The Dynamics of the Atmospheric Radiation Environment at Aviation Altitudes

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Acknowledgements

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Variabilities of the Atmospheric Radiation Environment

The Concern

The Source

The Problem

The Variabilities

The Concern

Single Event Effects vulnerability of on-board computers that regulate the:

- navigational
- flight control
- communication, and
- life support systems

has become an issue in advanced modern aircraft, especially those that may be equipped with new technology devices in terabit memory banks (low voltage, nanometer feature size, gigabit integration).

The Concern (Cont.)

To address this concern, radiation spectrometers need to fly continually on a multitude of carriers over long periods of time so as to accumulate sufficient information that will broaden our understanding of the very dynamic and complex nature of the atmospheric radiation environment regarding:

- Composition
- Spectral Distribution
- Intensity
- Temporal Variation
- Spatial Variation

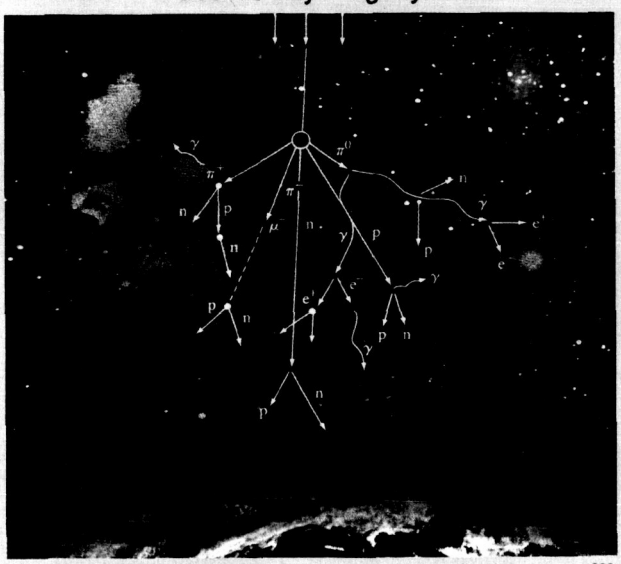
The Source

The energetic particle radiation at aircraft altitudes, from sea level to 60000 ft, is primarily the product of solar and galactic cosmic rays interacting with the constituents of the atmosphere, oxygen and nitrogen.

Thus, a single cosmic ray can generate a cascade of a multitude of secondary particles, of which protons and neutrons are the most important ones in terms of causing Single Event Effects in electronic devices on airplanes.

The Source

Cosmic Ray Progeny



IBM Journal of Research and Development, Vol. 40, No. 1, 1996

The Problem

Atmospheric radiation measurements were made in the past by numerous workers in several countries:

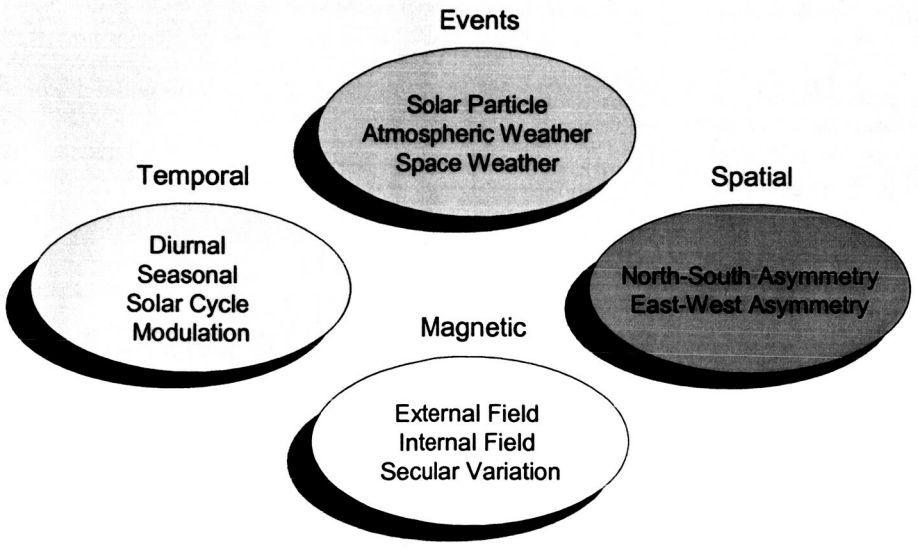
Bulgaria	Hungary
Canada	Japan
Czech Republic	Russia
France	UK
Germany	USA

Other ?

