Cosmic Rays and Cloud Cover

Jean-Claude Jodogne

Royal Meteorological Institute (RMI)
Ringlaan 3, Avenue Circulaire
B-1180 Brussels, Belgium

Introduction

- A Relevant features

  A1 On cosmic rays (CR)

  A2 On cloud cover (CC)

  A3 On ionization

- B CR and clouds

  B1 Revival of an old idea

  B2 Causal connection?

  B3 CLOUD experiments at CERN

- C Conclusions

Introduction

At the beginning of the 20th century, CTR Wilson showed in his "cloud chamber" the first tracks of cosmic rays visualized by water droplets along their trajectories. The idea that it could be how clouds appears was soon rejected as conditions in the cloud chambers are quite different in the atmosphere.

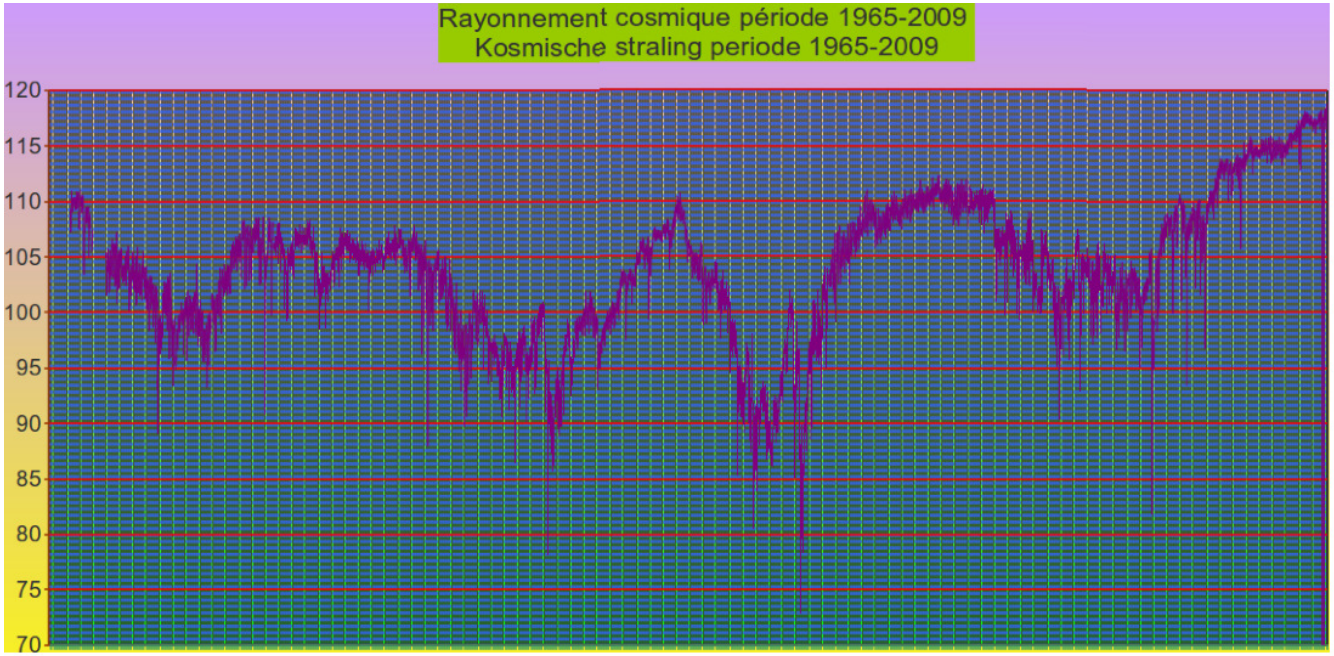
In 1959 E Ney suggested that ions produced by CR might act as condensation centers for cloud droplets and could have an influence on climate.

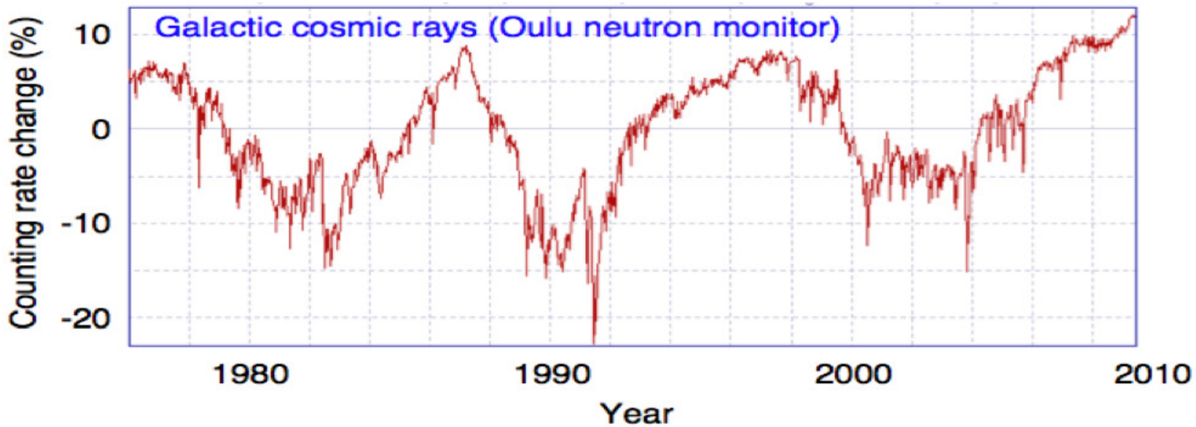
R Dickinson postulated in detail a CR-aerosol-cloud mechanism to explain solar-climate variability in 1975.

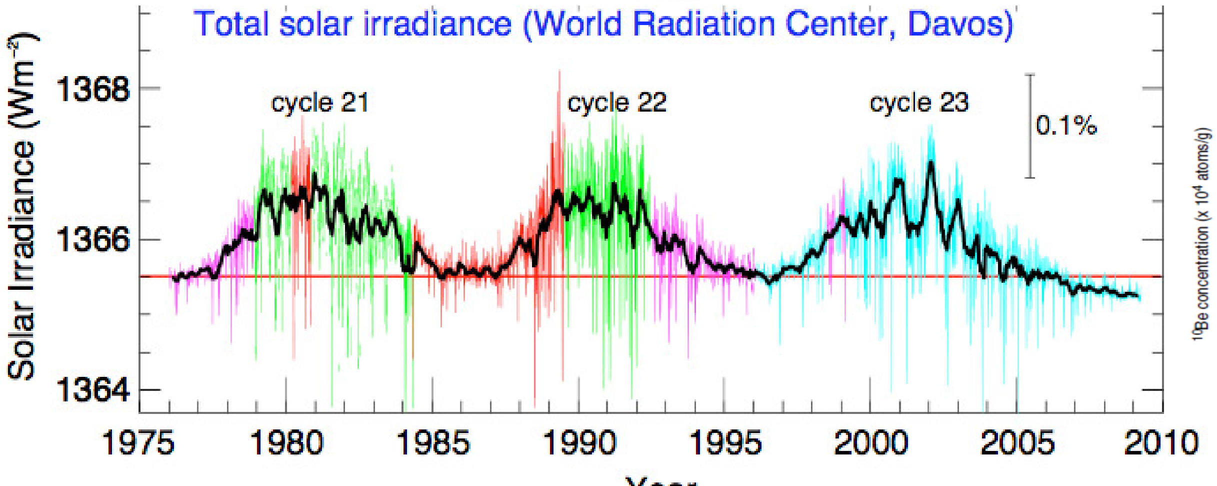
A Relevant features

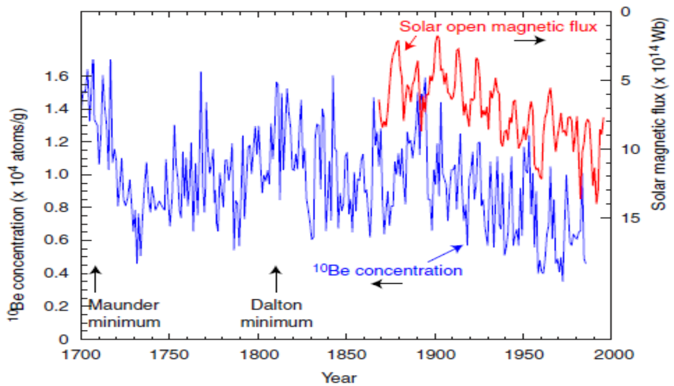
A1 On Cosmic Rays (CR)

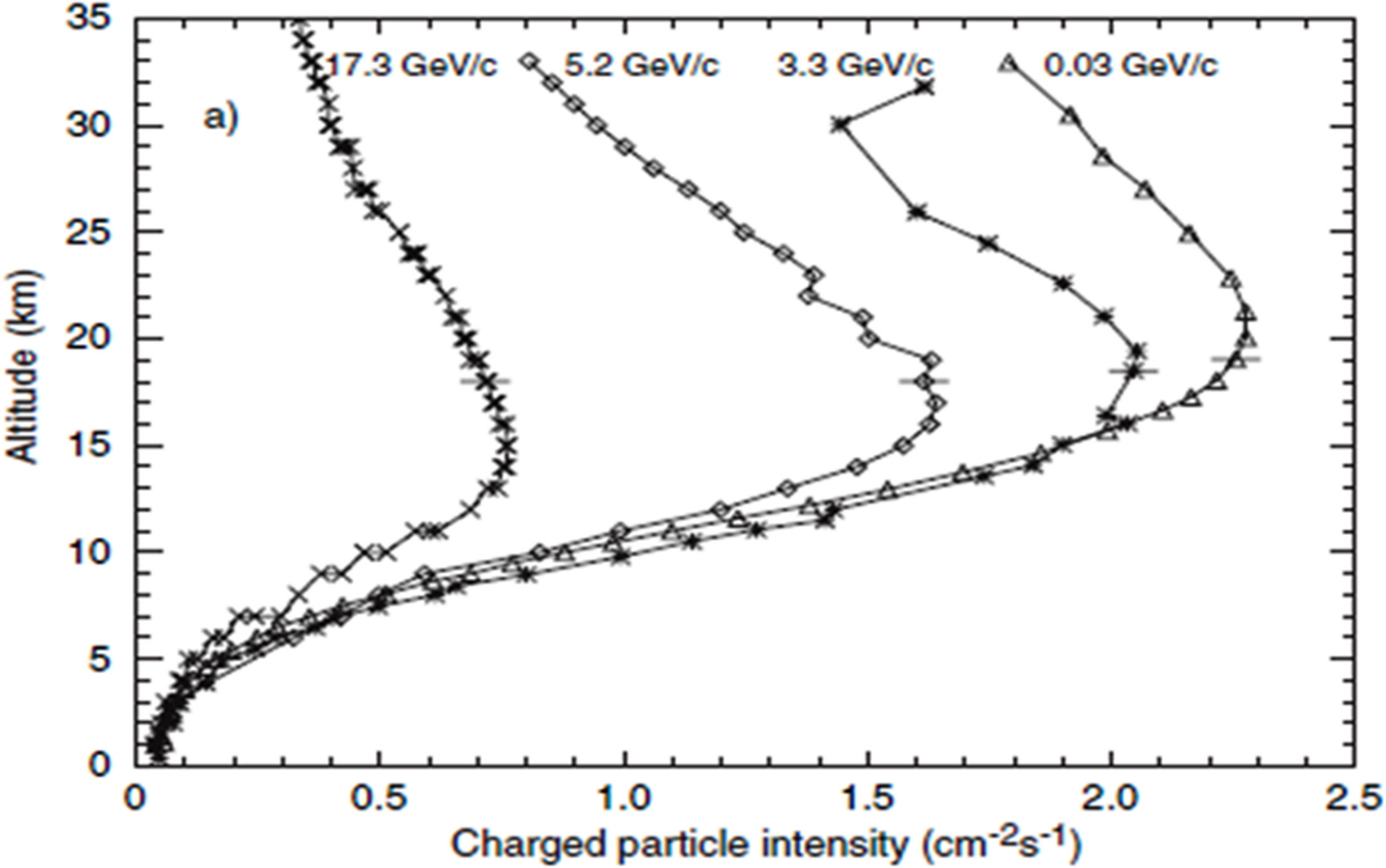
- Composition of primary component: protons (91%), alphas(6%), electrons (1%), nuclei, gammas
- … but fundamental interactions change the composition in the atmosphere, so muons dominate below 6 km
- Ground Level Enhancement (proton event or Forbush decrease)
- Solar cycle variations


