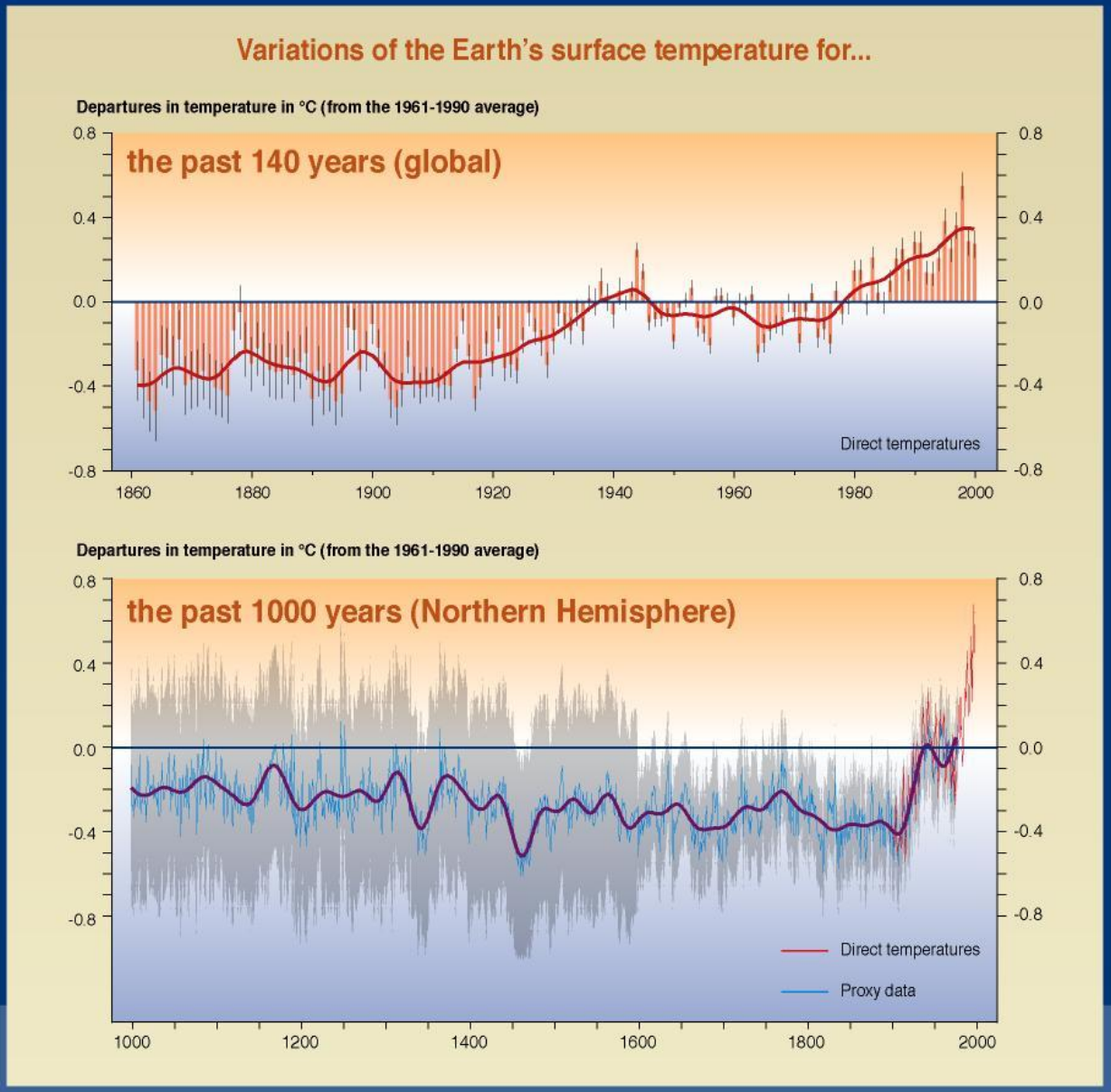
Cosmic Rays and Global Warming

T.Sloan - Lancaster University

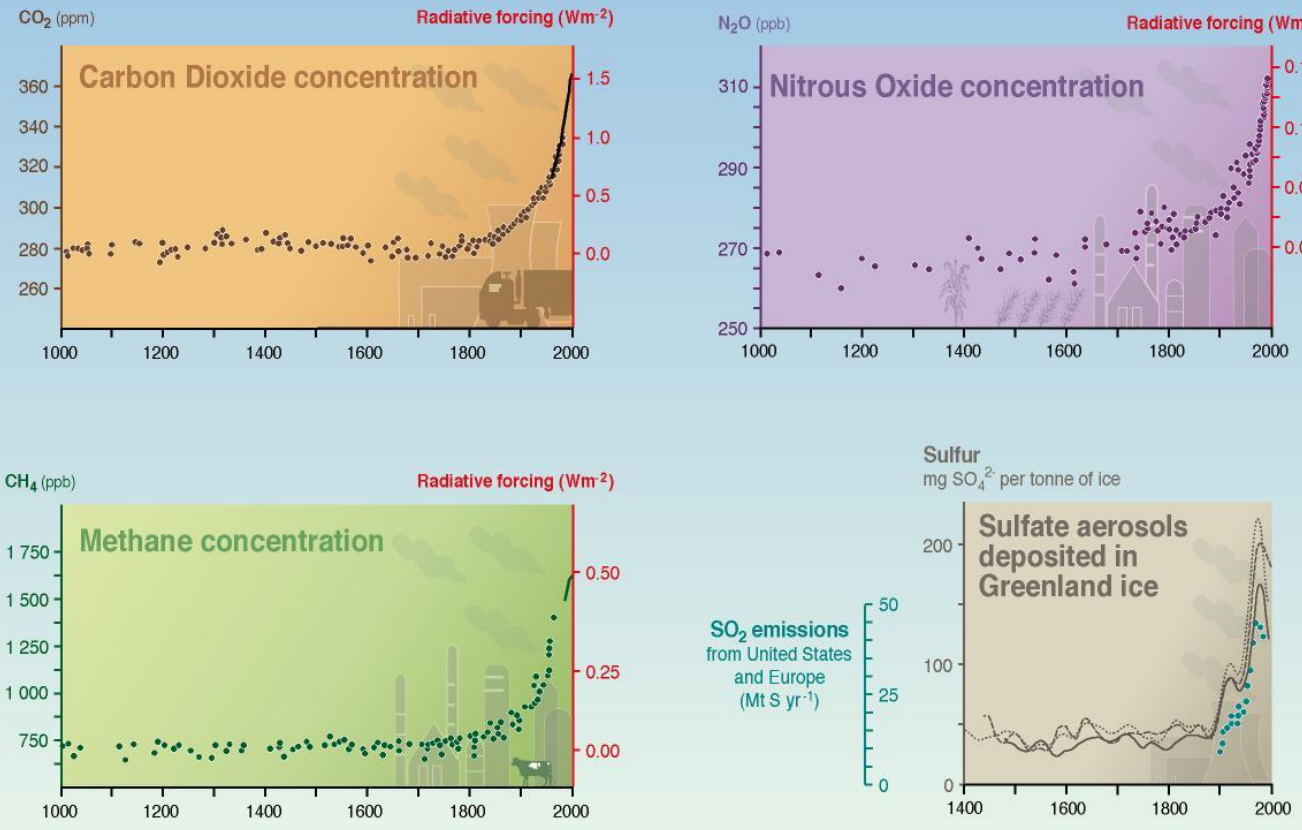
- Global warming – the case for it being anthropogenic
- Effects of the sun on cosmic rays (CR)
- Observed correlation with between low cloud cover (LCC) and solar activity.
- Is this correlation caused by cosmic rays?

Talk at RAL Nov 2010



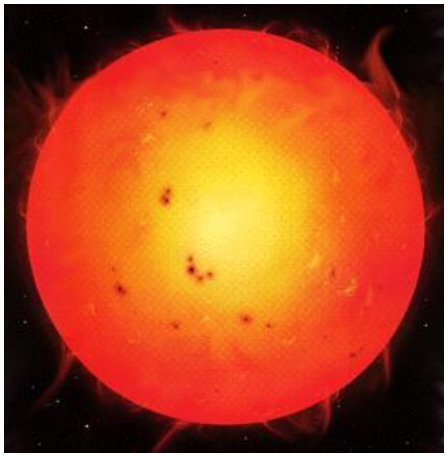
SYR - FIGURE 2-3

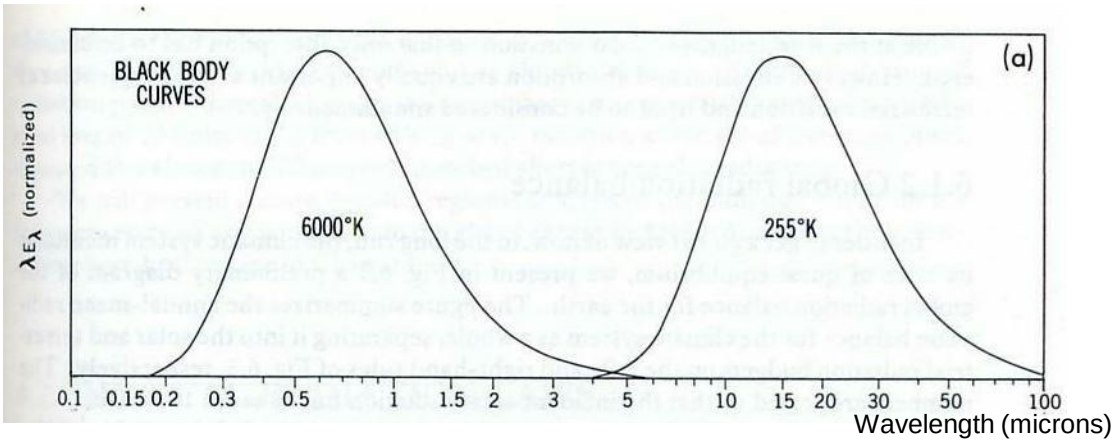
Indicators of the human influence on the atmosphere during the Industrial era



SYR - FIGURE 2-1
WG1 FIGURE SPM-

Sun warms the Earth – Earth reradiates energy





Sun's radiation (visible) Earth's radiation (infra red)

NB Earth at 255K (-18 C) if a perfect radiator, with no greenhouse gases in atmosphere (GHG = carbon dioxide, methane, water vapour)

Why is Earth NOT at -18˚C (on average)

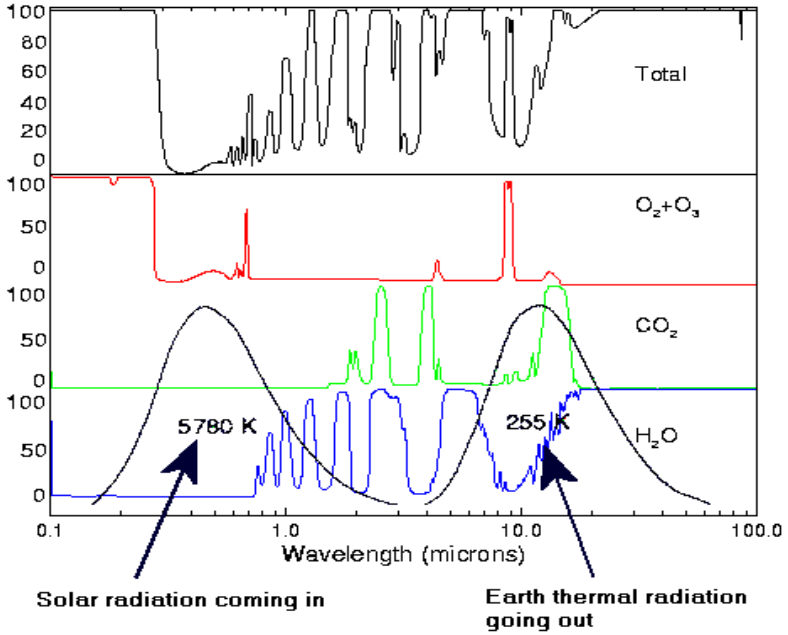
Naturally occurring GREENHOUSE gases – adds extra warming to an average of 14˚C.

Main greenhouse gases are
water vapour, carbon dioxide (CO_2) and methane (CH_4).

REASON – Greenhouse gases absorb infra red energy.
(But main gases in atmosphere nitrogen and oxygen do not aborb infra red radiation).

This absorption warms atmosphere allowing it to
act like a blanket around the Earth warming to 14˚C.

Adding greenhouse gases from burning fossil fuels gives more warming.



Infra red radiation from Earth absorbed in atmosphere by CO2 and water except

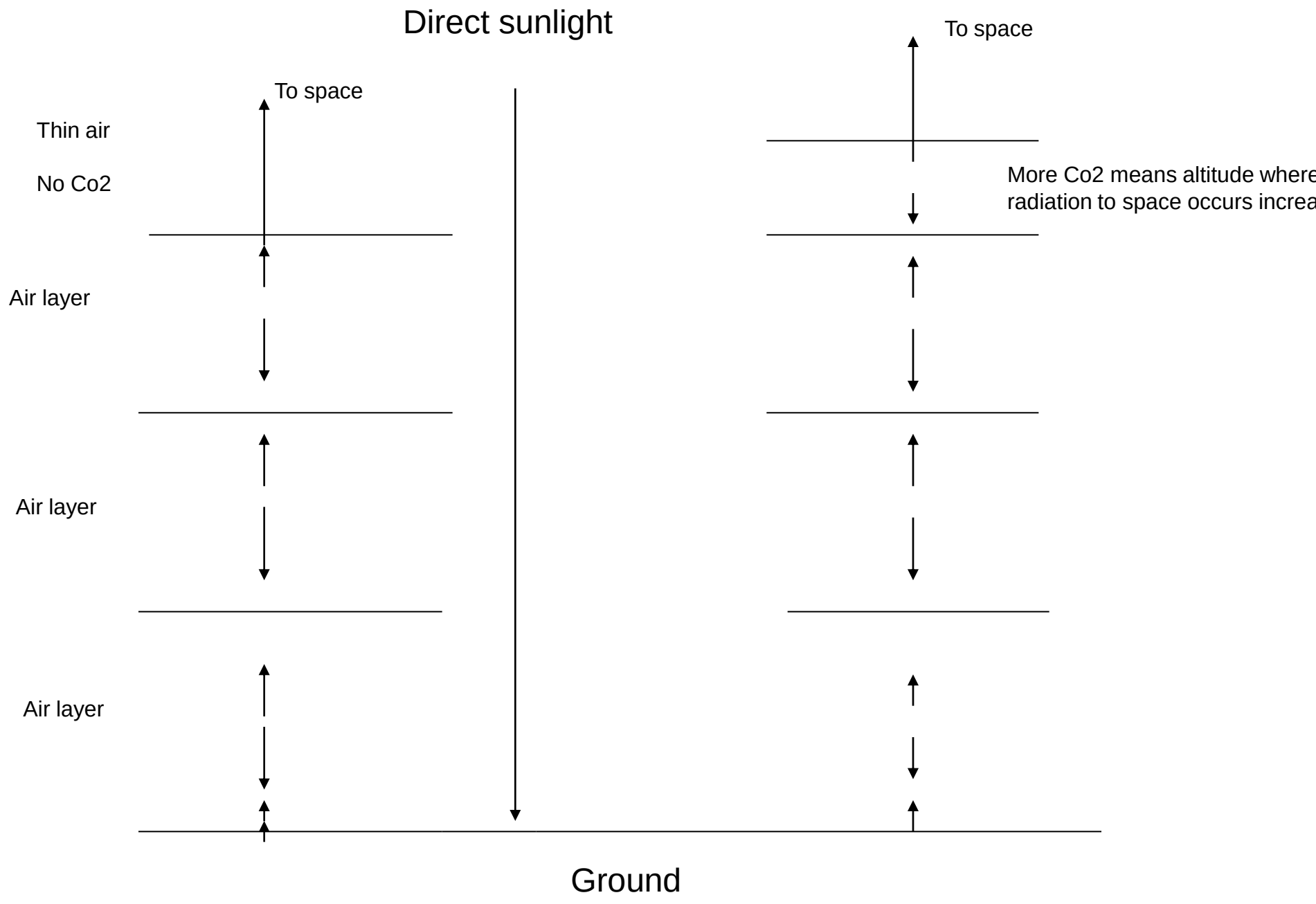
in gap from 8-13 microns.

Man made increase of CO2 leads to

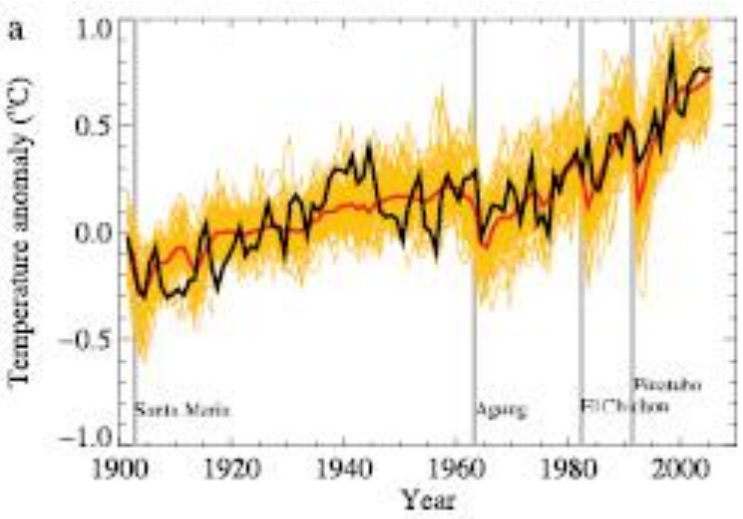
1.increases absorption in the gap

2.increases the height in the atmosphere at which radiation to space occurs

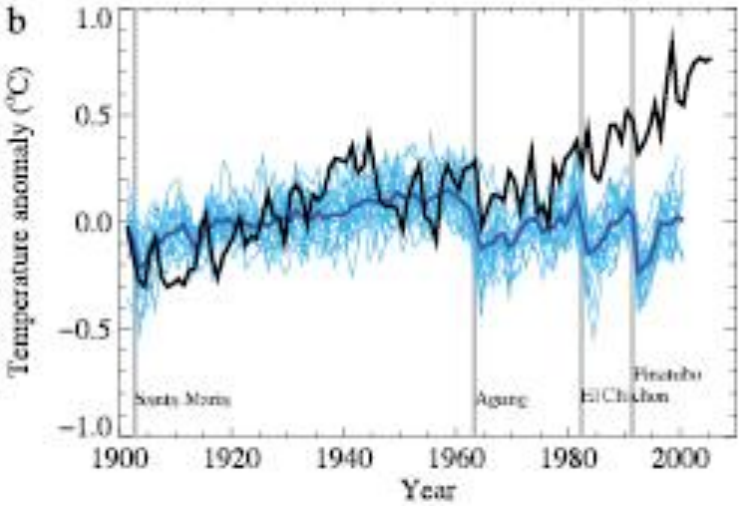
This is the man made global warming.


Direct sunlight
To space
To space
Thin air
No Co2
More Co2 means altitude where
radiation to space occurs increa
Air layer
Air layer
Air layer
Ground

Comparison of measured average global temperature and models.



Yellow = models with natural + man-made forcings



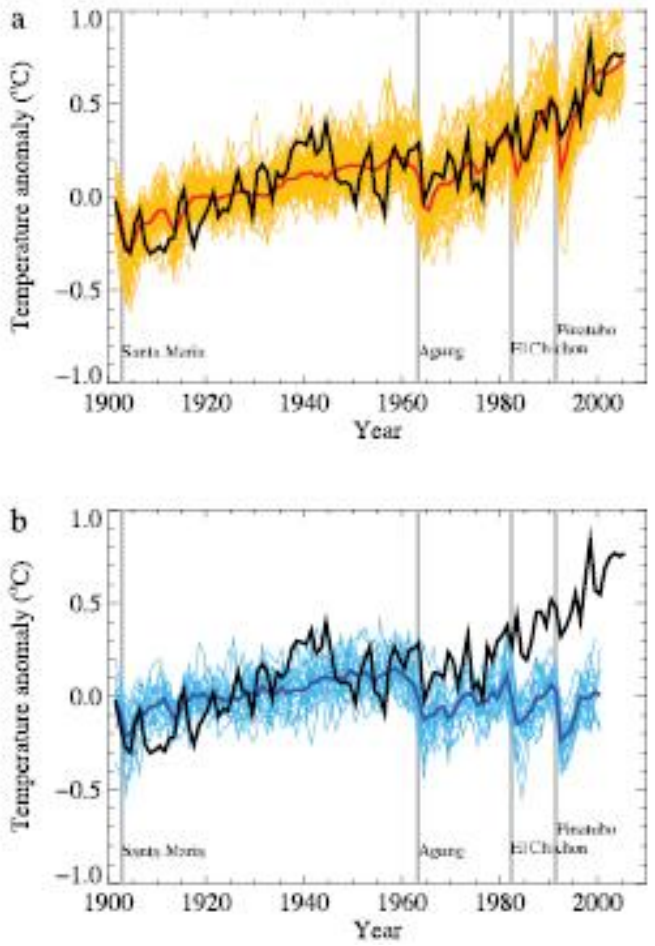
Blue = models with natural forcings only

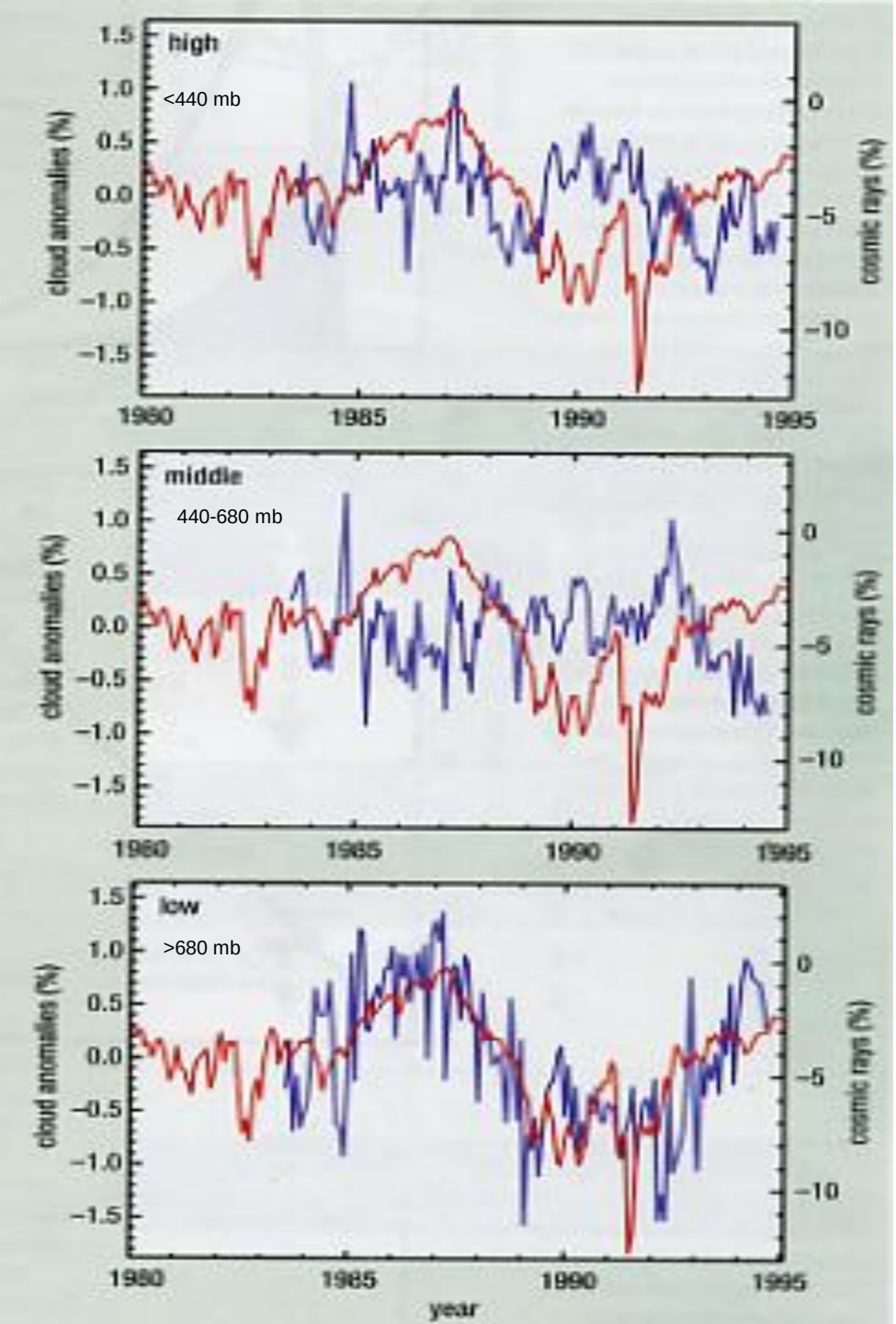
Is Global Warming Anthropogenic ? What room is there for doubt?