The Problem (Cont.)

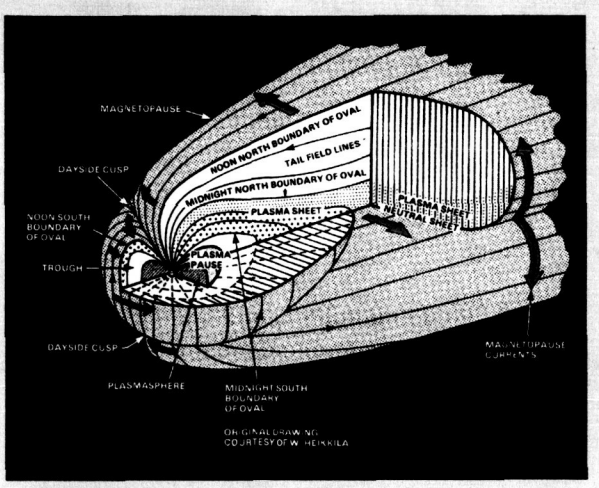
- However, these measurements were sporadic, isolated, uncoordinated, and without correlation to environmental conditions or long- and short-term variabilities.
- At this time, 10 major and minor changes can be identified that affect the atmospheric radiation levels.

Variabilities of Radiation Field at Aviation Altitudes



The Geospace Magnetosphere

- The interaction of the solar wind with the magnetosphere sets up a multitude of currents.



Total Field

- The totality of these currents represents the external field which is vectorially superimposed on the internal field of the Earth.
- The combination of the two is then the *"total field"* which experiences:
  - Slow changes in the internal field (long-term effects)
  - Fast changes in the external field (short-term effects)

Secular Variation

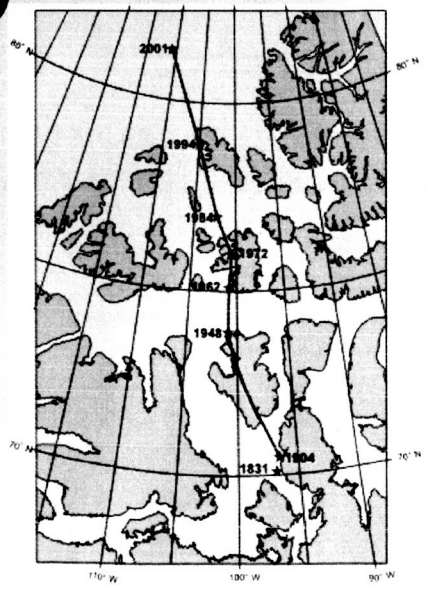
The Earth's internal magnetic field is constantly changing.

The rate at which it changes with time is called the *"Secular Variation".*

This change manifests itself in two ways: the *"Drift"* of the magnetic poles and the *"Shrinking"* of the field strength.

If this shrinking were to continue at the present rate, the Earth would experience another *"Magnetic Reversal"* in about 2000 years.

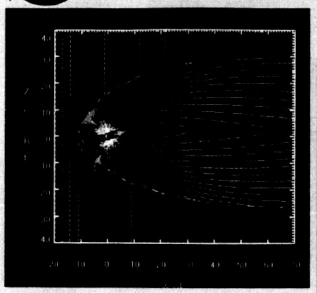
Long Term Movement of the North Magnetic Pole



Geological Survey, Canada

- Path of North Magnetic Pole (NMP) since discovery in 1831
- During last century, pole has moved a remarkable 1000 km
- Since 1970 the NMP has accelerated and is now drifting at more than 40 km/yr

Magnetic Field Dynamics

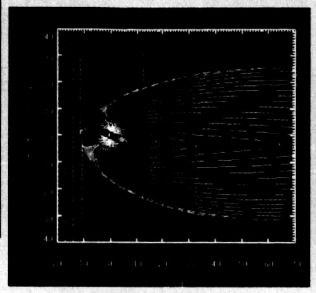


Process of convection transfers solar wind: mass, energy, and electric field into the magnetosphere.