Rayonnement cosmique période 1965-2009
Kosmische straling periode 1965-2009

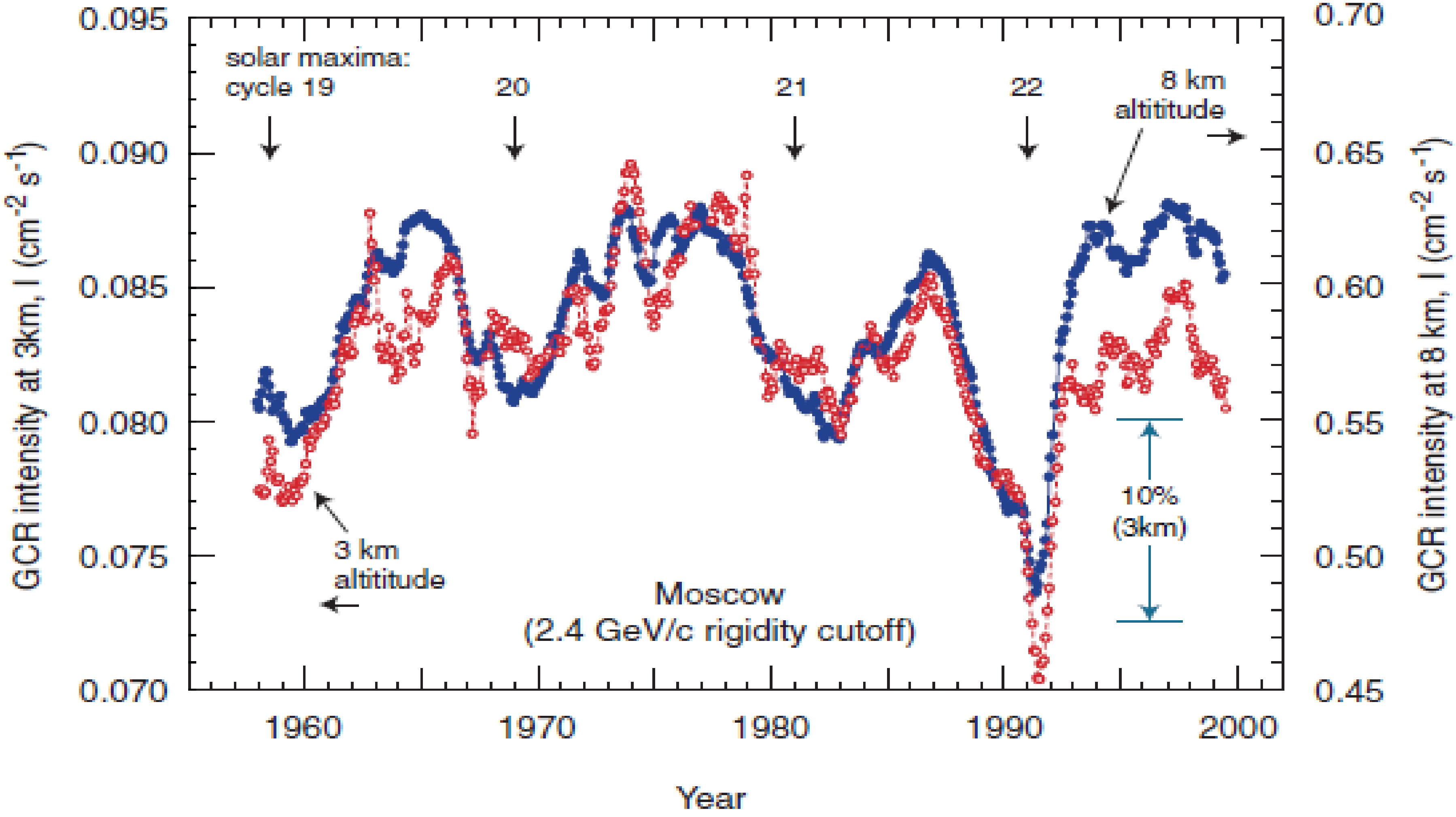

Galactic cosmic rays (Oulu neutron monitor)
Counting rate change (%)
Year


Total solar irradiance (World Radiation Center, Davos)
Solar Irradiance (Wm^{-2})
cycle 21
cycle 22
cycle 23
0.1%


Solar open magnetic flux
^{10}Be concentration (x 10^4 atoms/g)
Solar magnetic flux (x 10^{14} Wb)
^{10}Be concentration
Maunder minimum
Dalton minimum
Year



17.3 GeV/c
5.2 GeV/c
3.3 GeV/c
0.03 GeV/c
a)
Altitude (km)
Charged particle intensity (cm-2s-1)
0
5
10
15
20
25
30
35
0
0.5
1.0
1.5
2.0
2.5

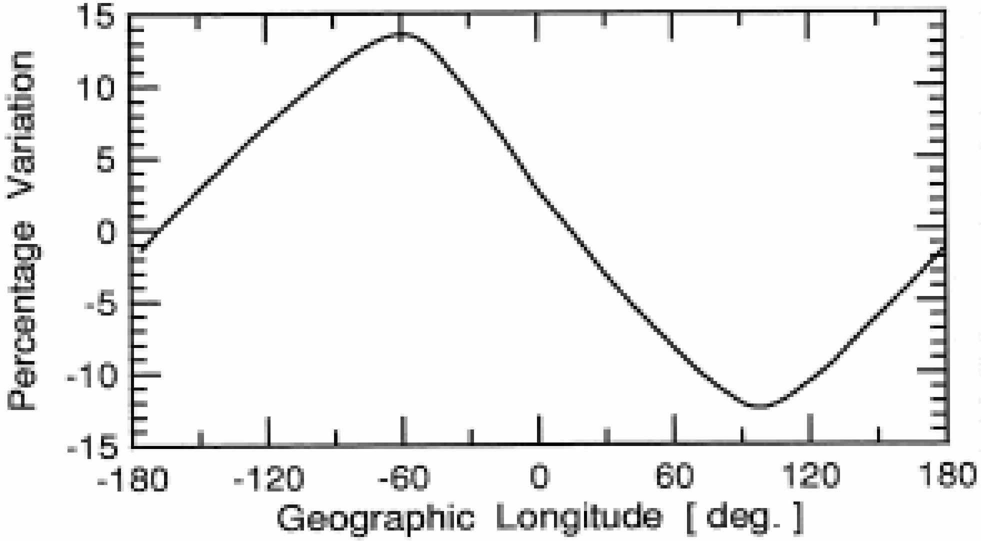


0.095
0.090
0.085
0.080
0.075
0.070
0.70
0.65
0.60
0.55
0.50
0.45
1960
1970
1980
1990
2000
Year
GCR intensity at 3km, I (cm-2 s-1)
GCR intensity at 8 km, I (cm-2 s-1)
solar maxima:
cycle 19
20
21
22
8 km
altititude
3 km
altititude
10%
(3km)
Moscow
(2.4 GeV/c rigidity cutoff)

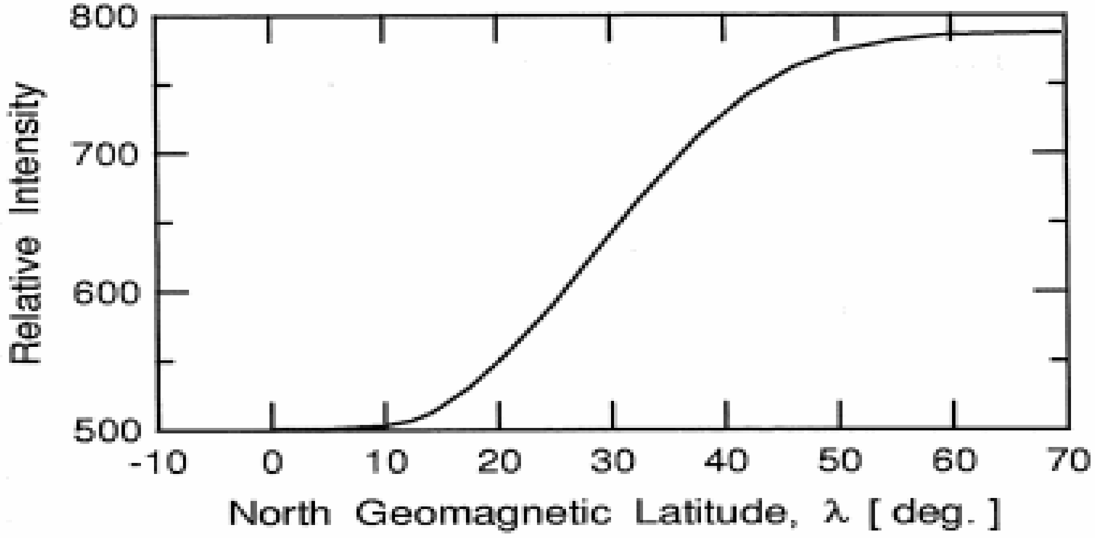
A Relevant features

A2 On Cloud Covers (CC)

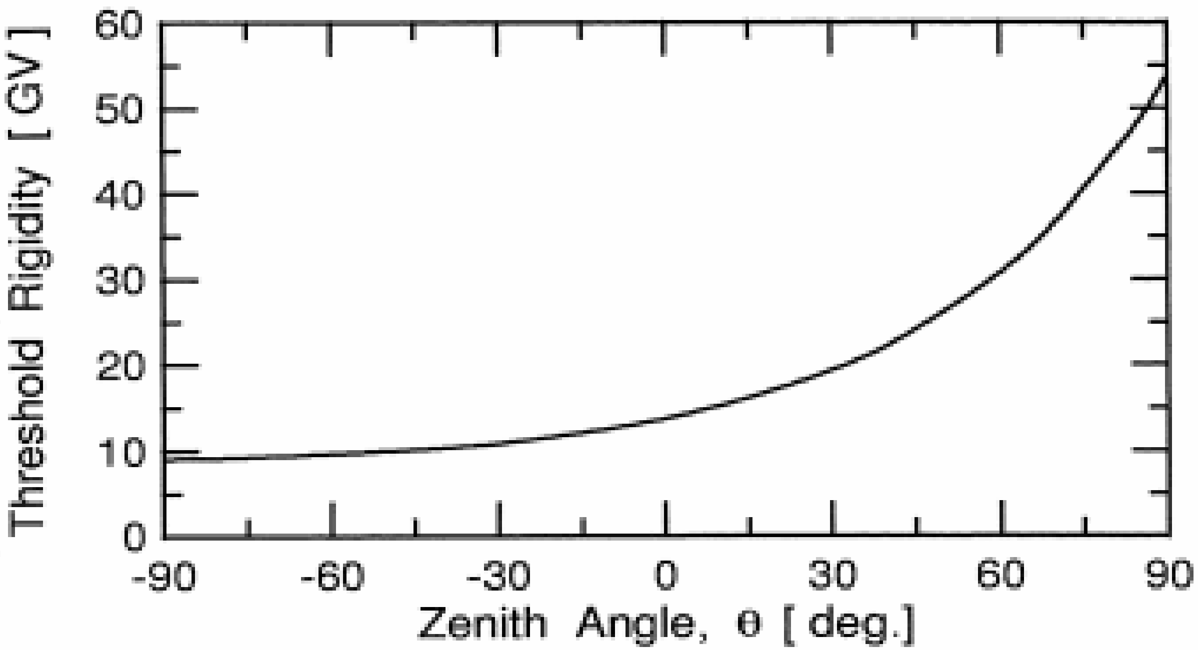
- Composition of primary component: protons (91%), alphas (6%), electrons (1%), nuclei, gammas, … but fundamental interactions change the composition in the atmosphere, so muons dominate below 6 km
- Earth magnetic field deviates the less energetic CR (rigidity cutoff in GV). Thus, intensity of CR varies with latitude and longitude.



