Correlation of Earth's cloud coverage and the Galactic Cosmic Rays (GCR) flux

Why the CLOUD experiment at CERN?

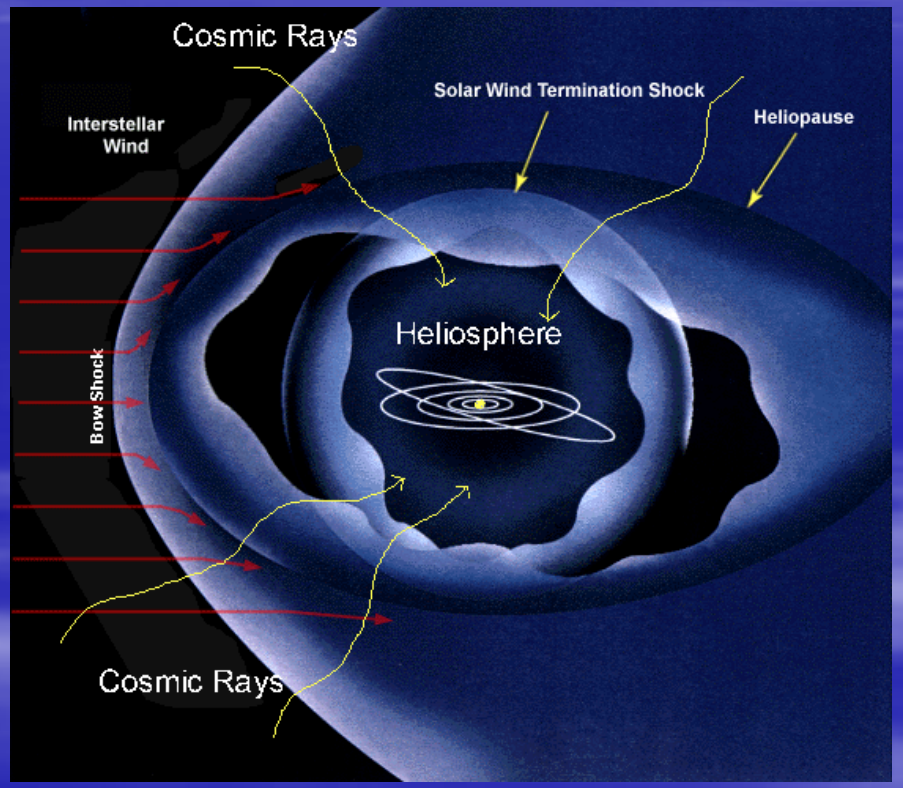
- There is a clear correlation between the 11 year sunspot cycle and the GCR
  - Intensity of the **G**alactic **C**osmic **R**ays arriving at the Earth's higher atmosphere is modulated by the 11 year sunspot cycle (magnetic field radiation)
- **The exact mechanism of cloud production is largely unknown**
  - Ions can grow via clustering and form aerosol particles → **C**loud **C**ondensation **N**uclei (CCN)
- GCR create through cascade (showers) ions
  - Evolve to CCN
    - **The net effect of clouds is cooling**

