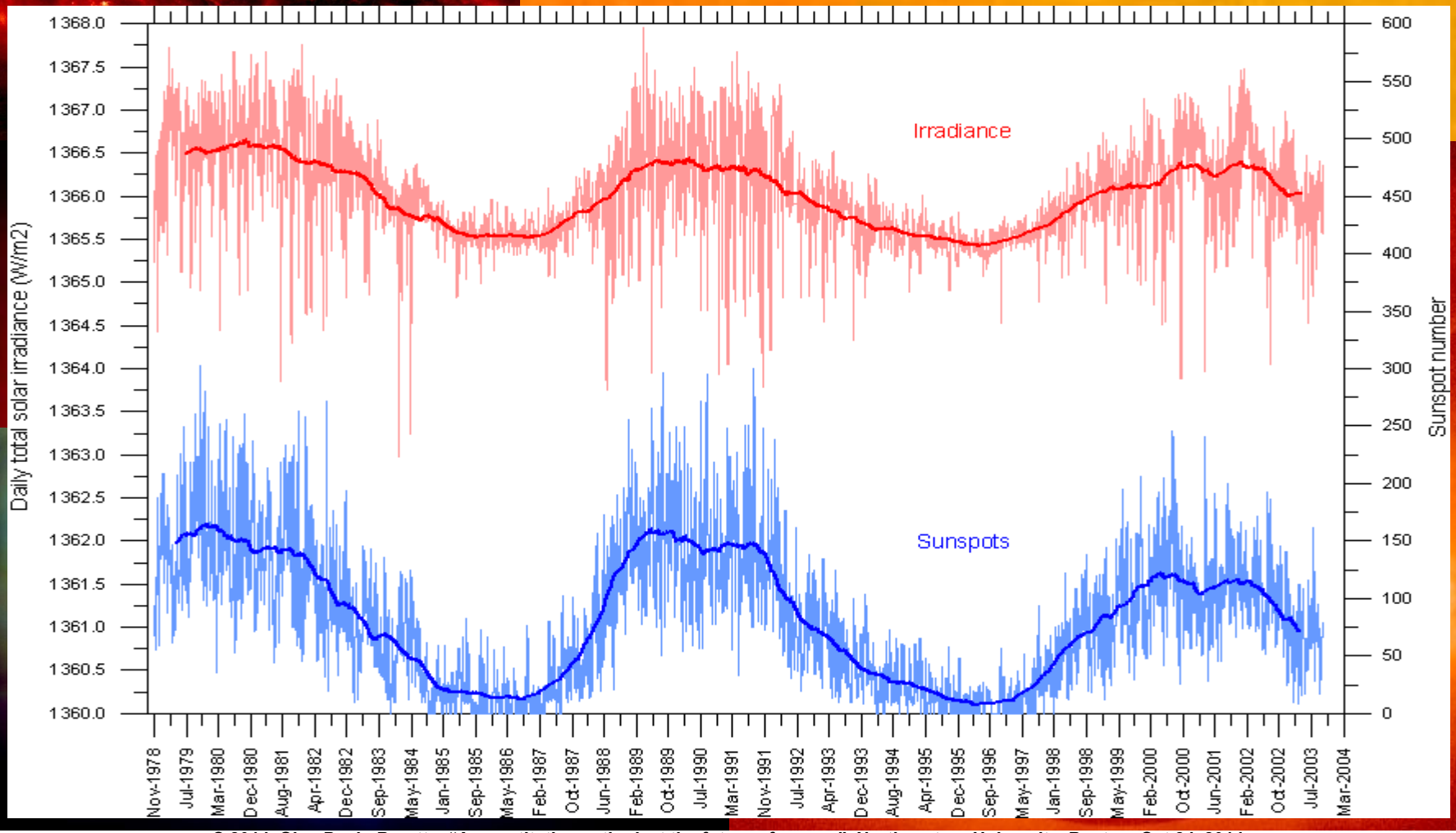
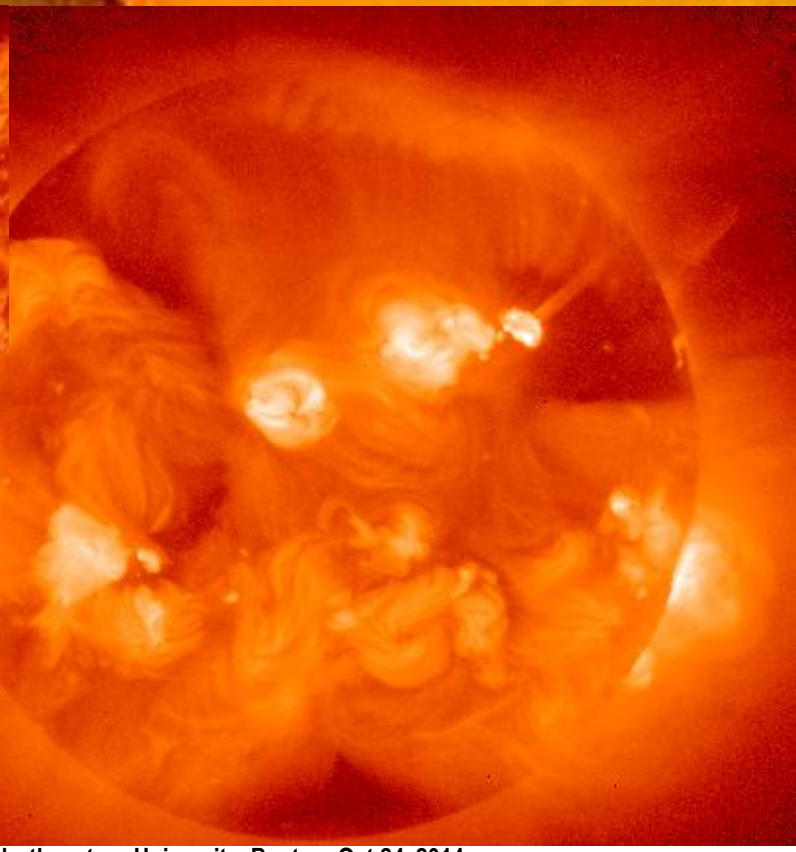
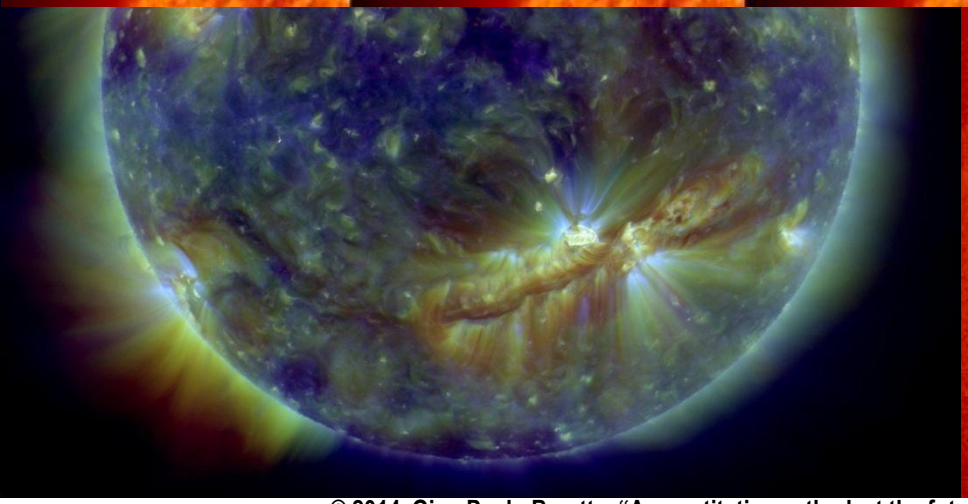