Current view by IPCC-”very likely” ie. 90% probable.

The IPCC think that it has a 10% chance of being wrong.

It is possible that the climatologists may have overestimated effects of greenhouse gases AND there is an unknown effect causing the warming of the last century – probability ~10%.





Enter Cosmic Rays

work by Marsh and Svensmark.

Is this the unknown effect ?

-Red curve = cosmic ray rate at ground level.

-Blue curve = Cloud Cover anomalies.

Anomaly=Average CC in month
- long term average for that month

Marsh and Svensmark observed that as the CR rate decreases with solar activity in solar cycle 22 so does global mean Low Cloud Cover (LCC).

They go on to hypothesise that CR ionization causes LCC.

The sun has become more active during last century (Lockwood and Stamper) and CR rate has decreased roughly 10%.

- i.e. less cloud cover now than in previous century
- i.e. more warming of the Earth by the sun.

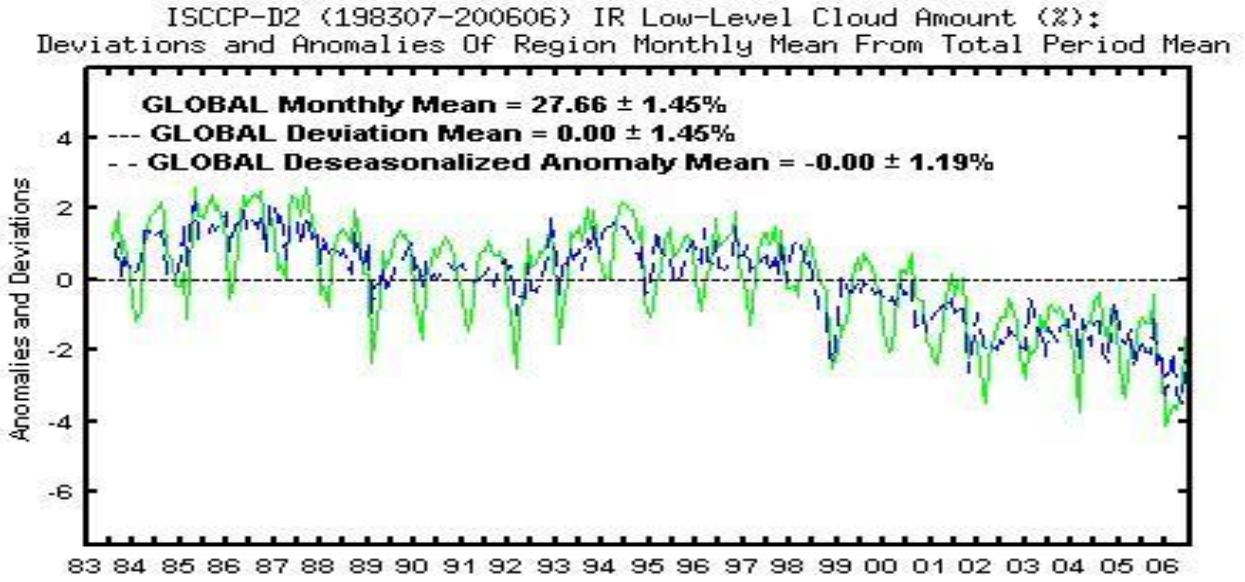
Marsh and Svensmark estimate radiative forcing due to this effect is close to 1.4 W/m^2.

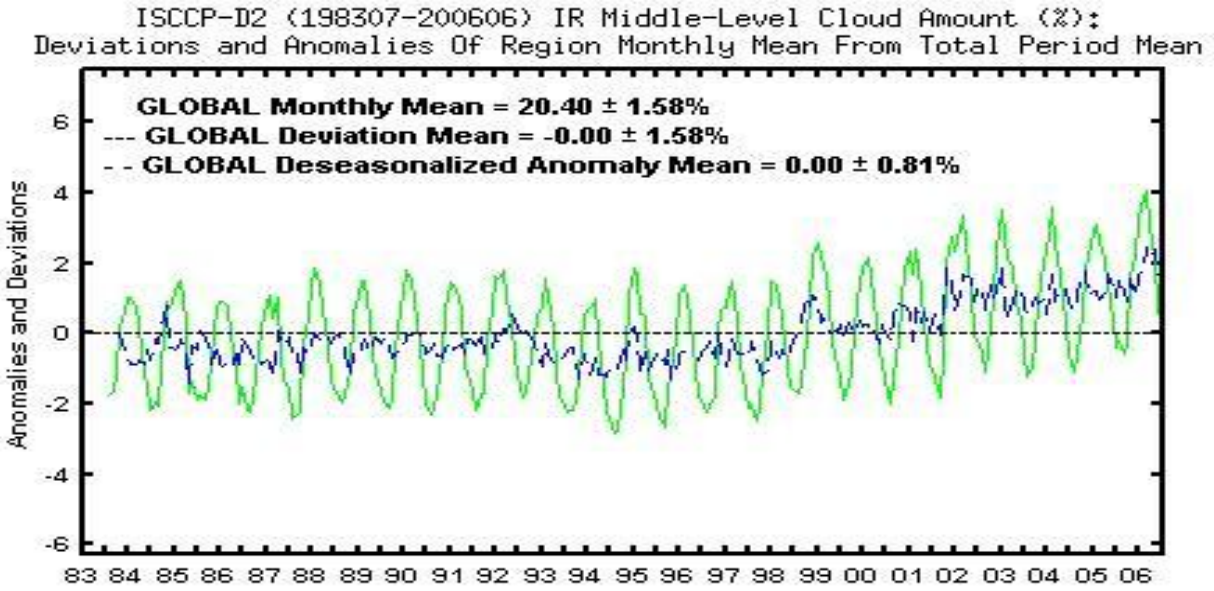
Do Changes to CR Rate cause changes in cloud cover (LCC)?

- Marsh and Svensmark see correlation between decrease in CR rate (decreased ionization) and decrease in LCC. From this they hypothesise that changes in ionization from CR cause changes in LCC.
- BUT CR modulation is correlated to sun spot number as are many other phenomena.
- Need corroborating evidence before accepting their hypothesis.
- Arnold Wolfendale and I have looked for such evidence.

Areas examined

- VRCO dependence
- Transient CR events (Forbush decreases and GLEs)
- Chernobyl nuclear accident
- Nuclear Bomb tests
- Long term variation
- Cycle 23



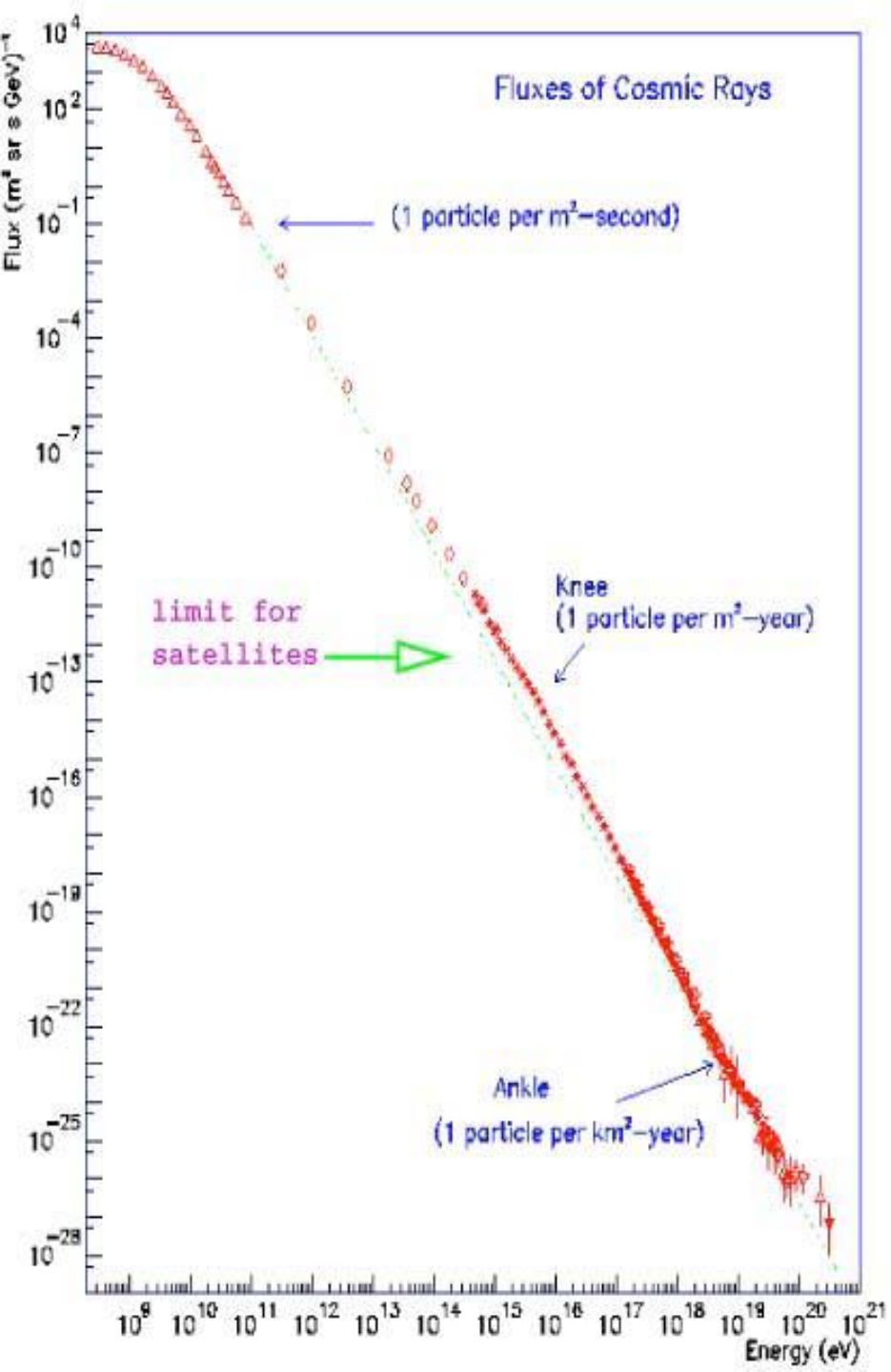


Look for dip
In Cycle 23
1995-2006

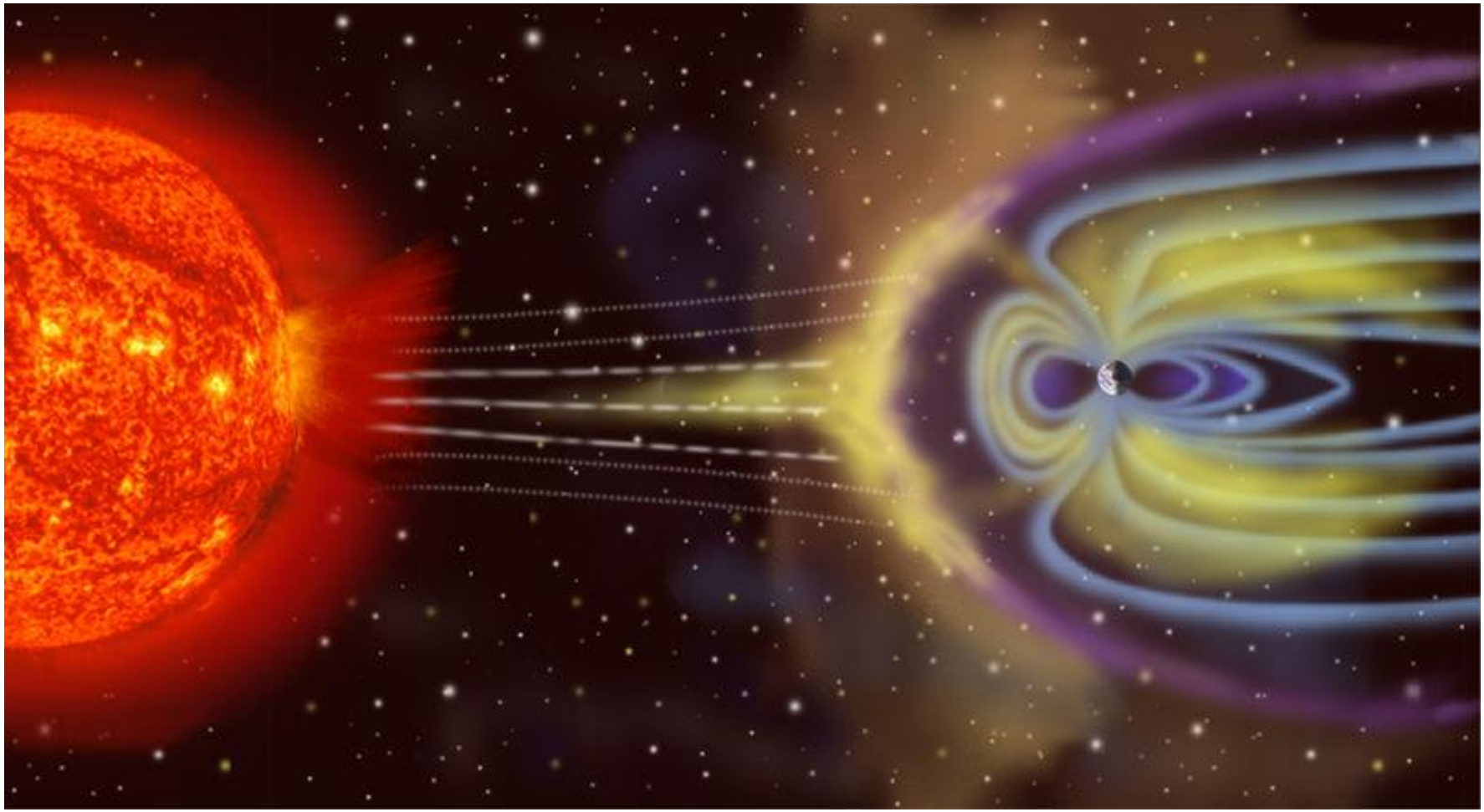
No convincing dip –
does not corroborate
the hypothesis.

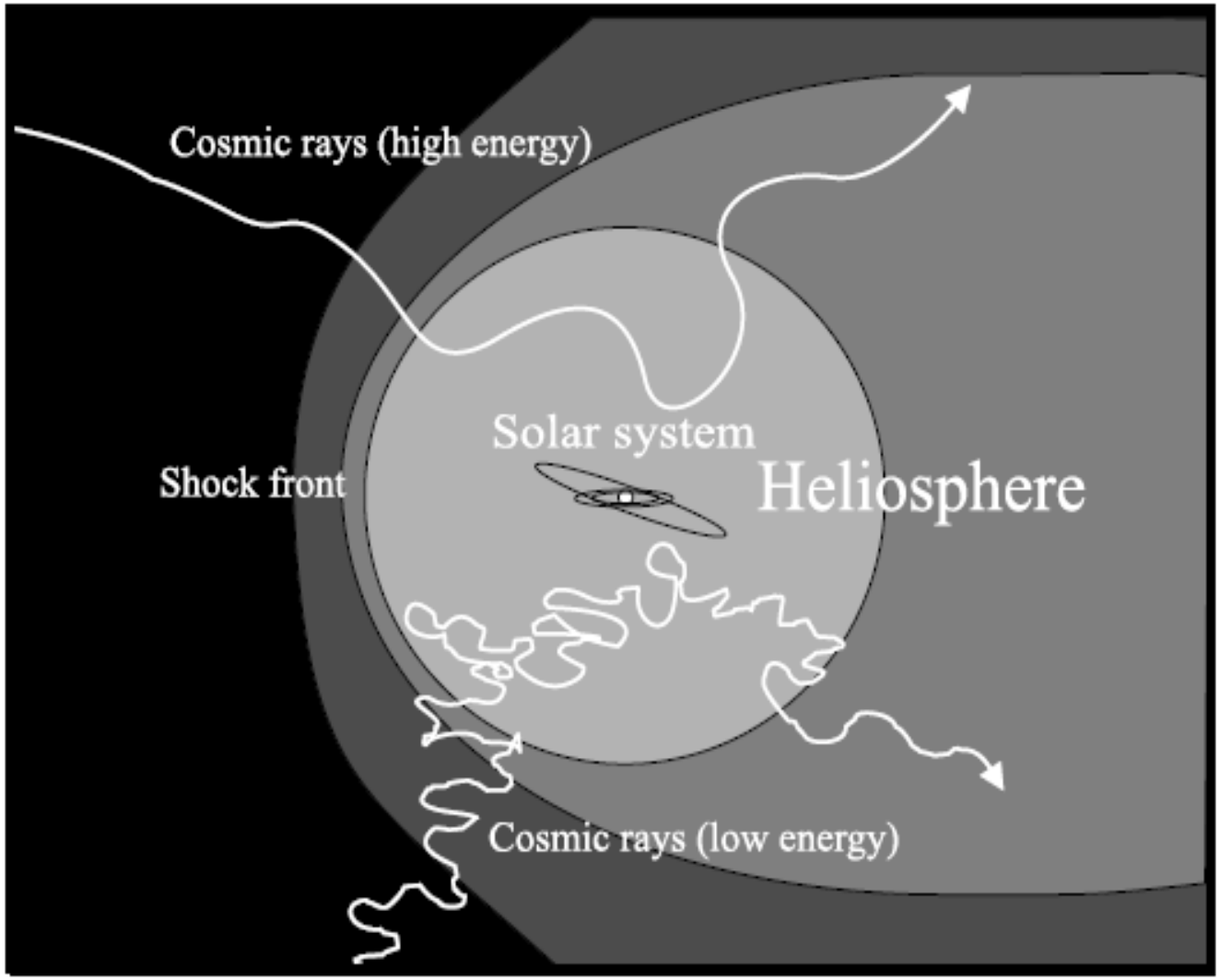
Never mind – keep going

Look at dependence on
magnetic latitude

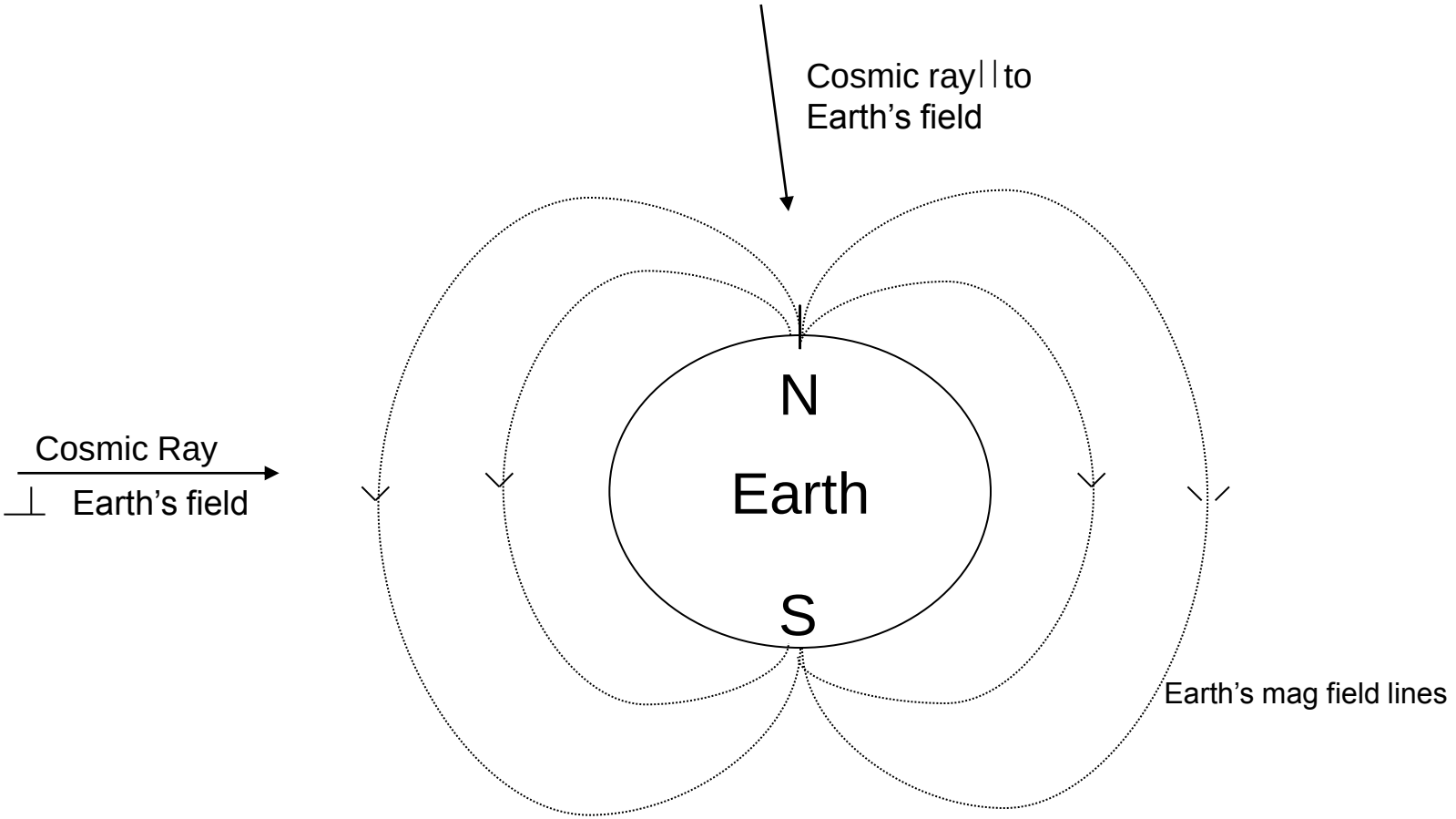


Most of the cosmic ray flux is at low energy – hence influence of interplanetary magnetic field generated by the solar wind.

