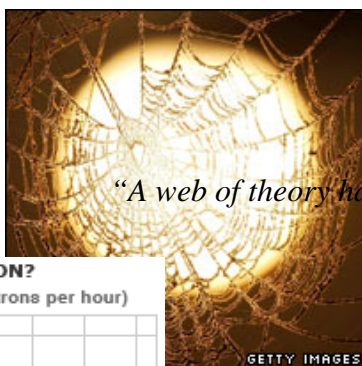
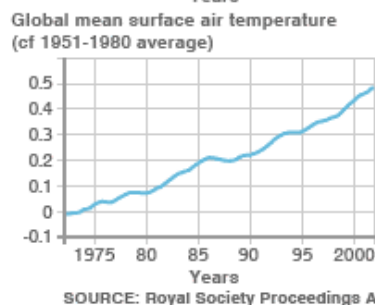
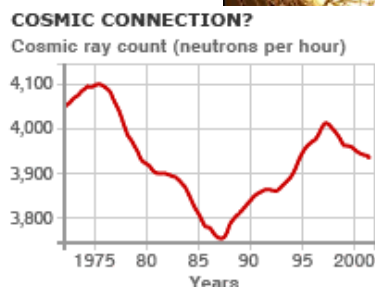


The Effect of Galactic Cosmic Rays on the Middle Atmosphere: a study using the Canadian Middle Atmosphere Model



"A web of theory has been spun around the Sun's climate influence"
BBC News, Nov 14, 2007



Robert Millikan, 1925

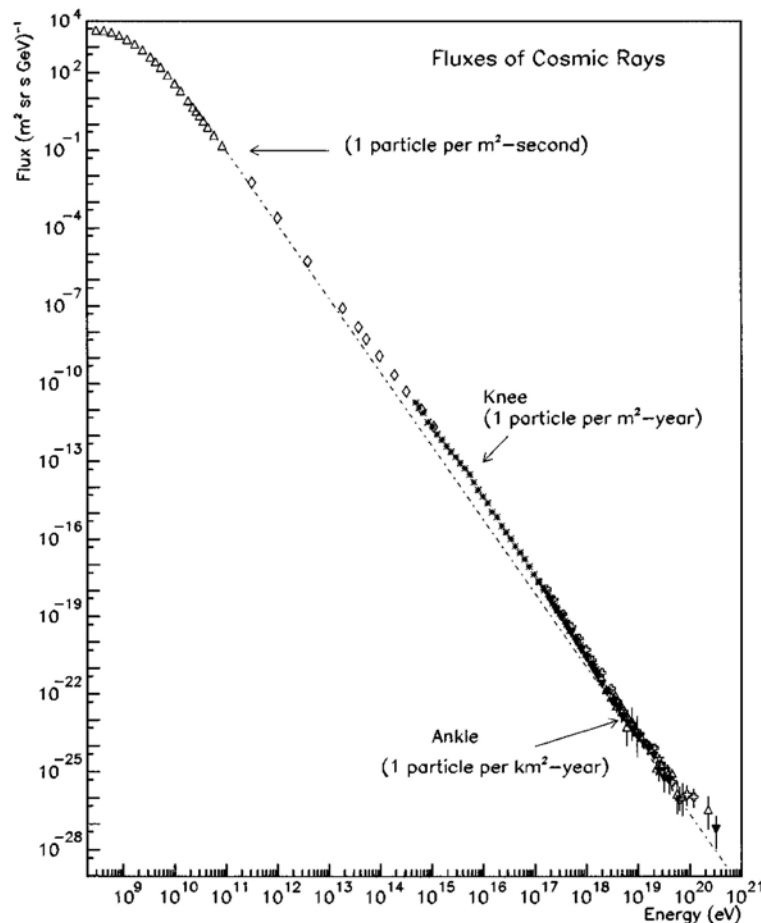
K. Semeniuk¹, C. Fu², V. I. Fomichev¹, I. G. Usoskin³, J. C. McConnell¹, and S. M. L. Melo²

1- York University, Canada.

2- Canadian Space Agency, Canada.

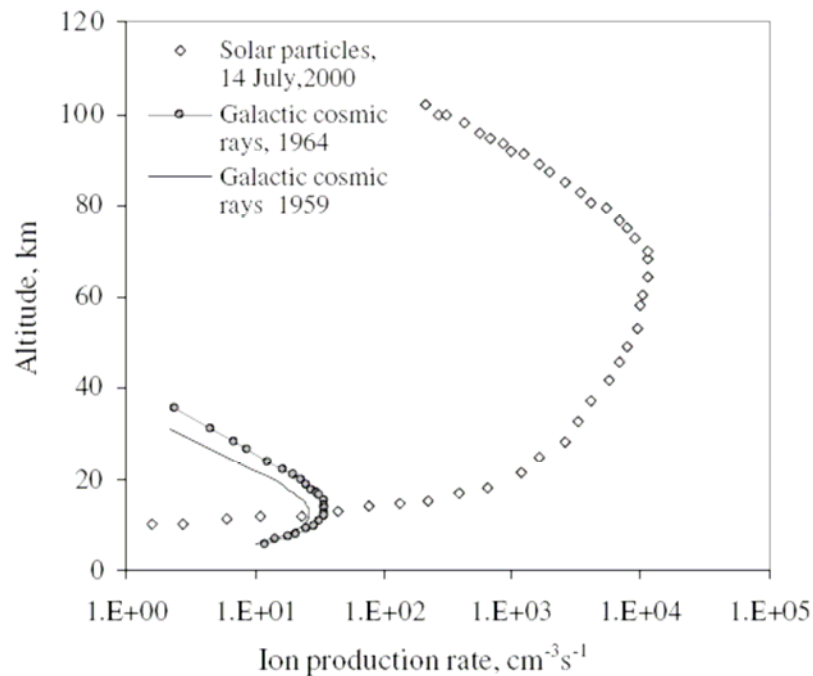
3- Sodankylä Geophysical Observatory, University of Oulu, Finland.

The term “cosmic ray” was introduced in 1925 by Robert Millikan of Caltech. A hot debate went on between Millikan and Compton: uncharged or charged particles?