# Solar activity: sunspots, flaring, and solar wind

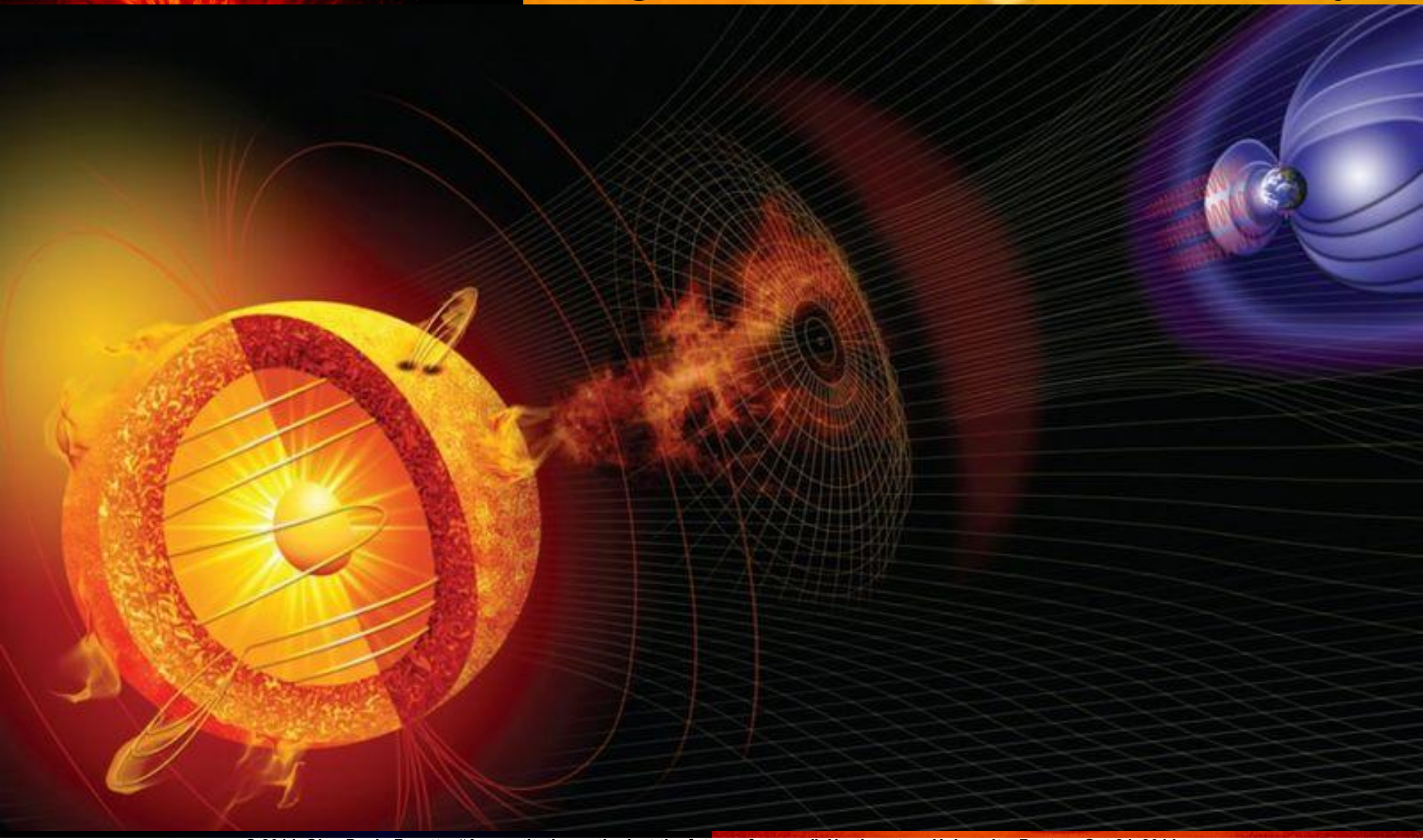
Caused by cyclic magnetic phenomena in the photosphere, it increases brightness only of order 0.1%, but it produces flares and solar wind (charged particles reaching the Earth and the other Planets).





# Solar activity: sunspots, flaring, and solar wind

Solar wind, deflected by the Earth's magnetic field, shields it from cosmic rays.