Percentage Variation
15
10
5
0
-5
-10
-15
-180
-120
-60
0
60
120
180
Geographic Longitude [deg.]



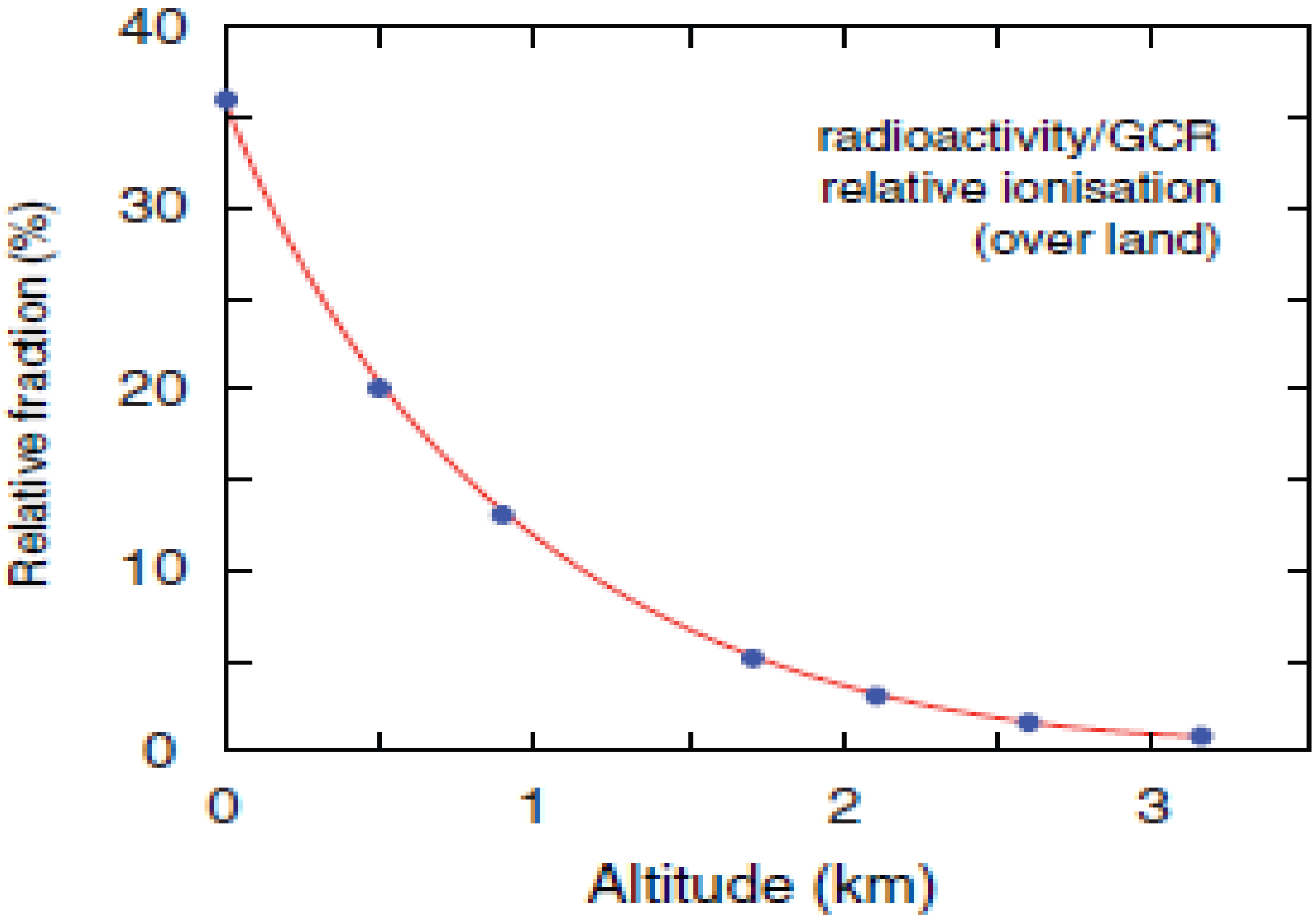
Relative Intensity
800
700
600
500
-10
0
10
20
30
40
50
60
70
North Geomagnetic Latitude, λ [deg.]



Threshold Rigidity [GV]
60
50
40
30
20
10
0
-90
-60
-30
0
30
60
90
Zenith Angle, θ [deg.]

A Relevant features

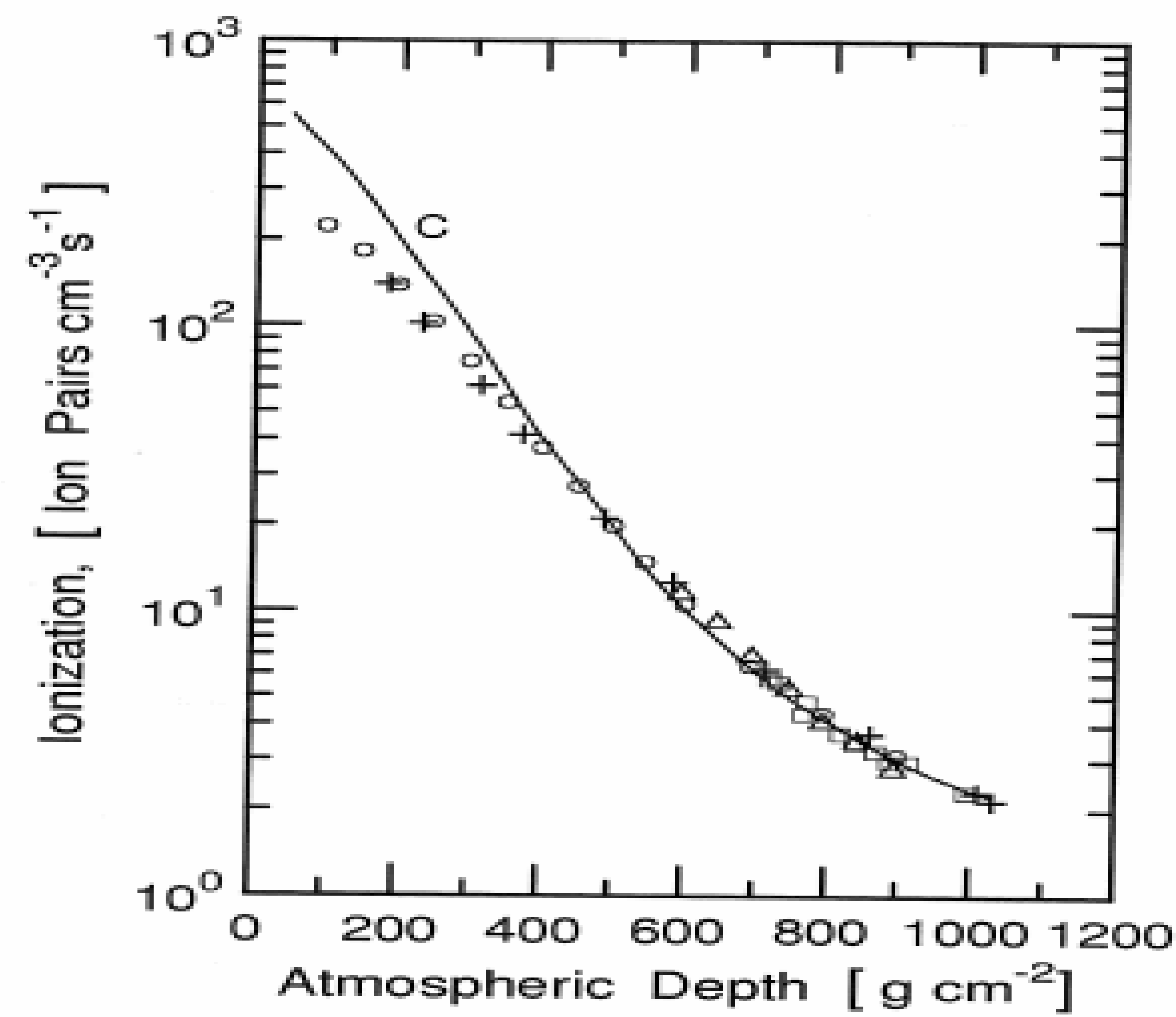
A3 On Ionization (from Radon)

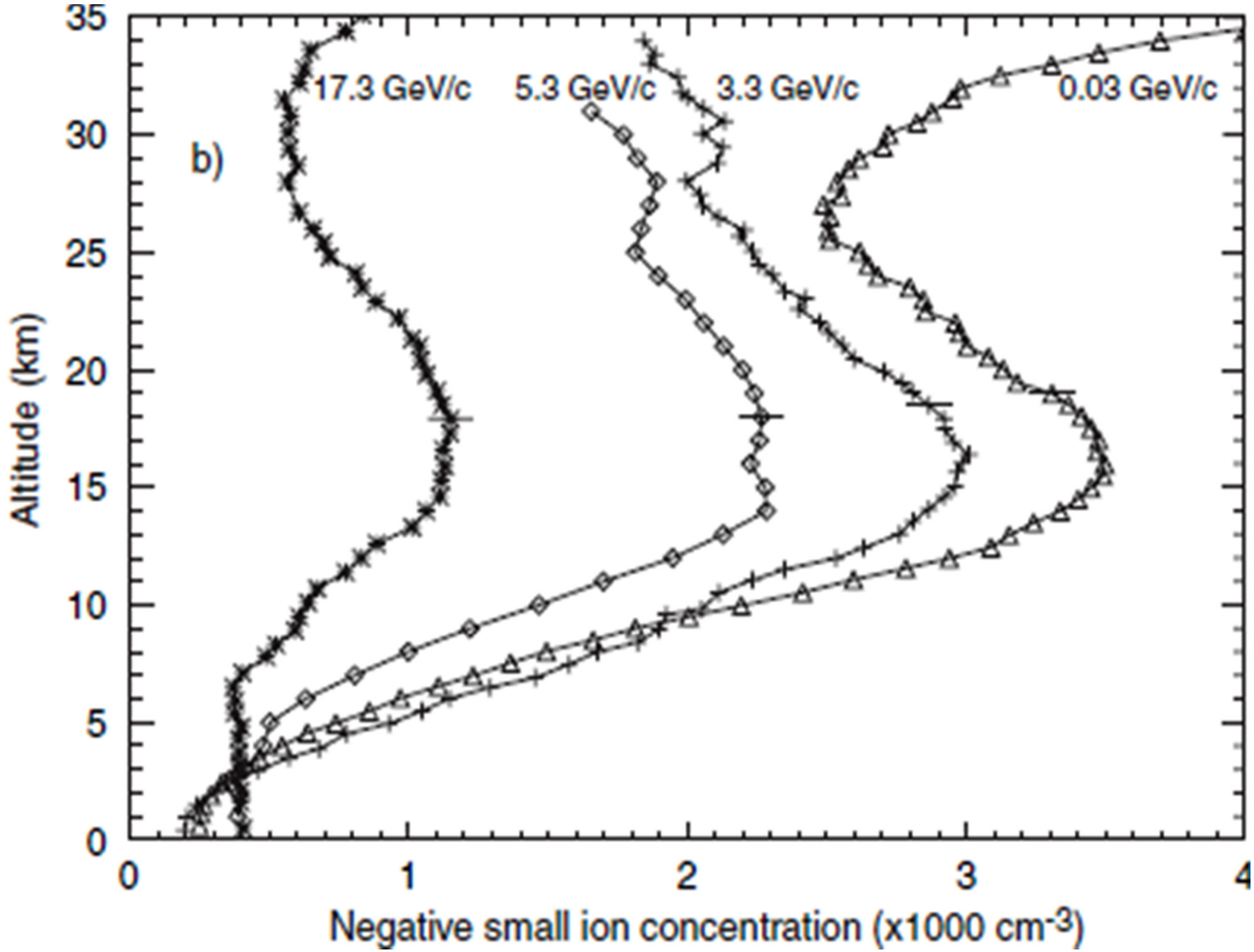


A3 On Ionization (from Cosmic Rays)

