ALOHA

E KOMO MAI

Reef trigger fish - Rhinecanthus rectangulus

Humuhumunukunukuāpua‘a

Triggerfish with a snout like a pig

GEOMAGNETIC CUTOFF RIGIDITY VALUES - A VALUABLE TOOL IN ANALYZING COSMIC RADIATION MEASUREMENTS ON THE EARTH AND IN NEAR-EARTH SPACE

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AFRL (Retired)
SSSRC, NASHUA, NH, USA

OUTLINE OF PRESENTATION

HISTORICAL SUMMARY
- Geomagnetic Field Models
- Trajectory-Tracing Procedure
- Cutoff Rigidity Definitions

ADVANCES IN KNOWLEDGE
- Non-Vertical Direction Values
- Long-term (Secular) Variations
- Daily Variations and Magnetospheric Field Models
- Changes Associated with Geomagnetic Disturbances

EXTENSION TO SPACECRAFT MEASUREMENTS
- Three-Dimensional Considerations
- Questions asked
- Requirements for Precise Measurements

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EARLY WORK IN CUTOFF RIGIDITY CALCULATIONS

STÖRMER

Hand Calculations in a Dipole Field

LEMAITRE and VALLARTA

Analogue Computer using an Eccentric Dipole

JORY, LÜST, KASPER et al.

Initial digital computers

QUENBY and WEBBER

Used non-dipole terms

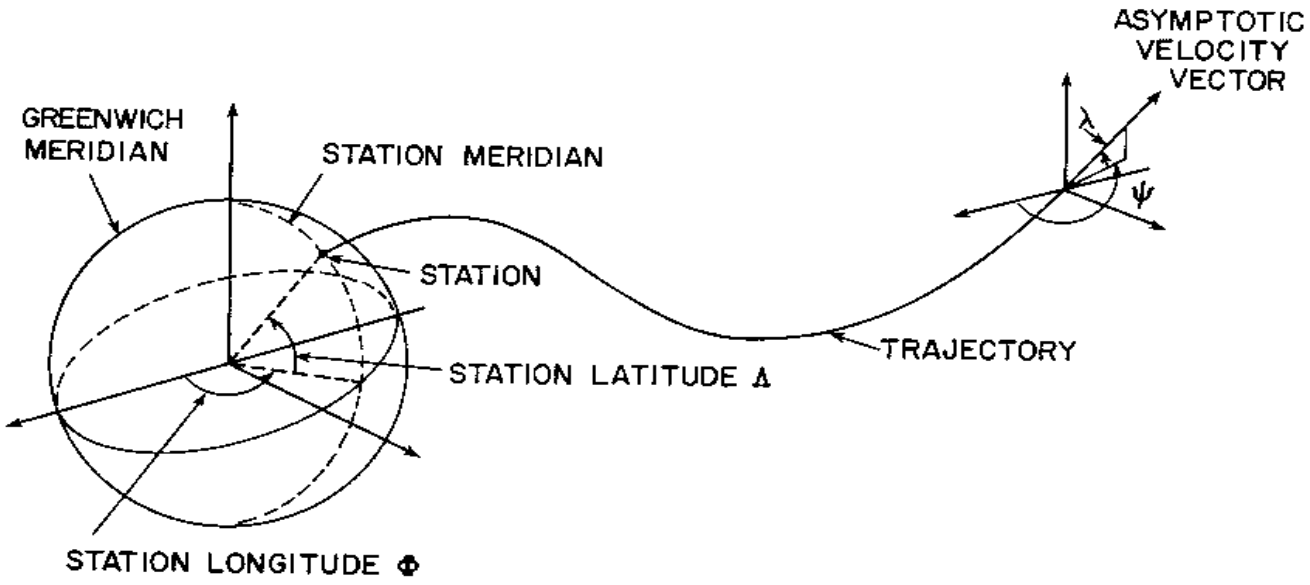
QUENBY and WENK

Hybrid of field line calculations and modified Störmer values

McCRACKEN

Numerical calculations on IBM 704 computer in a 6^{th} order geomagnetic field simulation

CONCEPT OF CHARGED PARTICLE TRACING IN A MAGNETOSPHERC FIELD MODEL



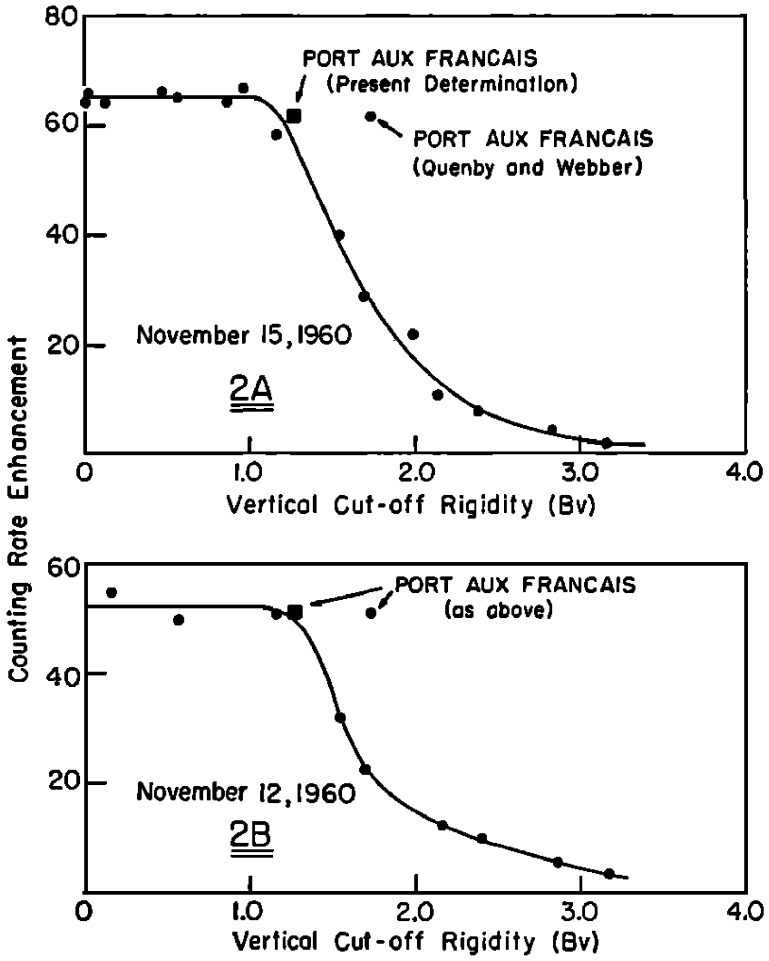
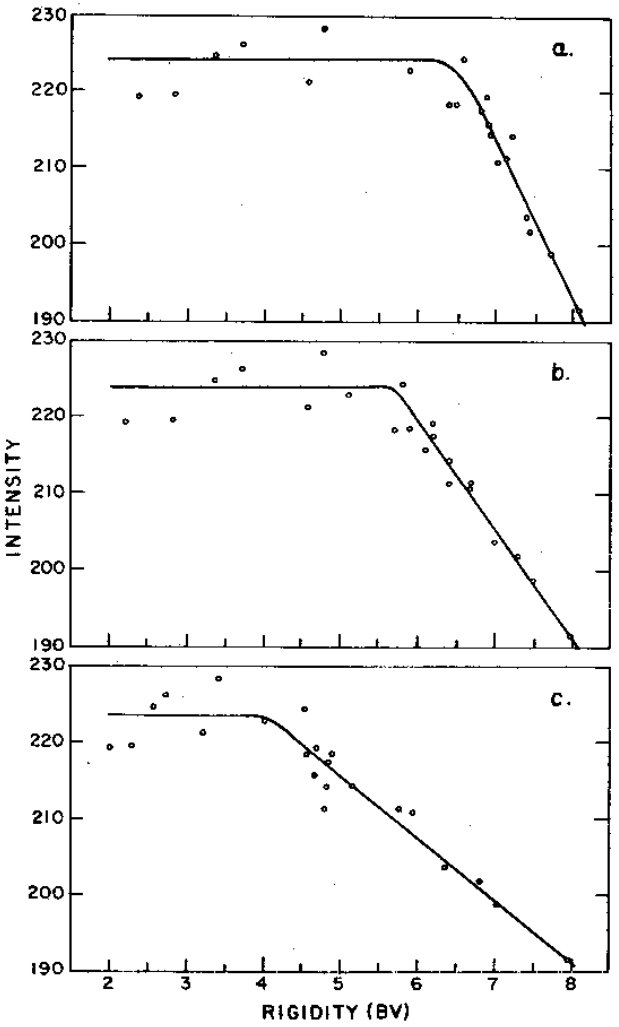


Fig. 2. The dependence of counting-rate enhancement upon vertical cutoff rigidity. The blacked-in circles indicate Quenby and Webber estimates.

