Impact of cosmic rays on climate change:
a new approach to climate studies?

A new approach: analysis of the interaction between atmospheric parameters and cosmic ray ionising component

Interdisciplinary effort required to scientific community for data collection and new model studies.

The Kyoto Protocol

The Kyoto Protocol is an international agreement linked to the United Nations Framework Convention on Climate Change, which **commits** its Parties by setting internationally binding emission reduction targets. Recognizing that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity, the Protocol places a heavier burden on developed nations under the principle of "common but differentiated responsibilities."
The Kyoto Protocol was adopted in Kyoto, Japan, on 11 December 1997 and entered into force on 16 February 2005. The detailed rules for the implementation of the Protocol were adopted at COP 7 in Marrakesh, Morocco, in 2001, and are referred to as the "Marrakesh Accords." Its first commitment period started in 2008 and ended in 2012.

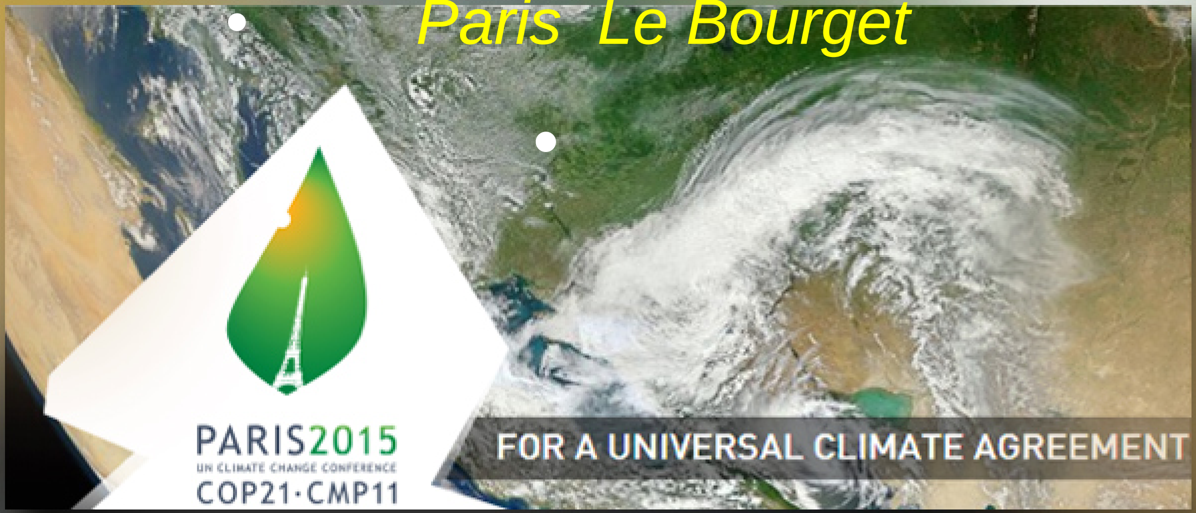
'20-20-20' objectives by 2020:

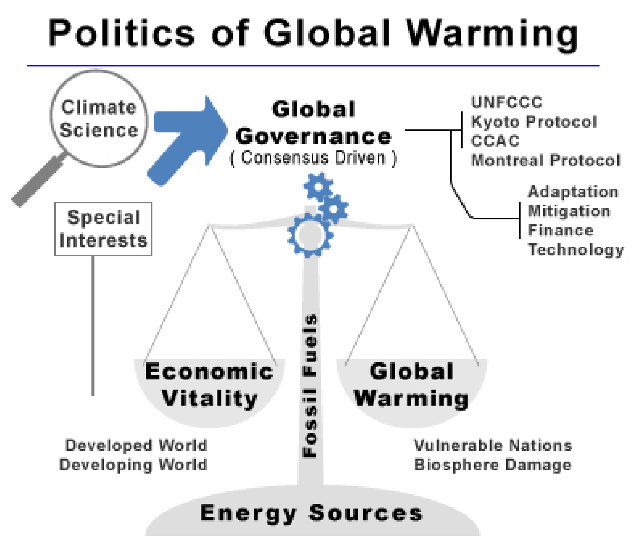
- 20 % reduction of GHG emissions (compared to 1990 levels),
- 20 % share of renewables energy
- 20 % saving of the Union's primary energy consumption

- XXI Climate Change Conference UNFCCC

30 Novembre - 11 December 2015

Paris Le Bourget





After Kyoto Protocol(1997) , a new agreement will be adopted at the Paris climate conference in December 2015 and implemented from 2020. It will take the form of a protocol, another legal instrument or 'an agreed outcome with legal force', and will be applicable to all Parties. It is being negotiated through a process known as the Durban Platform for Enhanced Action (ADP).

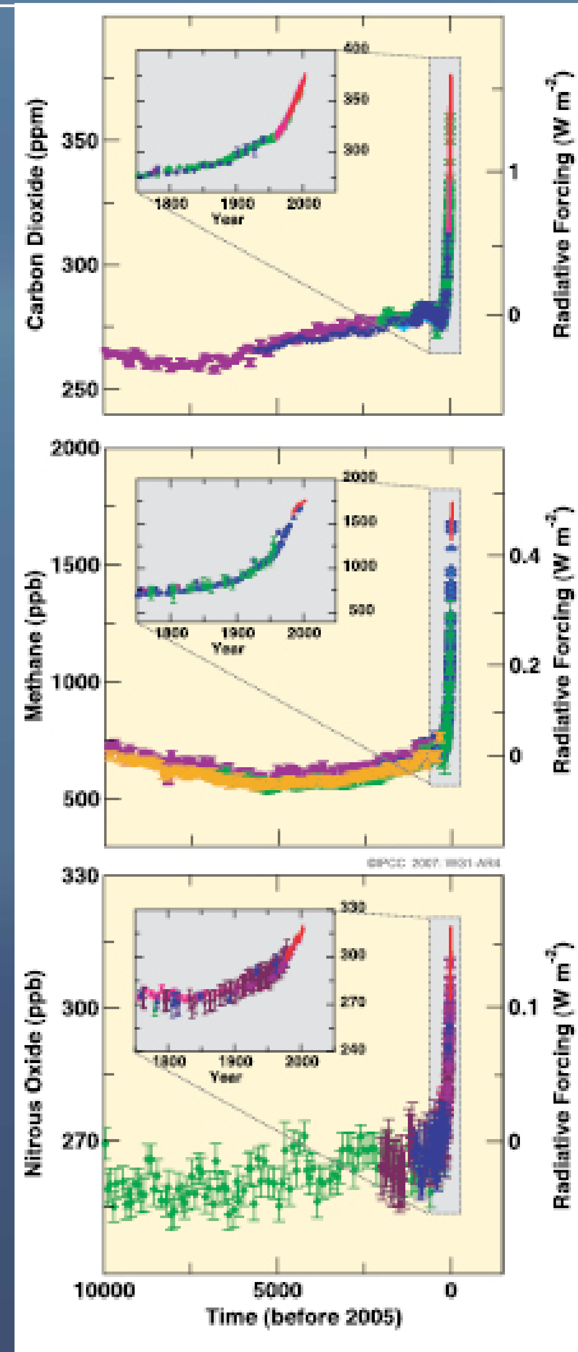
The IPCC V Report 2014

The Intergovernmental Panel on Climate Change (IPCC- director Hoesung Lee of the Republic of Korea) was founded in 1988 to assess ‘the scientific, technical and socioeconomic information relevant for the understanding of the risk of human-induced climate change’.

- Working Group 1 –
  The Physical Science Basis

- Working Group 2-
  Impacts, Adaptation, Vulnerability

- Working Group 3-
  Mitigation of Climate Change).



. Atmospheric concentrations of carbon dioxide, methane and nitrous oxide over the last 10,000 years (large panels) and since 1750 (inset panels).

Measurements are shown from ice cores (symbols with different colours for different studies) and atmospheric samples (red lines). 6.4}

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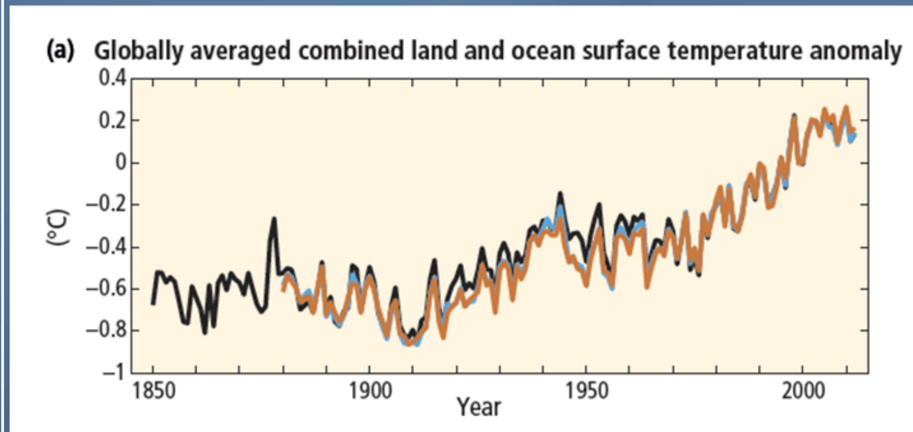
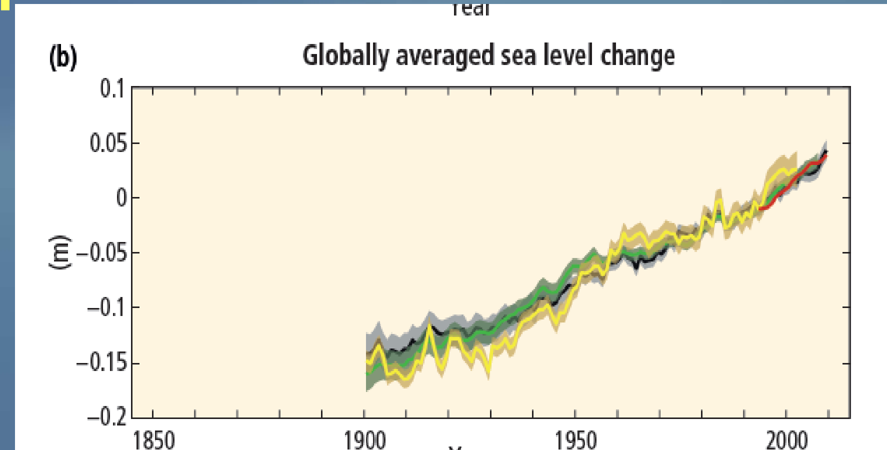
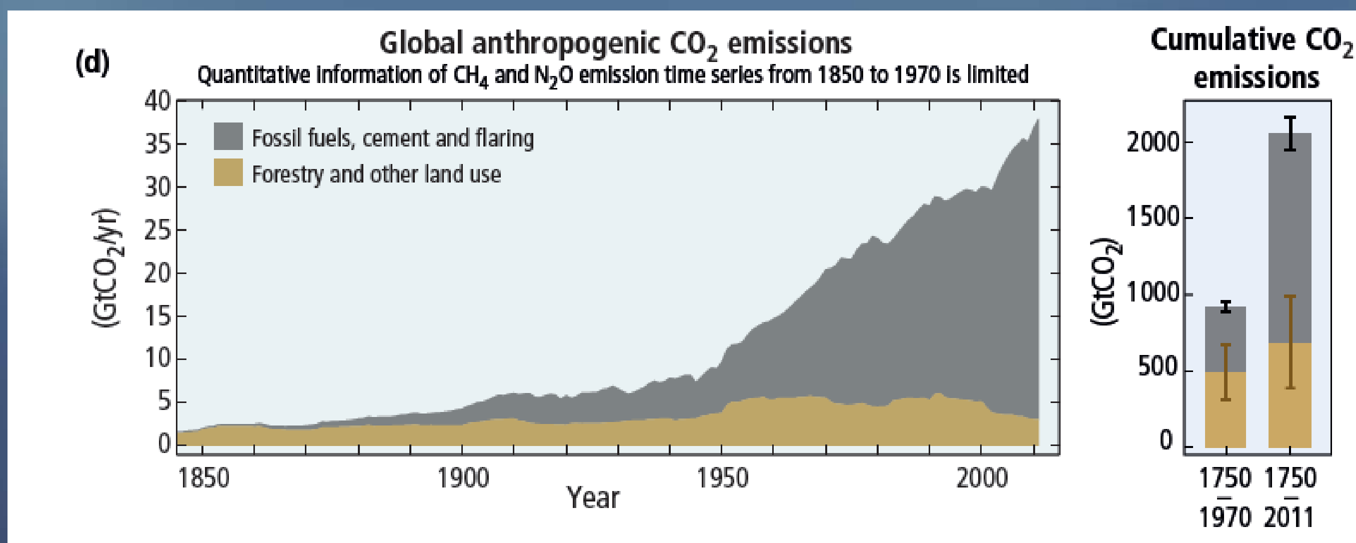
ICCP V report 2014







IMPACT ON CLIMATE CHANGE

In recent decades, changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. *{1.3.2}*

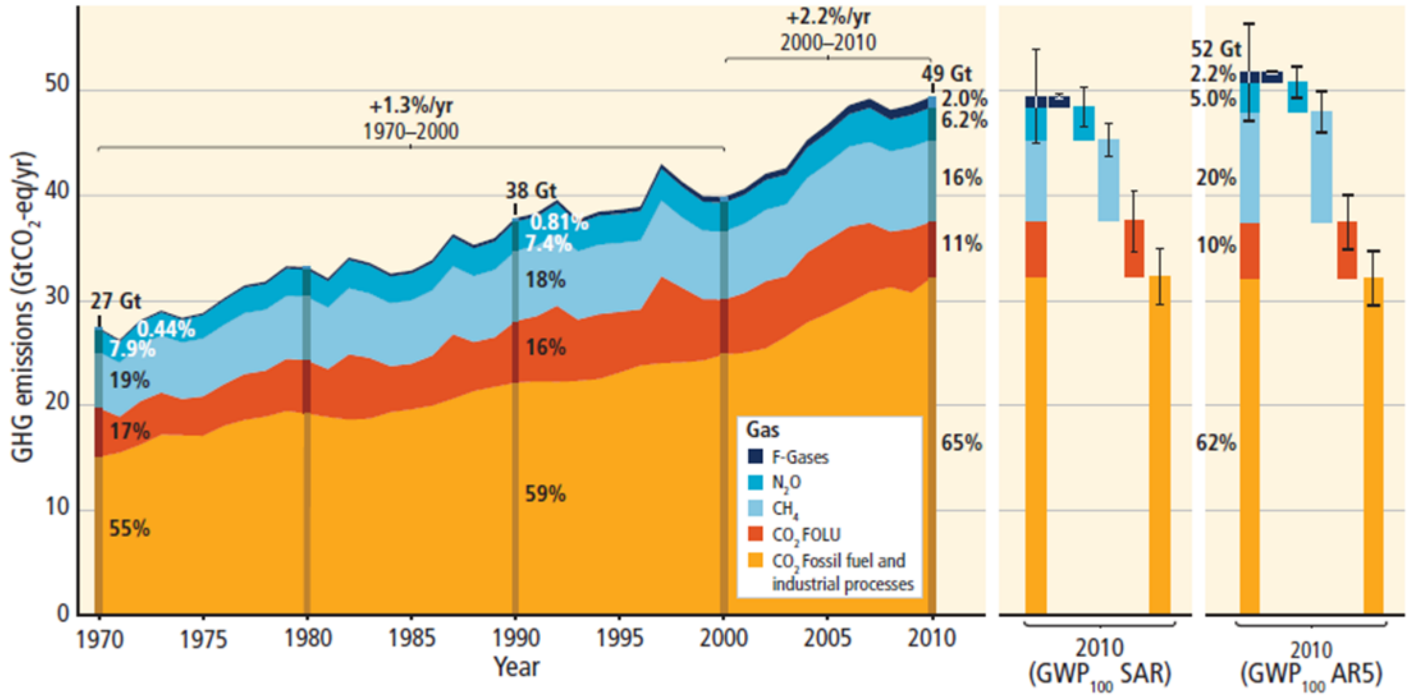


Figure SPM.2 | Total annual anthropogenic greenhouse gas (GHG) emissions (gigatonne of CO_2-equivalent per year, $GtCO_2$-eq/yr) for the period 1970 to 2010 by gases: CO_2 from fossil fuel combustion and industrial processes; CO_2 from Forestry and Other Land Use (FOLU); methane (CH_4); nitrous oxide (N_2O); fluorinated gases covered under the Kyoto Protocol (F-gases). Right hand side shows 2010 emissions, using alternatively CO_2-equivalent emission weightings based on IPCC Second Assessment Report (SAR) and AR5 values. Unless otherwise stated, CO_2-equivalent emissions in this report include the basket of Kyoto gases (CO_2, CH_4, N_2O as well as F-gases) calculated based on 100-year Global Warming Potential (GWP_{100}) values from the SAR (see Glossary). Using the most recent GWP_{100} values from the AR5 (right-hand bars) would result in higher total annual GHG emissions (52 $GtCO_2$-eq/yr) from an increased contribution of methane, but does not change the long-term trend significantly. {Figure 1.6, Box 3.2}