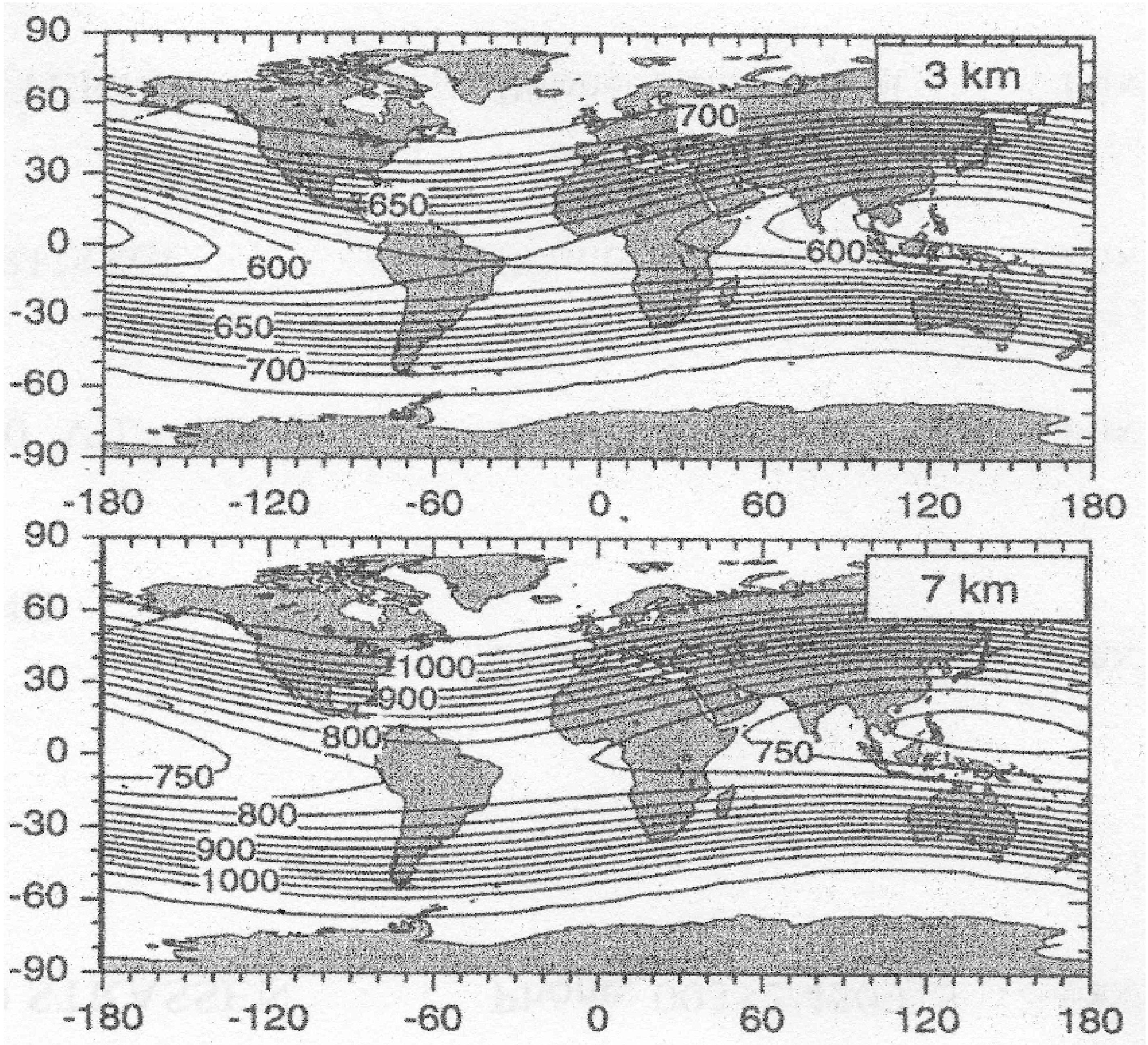
2 ion pairs/cm^3 s
at ground level

4 ion pairs/cm^3 s
at top of troposphere





Muons dominate at altitudes below 5-6 km



Globally longitudinally averaged, CR solar modulation gives
5% at equator and 50% at poles

B CR and Clouds

- B1 Revival of an old idea
- B2 Causal connection?
- B3 CLOUD experiments

On clouds

- three cloud level covers (from IR data only):

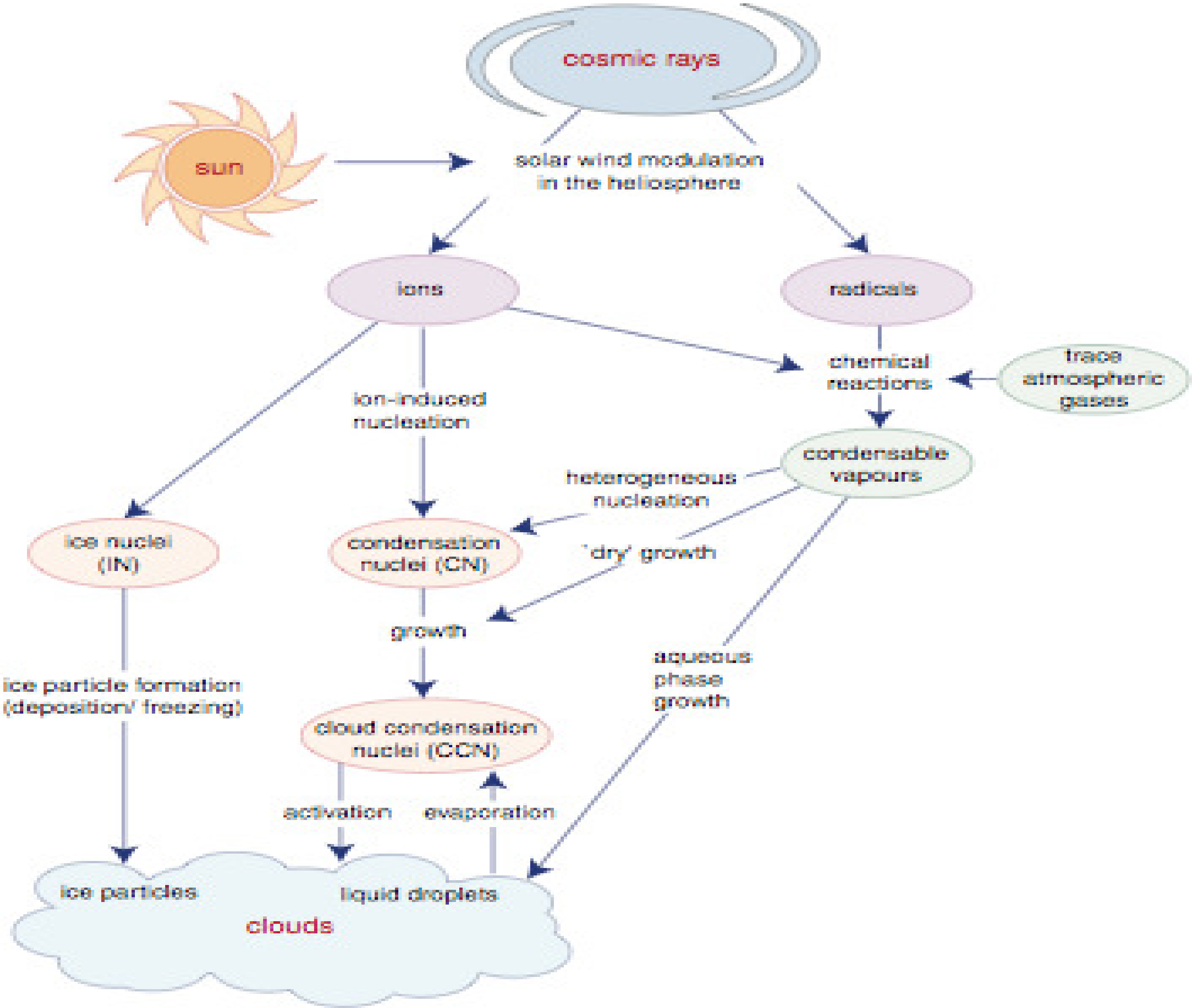
  Low (LCC) < 3,2 km (mean height 2km)

  Mid (MCC) (mean height 4,5km)

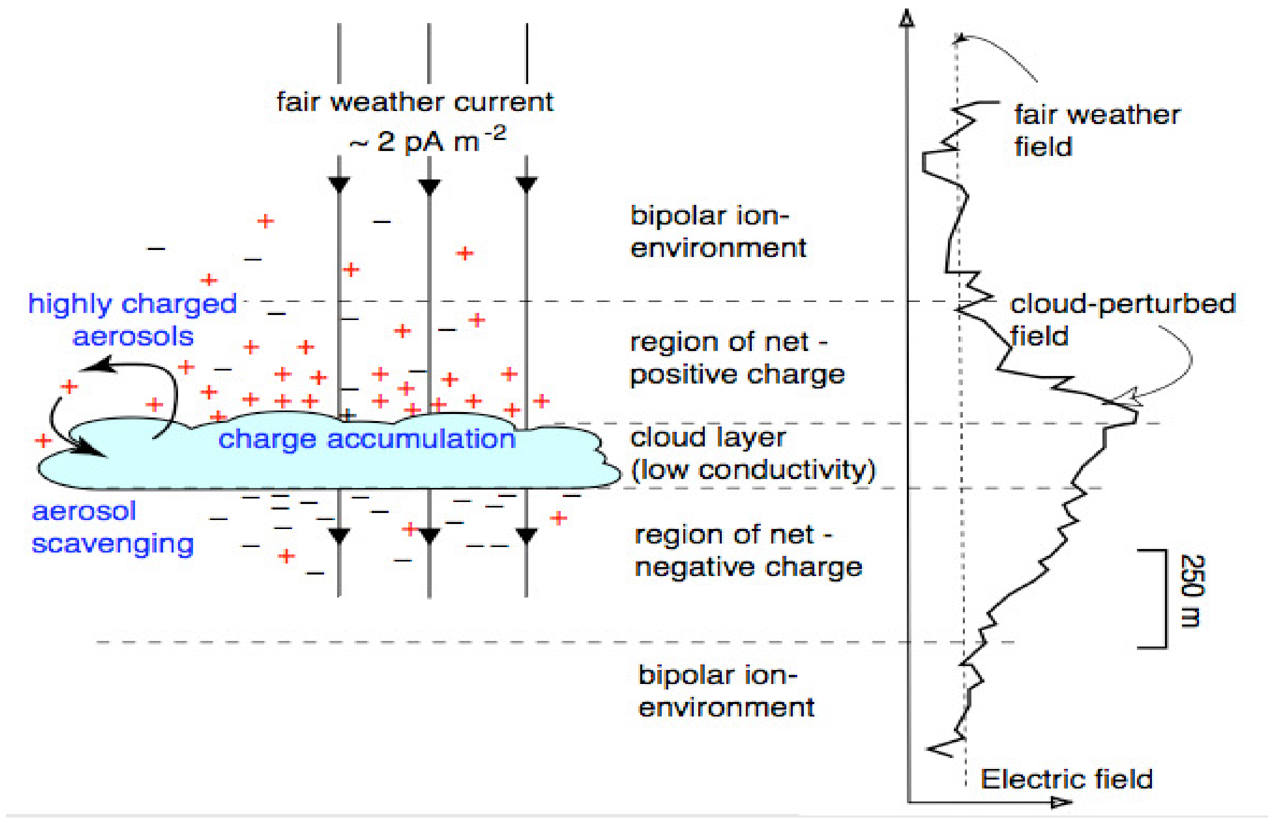
  High (HCC) > 6,4 km (mean height 10,5km)