COSMIC RAY INTENSITY RECORDED ON 1956-57 SOYA VOYAGE VS DIFFERENT VERTICAL CUTOFF RIGIDITY VALUES

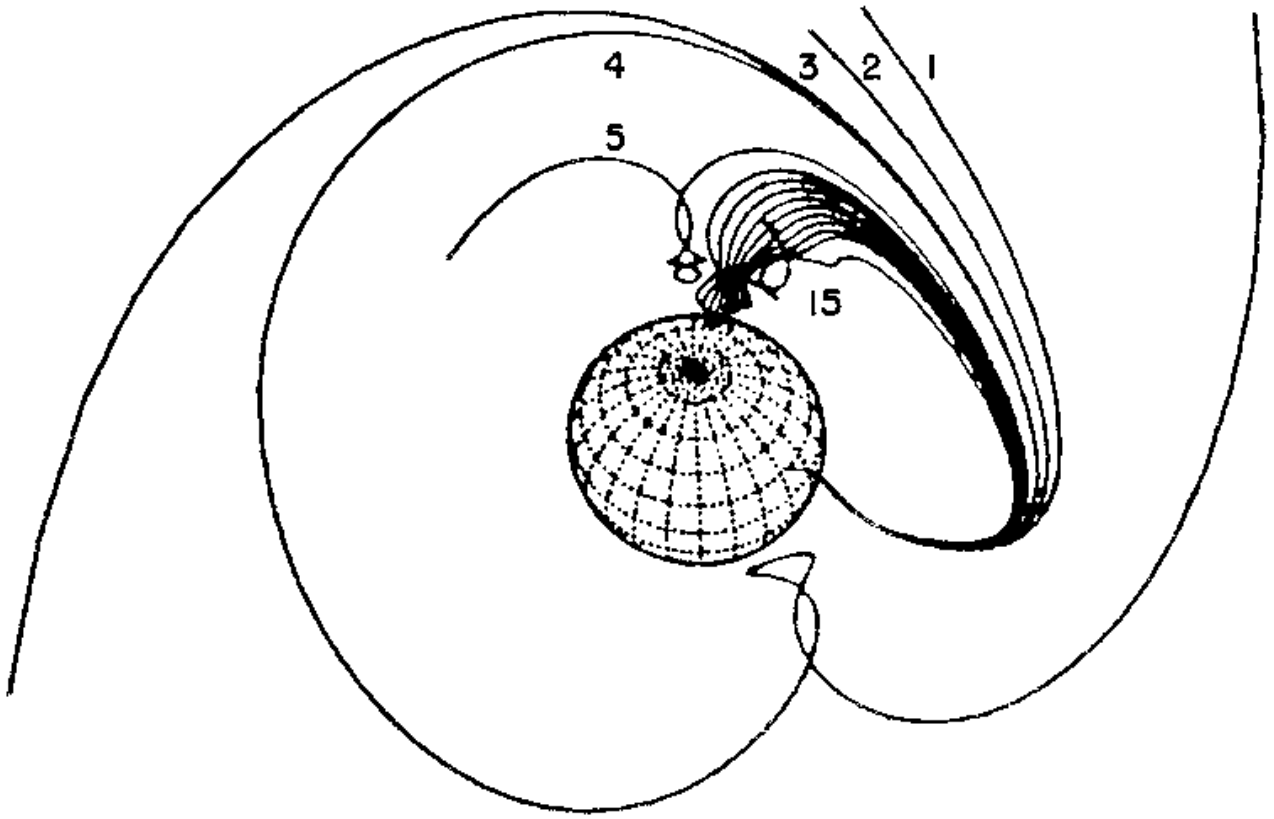


STÖRMER VALUES

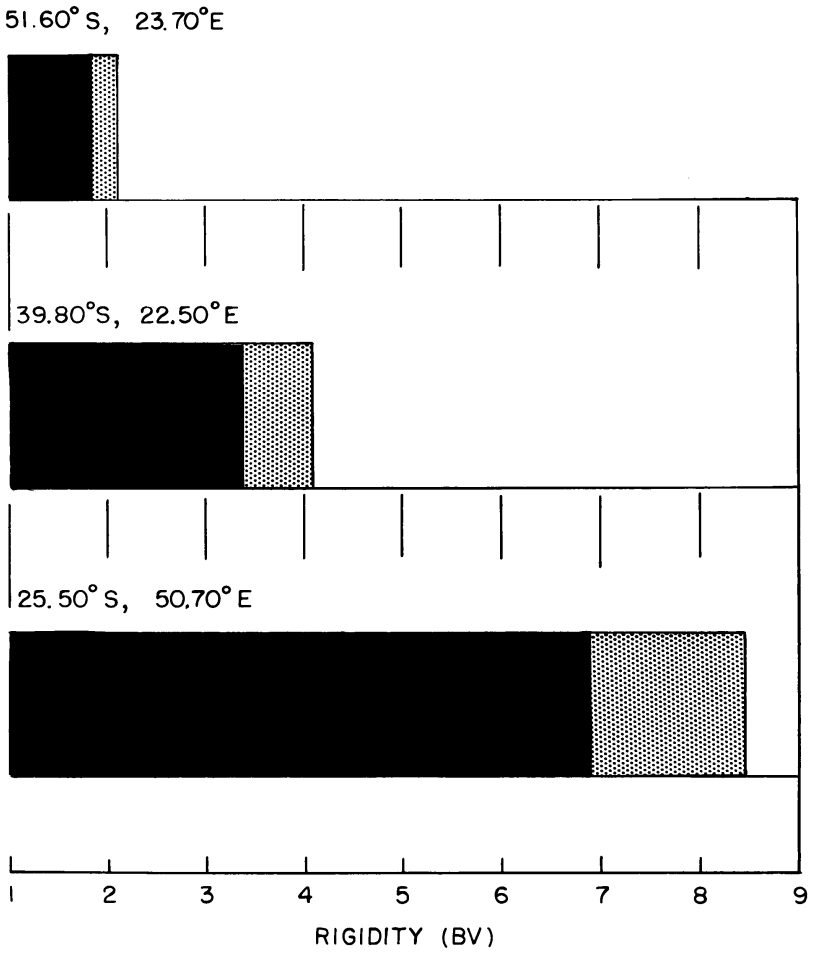
QUENBY AND WENK VALUES

VALUES CALCULATED BY THE TRAJECTORY-TRACING METHOD

EXAMPLES OF PROTON TRAJECTORIES IN A MODEL OF THE GEOMAGNETIC FIELD



REGIONS OF PROTON ACCESS TO SELECTED LOCATIONS

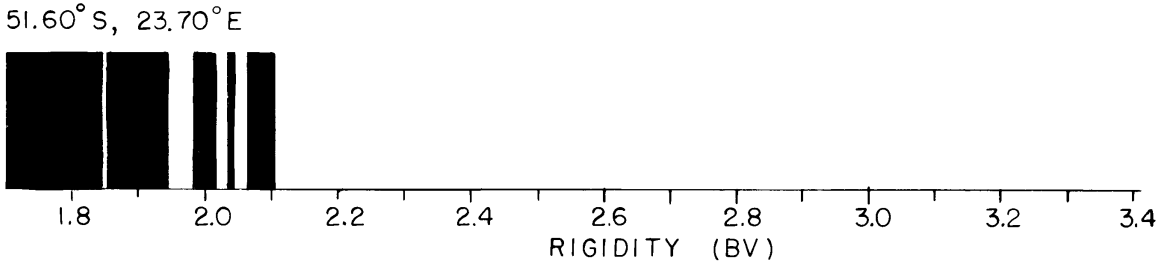


BLACK = ALL PARTICLES FORBIDDEN

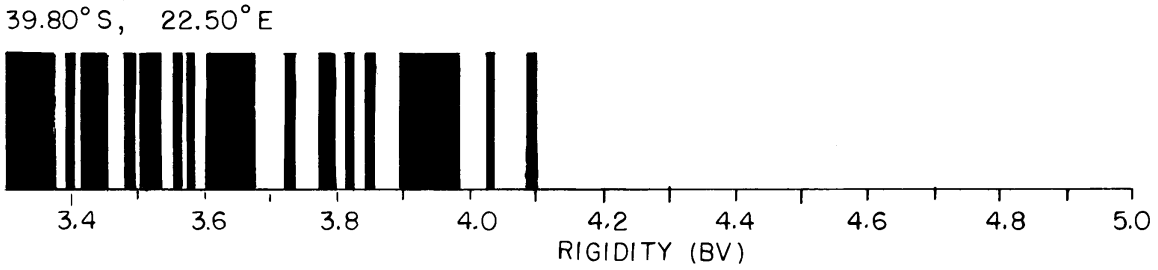
DOTTED = PENUMBRAL REGION (Mixed allowed and forbidden orbits)

WHITE = ALL PARTICLES ALLOWED

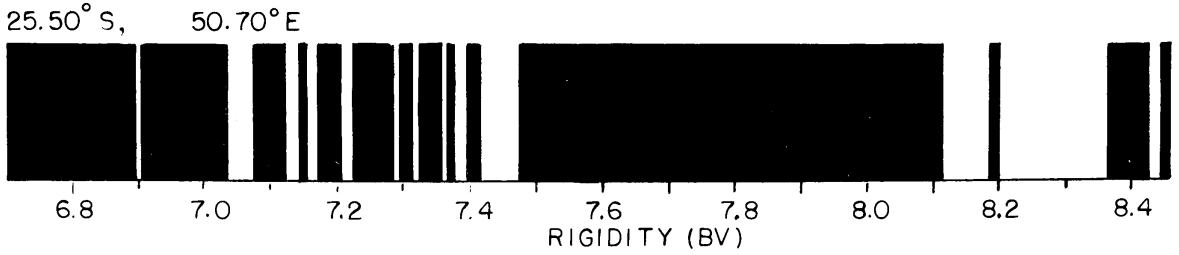
DETAILED ILLUSTRATION OF THE PENUMBRAL BANDS FOR HIGH, MIDDLE AND LOW LATITUDE LOCATIONS



Pc = 2.02 GV



Pc = 3.72 GV



Pc = 7.97 GV

CUTOFF RIGIDITY DEFINITIONS

P_U **Upper Cutoff Rigidity**
All particles above this value are allowed

P_L **Lower Cutoff Rigidity**
All particles below this value are forbidden

$P_U - P_L$ **Width of the Penumbra**

P_C **Effective Cutoff Rigidity (Corrected for the Penumbra)**

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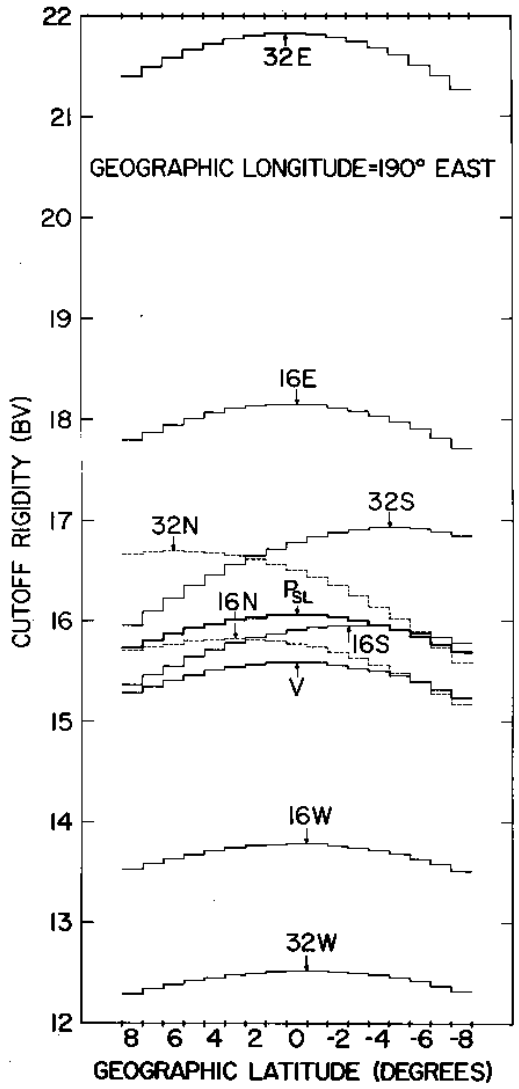
- **Three-Dimensional Considerations**
- **Questions asked**
- **Requirements for Precise Measurements**



CUTOFF RIGIDITIES AS A FUNCTION OF LATITUDE NEAR THE EQUATOR FOR DIFFERENT ZENITH AND AZIMUTH ANGLES

Angular directions = 16 and 32 degrees
Azimuth directions = N, E, S, W

V = Calculated vertical cutoff rigidity

P_{SL} = Angular corrected cutoff using differential response of a sea-level neutron monitor

CALCULATED VERTICAL CUTOFF RIGIDITY VALUES (DOTS) ALONG TWO GEOGRAPHIC LONGITUDE LINES VS. AN EXPECTED SMOOTH CURVE (SOLID LINE)

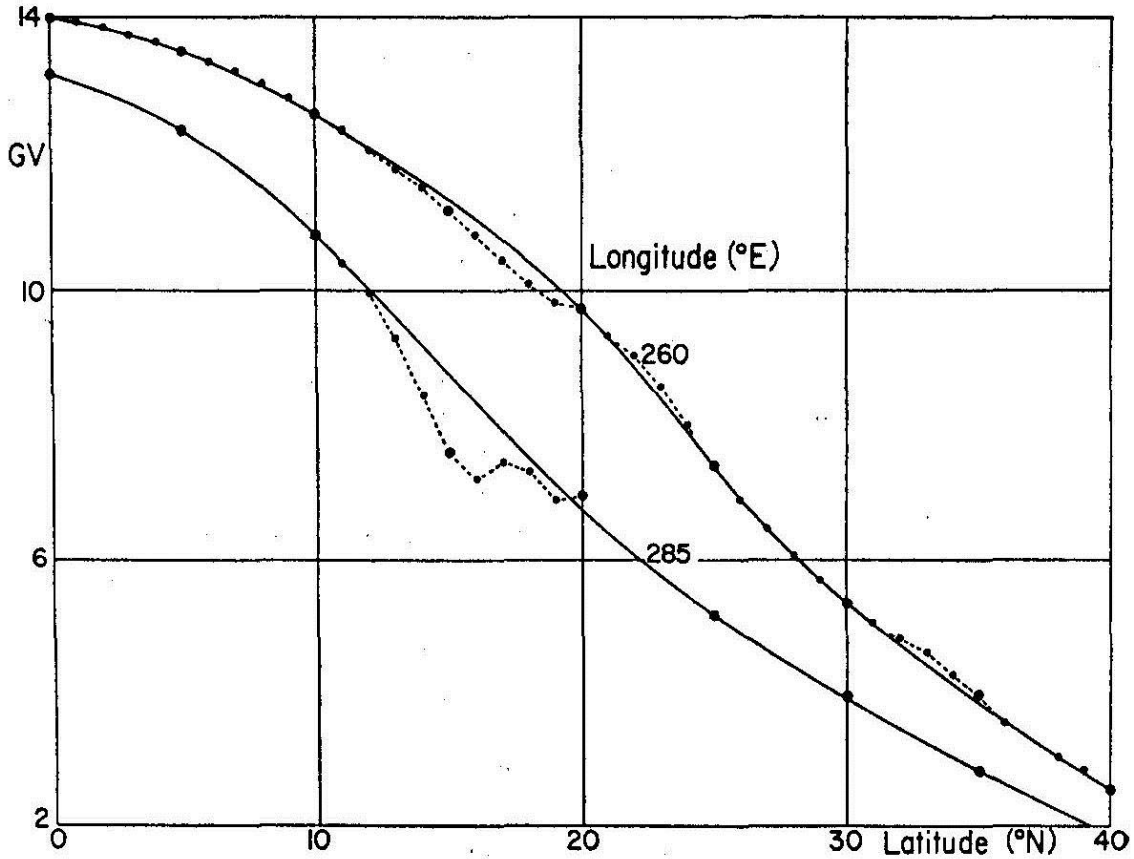


FIG. 3. The systematic nature of the deviations of vertical-trajectory cutoffs from smooth curves when plotted against geographic latitude. The larger points are the same as are shown in Fig. 2; the smaller points represent subsequent calculations made at intervals of 1° of latitude.