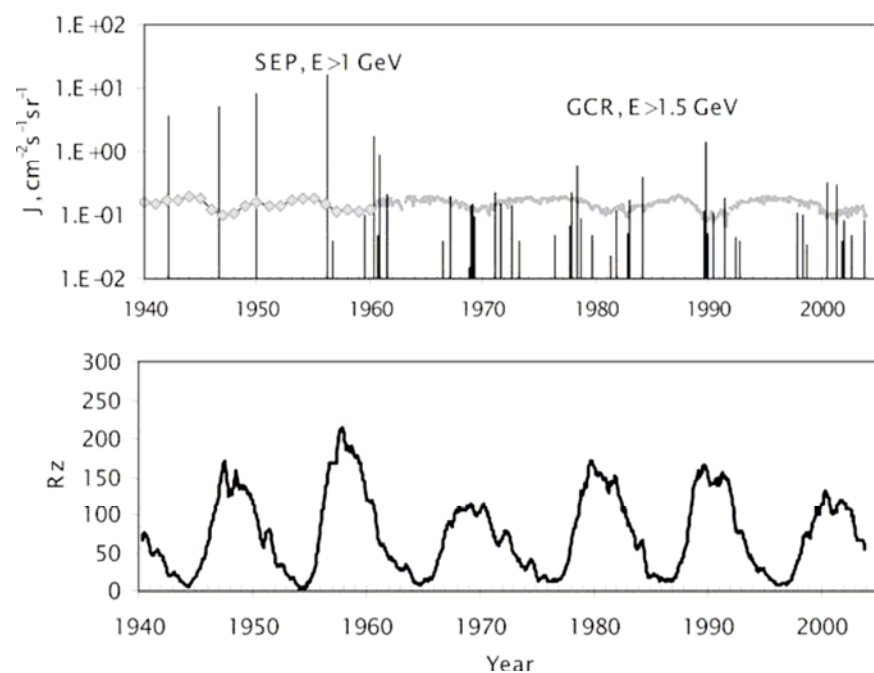


Cosmic rays: what are they?

- Low energy rays (less than 10 GeV) come from the sun.
- Supernovae may be the source of particles up to 10^{15} eV.
- The sources for ultrahigh energy cosmic rays are (probably) active galactic nuclei and gamma ray bursts.



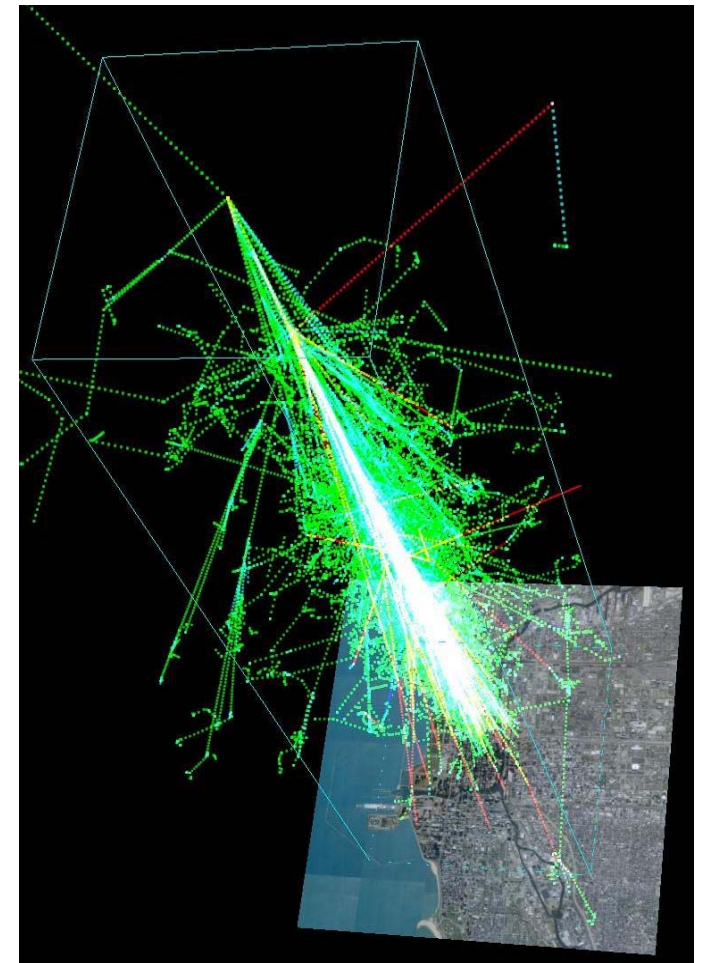
Ion production rate in the polar atmosphere during SEP event of 14 July 2000 (Quack et al., 2001) and due to galactic cosmic rays in the minimum (1964) and maximum (1959) phases of the 11-year solar cycle (Neher, 1971).



Upper panel: peak intensities of solar protons with $E > 1$ GeV derived from GLEs observations (vertical bars) and intensity of galactic cosmic ray with $E > 1.5$ GeV (grey curve). Lower panel: 7-month running averages of sunspot number values.

Cosmic Ray Induced Ionization (CRII)

- CR undergo nuclear interactions with the air
- Nucleonic, electromagnetic, muon cascade results in ionization of the ambiente air
- ions ultimately produce NO_x (*estimated in 1.25/ion par*) and HO_x (*estimated in 2/ion par*) affecting the atmospheric composition and dynamics.
 - Ruderman, 1974 and Ruderman and Chamberlain, 1975: increase in Nox will result in O₃ destruction.
 - Jackman et al, 1996: 2D model suggest that NO_x and HO_x increase by GCR may increase O₃



CRII and the atmosphere

Observations:

- Cosmic ray fluxes, and the ionization they produce in the atmosphere, are strongly modulated by solar activity.
- Observations show correlation between the cosmic ray flux temporal modulation and the changes in the dynamical, electrical and chemical states of the atmosphere both for long-term and day-to-day variations.

