Isotopes as tracers of climate change: atmosphere-biosphere-ocean studies

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Isotopes

Stable ($^{2}H/H$, $^{13}C/^{12}C$, $^{15}N/^{14}N$, $^{18}O(^{16}O$,…)

Radioactive

Natural

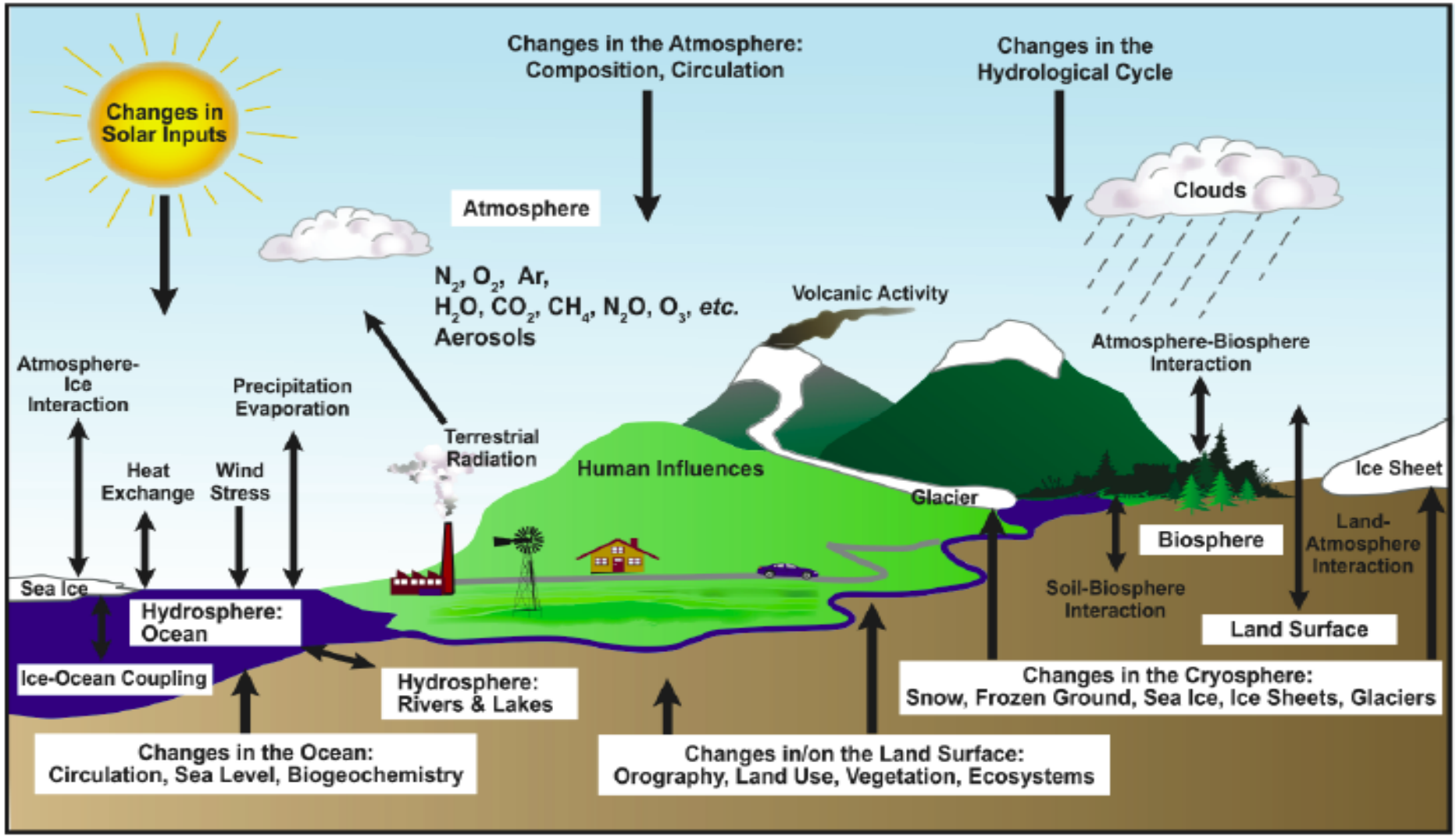
Cosmogenic (^{3}H, ^{10}Be, ^{14}C, ^{36}Cl,…)
Primordial (^{40}K, ^{232}Th, ^{238}U, …)
Radiogenic (^{222}Rn, ^{226}Ra, ^{210}Pb,…)

Anthropogenic (^{3}H, ^{14}C, ^{90}Sr, ^{129}I, ^{137}Cs, Pu,…)

Isotope Tracers

- ^{2}H – transport of air & water masses, exchange processes atmosphere-biosphere, atmosphere-hydrosphere,...
- ^{13}C – exchange processes, tracing fossil carbon,...
- ^{18}O – atmosphere-hydrosphere exchange, groundwater, seawater, past temperature records in ice,...
- ^{3}H - ($T_{1/2}$ = 12.32 y), water molecule (HTO) – transport of water masses, water dating...
- ^{10}Be - ($T_{1/2} = 1.39 \times 10^{6}$ y), aerosols, stratosphere-troposphere-ocean transport, ice cores, sediments...
- ^{14}C – ($T_{1/2}$ = 5730 y), stratosphere-troposphere exchange, fossil carbon record in the atmosphere – biosphere - ocean, atmosphere-ocean exchange,...
- ^{137}Cs – ($T_{1/2}$ = 30.17 y), mostly dissolved in seawater – processes in the water column, transport of water masses...
- ... and many other stable and radioactive isotopes...

Isotope Tracing of the Environment

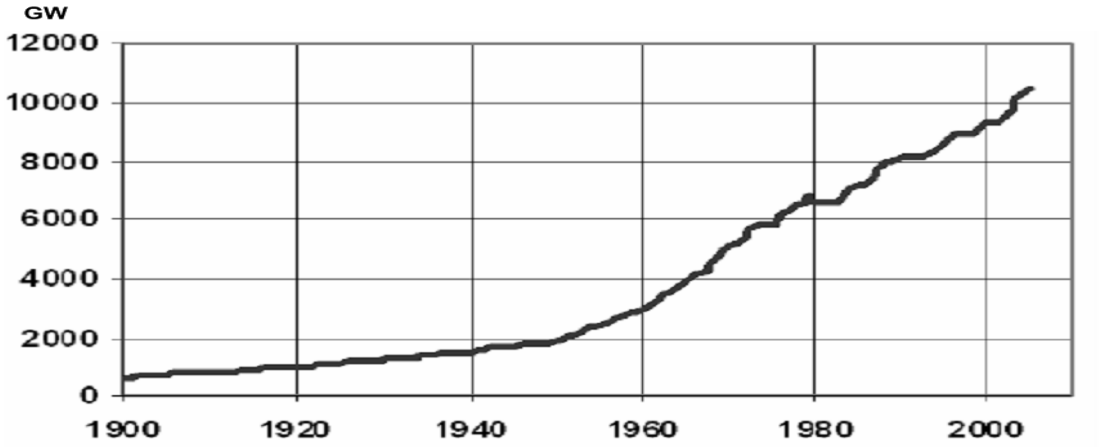


Timing

- **ANTHROPOCENE epoch (>1945 present) - a new epoch after the HOLOCENE epoch (10 ky)**
- **INDUSTRIAL era (150 years) – carbon, nitrogen, sulfur oxides, metals, organics,...**
- **NUCLEAR era (70 years) – anthropogenic radionuclides, nuclear bomb tests, global fallout, nuclear industry, nuclear accidents,...**
- **COSMIC era (50 years) – satellites, moon, garbage in the space ,...**

Energy vs. Environment

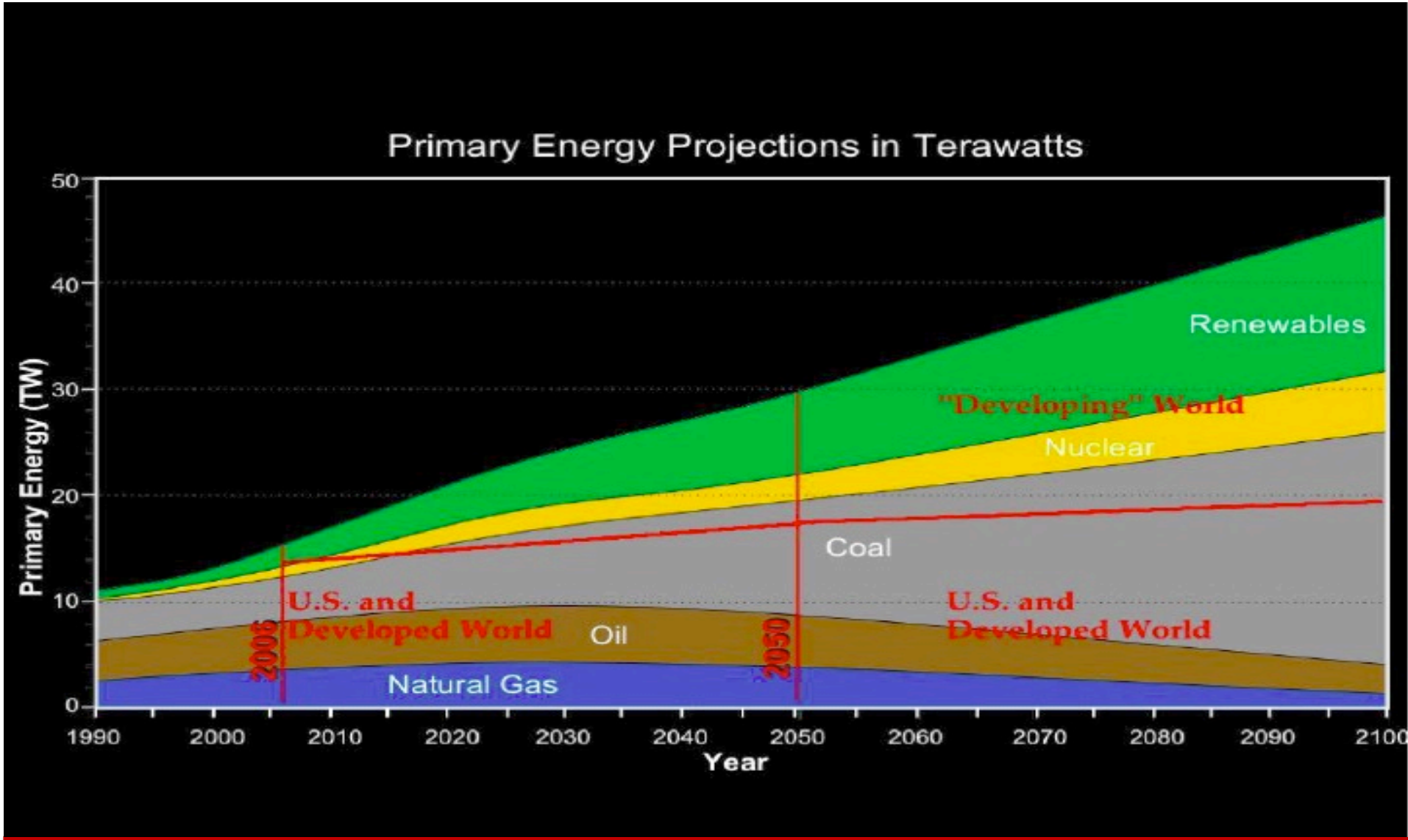
- New Philosophy : EGOCENTRIC vs. ECOCENTRIC approach: protection of the total environment – man, fauna, flora
- CLIMATE CHANGE – anthropogenic vs. natural processes, global impacts, politically driven science ?
- NUCLEAR acceptance by public ? – Chernobyl & Fukushima impacts, radioactive wastes
- RENEWABLE ENERGY SOURCES – sustainable for global development? BRICS countries, new world - thirsty for the energy, a new industrialization revolution – the east and south neads own revolution...



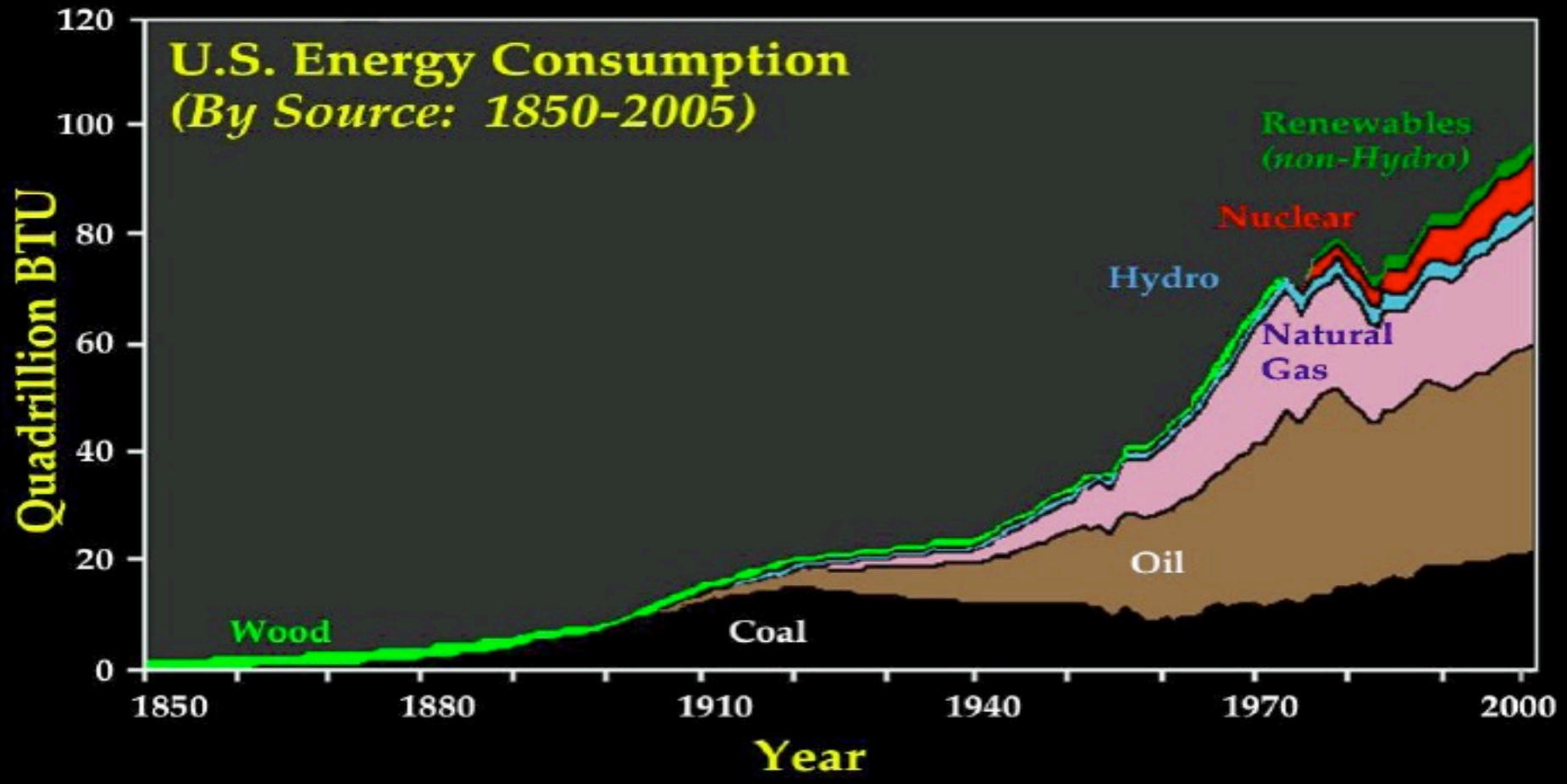
Energy consumption growth in 20th century