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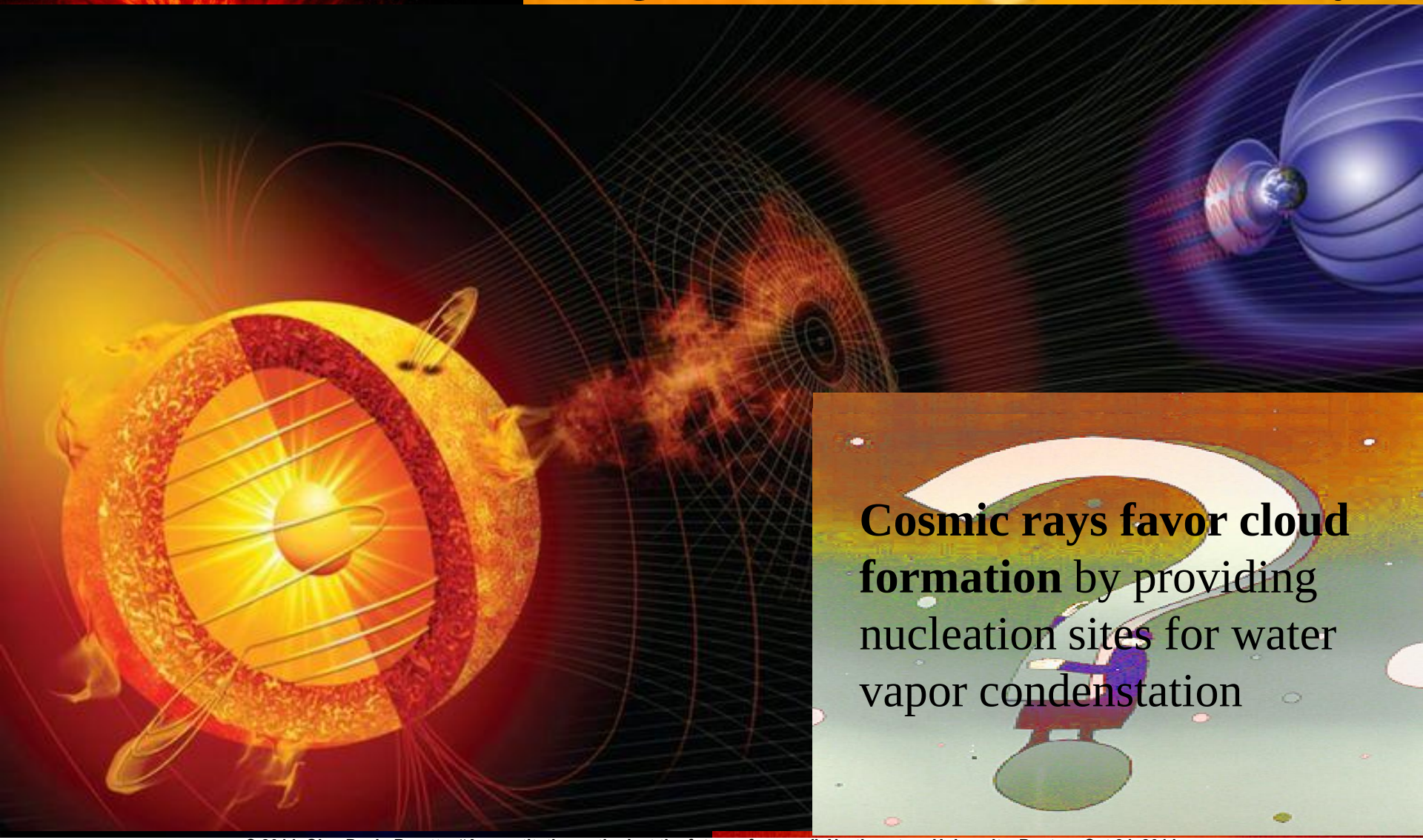

**Cosmic rays favor cloud formation** by providing nucleation sites for water vapor condenstation

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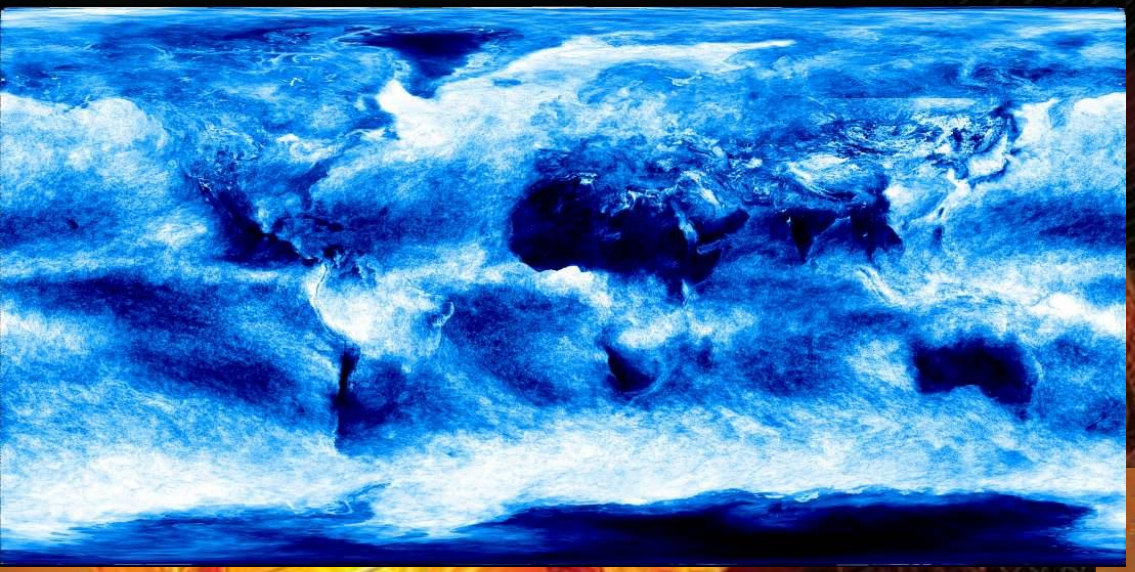
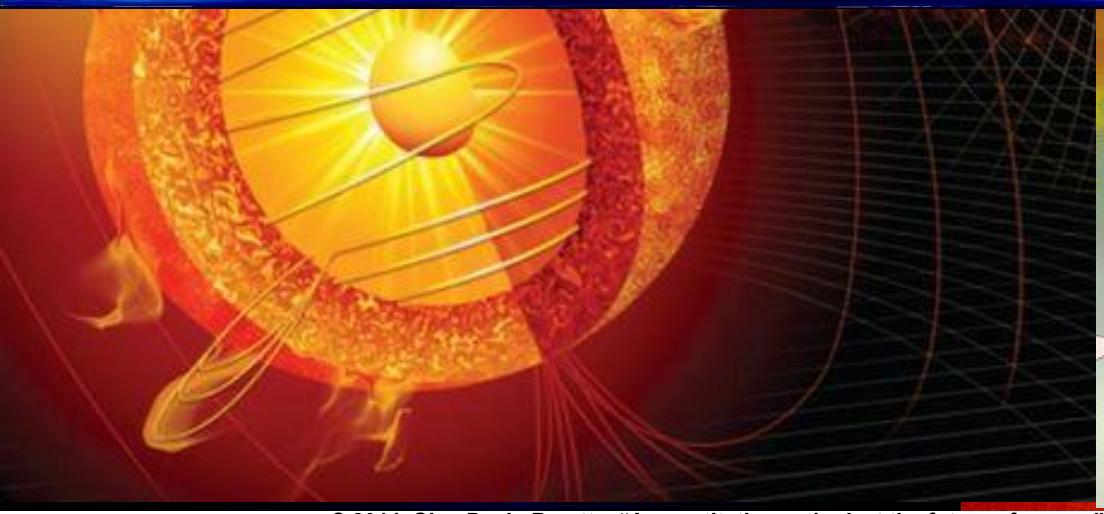
Clouds albedo