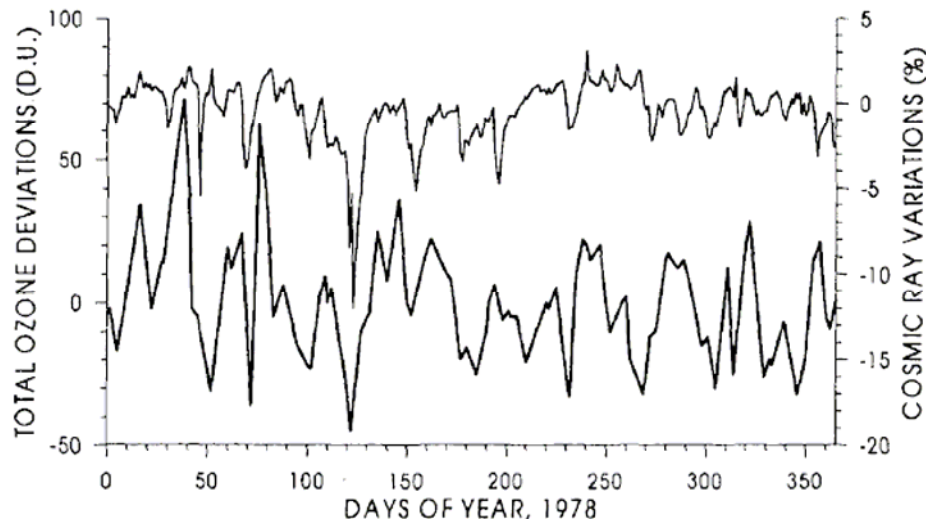
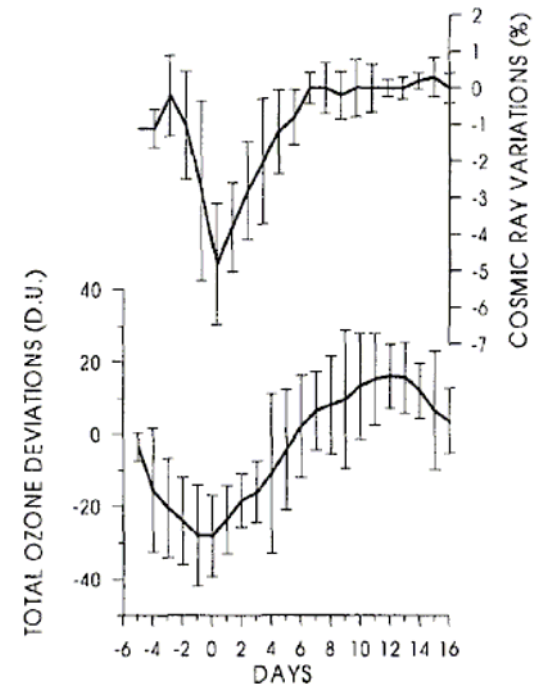


Fig. 1. Percentage variations of the neutron monitor count rate (top curve) and total ozone deviations smoothed by 30-day running averages (bottom curve) at Alma-Ata (43°N, 76°E) for the year 1978.



Superimposed epoch analysis of variations in cosmic ray intensity and total ozone content associated with 9 FD events in 1978. (Day-0 corresponds to the day with the minimum daily count rate of the neutron monitor).

Fedulina, Studia geoph. et geod. 42 (1998), 521-532

CRII 3D model

- A full 3D numerical model of Cosmic Ray Induced Ionization (CRIA) of the Atmosphere has been developed at SGO (Usoskin et al., JASTP, 66(18), 1791, 2004; Usoskin & Kovaltsov, JGR, 111, D21206, 2006).
- The model has been validated and recommended for use by COST-724 Action (European Cooperation in Scientific and Technical Research).

Program basis: CORSIKA (v. 6.204)

- EGS4 - electromagnetic interactions;
- HDPM - high-energy hadronic interactions;
- FLUKA (v.2003b) - low-energy (<80 GeV) hadrons;
- Curved atmosphere;
- Standard US atmosphere (N₂, O₂ and Ar as volume fractions 78.1%, 21% and 0.9%)

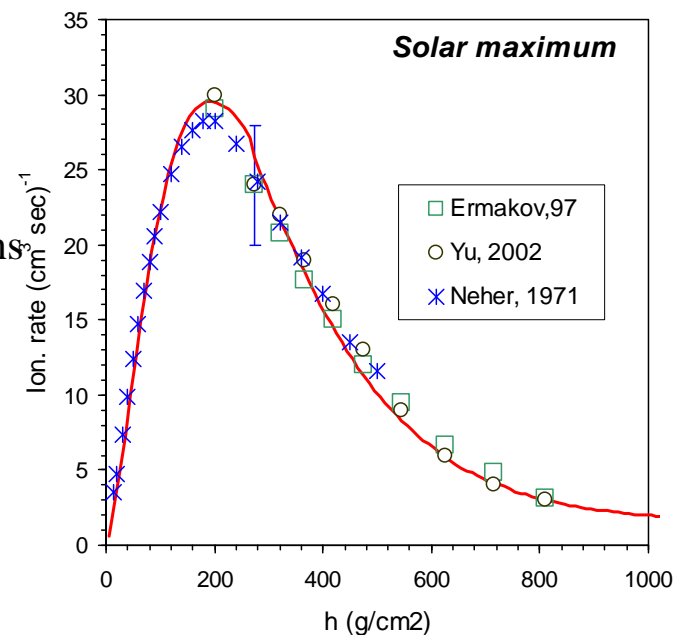
Physics behind: Monte-Carlo of the cascade, all included

CR particles: protons and α -particles explicitly, heavier species treated as α -particles.