Large energy consumption growth rates after the 1945s

World Energy Mix

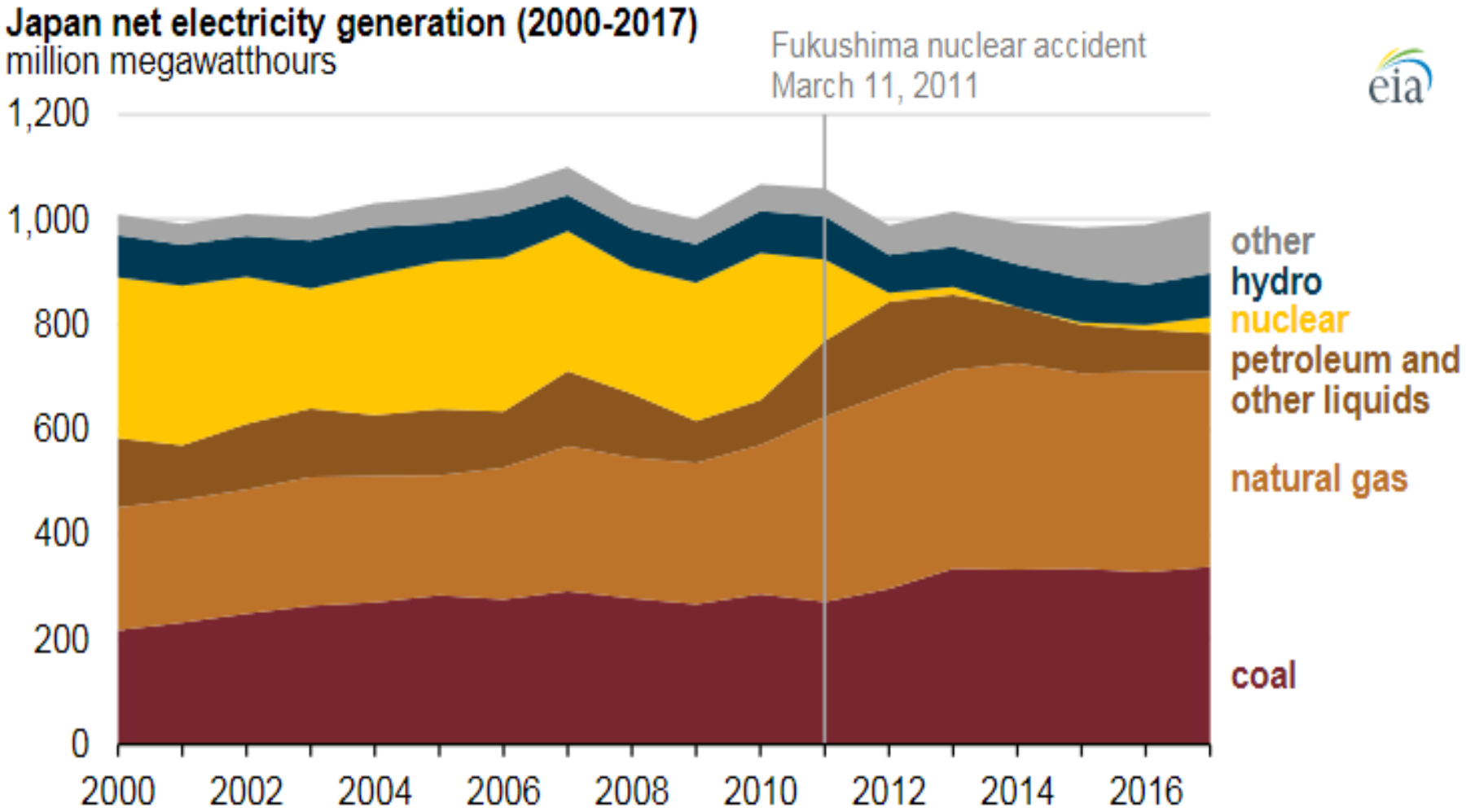


US Energy Mix

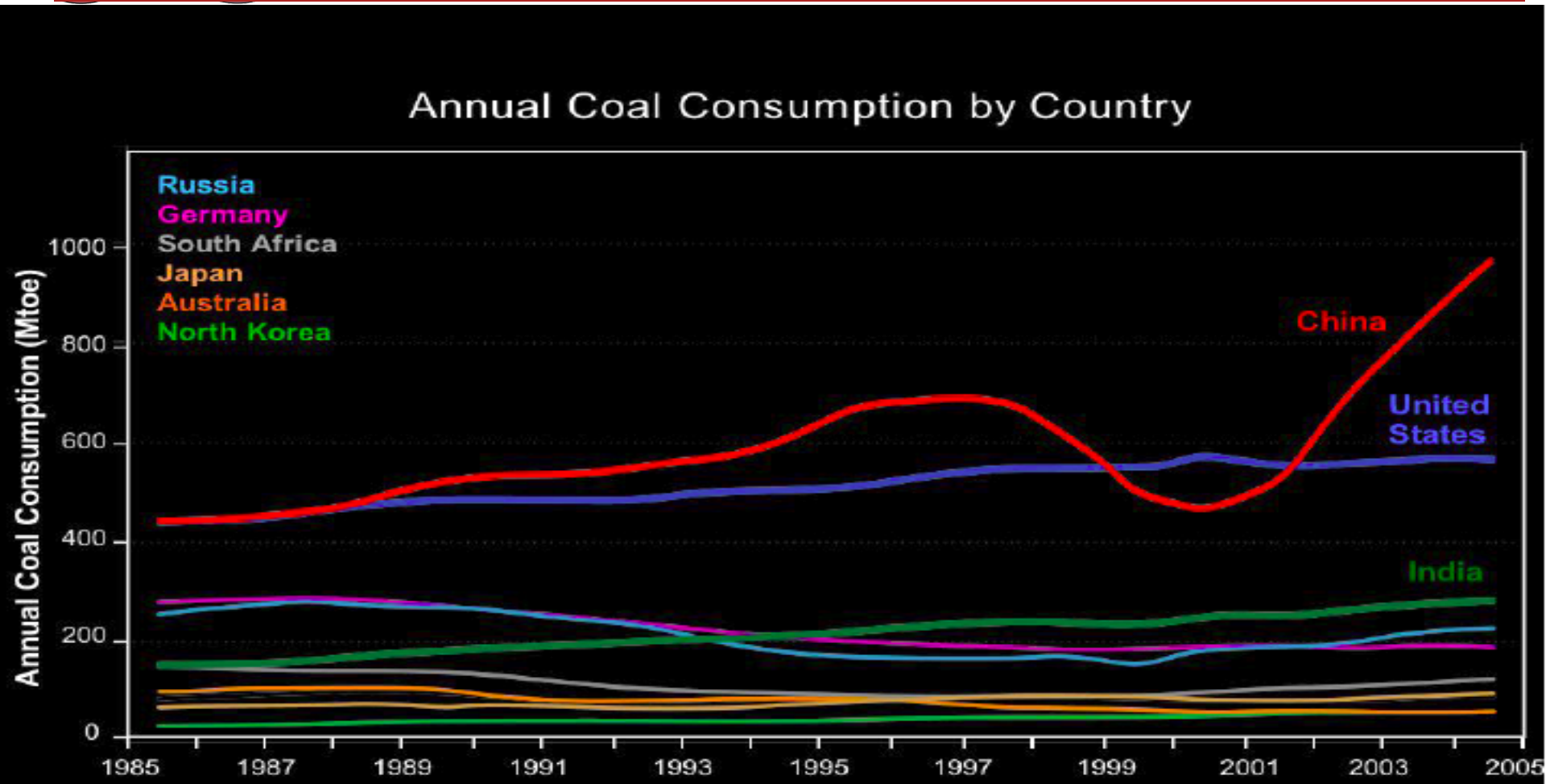


Source: 1850-1949, *Energy Perspectives: A Presentation of Major Energy and Energy-Related Data*, U.S. Department of the Interior, 1975; 1950-2005, *Annual Energy Review 2000*, Table 1.3.