NEUTRON MONITOR COUNTING RATES IN 1965-66 VS. CALCULATED VERTICAL CUTOFF RIGIDITY VALUES (Carmichael Survey)

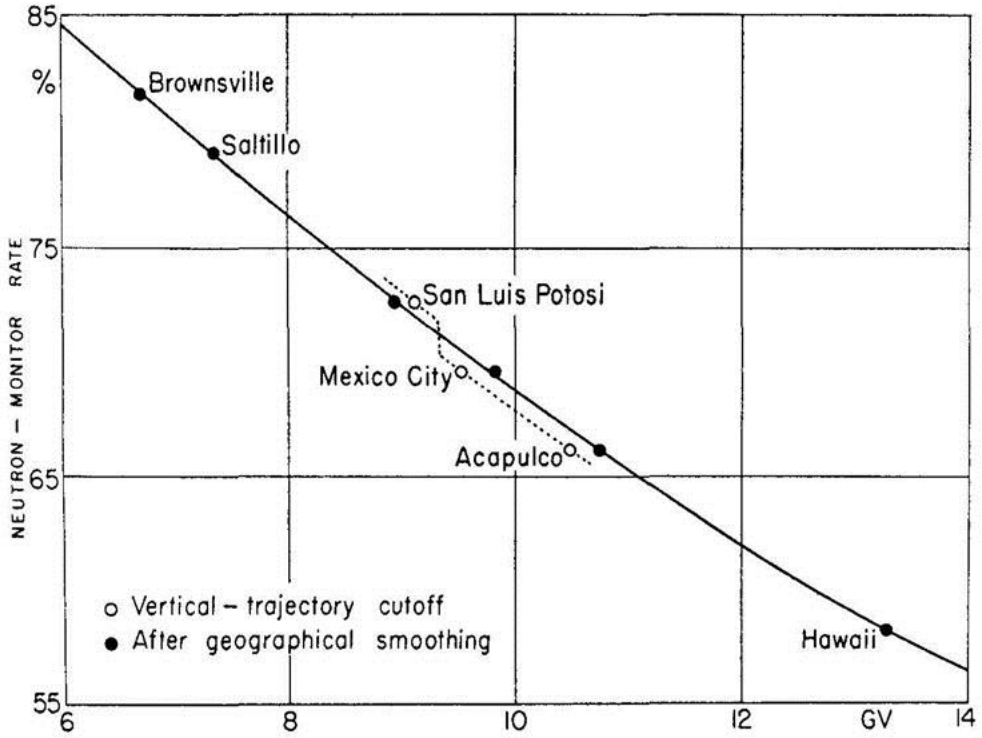
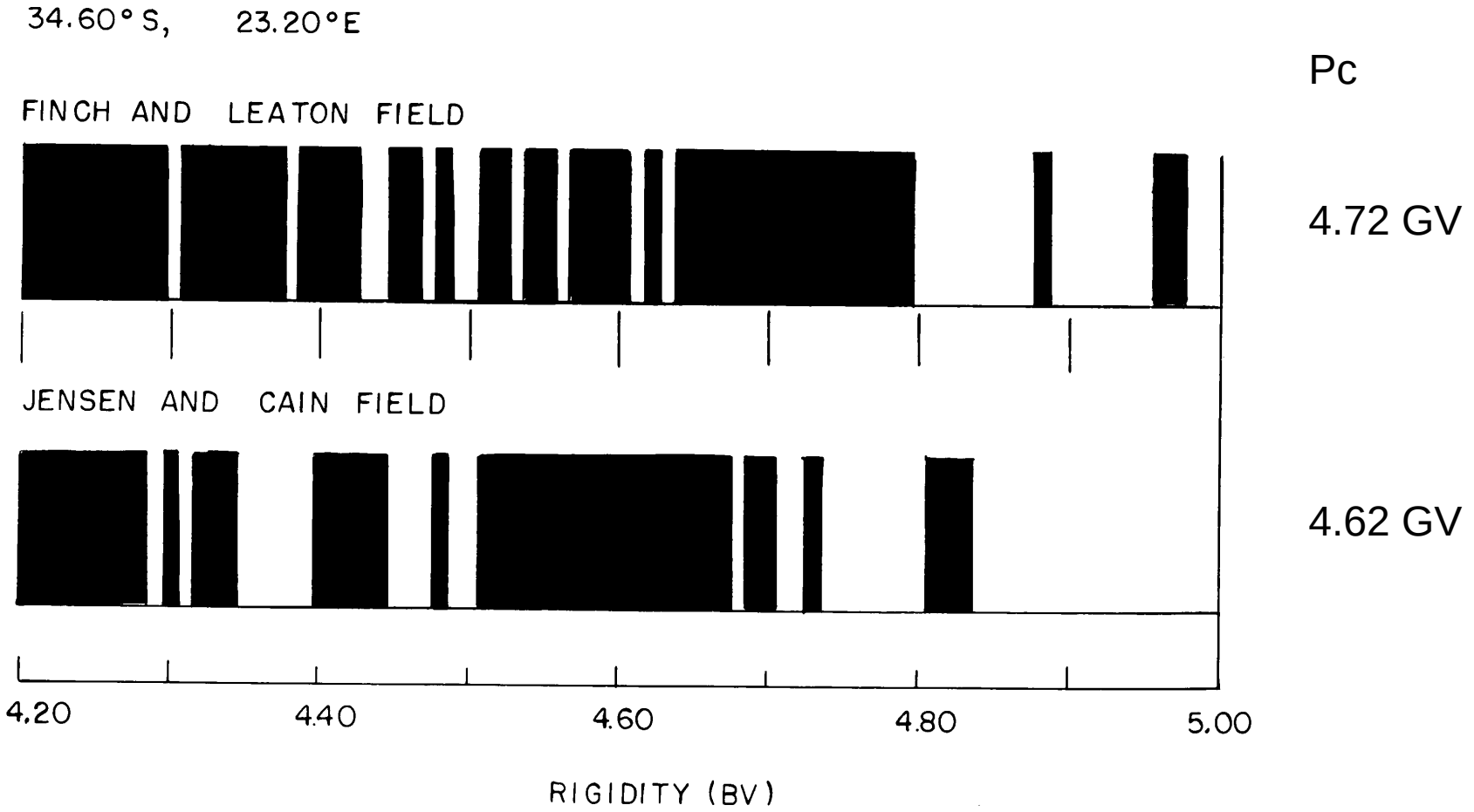


FIG. 1. The broken curve and open-circle points show neutron-monitor counting rates (reduced to a common depth in the atmosphere) plotted using geomagnetic rigidity cutoff values determined by the vertical-trajectory method. A discontinuity or kink in the curve occurs between San Luis Potosi and Mexico City. The full points exhibit the same data plotted after modification of the vertical-trajectory cutoffs by the geographical smoothing process illustrated in Fig. 2.

PENUMBRAL STRUCTURE USING THE F&L (1955) AND J&C (1960) FIELD MODELS



VARIOUS GEOMAGNETIC FIELD MODELS – 1965-1970

FINCH AND LEATON **EPOCH 1955**

JENSEN AND CAIN **EPOCH 1960**

IGRF (IAGA) **EPOCH 1965**

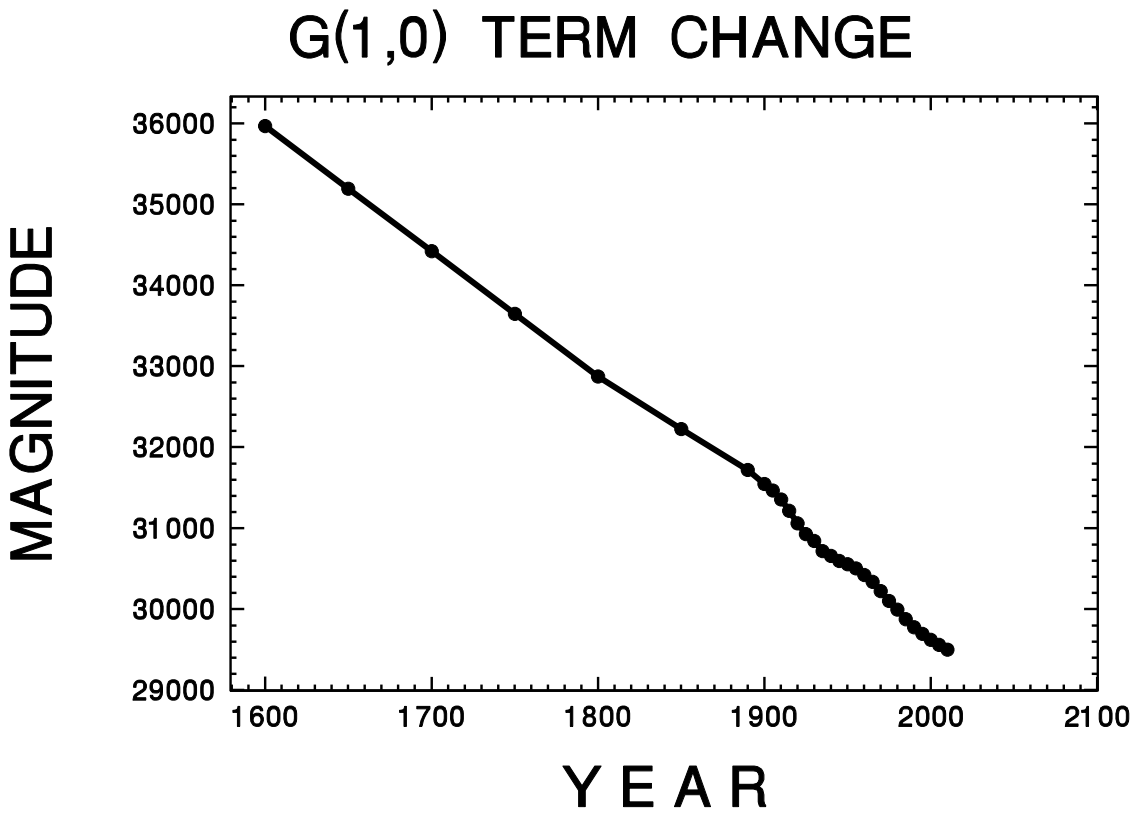
EPOCH 1955

EPOCH 1970 (PROJECTED)

EPOCH 1975 (PROJECTED)