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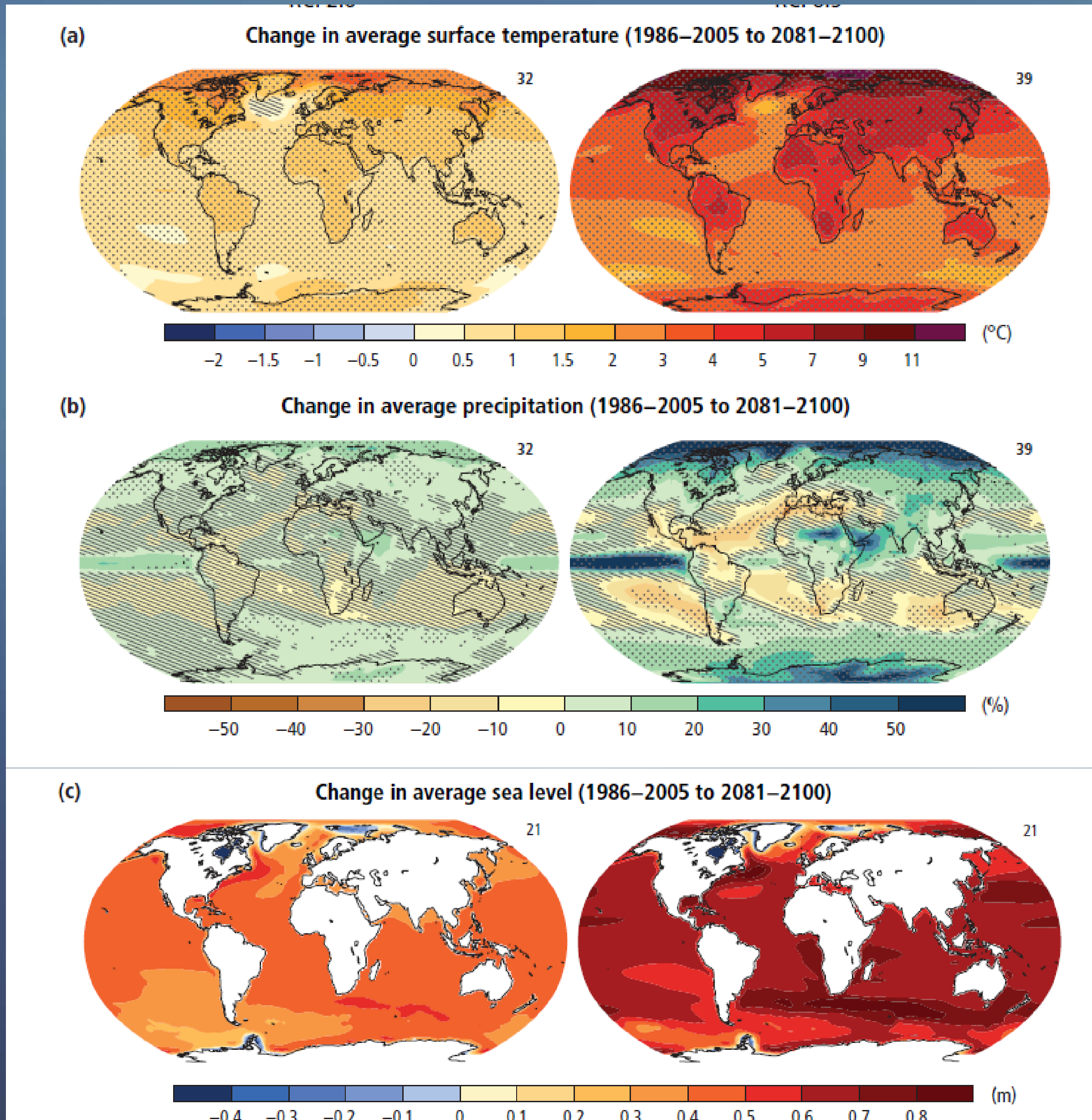
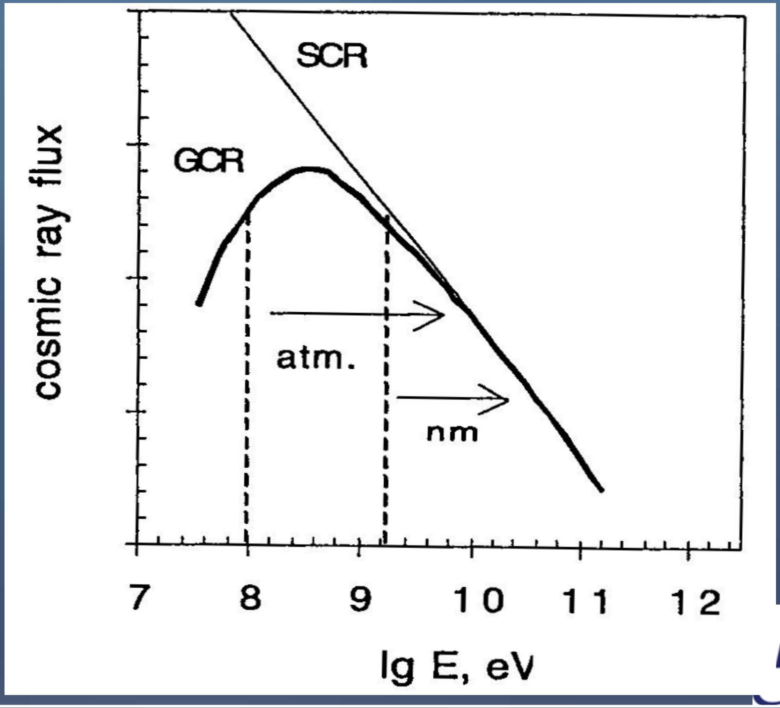

(a)
Change in average surface temperature (1986–2005 to 2081–2100)
32
39
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2 3 4 5 7 9 11
(°C)
(b)
Change in average precipitation (1986–2005 to 2081–2100)
32
39
−50 −40 −30 −20 −10 0 10 20 30 40 50
(%)
(c)
Change in average sea level (1986–2005 to 2081–2100)
21
21
−0.4 −0.3 −0.2 −0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8
(m)

COSMIC RAYS CHARACTERISTICS

GCR (Galactic cosmic Rays): galactic origin, GCR are generated outside the solar system, in supernovae explosions and accelerated by the shockwaves.

ACR (Anomalous Cosmic Rays): extragalactic origin, ACR are generated in the interplanetary space.

SCR (Solar Cosmic Rays): events following the 11 years cycle.



Primary radiation composition

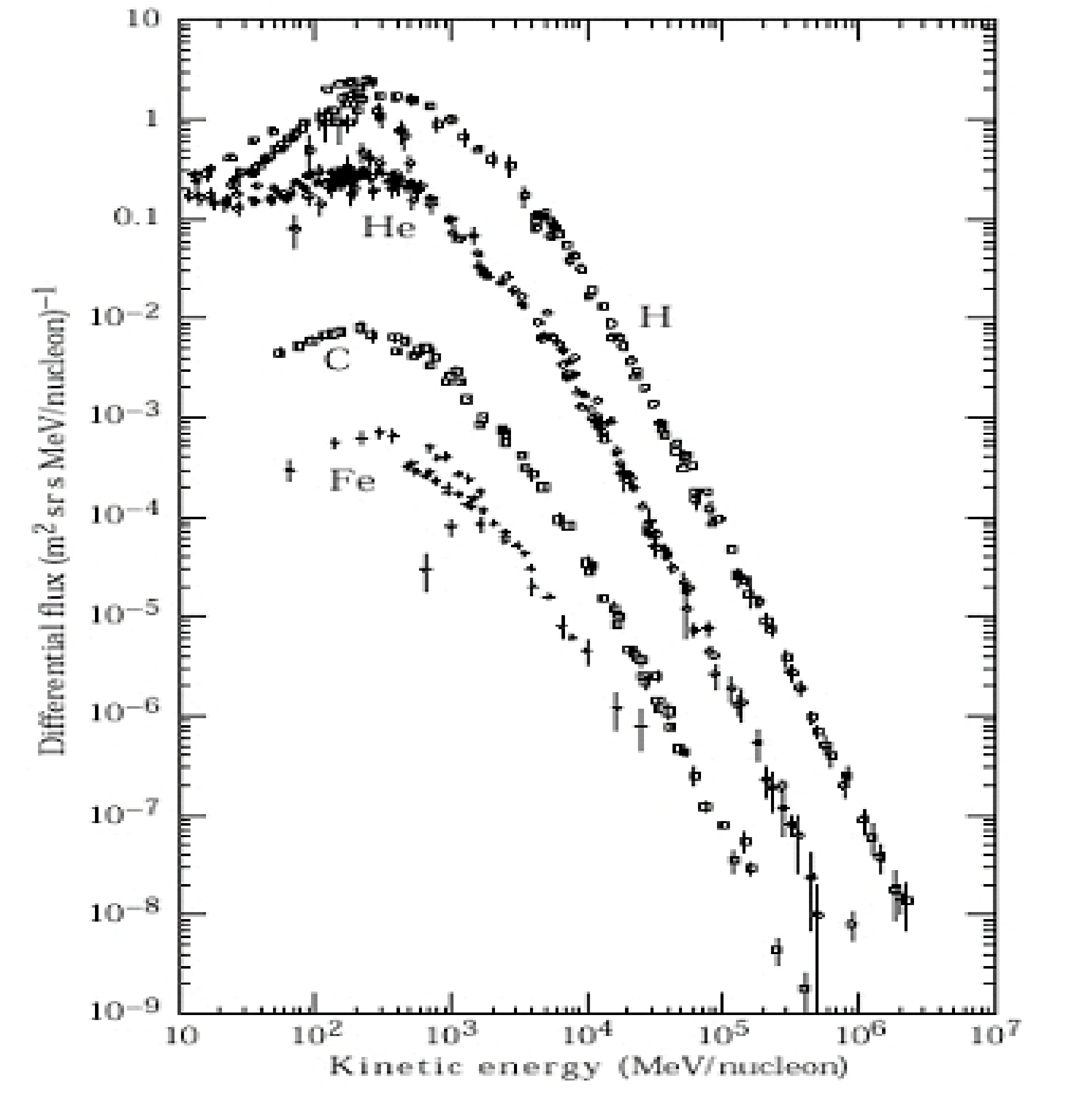
Primary radiation:

87% **protons**,

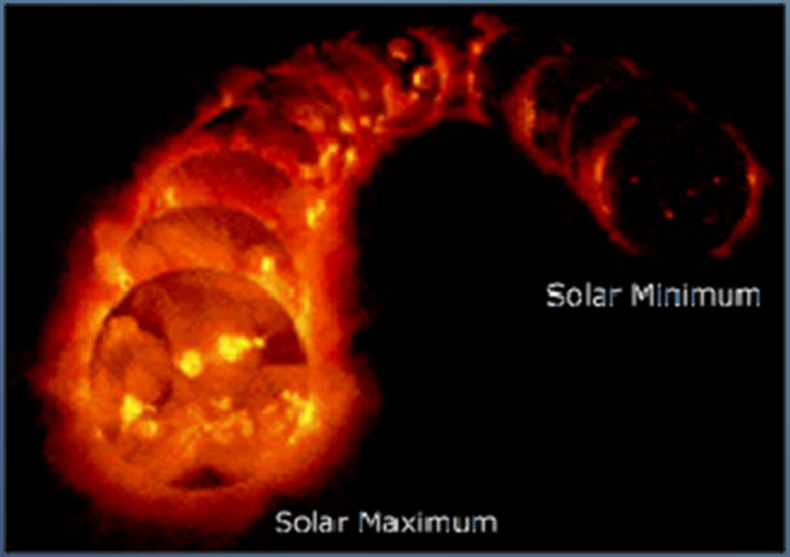
12% α particles,

1% **HZE**

(High Z Elements).



The sun is an active star



The sun is a G2V star

Sun mass 1.99 x 10^{30} kg

Mass density 1.4 g/cm^3

g: 274 m s^{-2}

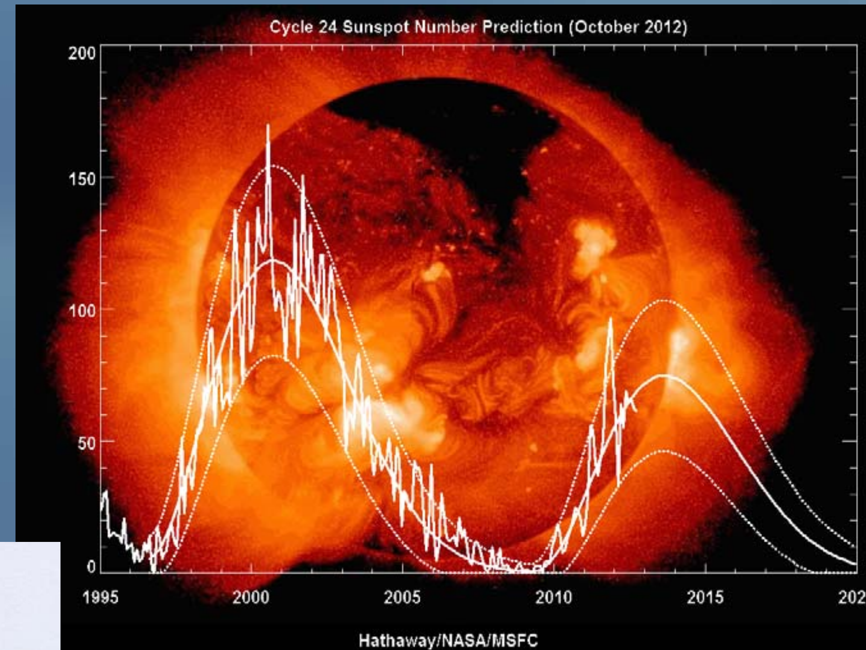
T: 5780 K

Revolution period around the galactic center: 250 Myrs
Position at 2/3 from the galactic center

Solar Activity

The solar magnetic field changes its polarity each sunspot maximum**.**

The total duration of the magnetic cycle is 22 years.



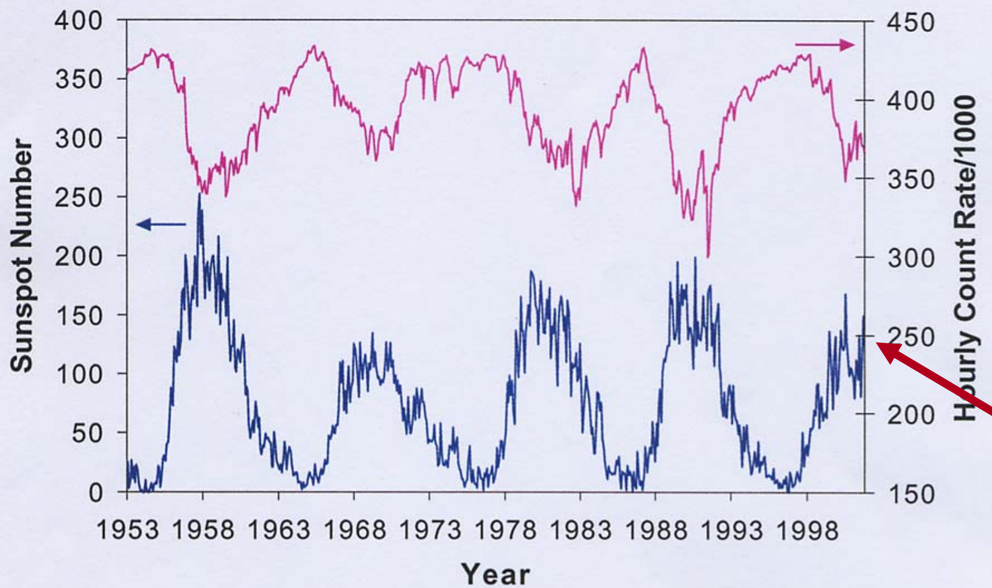


Figure 1.1 Plot of sunspot number and neutron count rate versus date. (—) Sunspot number per month (which is an indication of the activity of the sun);[3] (—) Monthly average of the hourly neutron count from the Climax, Colorado ground-based neutron monitor (which detects variations in the intensity of the cosmic ray neutrons which penetrate the Earth's atmosphere).[4]

The solar wind is a shielding for GCR.

Higher solar activity corresponds to lower cosmic ray flux on Earth.