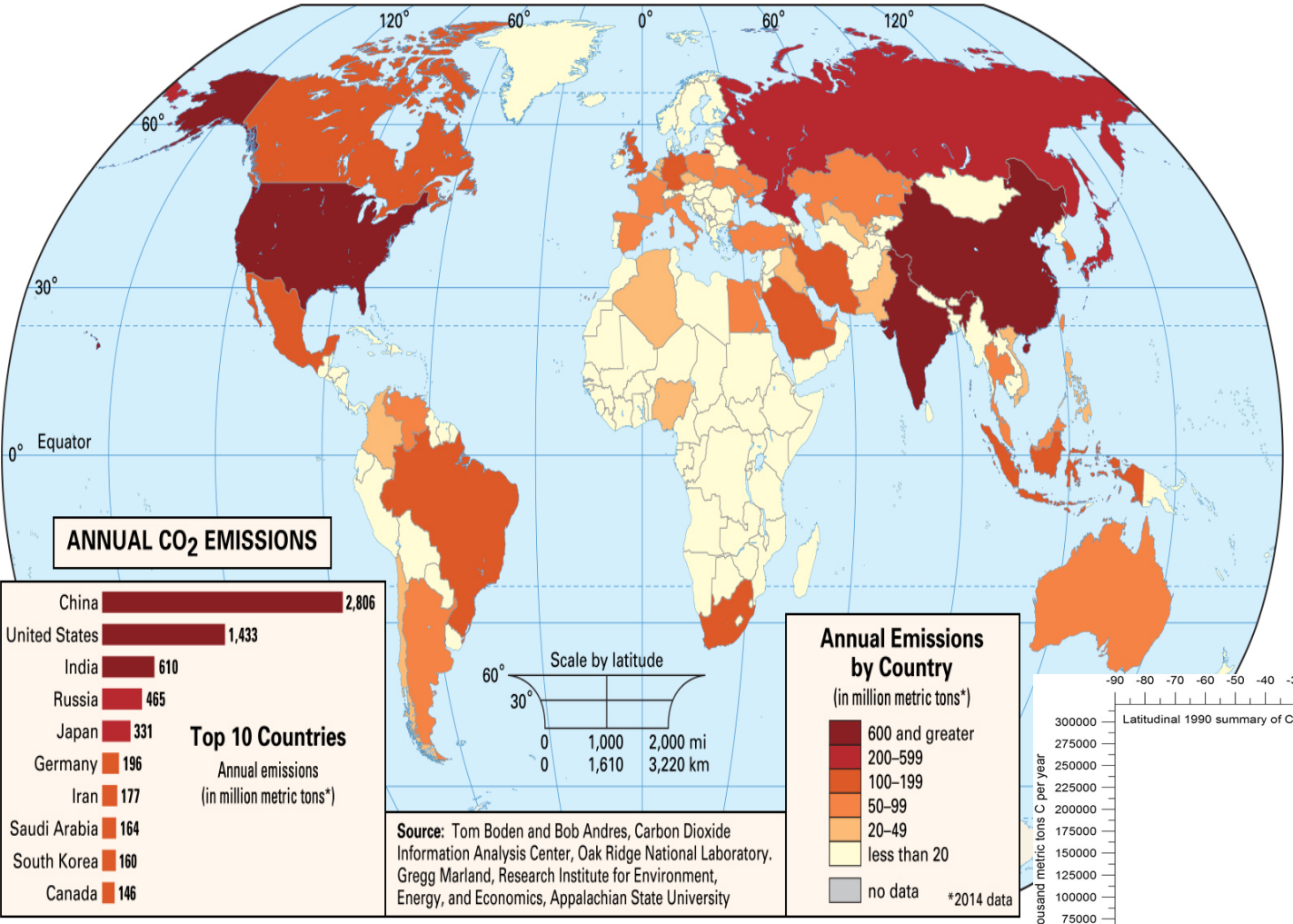
Japan Energy Mix

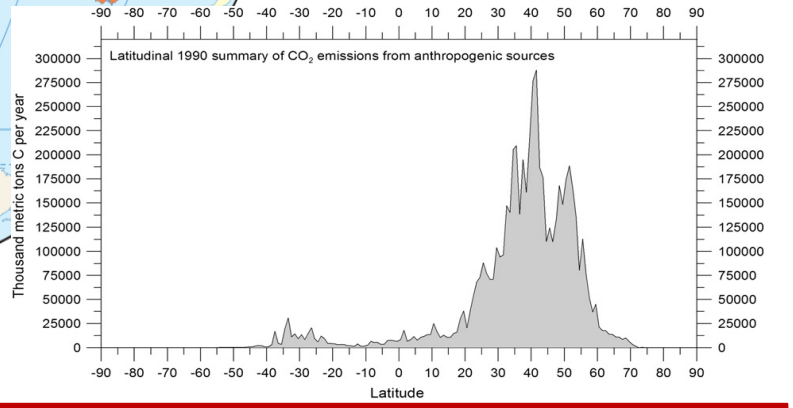


Coal Consumption



Annual CO_2 Emissions



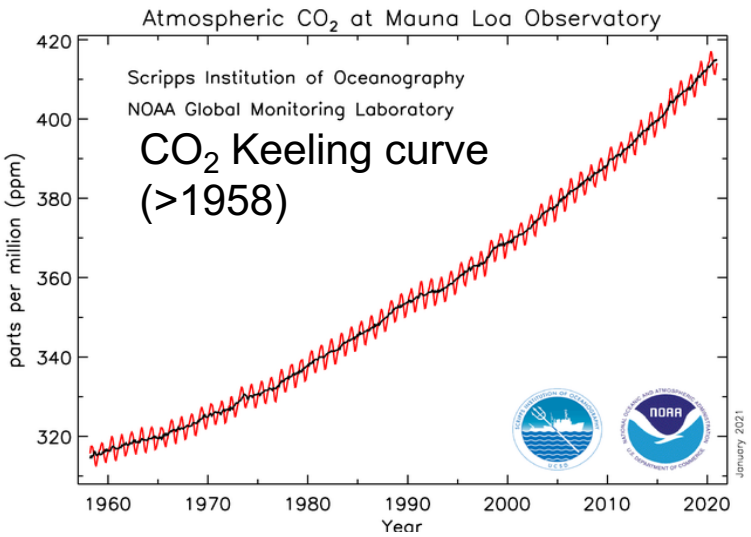


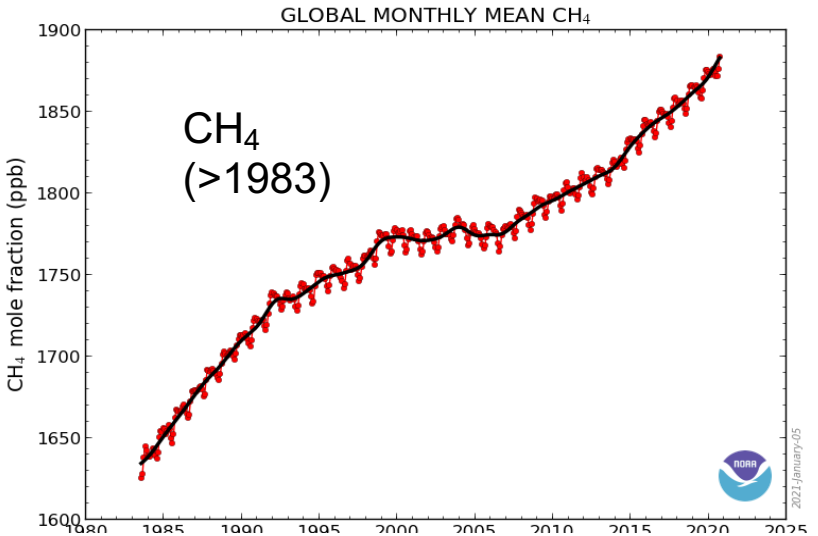
New industrial revolution

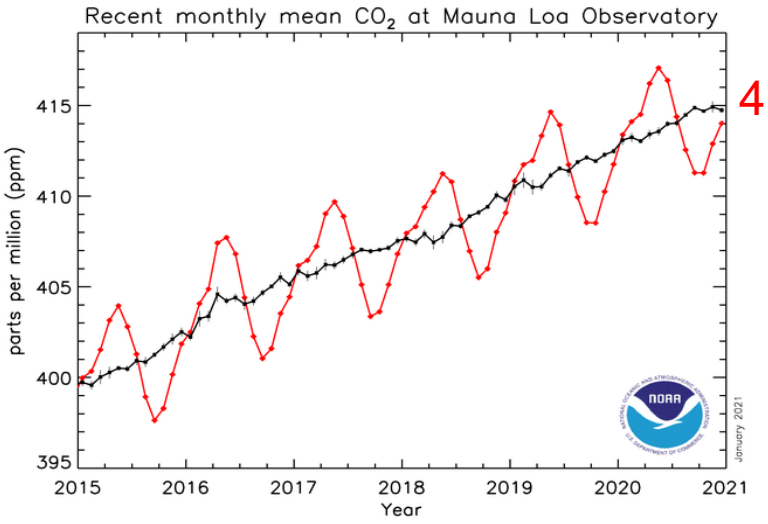
BRICS countries

Brasil, Russia, India, China, South Africa

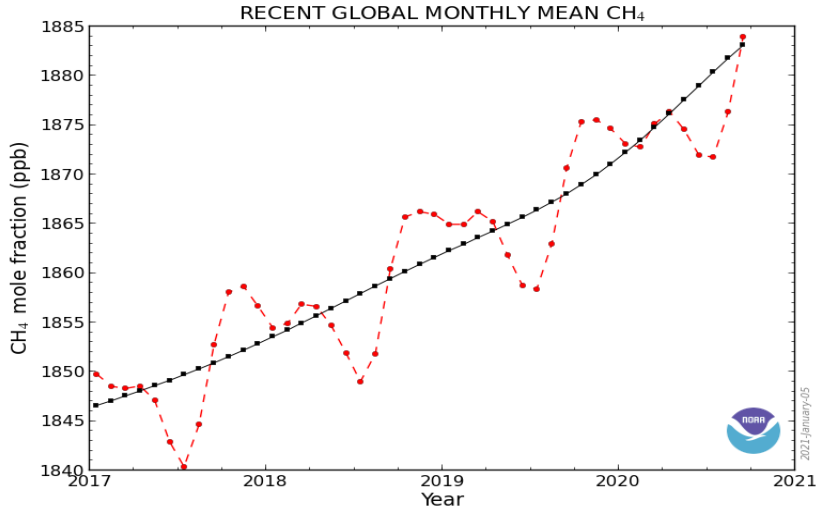
CO_2 & CH_4 Growth in the Air





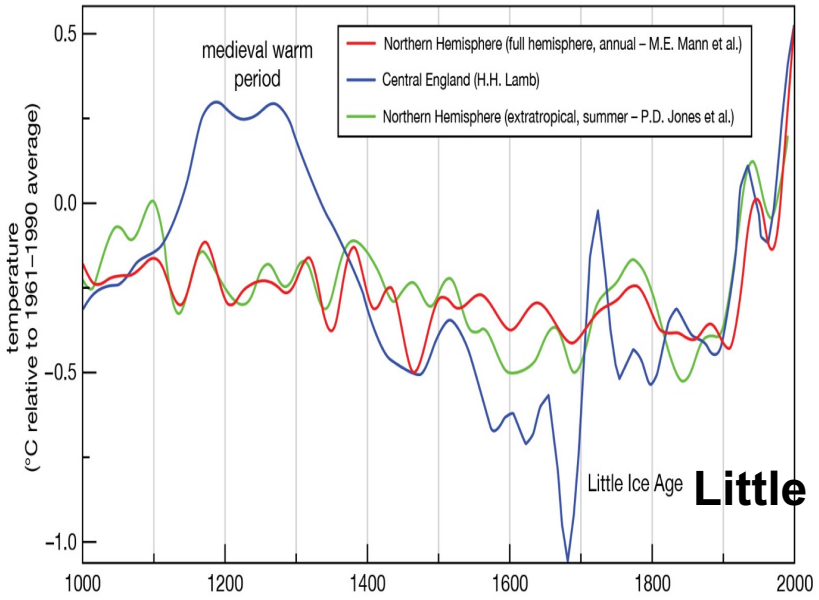


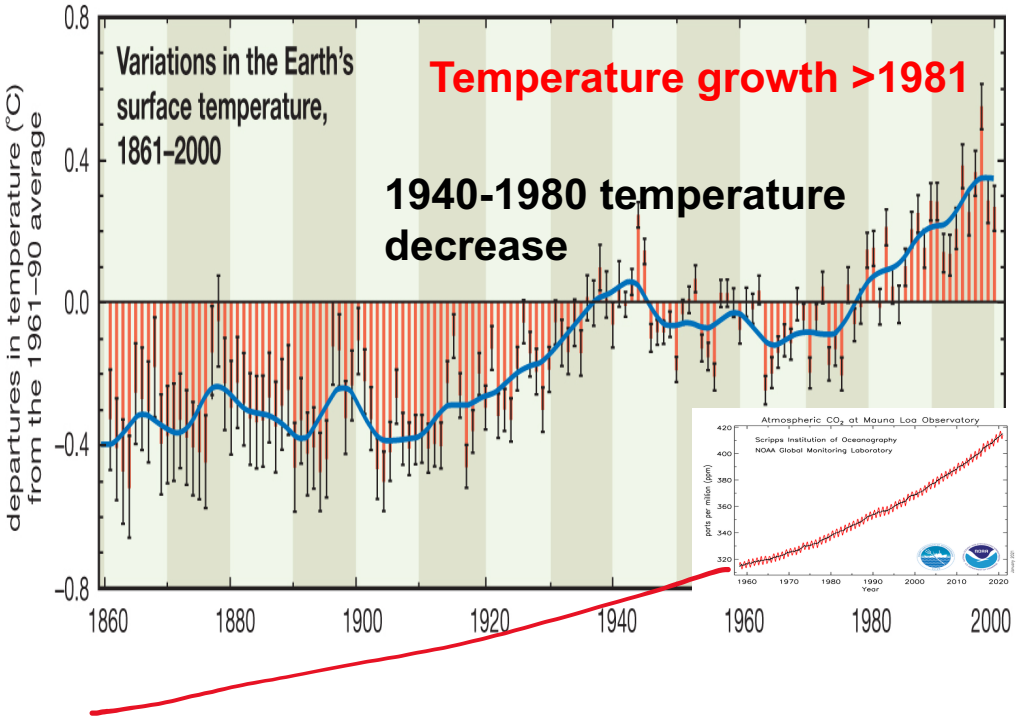
414 ppm



Temperature Records

Medieval Warm Period
1200-1350yr



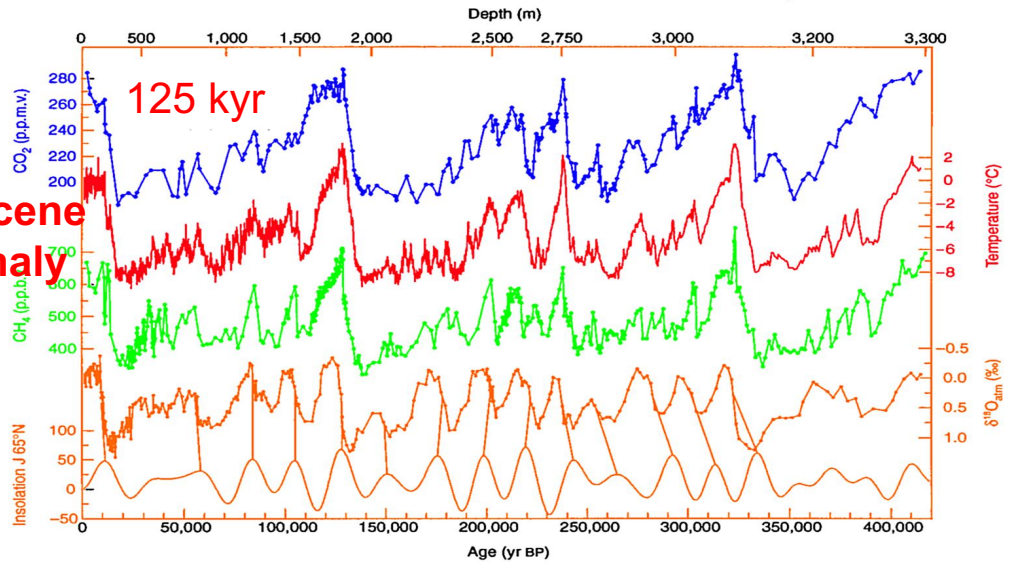


CO_2 @ 280 ppm

Little Ice Age (1350-1900 yr)

Mann et al., GRL 26(1999)759-762

Ice Core Temperature Records (<800 kyr)



Vostok Antarctica Ice Core, < 420 kyr

HOLOCENE temp. anomaly !!!

CO_2 follows temperature changes !!!

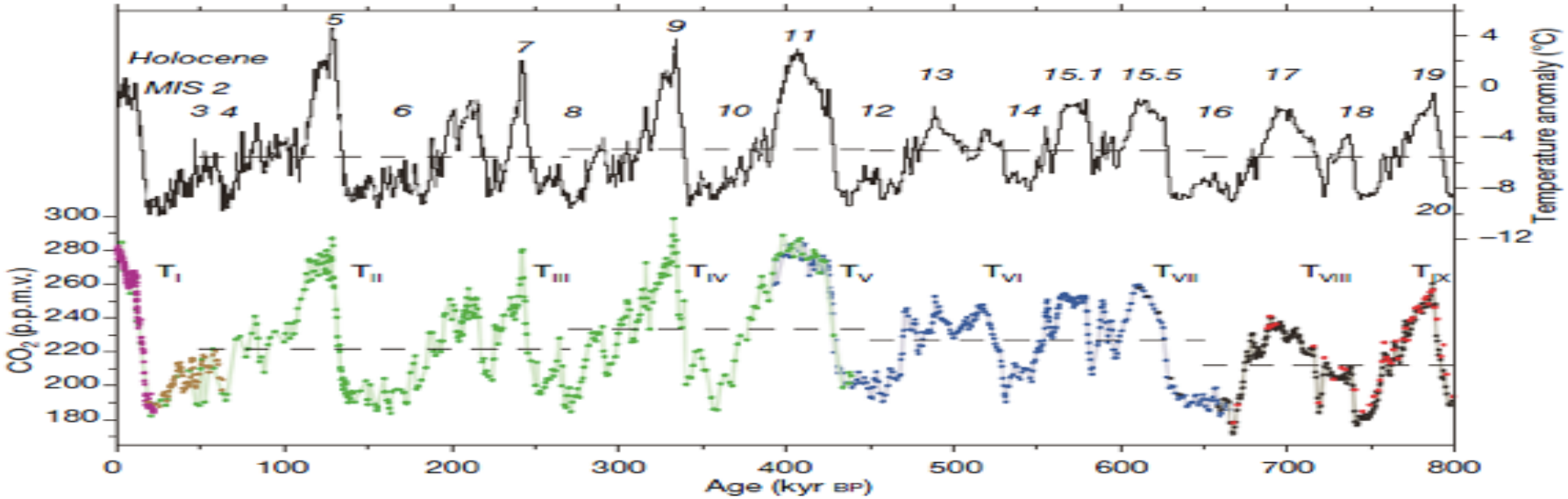
125 kyr Milankovitch cycle

(Petit et al., Nature, 399 (1999) 429-436)

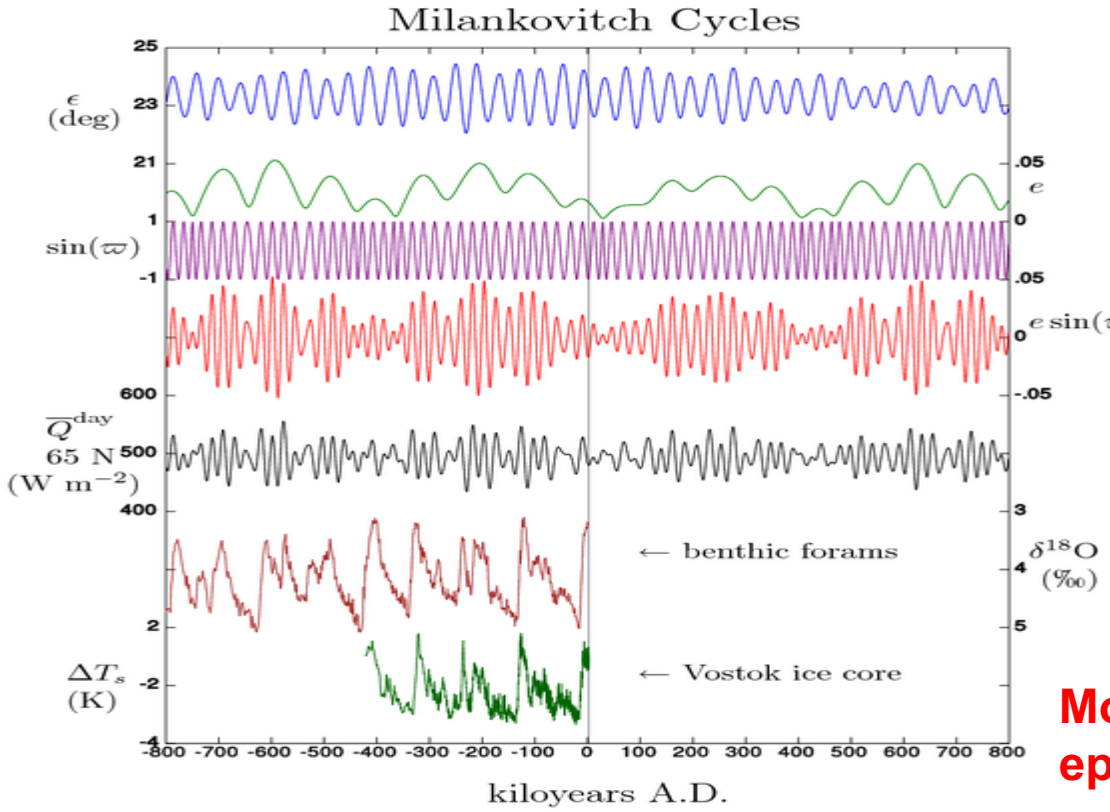
EPICA Antarctica Ice Cores, < 800 kyr

HOLOCENE temp. anomaly confirmed

Very good agreement during 400 kyr (Milankovitch cycles)



Milankovitch Cycles in Sun-Earth Relations



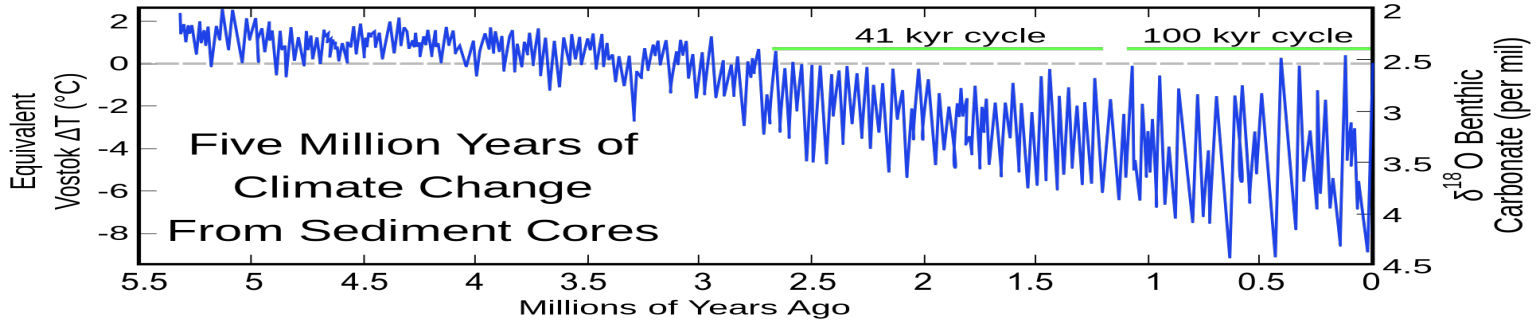
Obliquity (41 kyr)
Eccentricity (95, 125, 400 kyr)

Longitude of perihelion

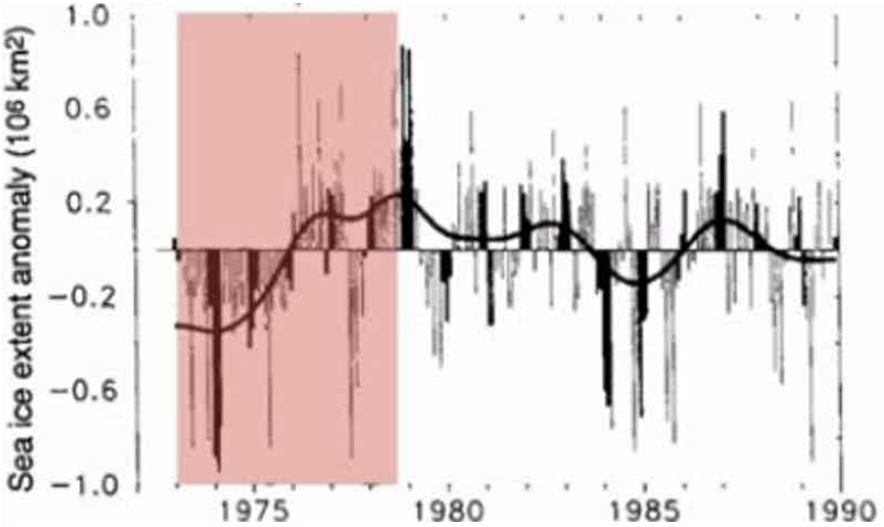
Precession (19, 22, 24 kyr)

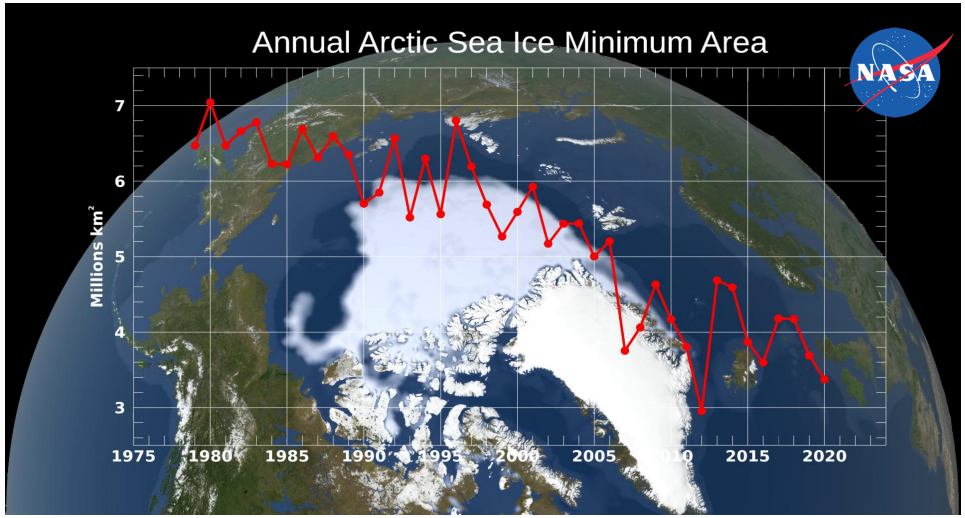
Solar forcing (variable)

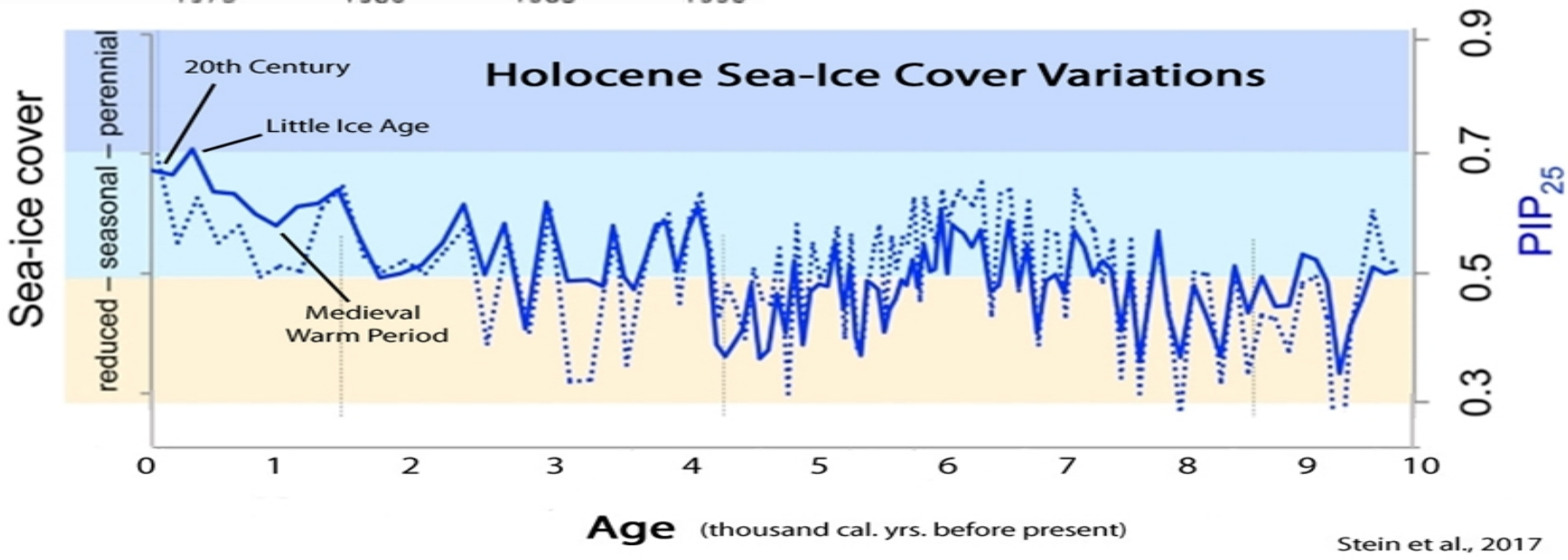
Mostly affecting the Pleistocene epoch (< 1 M yr)