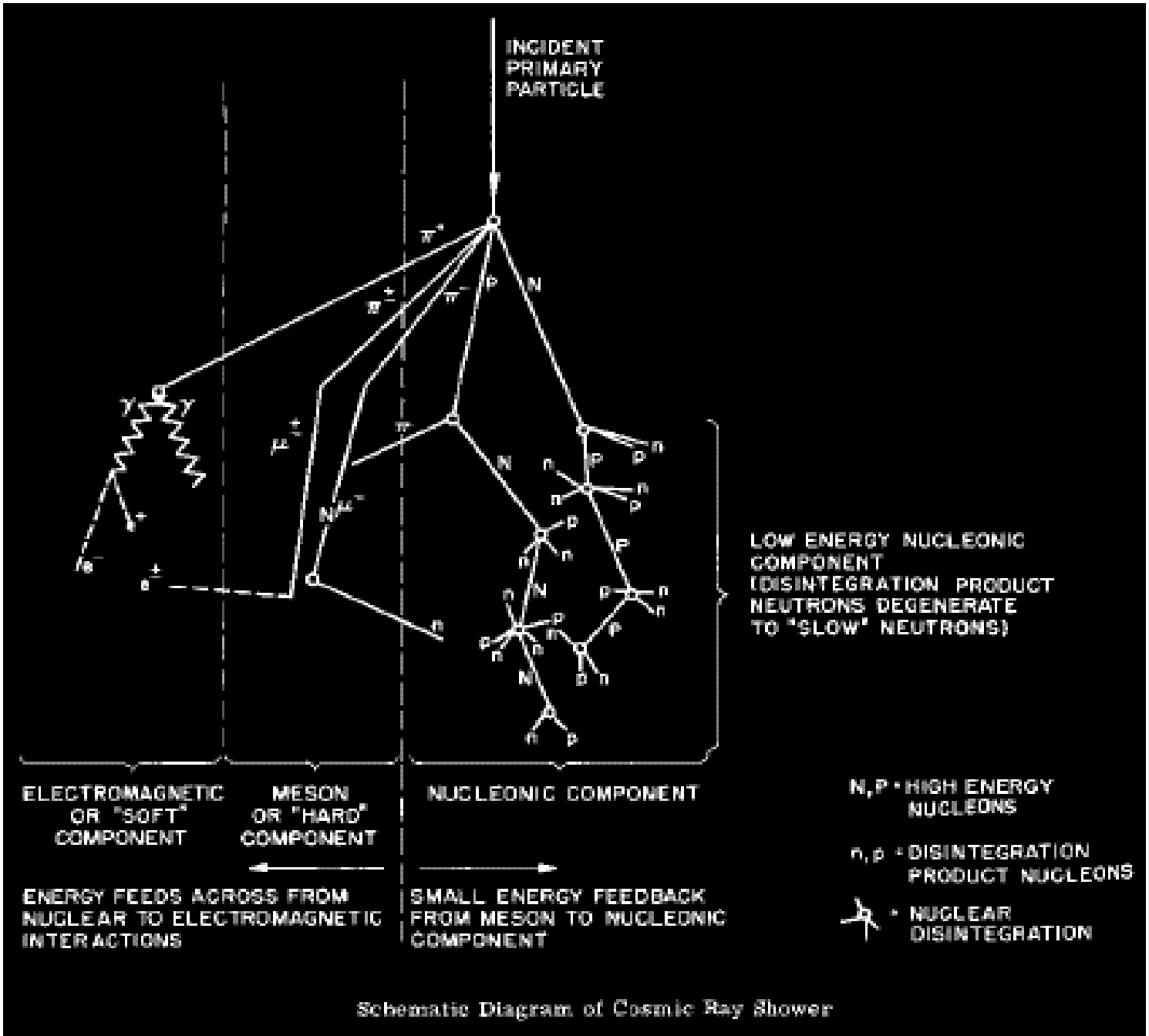



Cosmic rays (high energy)
Solar system
Shock front
Heliosphere
Cosmic rays (low energy)

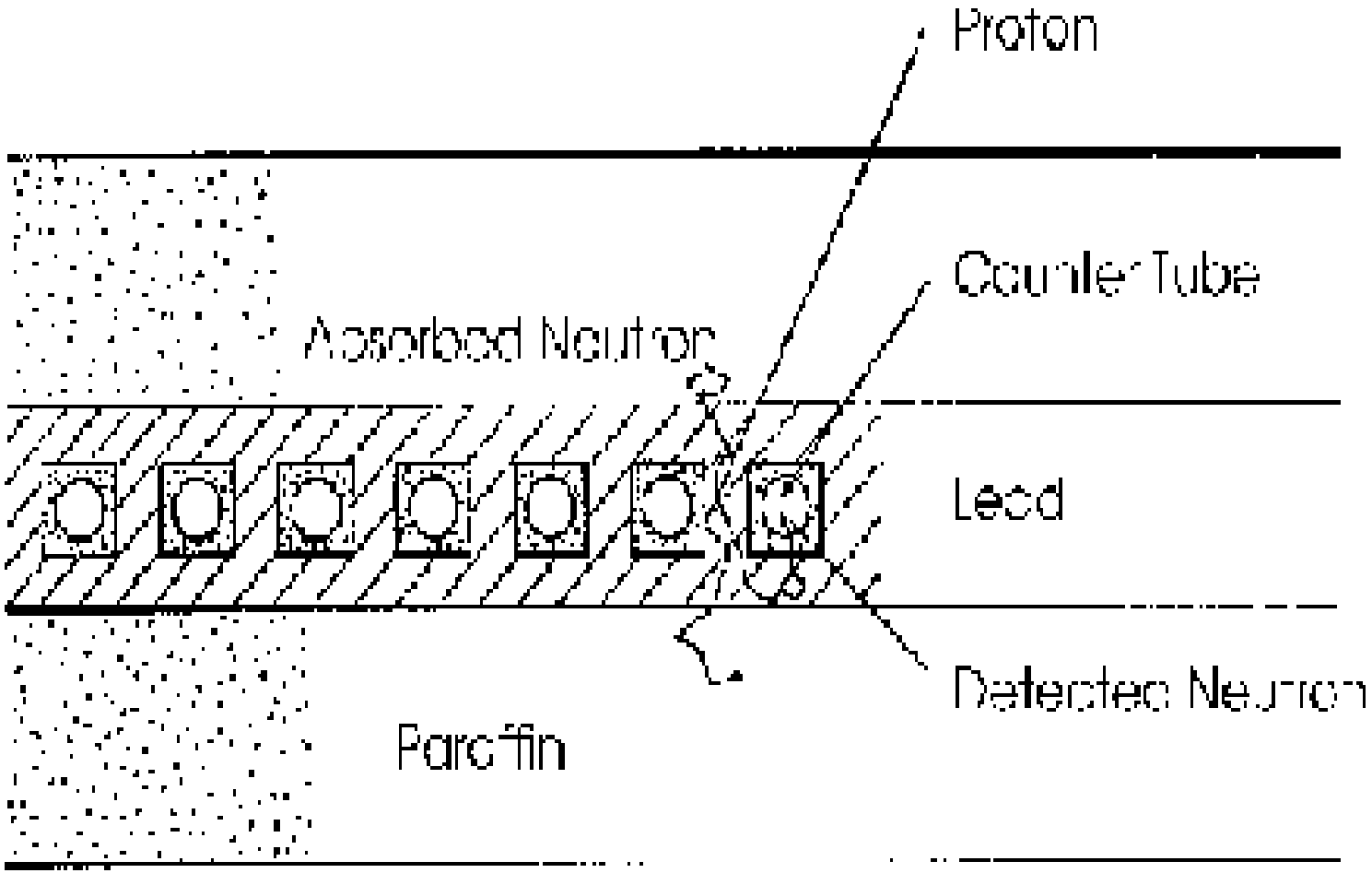
Once CR penetrates the IMF, has to survive Earth's magnetic field - vertical rigidity cut off (VRCO).



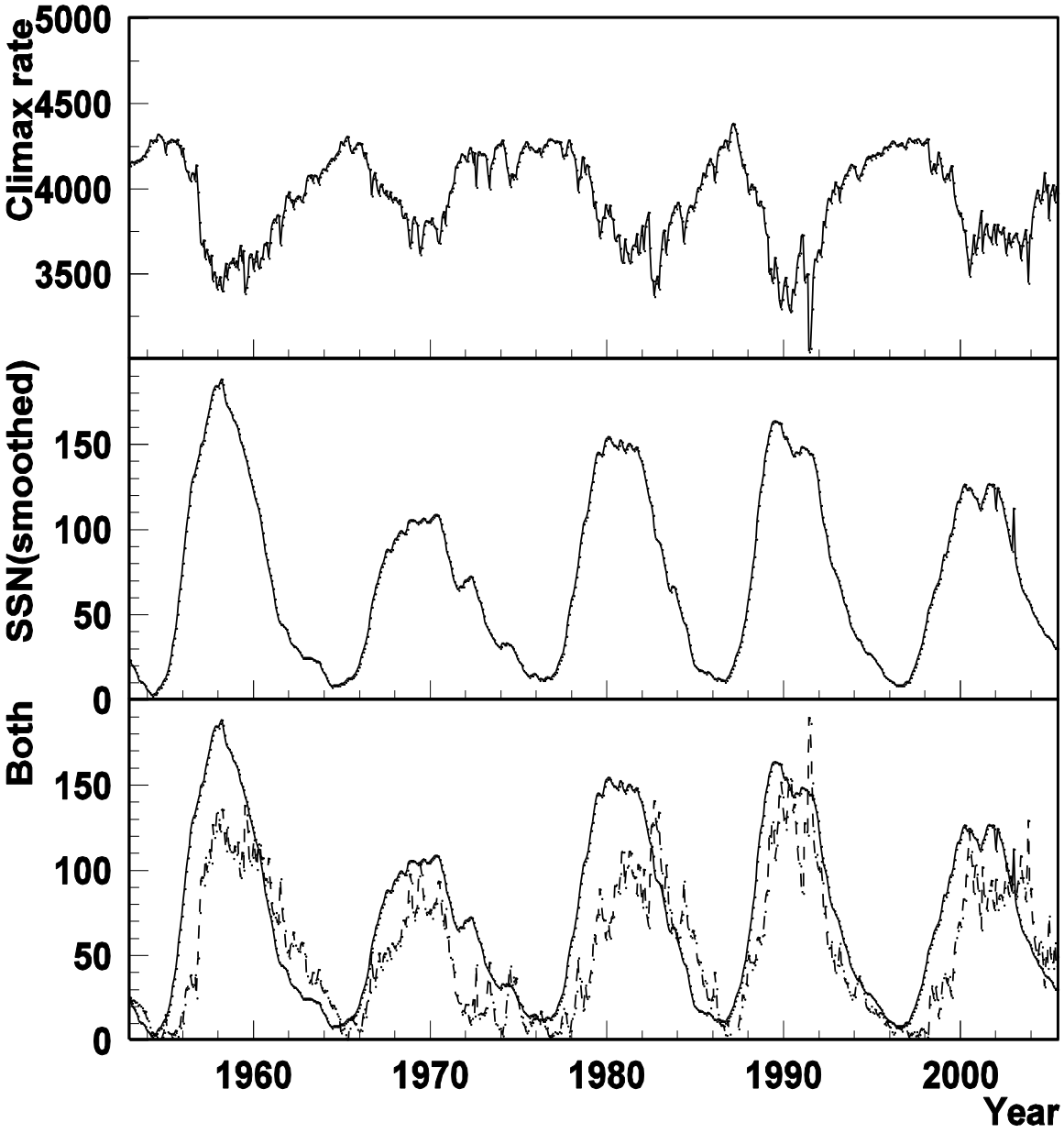
Measuring cosmic ray rates.

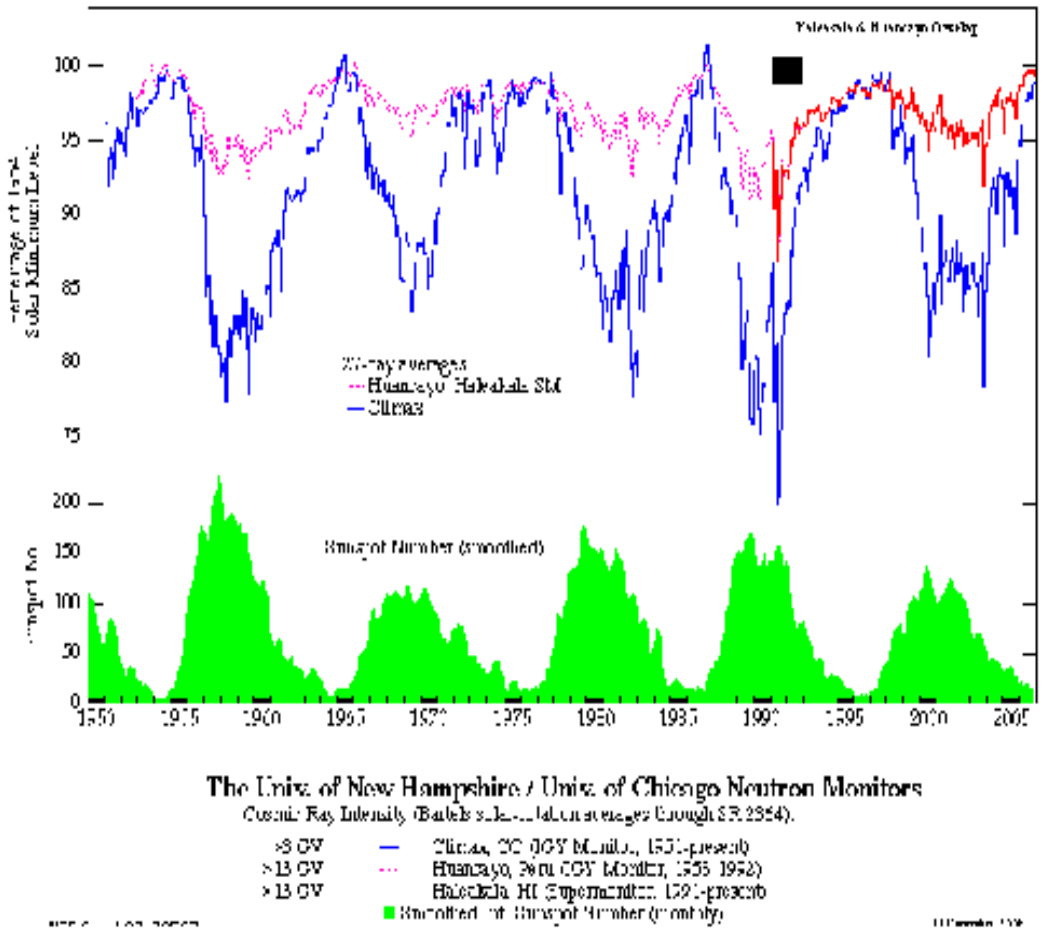


Schematic Diagram of Cosmic Ray Shower



Incident nucleons produce nuclear interactions in the lead.
Evaporation neutrons are thermalised by the paraffin.
The thermalised neutrons interact with He3 inside counter tubes ($n+He^3 \rightarrow p+H^3$ +770 kev) to produce an electronic impulse.


Climax rate
5000
4500
4000
3500
SSN(smoothed)
150
100
50
0
Both
150
100
50
0
1960
1970
1980
1990
2000
Year

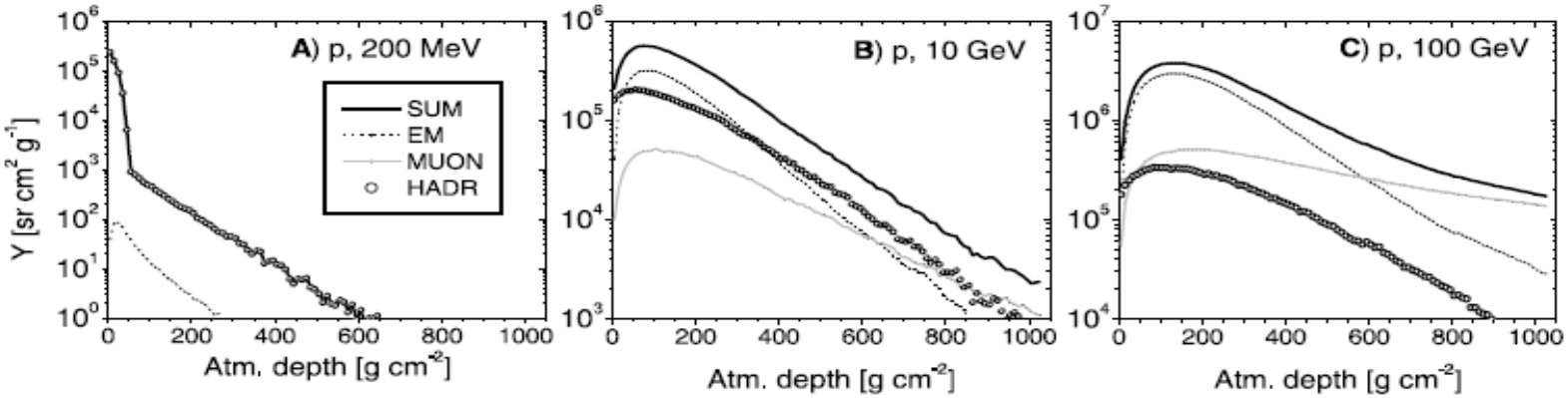


Red Huancayo
VRCO=12.9 GV

Blue – Climax
VRCO=3.0 GV

Green= Sun spot number.