Energy range: 10 MeV - 5000 GeV/nuc

Validity:

- below 100 g/cm² (15 km) -10%
- at 10 g/cm² (30 km) – a factor of 2

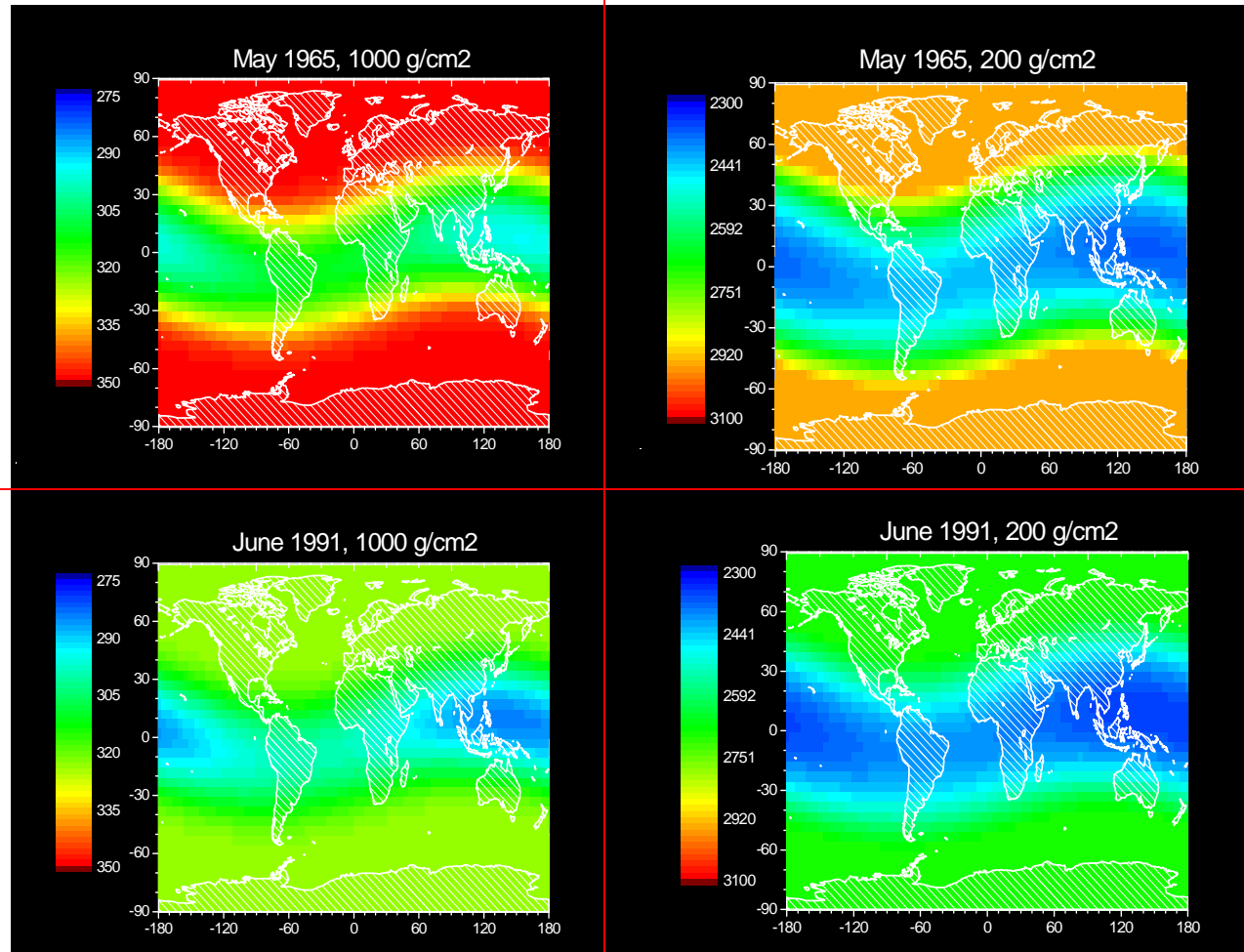


CRII 3D model

Ground level

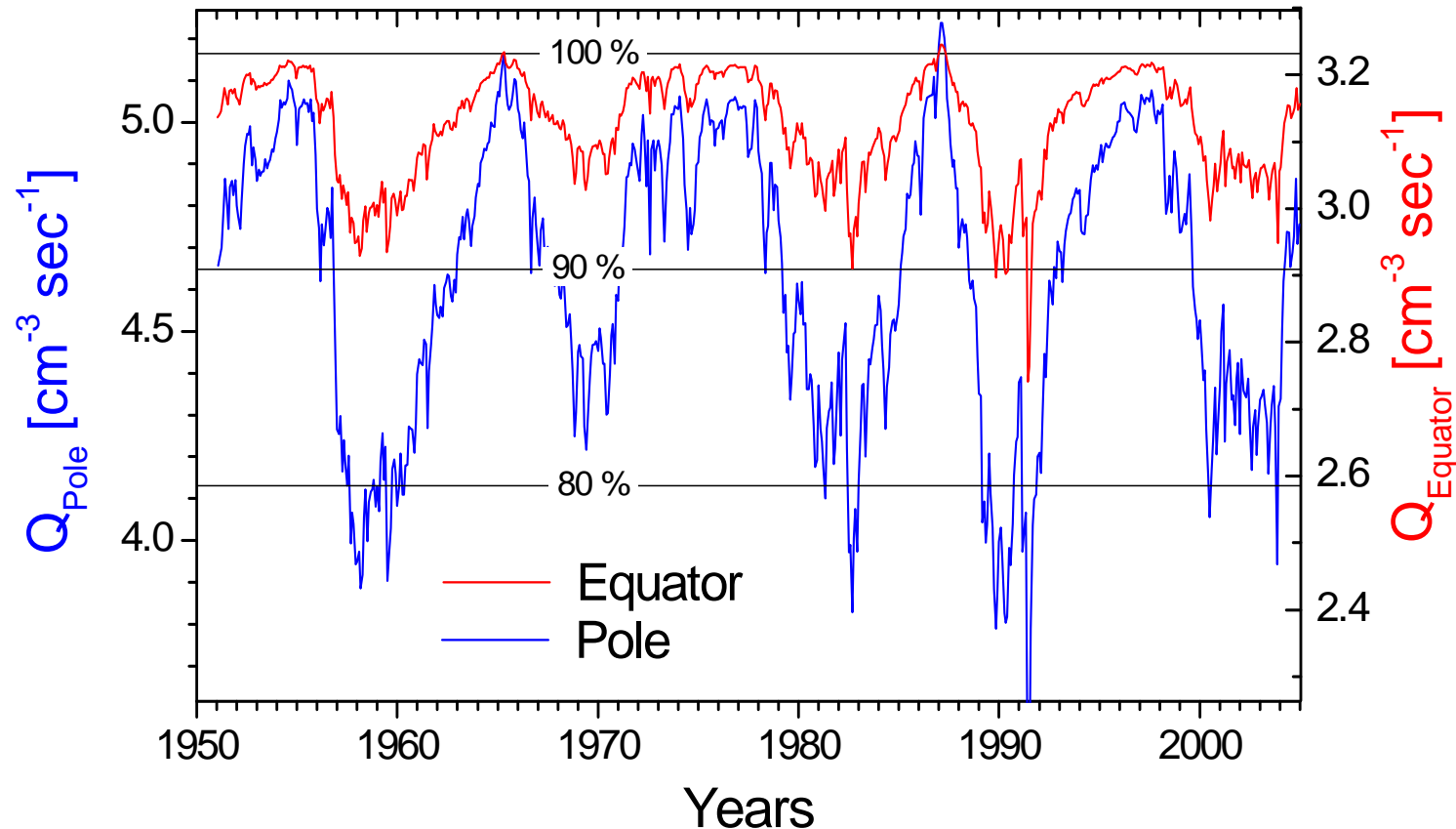
11 km altitude

Solar minimum



Solar maximum

CRII: last decades



CRII since 1951 at the atmospheric depth $x=700 \text{ g/cm}^2$ (about 3 km altitude) for polar regions and to the equator. The horizontal lines denote the percentage with respect to the value for May 1965 (100%).

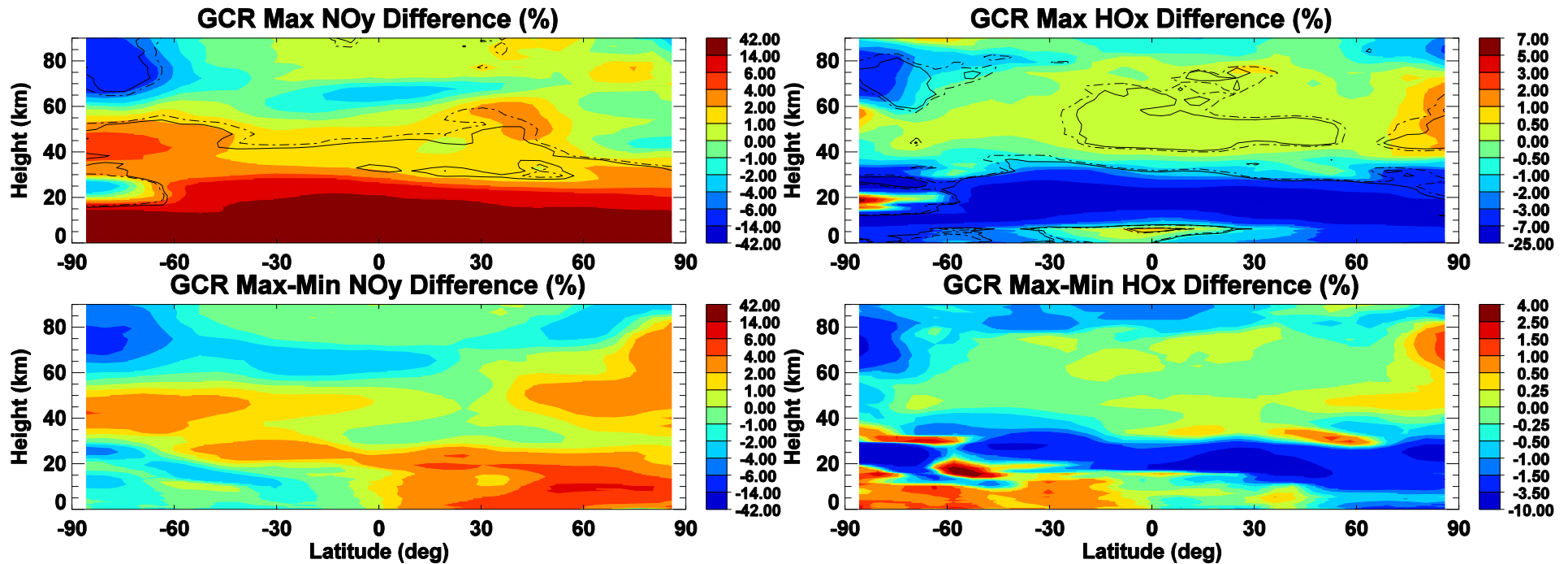
The Canadian Middle Atmosphere Model (CMAM) – V8

- **CMAM** is an upward extension of the Canadian Centre for Climate Modeling and Analysis (CCCma) **spectral General Circulation Model** (GCM) up to 0.0006hPa (roughly 100 km altitude). The spectral resolution is T31.
- **Incorporates:** radiation, interactive chemistry, gravity wave drag, as well as all the processes in the GCM.
- Includes full representation of stratospheric chemistry with all the relevant catalytic ozone loss cycles.
 - *102 gas phase reactions (including N_2O formation from ionization) and 12 heterogeneous on STS and ice (6 on each type of PSC).*
- **Limitations:**
 - - include a comprehensive troposphere (clouds, convection, hydrologic cycle) but no rainout of NO_y.
 - - no ion clusters chemistry in the troposphere.