Recent Arctic Sea Ice Cover Changes

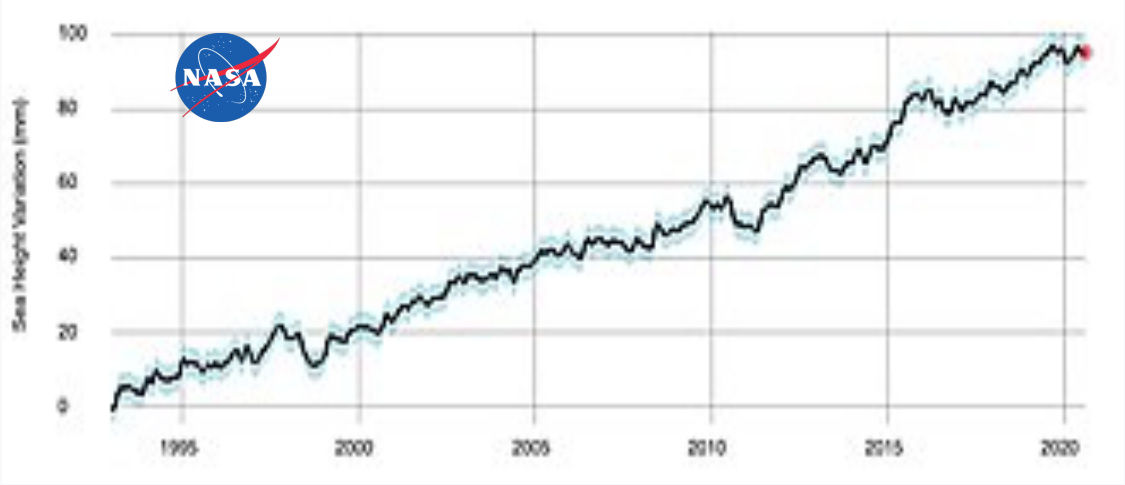






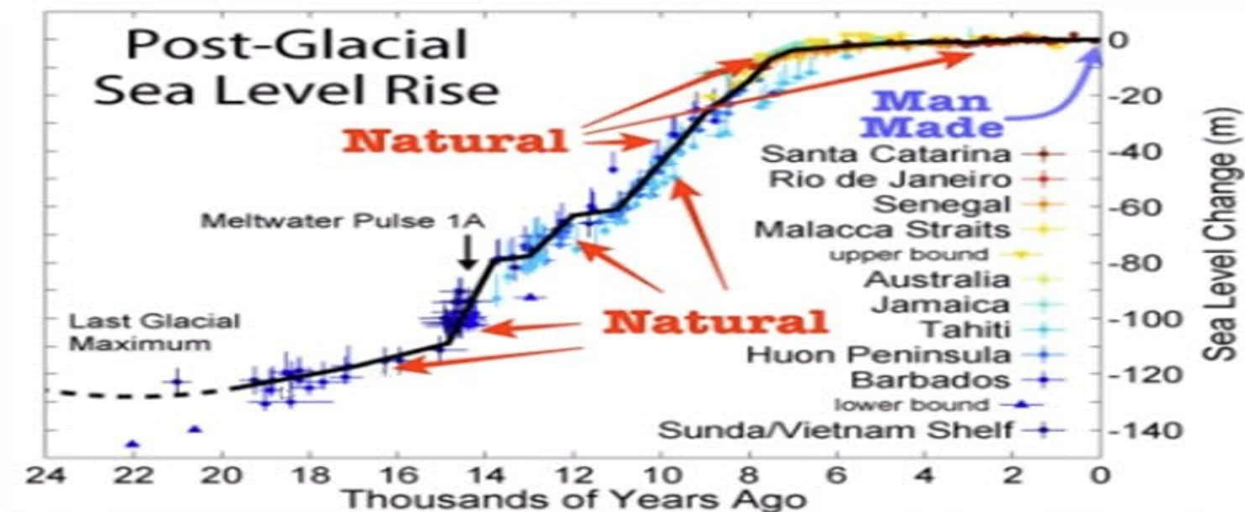
Stein et al., 2017

Sea Lever Rise



Modern era:

< 3 mm/year



Holocene (<8000 yr):

almost stable

Summary on Climate Changes

PAST CLIMATE CHANGES ON THE EARTH WERE CONTROLLED BY THE SUN

HOLOCENE : too high temperature during 10 kyr - Sun

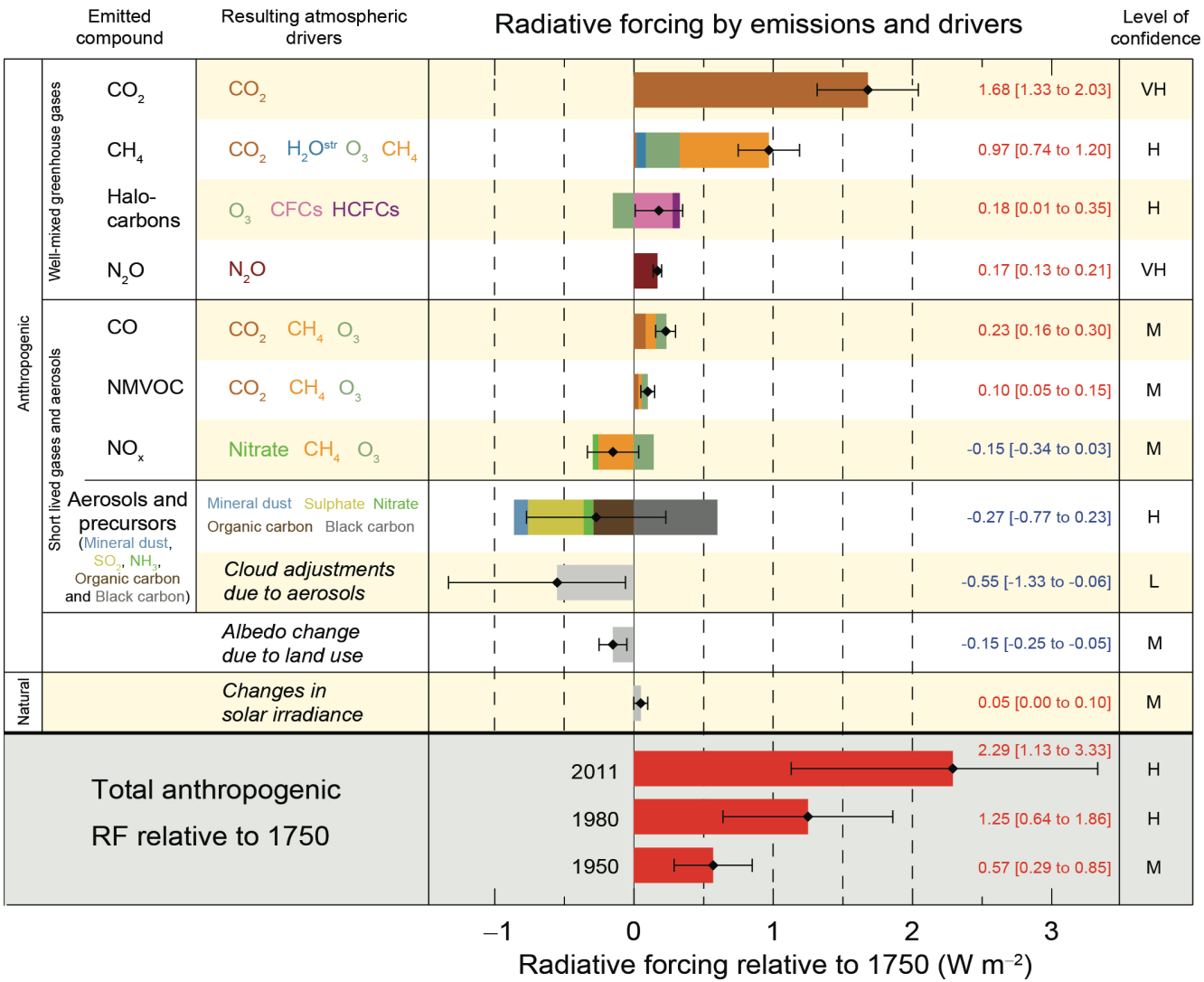
Recent climate change : anthropogenic – green-house gases

Next 100 years: - anthropogenic – green house gases ?

- natural – solar activity, a new Little Ice Age ?

- a combination of both ?

IPCC Summary on Climate Change (Radiative Forcing)



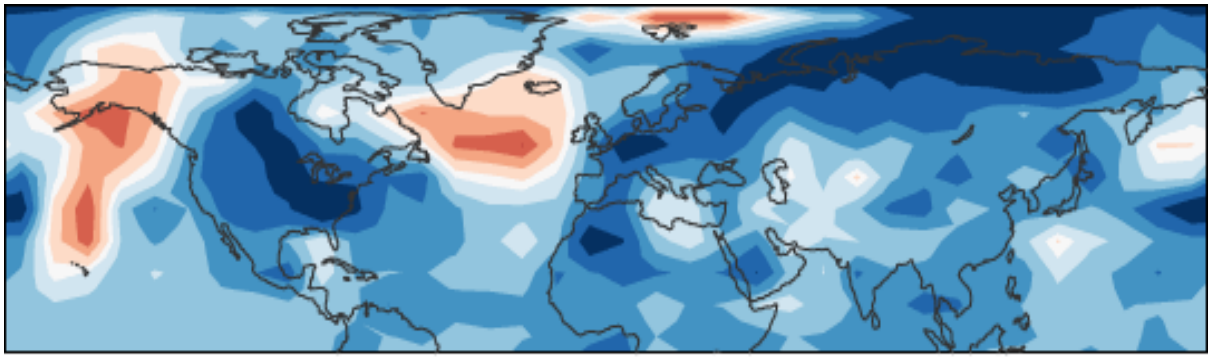
> 1750 AD

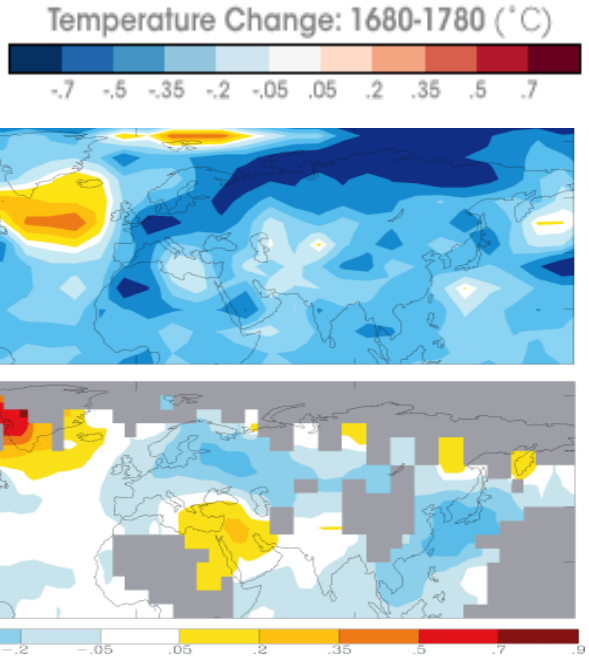
Anthropogenic
CO_2: 1.7 W/m²
CH_4+others: 1
Ozone: 0.3
Aerosols: 0.6
Total: 1.6 W/m²

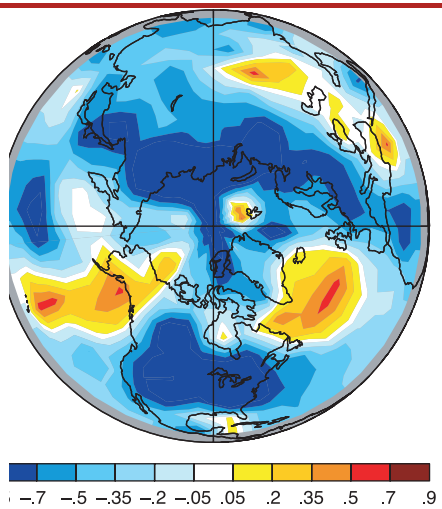
Natural
Solar irradiance:
0.1 – 0.3 W/m²
(may be higher with secondary effects)

Water vapours?
The main greenhouse gas !!!

Little Ice Age (Maunder Solar Minimum)



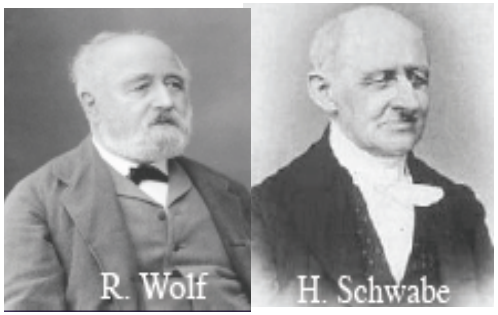


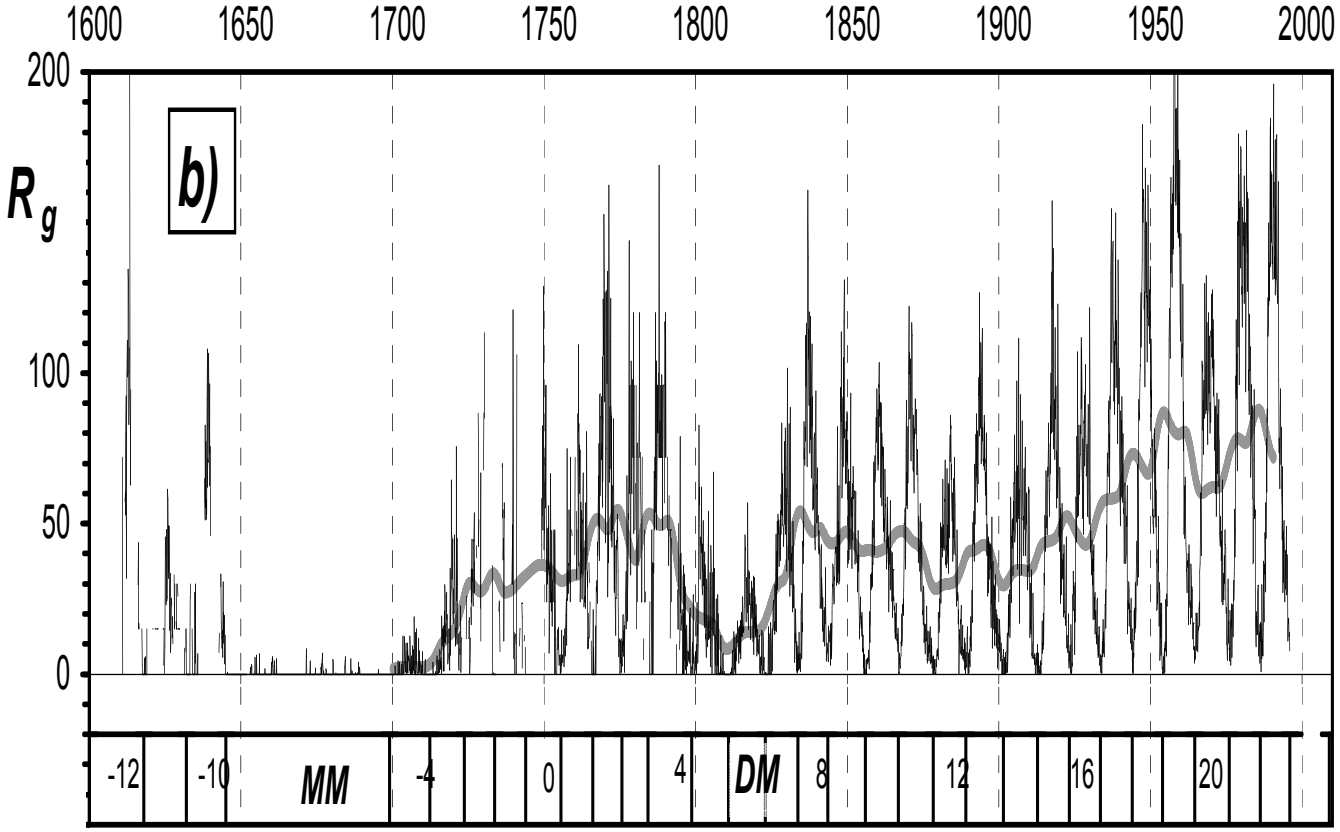


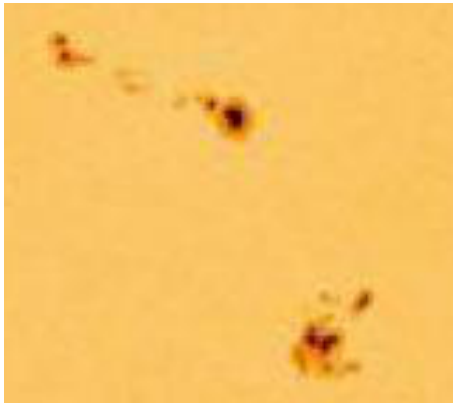
Shindell et al., Science, 294, 2001

Solar Cycles (11, 22 & 90 yr)

Sunspot numbers with time – Schwabe **11 yr solar cycle**
(Wolf > 1610)