Usoskin and Kovaltsov simulations of ionization yield in atmosphere

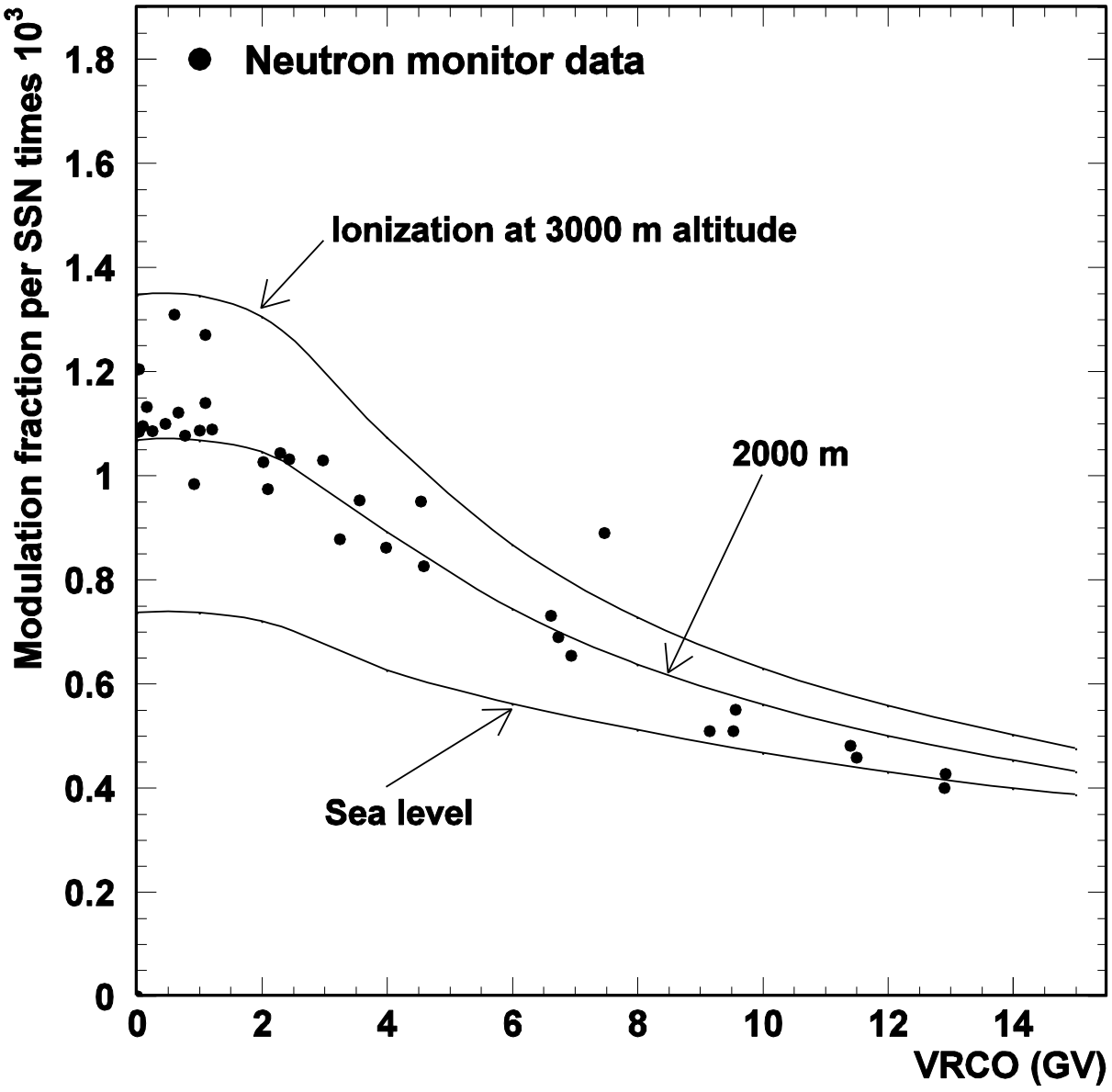


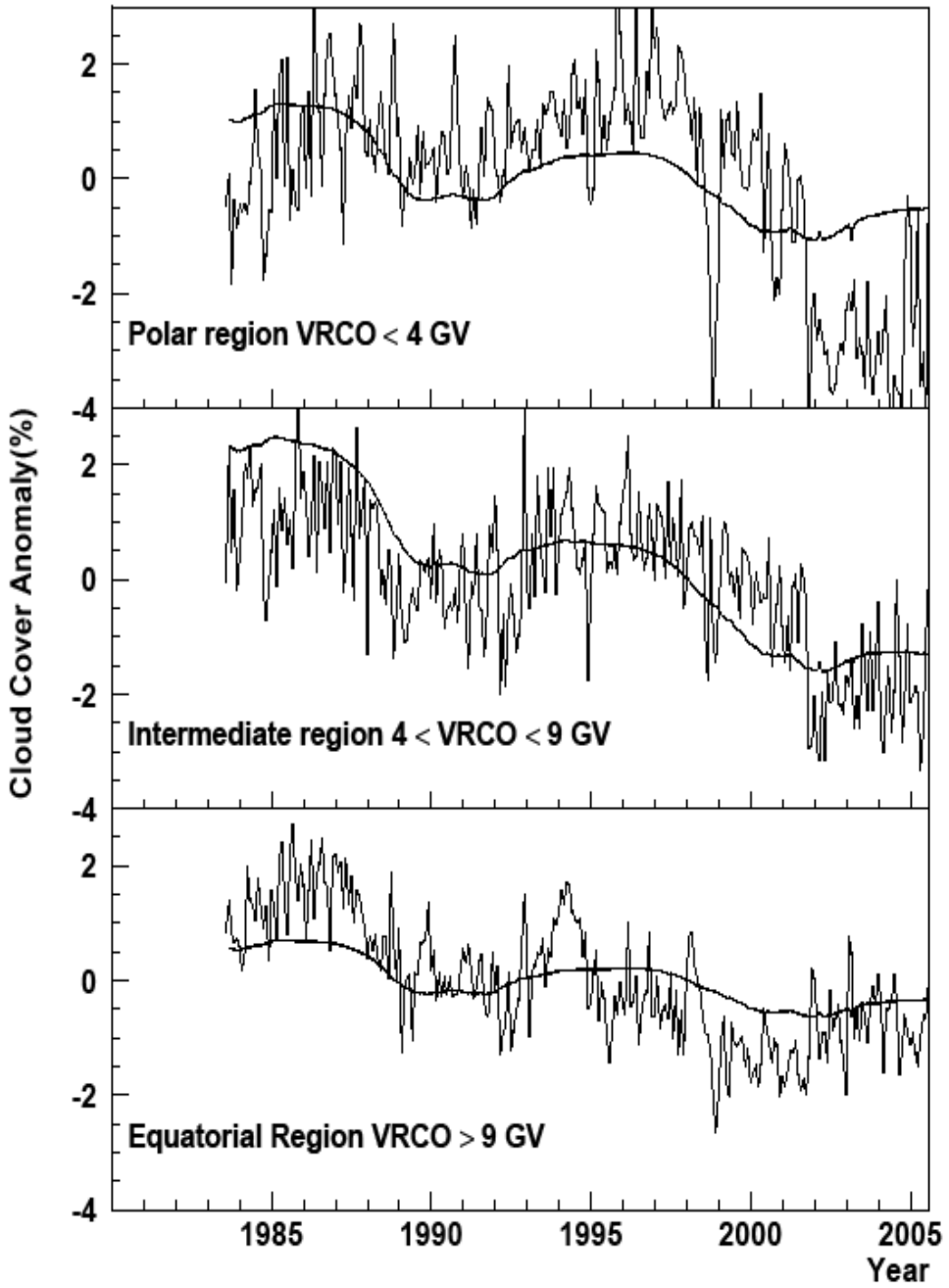
The 3 graphs show the ionization yield from different energy primary CRs.

For high energy primaries (~100 GeV) ionization dominated by muons

For intermediate energy (~10 GeV) muons, hadrons and electromagnetic.

For low energy primaries (< 1 GeV) hadrons dominate.

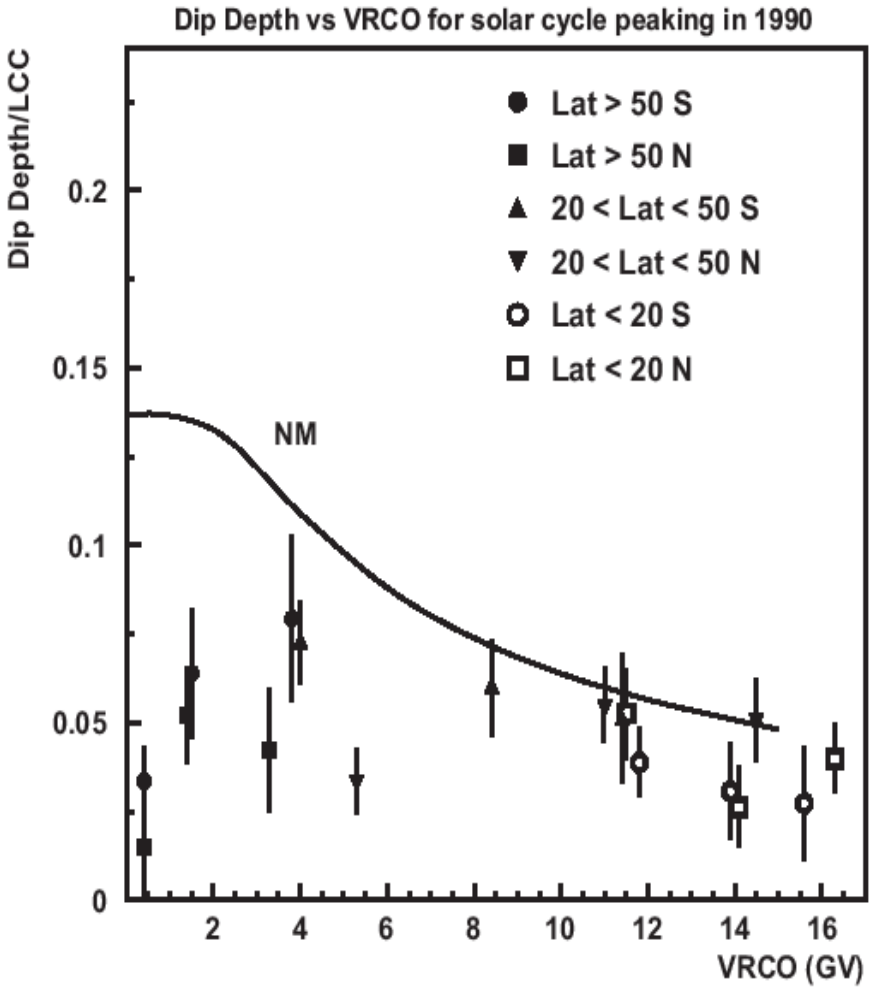

Neutron monitor data
Ionization at 3000 m altitude
2000 m
Sea level
Modulation fraction per SSN times 10^3
VRCO (GV)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
0
2
4
6
8
10
12
14



Reanalyse the data – dip in solar cycle 22 (1990) – not so evident in cycle 23 (2000)

Dip is approx constant with VRCO – NOT increasing – no corroboration

Smooth curve – MINUIT fit



Dip depth independent of magnetic latitude (VRCO).

Statistical analysis shows < 23% of the dip is caused by cosmic rays.

Assume that change in LCC is made up of a part Correlated with ionization and a part from another Source.

$$\text{i.e. } \Delta LCC = \Delta LCC_S + \Delta LCC_I$$
$$= \Delta LCC_S + \kappa \, \delta N/N$$

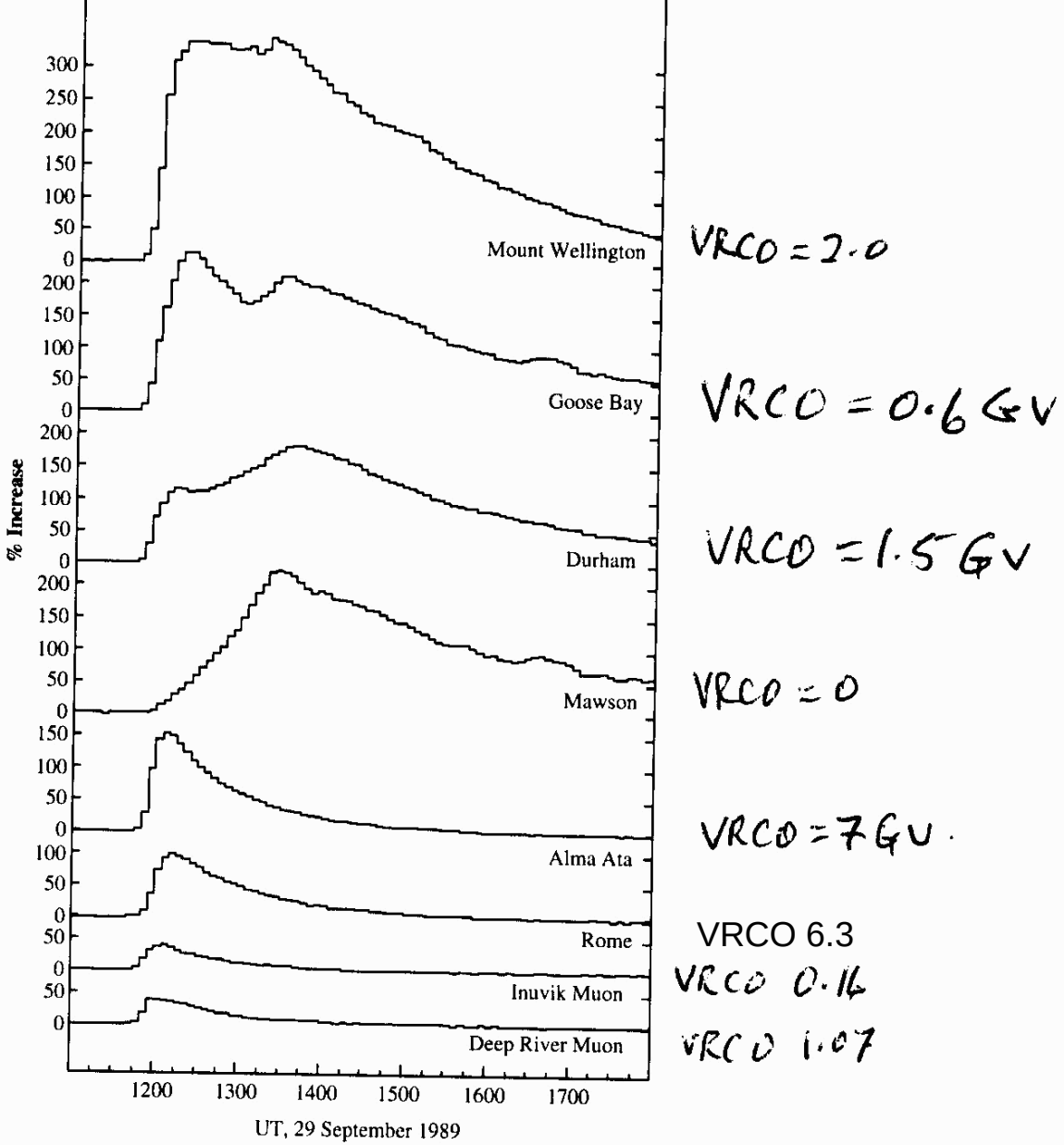
Fit a*flat + b* δN/N to data gives b=0.02±0.13
i.e. < 23% of the distribution correlates with the neutron modulation at 95% confidence level.

Conclude less than 23% of cloud cover change is due to change in ionization changes from CR.

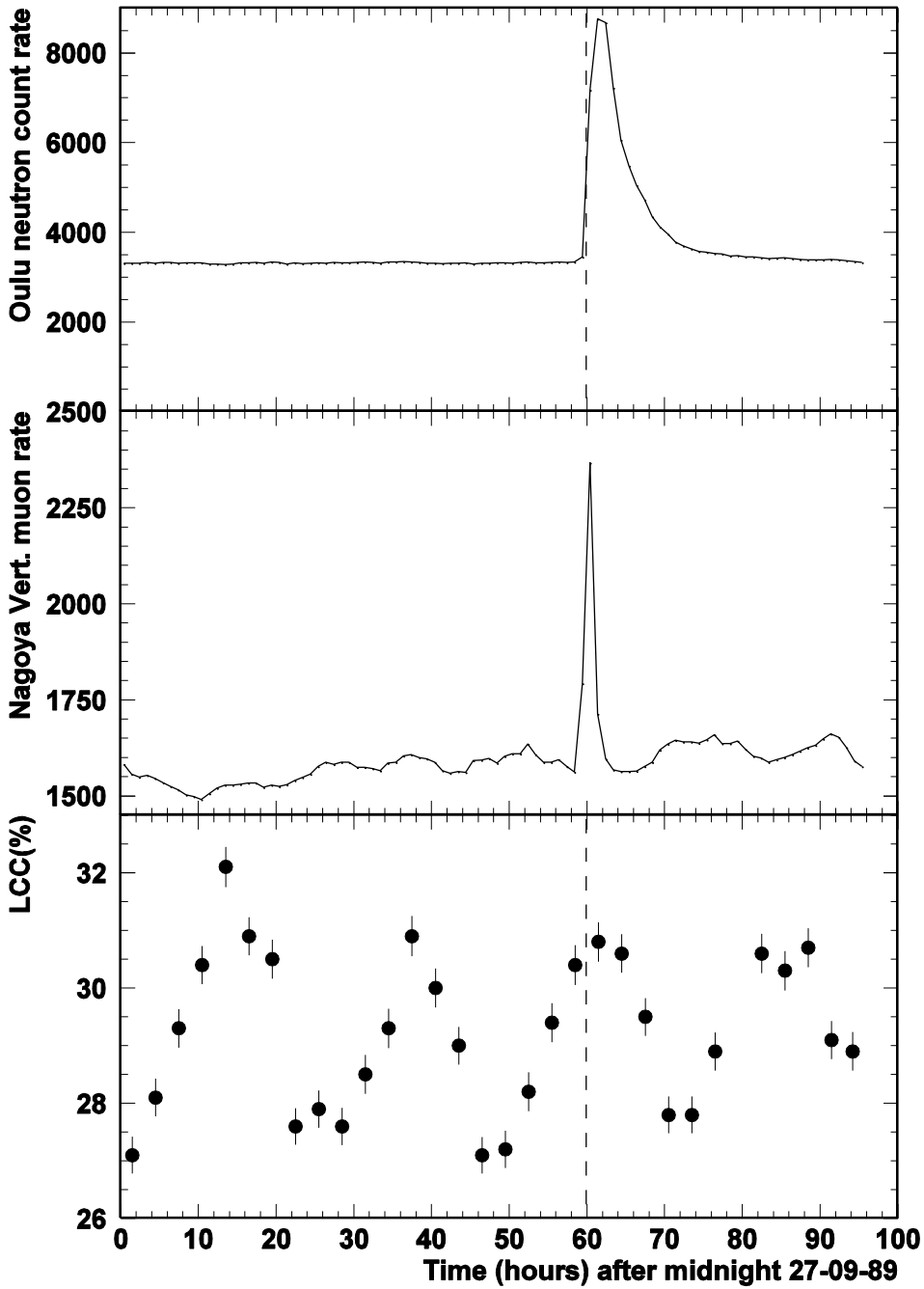
Look for other corroborative evidence.

Ground Level Events (GLE)

- About once a year sun belches out large particle fluxes which show up on CR monitors. Mostly quite small.
- Three mammoth events (double CR rate for a few hours) in the time we have cloud cover data. Only one of these shows up in the muon monitors – 29 Sept 1989.



igure 24: Cosmic ray increases at Mt Wellington, Goose Bay, Durham, Mawson, Alma-Ata and ome neutron monitors and Inuvik and Deep River muon telescopes between 1100 and 1800 UT ı 29 September 1989. (From Lovell et al. 1998).



GLE 29 Sept 1989

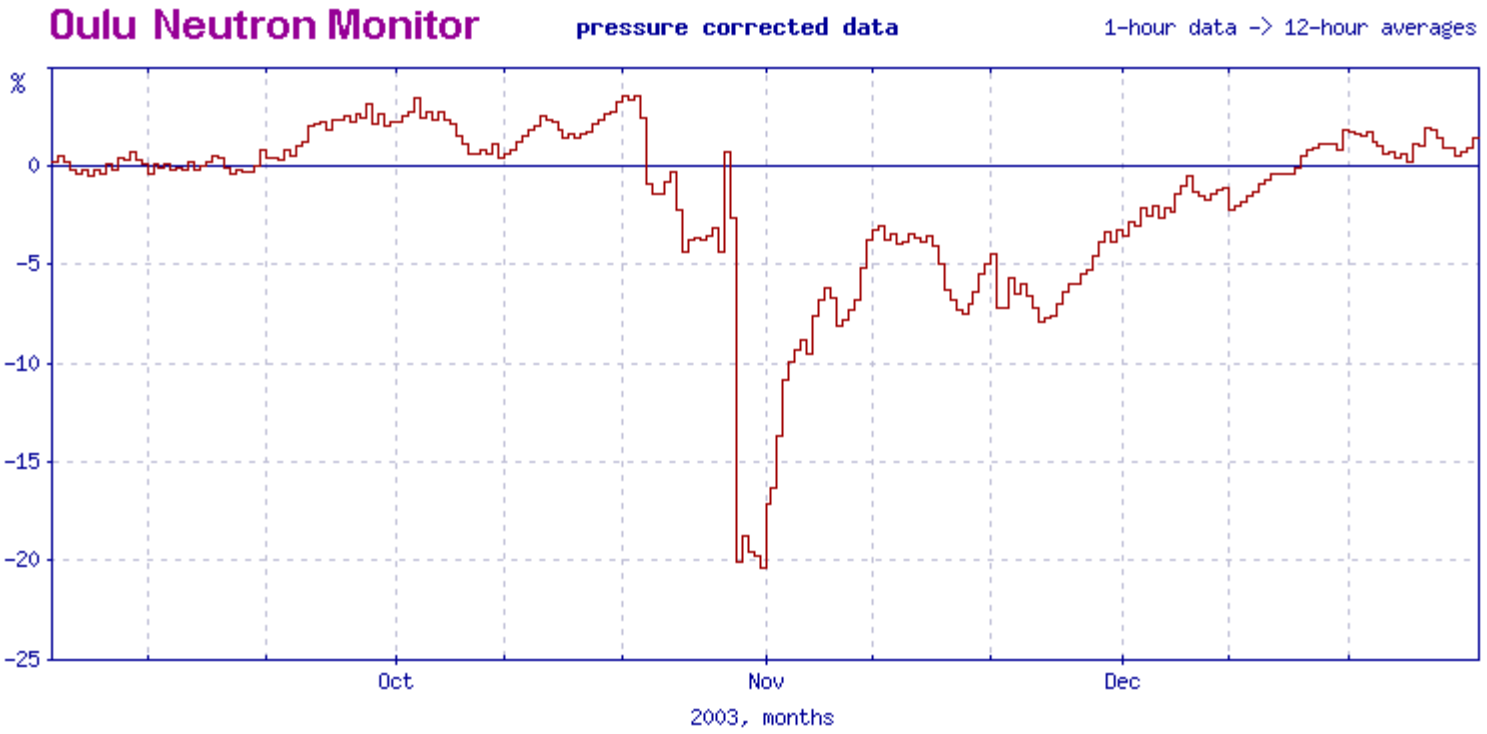
Oulu neutron monitor

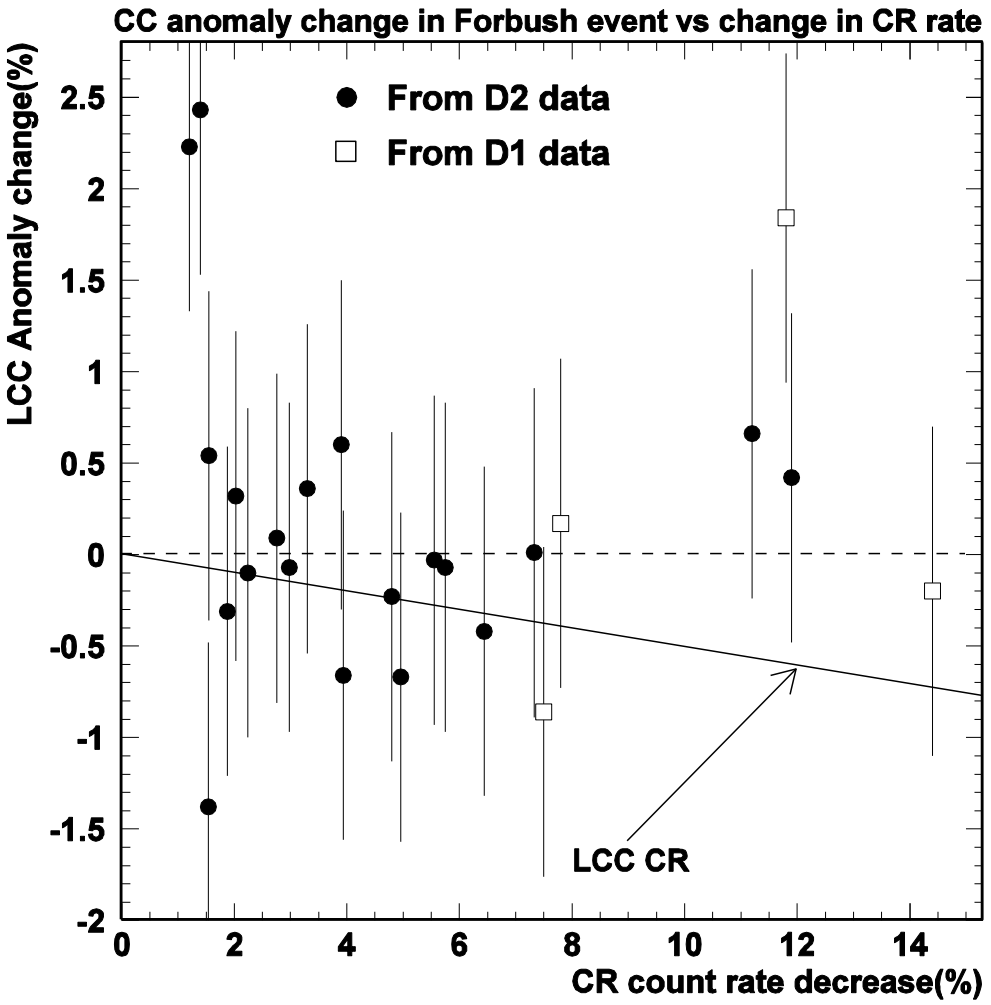
Nagoya muon monitor

LCC average over globe

No sign of excess after GLE.