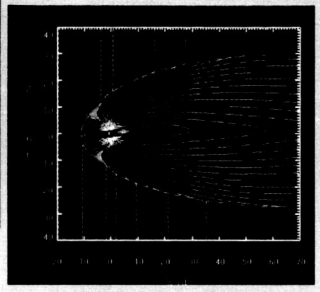
$DB = B_T - B_D$

(– DB) = yellow and red (depressed field)

(+ DB) = black and blue (compressed field)



Fluctuations in the magnitude and orientation of the interplanetary field induce dynamic changes of the magnetosphere resulting in magnetic storms.



Effects of diurnal rotation and yearly orbital motion around sun (dipole wobbling).

Rigidity

The capacity of the Earth's magnetic field to deflect incoming (galactic or solar) cosmic rays is expressed as *"Rigidity"*, in units of momentum over change:

$$R = P/z$$

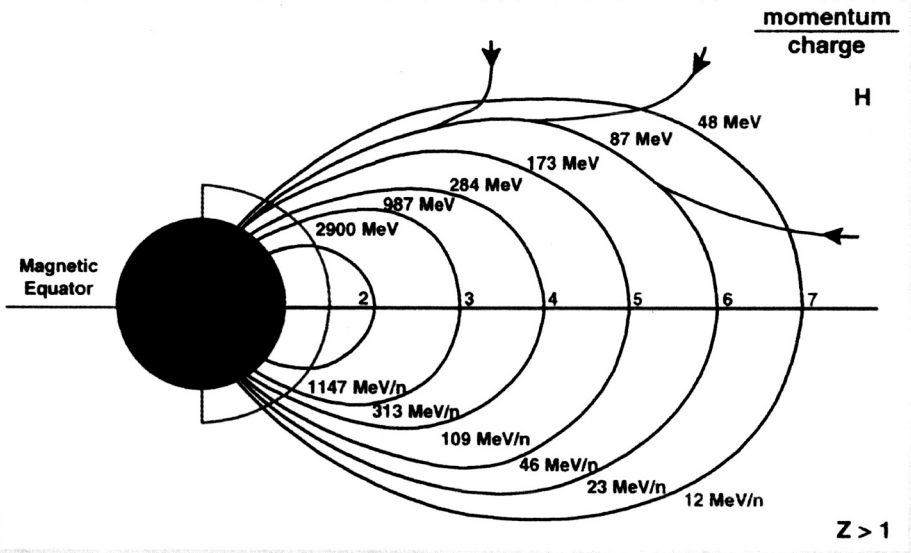
The degree of penetration depends on the energy of the cosmic ray particles, their level of ionization, and the strength of the magnetic field.

For galactic cosmic rays, we assume that they arrive at the vicinity of the Earth fully ionized.

The limiting value of rigidity is called "Cutoff Rigidity".

Magnetic Rigidity

Total Energy Required to Penetrate the Magnetosphere



Cosmic Ray Cutoff Parameters

R_C, E_C, L_C, λ_C

- They are equivalent and can be used interchangeably
- Conversion of the "R" to "L" is achieved through the relationship:

$$L_C = (k/R_C \times 10^{-3})^{0.5} \quad k = 14.3 \qquad (1)$$

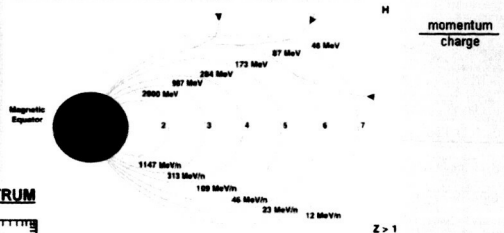
- The intersection of a field line "L" with the Earth's surface occurs at a magnetic latitude given by:

$$\lambda_C = \cos^{-1} (1/L_C)^{0.5} \qquad (2)$$

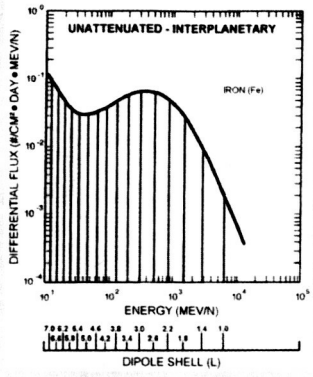
- The Cutoff energy is obtained from:

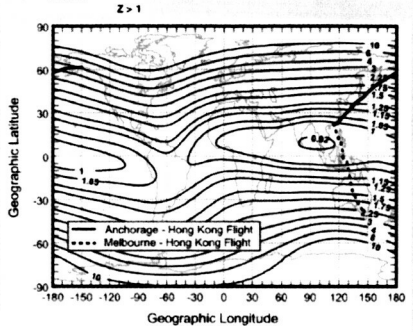
$$E_C = [(m_0c^2)^2 + (z/A \cdot R_C)^2]^{0.5} - m_0c^2 \qquad (3)$$

Magnetic Rigidity
Effects of Major Event



INSTANEOUS COSMIC RAY SPECTRUM





L-Shells at 10 km Aircraft Altitude

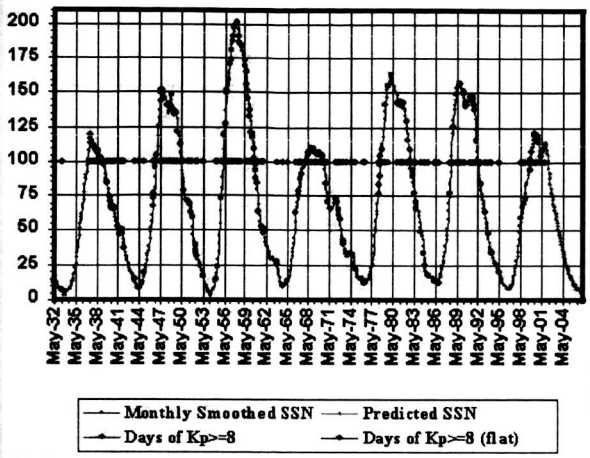
The Myth About Geomagnetic Activity

Popular opinion holds that geomagnetic activity begins to subside ever increasingly at the decline of the solar cycle.

The Reality

Severe geomagnetic storm intervals can occur at almost anytime during a solar cycle, with a slightly heavier preference for the years of solar maximum and during the declining years of the solar cycle.

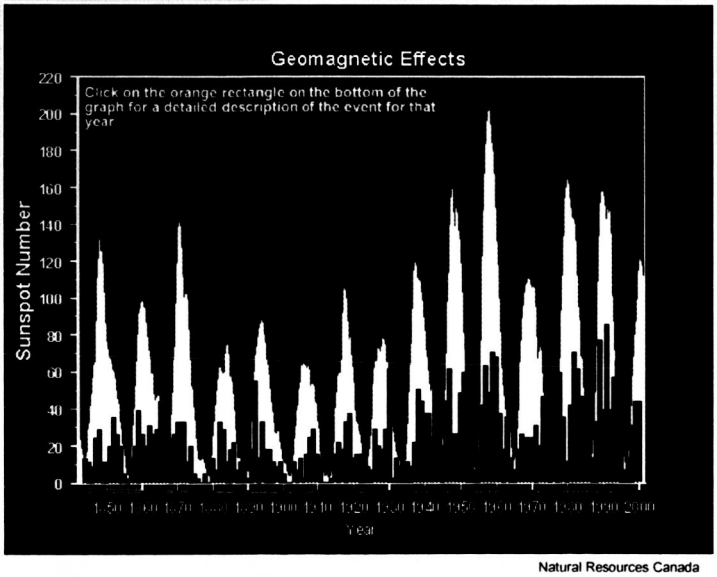
The Reality



Historically, some of the most intense geomagnetic storms have occurred during the declining years of the solar cycle. This confirms the fact that significant space weather activity can occur at any time during the solar cycle.

Statistically, the declining years of the solar cycle are the most stormy in terms of geomagnetic activity.