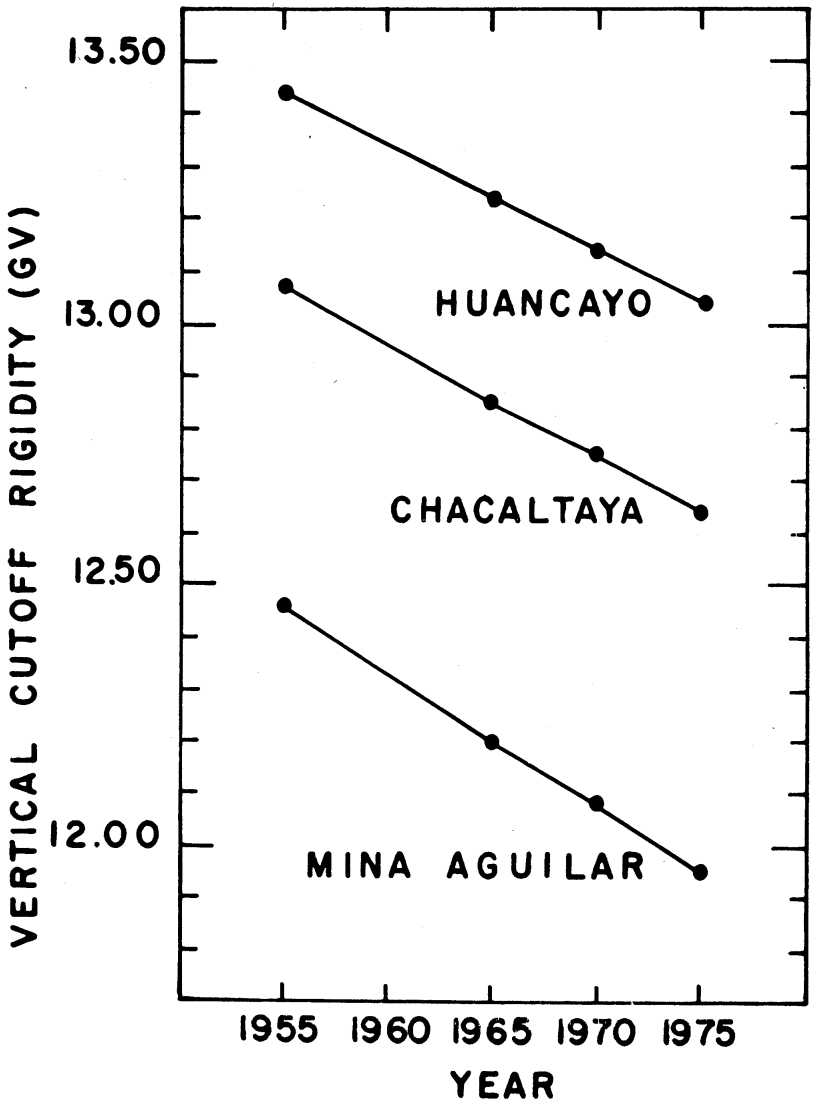
1975 PROJECTION NOT ADEQUATE

CHANGE IN THE GEOMAGNETIC DIPOLE TERM 1600-2010



The dipole term decreased ~17.8% over 400 years.

Note: The H component at Hermanus, South Africa decreased ~18% over 50 years (1958-2007).



VERTICAL CUTOFF RIGIDITY VALUES FOR THREE SOUTH AMERICAN LOCATIONS 1955-1975

All locations have a sharp cutoff (i.e. no penumbra).

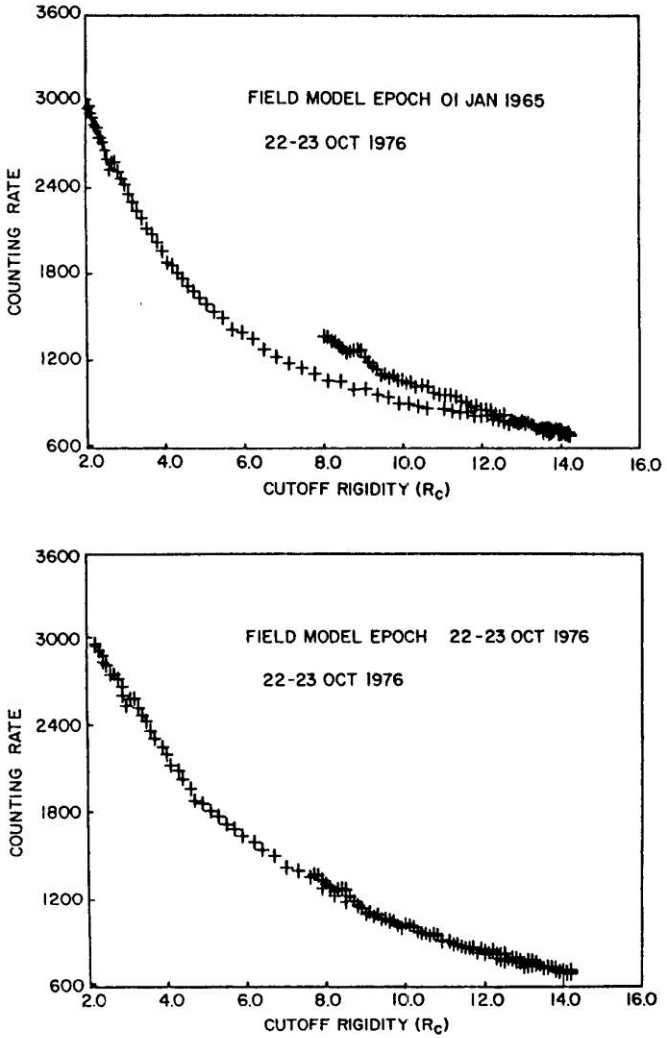


Fig. 4. Cosmic ray intensity data obtained on an airline flight between South Africa and New York City in October 1976 as plotted against vertical cutoff rigidities calculated using the 1965.0 geomagnetic field model (top) and against vertical cutoff rigidities appropriate for October 1976 (bottom). The "upper" section of the curve (between 8 and 12 GV) in the top panel are the intensity data obtained in the southern hemisphere between South Africa and the equatorial region; the "lower" section of the curve are the intensity data obtained in the northern hemisphere between the equatorial region and New York City.

Cosmic ray intensity data on airline flight between South Africa and New York City, October 1976

Top: Counting rate plotted against 1965 field model. Upper section of the curve in Southern Hemisphere; lower part of curve in Northern Hemisphere

Bottom: Counting rate plotted against vertical cutoff rigidities appropriate for 1976.

CHANGE IN VERTICAL CUTOFF RIGIDITY VALUES 1965-1980

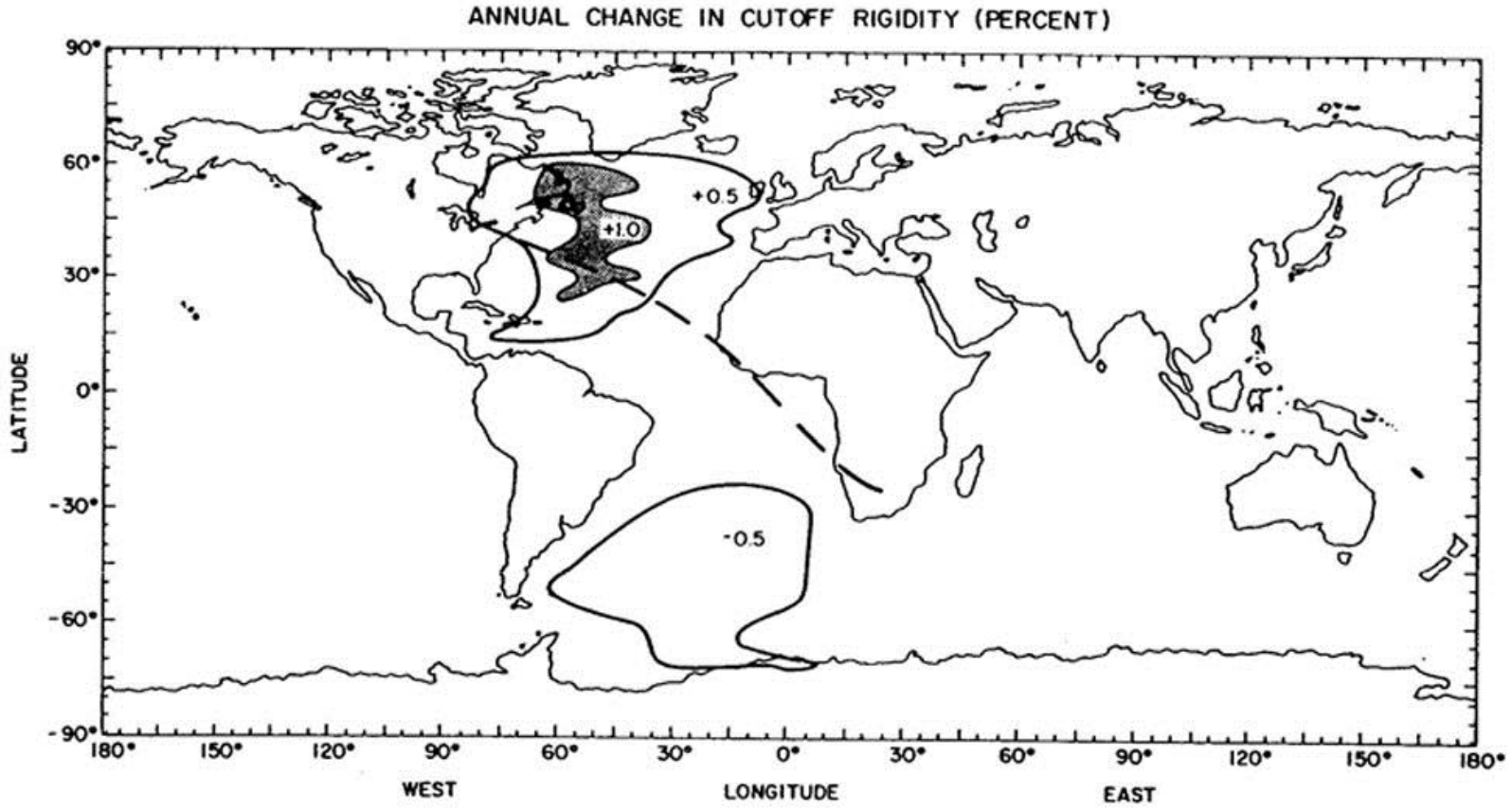


Fig. 6. Contours of averaged annual change of vertical cutoff rigidities between 1965.0 and 1980.0. The dashed line indicates the route of the airline flight between South Africa and New York City in October 1976.