Forbush Decreases in CR rate – do they lead to changes in LCC ?





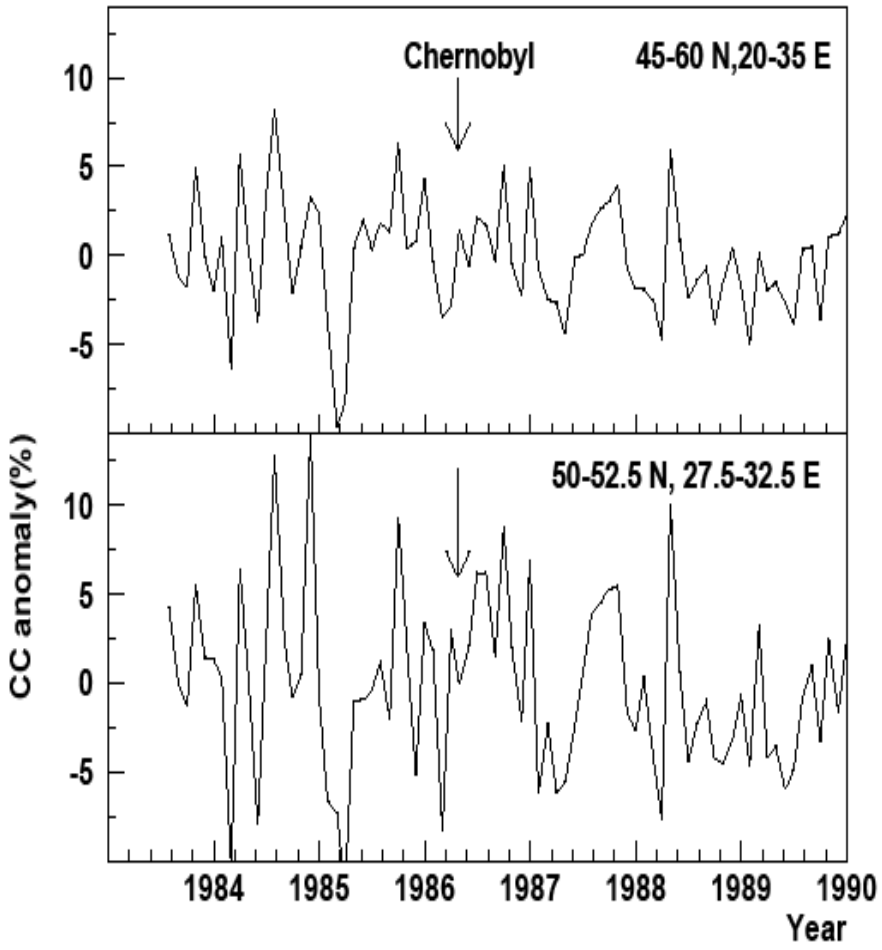
Data more consistent with null (dashed) line than with that expected from LCC CR correlation

Radon in India – hot spots known about.

No sign of increase cloud cover in vicinity of these hot spots.

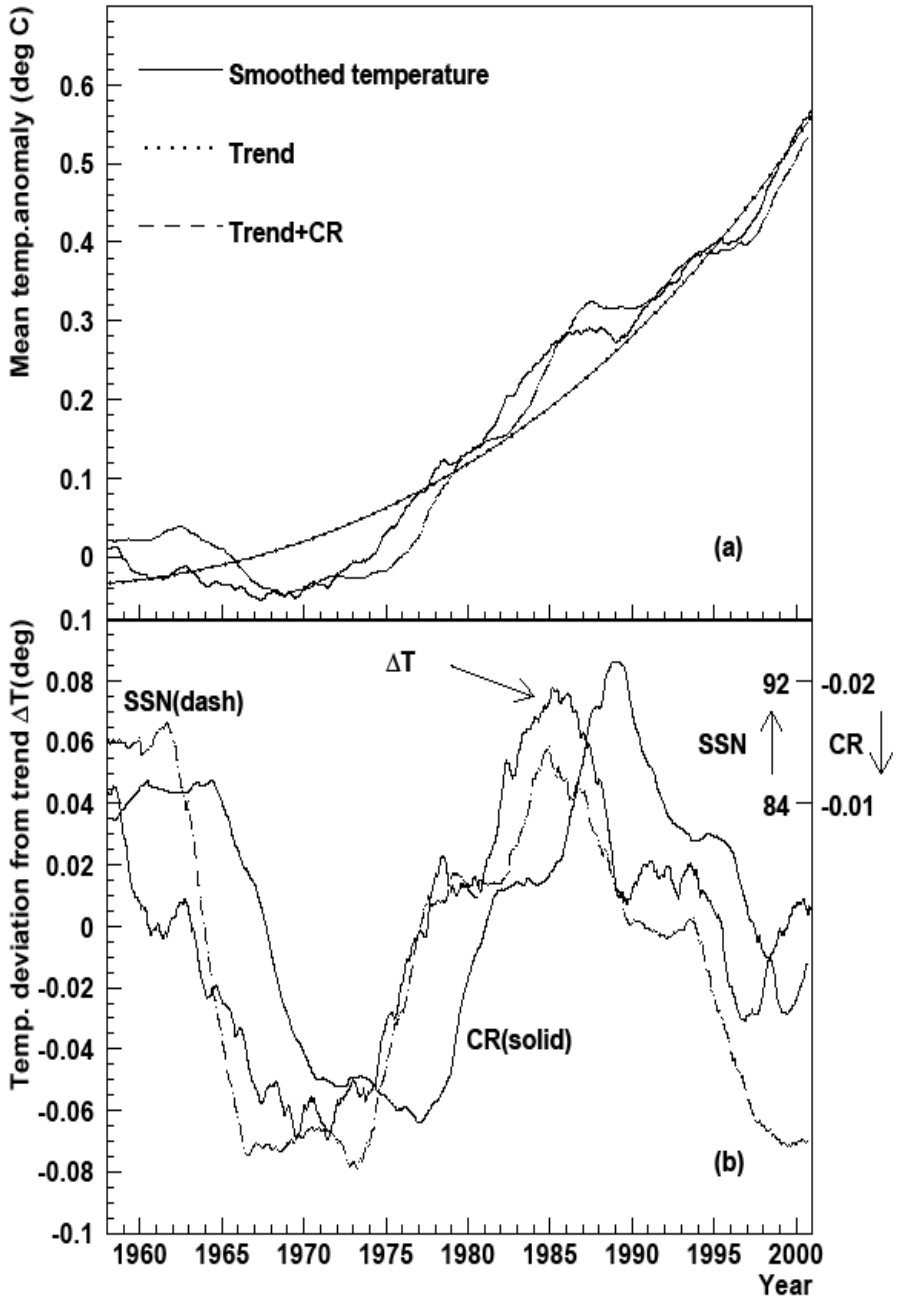
Nuclear weapons tests – no indication that they affect the cloud cover in regions remote from the test where ionization levels high.

Chernobyl nuclear accident



Gave a large release of radioactivity into the air which spread across Europe. No sign of an increase in LCC

Need to assume weather conditions right for cloud formation.



Did we find something ?

Do 11 year smoothing of temp, CR and SSN.

Seem to vary in step but CR delated by ~2 Years.

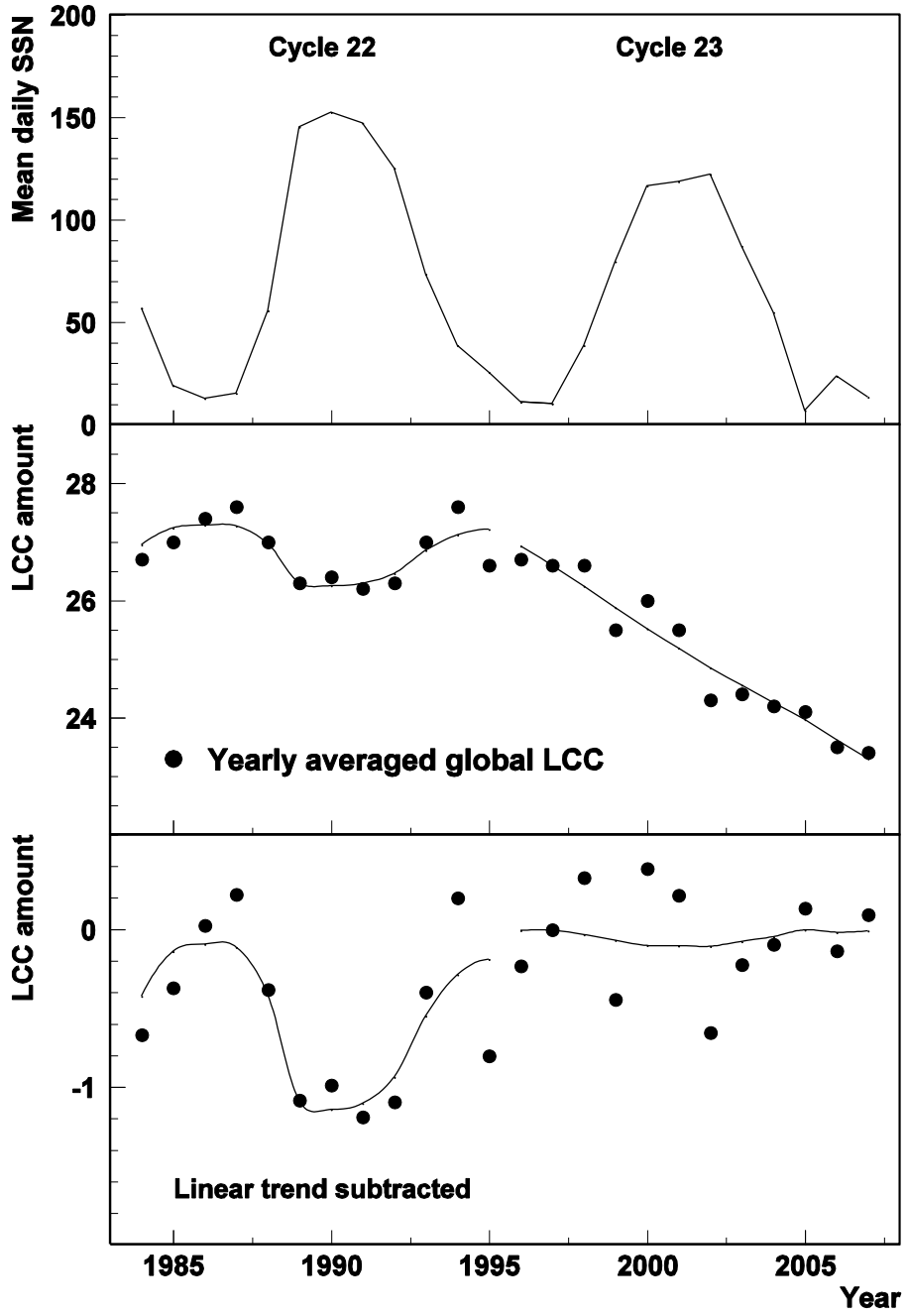
Therefore if there is an effect looks more like solar irradiance variation.

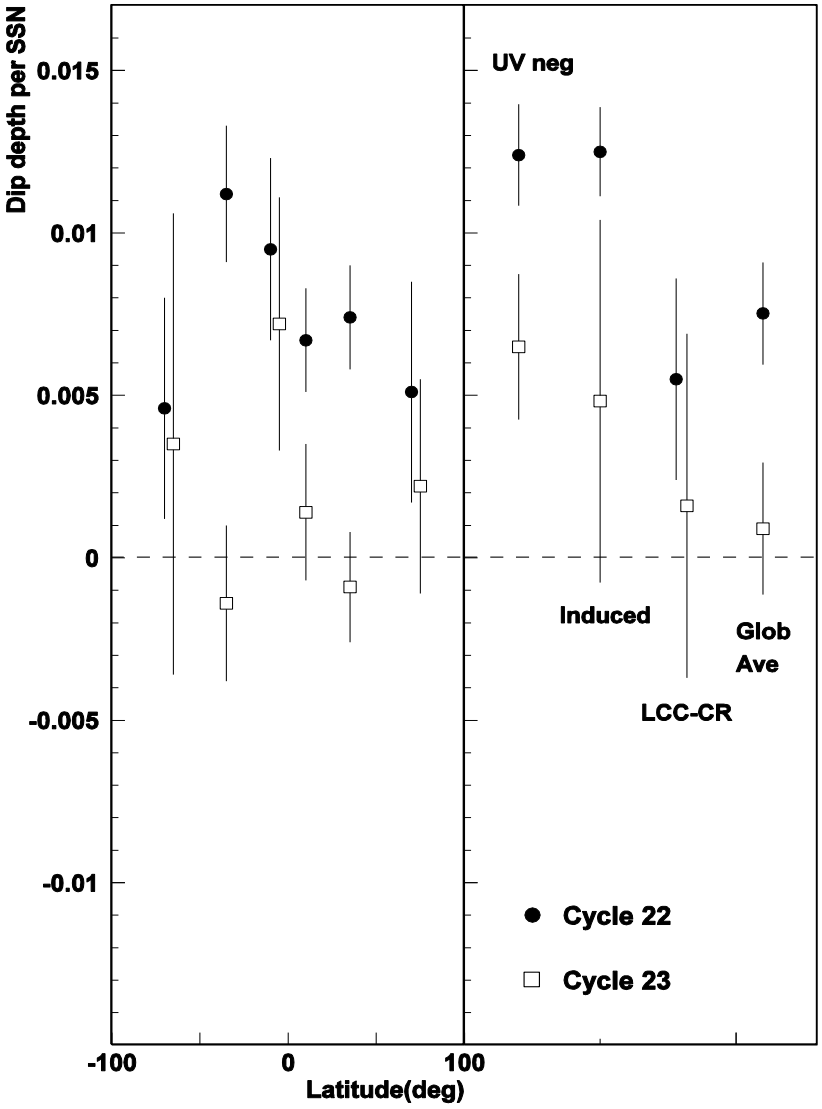
Assume it is due to CR – CR modulation is 1.5% which is less than long term change in same period. Temp modulation = ± 0.07 deg C.

Therefore CR produce a change of < 0.07 deg i.e. < 14% of global warming since 1956.

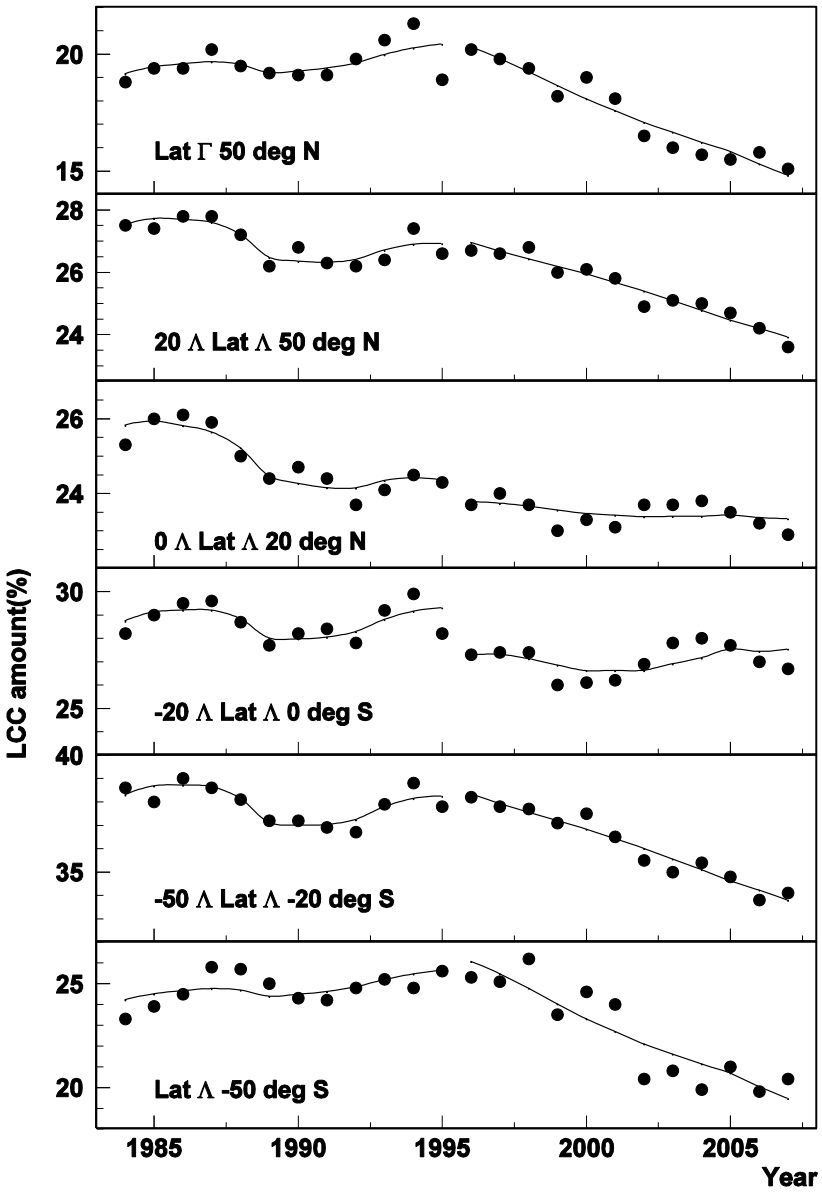
Conclusions

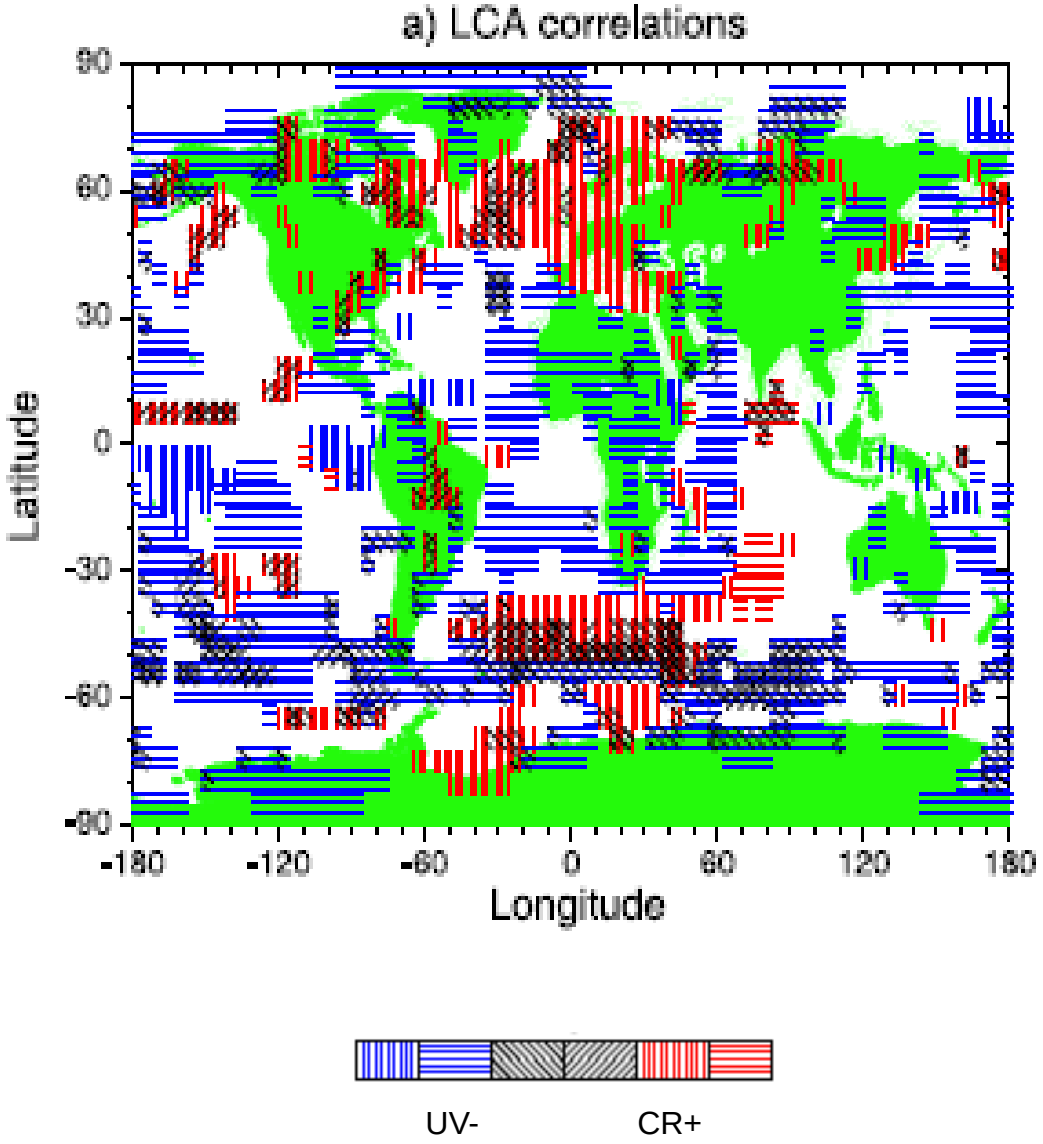
- Looked for evidence to corroborate the hypothesis that cosmic rays and clouds are correlated – none found.
- The effect on global warming is < 23% at 95% CL in one test or < 14% at unknown CL in another test.
- This is not to say that the effect is zero but its contribution to global warming is small.