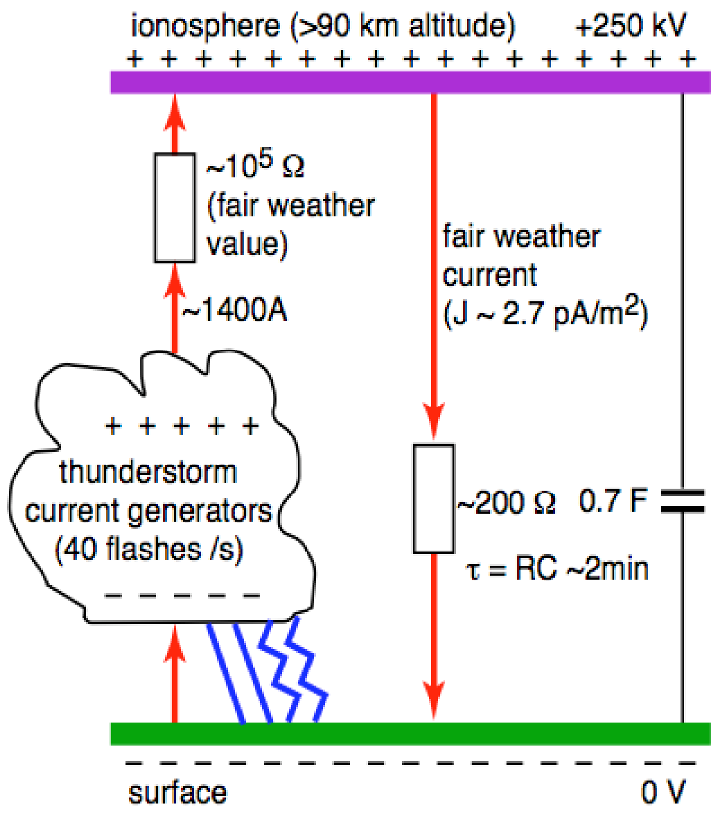
  early ISCCP data critizised
- LCC has a net cooling effect
- Observed variations of LCC are about 1,7% absolute ($1W/m^2$ of Earth's rad. budget)
- Two potential mechanisms (others may appear):

clean air (IMN) and near thunderstorm



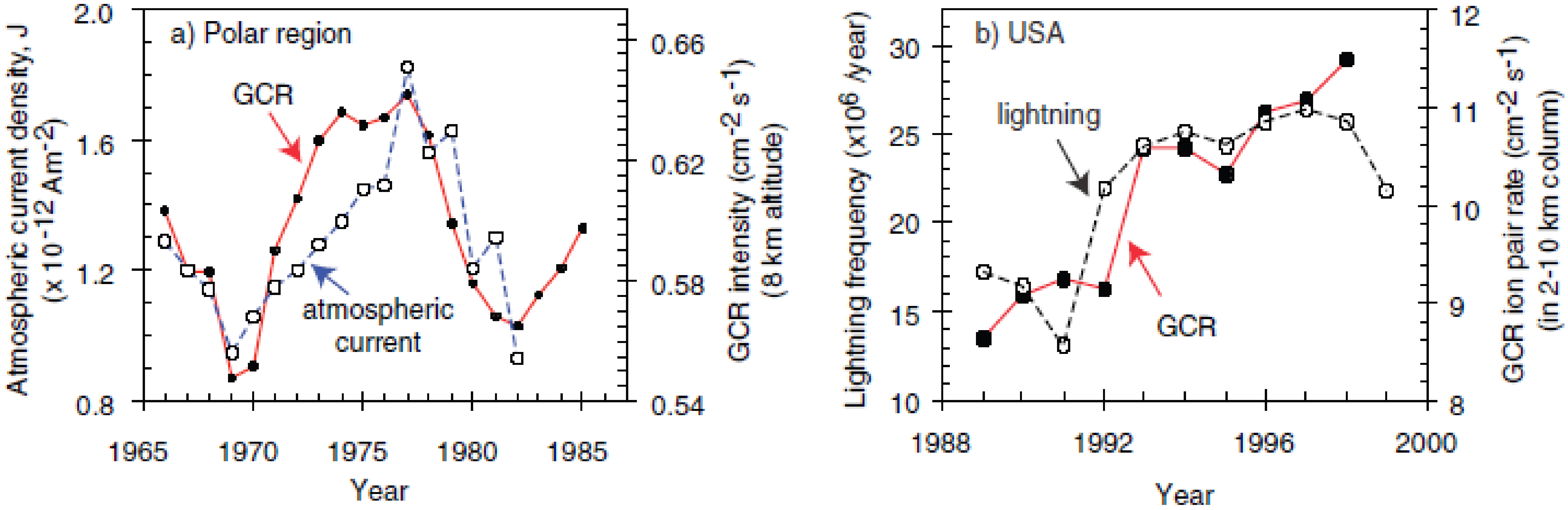
cosmic rays
sun
solar wind modulation
in the heliosphere
ions
radicals
chemical
reactions
trace
atmospheric
gases
ion-induced
nucleation
condensable
vapours
heterogeneous
nucleation
ice nuclei
(IN)
condensation
nuclei (CN)
'dry' growth
growth
aqueous
phase
growth
ice particle formation
(deposition/ freezing)
cloud condensation
nuclei (CCN)
activation
evaporation
ice particles
liquid droplets
clouds



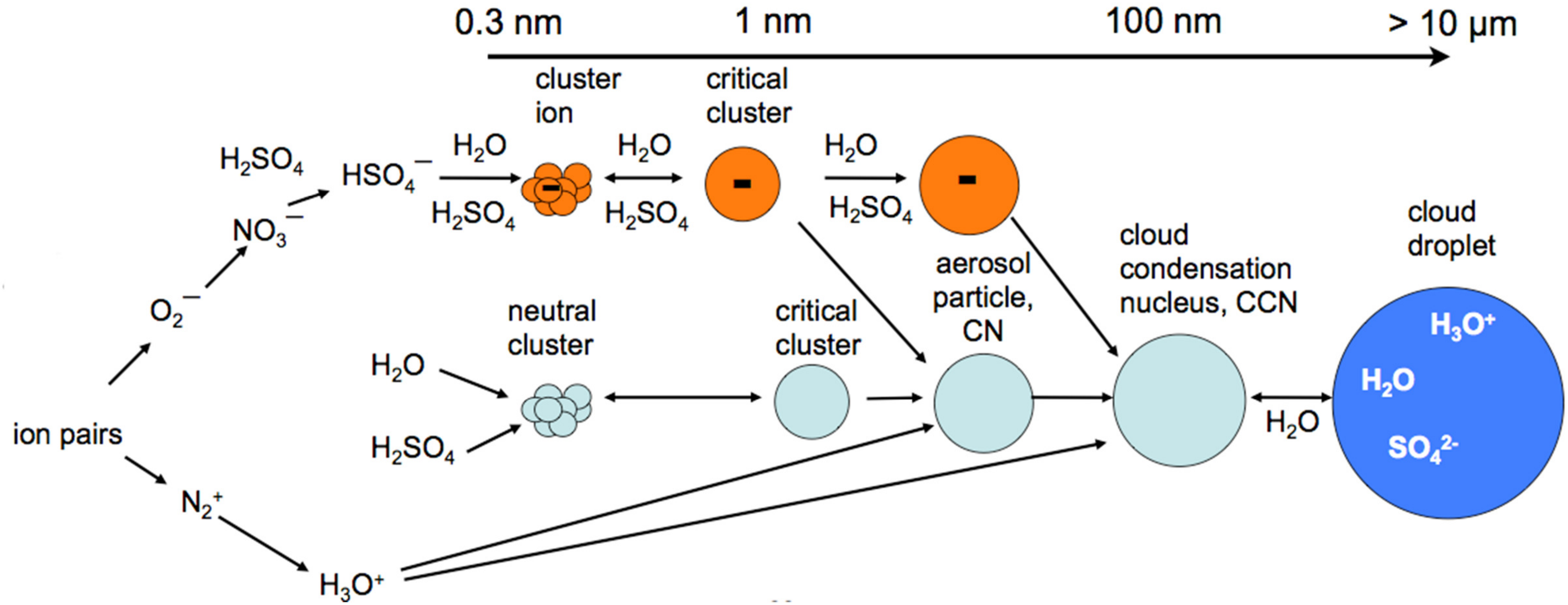


Near thunderstorm mechanism or electroscavenging

CR shower > 10^{14}eV (solar modulated CR <10 GeV)



a) Polar region
GCR
atmospheric current
Atmospheric current density, J (x 10-12 Am-2)
GCR intensity (cm-2 s-1) (8 km altitude)
Year
b) USA
lightning
GCR
Lightning frequency (x106 /year)
GCR ion pair rate (cm-2 s-1) (in 2-10 km column)
Year



Clean air mechanism or ions mediated nucleation (IMN)

There are many variations in ion concentration both temporarily and spatially which have no LCC association (diurnal, seasonal,...)

B1 Revival of an old idea

- Ney (1959) and Dickinson(1975) suggested a role of ions
- Svensmark & Friis-Christensen JATP 1997 (SFC)

mixture of 1984-1990,5 TCC ⟺ CR nm data correlate (fig)

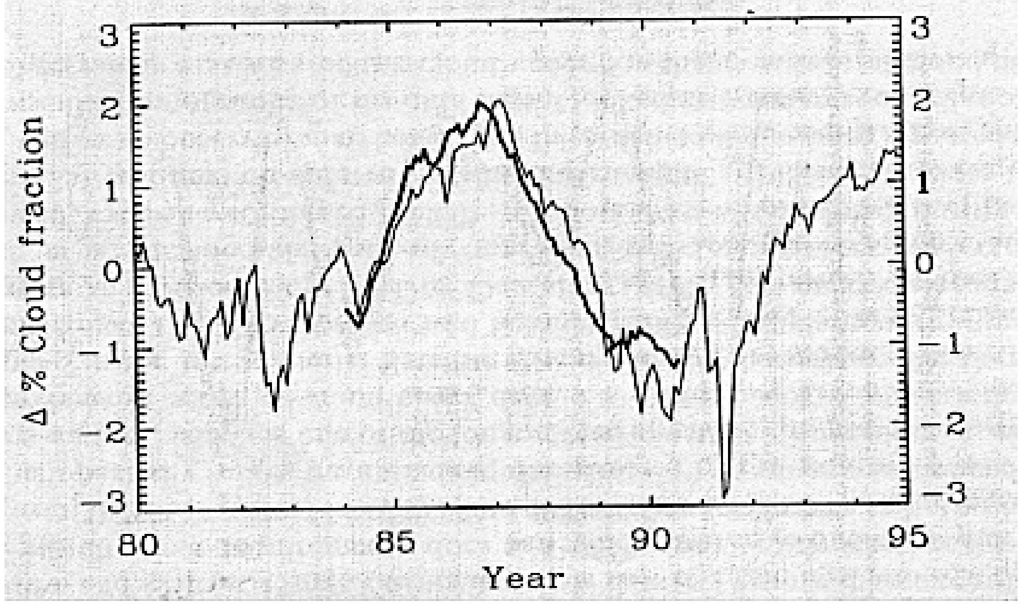
First sentence of discussion: « *The results indicate that there is a direct connection between cloudiness and the intensity of CR.* »