Solar Activity and Solar Flares

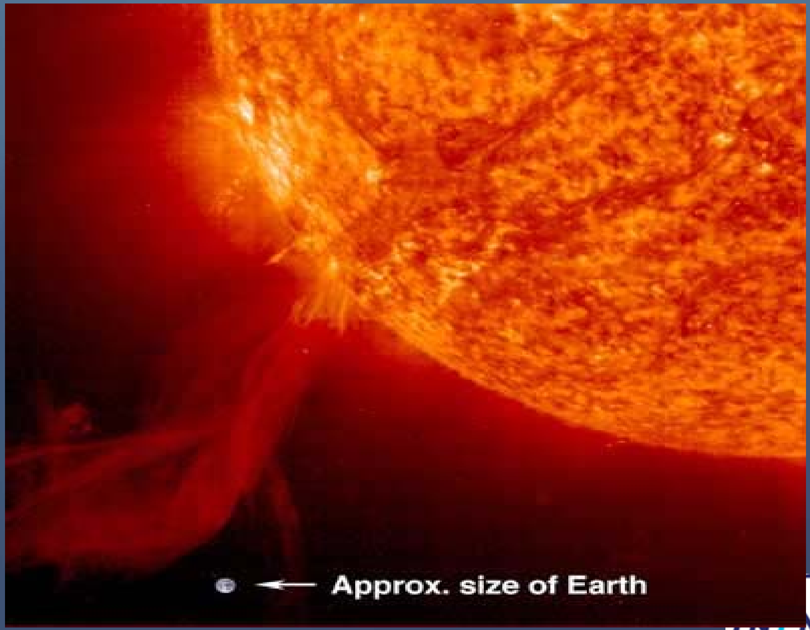
- **The solar activity is described by sunspot numbers, characterized by an 11-year cycle.**
- **Solar surface is periodically characterized by outstanding events (*solar flares, Coronal Mass Ejections, Filament Disruptions*).**

The sunspot number unit is the Wolf number:

$$R = K(10g+m)$$

Single spot

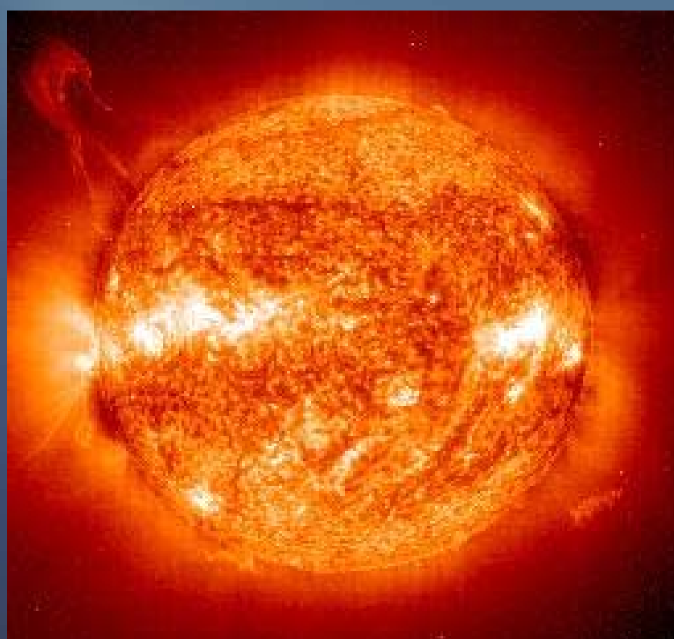
Group of spots

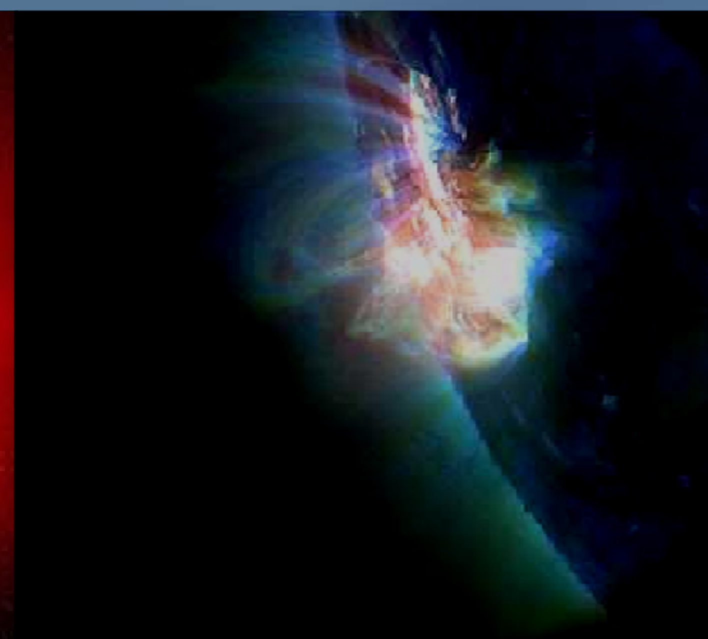


Solar wind is a continuous outward flow of plasma from the sun corona
(mainly protons and electrons)

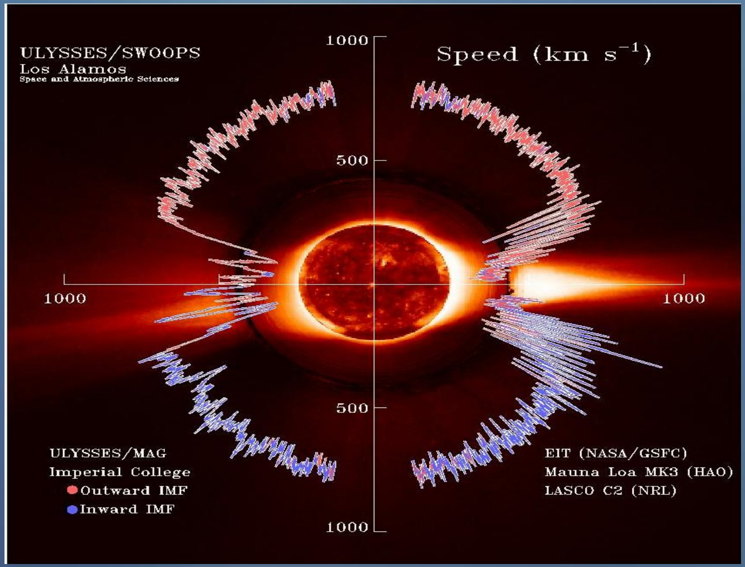
SPE – Solar Particle Events

Solar particle-event radiations (SPE) are in general large clouds of **charged particles** (mainly protons and helium nuclei in a wide range of energy) **released from the sun by gigantic eruptions during solar storms**.

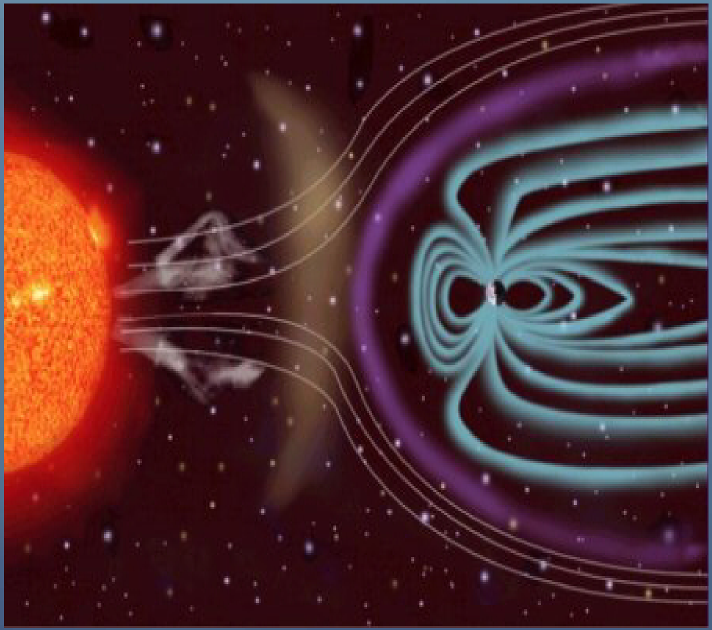




Modulation of Galactic Cosmic Rays by the solar wind



The solar wind streams off the Sun in all direction at speed of about 400 km/s



The effect on the energy of charged cosmic rays at the earth orbit is a retarding potential:

- **high solar activity - 1000 MV-**
- **grand solar minima - 0 MV-**
- **at present - 550 MV -**

The geomagnetic field also partially shields the earth:
13 GeV/n at equator
3GeV/n at mid latitudes
0GeV/n at geomagnetic poles

COSMIC RAYS in atmosphere

Secondary radiation is produced by interaction of primary cosmic rays with atmospheric nuclei O16(22%) and N 14 (78%));

The atmospheric cascade is characterized by:

1. **N component** (nucleonic component), which includes all the particles that are subjected to strong interaction;

2. **Soft component** (electromagnetic component), which consists of electrons, positrons and electromagnetic quanta;

3. **Hard component** (muon component).

Cosmic ray variability on Earth

The CGR intensity on Earth depends on:

- Altitude (Depth in atmosphere)
- Latitude (Geomagnetic conditions)
  (3.6 times higher at poles than at equator)
- Periodicity of Solar activity
- Atmosphere composition
  (natural and anthropogenic)

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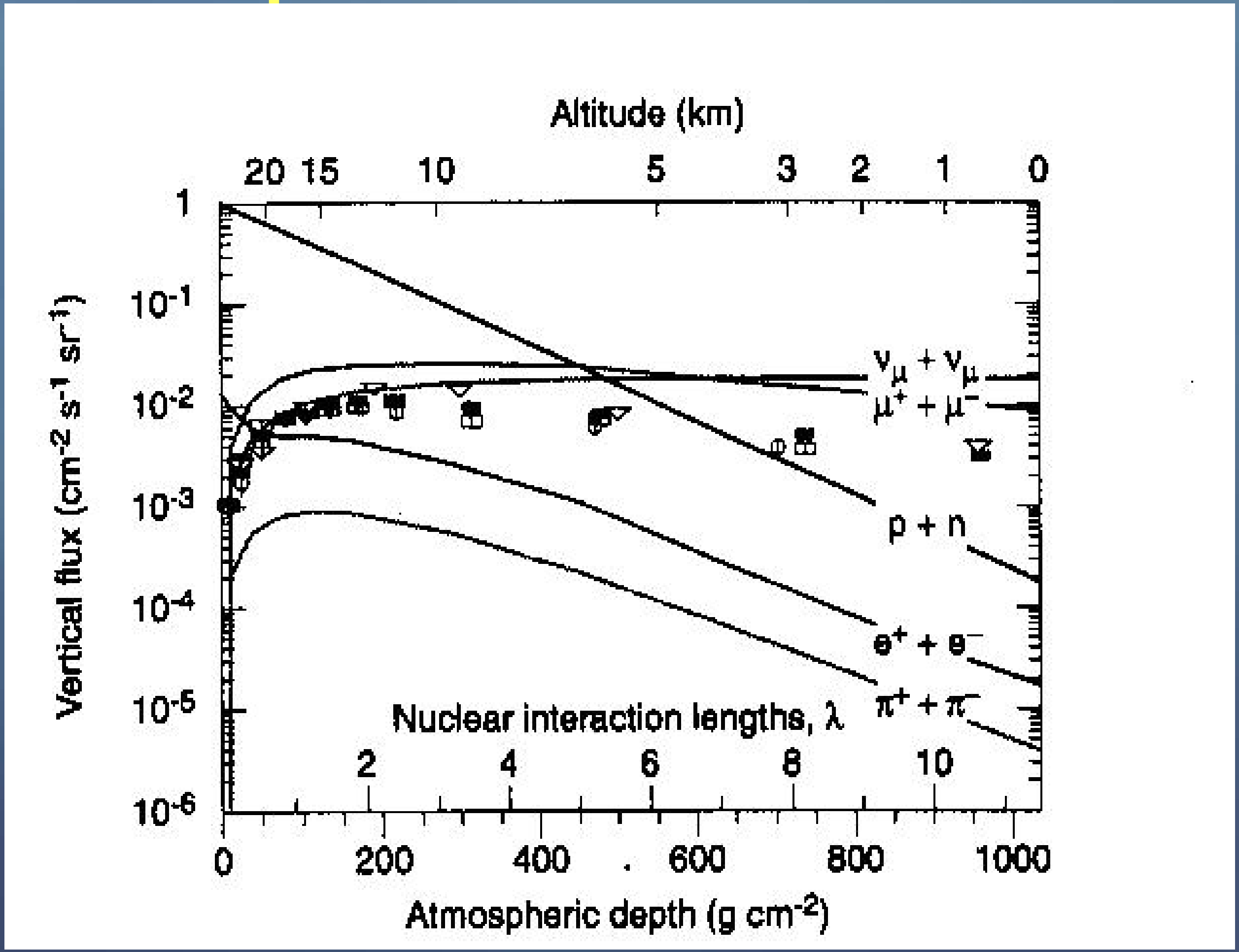
Secondary radiation composition

0 (g cm^{-2}) = 50 km o.s.l
Top of atmosphere

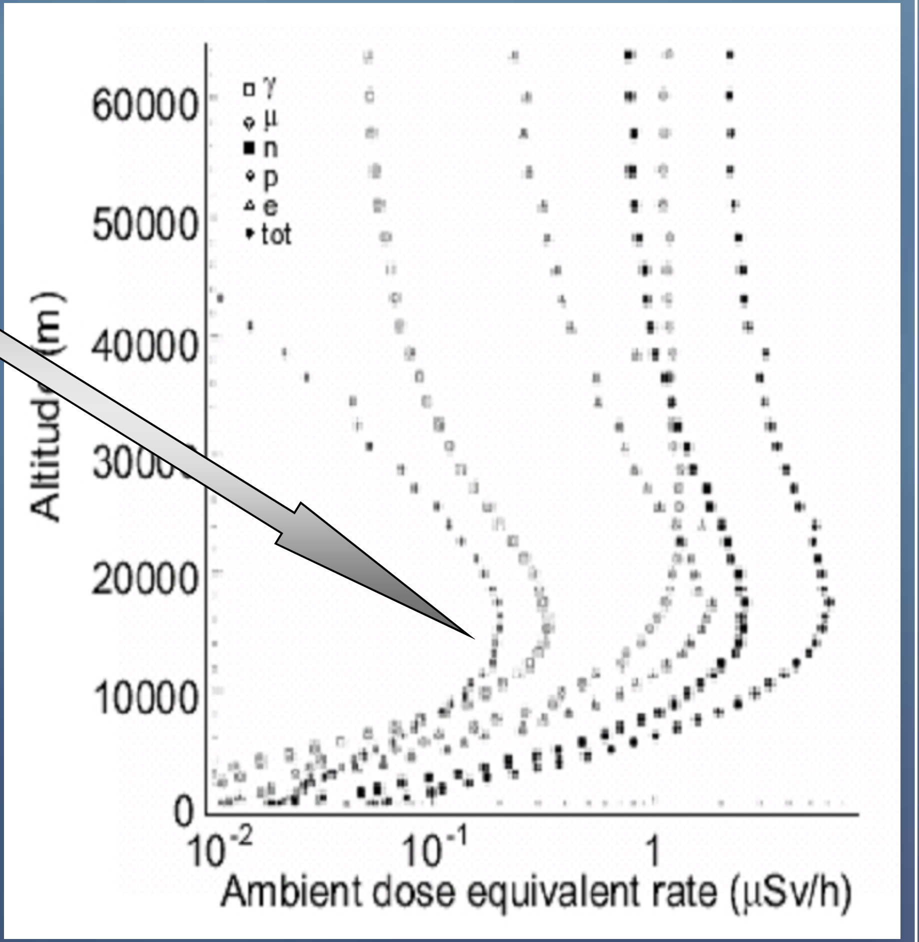
1000 (g cm^{-2}) = 0 km
Ground level



Secondary Radiation

Pfotzer Maximum

The secondary radiation intensity has a maximun between 12.000 – 20.000 m (in dependence of latitude and solar activity) where the production and the absorption in atmosphere are in equilibrium



The Sun is a driving factor for the climate on the Earth

Evidences both from recent observations and from climate proxies suggest that solar variability represents an important contribution to climate changes.

BUT…

Variations of solar irradiance are too small to account for the climate variability

Therefore …

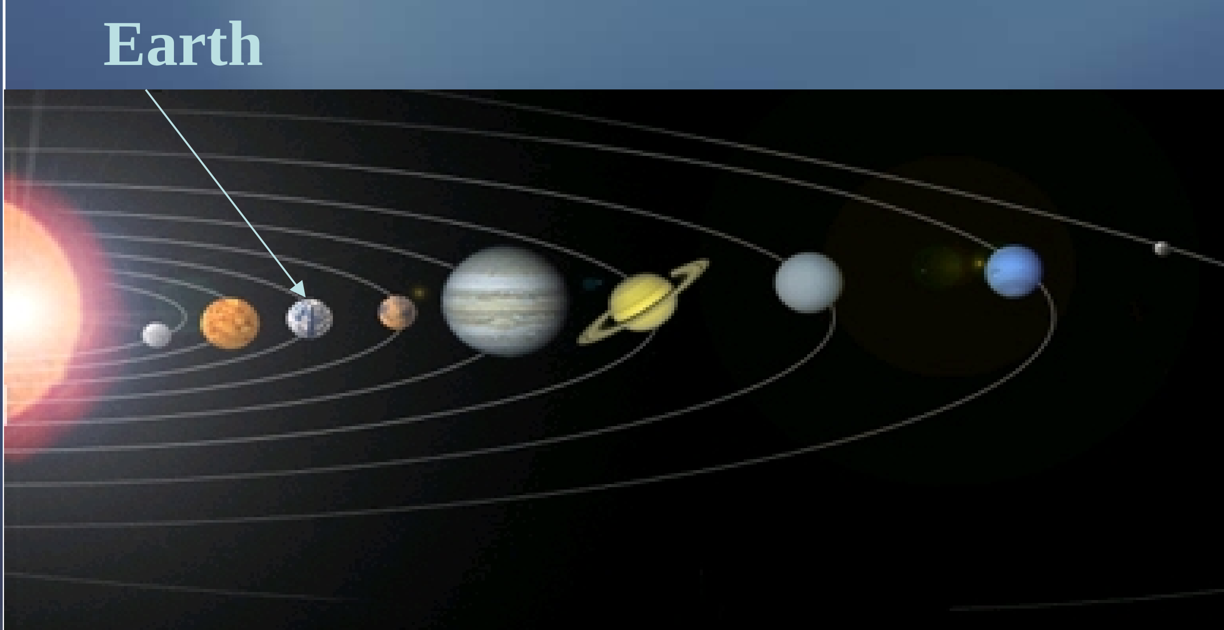
other mechanisms could exist to amplify the solar variations

↓

Interaction of cosmic rays with the Earth atmosphere

Earth's atmosphere

- Earth is the only planet with an atmosphere composed of Nitrogen and Oxygen and with liquid water.
- The Sun - Earth distance gives a suitable temperature and regulates the atmosphere.
- The atmosphere maintains a steady state through the interaction with ocean, biosphere, lithosphere, solar activity.



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Atmosphere characteristics

Thermosphere: T= 1000 K

High ionization, thermal conduction

Mesopause T= -93 C

Mesosphere

Coldest region of atm

Stratopause: T= -3 C

Stratosphere

(horizontal motion)

Tropopause: T= 200 K

Troposphere

(convective motions)

Upper atm.

Middle atm.

Lower atm.