Geomagnetic Effects

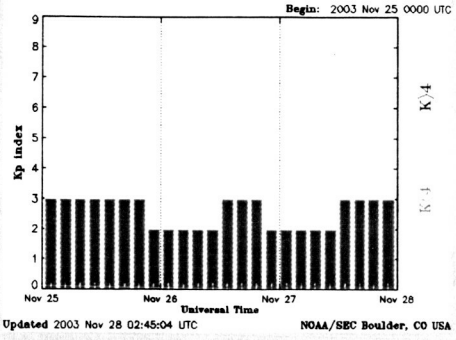


Natural Resources Canada

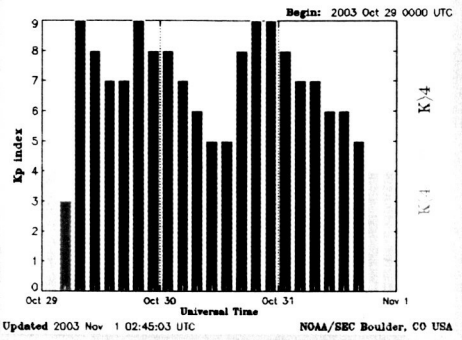
The Magnetic Activity Index Kp

Magnetic activity indices were designed to describe storm induced variations in the geomagnetic field. Kp is such an index.

It is derived by 13 geomagnetic observatories between 44 degrees and 60 degrees northern or southern geomagnetic latitude, on a scale from 0 to 9.



Low Kp activity period



Severe storm of maximum intensity

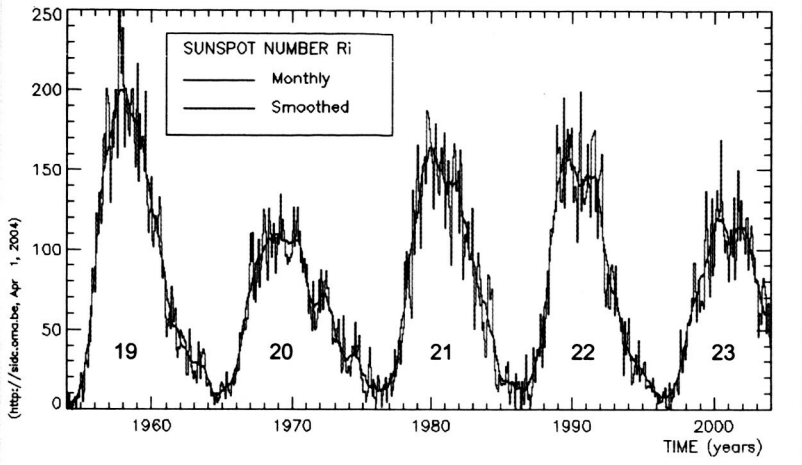
The Truth About Solar Cycles

In modern times, when referring to solar cycles, the prevailing concept is to think of them in terms of a fixed 11-year duration, which is probably a good average.

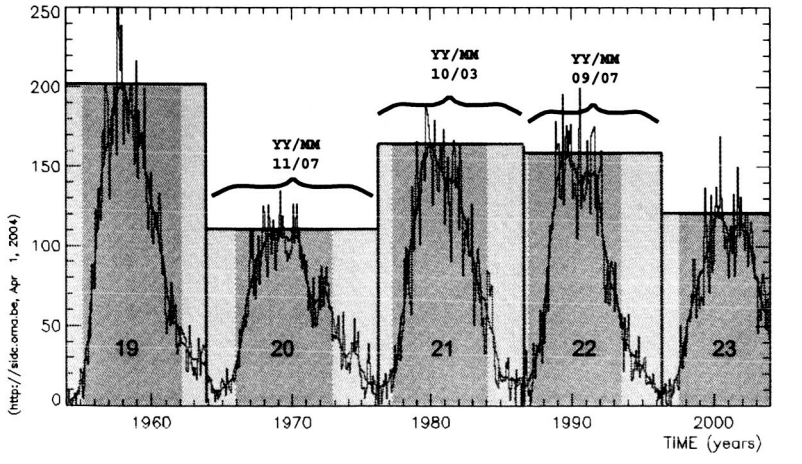
The actual length of solar cycle is really unpredictable and may vary from a short 9-year to a long 13-year period.

- The active phase of a solar cycle is defined as a 7-year period starting 3 years before the absolute maximum sunspot number and ending 4 years after.
- The remaining time is classified as "solar minimum".
- Since the active phase is constant, and solar cycles vary in length, the solar minimum period is (by necessity) a cycle variable.