Some facts about the Sun

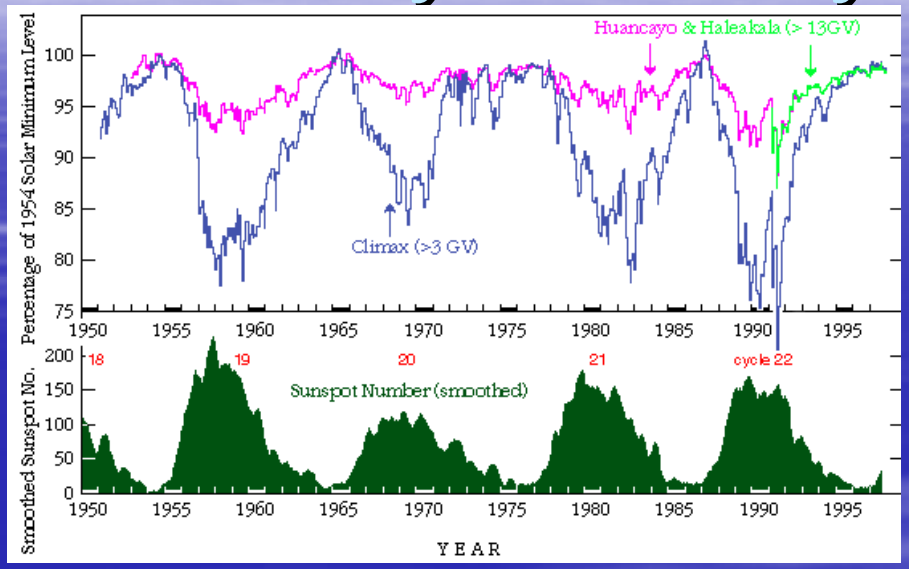
- Solar wind:
  - Continuous outward flow of p, e^- and ~5 % He nuclei, from the plasma of the Sun's corona
  - The solar wind carries also magnetic fields and creates a huge "Heliosphere" that extends out to 50-100 AU (well beyond the orbit of Neptune)
- At the Earth's orbit:
  - V_{sw} ~350-800 km/sec, I~(0,5-5)x10^8 particles/cm^2sec
- Magnetic fields
- Coupled to the sunspot 11 year cycle
  - At sunspots the H_{sun}~2.500 Gauss (H_{Earth}~0,3 Gauss)
  - The H_{sun} starts as a dipole and at the end of the 11 year cycle it ends through magnetic recombination as dipole (but of opposite polarity)
  - H_{dipole}~50 Gauss

The Sun's environment/Cosmic rays

- Cosmic Rays
  - CR ≡ p, He^{2+}……Fe^{n+}
  - Charged particles ⇒ "focused"/directed/deviated by magnetic fields
- Origin of CR
  - **Galactic cosmic rays** (GCR)
  - **Solar cosmic rays** (SCR)
  - **Anomalous cosmic rays** (ACR)
- E_{CR} : ~0 to > ~ 10^{15} GeV
- For comparison: LHC at CERN: ~7 Tev (7 x 10^3 GeV)



Data: Cosmic rays vs 11 year cycle

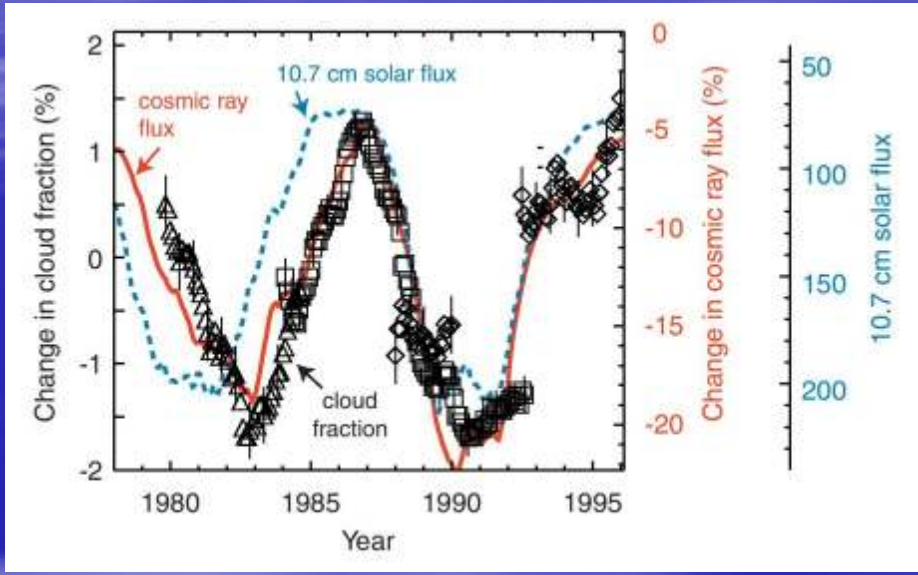


- Neutron monitor data
- Clear correlation f(geomagnetic latitude of station)
- **Strong** Solar activity $\Rightarrow$ **Low** GCR flux
- **Weak** Solar activity $\Rightarrow$ **High** GCR flux