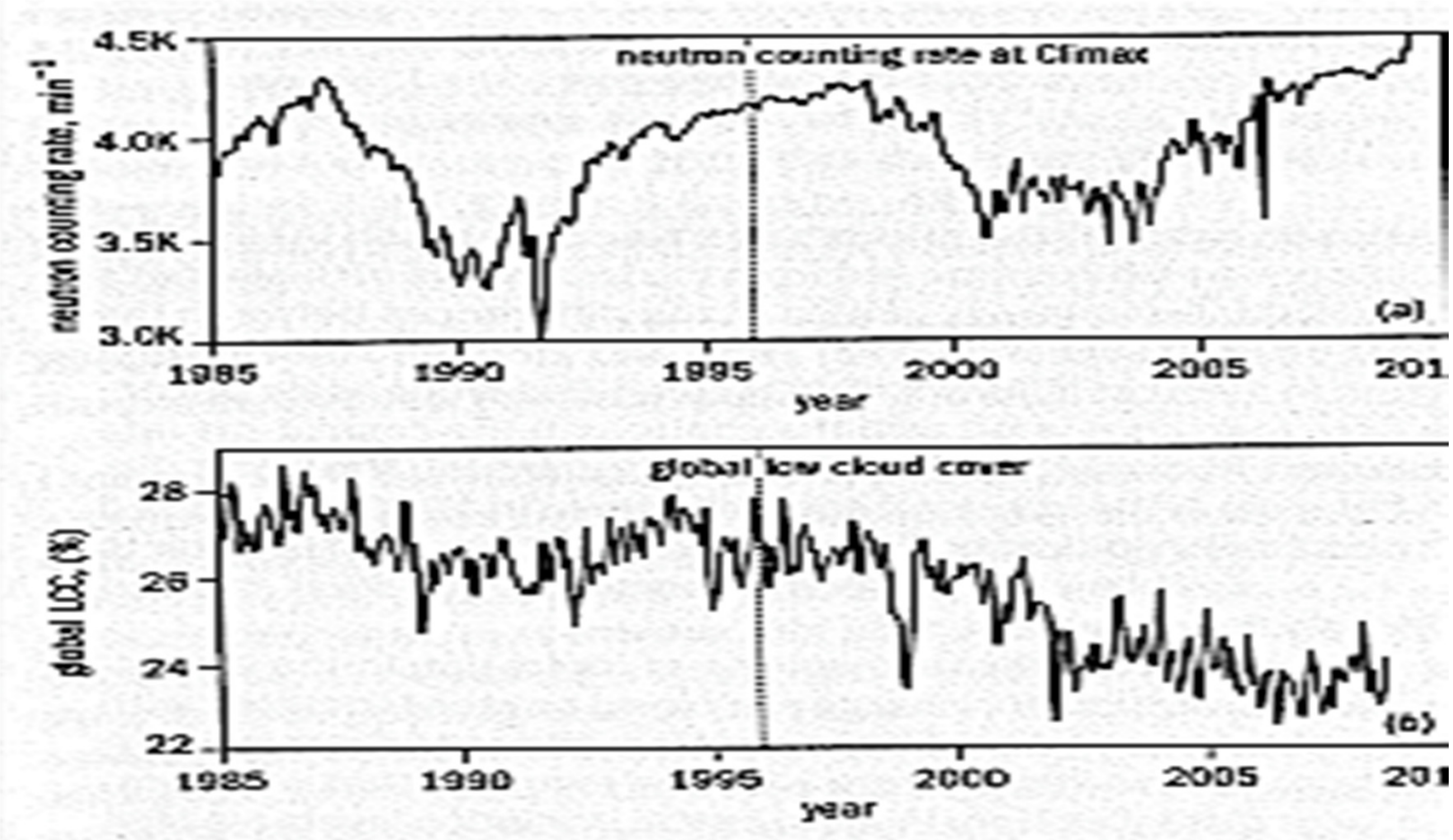
- Marsh & Svensmark Ph.Rev.Let. 2000 LCC replaces TCC
- Pallé & Butler AG 2000 were more careful (fig)
- Reactions: Kernthaler et al G.Rev.Let.1999 ; Laut JATP 2003:

« correlations were obtained by incorrect handling of physical data »

- P.B.&O'Brien JATP 2004 used a model of CR ionization at altitudes of 2-7,5-10,5 km. They conclude that the correlation disappears after 1991 (non significant 1984-2001) (fig)

H. Svensmark and E. Friis-Christensen



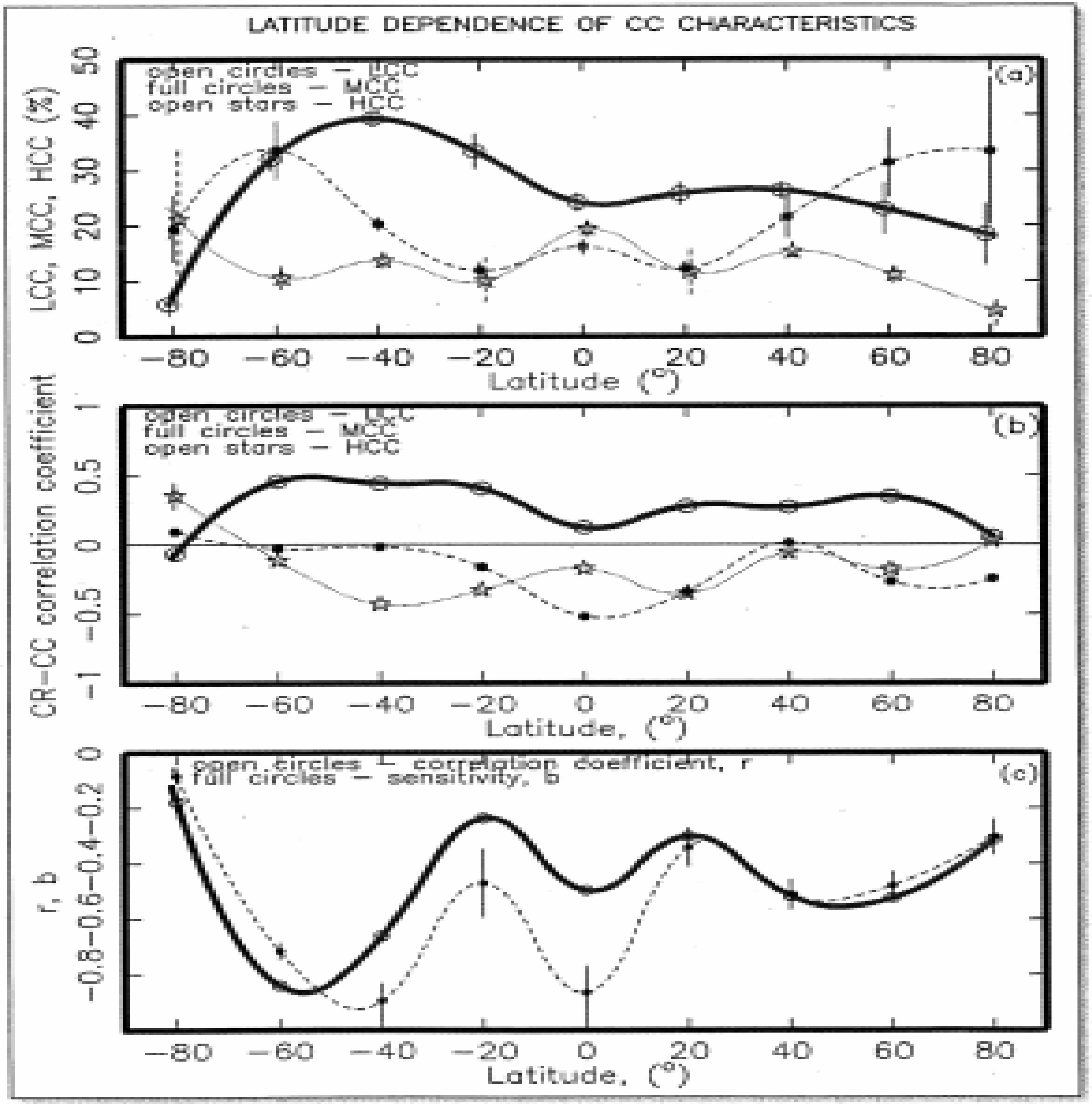


B2 CR people doubts of causal connection

- Common oscillations of 4 quantities: global mean temperature - mean daily SSN -CR ionisation rate -Solar irradiance
- Several papers describe the search to corroborate the causal connection:

Sloan & Wolfendale Env.Res.Let.2008 using the same data ISCCP-D2 : neither amplitude variations with VRCO nor the arrival times corroborate the causal connection. Three very large GLE for several hours show no clouds anomaly. (fig)

Erlykin, Gyalai, Kudela, Sloan & Wolfendale JATP 2009 *failed to find any evidence for the role for ions in enhancing the probability of cloud droplet formation at least in the lower atmosphere* (< 3,2km)



▲ **FIG. 3: The latitude dependence of Low-, Medium- and High-Cloud Cover characteristics (a) absolute values of LCC, MCC and HCC; (b) correlations with cosmic ray intensity (Climax neutron monitor); (c) the correlation coefficient (red) and sensitivity (black dashed curve) of MCC to LCC, from [12].**

B2 CR people doubts of causal connection

a) looking for correlation of LCC with regions of high radon concentration in India they find no more cloud cover (eff25%)

b) What about nuclear bomb tests in the atmosphere? Analysing the data of Bravo test 15 Mt 1954 where the radiation level produce $5\ 10^7$ ion pairs/cm3 (7 orders of mag. higher than CR) there were no effect on CC so the efficiency for conversion of ions to cloud droplets must be low (< 0,01 %)

c) In 1986, during the Chernobyl catastrophe, ionisation near Chernobyl was 15 times (3 times in the fall out region) higher than CR. No significant effect on CC. (eff. < 3%)

d) Checking the correlation of LCC & CR as function of geomagnetic latitude or VRCO pts should follow the NM curve. Moreover to reproduce the 1984-1990 correlation with causal connection, the efficiency needed is 50%! (fig)

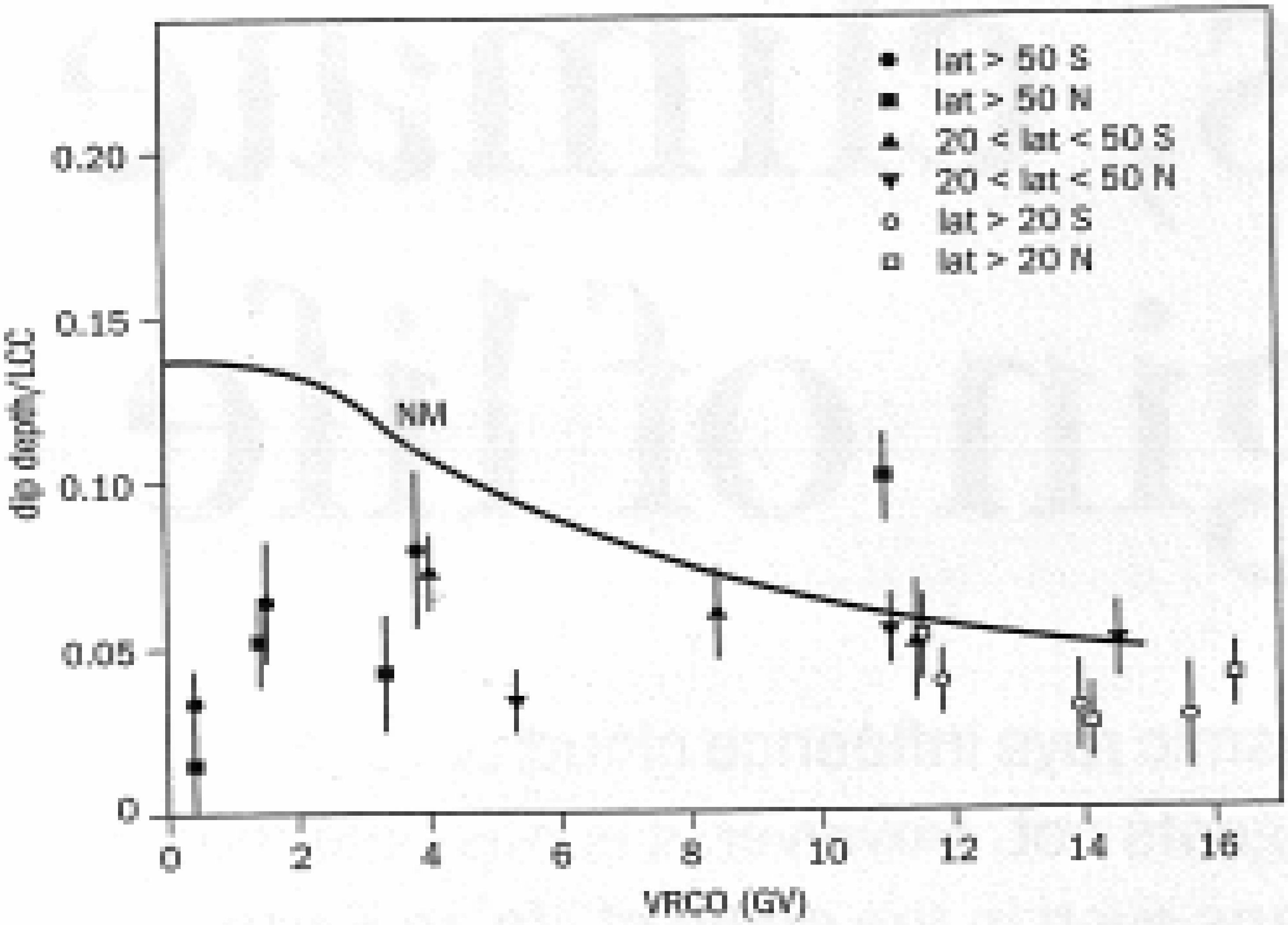


Fig. 2. The depth of the dip in low cloud cover (LCC) in 1990 compared with the LCC values in 1985 and 1995 for data at different geomagnetic latitudes, represented by the vertical rigidity cut-off (VRCO). The curve labelled NM shows the variation in cosmic rays over the 11-year solar cycle, also plotted against VRCO. The values are grouped into the geographical latitude ranges indicated.