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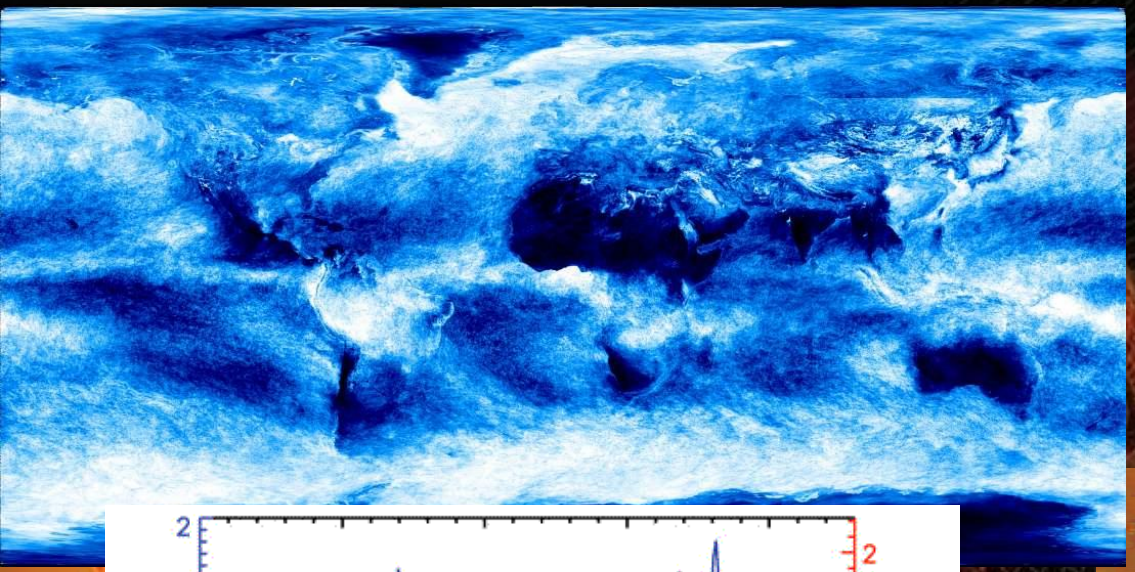
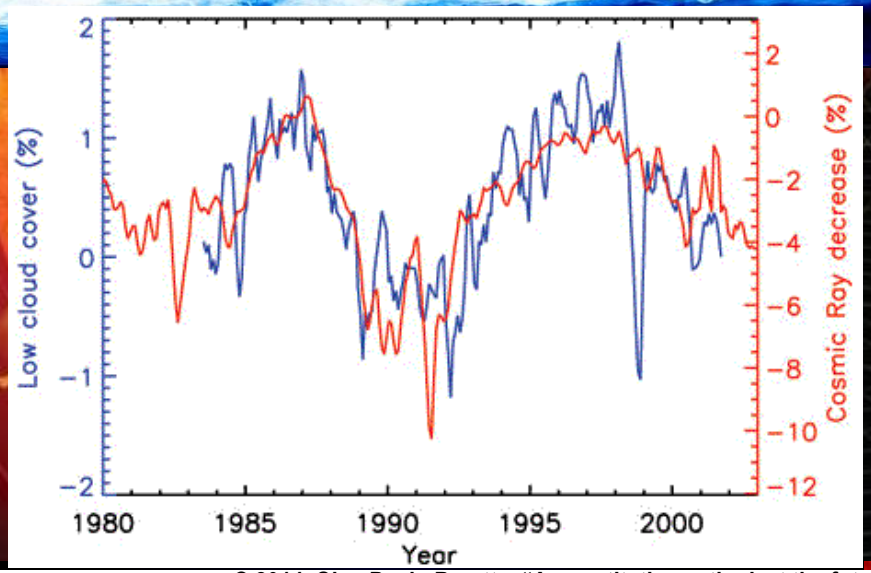
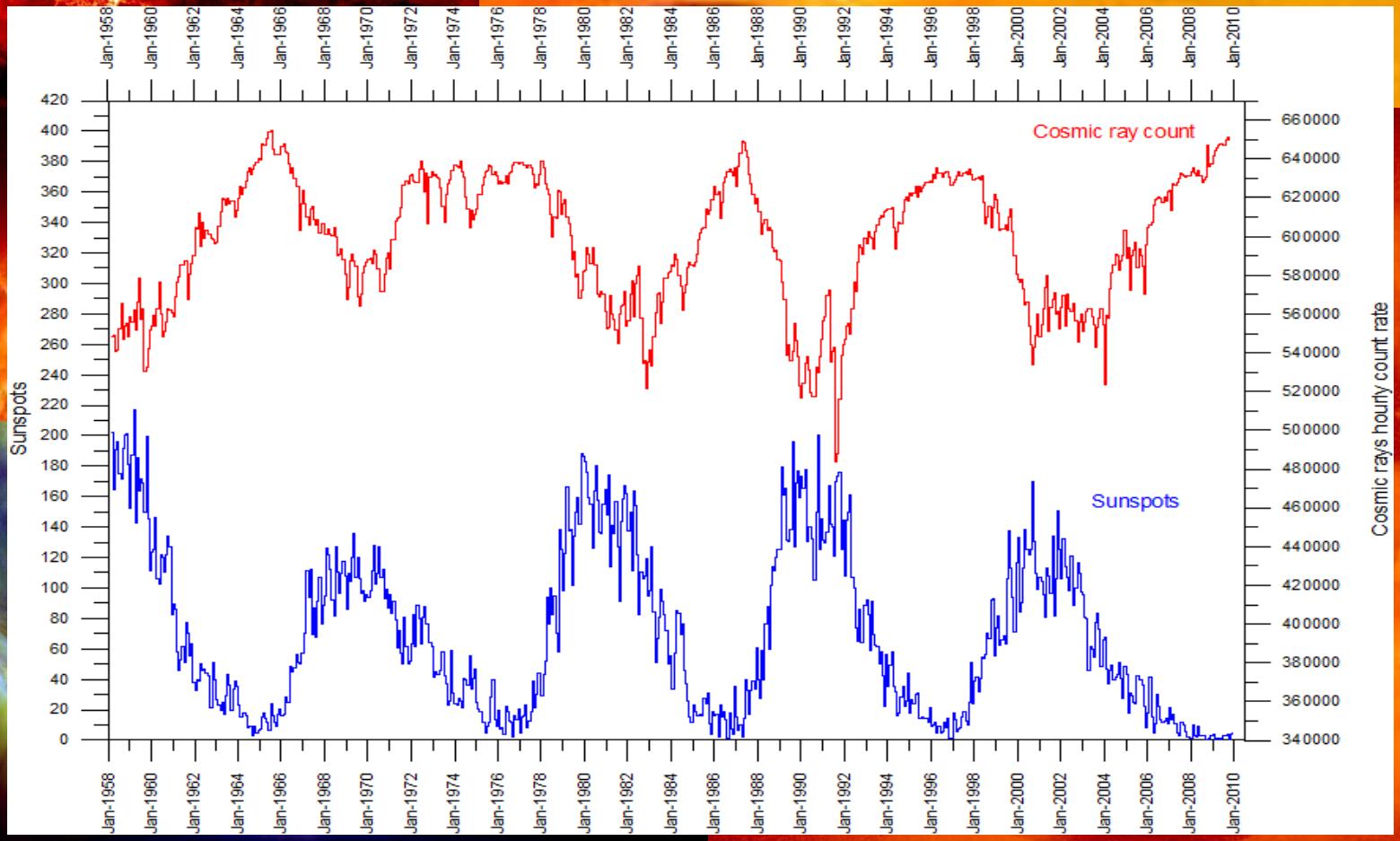