GCR, Sun, Earth clouds, Climate

- Is there a path of events connecting the 4 processes ?
  - Solar wind → GCR → Clouds → Climate
- Indeed we do have some evidence
  - Henrik Svensmark & Eigil Friis-Christensen
    - "Variation of Cosmic ray flux and global cloud coverage-a missing link in solar-climate relationships
      - *Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 59, No. 11, pp. 1225-1232, 1997*

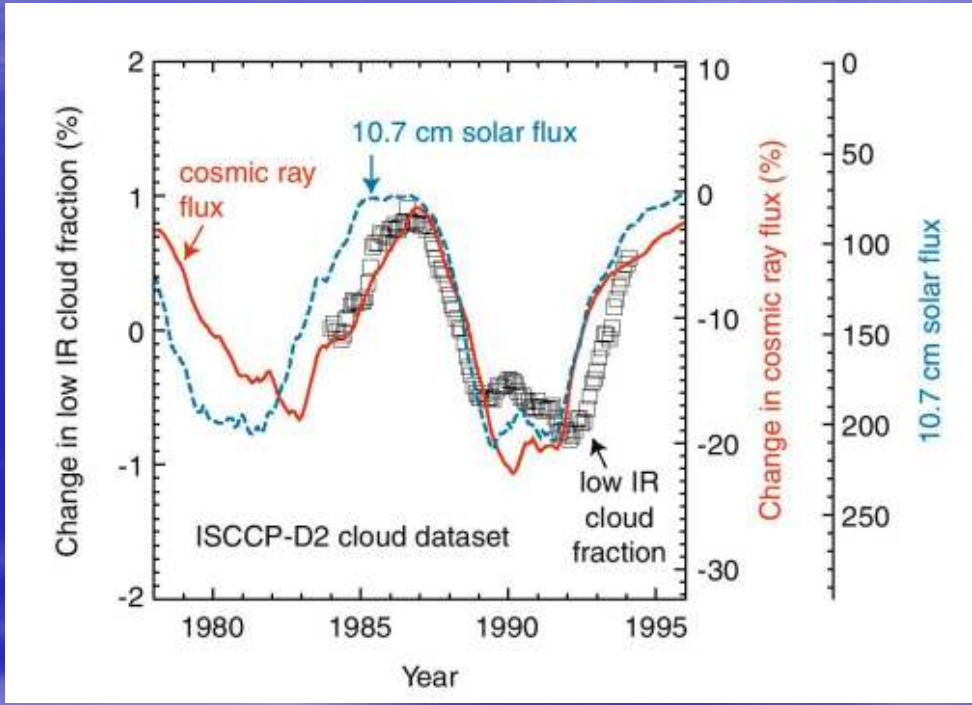
Satellite Cloud data vs. CR flux



- Absolute % variation of global cloud cover
- satellite data points
  - Cloud data (only oceans)
  - Nimbus7 (triangles)
  - DMSP southern hemisphere (diamonds)
  - ISCCP-C2 ocean data with tropics excluded (squares)
- Cosmic Ray data (Red)
  - From the Climax monitor (Red line)
- Solar λ=10,7 cm μwave flux
  - Dashed blue line
- Data smoothed with a 12-month running average

Improved satellite cloud data

- International Satellite Cloud Climate Project D2 data
  - 5 geostationary
  - 2 polar orbiting
  - Measurements at:
    - Visible λ~0,6 *μm*
    - Near infra-red λ~3,7 *μm*
    - Infra-Red λ~10-12 *μm*
- Best match:
  - Low (~<3,2 km) IR clouds