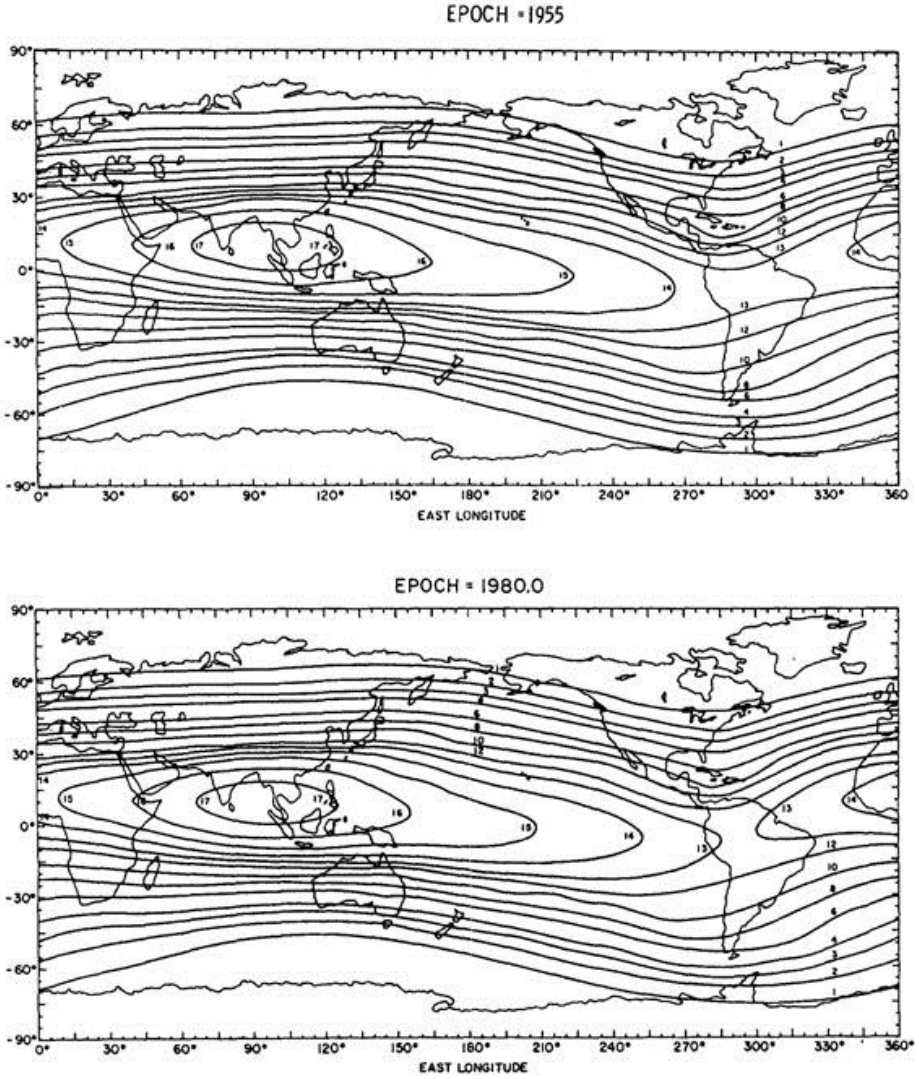


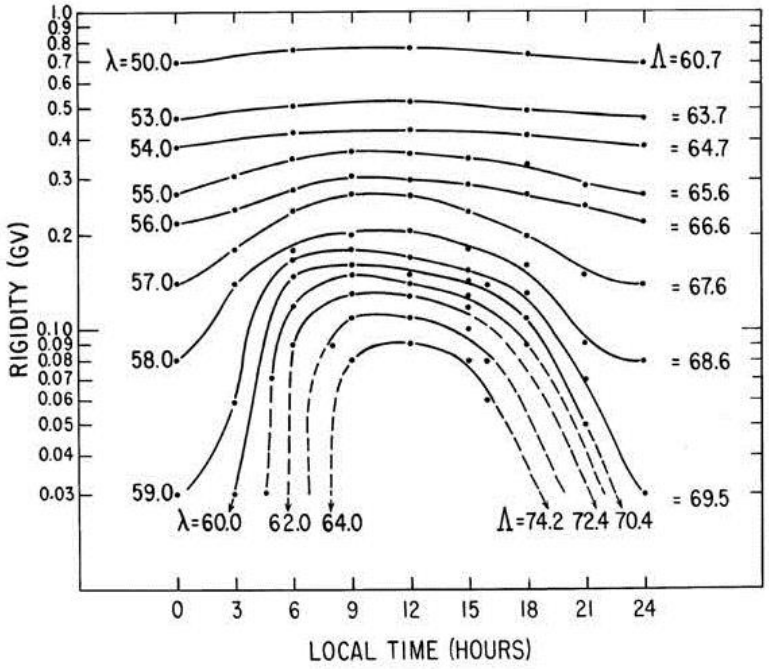
Fig. 3. Contours of vertical cutoff rigidities (in units of GV) as calculated using the Finch and Leaton magnetic field coefficients for Epoch 1955 (top). Contours of vertical cutoff rigidities as calculated using the International Geomagnetic Reference Field for Epoch 1980 (bottom).

CONTOURS OF VERTICAL CUTOFF RIGIDITY PLOTTED ON A WORLD MAP

Top: Epoch 1955

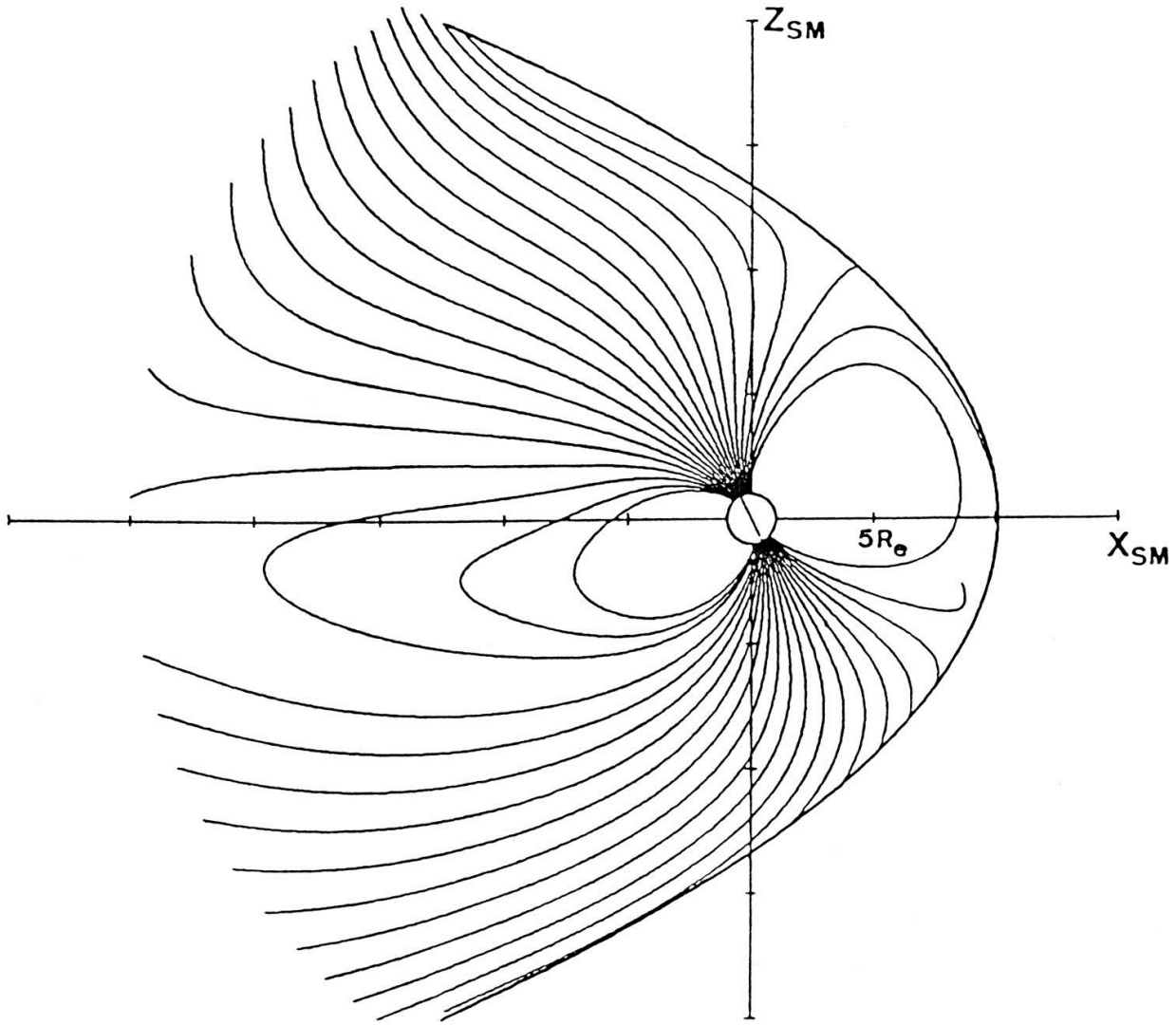
Bottom: Epoch 1980

CALCULATED HIGH LATITUDE DAILY CUTOFF RIGIDITY VARIATION ALONG THE 260 DEGREE MERIDIAN



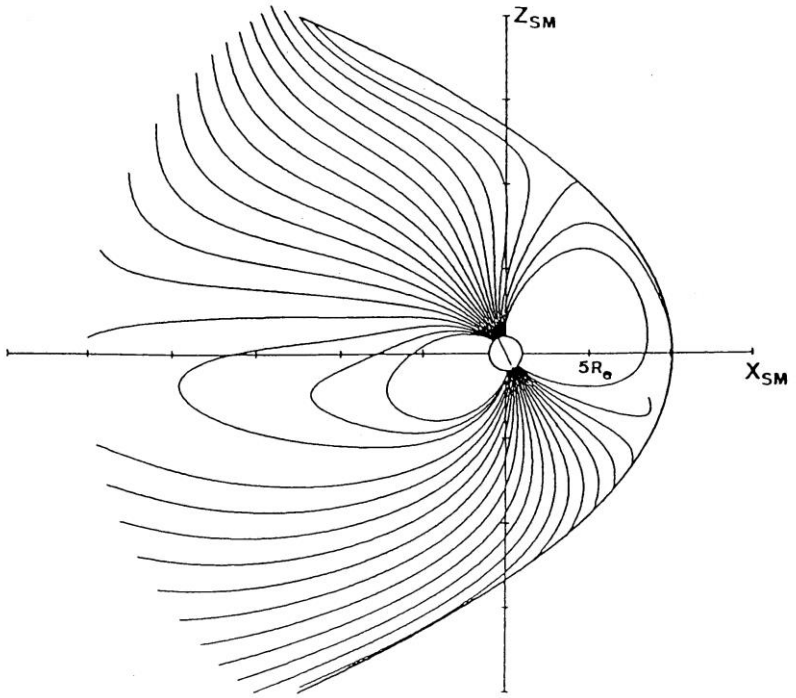
Field model:
Finch and Leaton plus external model of Mead and Williams

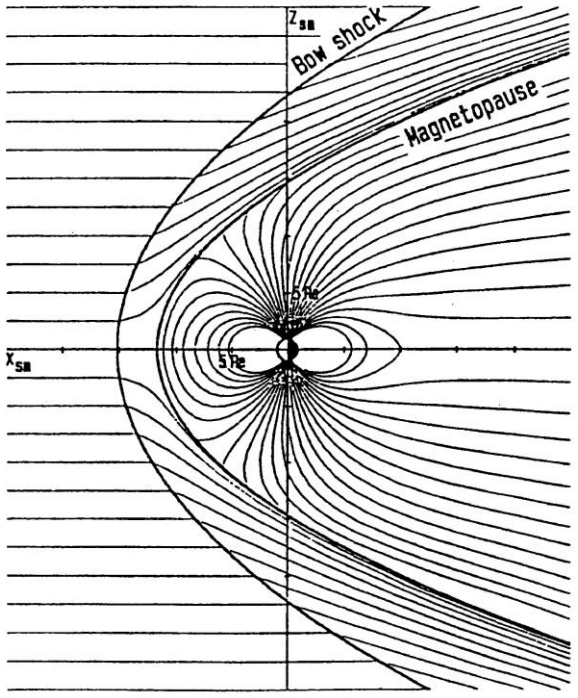
TSYGANENKO (1989) MODEL MAGNETOSPHERE



Over the years more parameters were included in the mathematical models of the magnetosphere.

Dynamic modes are presently being developed; these are extremely complex involving both interplanetary and magnetospheric parameters





MAJOR PARAMETERS OF MAGNETOSPHERIC MODELS

LOCAL TIME

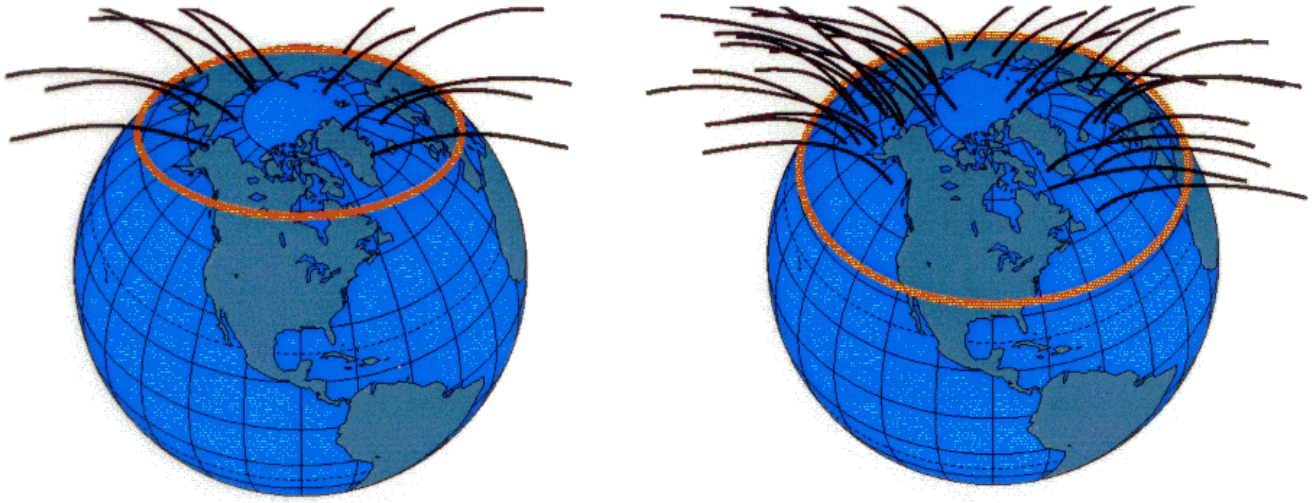
SEASON OF THE YEAR

GEOMAGNETIC FIELD VARIATION (Kp or Dst value)

INTERNAL FIELD EPOCH

These magnetospheric models have been extremely useful for the study of high energy solar proton events and for the calculation of radiation dosage on spacecraft.