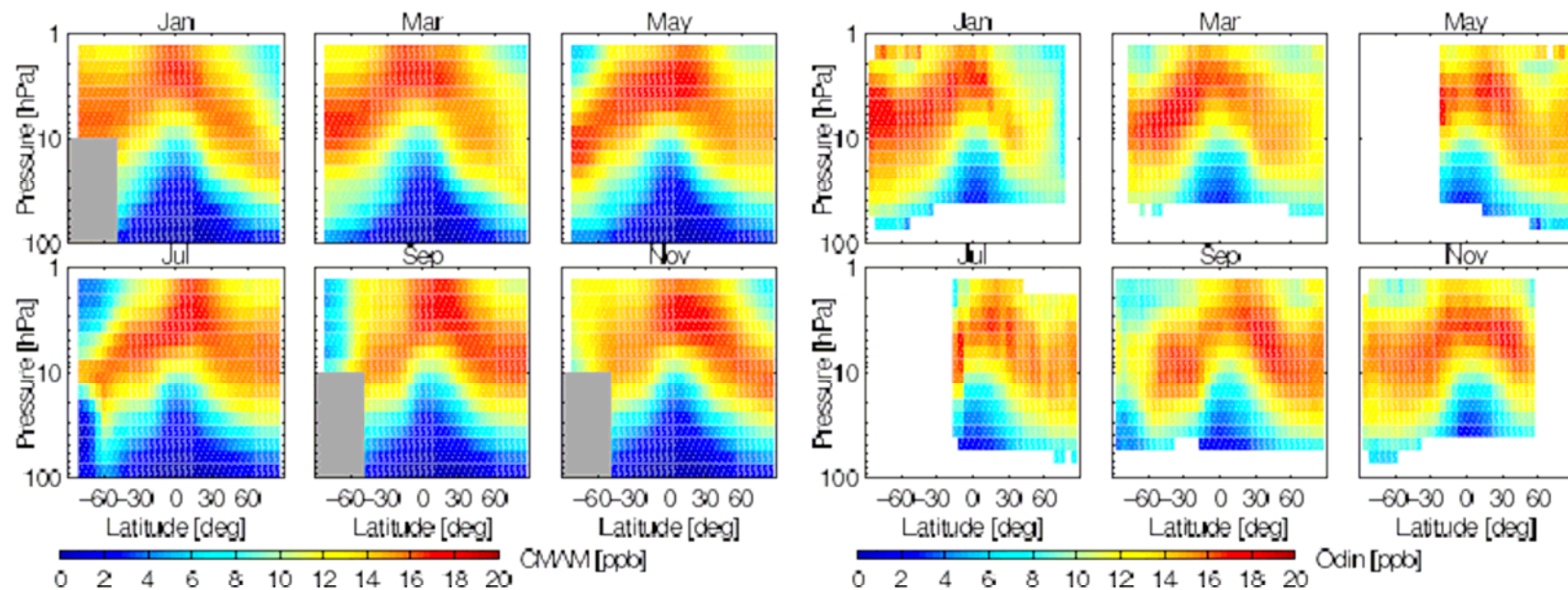
The Canadian Middle Atmosphere Model (CMAM) GCR experiment

- Using the CMAM V8
- Adopting Usoskin and Kovaltsov (JGR 2006) 3D model for CR induced ionization in the atmosphere (as shown before).
- Assuming the ratio of 1.25 NO_x and 2.0 HO_x per ion pair.
- Time frame: 1979 to 2006 (28 years model run).
- Control run done without CR_{II} forcing.

CMAM – GCR forcing experiment results: NO_y and HO_x

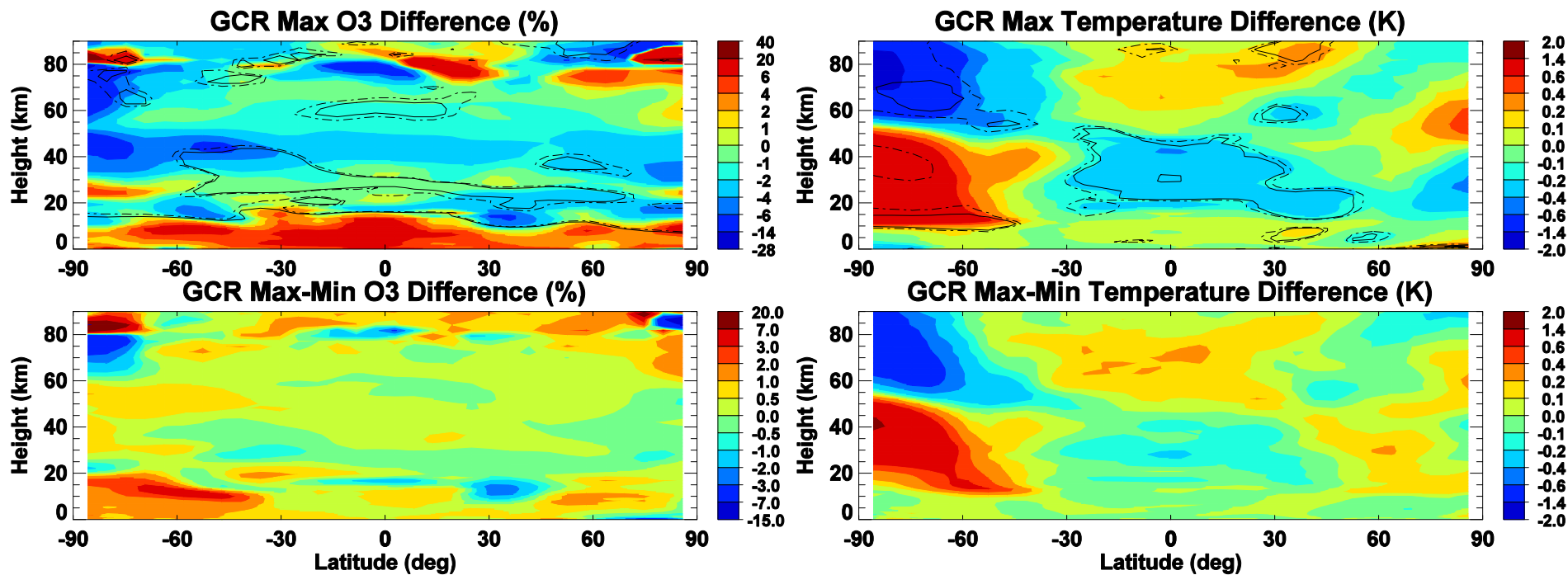


From the enhancement of NO_y shown before, the inclusion of CRII in the CMAM brings the model closer to the measurements