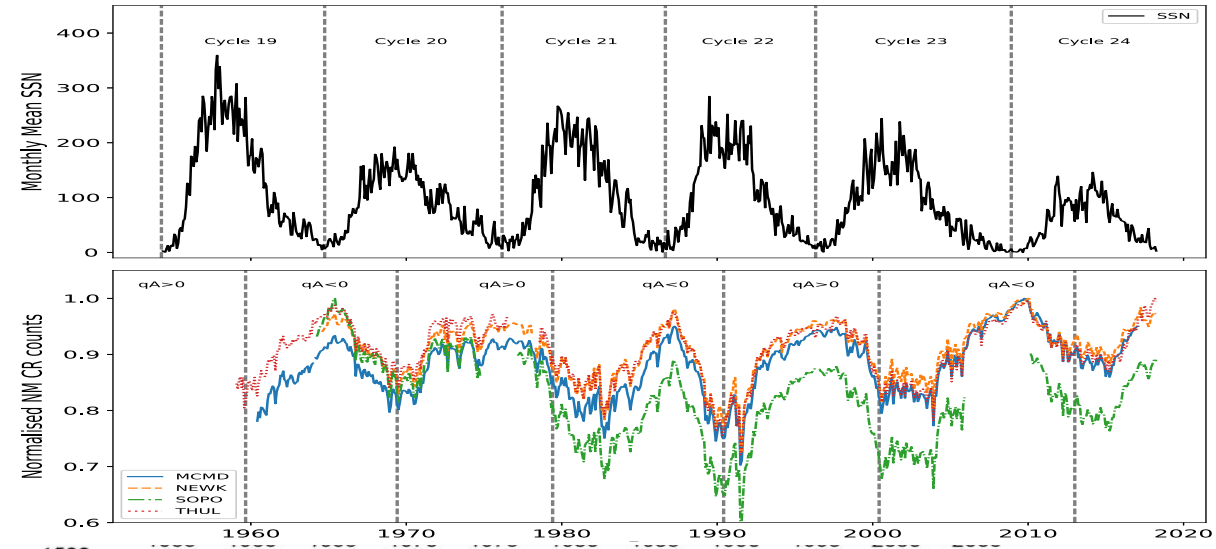






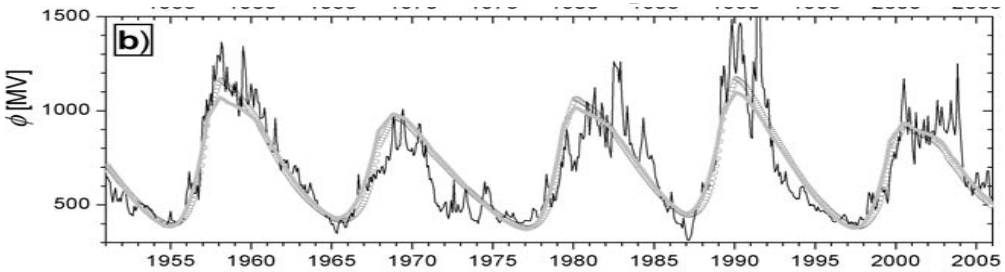
Centennial Gleissberg Cycle 90-100 yr

Cosmic Rays vs Solar Activity

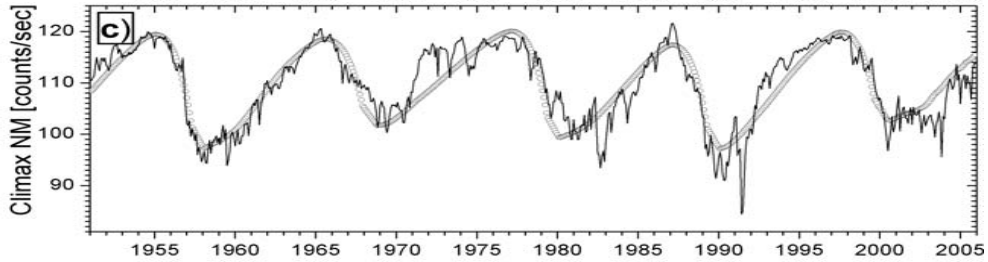


Sunspot numbers

Data from several neutron monitors - **anticorrelated with solar activity**



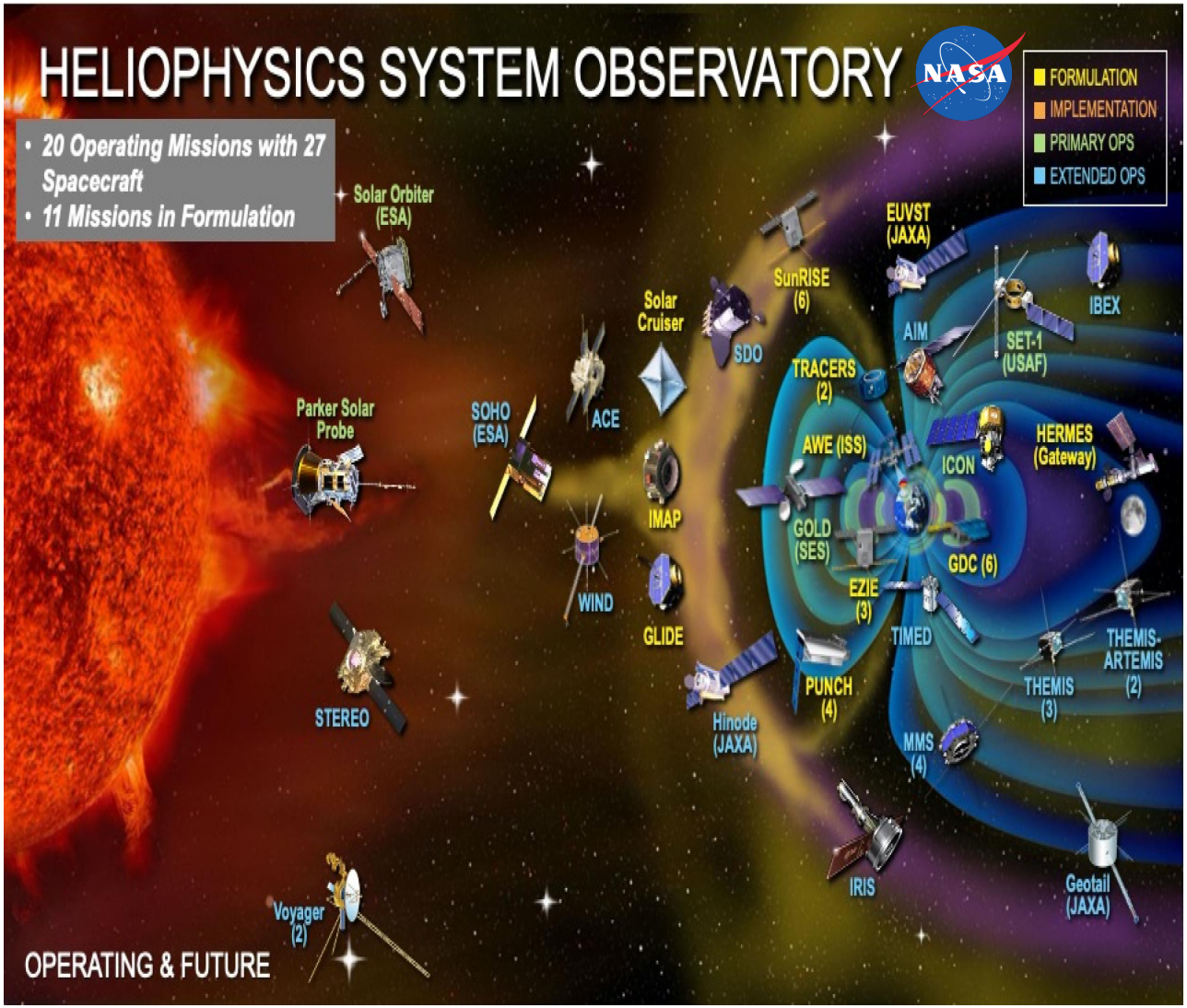
Modulation potential of Sun on Galactic Cosmic Rays (GCR)



Neutron monitor data - GCR flux In the atmosphere

Ross & Chaplin, Solar Phys. 294, 2019; Alanko-Huotari et al., Solar Phys., 238, 2006

Sun-Earth Impacts



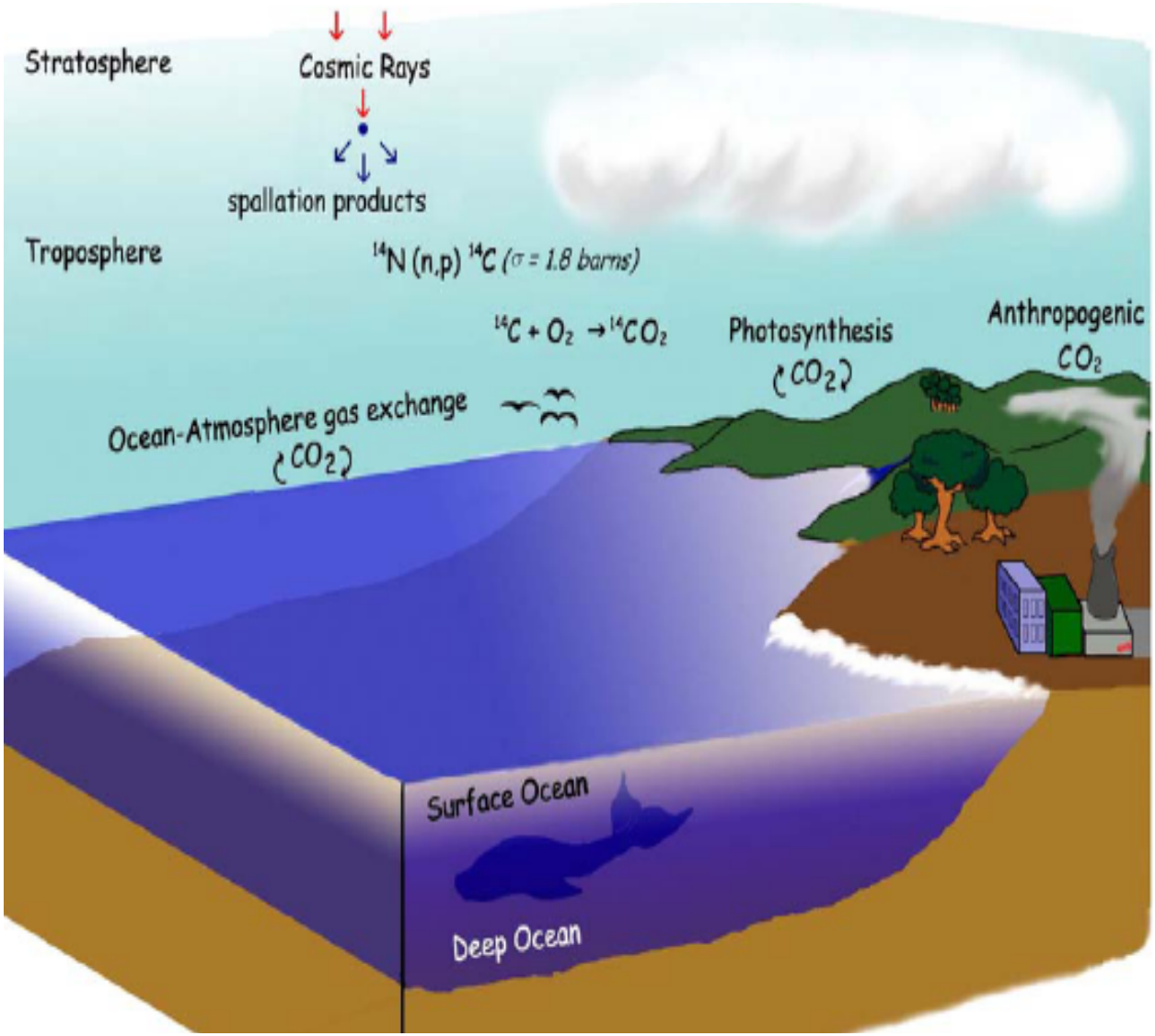
Solar modulation of the galactic cosmic ray flux in the heliosphere and on the Earth

Solar wind

11-yr, 22-yr, 90-yr… solar cycles

Already detail Information on Sun – Earth impacts is avaiable

Cosmogenic Radionuclides

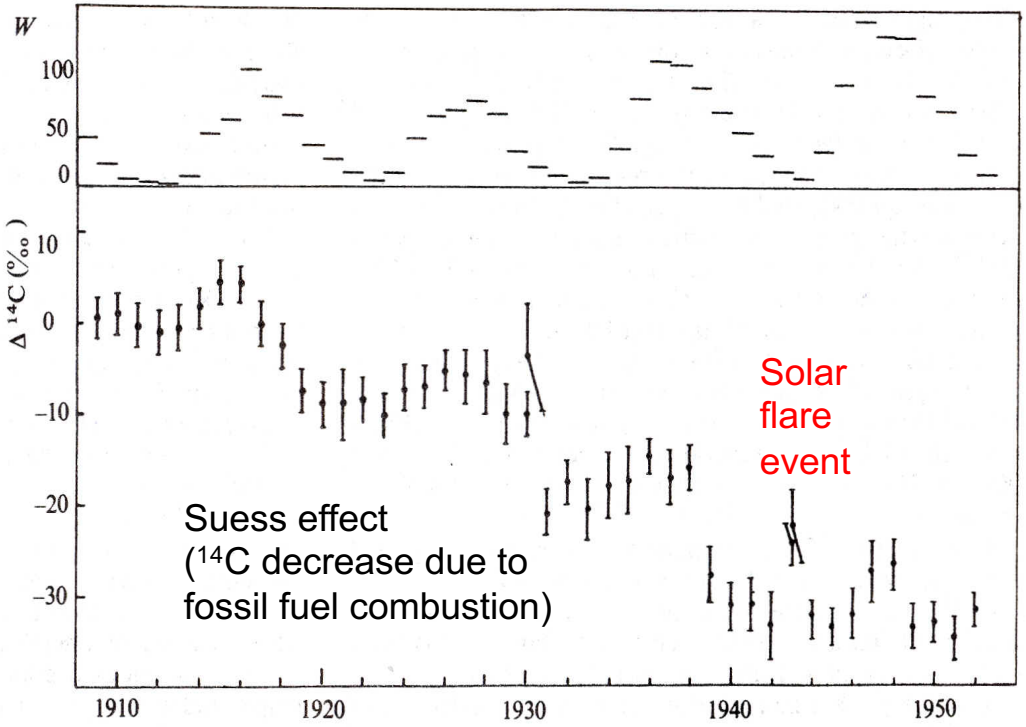


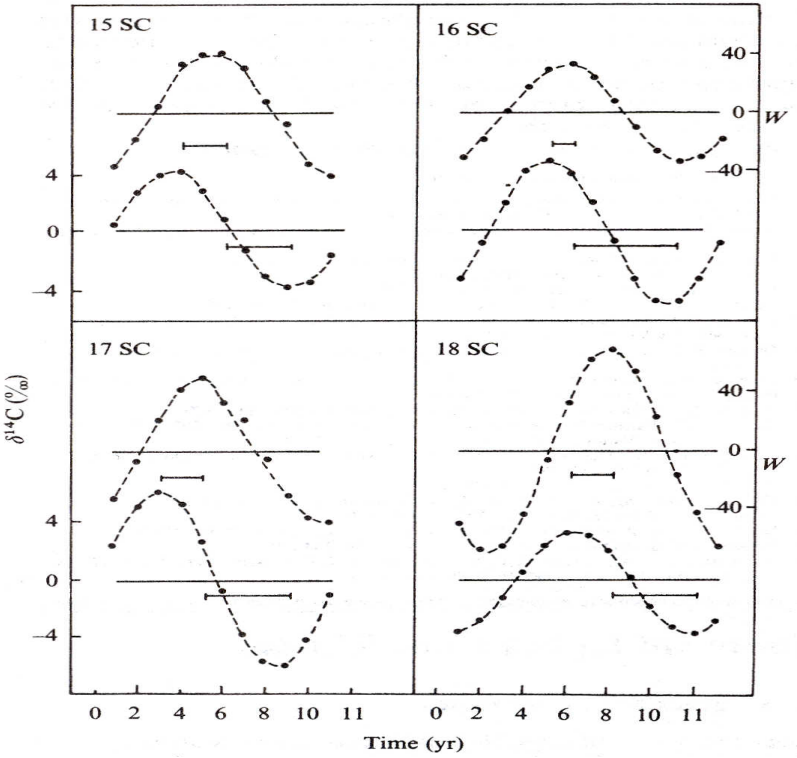
Produced by interactions of CRs with atmosphere (^{3}H, ^{14}C, ^{7}Be, ^{10}Be, ^{26}Al, ^{36}Cl, ^{53}Mn, ^{129}I,…)

As GCR are modulated by Sun, they can be used for solar activity studies

If stored in archives (tree-rings, ice, sediments,corals, stalactites/stalagmites), they can be used for past solar activity studies

^{14}C in Wine Samples (1909-1952)





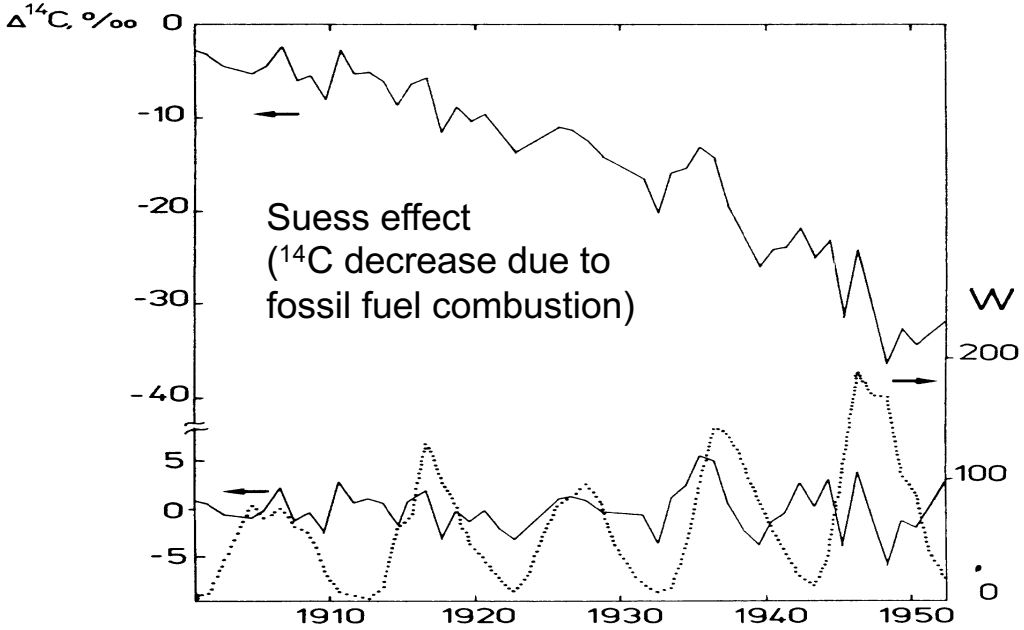
$^{14}C(t)$ and W(t) rows for four 11-yr solar cycles (1909-1952)

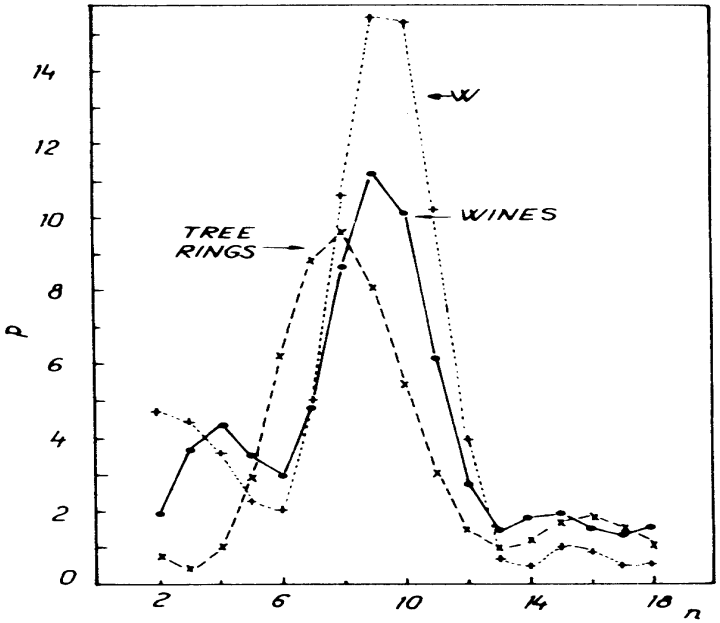
^{14}C amplitude variations: 3.3-5.6 ‰ for different solar cycles (average 4.3 ± 1.1 ‰)