PICTORIAL CONCEPT OF THE EQUATORWARD EXTENSION OF THE POLAR CAP DURING GEOMAGNETIC DISTURBANCES

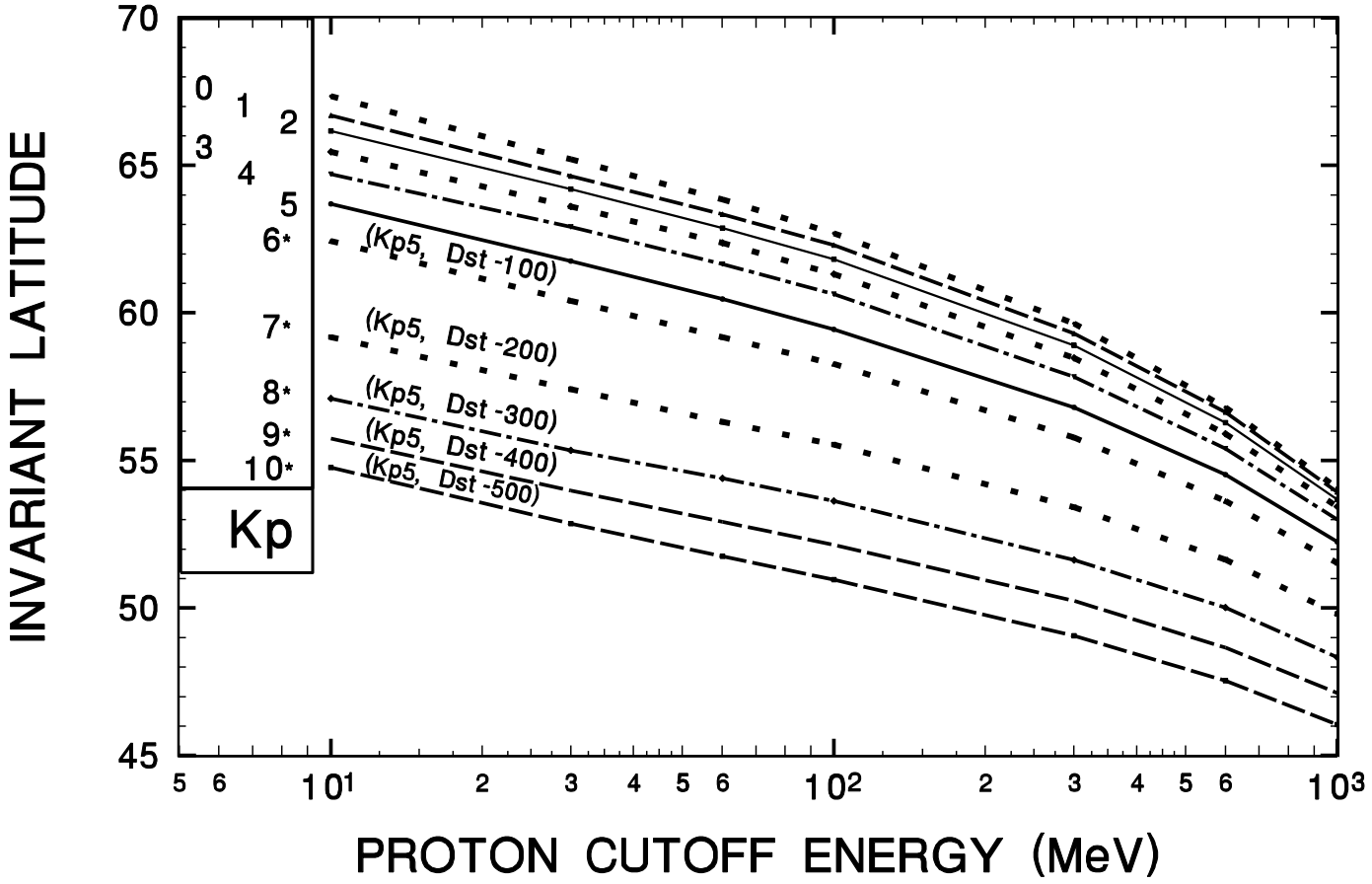


NORMAL GEOMAGNETIC CONDITIONS

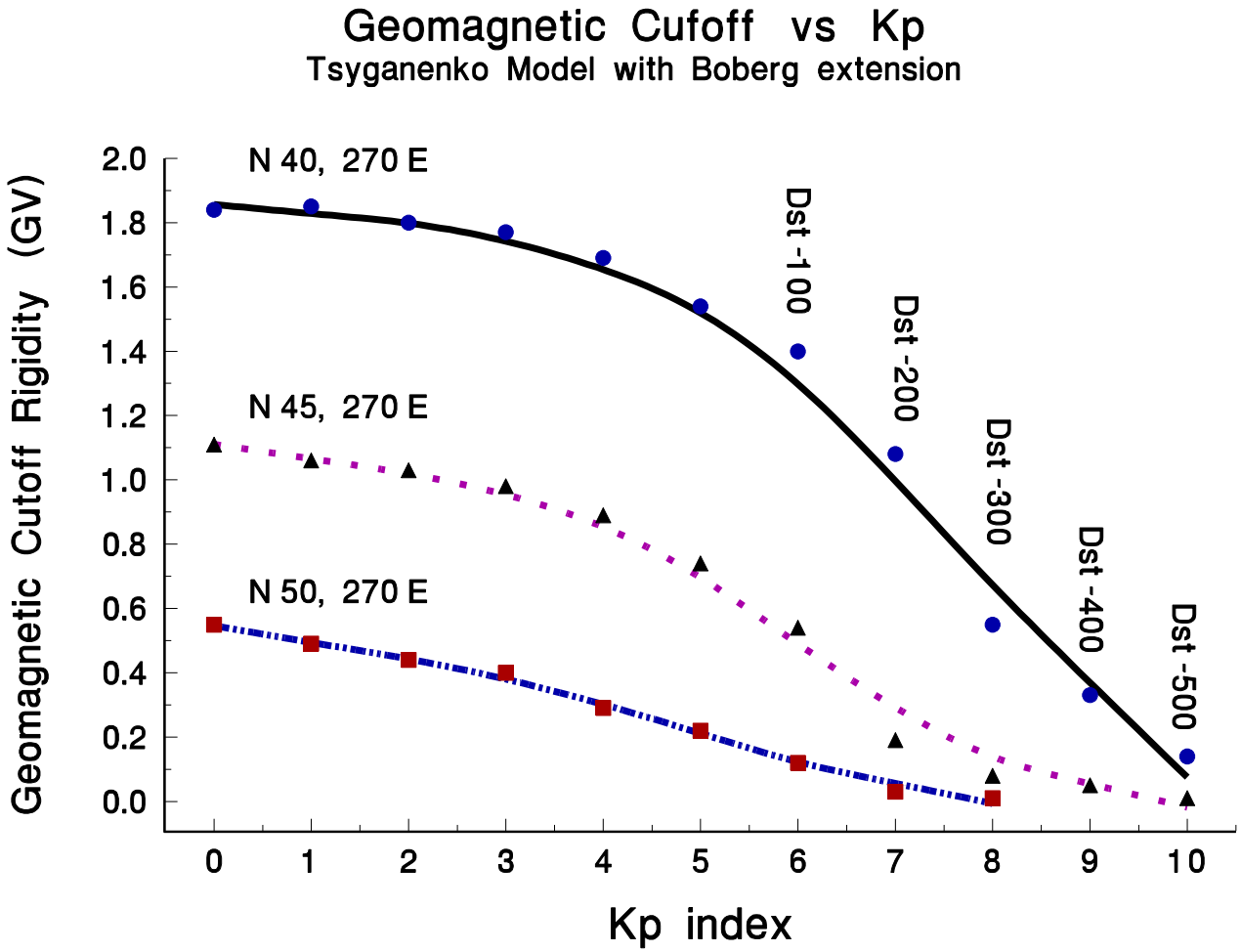
SEVERE GEOMAGNETIC DISTURBANCE

Conceptual view of solar proton access to the northern polar regions during
(left) quiescent conditions and
(right) disturbed conditions when the auroral oval is displaced equatorward.

CHANGE IN CUTOFF DURING GEOMAGNETIC DISTURBANCES



RULE OF THUMB: 0.75 DEGREE SHIFT EQUATORWARD FOR EACH INCREMENT OF Kp VALUE


Geomagnetic Cufoff vs Kp
Tsyganenko Model with Boberg extension
Geomagnetic Cutoff Rigidity (GV)
Kp index
N 40, 270 E
N 45, 270 E
N 50, 270 E
Dst -100
Dst -200
Dst -300
Dst -400
Dst -500
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
6
7
8
9
10