B3 CLOUD experiment at CERN

- Scientific goals (2006)
- Requirements (2009)
- Typical run (2011)
- First results (2011)

The CLOUD project aims to study the influence of galactic cosmic rays on the Earth's climate through the media of aerosols and clouds.

The primary scientific goals of the CLOUD experiment are as follows:

1. To study the link between cosmic rays and the formation of large ions, aerosol particles, cloud droplets, and ice crystals.
2. To understand the microphysical mechanisms connecting cosmic rays to changes in aerosol and cloud particle properties.
3. To simulate the effects of cosmic rays on aerosol and cloud properties under atmospheric conditions.

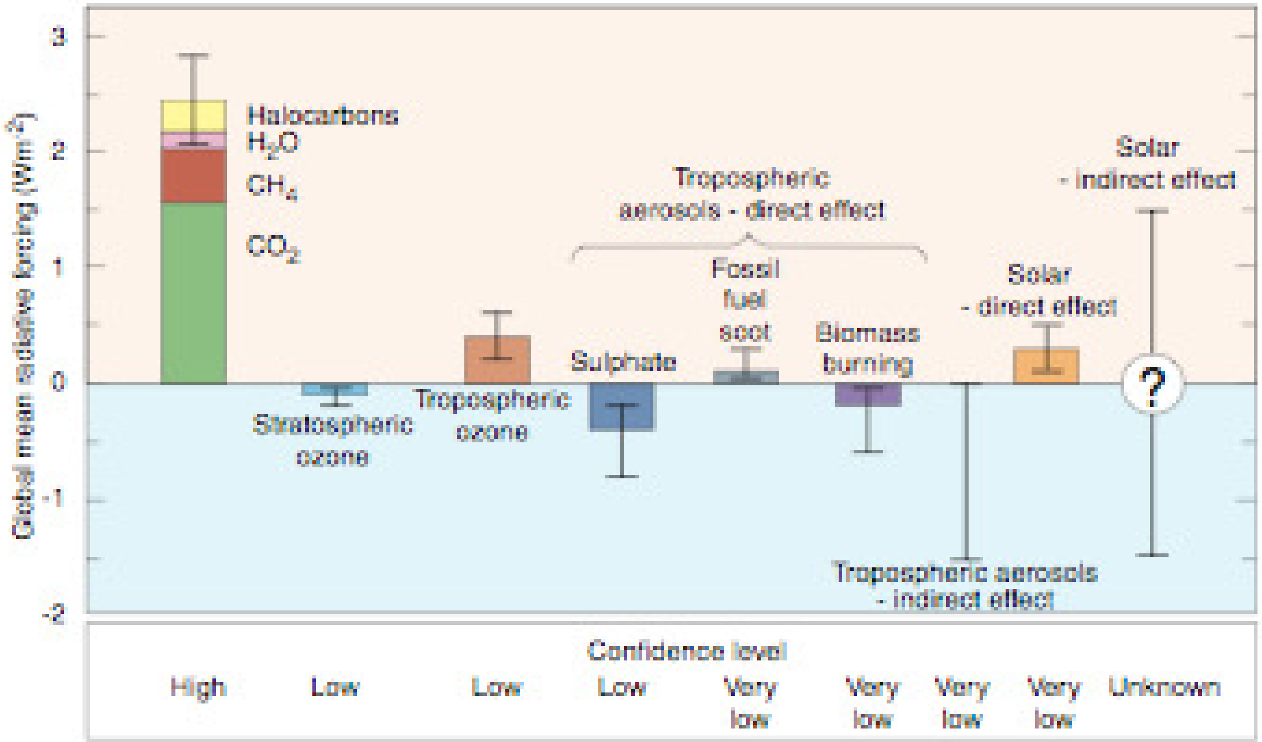
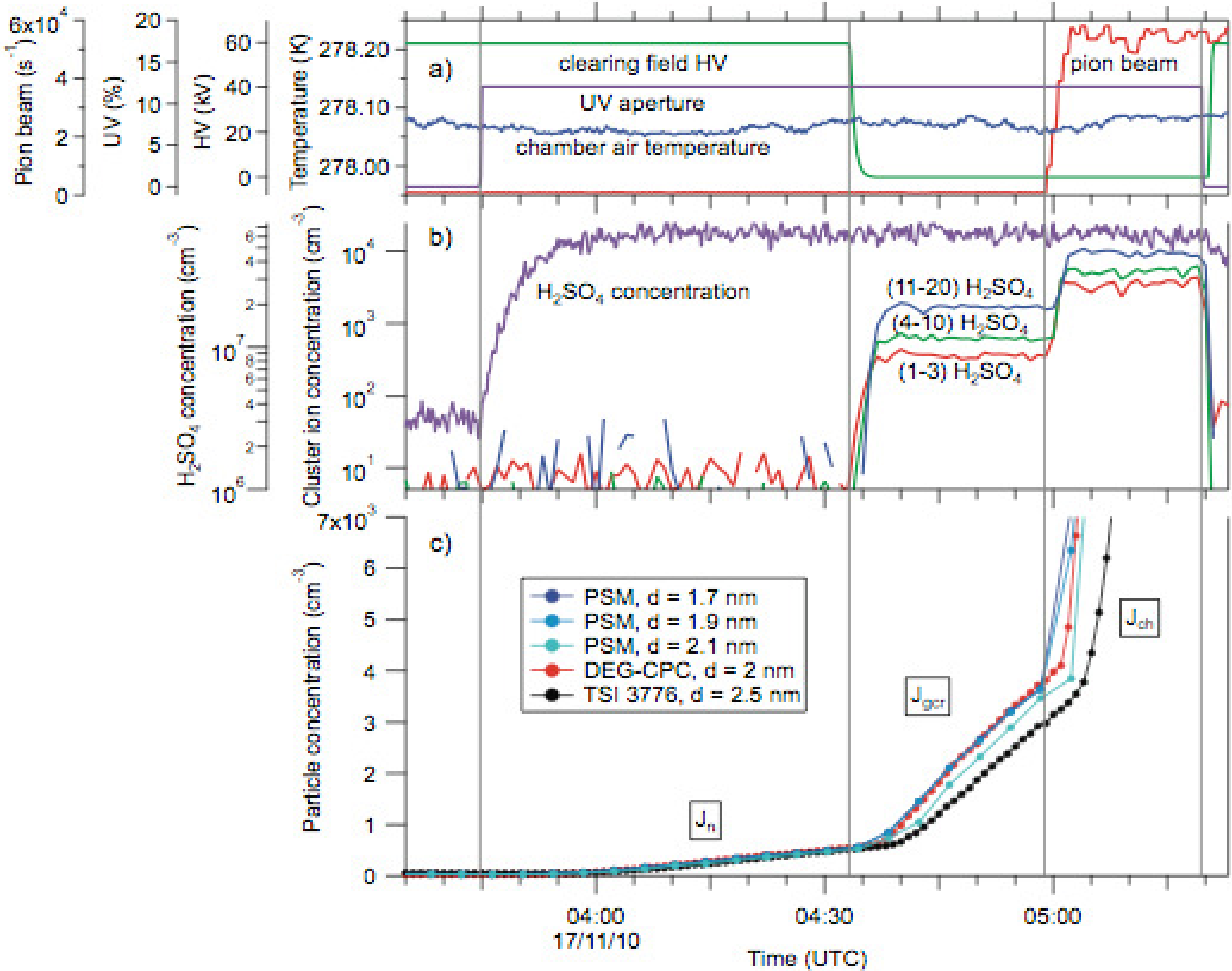


Figure 1: IPCC estimates of the global annual averaged radiative forcings due to changes in anthropogenic greenhouse gases and aerosols from 1850–1992 (first seven columns of the figure) [8]. Positive forcings lead to a warming and negative forcings cause a cooling. Natural changes due to the Sun are indicated by the final two columns; the first is the IPCC estimate of changes in solar output over the same period and the second concerns the present CLOUD proposal to study of the influence of galactic cosmic rays on cloud formation. Since the galactic cosmic ray flux is modulated by the solar wind, this would provide a mechanism for indirect solar radiative forcing.

- Large chamber:
  - Diffusion lifetime of aerosols/trace gases to walls ~L^2
  - Dilution lifetime of makeup gases ~L^3

  => 3m chamber has typically 5-10 hr lifetimes
- Ultra-clean conditions:
  - Condensable vapours, eg. [H_2SO_4] ~0.1 pptv
  - Ultrapure air supply from cryogenic liquids
  - UHV procedures for inner surfaces, no plastics
- Temperature stability and wide T range
  - 0.1°C stability
  - Fibre-optic UV system for photochemistry
  - -90C → +100C range
- Field cage up to 30 kV/m:
  - Zero residual field
- Particle beam
  - Wide beam for ~uniform exposure
- Comprehensive analysers (measure "everything", as for collider detectors...)
  - Mass spectrometers for H_2SO_4, organics, aerosol composition



a)
clearing field HV
UV aperture
chamber air temperature
pion beam
Pion beam (s^{-1})
UV (%)
HV (kV)
Temperature (K)
b)
H_2SO_4 concentration
(11-20) H_2SO_4
(4-10) H_2SO_4
(1-3) H_2SO_4
H_2SO_4 concentration (cm^{-3})
Cluster ion concentration (cm^{-3})
c)
PSM, d = 1.7 nm
PSM, d = 1.9 nm
PSM, d = 2.1 nm
DEG-CPC, d = 2 nm
TSI 3776, d = 2.5 nm
J_n
J_{gcr}
J_{ch}
Particle concentration (cm^{-3})
04:00
17/11/10
04:30
05:00
Time (UTC)