Solar Cycle Reality

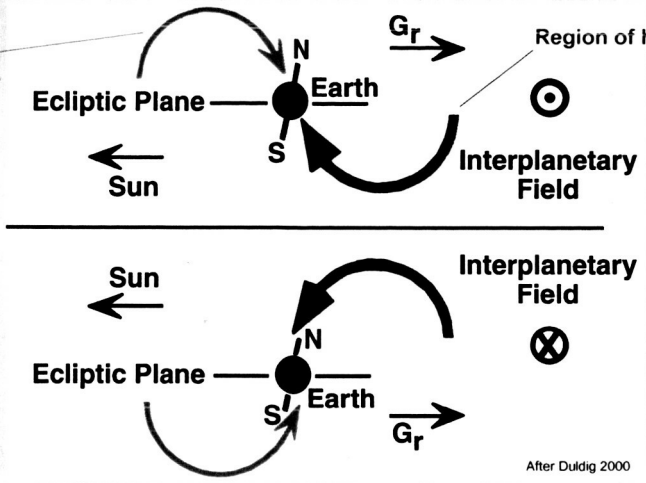


Solar Cycle Reality



Cosmic Ray N-S Anisotropy and its Dependence on the IMF Direction

The N-S anisotropy arises from the gyro-orbits of cosmic ray particles about the IMF.

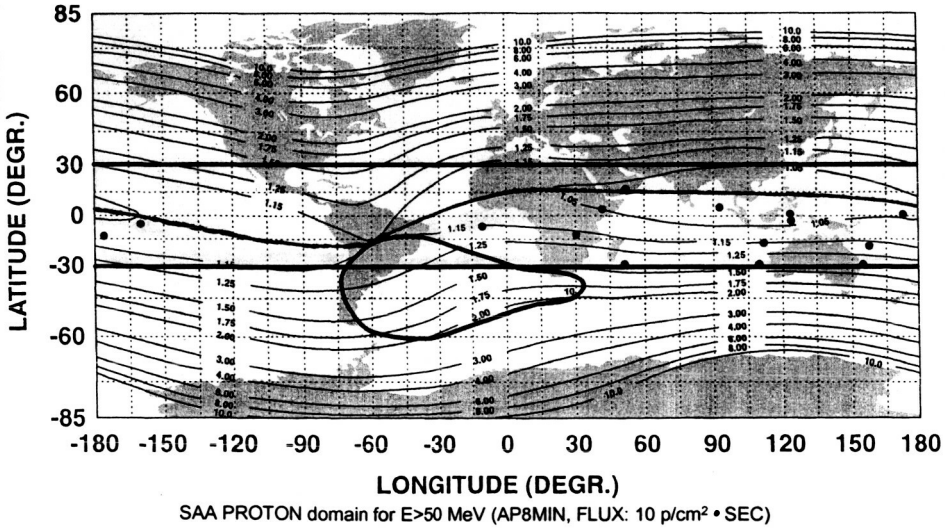


After Duldig 2000

Cosmic Ray North-South Asymetry

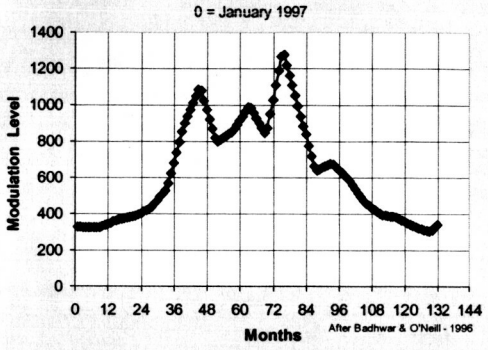
L-Contours at 500 km for Solar Min (IGRF95, Epoch 1995)

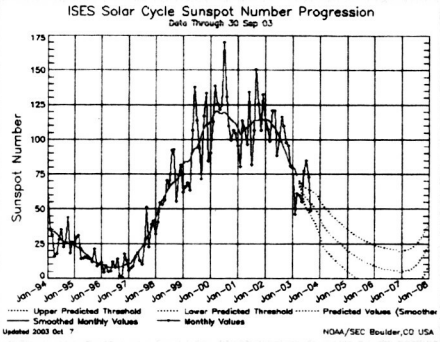
STS-95: Cosmic Ray Measurements (1998)