**Cosmic rays favor cloud formation** by providing nucleation sites for water vapor condenstation.

# Solar activity: sunspots, flaring, and solar wind

more sunspots → more solar activity → more solar wind → fewer cosmic rays →(?) fewer clouds → smaller albedo → more effective solar heating → global warming.



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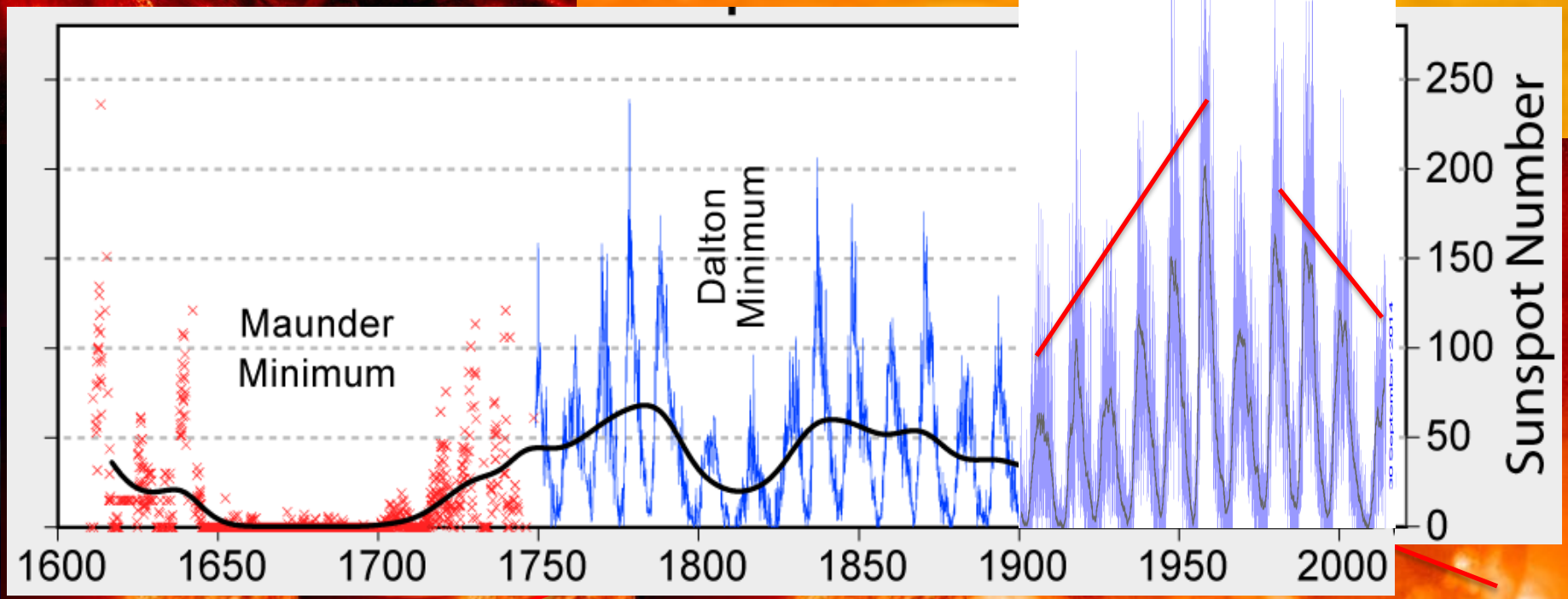

