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Some of the Terrestrial Effects of AR 5395

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Overview of AR 5395

Active Region 5395 was extraordinary for both its flare production for a complete disk transit and for one of the largest geomagnetic storms on record.

By any measure, Active Region 5395 was a spectacular flare producer. The Space Environment Services Center classifies peak flare intensity by both the peak flux in the 1-8A X-ray band and optically by peak Hα intensity and area. Routine measurement of full disk X-ray fluxes began in 1974. A simple measure of the flare productivity of an active region is to sum the peak X-ray intensities of the flares observed from that region. Using that measure, figure 1 illustrates the "top ten" flare producing regions since 1974 and the smoothed sunspot number during that period. Active Region 5395 was by far the most prolific X-ray flare producer during the last 15 years. Additionally, two of the larger flares (06 and 10 March) were remarkable in that their complete X-ray durations approached 24 hours. Figure 2 illustrates the X-ray flare activity during the disk transit of Active Region 5395. A total of 11 class X and 48 class M flares were observed.

A moderate intensity solar proton event (at particle energies greater than 10 MeV) was detected by NOAA geosynchronous sensors beginning at 08/1735UT. It decayed below event threshold near 14/1135UT and began again at 17/1855UT due to a large flare from Active Region 5395 while in the western hemisphere. This final near earth proton event finally ended near 20/1200UT.

The great geomagnetic storm of 13-14 March is attributed to a long duration X4/3B flare from Active Region 5395 which occurred at 10/1922UT from N31E22. Geomagnetic disturbances are measured and defined by several methods.

One classical measure of storm conditions is the three hourly K index. The K index is a measure of the maximum deflection of the intensity or direction of the geomagnetic field minus the normal quiet day variations. K indices are quasi-logarithmic and range in value from 0-9 with a K of nine denoting the most severe geomagnetic storm conditions. The eight daily K indices form the basis for the daily A index or other time scale indices.

The Institut fuer Geophysik in Gottingen, Germany calculates a daily A "planetary" index of geomagnetic conditions from 13 magnetic observatories located near the 50th geomagnetic latitude. This A index for 13 March was 246 - the second largest on record since 1932 when the data series began. The largest daily value in this record occurred on 13 November 1960 at an A index of 280.

A longer measure of geomagnetic disturbances is the aa index. The Institut de Physique du Globe de Paris derives this 12 hour index from the K indices of two antipodal magnetic observatories, and has done so since 1868. In that record, the 13 March storm ties with the 13 November 1960 storm at a value of 462. This value is the third largest in that record. The highest aa values were 546 on 25 September 1909 and 477 on 18 September 1941. By these and the other various measures of geomagnetic activity, the storm of 13 March 1989 from Active Region 5395 was extraordinary - easily the most severe in almost 30 years.

Some Specific Terrestrial System Effects from AR 5395

Radio propagation suffered severely during the transit of Active Region 5395 from 06-20 March 1989. During X-ray flares of class M or X peak flux, short wave (3-30 MHz) transmissions in or through the daylit hemisphere can experience complete fadeout due to increased ionization in the Earth's ionosphere. This occurred almost 60 times due to flare activity from Active Region 5395. Complete outages in excess of 12 hours were experienced during the great flares of 06 and 10 March.

During the geomagnetic storm of 13-14 March, high frequency communications were all but absent. This is due to signal penetration through the ionosphere due to auroral electron precipitation and dynamic compositional storm effects (Figure 3). Inversely, VHF (30-300MHz) signals were enhanced by "auroral E" propagation where auroral charged particle precipitation increases the electron content at low altitudes.

The disk transit of Active Region 5395 occurred near the vernal equinox. This resulted in severe radio noise interference between geosynchronous satellites and ground stations when the sun was within the field of view of the antenna and a flare was in progress. This noise interfered with transmissions from some communications satellites and for a time interrupted cloud image transmissions from the nation's weather satellites.