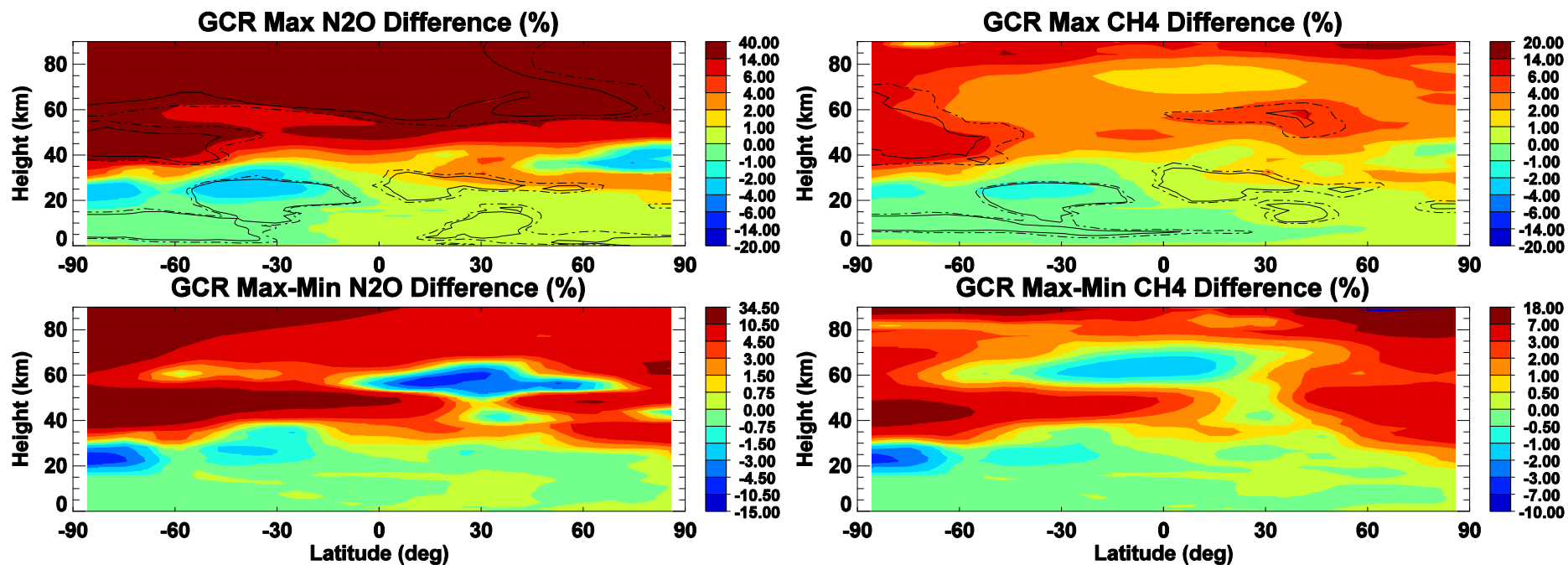


- left panel: CMAM (no CRII forcing) NO_y mixing ratios
- right panel: Odin NO_y climatology, (Brohede et al, ACPD 2008)

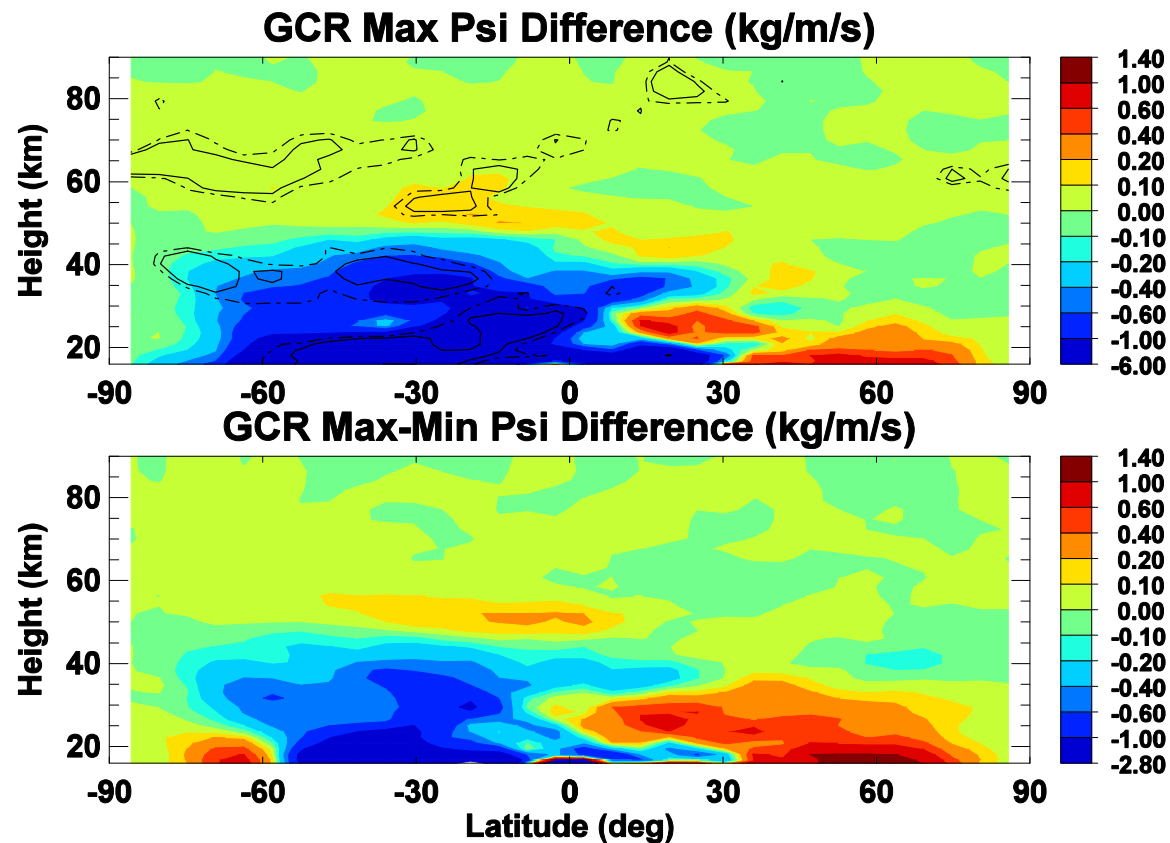
CMAM – GCR forcing experiment results: O₃ and T



CMAM – GCR forcing experiment results N_2O and CH_4



CMAM – GCR forcing experiment results Streamfunction



Intensification of the Brewer-Dobson circulation, especially in the SH stratosphere?
- *our results may be limited by the lack of a full tropospheric chemistry*

Summary

- GCR was introduced as forcing in the CMAM. Results are still being analyzed.
- *GCR is represented using the 3D induced ionization rates calculated by Usoskin and Kovaltsov (2006).*
- from the best of our knowledge this is the first study where a detailed CRII scheme is implemented into the comprehensive middle atmosphere model.
- *Forcing through chemistry: NO_x and HO_x are produced. Aerosols or cloud nucleation are not included in the model.*
- The effect is an evident enhancement of NO_y in the model, which in first analyses brings the model results closer to observations.
- *However, effect on O₃ is not evident being within model variability. This is most probably the compensatory effects of NO_y increase and HO_x decrease.*
- Global temperature effect is not significant.