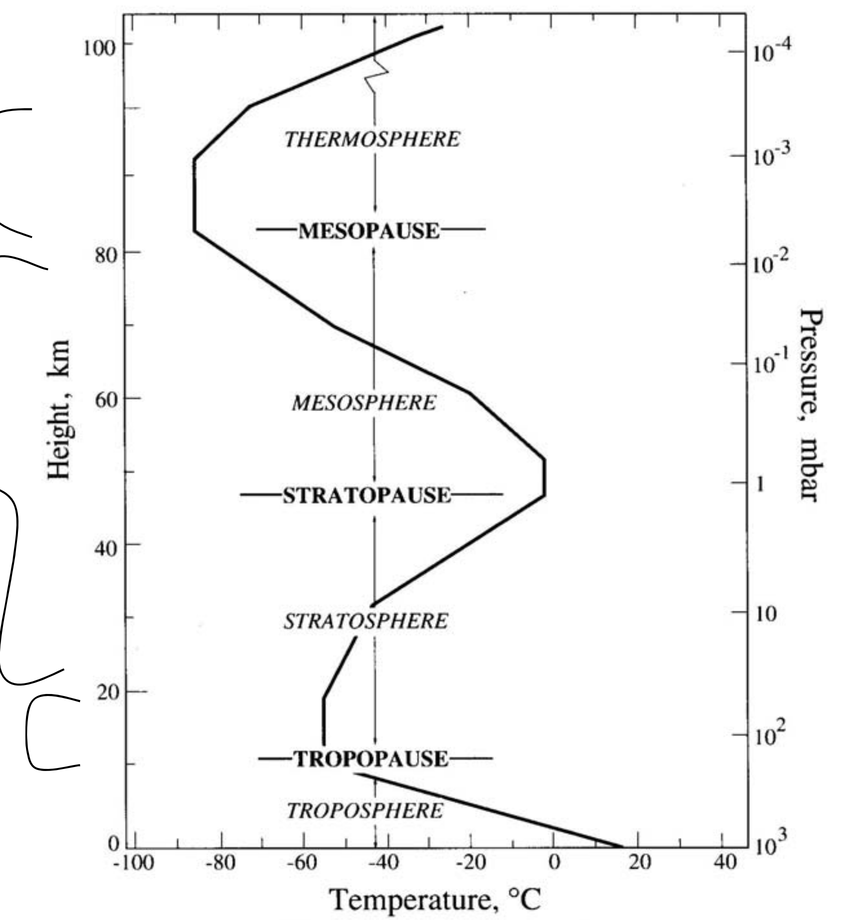


FIGURE 1.1 Layers of the atmosphere.

Atmosphere composition

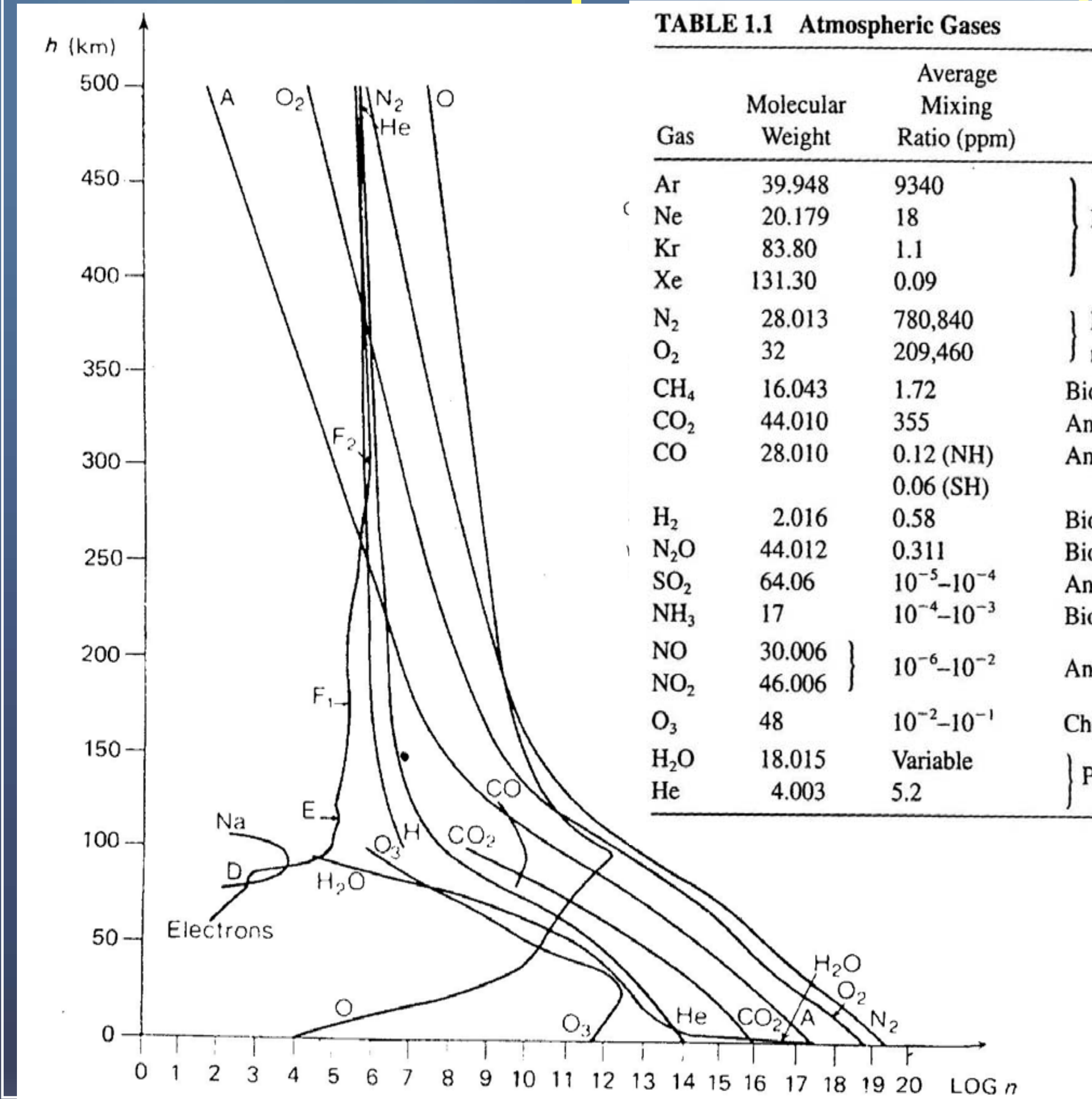


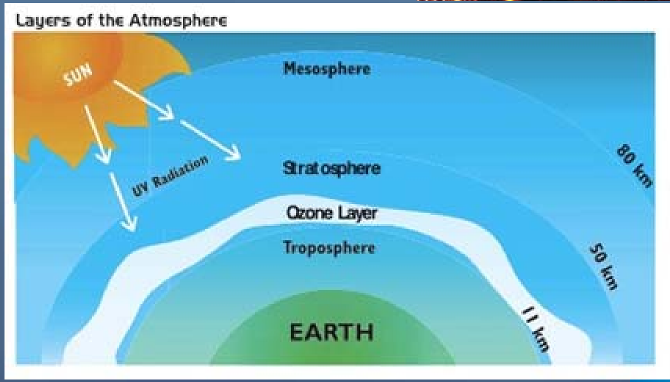
TABLE 1.1 Atmospheric Gases

Gas	Molecular Weight	Average Mixing Ratio (ppm)	Cycle	Status
Ar	39.948	9340	No cycle	Accumulation during Earth's history
Ne	20.179	18		
Kr	83.80	1.1		
Xe	131.30	0.09		
N_2	28.013	780,840	Biological and microbiological	?
O_2	32	209,460		
CH_4	16.043	1.72	Biogenic and chemical	Quasi-steady-state or equilibrium
CO_2	44.010	355	Anthropogenic and biogenic	
CO	28.010	0.12 (NH) 0.06 (SH)	Anthropogenic and chemical	
H_2	2.016	0.58	Biogenic and chemical	
N_2O	44.012	0.311	Biogenic and chemical	
SO_2	64.06	10^{-5}–10^{-4}	Anthropogenic, biogenic, chemical	
NH_3	17	10^{-4}–10^{-3}	Biogenic and chemical	
NO	30.006	10^{-6}–10^{-2}	Anthropogenic, biogenic, chemical	
NO_2	46.006			
O_3	48	10^{-2}–10^{-1}	Chemical	
H_2O	18.015	Variable	Physicochemical	
He	4.003	5.2		

Relevant atmospheric effects correlated with CR variability

- Thunderstorms and Lighting

- Ozone Depletion



- Low Cloud (3000-4000 m) formation

Thunderstorm and lighting formation

September 1967F

- ull An increase in the cosmic-ray component (*E* > 500 kev) was found to accompany thunderstorms. Flux increases were typically 5%. The nature of the count increase is not known.

April 2015 “Cosmic rays reveal the secrets of thunderstorms : High-energy particles from distant space could help to illuminate the origin of lightning”. Davide Castelvecchi Nature, 23 April 2015

- Measurements of the electric fields in clouds could help to solve the one of biggest open questions in atmospheric science. Lightning is a channel of electrical conduction that briefly opens up in the atmosphere and partially restores the balance of electric charges, either between different layers of a cloud or between a cloud and the ground. But scientists do not yet understand what triggers it.
- The electric fields are strong, but are not sufficient in themselves to convert air from an electric insulator to a conductor. Cosmic rays can be the trigger

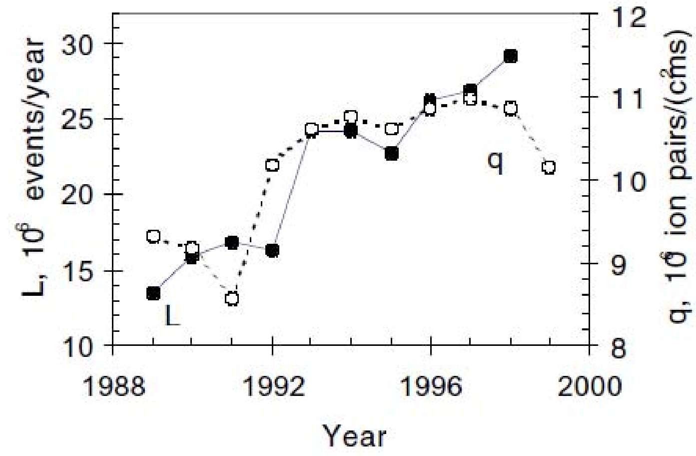


Fig. 26. The yearly number of lightning *L* detected in United States in 1989-1998 (black points, from [36]) and ion production rate *q* in the air column (*h*=2-10 km) of the middle latitudes (open points).

$$J=N(h)\ \sigma(h)\ \rho(h)\ k(h)\ E(h)/[M\ \beta(h)]. \qquad (7)$$

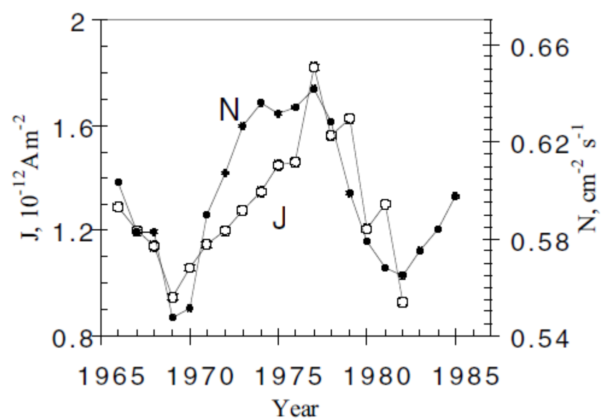
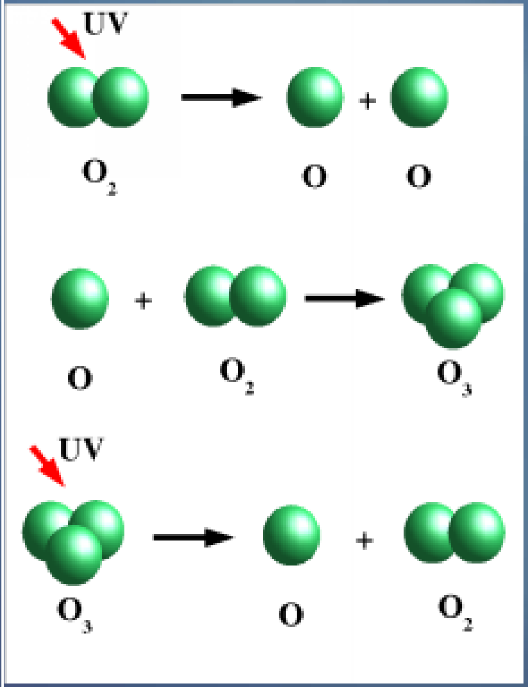


Fig. 22. The yearly average values of atmospheric electric current J(h) (from [19]) and cosmic ray flux N(h) at h≈8 km in the polar region.

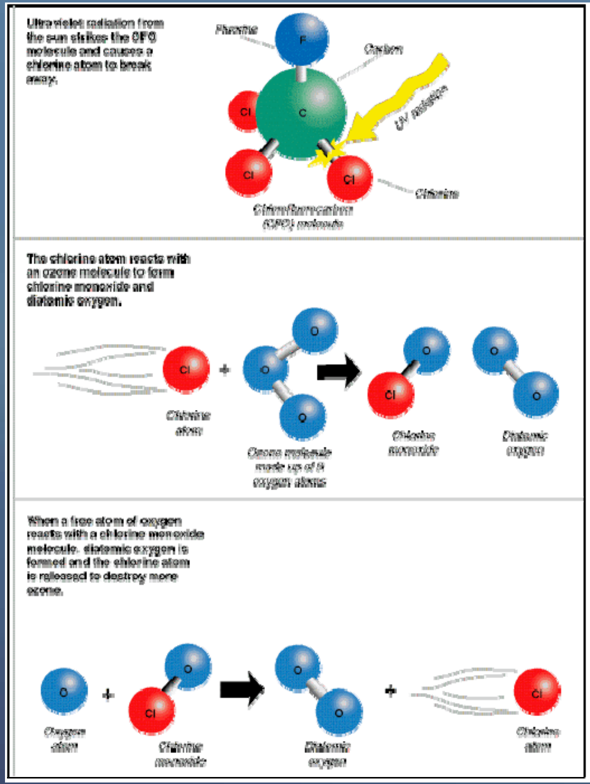
Y.I. Stozhkov, N.S. Svirzhevsky, and V.S. Makhmutov
Lebedev Physical Institute, Russian Academy of Sciences, Moscow, Russia (2000)