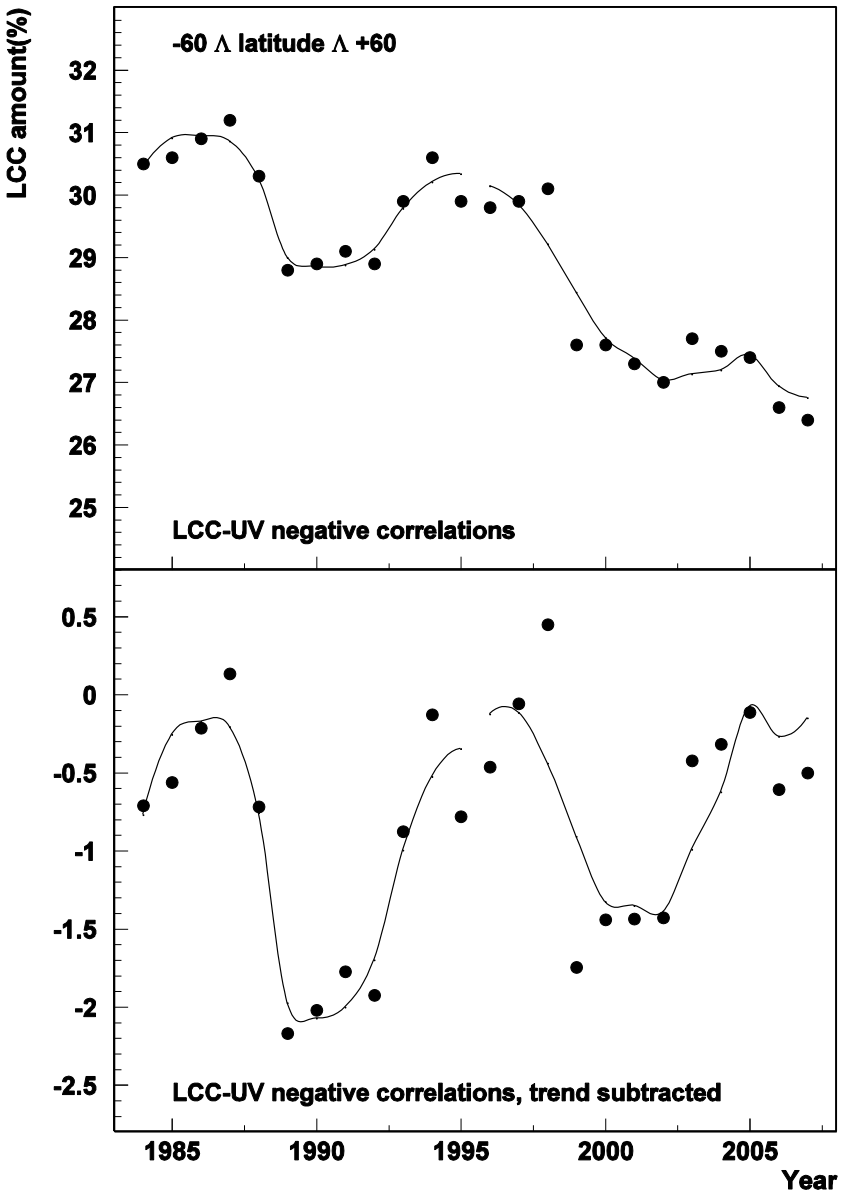

Mean daily SSN
200
150
100
50
0
Cycle 22
Cycle 23
LCC amount
28
26
24
Yearly averaged global LCC
LCC amount
0
-1
Linear trend subtracted
1985
1990
1995
2000
2005
Year



Only statistically significant dip
Is UVneg correlations.


LCC amount(%)
Lat Γ 50 deg N
20 Λ Lat Λ 50 deg N
0 Λ Lat Λ 20 deg N
-20 Λ Lat Λ 0 deg S
-50 Λ Lat Λ -20 deg S
Lat Λ -50 deg S
Year
1985
1990
1995
2000
2005


a) LCA correlations
90
60
30
0
-30
-60
-90
Latitude
-180
-120
-60
0
60
120
180
Longitude
UV-
CR+



Cycle 22 and 23 clearly visible
These squares cover ~20% of the Earth's surface.

Svensmark argument on radiative forcing due ionization.

- Albedo from LCC = 17 W/m^2
- Dip depth ~2% is 7% change in LCC
- Global warming due to cycle 22 dip =0.07*17=1.2 W/m2
- Long term cosmic ray change is ~1.2 times that due to solar cycle – so total radiative forcing due to LCC change

  ~ 1.4 W/m2.

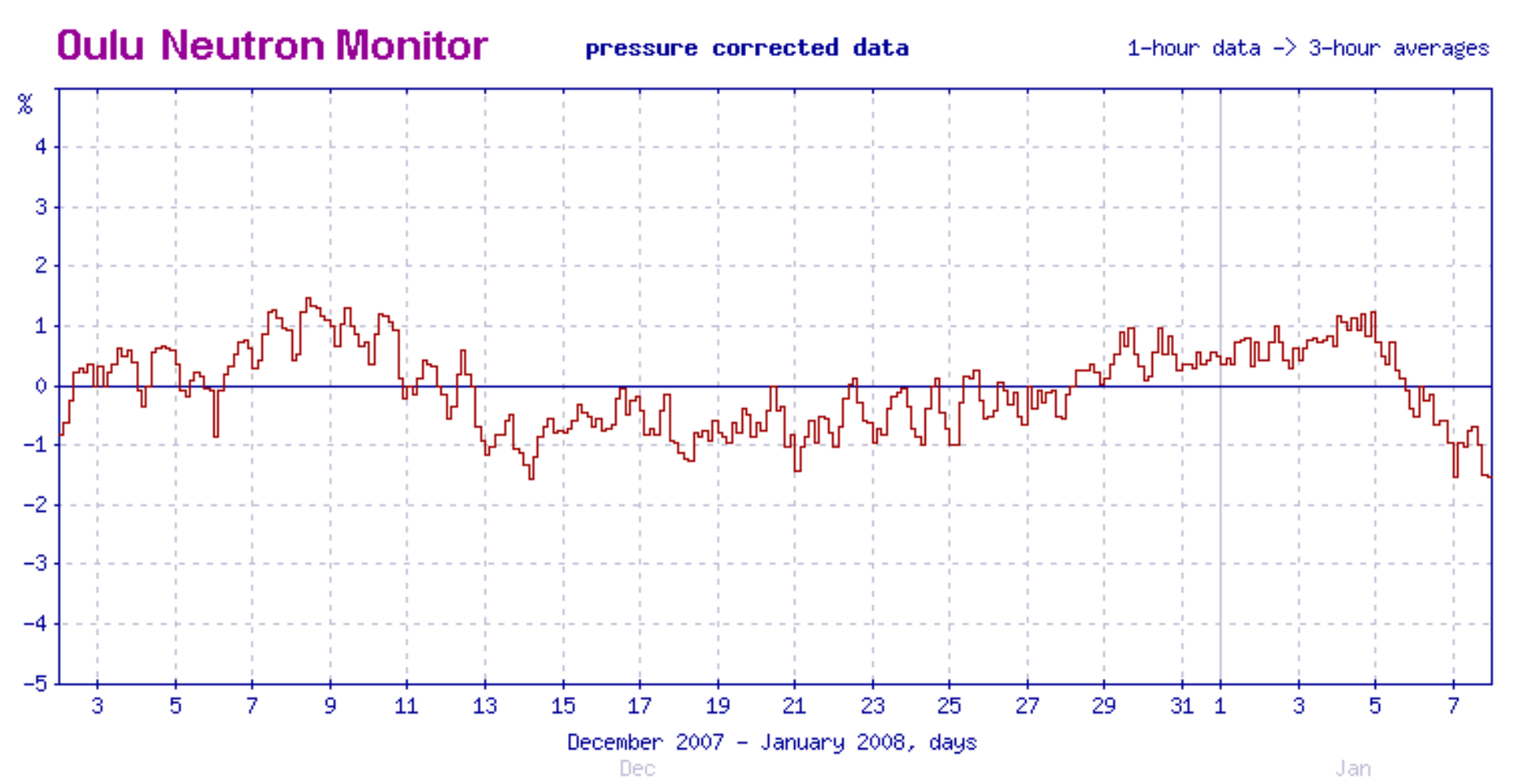
Our view

- We see equal LCC dips in cycles 22 and 23 over ~20% of the Earth.
- We only see this in squares where there is a large cor.coeff. Between UVI and LCC.
- Probably not ionization although there is a connection between aerosol formation and ionization – SKY – CLOUD projects.
- Radiative forcing could be 0.2*1.4 W/m^2 i.e. ~0.3 W/m^2

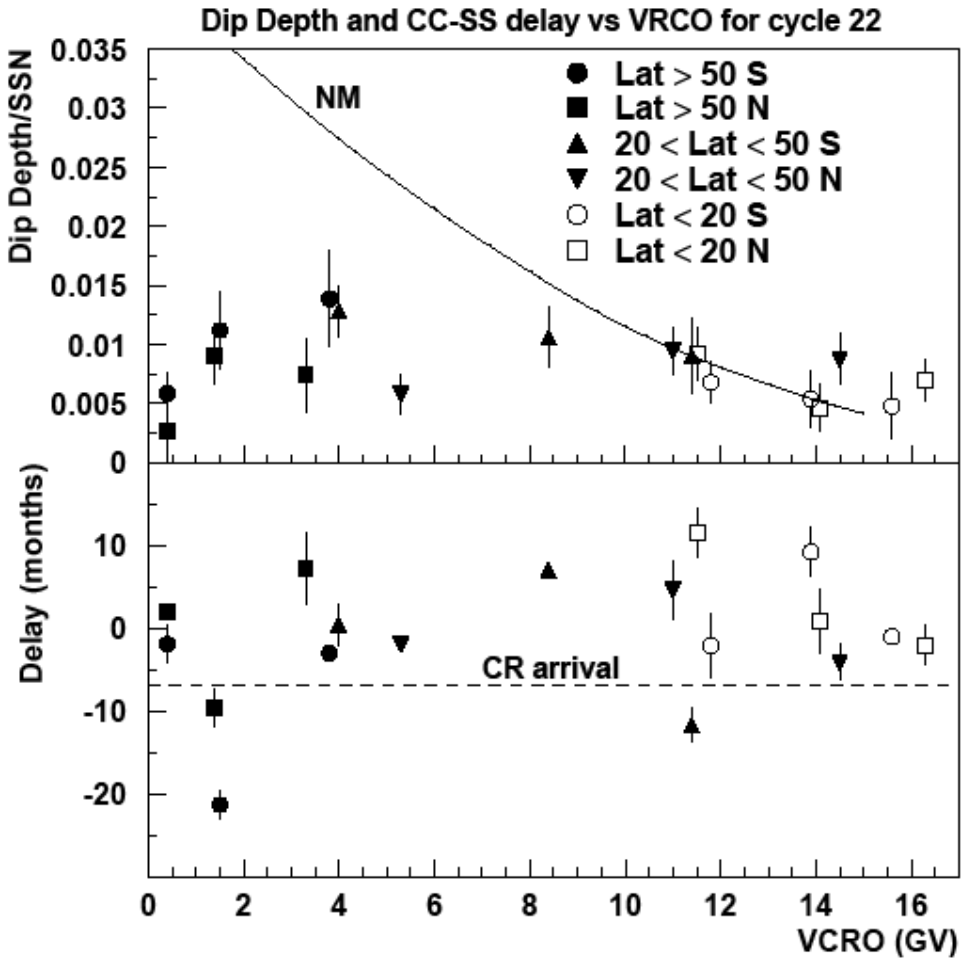

DARK
MATTER
Building
Research

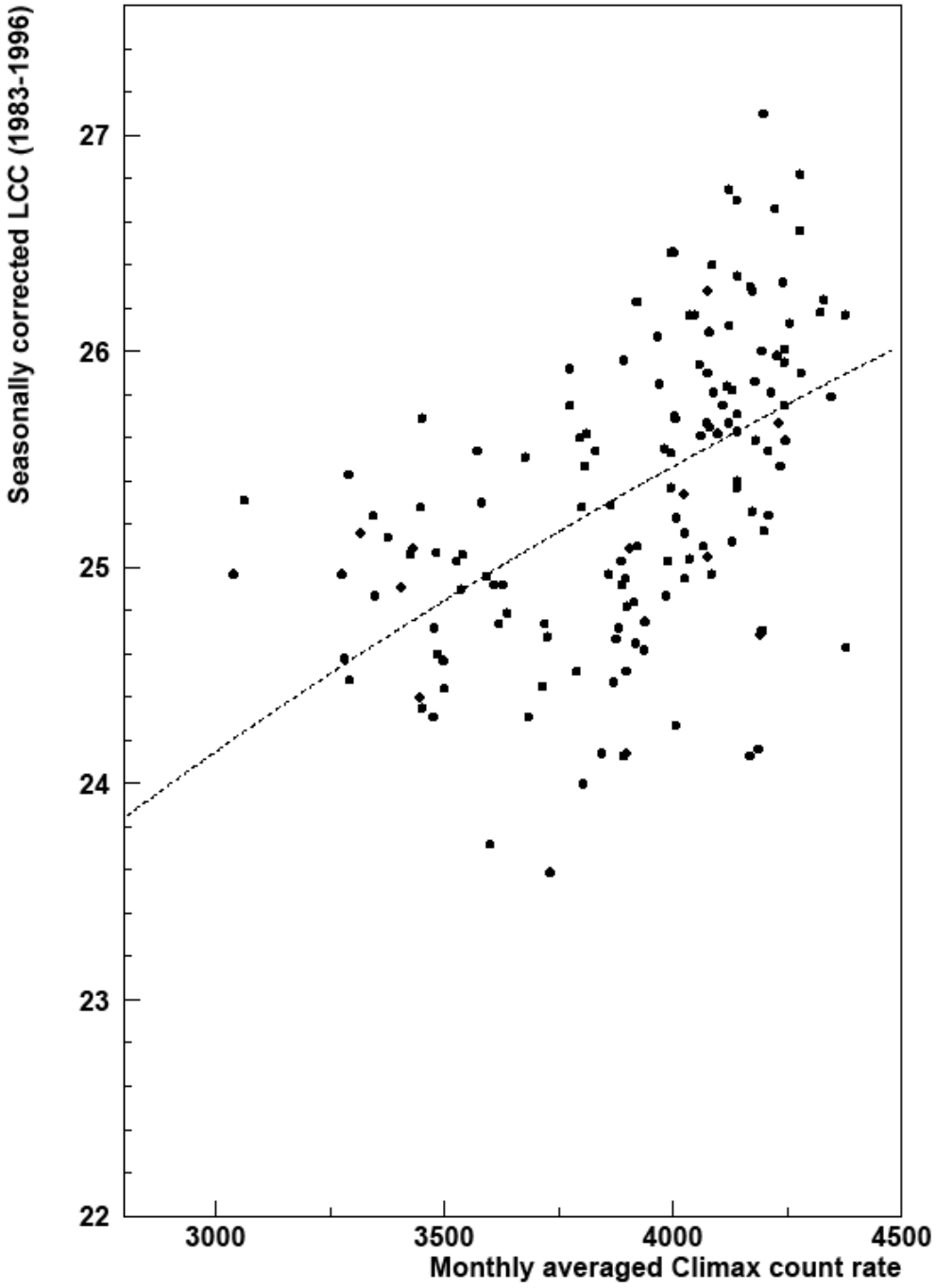
Conclusions

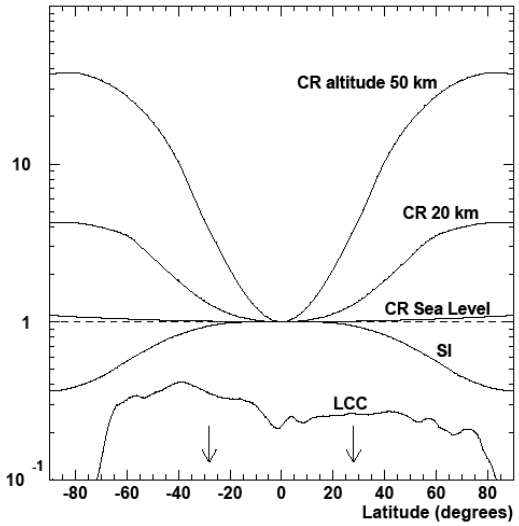
- Dip in global average LCC seen in cycle 22 everywhere but cycle 23 dip rarely.
- No corroborative evidence found that ionization affects LCC.
- Solar activity seen in UVI-LCC correlations in both cycles 22 and 23
- Which could imply a radiative forcing of ~0.3 W/m^2 - watch this space.

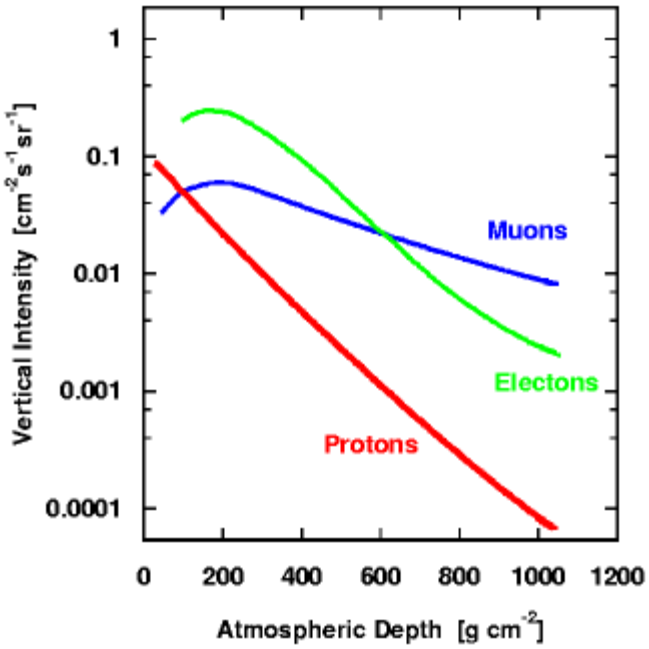


Last month's Oulu data – NB 24 hour period
Of ~1% << LCC modulation of 13%


Dip Depth and CC-SS delay vs VRCO for cycle 22
Dip Depth/SSN
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
NM
Lat > 50 S
Lat > 50 N
20 < Lat < 50 S
20 < Lat < 50 N
Lat < 20 S
Lat < 20 N
Delay (months)
10
0
-10
-20
CR arrival
0
2
4
6
8
10
12
14
16
VCRO (GV)


Seasonally corrected LCC (1983-1996)
27
26
25
24
23
22
3000
3500
4000
4500
Monthly averaged Climax count rate


CR altitude 50 km
CR 20 km
CR Sea Level
SI
LCC
10
1
10 -1
-80 -60 -40 -20 0 20 40 60 80
Latitude (degrees)


1
0.1
0.01
0.001
0.0001
Vertical Intensity [cm-2 s-1 sr-1]
Muons
Electons
Protons
0
200
400
600
800
1000
1200
Atmospheric Depth [g cm-2]