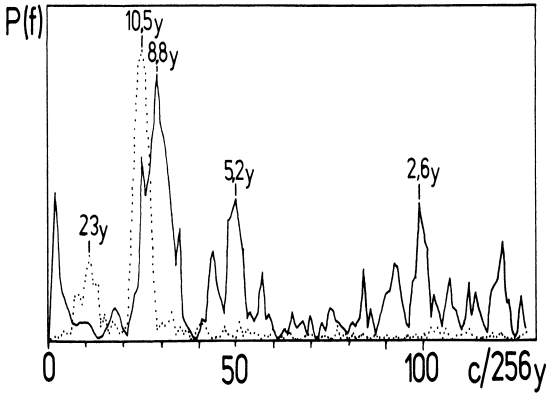
Time shift between W maxima and ^{14}C minima: 3.5-5 yr (depending on the solar cycle)

Burchuladze, Povinec et al., Nature 287, 1980

^{14}C in Tree-rings (1900-1954)







Cyclogram analysis:

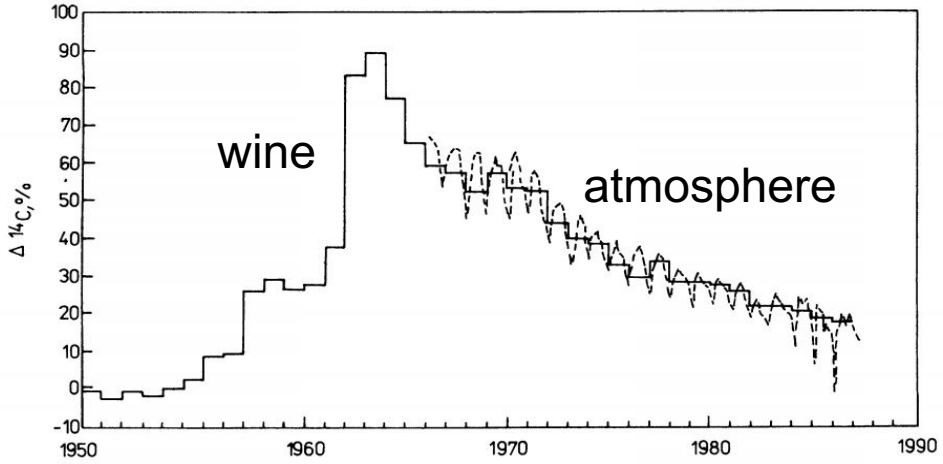
^{14}C amplitude: 2.5±0.5‰
Phase shift: 3-5 yr

Comparison of ^{14}C (wines and tree-rings) and W (sunspot numbers, anticorrelated) time series

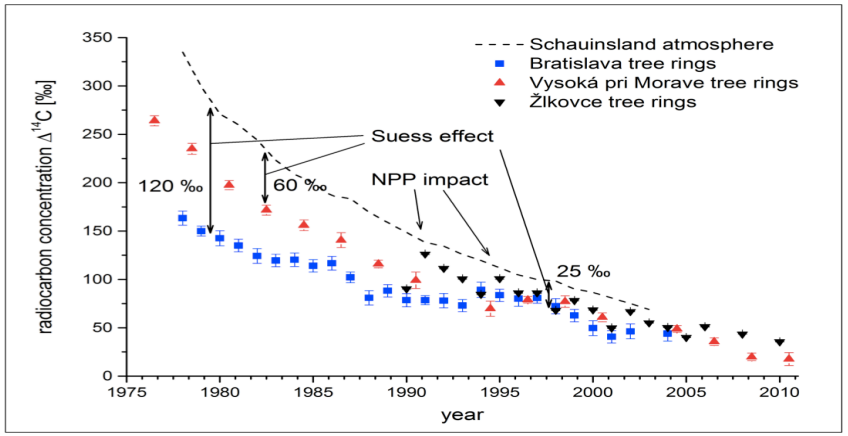
Attolini, Povinec et al.,Radiocarbon 31, 1989

Povinec et al., Radiocarbon 25, 1983

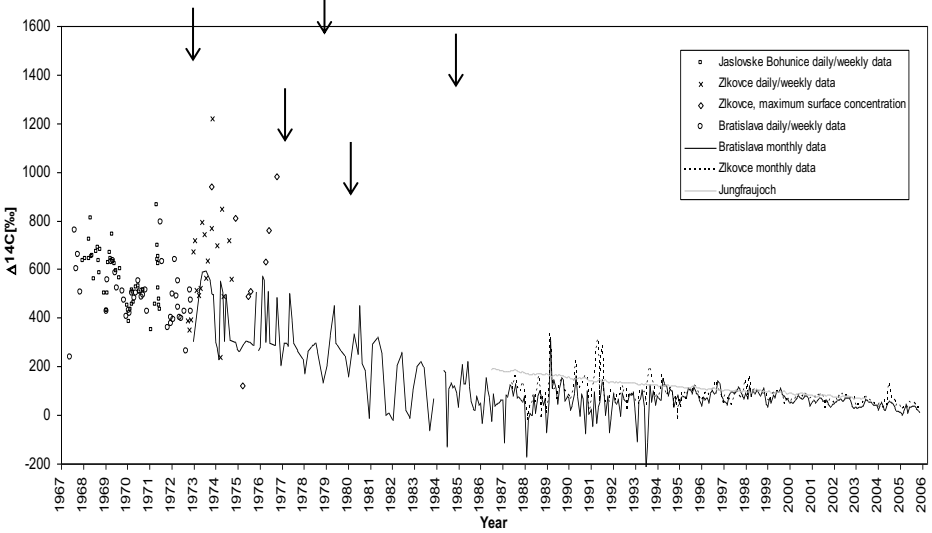
^{14}C Bomb Effect



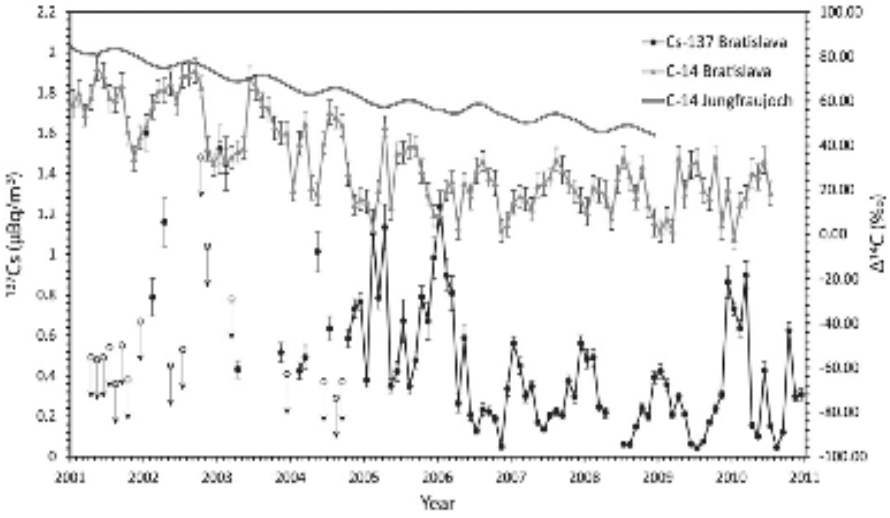
Burchuladze, Povinec et al., Radiocarbon, 1988