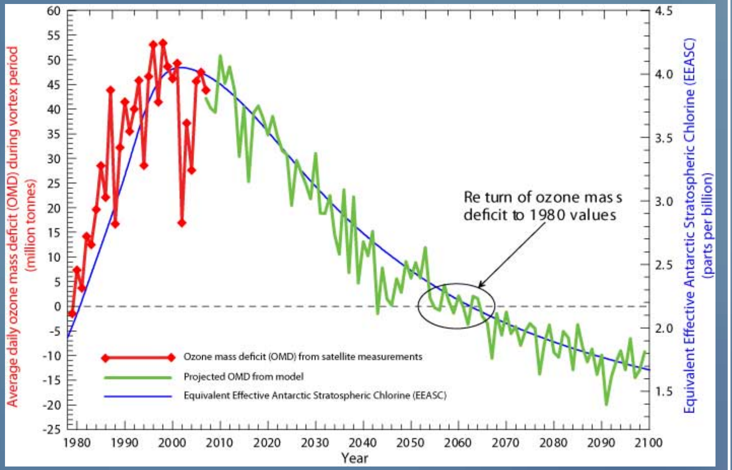
Ozone formation and depletion

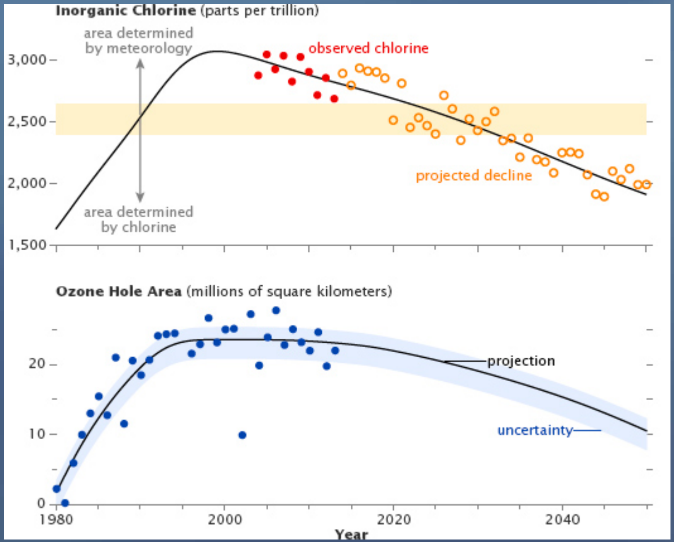


UVC (λ= 280 nm)
In natural equilibrium

Cl + O3 --> ClO + O2
ClO + O --> Cl + O2
O3 + O --> 2O2







Correlation between ozone hole area and CFCH concentration

Destruction cathalyzed by CFCH

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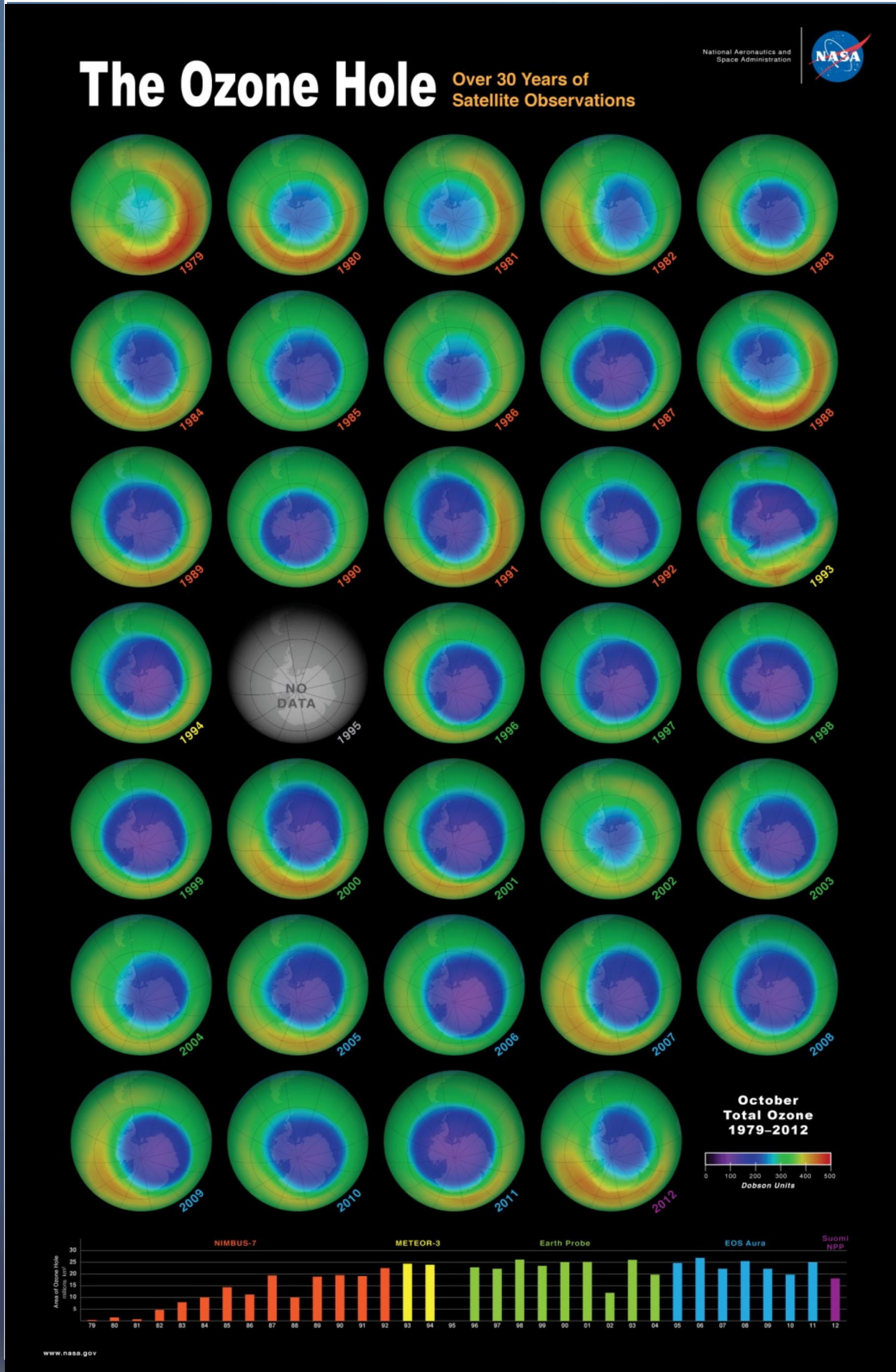
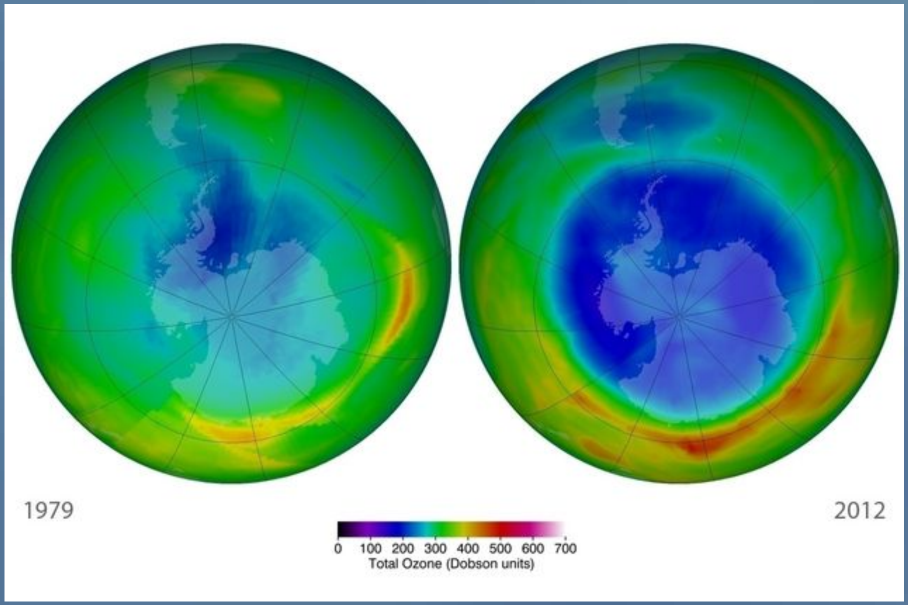
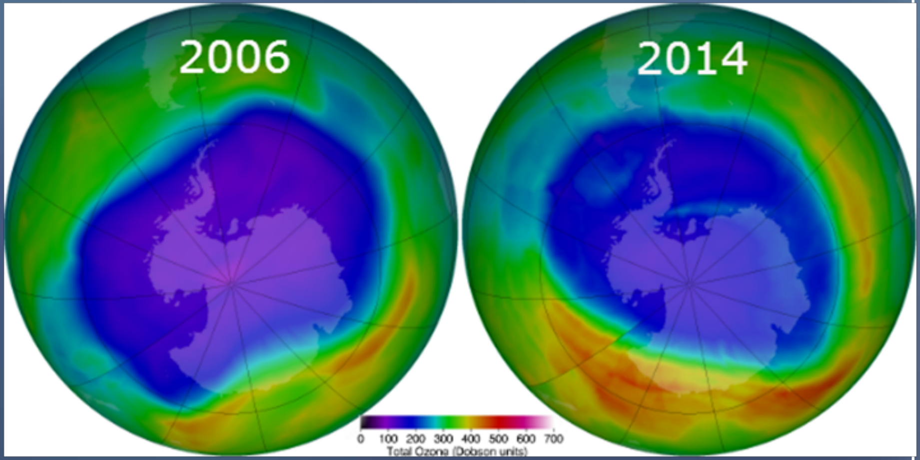




Ozone layer over Antarctica :reduction



Ozone layer over Antarctica:recovery

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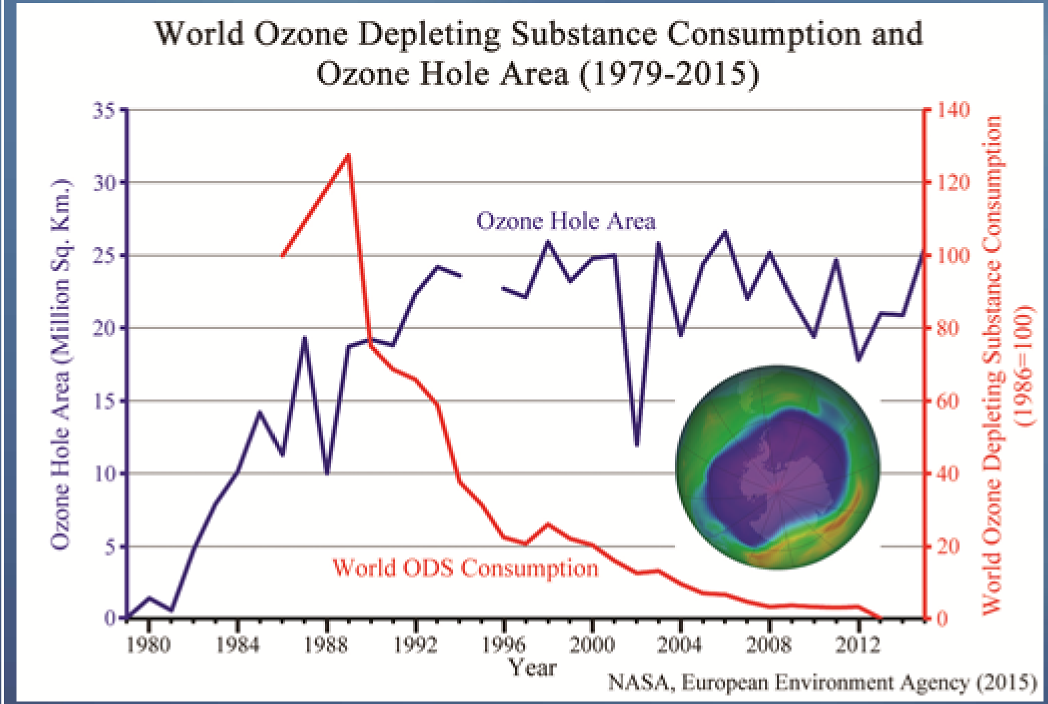


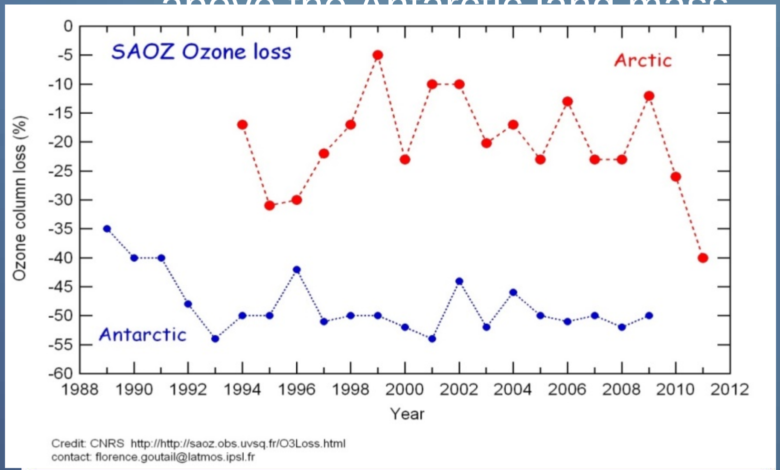
Scientists are mixed on when the stubborn Ozone Hole will disappear.

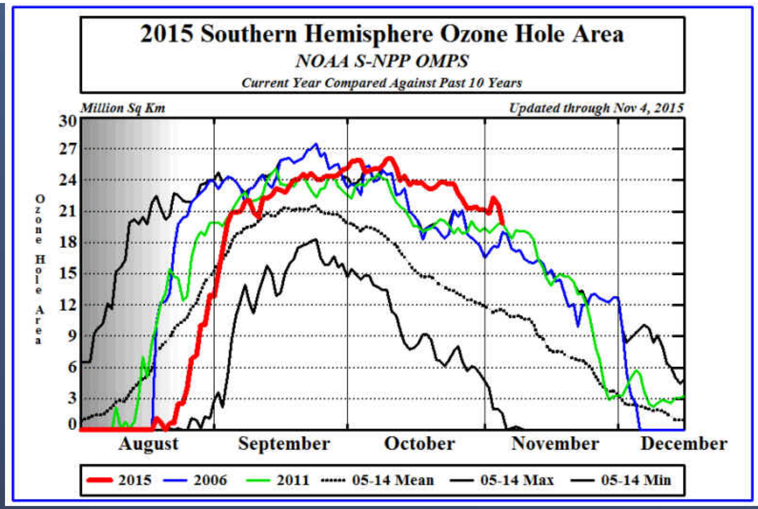
NASA recently announced that the hole will be half-closed by 2020. Others forecast that it will not begin to disappear until 2040 or later.

But the longer the hole persists, the greater the likelihood that the ozone layer is dominated by natural factors, not human CFC emissions.

OZONE HOLE IN ANTARCTICA

In Antarctica, due to the extremely low prevailing temperatures, water and nitric acid condense to form ice clouds, known as polar stratospheric clouds. In addition, during the long dark Antarctic winter, stratospheric winds move in a circular pattern over the polar region creating a polar vortex that isolates the air above the Antarctic land mass.





Because nitric acid is tied up in the ice particles, the concentrations of oxides of nitrogen in the gaseous phase are significantly reduced.
This in turns slows down the rate of conversion of chlorine oxide to therelatively inert chlorine nitrate

Similar phenomena, but with reduced intensity, are present over the Arctic

On Oct. 2, 2015, the ozone hole expanded to its peak of 28.2 million square km, due to unusually cold temperature and weak dynamics in the Antarctic stratosphere. In comparison, last year the ozone hole peaked at 24.1 million square km on Sept. 11, 2014. Compared to the 1991-2014 period,

Ozone Layer distruction

Solar proton Theory

Solar storms destroy ozone. When protons bombard the upper atmosphere, they break up molecules of gases like nitrogen and water vapor. Once freed, those products readily react with ozone molecules and reduce the ozone layer

"*The effect of solar proton events (SPE)on Ozone and other components*" *C.Jackman, R-Mc Peters, NASA Goddard Space Flight Center (2000)*

- It was generally accepted for many decades (1974) that the Earth's ozone layer was depleted by the sun's ultraviolet light-induced destruction of CFCs in the atmosphere
  - At present there is evidence that both GCR (Galactic Cosmic Rays) and SCR (Solar Cosmic Rays) inpact on the Ozone depletion

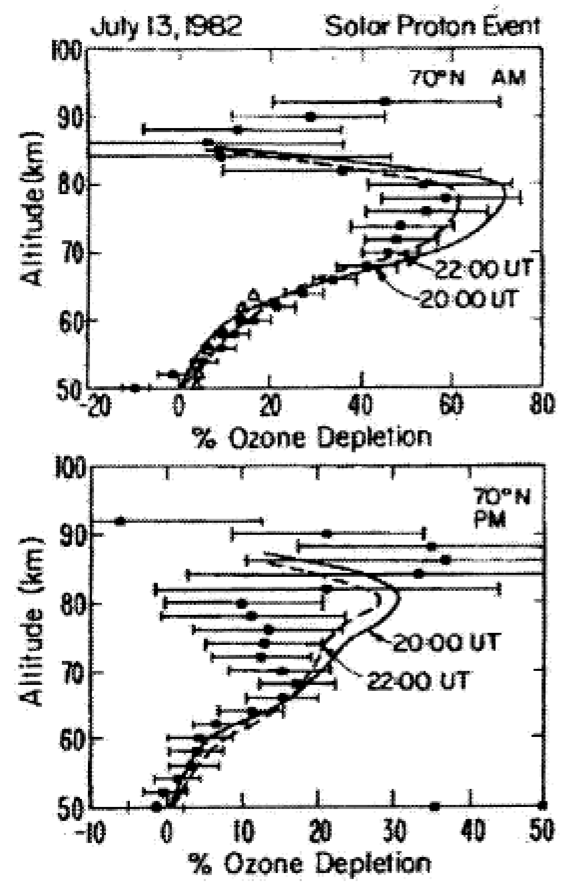


Figure 9. Taken from Fig. 3 of Solomon et al. [1983]. Observed ozone depletion on July 13, 1982 at 70°N latitude on the AM and PM portions of the Solar Mesosphere Explorer (SME) orbit (each point represents a mean of three orbits on July 13, 1982 near 1830, 2120, and 2206 UT). Triangles denote data from the UV spectrometer. Model calculated profiles for 2000 and 2200 UT are shown.

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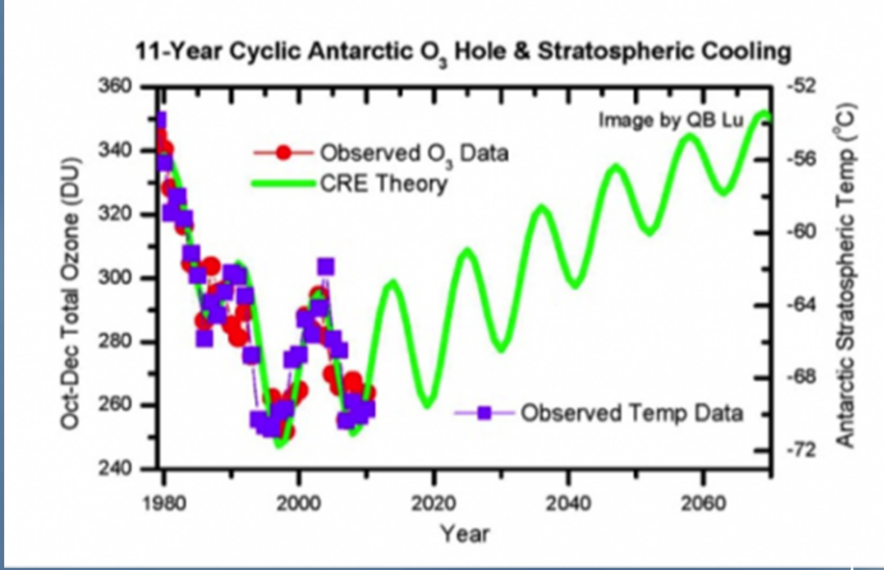
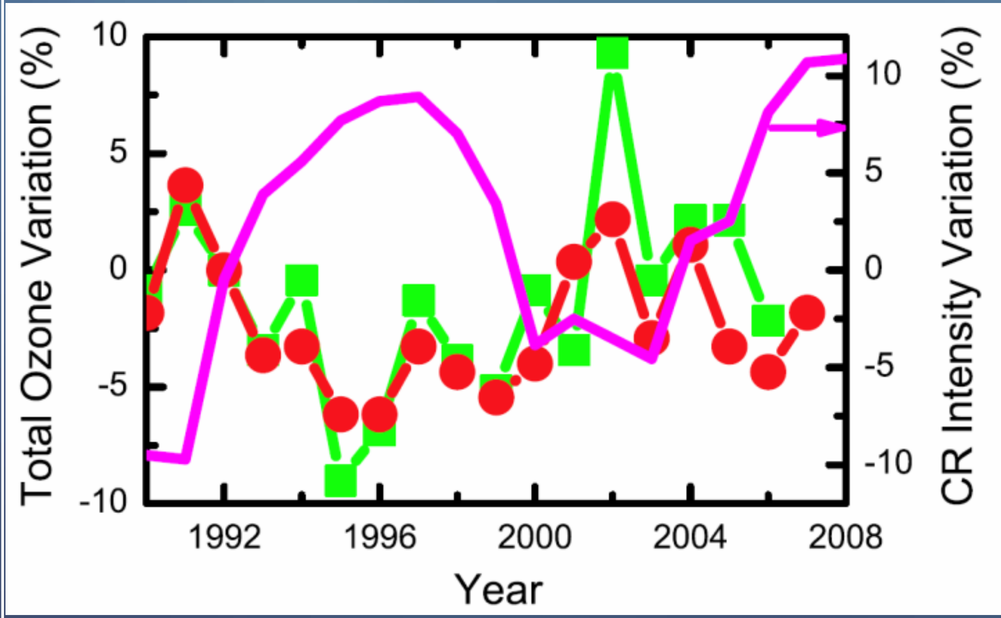
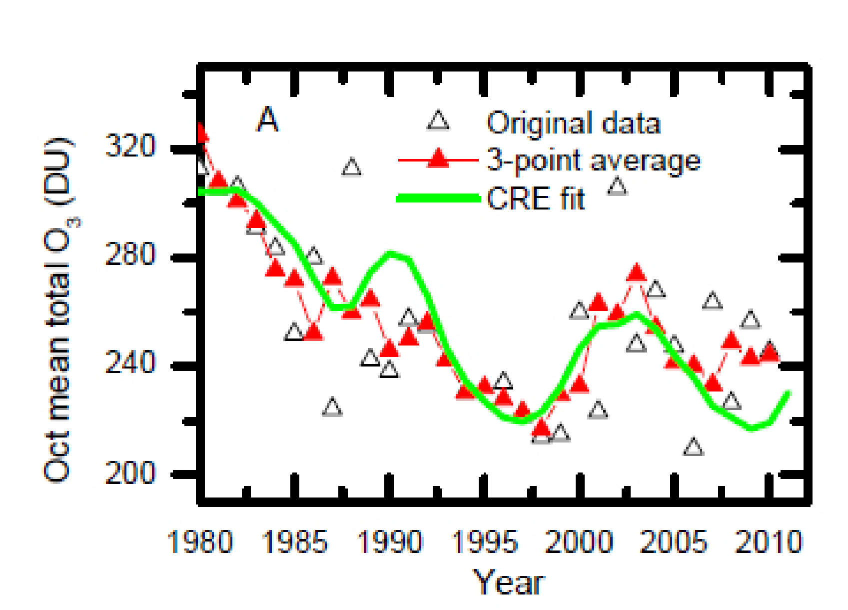
CRE theory; cosmic rays play the dominant role iozone-depleting mechanism

"New Theories and Predictions on the Ozone Hole and Climate Chang e" (2015)
Qing-Bin Lu (University of Waterloo, Canada





Percentage variations of CR flux (solid magenta line) and annual mean total O3 measured at two Antarctic stations, Faraday/Vernadsky (in red and green).