(from the Vostok ice core)
Global

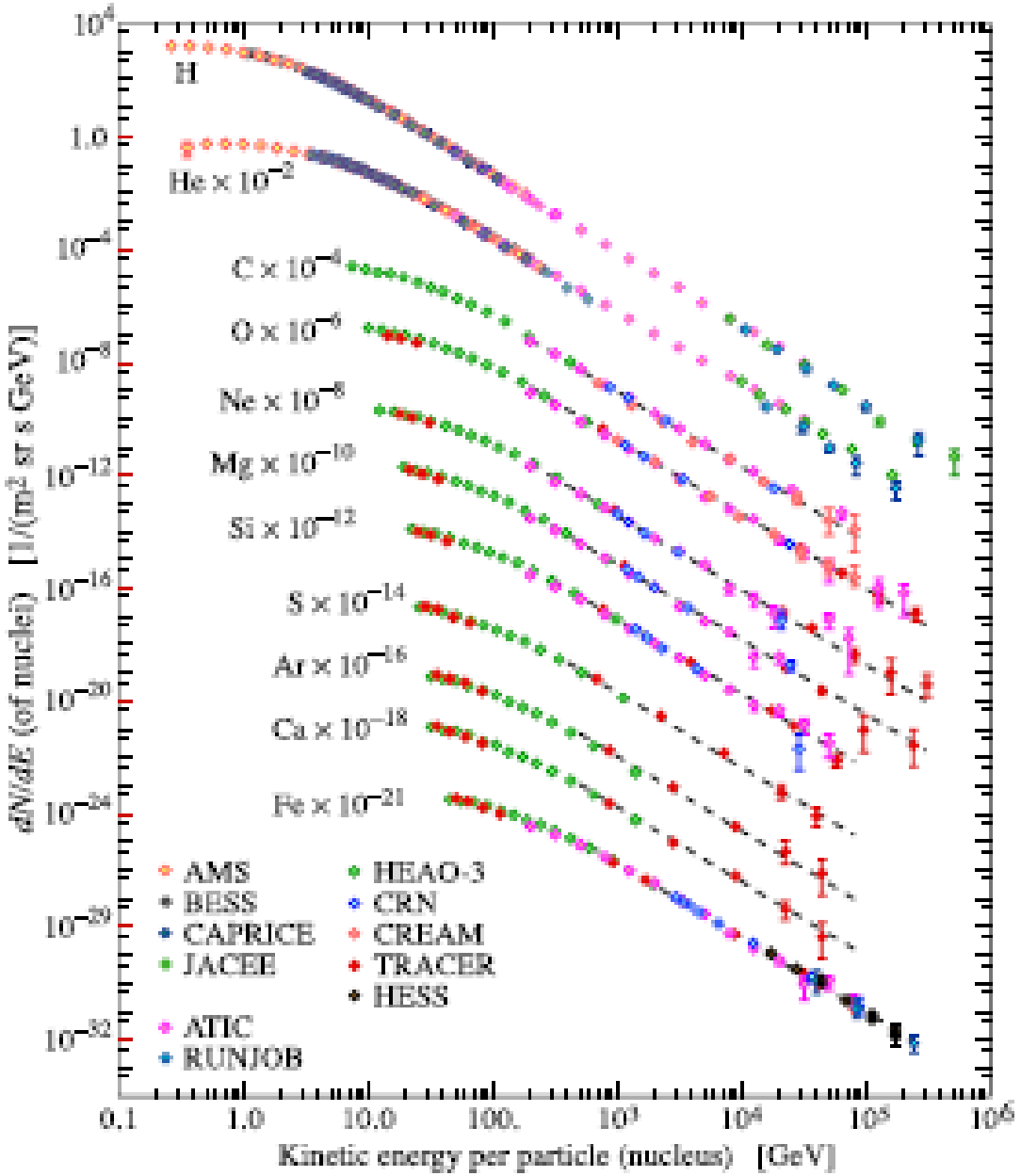
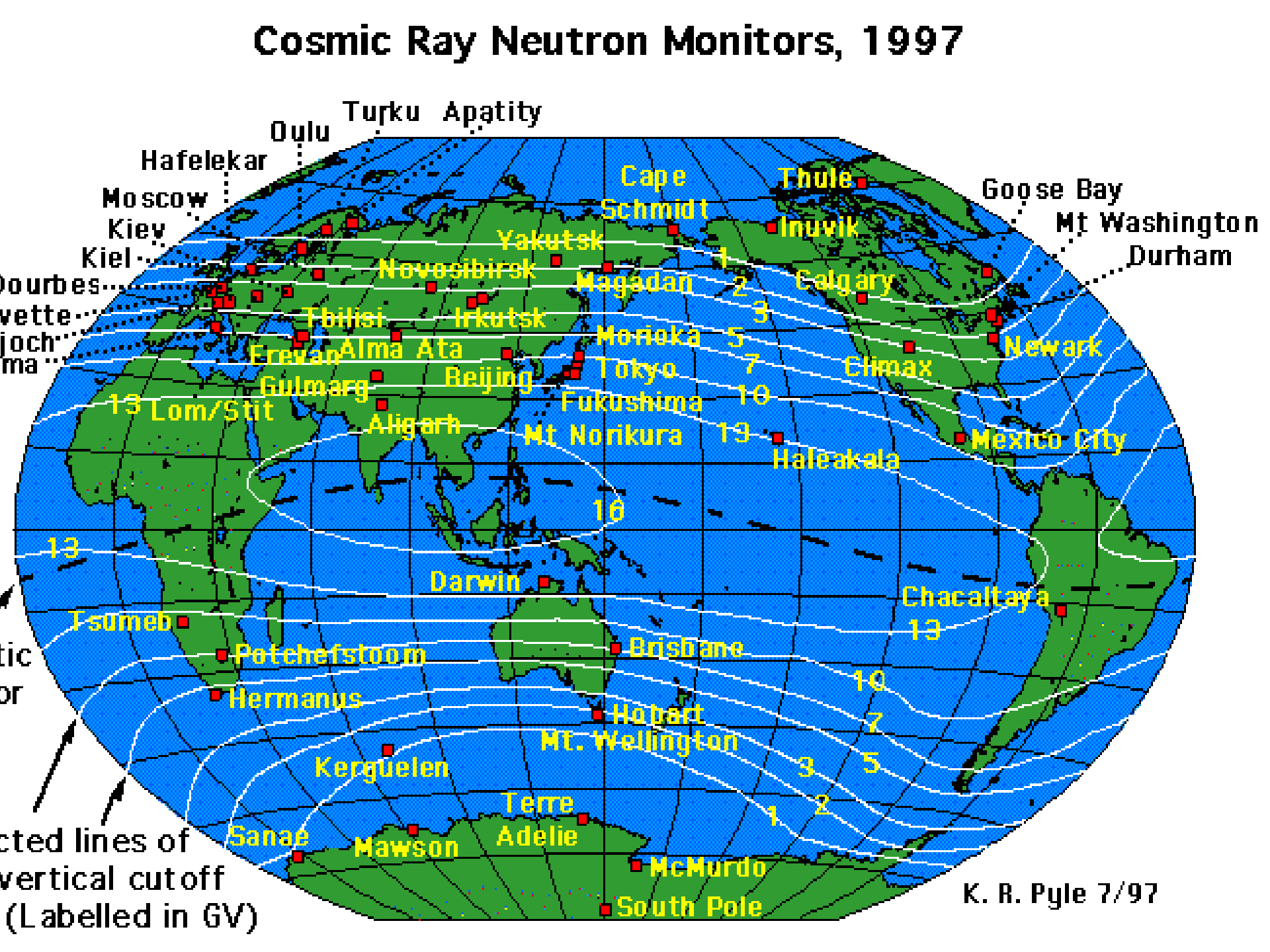
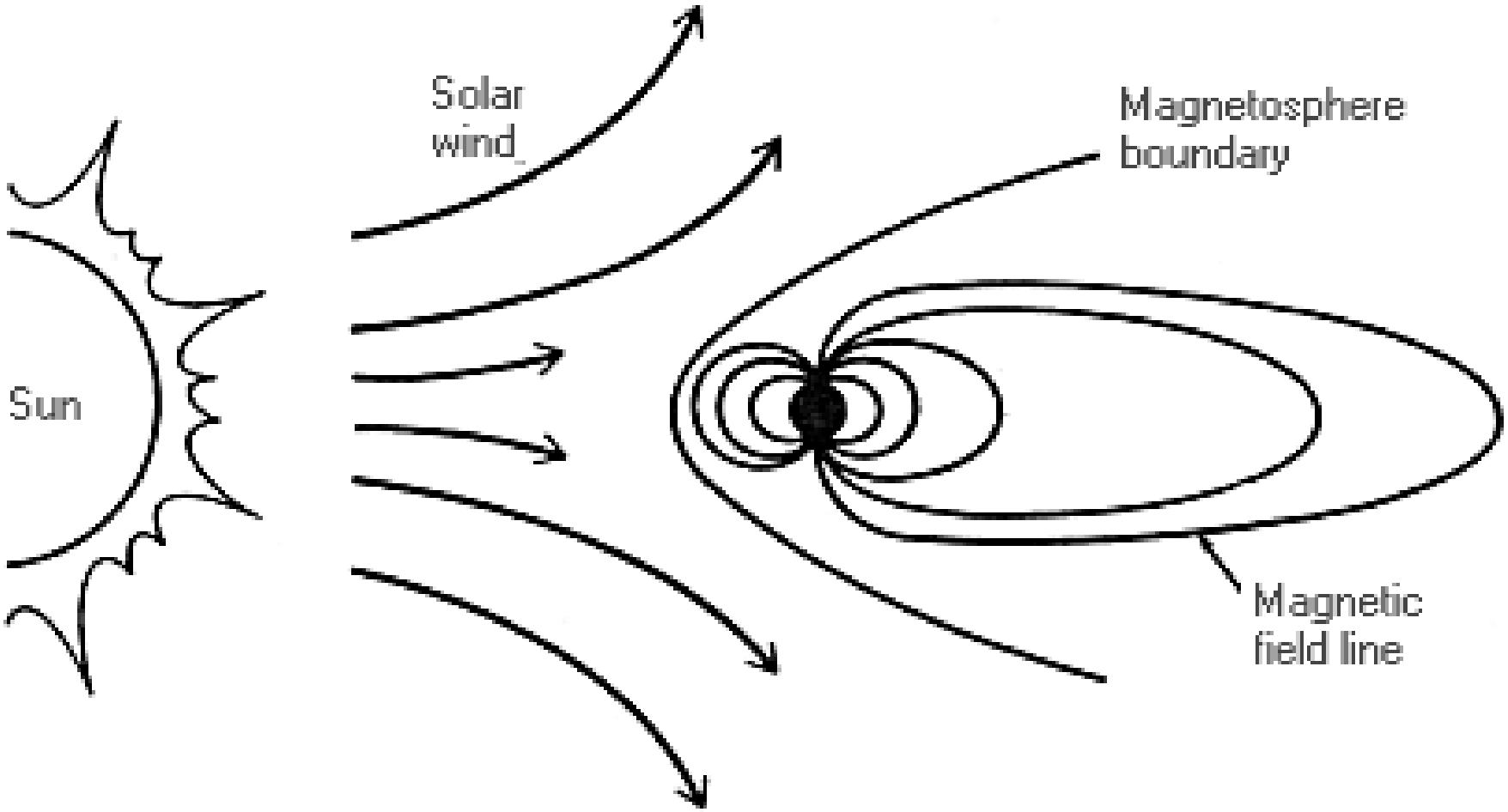
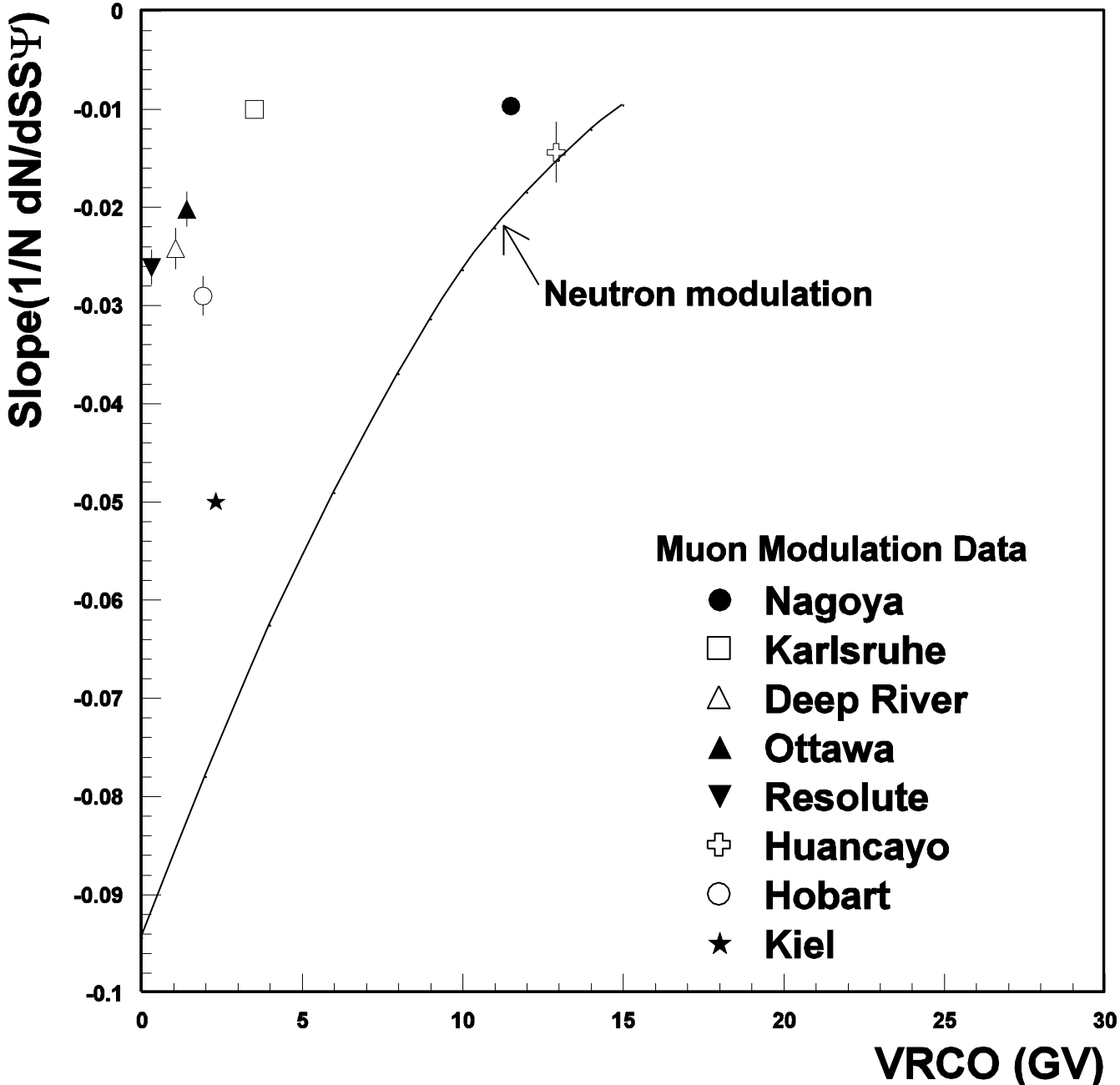


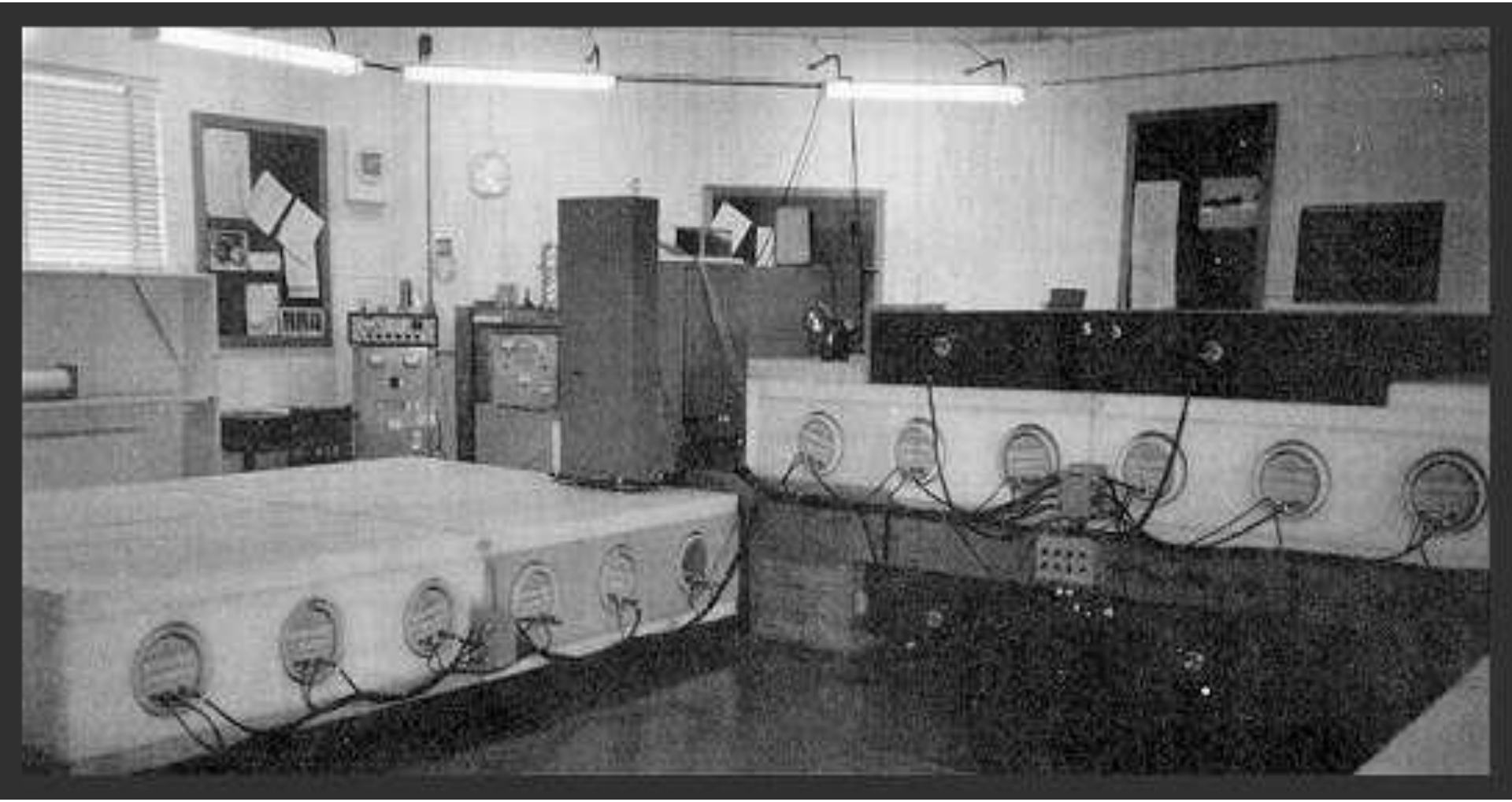
Figure 24.1: Major components of the primary cosmic radiation from Refs. [1–12]. The figure was created by P. Boyle and D. Muller. See full-color version on color pages at end of book.


Cosmic Ray Neutron Monitors, 1997
Turku
Apatity
Oulu
Hafelekar
Moscow
Kiev
Kiel
Dourbes
vette
joch
ma
Cape Schmidt
Thule
Inuvik
Goose Bay
Mt Washington
Durham
Yakutsk
Novosibirsk
Magadan
Calgary
Tbilisi
Irkutsk
Moneka
Newark
Erevan
Alma Ata
Beijing
Tokyo
Climax
Gulmarg
Fukushima
13 Lom/Stit
Aligarh
Mt Norikura
Haleakala
Mexico City
10
13
Darwin
Chacaltaya
Tsumeb
Brisbane
Potchefstoom
Hermanus
Hobart
Mt. Wellington
Kerguelen
Terre Adelie
Sanae
Mawson
McMurdo
South Pole
1
2
3
5
7
10
13
tic
or
cted lines of
vertical cutoff
(Labelled in GV)
K. R. Pyle 7/97

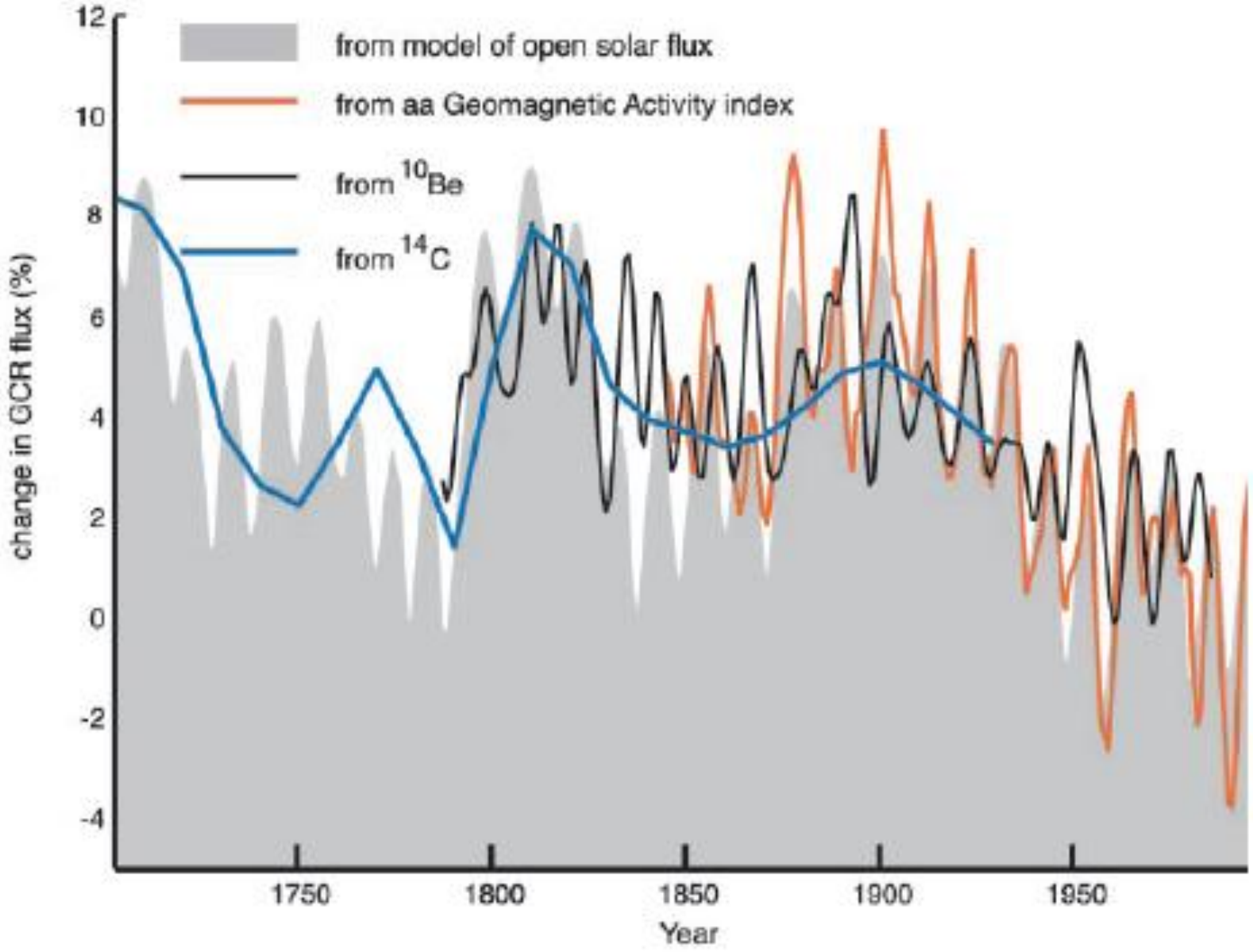

Solar
wind
Magnetosphere
boundary
Sun
Magnetic
field line


Slope(1/N dN/dSSΨ)
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
-0.1
0
5
10
15
20
25
30
VRCO (GV)
Neutron modulation
Muon Modulation Data
Nagoya
Karlsruhe
Deep River
Ottawa
Resolute
Huancayo
Hobart
Kiel