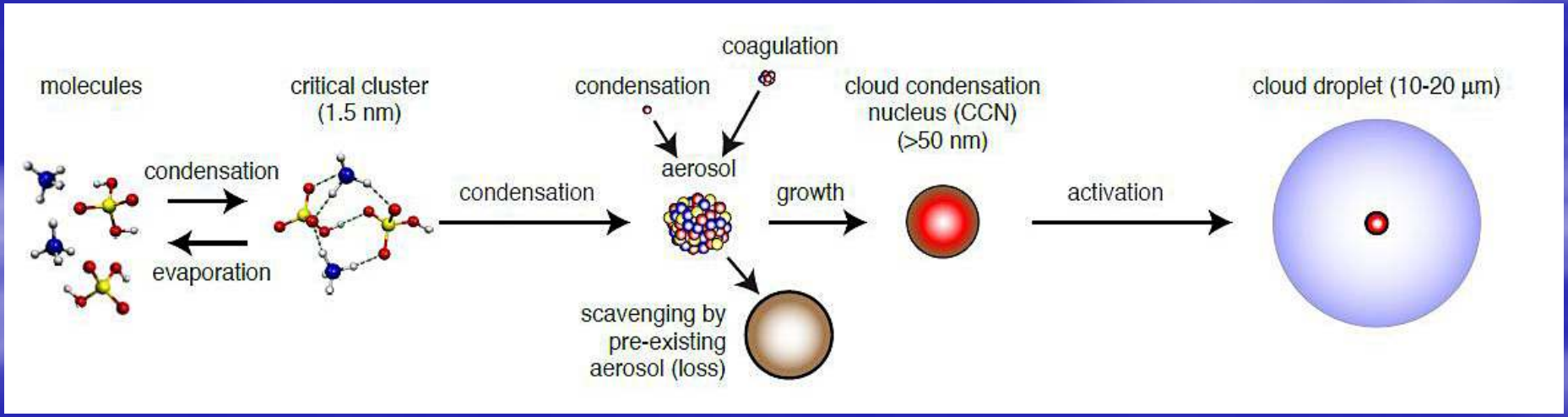
Observation on clouds

Parameter	High Clouds		Middle Clouds		Low Clouds	Total
	Thin	Thick	Thin	Thick	All	
Global ftraction (%)	10,1	8,6	10,7	7,3	26,6	63,3
Forcing (relative to clear sky):						
Albedo (SW radiation) (Wm^{-2})	-4,1	-15,6	-3,7	-9,9	-20,2	-53,5
Outgoing LW radiation (Wm^{-2})	6,5	8,6	4,8	2,4	3,5	25,8
Net forcing (Wm^{-2})	**2,4**	**-7,0**	**1,1**	**-7,5**	**-16,7**	**-27,7**

- **E**arth **R**adiation **B**udget **E**xperiment (ERBE) data
  - Clouds reflect more energy than they trap
- 63 % of Clouds $\rightarrow$ ~ - 28 Wm^{-2}
  - **+**XX $\Rightarrow$ Warming, **-**XX $\Rightarrow$ Cooling