Kontuľ et al., JRNC 318, 2018

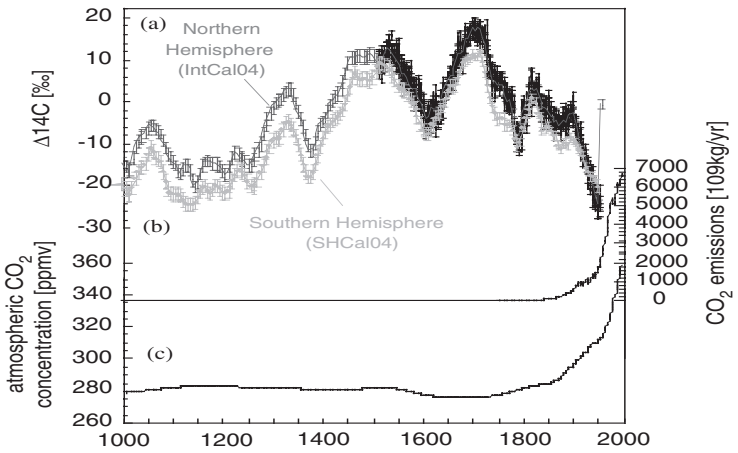


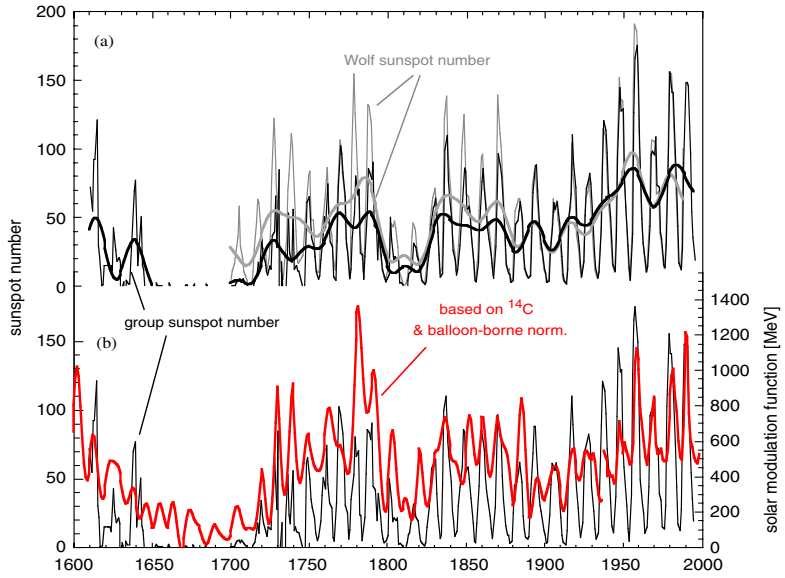
Povinec et al., JER 100, 2009

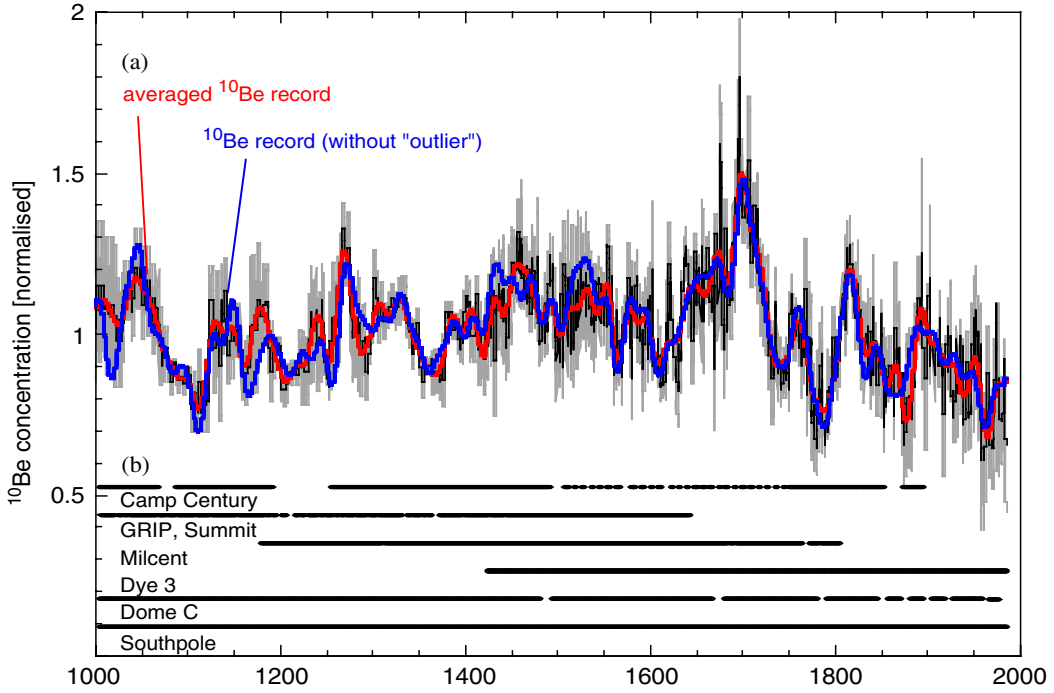


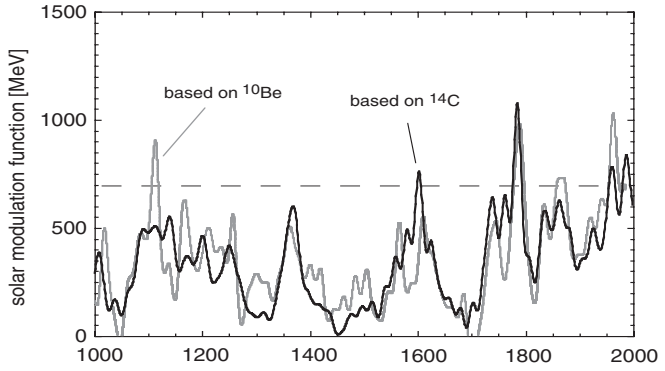
Povinec et al, JER 108, 2012

Solar Modulation of ^{14}C & ^{10}Be







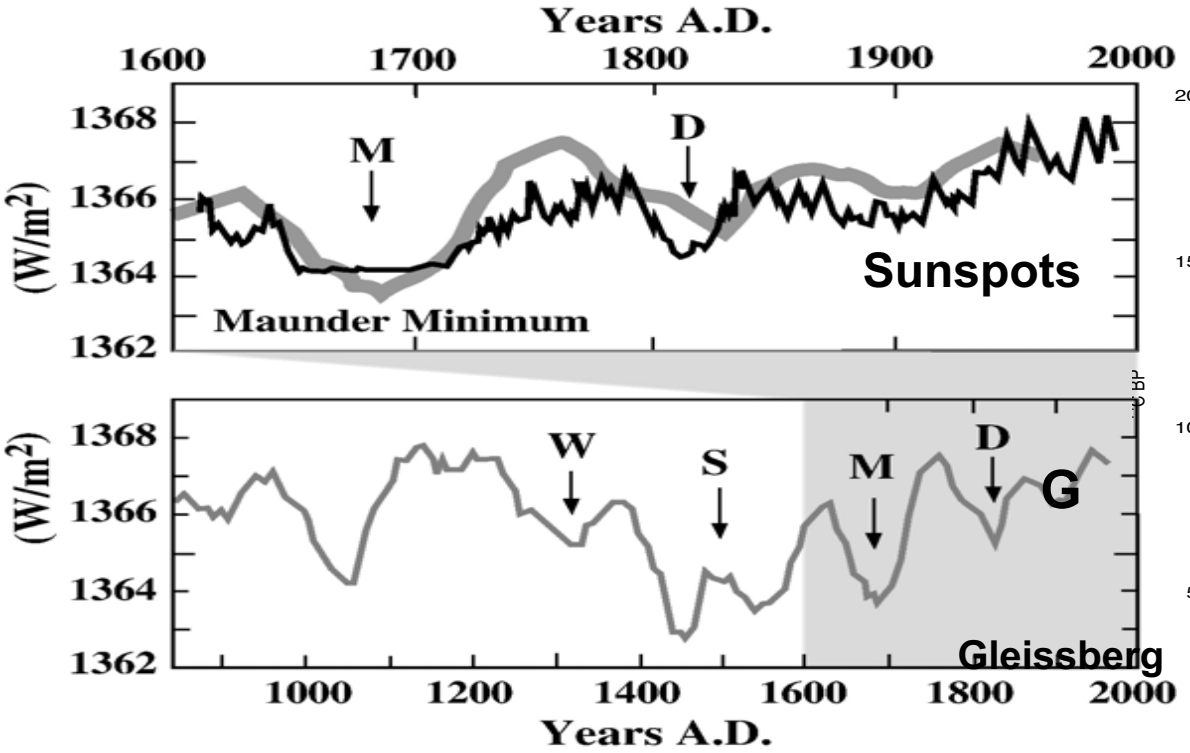


Muenster & Beer, JGR, 2012

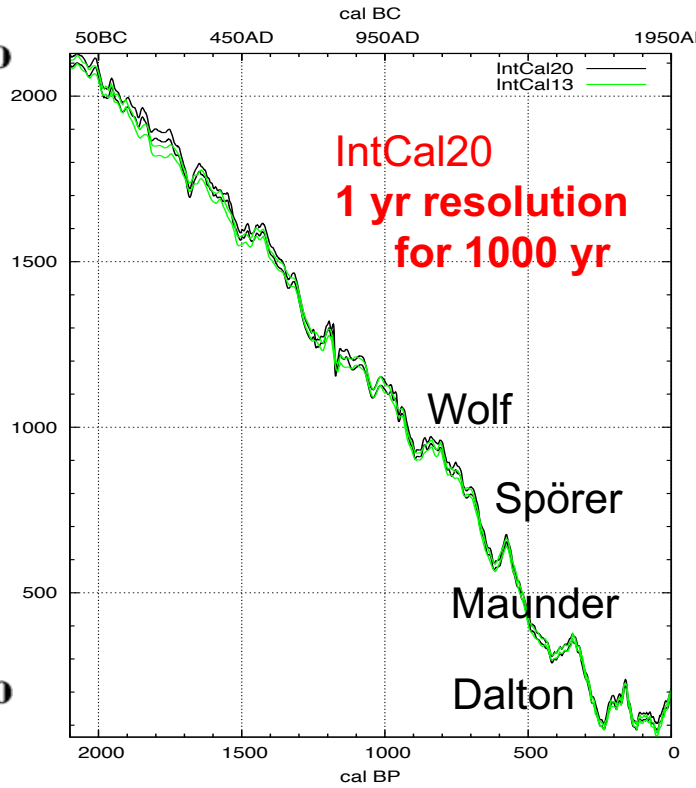
14C – (n,p) reaction
10Be - spallation

Comparison of Solar modulation funcion based on ^{14}C and ^{10}Be data

Reconstruction of Solar Irradiance Based on Sunspots and ^{14}C Levels



Bard & Frank, EPSL 248, 2006

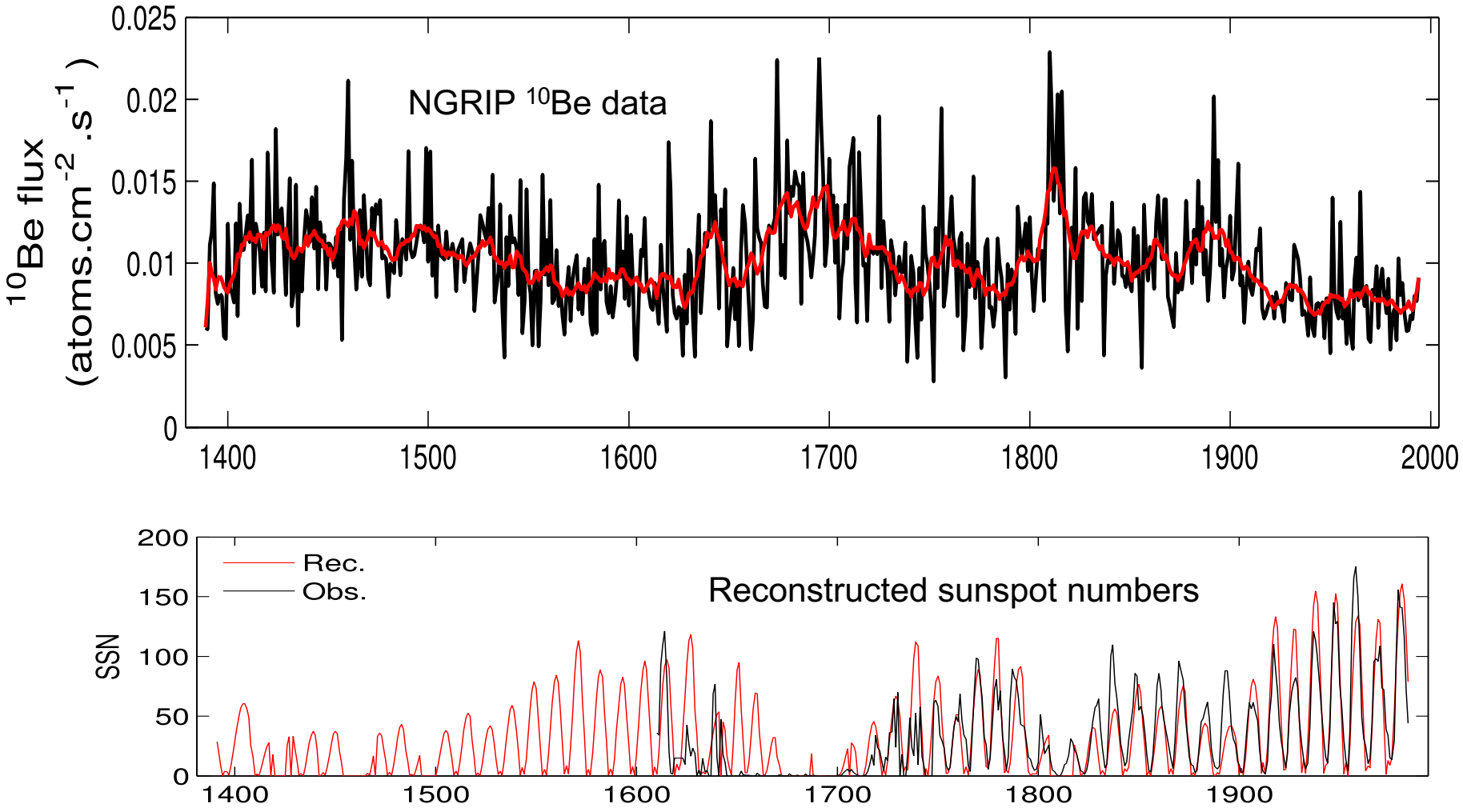


Reimer et al., Radiocarbon, 62, 2020

Grand Solar Minima

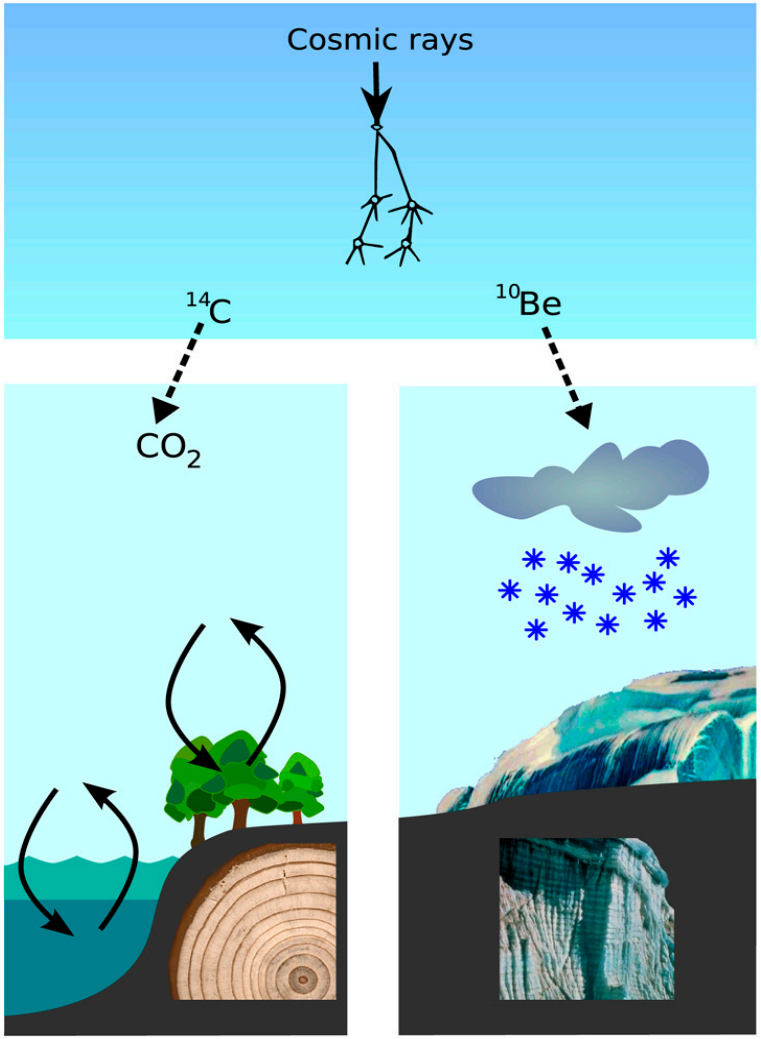
Maunder minimum (1645-1715) ; Spörer minimum (1416-1534); Wolf minimum (1282-1342); Dalton minimum (1798-1822) ; Gleissberg minimum (1889-1901)

Reconstruction of the Solar Activity From ^{10}Be in GRIP Ice Core

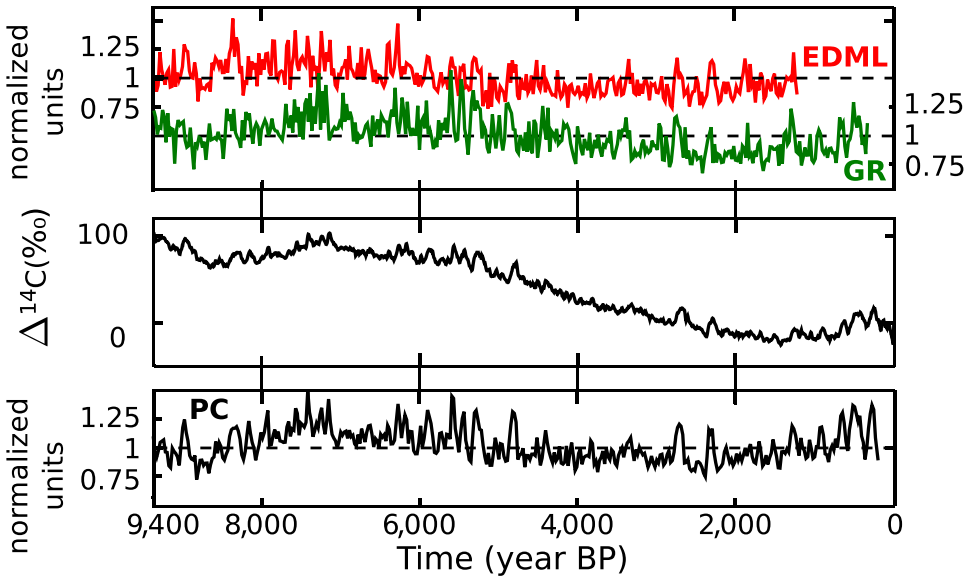


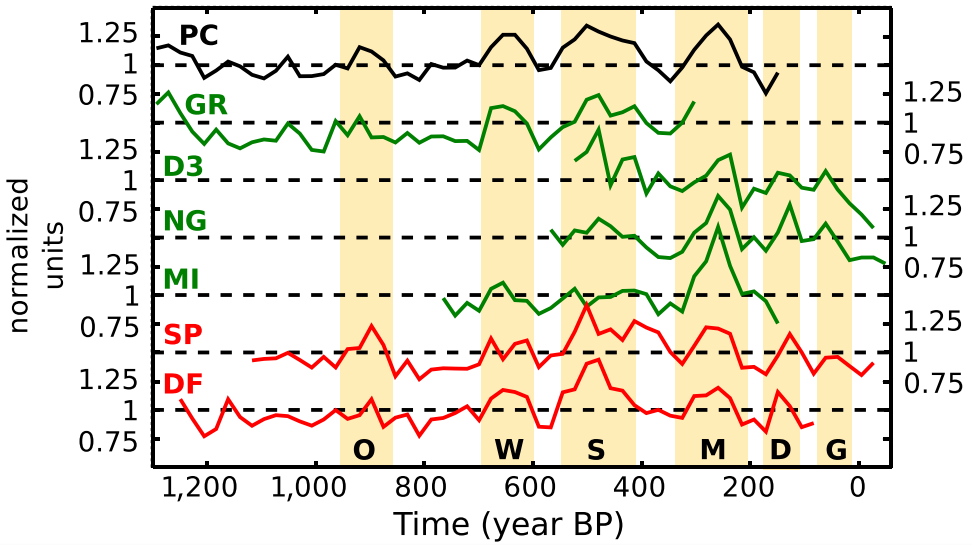
Inceoglu et al., Solar Phys., 2014

^{14}C and ^{10}Be in ice cores (<9400 yr)

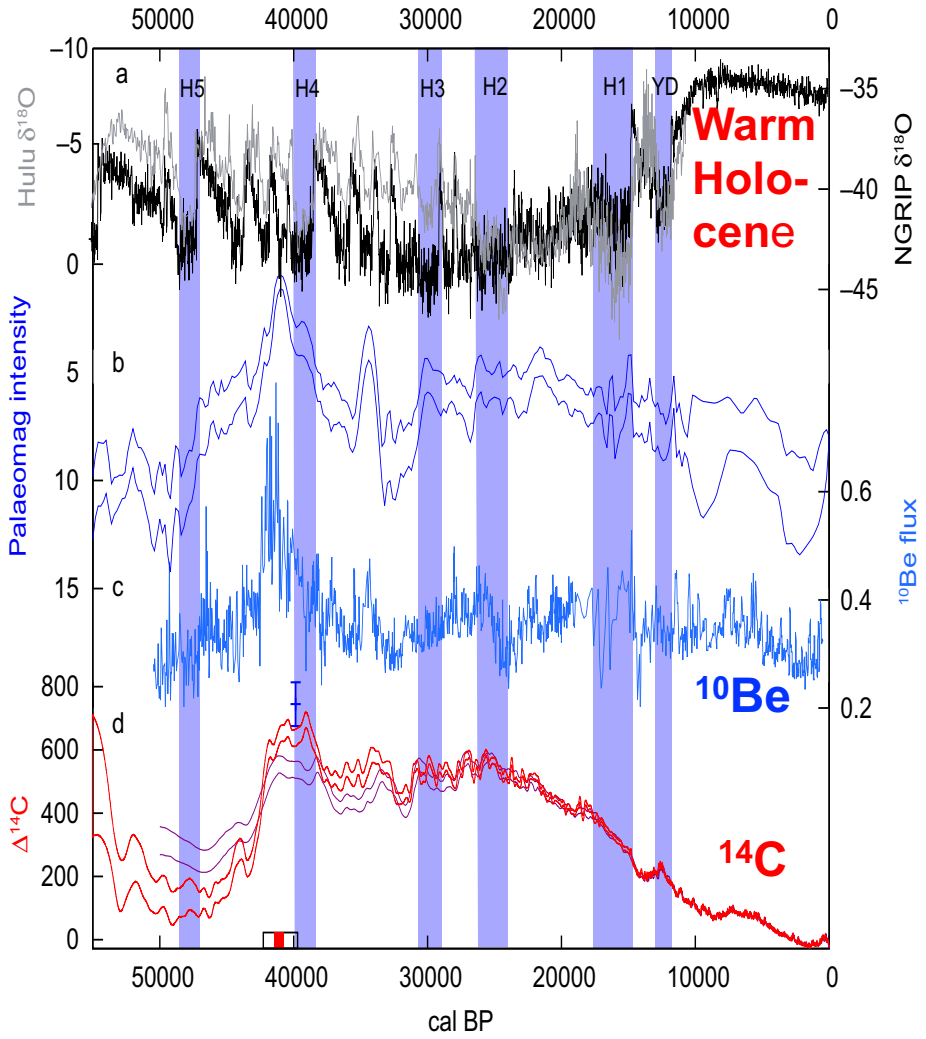


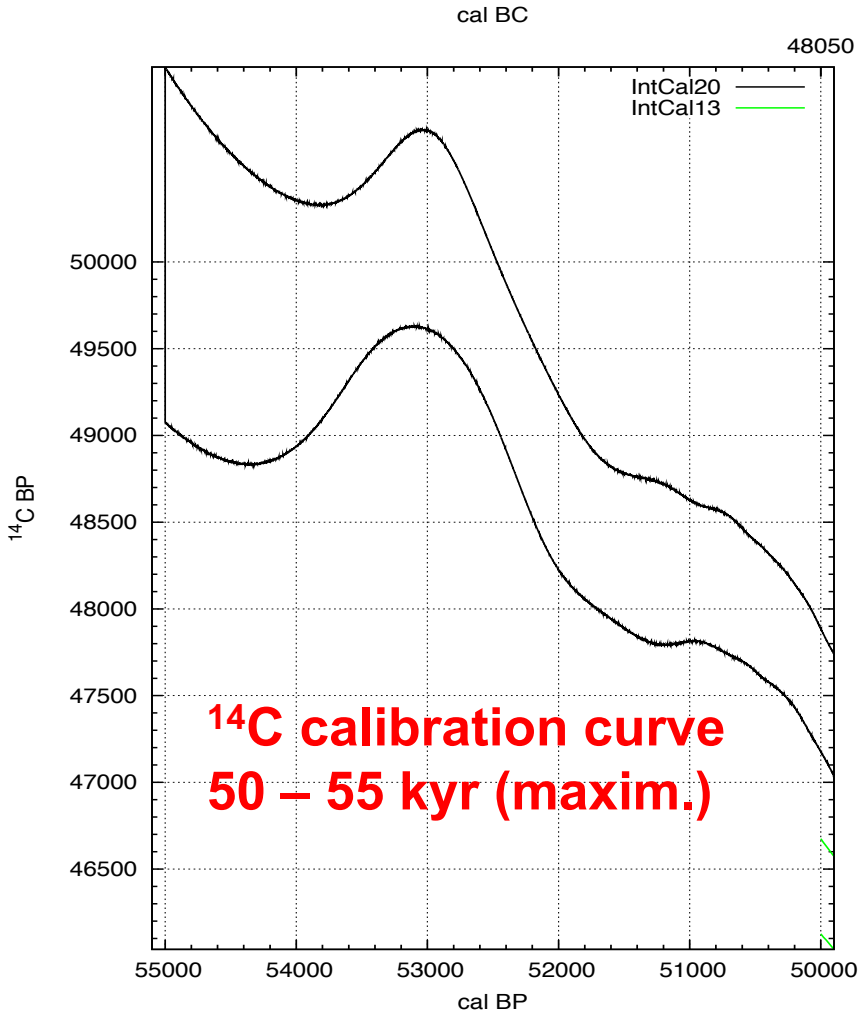
Steinhilber et al., PNAS, doi/10.1073/pnas.1118965109





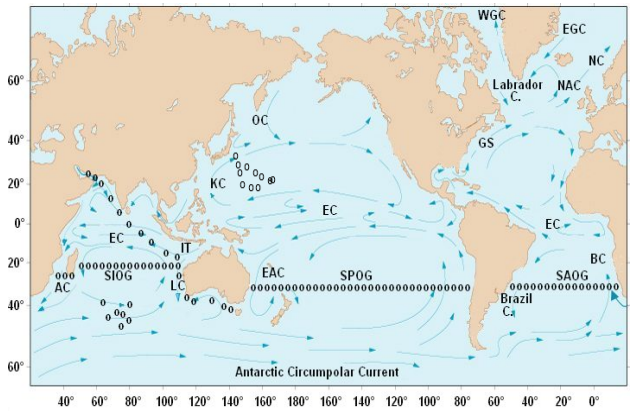
^{14}C IntCal2020 (tree rings, corals,…) and ^{10}Be (ice cores)