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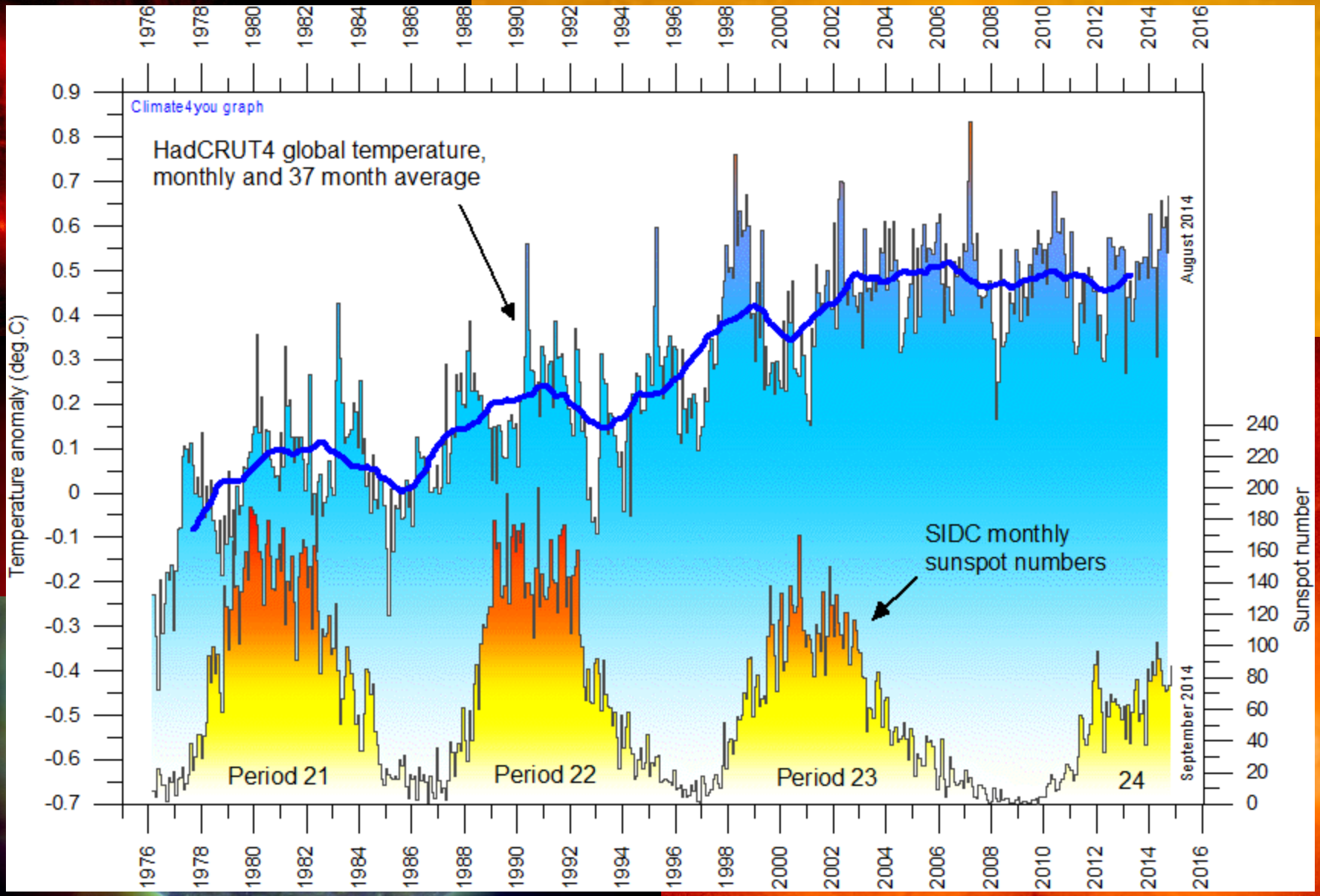
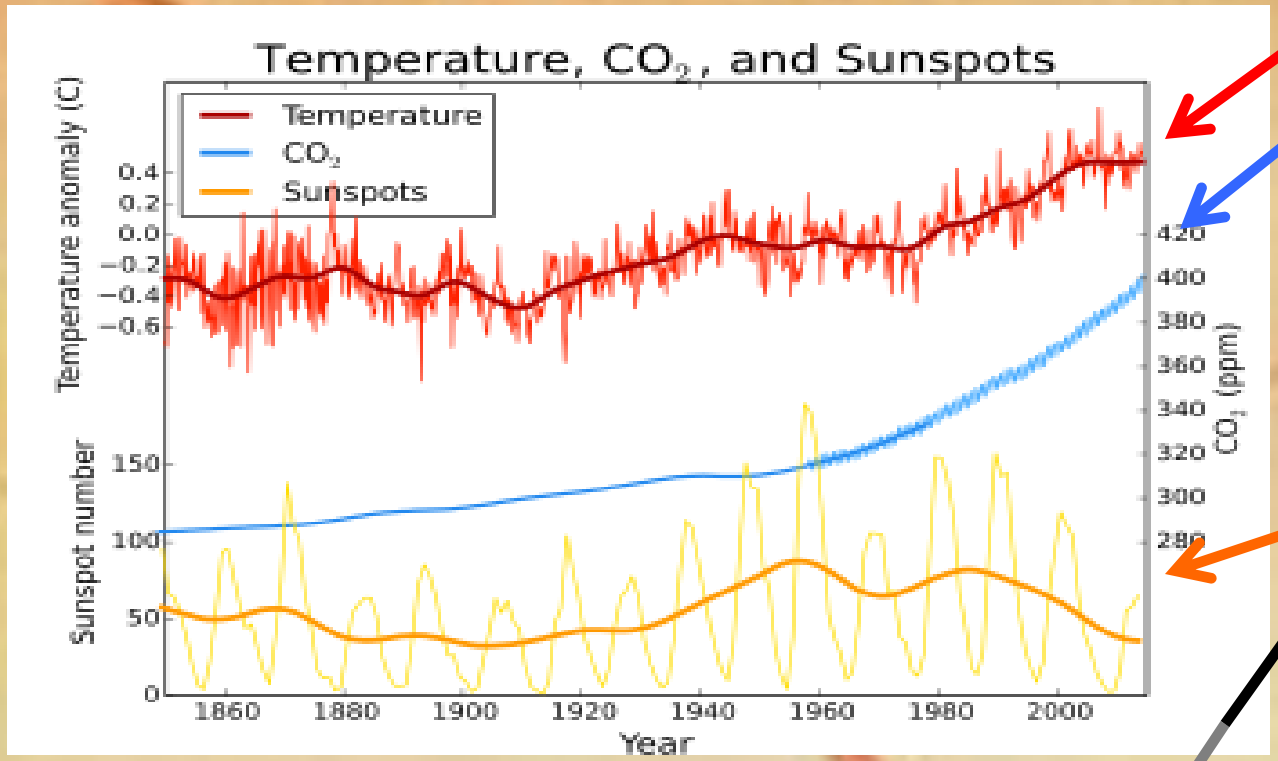