Future work:

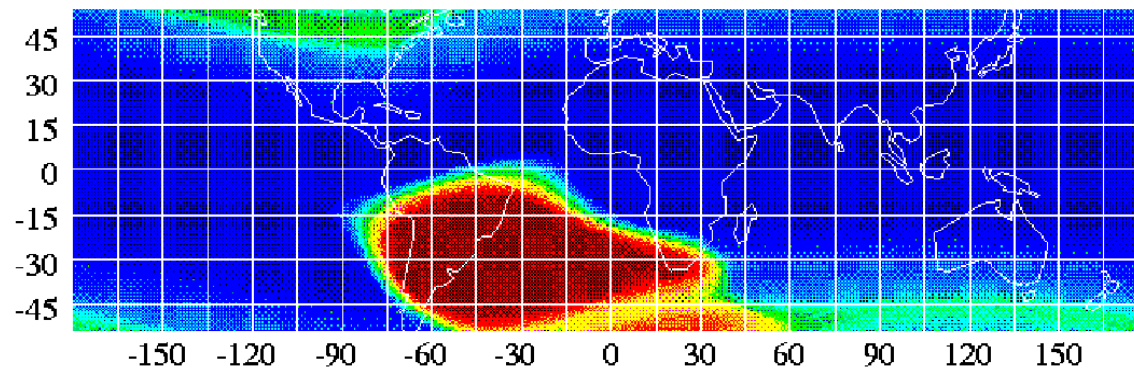
This work is part of the C-SPARC project and is aimed to study the solar forcing on the atmosphere using the CMAM. We show here the preliminary results for the GCR part. Further work include:

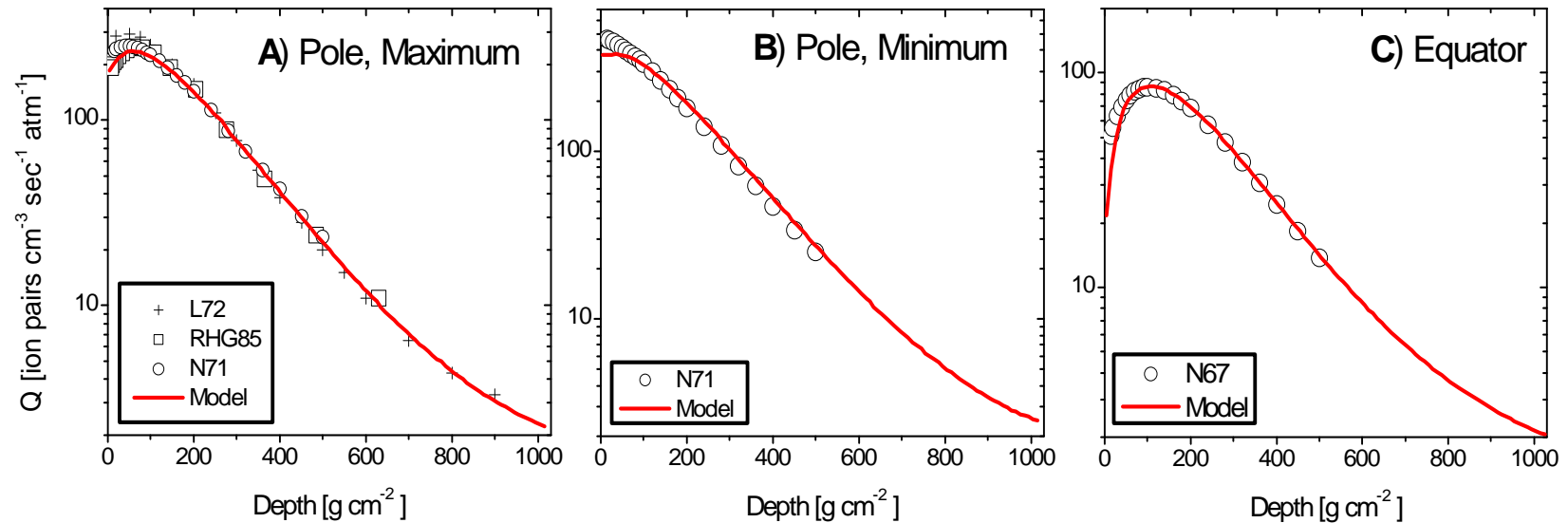
- *Study the atmospheric response to other particle precipitation processes (SPE, Auroral) and to variation in solar irradiance;*
- *Both the regular and extended (with the lid at ~250 km) versions of the CMAM are planned to be used*
- *Based on the CMAM results, we are planning to build an hierarchy of different processes potentially responsible for the atmospheric response to solar variability in different regions of the middle atmosphere.*

We are working together with other chemistry-climate model groups as part of the PICARD satellite mission. First Worksop in Toronto on July 10-11, 2008.

Backup Slides

Image of the South Atlantic Anomaly (SAA) taken by the ROSAT satellite. Image reflects the SAA at approximately 560Km.





-Example of comparisons of the *model* CRII with direct ionization rate measurements.

A) Polar regions during the solar maximum.

B) Polar regions during the solar minimum.

C) Equatorial region ($P_C = 15$ GV) during solar minimum ($\phi = 420$ MV).

Symbols correspond to [Lowder et al., 1972 - L72]; [Rosen et al., 1985 - RHG85], [Neher, 1967 - N67], and [Neher, 1971 - N71].