Two figures showing the 11-year cycle in the Antarctic ozone hole and the cosmic ray induced reaction (CRE).

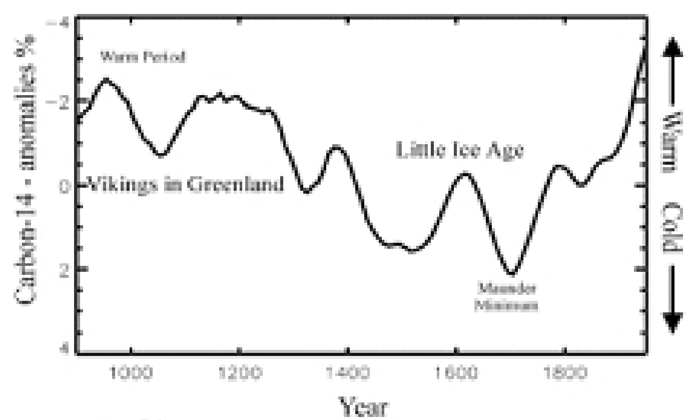
A celestial driver for climate change?

Both historical and recent observations suggest that cosmic rays may play a significant role in the climate processes, on different time scale.

- Ten of years
- Hundred of years
- Million of years

GCR in the past : proxies as C14, Be7, Cl36, in ice or fossil sediments

GCR in the recent period: from Neutron Monitor



Changes in the ^{14}C levels over the past 1000 years, relative to 1950.
Variability in ^{14}C is mainly due to changes in solar activity
Pictures from: Space Science Review 00: 1-16, 2000.

Proxies from ^{14}C in ice cover

Cosmogenic nuclei

Cosmic rays generate unstable nuclides in two principal ways:
by direct bombardment of target atoms (causing atomic fragmentation or ‘spallation’),
and by the agency of cosmic-ray-generated neutrons.

$$^{14}_{7}N + n = {}^{14}_{6}C + p$$

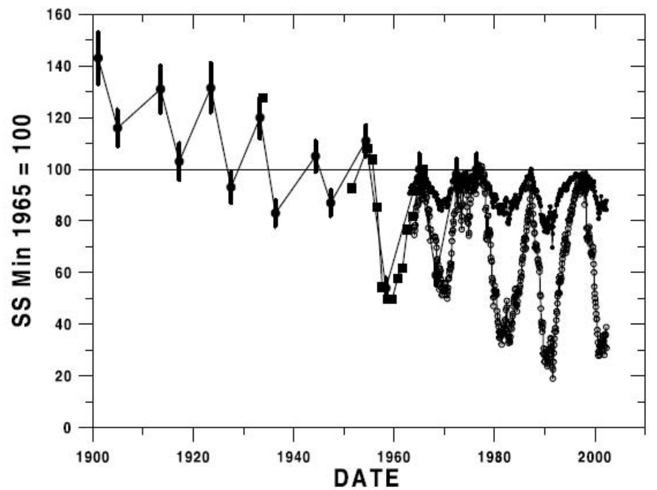
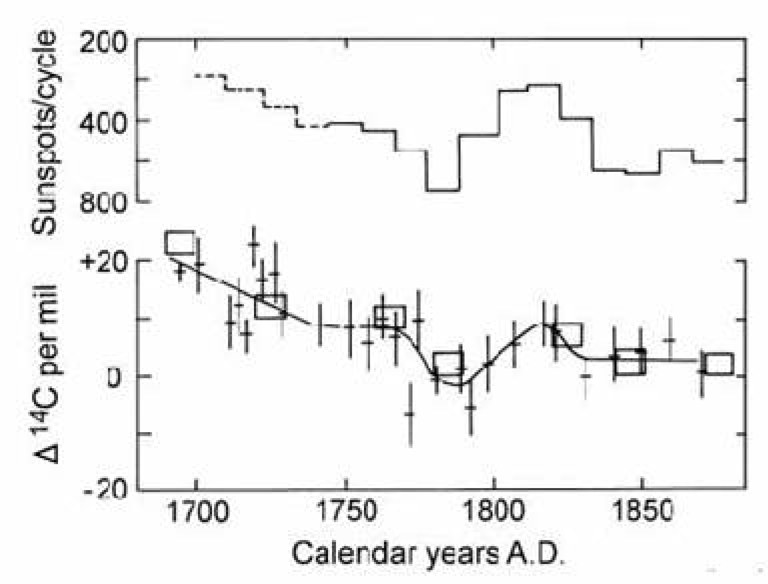


Figure 8. Temporal variations of cosmic rays and ^{10}Be observed from 1933 to the present. All variations are normalized to 100 for the average of the solar minima in 1965 and 1976. The cosmic ray data shown include (1) high-latitude Mt. Wash plus Climax neutron monitor (solid circles); (2) integral >70 MeV cosmic ray rates from spacecraft [*Lockwood et al.*, 2001] (open circles); (3) high-altitude balloon data from ionization chambers [*McCracken and McDonald*, 2001; *Neher*, 1967] (solid squares); (4) ^{10}Be concentrations at minima and maxima of the solar cycle [*McCracken and McDonald*, 2001] (large solid circles with error bars).



Plots of sunspot activity and relative ^{14}C activity,
expressed as parts per mil, to show coherent anti-correlation in the 17th and 18th centuries

The Sun is a driving factor for the climate on the Earth

Evidences both from recent observations and from climate proxies suggest that solar variability represents an important contribution to climate changes.

BUT…

Variations of solar irradiance are too small to account for the climate variability

Therefore …

other mechanisms could exist to amplify the solar variations

↓

Interaction of cosmic rays with the Earth atmosphere

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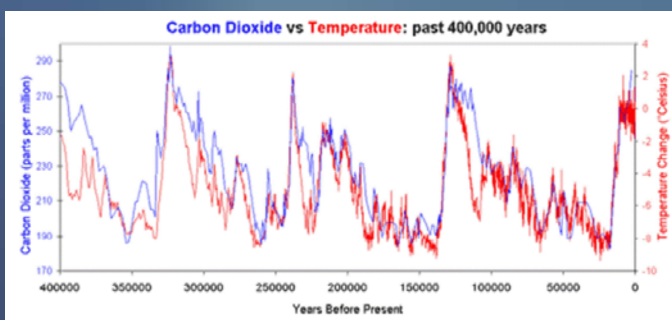
Global warming forcing factors

North Hemisphere relative temperature growth from 1610 to 1995

ΔT [°C] = 0.8°

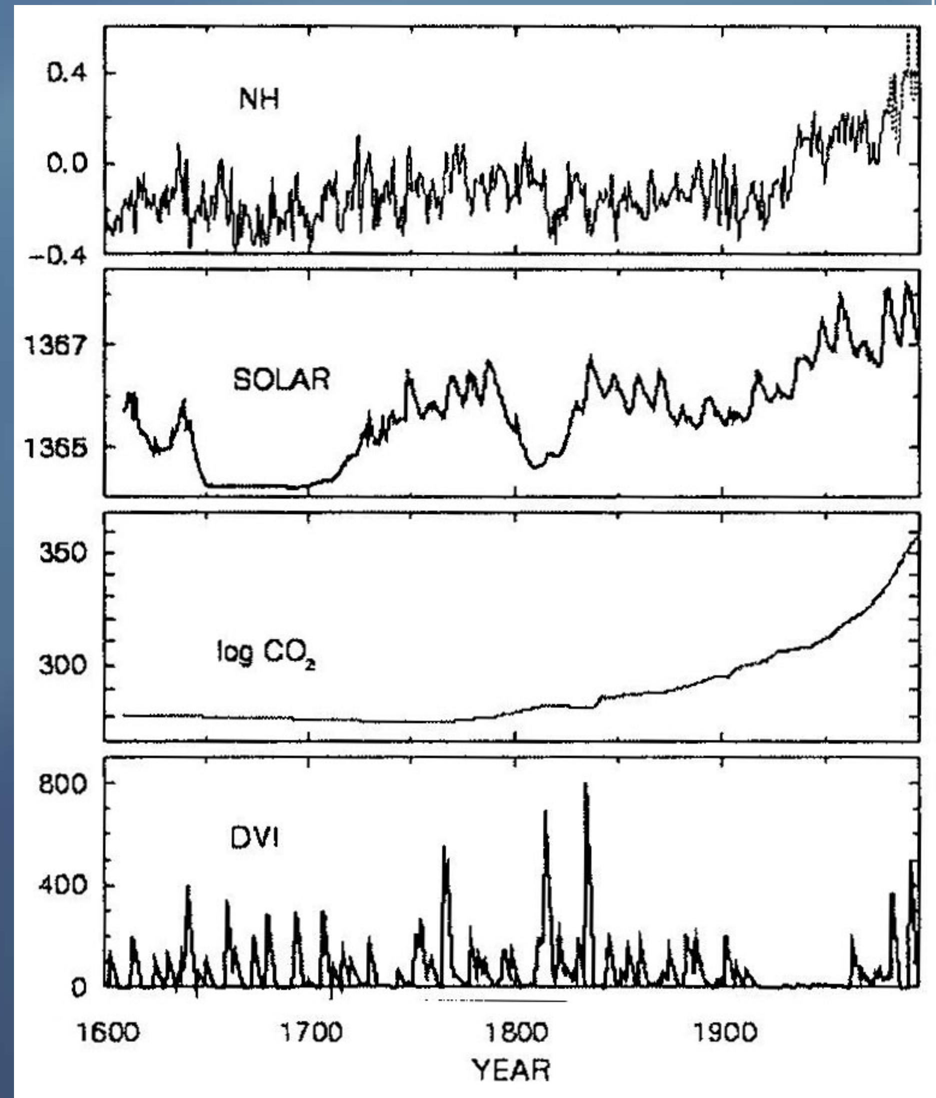
Solar irradiance

ΔW [W/m^2]= 0.08



CO_2

Vulcanic dust index



Growth of some anthropogenic products and greenhouse effects

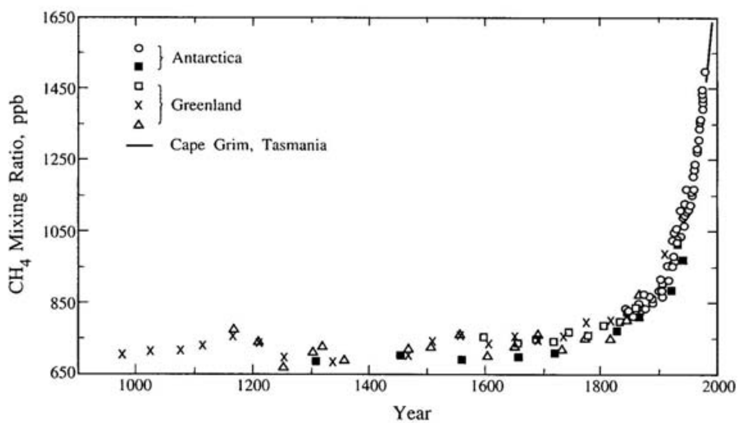


FIGURE 2.8 Methane mixing ratios over the last 1000 years as determined from ice cores from Antarctica and Greenland (IPCC, 1995). Different data points indicate different locations. Atmospheric data from Cape Grim, Tasmania, are included to demonstrate the smooth transition from ice core to atmospheric measurements.

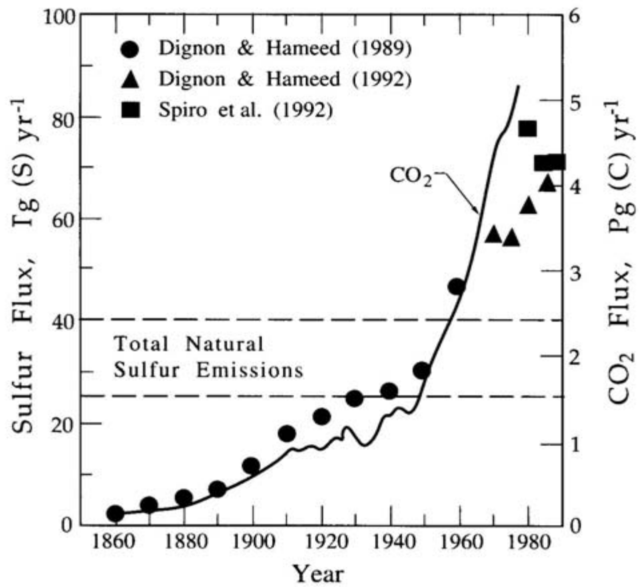


FIGURE 2.1 Global anthropogenic SO_2 and CO_2 emissions since 1860 (Berresheim et al., 1995). Data are from Dignon and Hameed (1989; circles), Hameed and Dignon (1992; triangles), and Spiro et al. (1992; squares). CO_2 emissions (solid curve) are shown for reference. Dashed lines indicate the estimated range for the global natural sulfur flux (excluding seasalt sulfate).

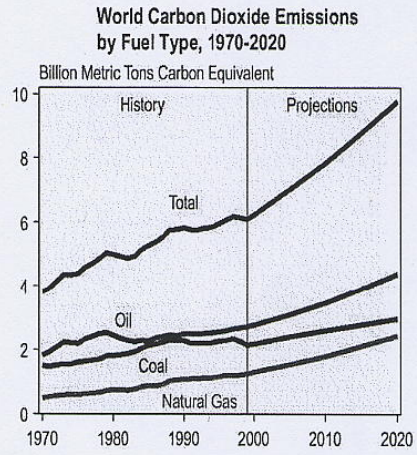


Figure 7.7: World Carbon Dioxide Emissions (US Dept. of Energy)

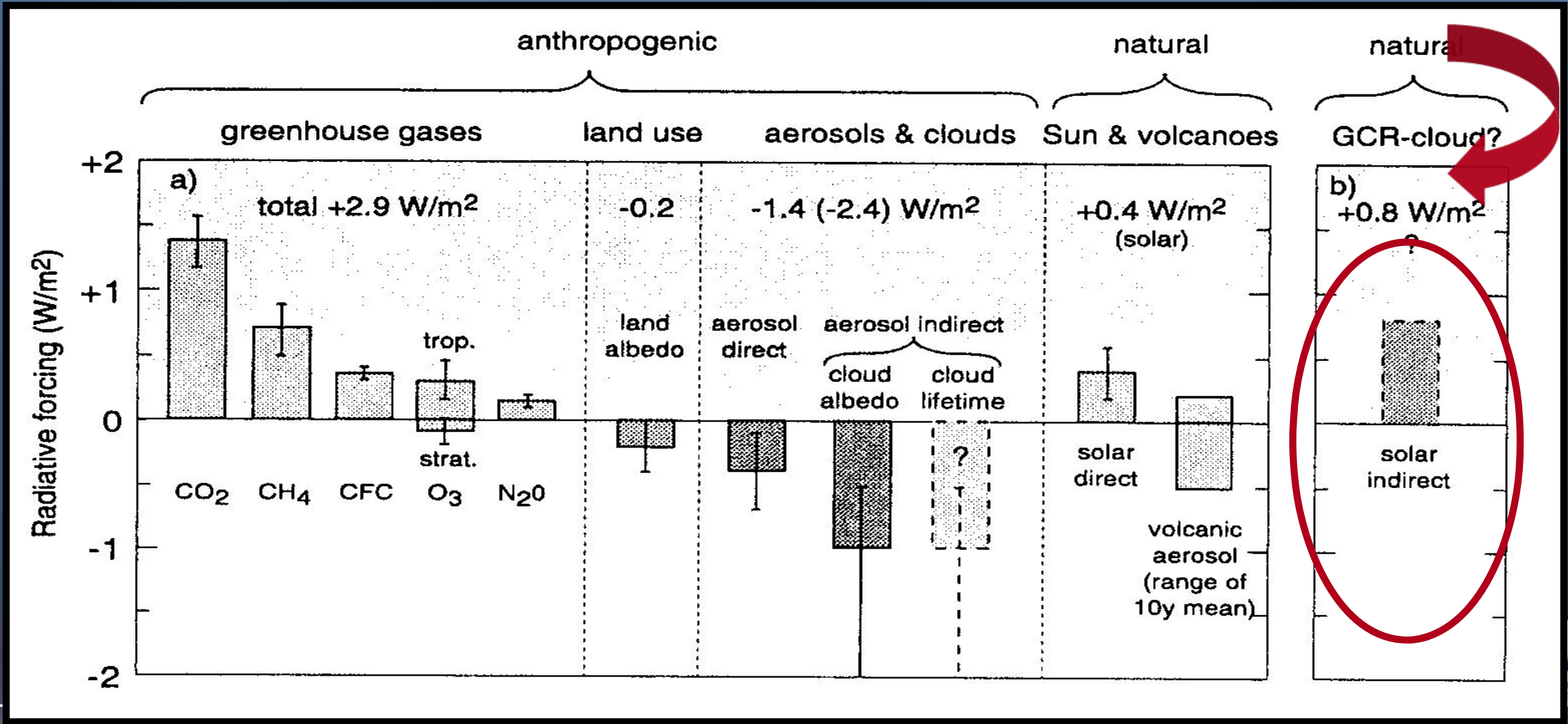
Greenhouse gas absorbs energy
at longer wavelenghts
and traps heat radiated by the surface:
the atmosphere is transparent
to solar radiation but opaque to IR