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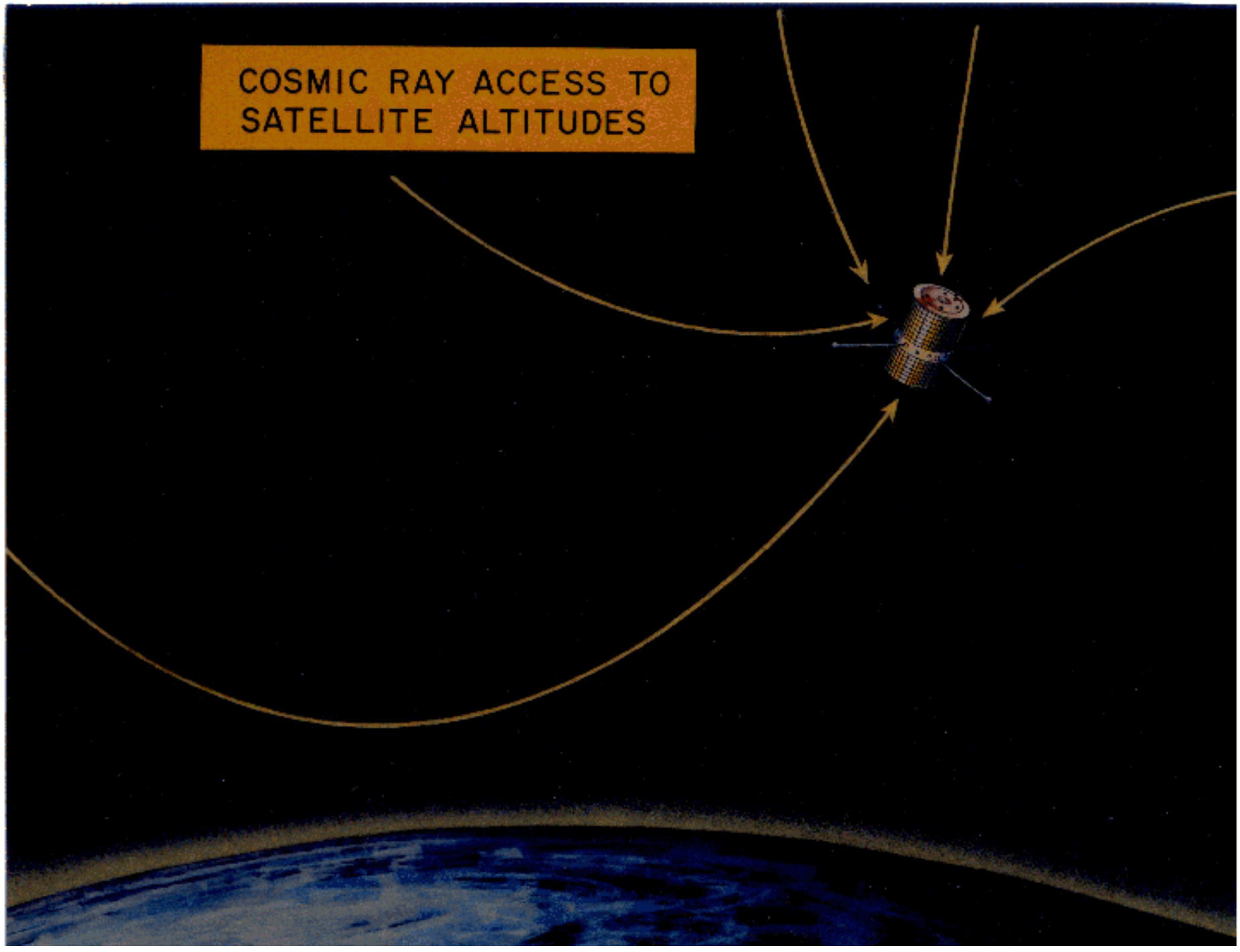
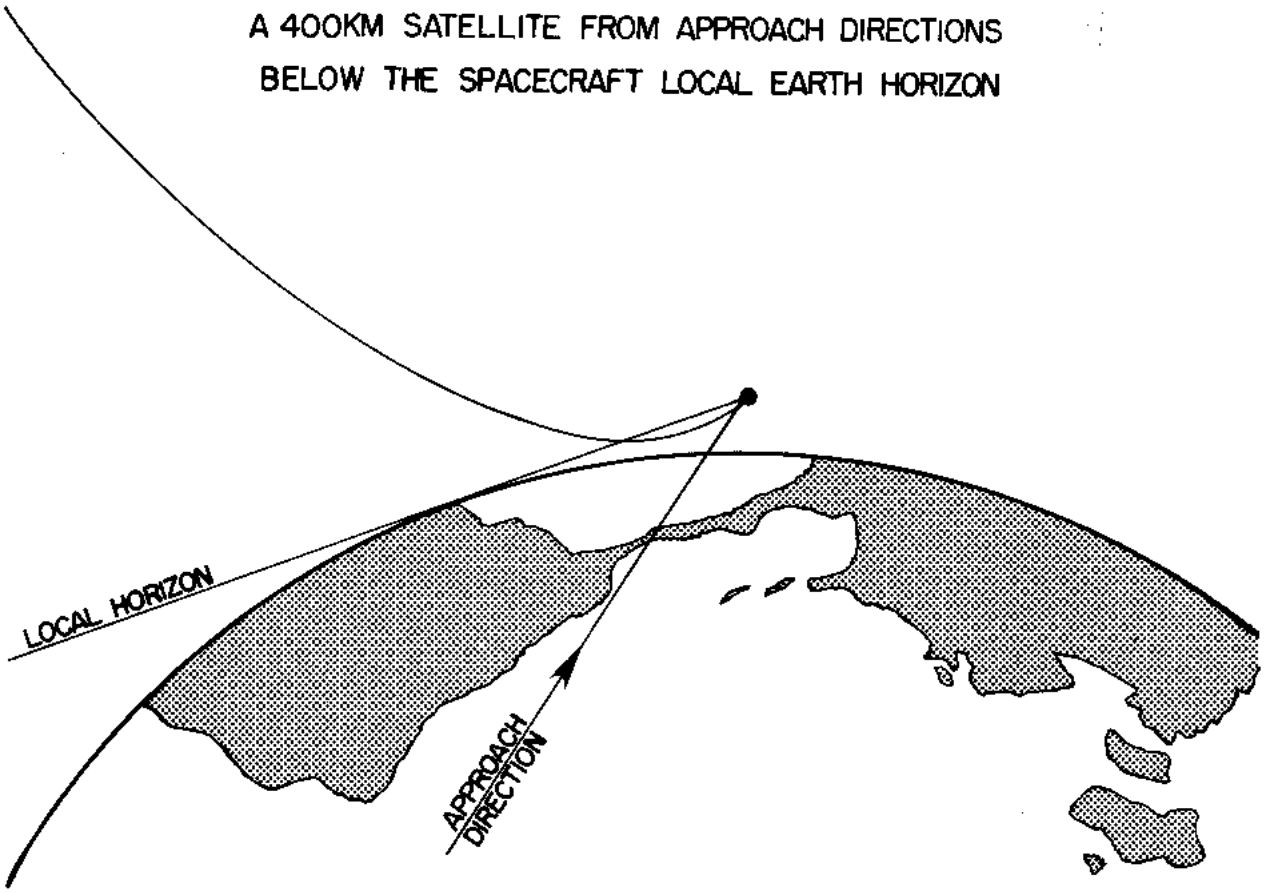
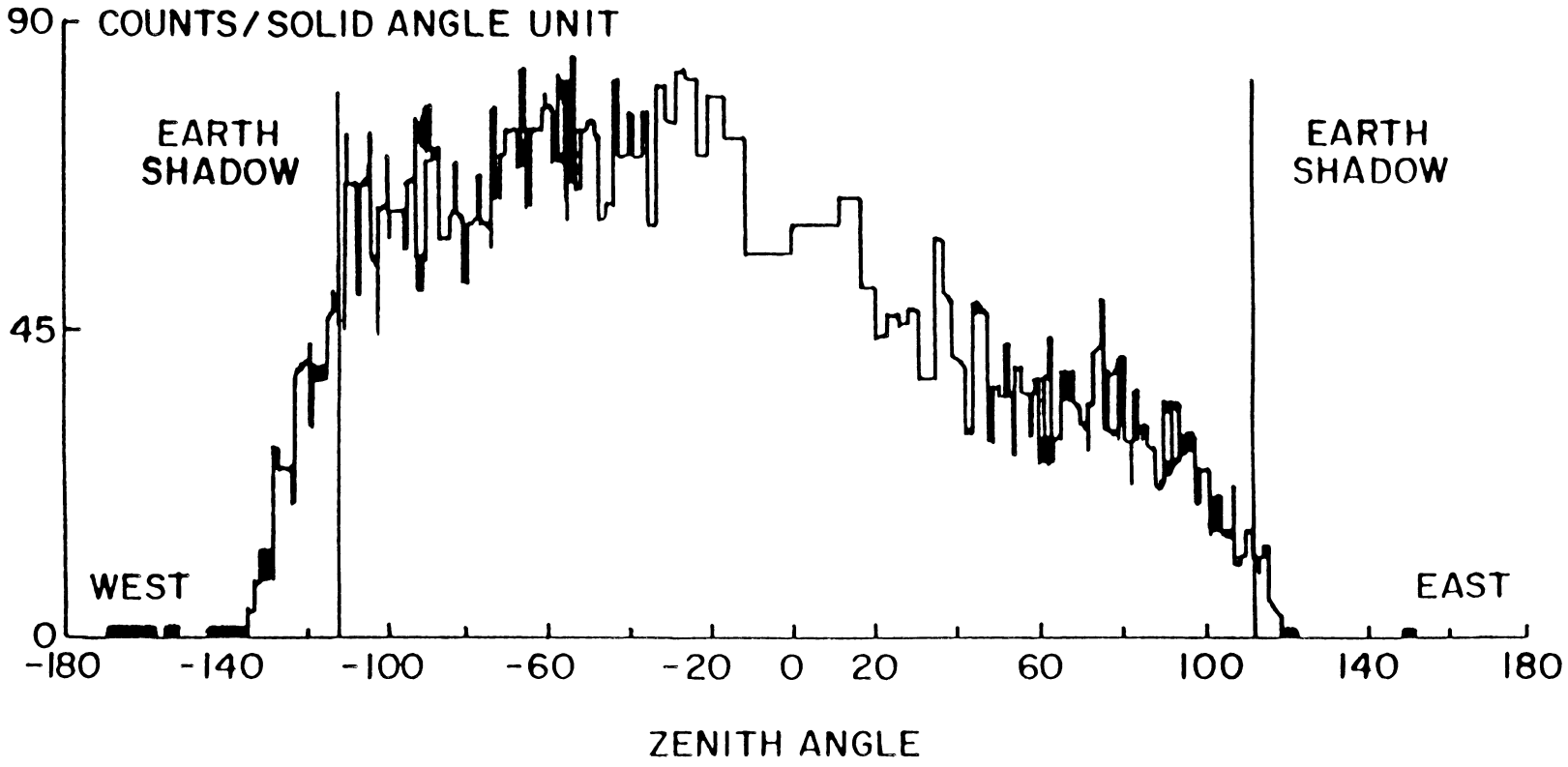
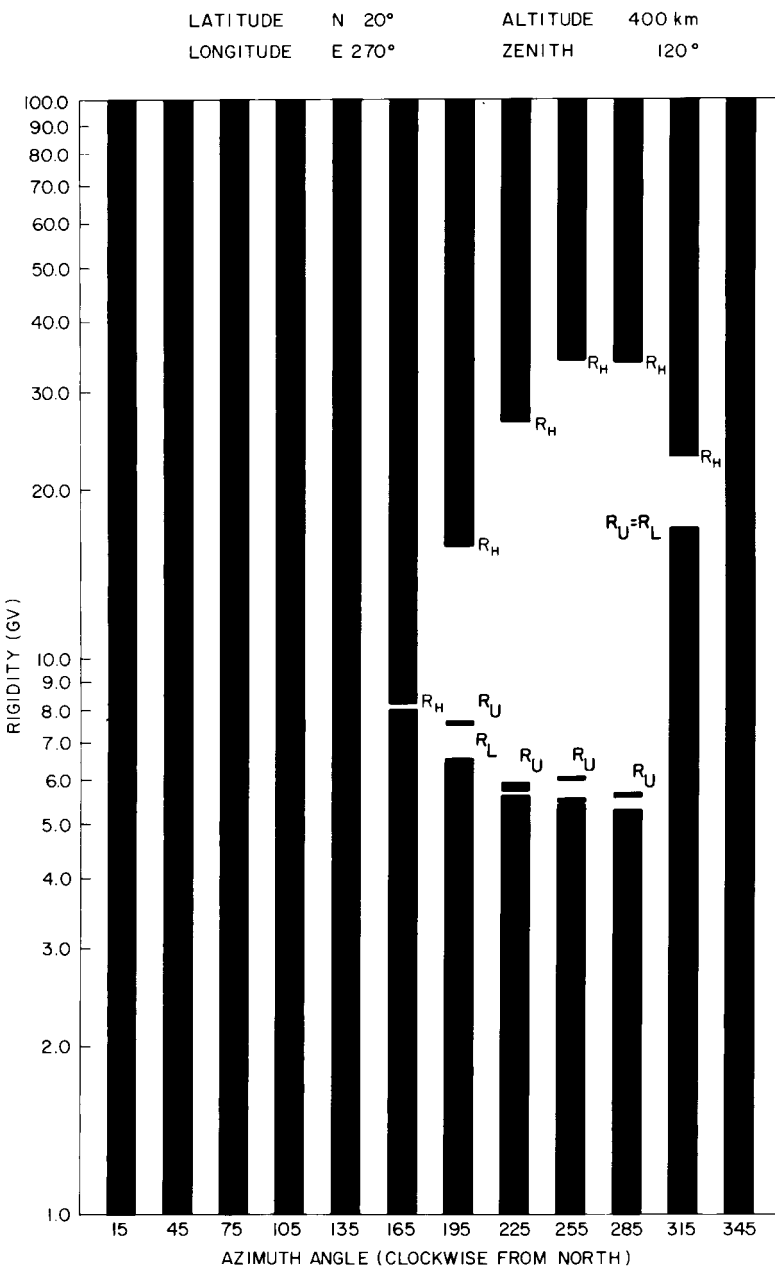
  - **Three-Dimensional Considerations**
  - **Questions asked**
  - **Requirements for Precise Measurements**


COSMIC RAY ACCESS TO
SATELLITE ALTITUDES

COSMIC RAY TRAJECTORY BENT UP TO ENCOUNTER
A 400KM SATELLITE FROM APPROACH DIRECTIONS
BELOW THE SPACECRAFT LOCAL EARTH HORIZON




90
COUNTS/SOLID ANGLE UNIT
EARTH SHADOW
EARTH SHADOW
45
WEST
EAST
0
-180
-140
-100
-60
-20
0
20
60
100
140
180
ZENITH ANGLE