Solar activity → Q3? → Cosmic rays → Q3? → Climatic changes

## Question 3: could climatic changes be caused by solar activity?

## Answer: probably: some evidence does suggest this to be the case.

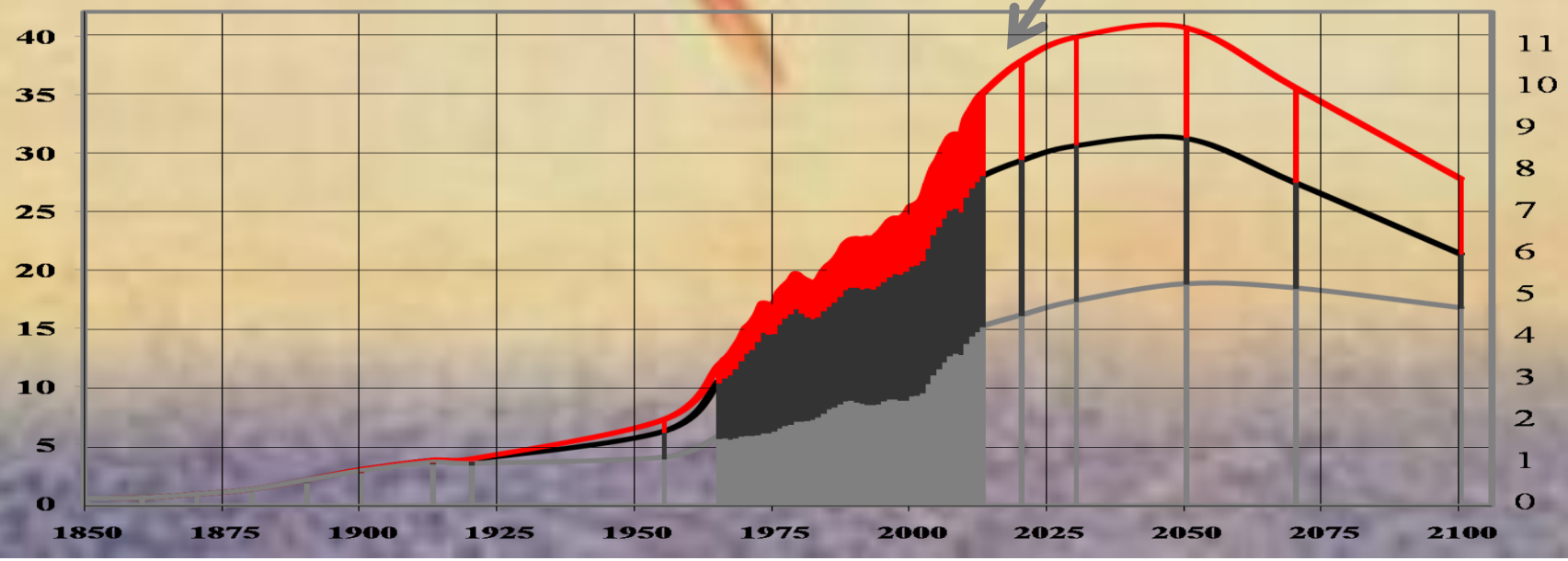
- correlation between cloud cover and earth's albedo
- correlation between cloud cover and cosmic rays
- correlation between cosmic rays and solar activity as measured by sunspots
- correlation between current global cooling and weak sunspot cycle




**T** and **CO2 concentrations** are INTEGRATED effects of several phenomena

Complex **modeling** (requiring assumptions on many many factors)