Aerosol formation, Nucleation process

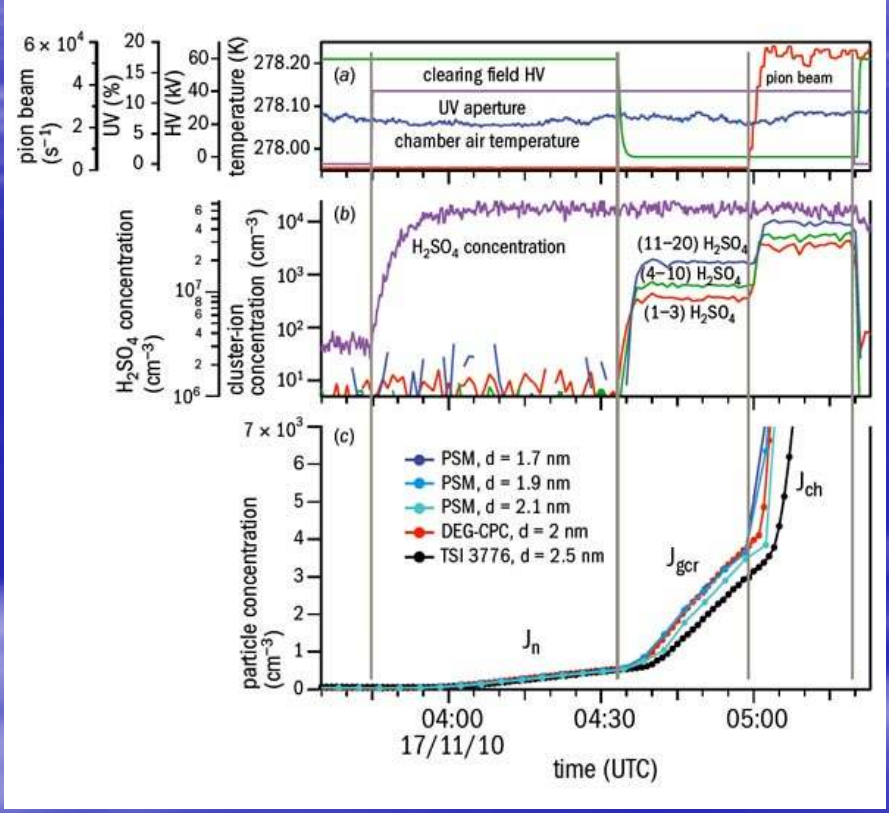
- 50% of cloud droplets ⇔ nucleated by aerosol particles
- Physical mechanism? Largely unknown
- CLOUD (**C**osmics **L**eaving **Ou**tdoor **D**roplets)
- Model:



CLOUD experiment at CERN

- 2 x 2 x 2 m^3 chamber stainless steel cloud chamber
  - Temperature operation
    - 300 K to 183 K
  - Temperature stability
    - ~0,01 K
- Gas impurities:
  - $< 1/10^{12}$ (one part per trillion)
- Nucleation process of selected gases
  - Internal electrical (ion) clearing field
- Photolytic reactions
  - UV illumination (fibre-optic)
- Concentration measurements
  - Advanced Mass spectrometers
- Cosmic rays simulation
  - PS π^+ beam p~3,5 GeV/C

“Runs” and Results



- First Runs:Formation of new particles from:
  - H_2SO_4, NH_3 and H_2O vapours
  - Nucleation/atmosphere
- Enhancement of atmospheric aerosol from GCR

Results (I)

- The nucleation measured in the chamber occurs at only 1/10 to 1/1000 of the rates observed in the lower atmosphere:
  - H_2SO_4, NH_3 and H_2O vapours **cannot** account on their own for the observed atmospheric nucleation
- There must be additional nucleating vapours
- Which ones?
  - Natural or anthropogenic?
- **The climate models for cloud forming have to be revised**

Results (II) & next steps

- CLOUD has found that natural rates of atmospheric ionization caused by GCR substantially enhance nucleation (by a factor ~10) particularly in the cool temperatures of the mid-troposphere (about 5 km altitude) and above
- Next steps:
  - Investigate the role of biogenic organic vapours in atmospheric nucleation and the effect of GCR in these processes

Appendix: Neutron Monitor Stations

Station	Land	Coordinates		Altitude m	Cutoff Rigidity GeV/c
Huancayo	Peru	S12	W75	3.400	12,92
Calgary	Canada	N51	W114	1.128	1,09
Climax	USA	N39	W106	3.400	2,99
Deep River	Canada	N46	W77	145	1,02
Moscow	Russia	N55	E37	200	2,42