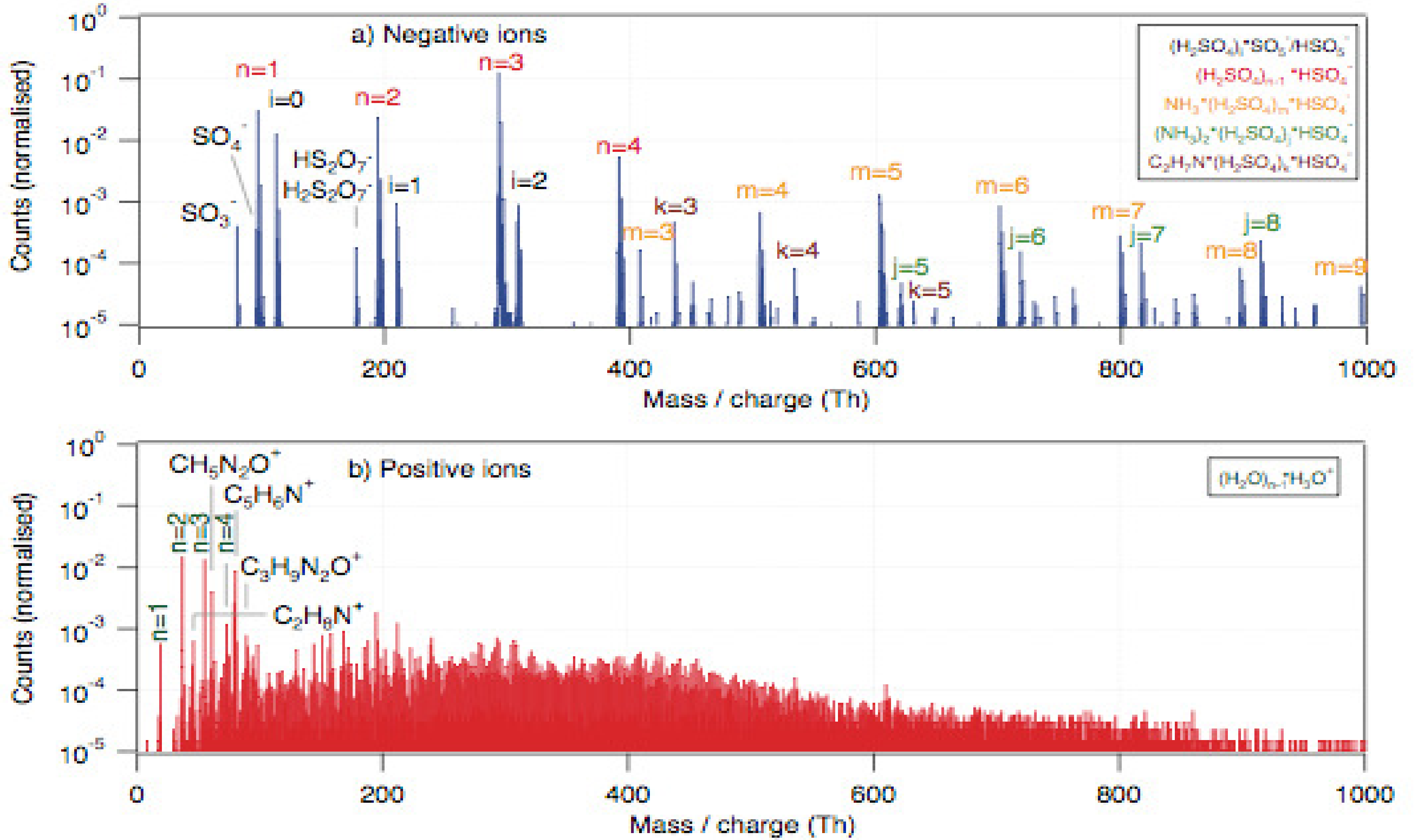


Fig. S 3. Cluster spectra examples. Examples of raw APi-TOF spectra at 292K: a) negative and b) positive ions. The run conditions are $[H_2SO_4] = 10^9$ cm^{-3}, $NH_3 = 35$ pptv, RH = 38%, and $J_{ch} \sim 10$ cm^{-3}s^{-1}.

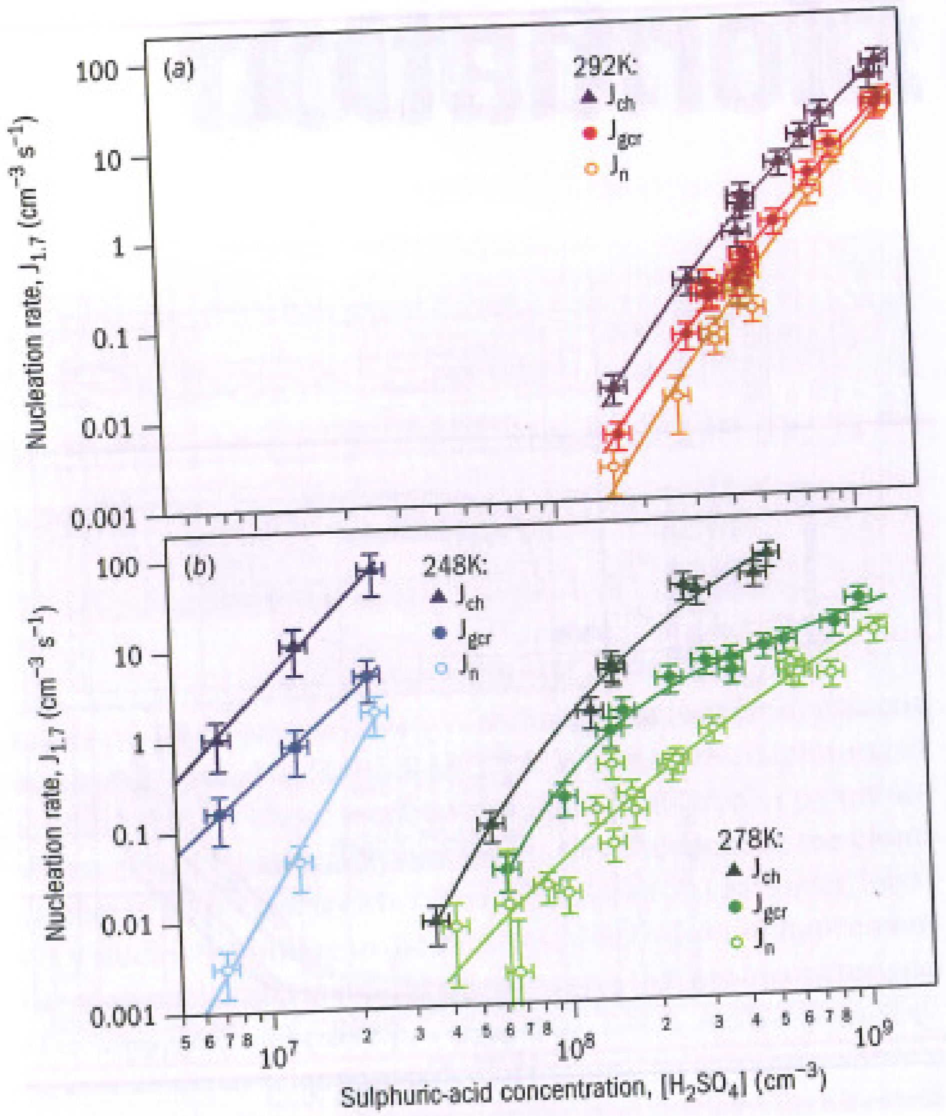
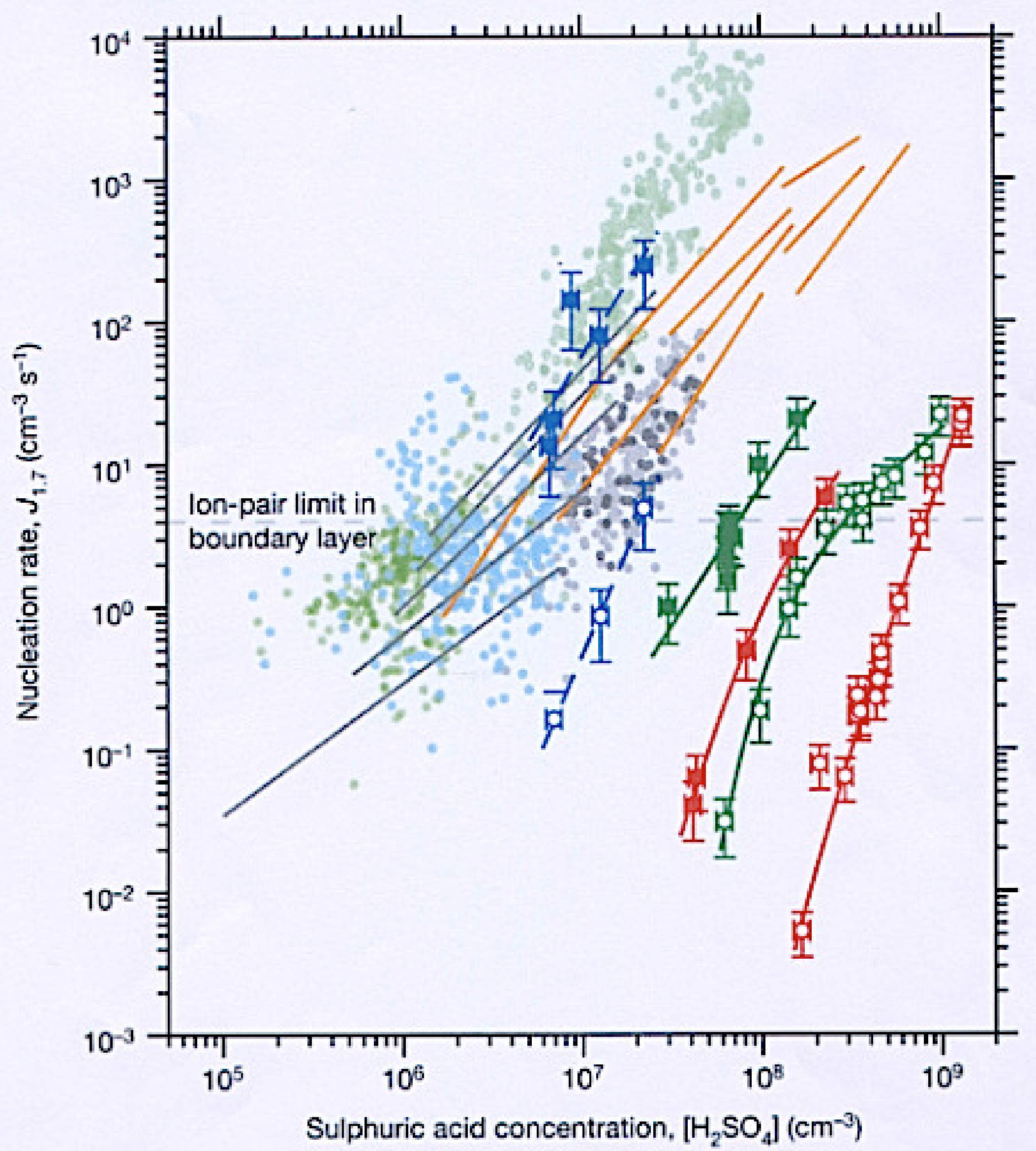


Fig. 2. Neutral, GCR and charged (pion beam) nucleation rates, J_n, J_{gcr} and J_{ch}, respectively, measured by CLOUD as a function of sulphuric-acid concentration at 38% relative humidity (RH) at a) 292 K, b) 248 K and 278 K. A clear enhancement is seen for the GCR and pion beam conditions, indicating the importance of ion-induced nucleation.

Figure 5: Nucleation rate comparison.



Outcome of the CLOUD experiment

- The most likely nucleating vapors(sulphuric acid and ammonia) cannot account for the nucleation observed in the lower atmosphere (1/10 – 1/1000 of the rate observed)
- There are other agent(s) for nucleation
- Natural rates of atmosphjeric ionization from CR substantially enhance nucleation in the cool temperature of the mid-troposphere (5 km) and above
- However, it is premature to conclude that CR have a significant influence on clouds and climate
- So far, CLOUD has only measured the formation rate of aerosols of a few nanometre size range, which is far too small to seed clouds.

C

Conclusions

- Correlation does not mean causality!
- LCC are not globaly correlated with CR
- CR ionization may be important for thunderstorm and/or global electric circuit
- As solar irradiance brings 10^8 more energy than CR and correlated better than CR with LCC, why not study his effect
- Laboratory investigations of physical mechanisms are of crucial importance.