Global mean radiative forcing of the climate 1750-2000

Physical paths connecting variation of the Sun to the Earth climate:

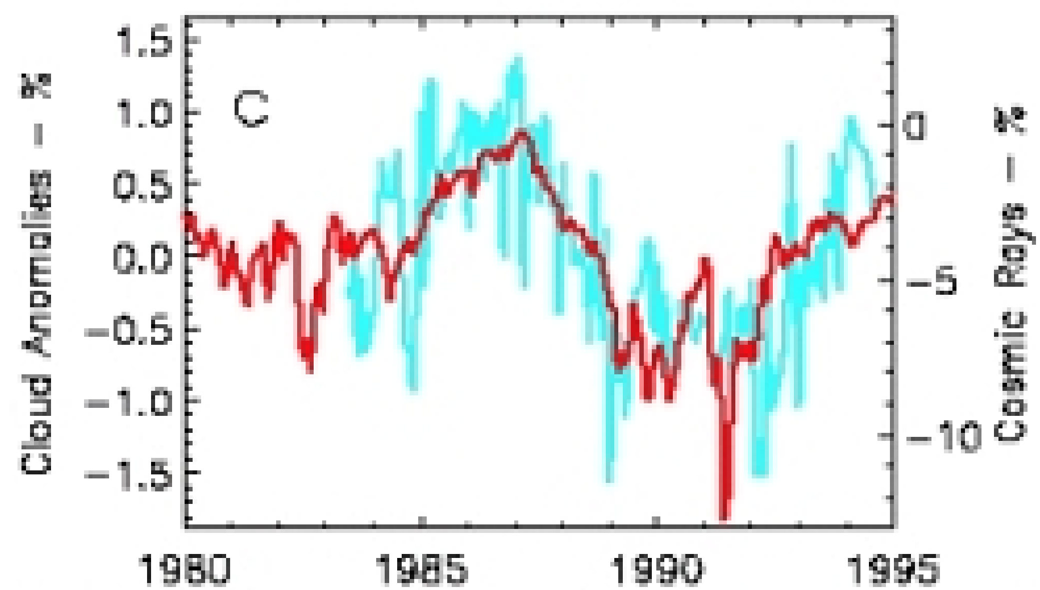
- Solar electromagnetic radiation: 0.1 W/m^2 per solar cycle
  <TOO LOW>
- Solar wind interaction with magnetosphere: low energy particles
  only significant in polar regions

GCR modulated by solar activity -Cloud Cover



The Cloud Mystery

During the last solar cycle Earth's cloud cover underwent a modulation in phase with the cosmic ray flux. Assuming that there is a causal relationship between the two, it is expected and found that Earth's temperature follows more closely decade variations in cosmic ray flux than other solar activity parameters. If the relationship is real the state of the Heliosphere affects Earth's climate. *"Cosmic rays and earth's climate» Henrik Svensmark Danish Space Research Institute, DK-2100 Copenhagen Ø, Denmark*



Blue: Monthly mean values for global anomalies of low cloud cover
Red: Galactic cosmic ray fluxes (normalised to May 1965), used as a proxi for solar variability

Satellite observations

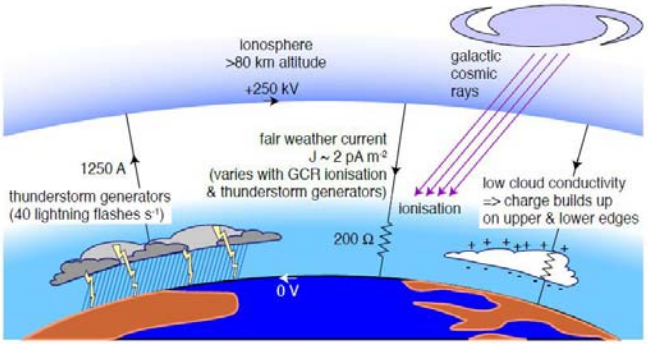
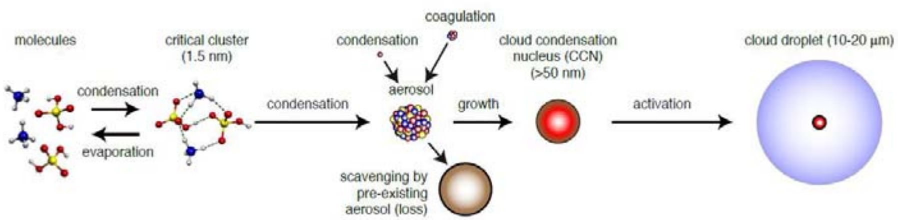
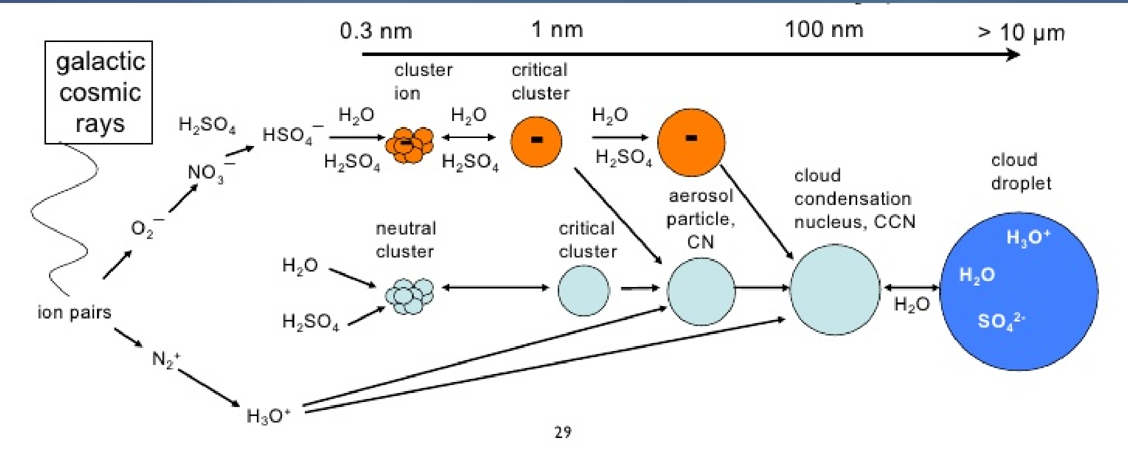


Fig. 3: The ion-aerosol "near-cloud" mechanism [10]. Highly charged aerosol particles develop at cloud boundaries due to the build-up of space charge from the fair weather current. These charged aerosol particles may then become entrained by clouds and possibly enhance the formation of ice particles.





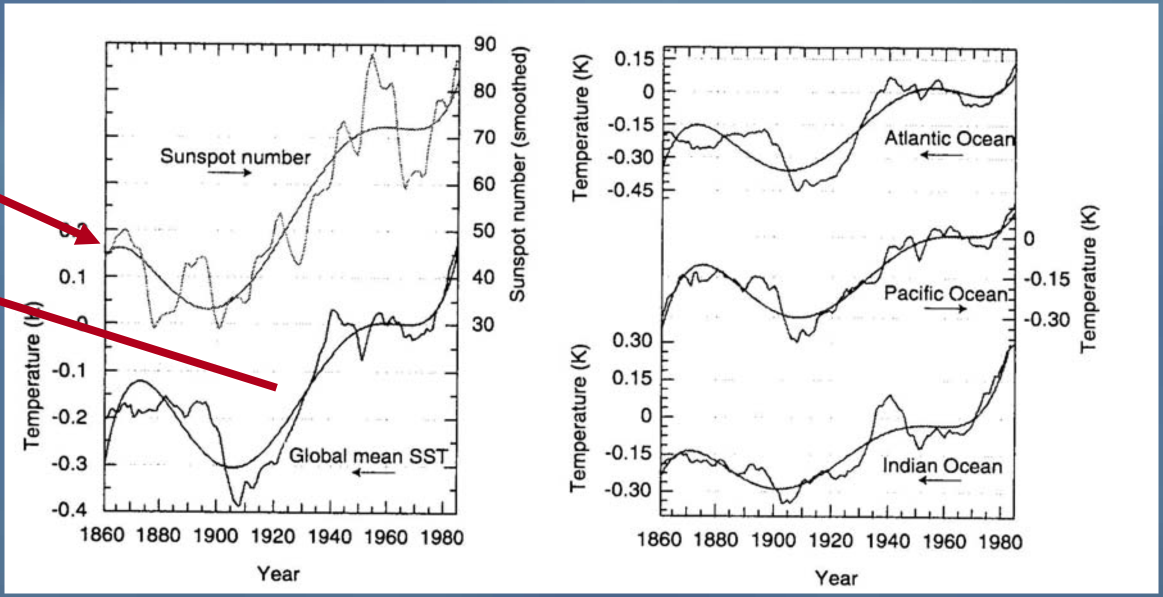
Since cosmic rays dominate the troposphere ionization,
an increased solar activity will translate into a reduced ionization, and empirically, also to a reduced low altitude cloud cover.

Since low altitude clouds have a net cooling effect (their "whiteness" is more important than their "blanket" effect), increased solar activity implies a warmer climate. Intrinsic cosmic ray flux variations will have a similar effect,one
wever, which is unrelated to
ar activity variations.

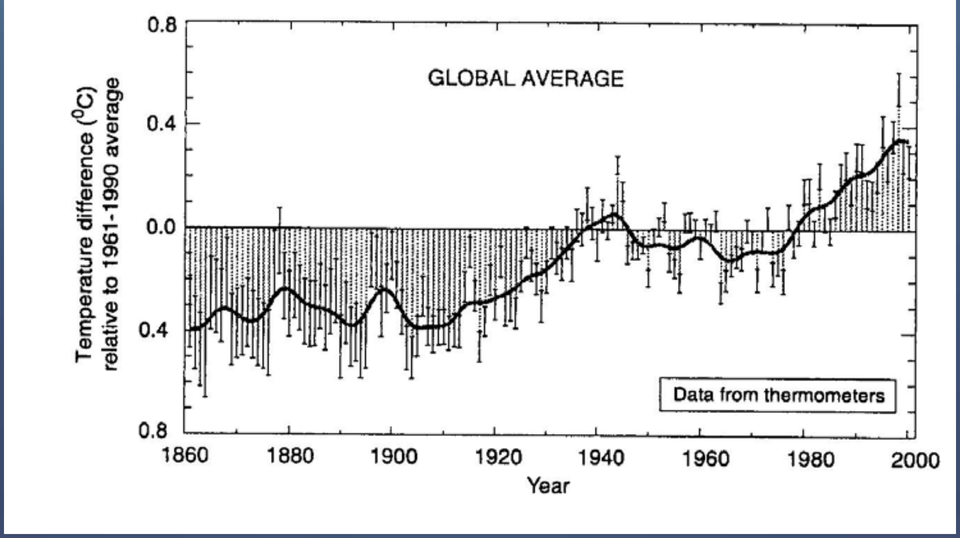
The global system response

Sunspot number

Annual and
11-year cycle
mean sea- surface
temperature
(1860-1985)



Global mean
surface
temperature of
the Earth
(1860-2001)



The Sun-Earth link

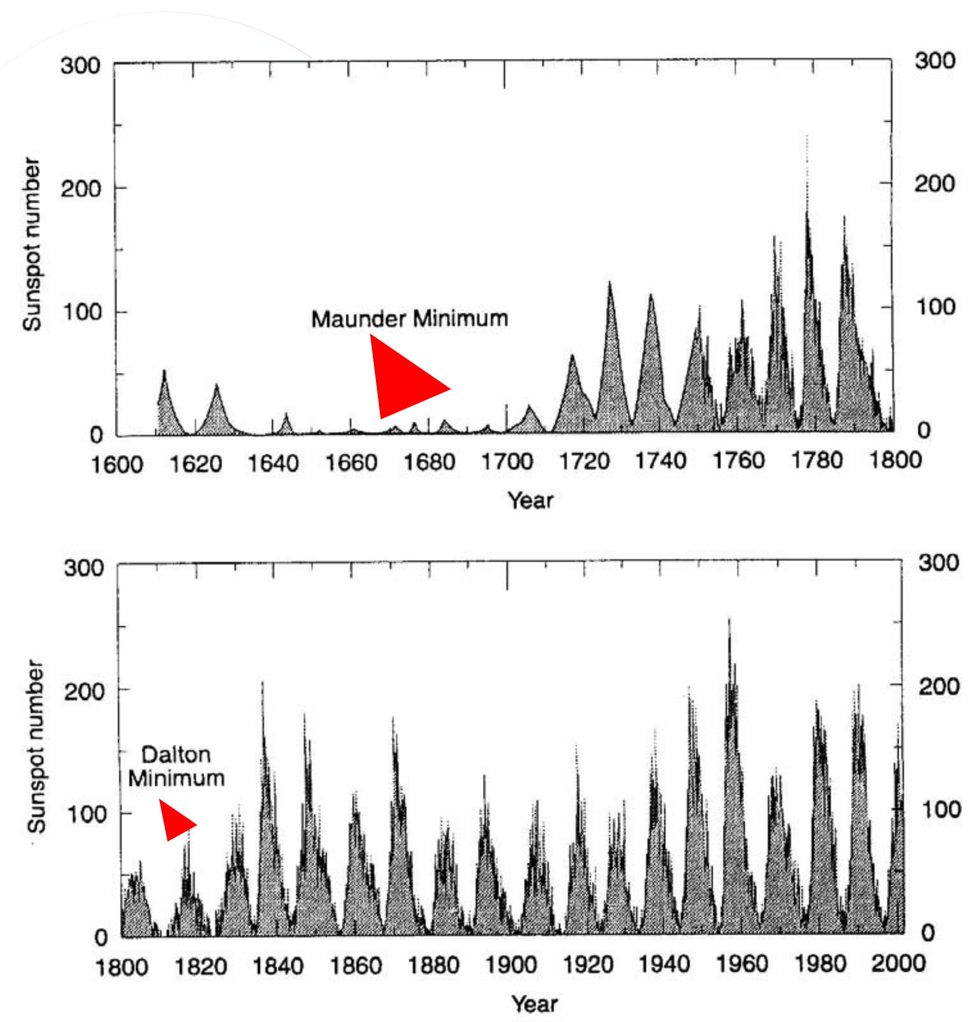
Sunspots from 1610-2001

(1600-1890 little Ice Age)

Maunder Minimum: 1600-1720

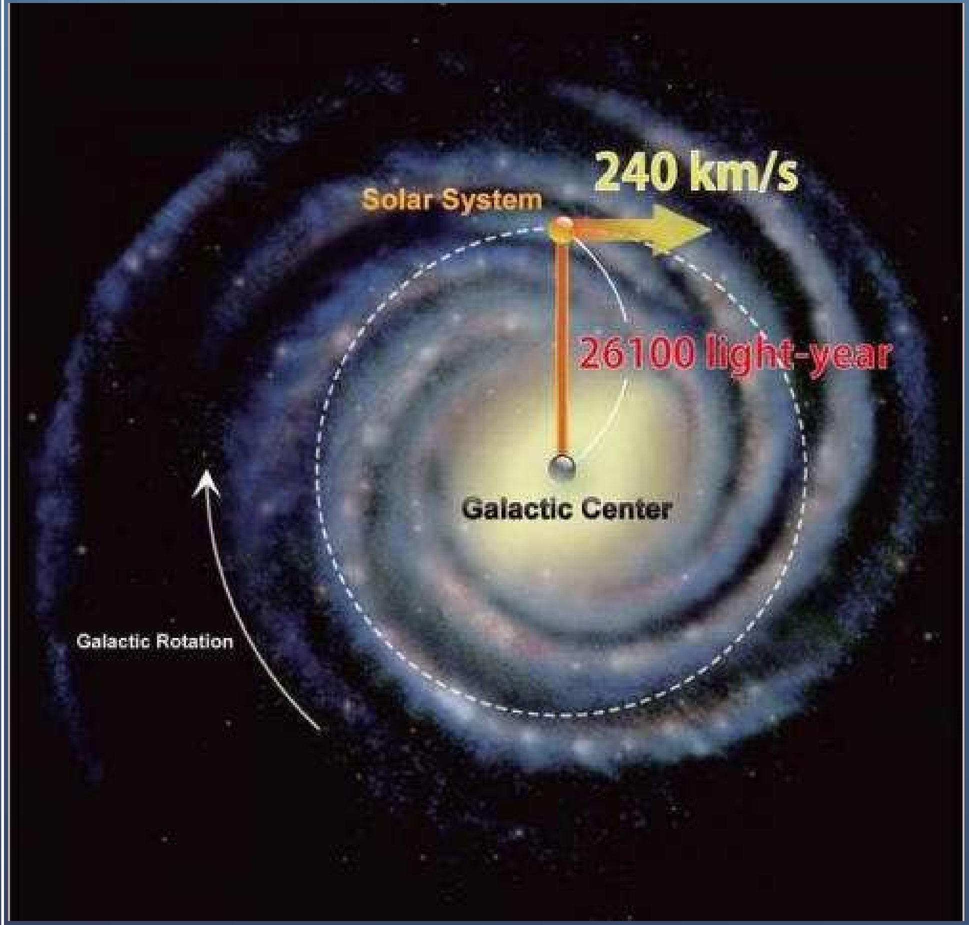
During the period of Louis XIV, Le roi Soleil, (1643-1715) the Seine and the River Thames in London were regularly frozen.