LATITUDE N 20°
LONGITUDE E 270°
ALTITUDE 400 km
ZENITH 120°
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
RIGIDITY (GV)
R_H
R_U
R_L
$R_U=R_L$
15
45
75
105
135
165
195
225
255
285
315
345
AZIMUTH ANGLE (CLOCKWISE FROM NORTH)

CUTOFF RIGIDITY DEFINITIONS

P_U **Upper Cutoff Rigidity**
All particles above this value are allowed

P_L **Lower Cutoff Rigidity**
All particles below this value are forbidden

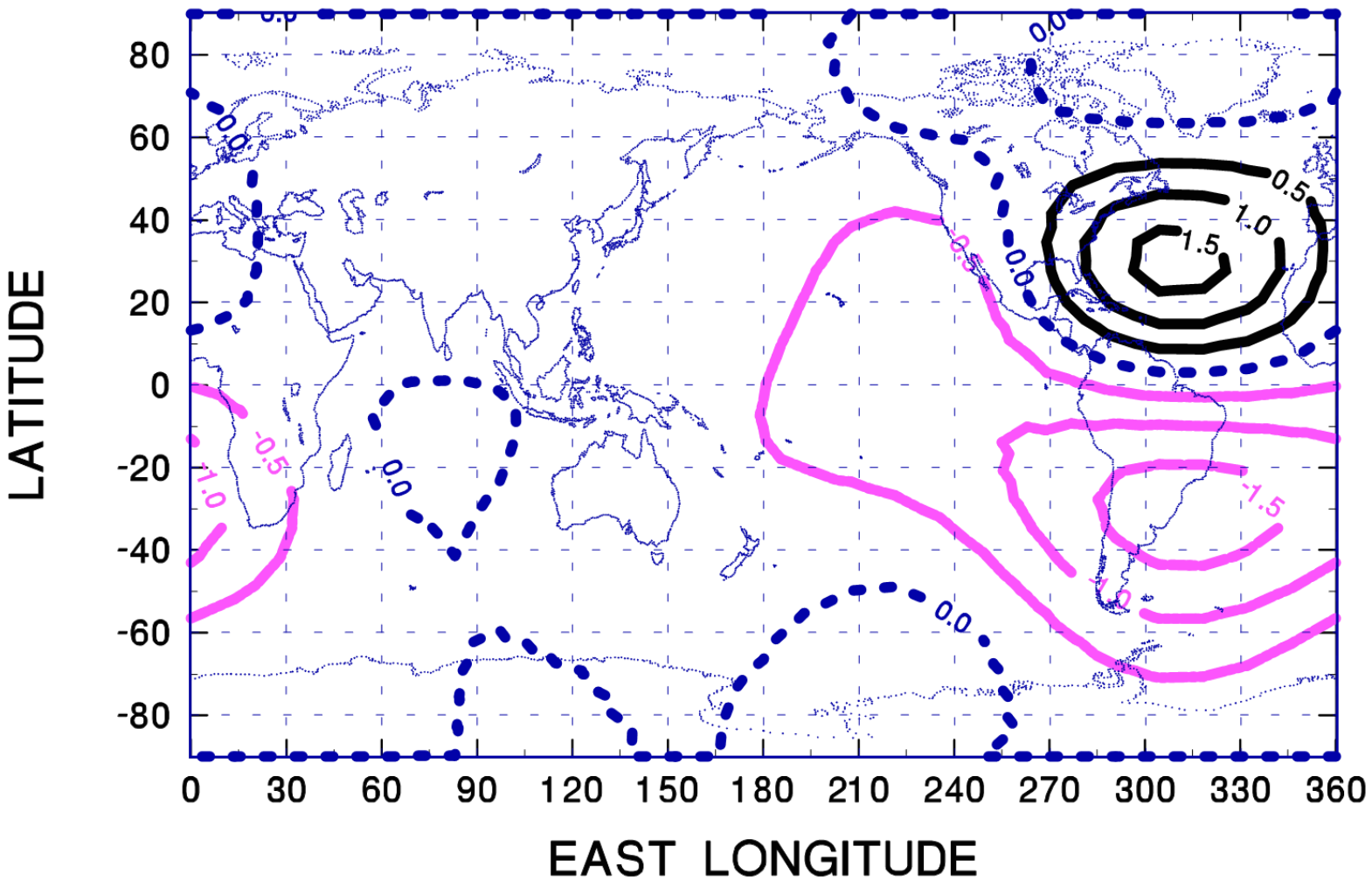
$P_U - P_L$ **Width of the Penumbra**

P_C **Effective Cutoff Rigidity (Corrected for the Penumbra)**

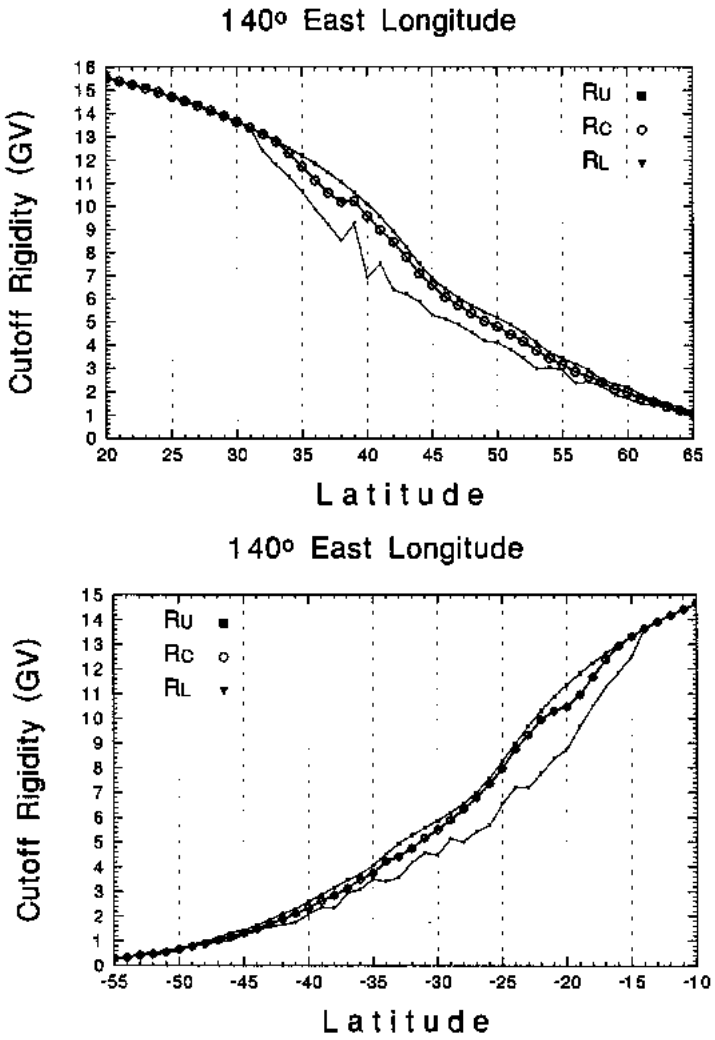
P_H **Horizon-limited Rigidity**
Appropriate for Spacecraft Observations

1950 - 2000

Change in Cutoff Rigidity (GV)



DISCONTINUITIES STILL EXIST IN CALCULATING VERTICAL GEOMAGNETIC CUTOFF RIGIDITIES ALONG GEOGRAPHIC LONGITUDES

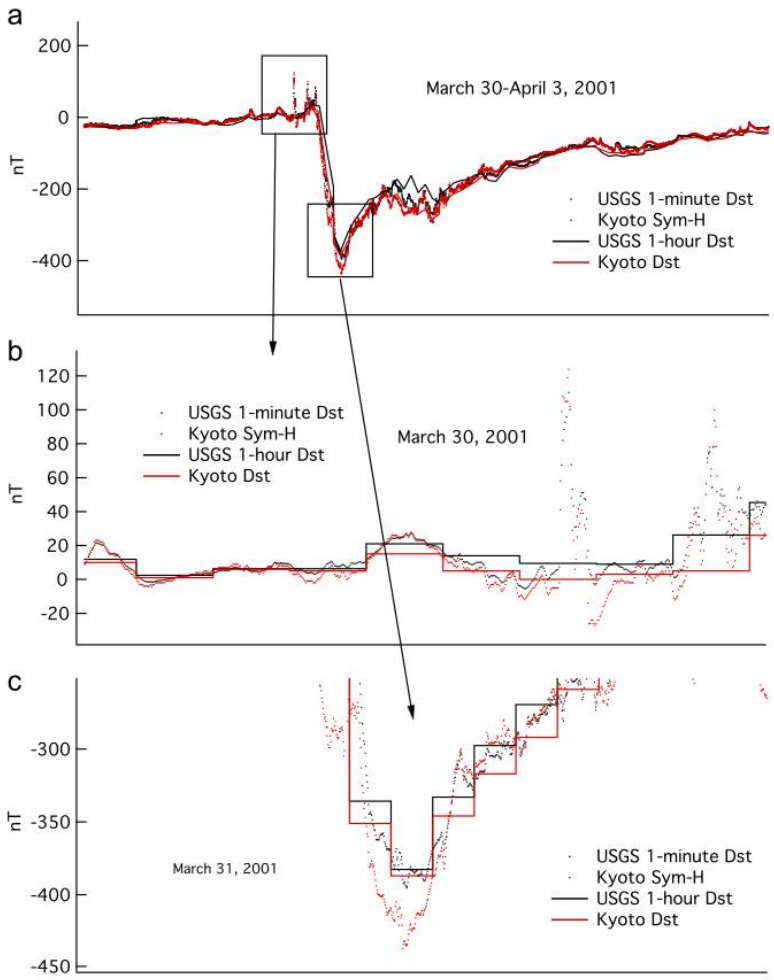


QUESTIONS ASKED

- **How quick and how much does the geomagnetic cutoff change during intense solar events?**

- **The cutoff does not change during a solar event. It changes when there is a major geomagnetic disturbance usually initiated by a solar event. During those times the cutoff can decrease as much as 1.0 GV over a two-hour period at an initial cutoff rigidity value of 1.8 GV.**

CHANGES IN Dst DURING MAJOR MAGNETIC STORM IN 2001



HOURLY CHANGES

03-04 UT -0.56 Dst/Min

04-05 UT -2.47 Dst/Min

05-06 UT -1.77 Dst/Min

06-07 UT -1.48 Dst/Min

07-08 UT -0.62 Dst/Min

OVERALL EVENT

03-08 UT -83 Dst/hour decrease

Max value = -387 nT

Changes in vertical cutoff rigidity along 270° longitude during the initial portion of the 31 March 2001 geomagnetic storm

	40°N	45°N	50°N	
04-05 UT	1.8	1.1	0.6	GV
05-06 UT	1.2	0.4	0.1	GV
06-07 UT	0.8	0.1	0.0	GV

QUESTIONS ASKED

- **Are all particles above cutoff primaries?**
- Above the upper cutoff almost all particles are primary GCR. For satellite observations, particles arriving from high zenith angles may be albedo particles generated from the interaction of a high energy particle with a nucleus in the high atmosphere.

QUESTIONS ASKED

- **Are geomagnetic cutoffs above 0.5 GV stable with time during quiescent conditions?**
- There are minor daily variations between 0.5 and ~2.0 GV.
- Over a long time period (years) the secular variation must be considered. This is a function of specific location.

QUESTIONS ASKED

- **Can secondary particles accelerated by the CME shock be confused as primary particles?**
- The shock accelerates the ambient cosmic ray particle flux. If there are solar particles in the ambient flux at the same time, these particles are also accelerated.

Suggestions for the Analysis of precise measurements

- To analyze precise measurements you need the following:
- Cutoff rigidity at the time of measurement for the direction of the particle
  - Function of geomagnetic conditions and, to a lesser extent, the geomagnetic field epoch.
  - For geomagnetic field model tracing, a model of the magnetosphere including a high order internal field is recommended.

MAHALO NUI LOA FOR LISTENING

HAWAII THE LAND OF THE RAINBOWS