**Solar activity** and **CO2 immissions** are just two INSTANTANEOUS forcing effects

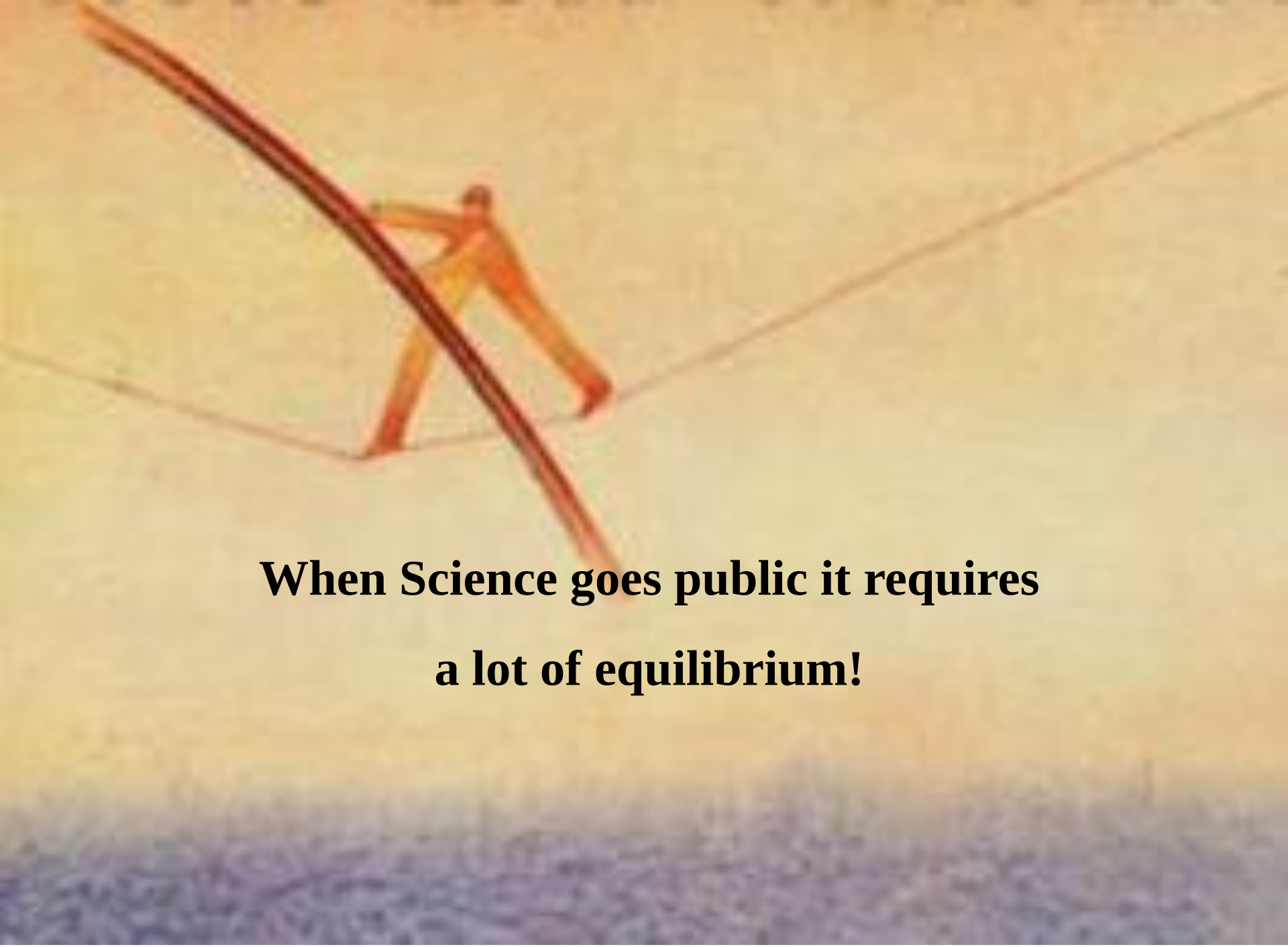


# Sustainable development is tricky!

False hopes on single and simple solutions,
are fed on bad information and cheap futurology.
They cause waste of resources.

Examples:

- the ‘mirage’ of a hydrogen economy
- market distortions due to impulsive energy policies



**When Science goes public it requires**

**a lot of equilibrium!**

# Has a serious alert been called for climatic changes?

Climate change is not felt as the most important problem for the future of human kind. There are other more serious priorities (Copenhagen Consensus 2012):

- - malnutrition in poor countries
- - alphabetization
- - deseases (malaria, tuberculosis, AIDS in particular)
- - availability of vaccins (Ebola?)

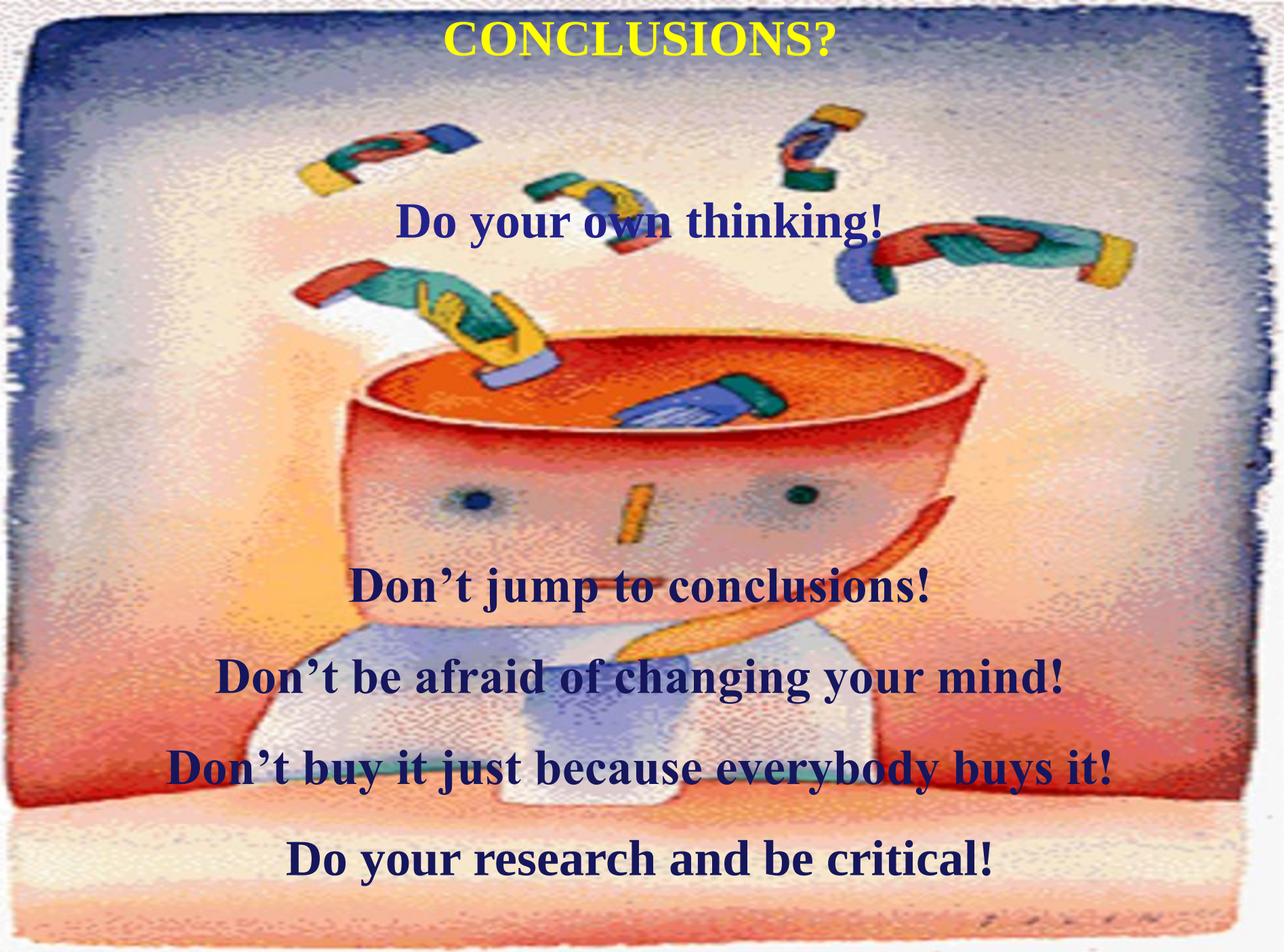
Limiting the effects of climate change is only listed as the 6° position (not cited as global warming)

It is clear that climate changes, among the many problems that afflict human kind, is still felt as a minor problem.

# What should we do?

- The primary objective should be to get prepared to control and limit the predictable damages that will be caused by climate change, whether it be of anthropic or natural origin.
- Do whatever is within certain anthropic reach to contain, control, or reduce causes of global warming
- The objective cannot be reduced to just that of reducing anthropic $CO_2$ immissions, because there is no certainty that they are the only phenomenon responsible for the increase in $T_{gm}$ during the last quarter of the last century.

# CONCLUSIONS?



**Do your own thinking!**

**Don’t jump to conclusions!**

**Don’t be afraid of changing your mind!**

**Don’t buy it just because everybody buys it!**

**Do your research and be critical!**