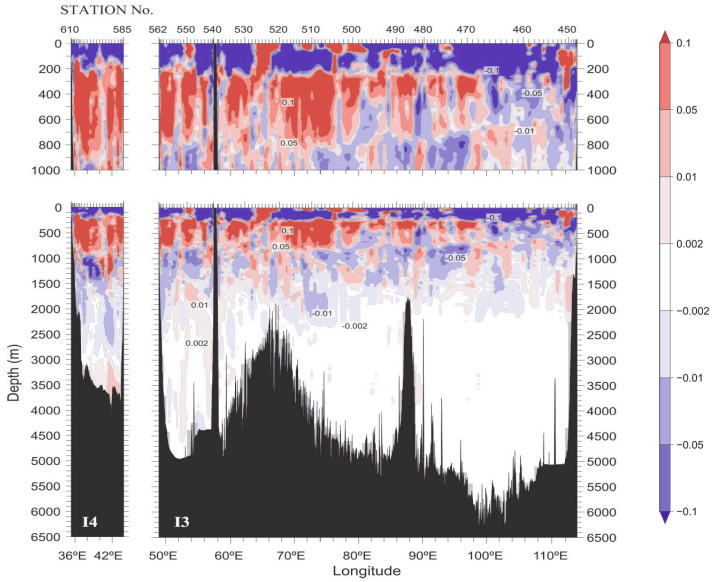


Reimer et al., Radiocarbon, 62, 2020

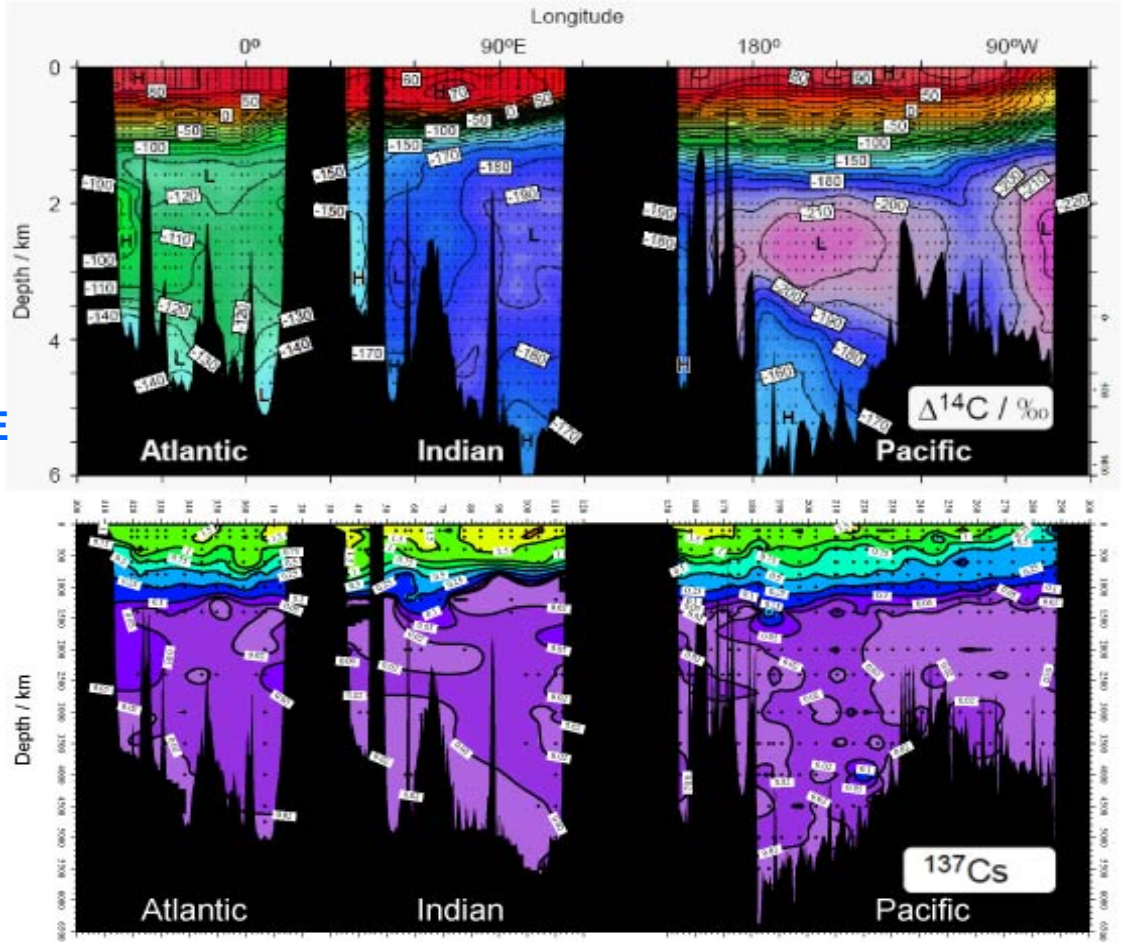
Beagle 2003/04) – Round the Globe expedition (JAMSTEC)



Increased salinity levels in bottom waters between WOCE´95 and BEAGLE

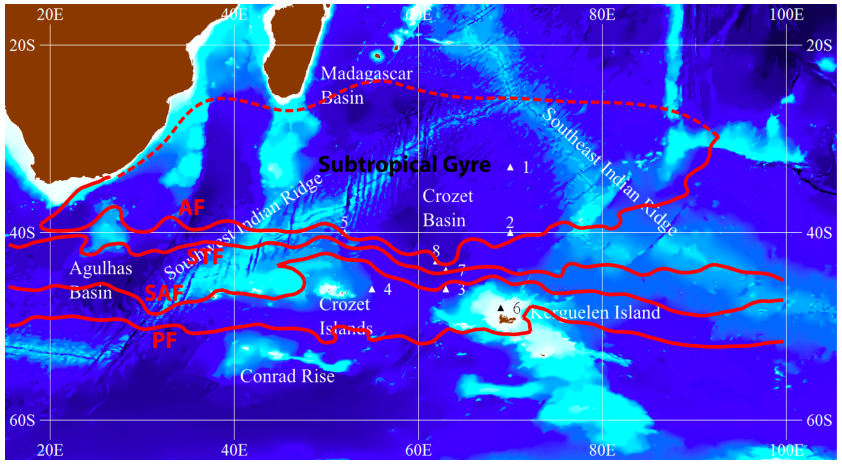


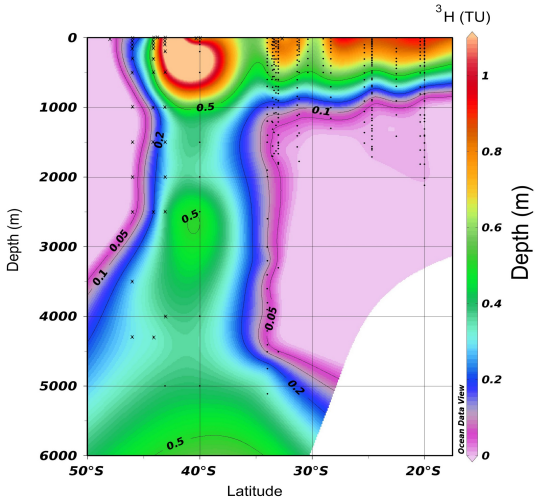
^{14}C and ^{137}Cs BEAGLE/SHOTS data

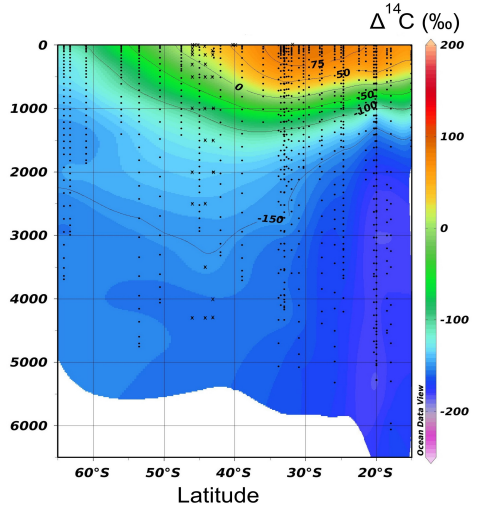


Special Issue *Progress in Oceanography*, 2012:
Aoyama et al., Kumamoto et al., Hirose et al., Povinec et al.

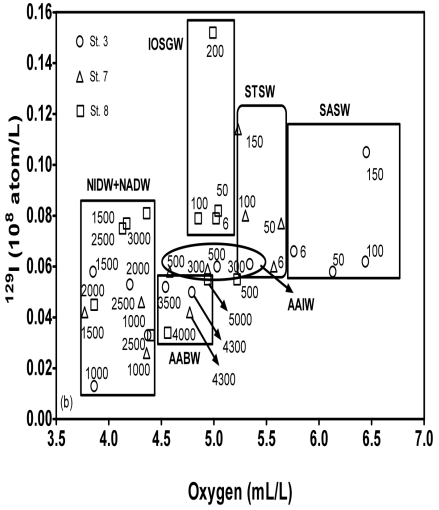
^{3}H, ^{14}C, ^{129}I in the South Indian Ocean (ANTARES IV

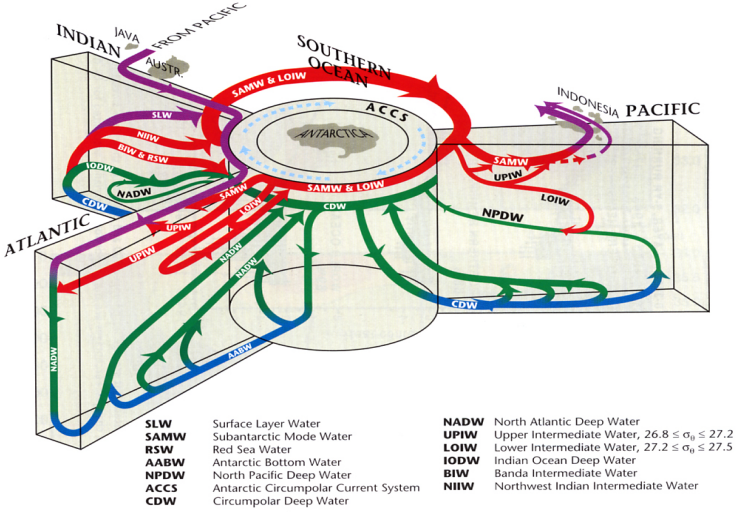


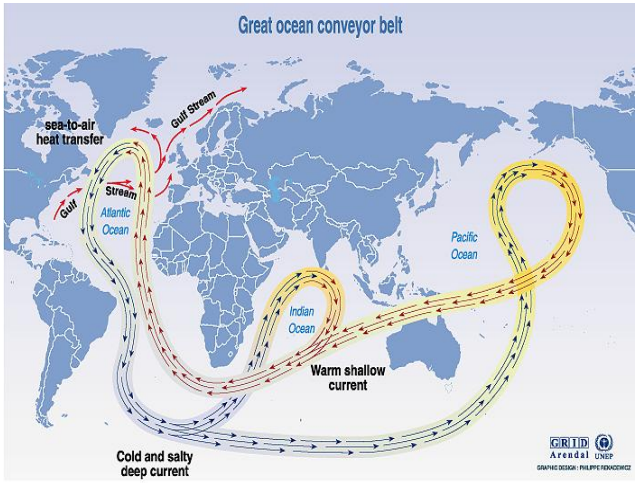




CO_2 sequestration - Bottom water formation - OCEANS CONTROL THE CLIMATE !!







Povinec et al., *Earth Planet. Sci. Lett.*, 2014

Broecker, Climate Change, 1995

Expected Climate Changes in this Century

Anthropogenic vs. Solar effects
(cosmic rays, aerosols, ozone, CLOUD experiment in CERN)

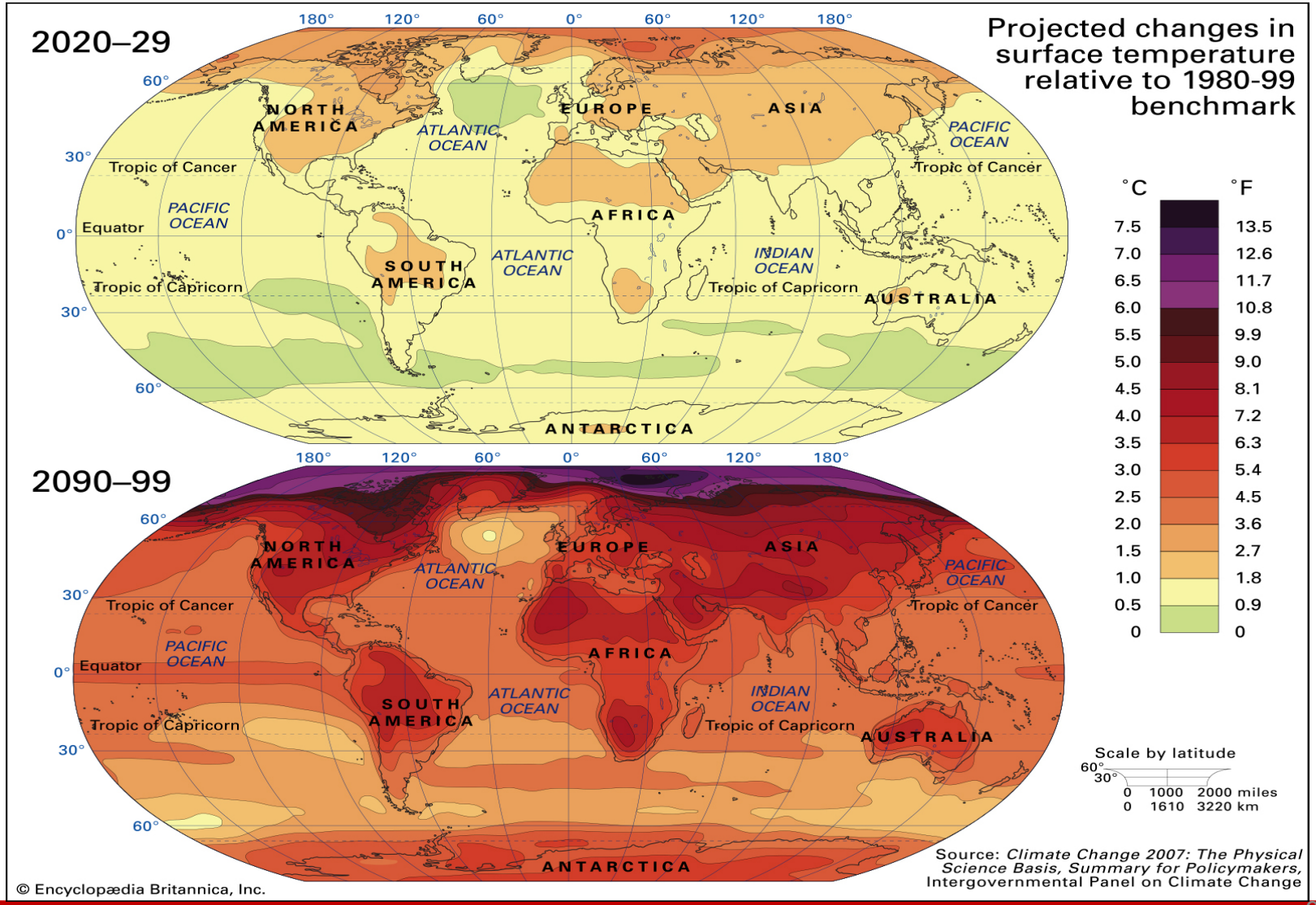
Further grows of green house gases (CO_2, CH_4, N_2O, fluorinated gases) **and aerosols** – also health effects – millions of people are dying per year due to atmospheric pollution

Further problems:
Anthropogenic: Deforestation, Land use
Natural: Volcanic eruptions, Astronomical effects, El Niño/ENSO, AMO
Permafrost ???

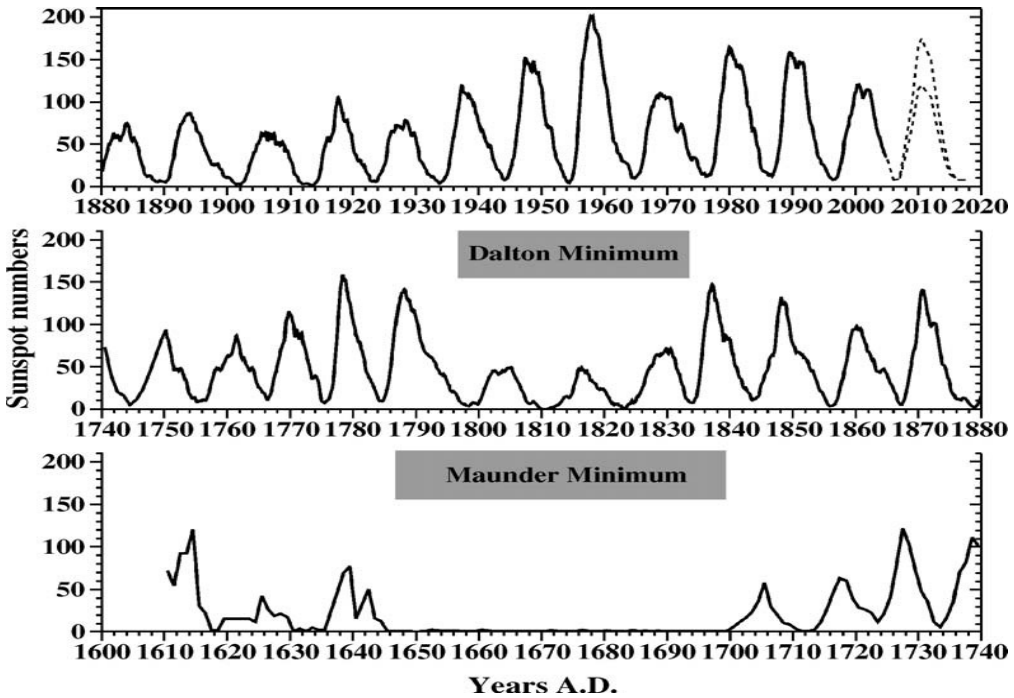
Green house gases vs. past climate changes
Growing (or stable temperature) vs. e.g. Little Ice Age

The end of the Holocene warm epoch ???
Will the Anthropocene continue as a warm epoch ???

IPCC Predictions



Future Solar Activity Cycles



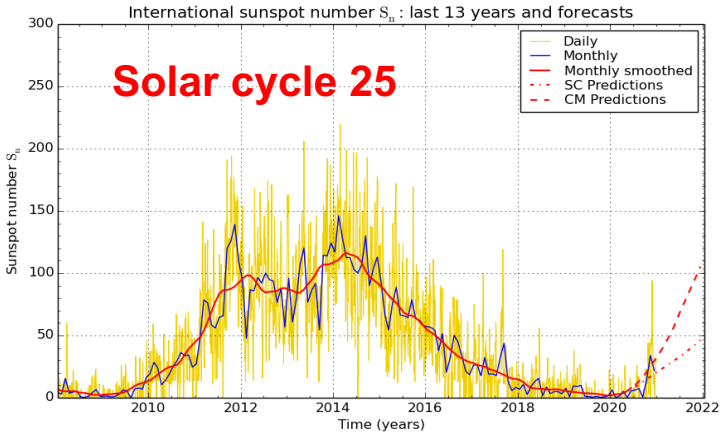
Grand Solar Activity Minima

Wolf minimum 1282-1342

Spörer minimum 1416-1534

Maunder minimum 1645-1715

WE NEED MORE INFORMATION ON PAST SOLAR ACTIVITY CYCLES – THE ROLE FOR ^{14}C and ^{10}Be RADIOISOTOPES



New 11-yr solar cycle started !!!
What about the next one ?

Will be soon there Super Grand Solar Activity Minimum, similar to Maunder minimum ???

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