Dalton minimum: 1800-1840



Long term climate Changes : Million of years

The solar system in the galaxy



"Cosmic Year: the time taken for one complete revolution of the Sun around the entire center of the galaxy; about 250 million years."

About 20 revolution in 5 billions of years

Each time we cross a galactic arm, we should expect a colder climate. Current data for the spiral arm passages gives a crossing once every
135 ± 25 Million years.

The observed period of the occurrence of ice-age epochs on Earth **is 145 ± 7 Myr**

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Nir J. Shaviv, *Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem,*
Ján Veizer, *Institut für Geologie, Mineralogie und Geophysik, Ruhr Universität, 44780 Bochum, Germany, and Ottawa-Carleton Geoscience Centre, University o*

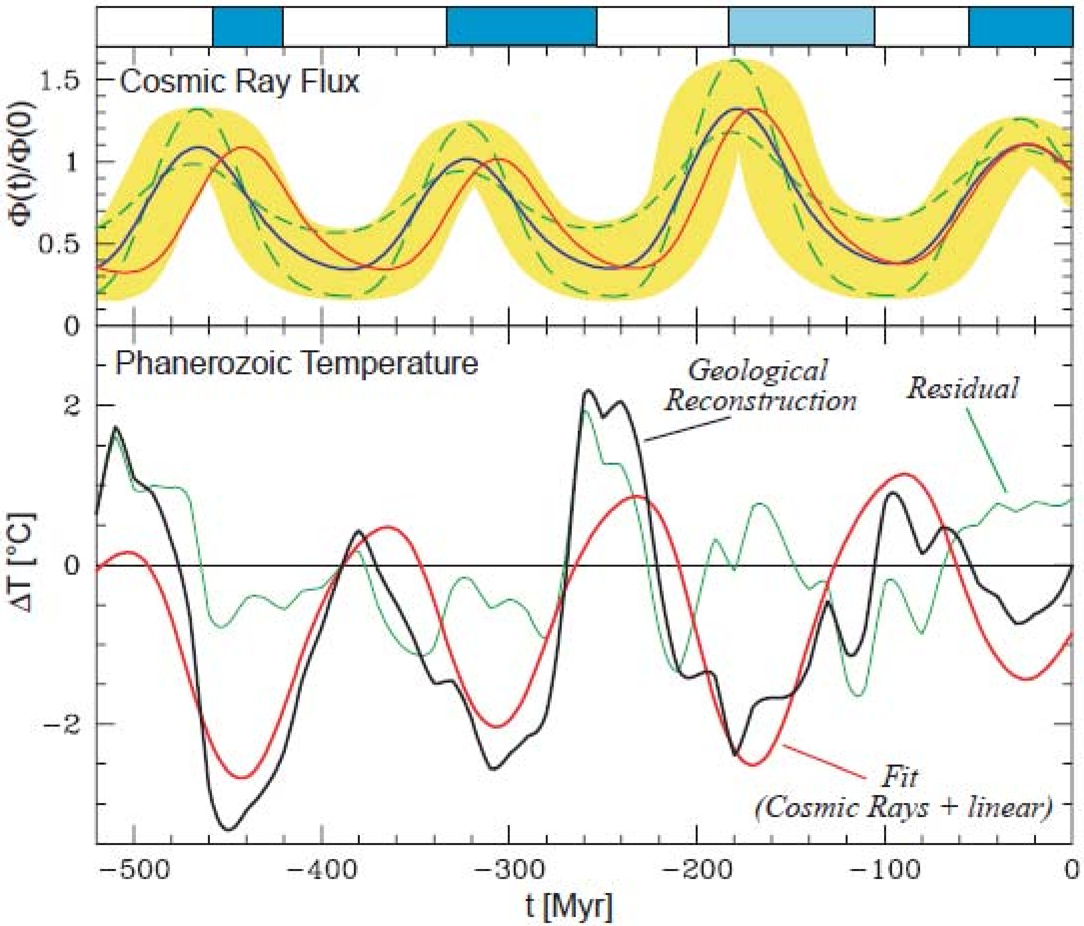


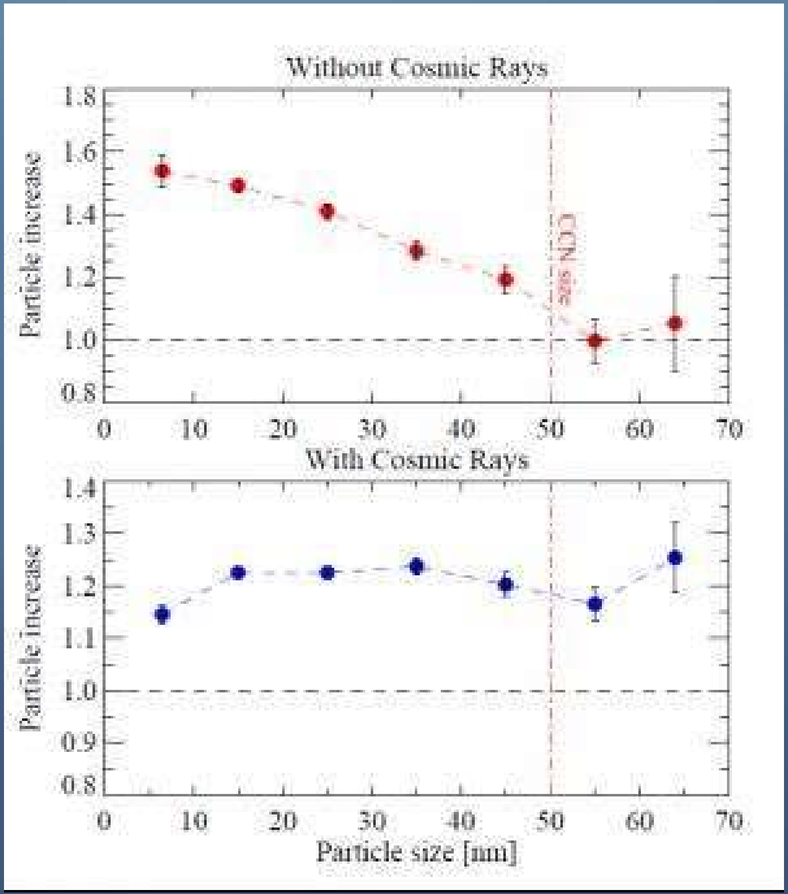
Figure 2. The cosmic ray flux (Φ) and tropical temperature anomaly (ΔT) variations over the Phanerozoic. The upper curves describe the reconstructed CRF using iron meteorite exposure age data (Shaviv, 2002b). The blue line depicts the nominal CRF, while the yellow shading delineates the allowed error range. The two dashed curves are additional CRF reconstructions that fit within the acceptable range (together with the blue line, these three curves denote the three CRF reconstructions used in the model simulations). The red curve describes the nominal CRF reconstruction after its period was fine tuned to best fit the low-latitude temperature anomaly (i.e., it is the "blue" reconstruction, after the exact CRF periodicity was fine tuned, within the CRF reconstruction error). The bottom black curve depicts the 10/50 m.y. (see Fig. 1) smoothed temperature anomaly (ΔT) from Veizer et al. (2000). The red line is the predicted ΔT_{model} for the red curve above, taking into account also the secular long-term linear contribution (term $B \times t$ in equation 1). The green line is the residual. The largest residual is at 250 m.y. B.P., where only a few measurements of $\delta^{18}O$ exist due to the dearth of fossils subsequent to the largest extinction event in Earth history. The top blue bars are as in Figure 1.

Experimental studies

- DTU's SKY2 experiment - University of Denmark
- The CLOUD Experiment at CERN

DTU's SKY2 experiment - University of Denmark

Simulating what could happen in the atmosphere, the DTU's SKY2 experiment shows molecular clusters (red dots) failing to grow enough to provide significant numbers of "cloud condensation nuclei" (CCN) of more than 50 nanometres in diameter.
This is what existing theories predict.
But when the air in the chamber is exposed to ionizing rays that simulate the effect of cosmic rays, the clusters (blue dots) grow much more vigorously to the sizes suitable for helping water droplets to form and make clouds.
Credit: Technical University of Denmark



Cosmic rays and climate change

- 1998 Influence of Cosmic Rays on Earth's Climate

  Henrik Svensmark, Phys. Rev. Lett. **81**, 5027 –November 1998

  professor in the Division of Solar System Physics at the Danidh National Space Institute , Copenaghen

- **2004** ATPROMO (**AT**mosphere **P**arameters and **R**adiation **O**n **M**ountain **O**bservatories) Project for Network of excellence -25 Institutions, 250 Researchers, 10 High Mountain Observetories-

- 2009 experiment CLOUD at CERN is designed to mimic conditions in the Earth's atmosphere. By firing beams of particles from the lab's Proton Synchrotron accelerator into a gas-filled chamber, they have discovered that cosmic rays could have a role to play in

  climate by enhancing the production of potentially cloud-seeding aerosols.

- The CLOUD study shows that the oxidised biogenic vapours bind with sulphuric acid to form embryonic particles which can then grow to become the seeds on which cloud droplets can form. This result follows previous measurements from CLOUD showing that sulphuric acid alone could not form new particles in the atmosphere as had been previously assumed.
- amines, that have previously been shown by CLOUD to cluster with sulphuric acid to produce new aerosol particles in the atmosphere. Amines, however, are only found close to their primary sources such as animal husbandry, whereas alpha-pinene is ubiquitous over landmasses.

The CLOUD Experiment at CERN

- A stainless steel chamber of volume $26 m^3$, filled with synthetic air made from liquid nitrogen and liquid oxygen.
- Small quantities of other gases such as sulphur dioxide or organic compounds are added, and aerosol particles are formed and characterised.
- Experiments focus on measuring the rate of formation of aerosol particles with different mixtures of gases in the chamber, and investigating the effect of ionisation on this formation rate.
- The ionisation produced by cosmic rays can be enhanced with a high energy particle beam from the CERN Proton Synchrotron, or removed with a strong electric field.
- In addition, if the humidity inside the chamber is close to 100%, cooling achieved by fast adiabatic expansion can be used to make clouds in the chamber.
- At warm temperatures, this allows chemical processes inside cloud droplets to be studied and, at lower temperatures, experiments on ice microphysics are carried out.

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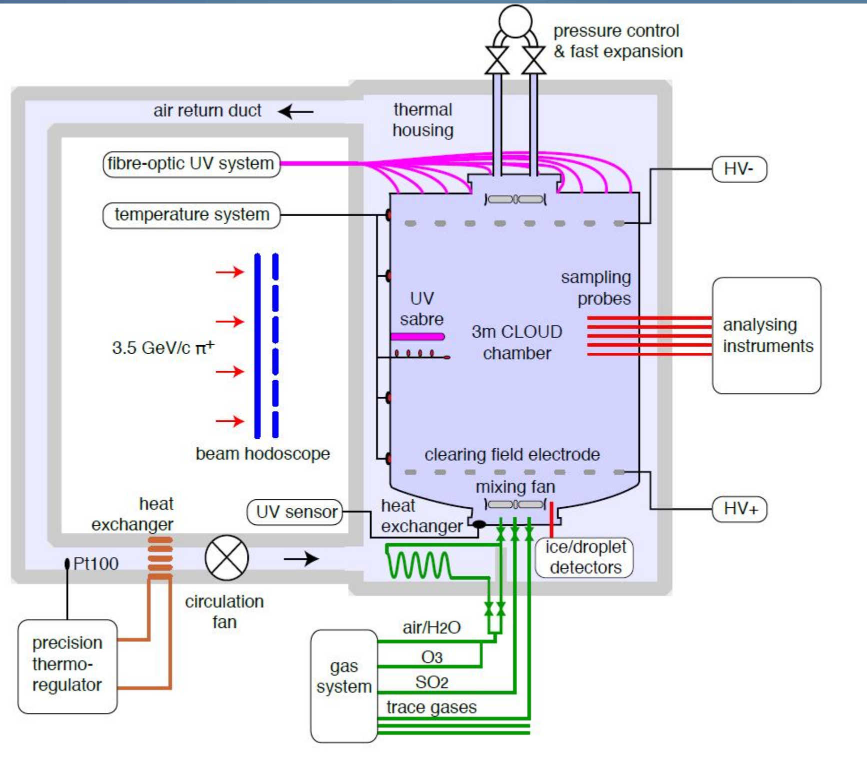
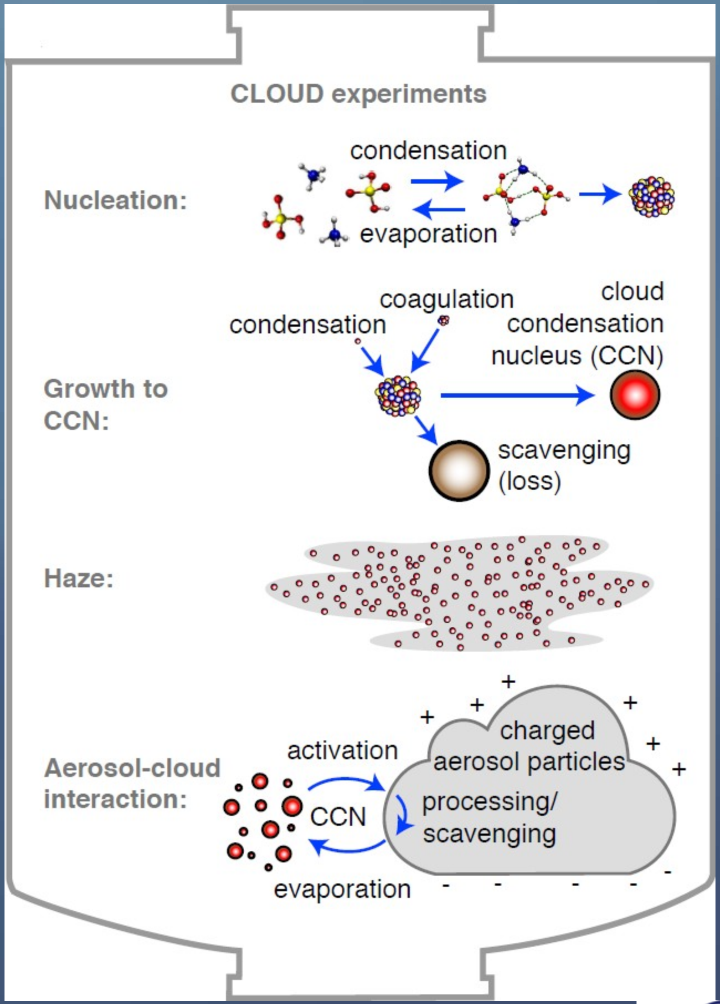
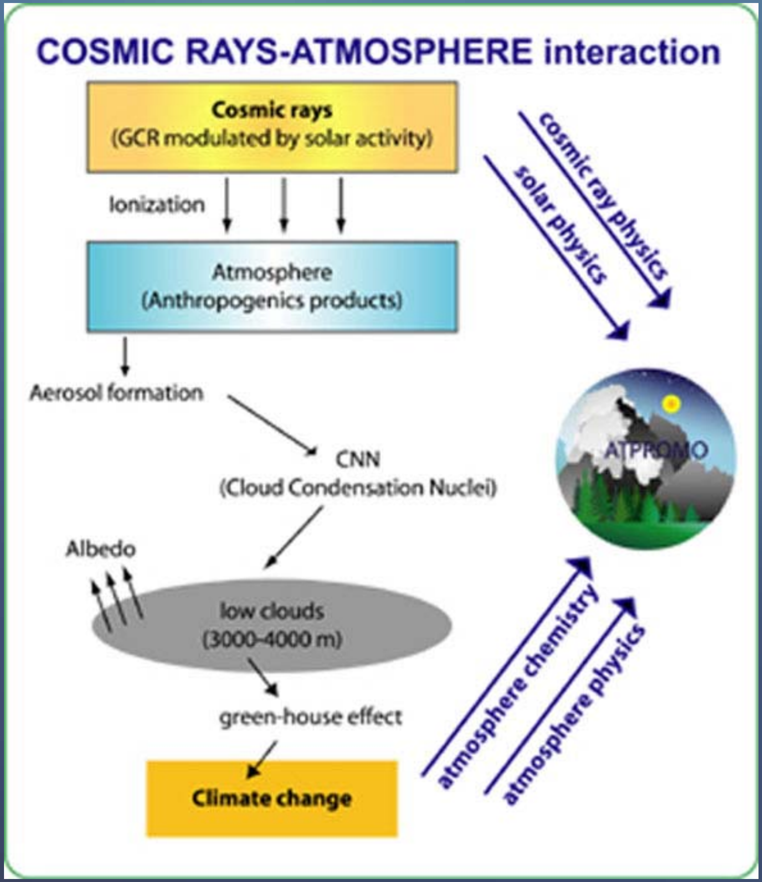


Fig. 5: Schematic of the CLOUD experiment in 2012.



ATPROMO
(ATmosphere Parameters and Radiation On Mountain Observatories)



Interdisciplinary research involving:

- Solar Physics
- Cosmic Rays Physics
- Cosmic Rays Detection
- Ionizing Radiation Dosimetry
- Atmosphere Physics
- Atmosphere Chemistry
- Atmosphere Modelling
- Air Shower Simulation

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Figure … s and

range