The Inuvik Neutron Monitor



Cosmic ray intensity vs time since 1700

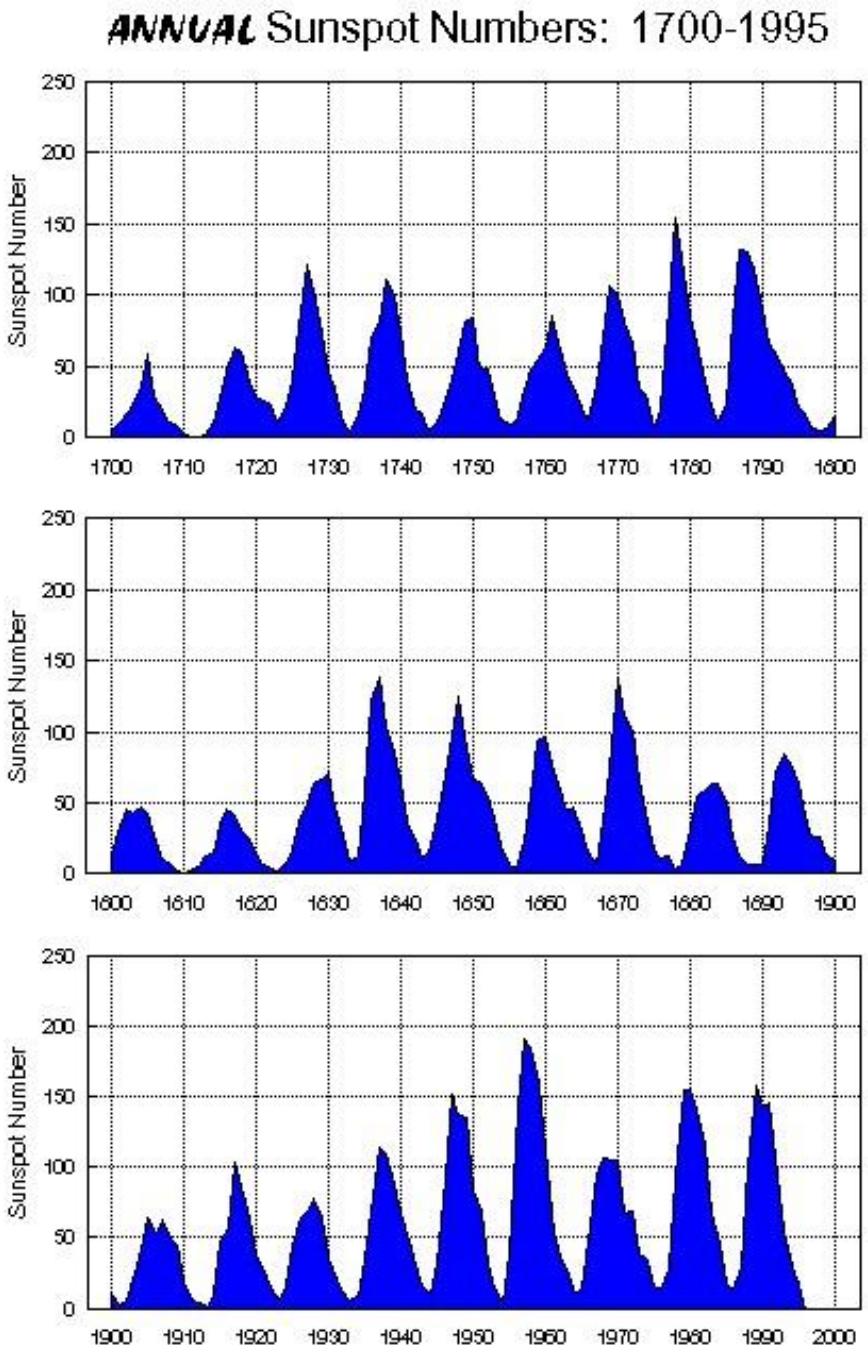


Conclude that –

Amplitude of the dip does not vary with VRCO

The arrival time of the dip is more consistent with the onset of the increase of the mean sun spot number NOT with the arrival time of the CR increase

Therefore these data do not corroborate the Marsh And Svensmark hypothesis that a large fraction of LCC is caused by ionization.



The Restless Sun

- has an 11 year cycle.
- Solar magnetic field reverses every 11 years so these are half cycles of what is really a 22 year cycle.

- Electric currents come from solar wind which peak at solar max.

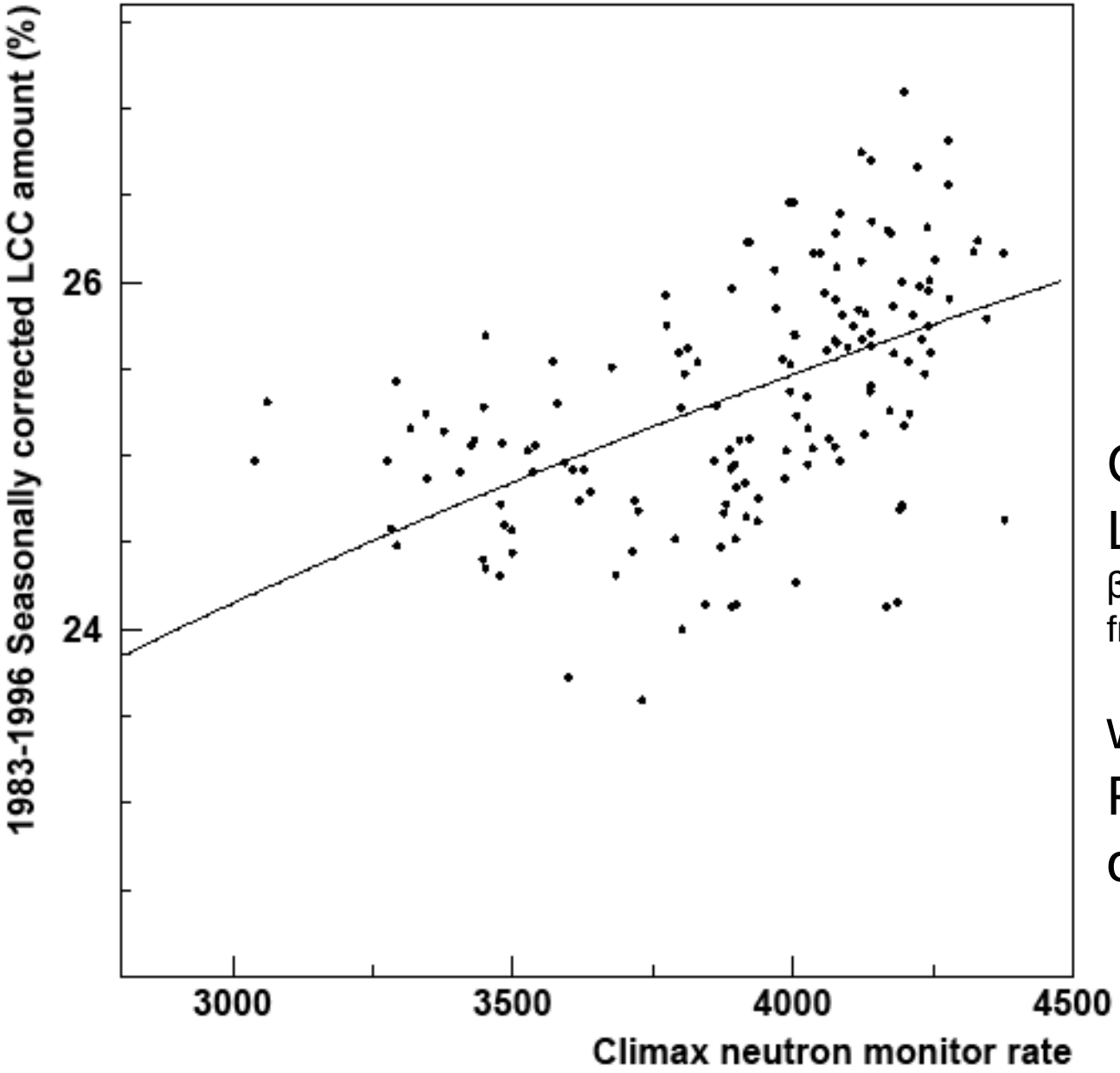
- These currents generate the interplanetary magnetic field which deflects lower energy cosmic rays.

Ionization in the Air

Ions formed within times of nsecs

- Other molecules attach to form small ion clusters – concentration n cm^{-3}
- LCC proportional to n
- Large ion clusters are formed when small ions attach themselves to much larger neutral aerosol particles – concentration N cm^{-3}
- Equilibrium when formation rate = loss rate due to recombination.
- Therefore $q = a\, n^2 + b\, n\, N$

Look at correlation during dip (solar cycle 22)



Curve = fit

$LCC=\beta+A\,N^{\alpha}$

β=amount not coming from ionization

with β set to zero.

Fitted value of

$\alpha = 0.185 \pm .026$

$$q = a\, n^2 + b\, n\, N$$

The first term is expected to be largest
i.e. n (LCC) is proportional to $q^{1/2}$

BUT there could be a contribution from the second term which is linear in n

i.e. LCC coming from ionization should be proportional to something between $q^{1/2}$ to linear in q

Slope $\alpha = 0.185 \pm .026$ significance assuming correlation is real

- If LCC proportional to n

  proportional to q^{ξ}

  proportional to N^{α}

- Calculus…. $\alpha = a_1 a_2 \xi$

- a1 = (δq/q)/(δη/η) and a2=(δη/η)/)/(δN/N)
- δη/η = fraction change in global average neutron monitor rates during solar cycle = 11 ± 1%
- δN/N = 19% = change for Climax data.
- δq/q =6 ± 3% (our estimate – next slide).

- Therefore $\xi = 0.58 \pm .29$ i.e. 0.5 within errors.

Assume LCC (proportional to n) cannot vary faster than linearly with q i.e. $\xi = 1$ i.e. slope $\alpha = 0.48$

This gives an intercept on the correlation plot of $\beta = 15.5\%$. The mean LCC=25%.

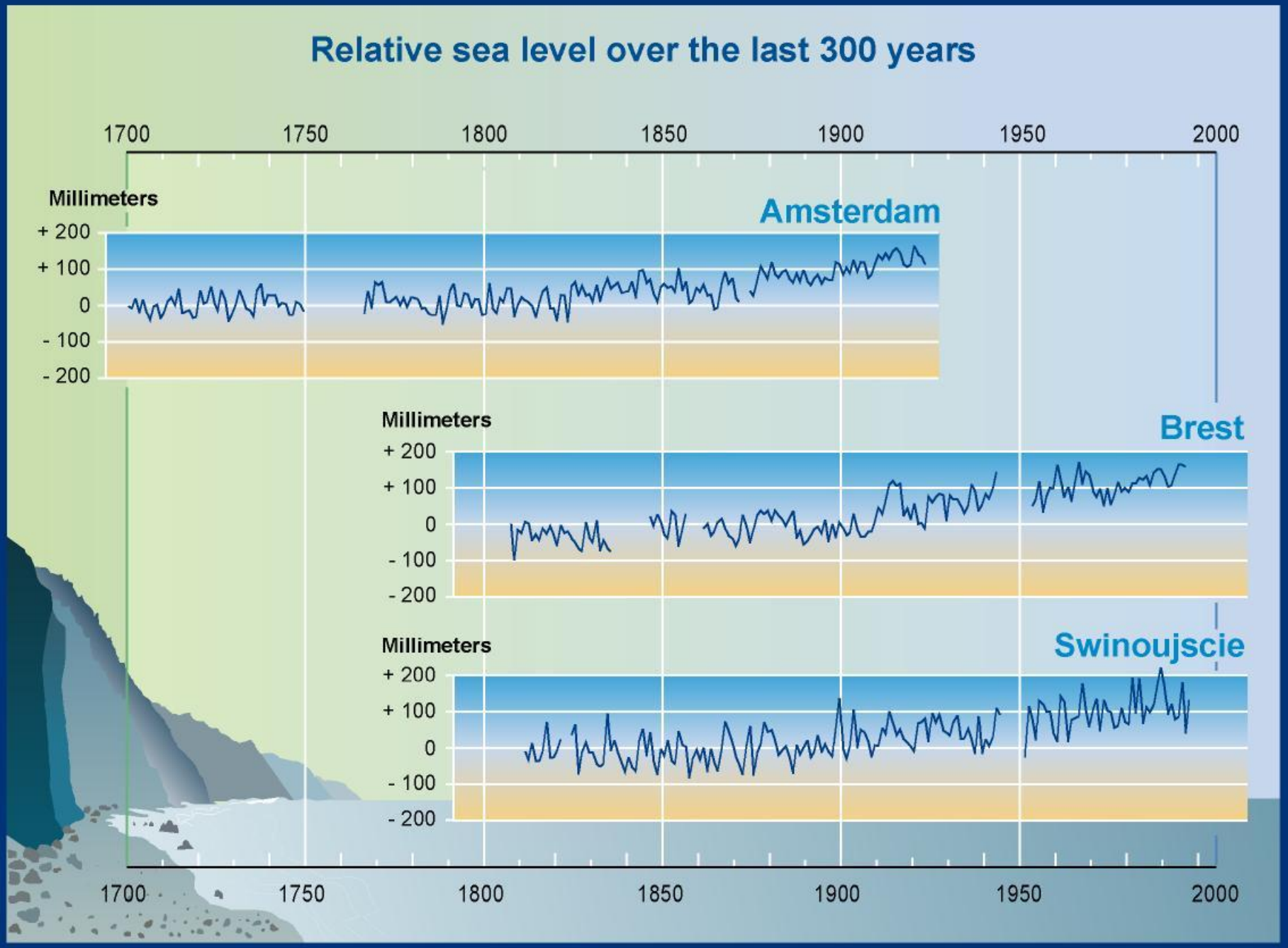
The fit with $\xi=0.5$ gives $\beta=0$

So if $\xi < 1$ cloud fraction due to other sources than ionization is less than15.5/24.6 =0.6 i.e. fraction due to ionization is more than 0.4

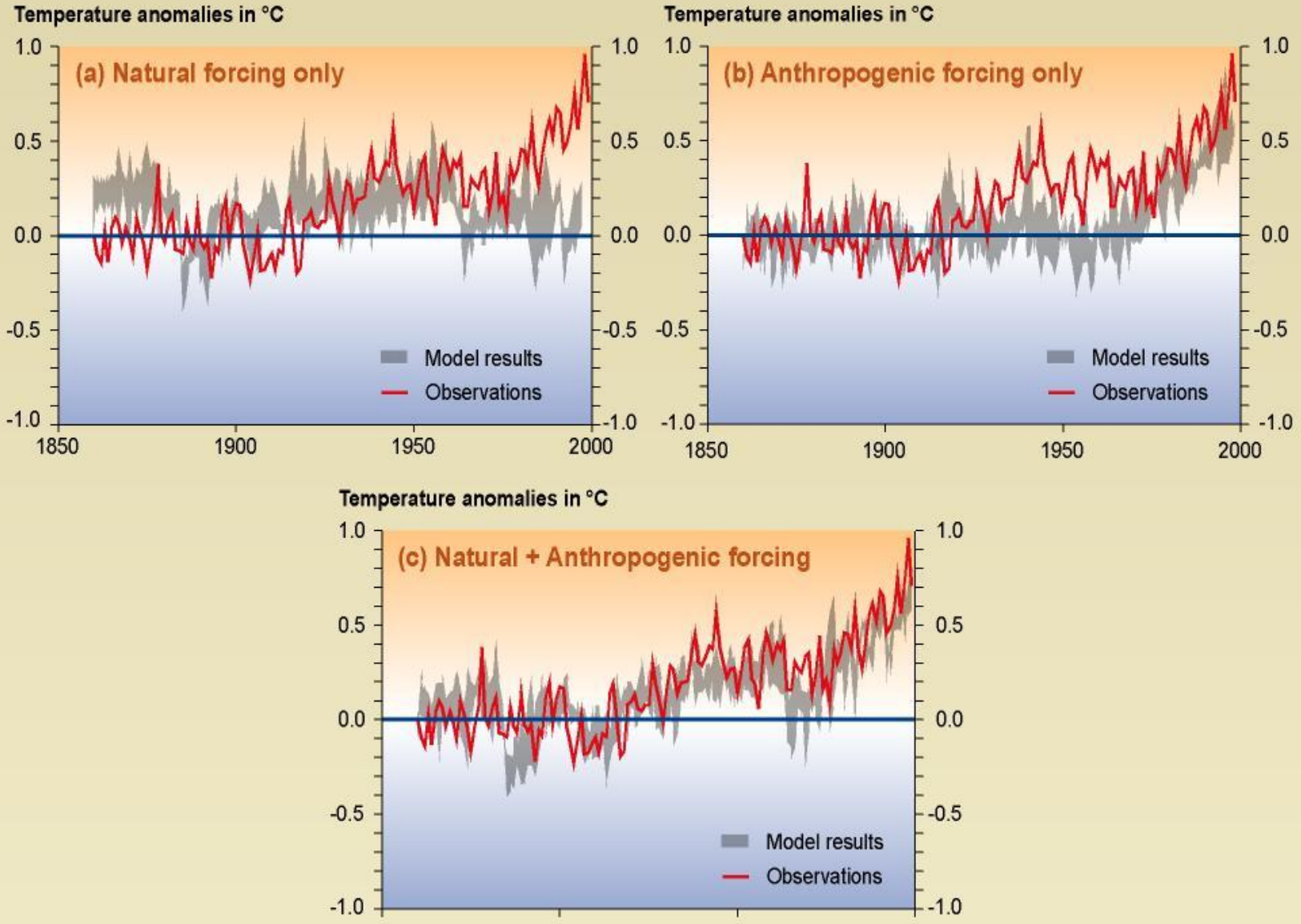
Hence if Marsh and Svensmark are right a large fraction of the LCC is produced by ionization.

Conclusions

- Hypothesis that changing ionization from cosmic rays leads to changes in cloud cover IS NOT CORROBORATED.
- Hence changing cosmic ray ionization rate does not significantly change the cloud cover.
- Cosmic rays are not the cause of global warming.

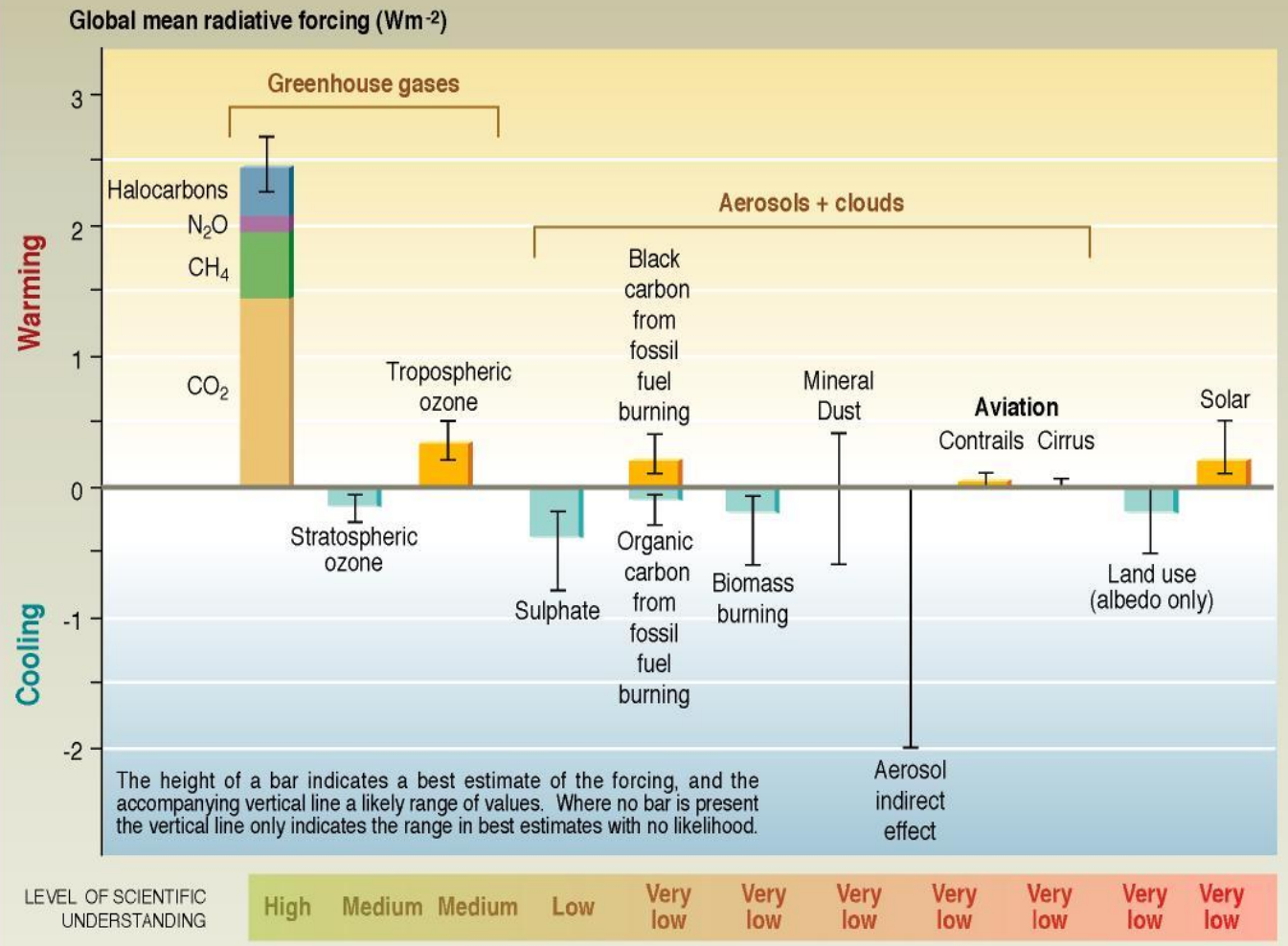

Relative sea level over the last 300 years
1700
1750
1800
1850
1900
1950
2000
Millimeters
+ 200
+ 100
0
- 100
- 200
Amsterdam
Millimeters
+ 200
+ 100
0
- 100
- 200
Brest
Millimeters
+ 200
+ 100
0
- 100
- 200
Swinoujscie
1700
1750
1800
1850
1900
1950
2000

Comparison between modeled and observations of temperature rise since the year 1860



SYR

Anthropogenic and natural forcing of the climate for the year 2000, relative to 1750



SYR - FIGURE 2-2

Is Global Warming Anthropogenic ?

- Current view by IPCC- very likely i.e. 90% probable.

- 10% probability is the IPCC estimate of
  - The model of the effect of green house gases to be wrong
  - AND there is another effect, at present unknown, which accounts for the warming.
  - AND it is of the right sign.

Latitude dependence of the effect