SAA PROTON domain for E>50 MeV (AP8MIN, FLUX: 10 p/cm² • SEC)

Solar Cycle Modulation
GCR Modulation Parameter

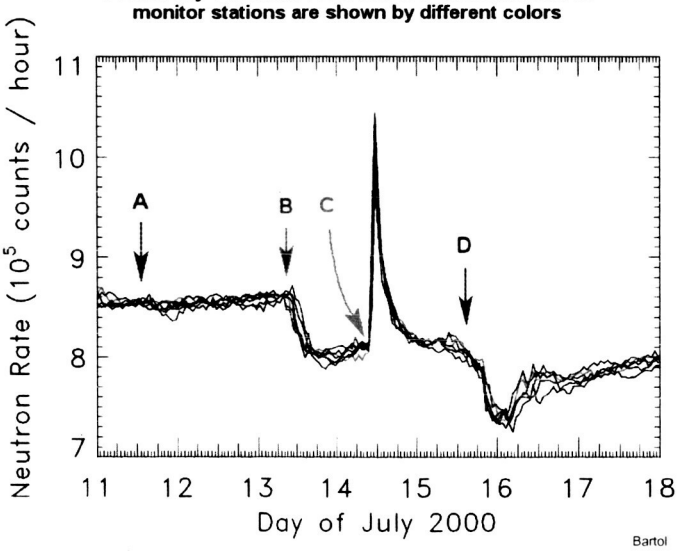




Note: Model includes accounting for the Solar Magnetic Field Polarity

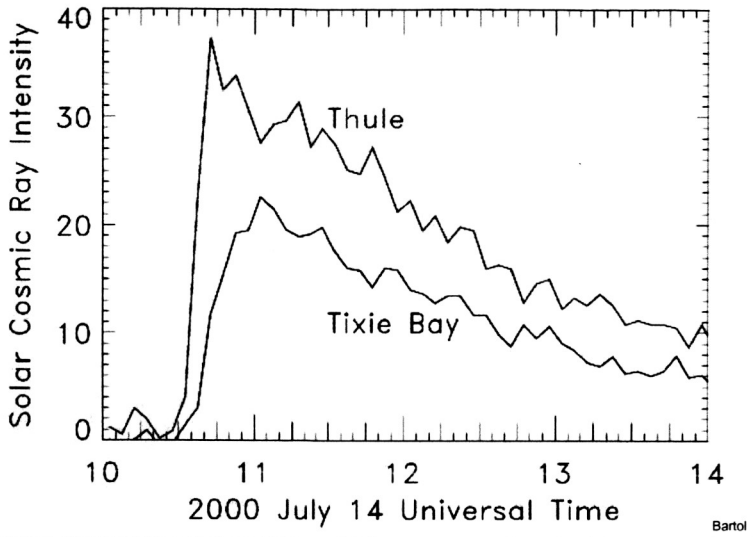
Cosmic Ray During High Solar Activity

Cosmic ray variations recorded at 7 different neutron monitor stations are shown by different colors



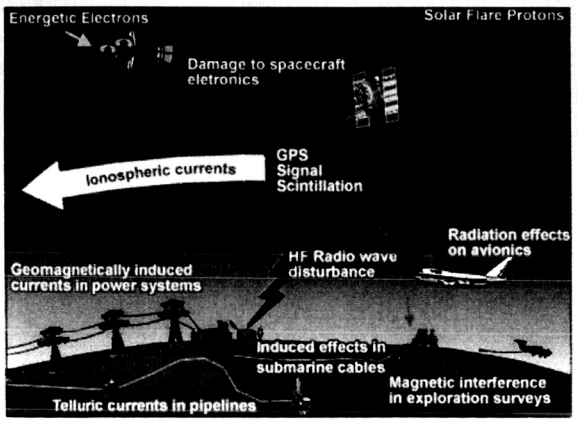
The Bastille Day Event

as seen by 2 stations of *Spaceship Earth*



Space Weather

- Space weather phenomena have a variety of effects on technology:
  - in space
  - in the atmosphere
  - on the ground
  - below ground and sea level



Atmospheric Weather

- There are indications that atmospheric weather (hurricanes, tornados, thunderstorms) affect the local radiation levels but there are not sufficient data available at this time to quantify these effects.