Satellite operators experienced other system effects during the great magnetic storm of 13-14 March. During geomagnetic storms, the neutral atmosphere is heated increasing the drag on orbiting spacecraft below approximately 1000 km altitude. The result is in track and cross track errors in spacecraft location from that modeled and used by spacecraft operators. Since nearly every orbital object has a unique shape, composition, and cross section, the drag effect is unique for each. Figure 4 illustrates the in and cross track errors experienced by the OSCAR series of navigational satellites during the 13-14 March storm. Accurate satellite location to less than 30 meters is required to derive accurate terrestrial locations from navigation satellites. During the storm, all OSCAR satellites were taken out of service for between a few days to a week for the lowest altitude spacecraft.

The U. S. Air Force and U. S. Navy routinely monitor the position of orbiting objects. Figure 5 illustrates the number of uncorrelated targets tracked by the Navy (over 5000) resulting from tracking errors due to the March geomagnetic storm. Each of these objects had to be reidentified.

The NOAA TIROS weather satellites experienced another problem related to increased atmospheric drag. Momentum wheels are the primary method used to orient these spacecraft. During the severe geomagnetic storm, the wheels spun up to design tolerance in an attempt to maintain attitude control (figure 5). Emergency backup systems engaged and control was maintained. If the storm had continued another 24 hours, control could have been lost.

The Space Shuttle was aloft during the March storm. The primary mission was the deployment of a TDRS communications satellite. The TDRS traverse to geosynchronous altitude was difficult with attitude control a serious problem. Ground rules for the subsequent launch of the Magellan spacecraft were developed to not begin its interplanetary flight during such conditions. The Shuttle itself experienced drag approximately 15% greater than on previous flights. Continual updates were required to ensure uninterrupted communications and accurate tracking.

Probably the most severe and publicly known effect of the 13-14 March storm was the Quebec power failure. During storm conditions, the fluctuating magnetic field induces currents in long conductors such and pipe lines and power lines. The fundamental period of geomagnetically induced currents (GIC) is on the order of several minutes and quasi dc compared to the normal 60 Hz or 50 Hz power grid frequency. This leads to half- cycle saturation of power transformers due to simultaneous ac and dc excitation, system voltage and frequency excursions, and tripping of protective relays. At 2:45 am local time on 13 March, Hydro-Quebec, Montreal, Canada suffered a system wide blackout and more than nine hours were required to restore service. At nearly the same moment there was also a voltage loss on half a dozen power distribution lines in middle and southern Sweden. Many other power systems experienced significant transmission anomalies but maintained service.

This brief overview, with some specific examples, is intended to illustrate only some of the more dramatic terrestrial effects resulting from flare activity in Active Region 5395. Material was gathered from several sources, especially from a presentation to the AGU in May, 1989 by J. A. Joselyn.

NOAA DATA AVAILABLE FROM THE NATIONAL GEOPHYSICAL DATA CENTER ON THE DISK TRANSIT OF ACTIVE REGION 5395

1. Continuous (3 second resolution) full disk X-ray fluxes in the 1-8A and .5-4A bands.
2. Continuous (5 minute resolution) energetic particle fluxes.
3. Selected imagery of Active Region 5395 in H-alpha and white light from the Holloman, New Mexico and Learmonth, Australia SOON observatories. Spatial resolution approximately .5 arcsec/pixel in 512 x 512 format.
4. Continuous (to one minute resolution) geomagnetic field measurements and indices.

USAF DATA AVAILABLE FROM THE NATIONAL GEOPHYSICAL DATA CENTER ON THE DISK TRANSIT OF ACTIVE REGION 5395

1. 35mm film patrol imagery from 5 SOON sites.
2. Regional magnetograms (5 arcsec resolution - several/day).
3. Radio burst (discrete and swept frequency) profiles.
4. Video of selected flares observed by the Holloman Observatory.

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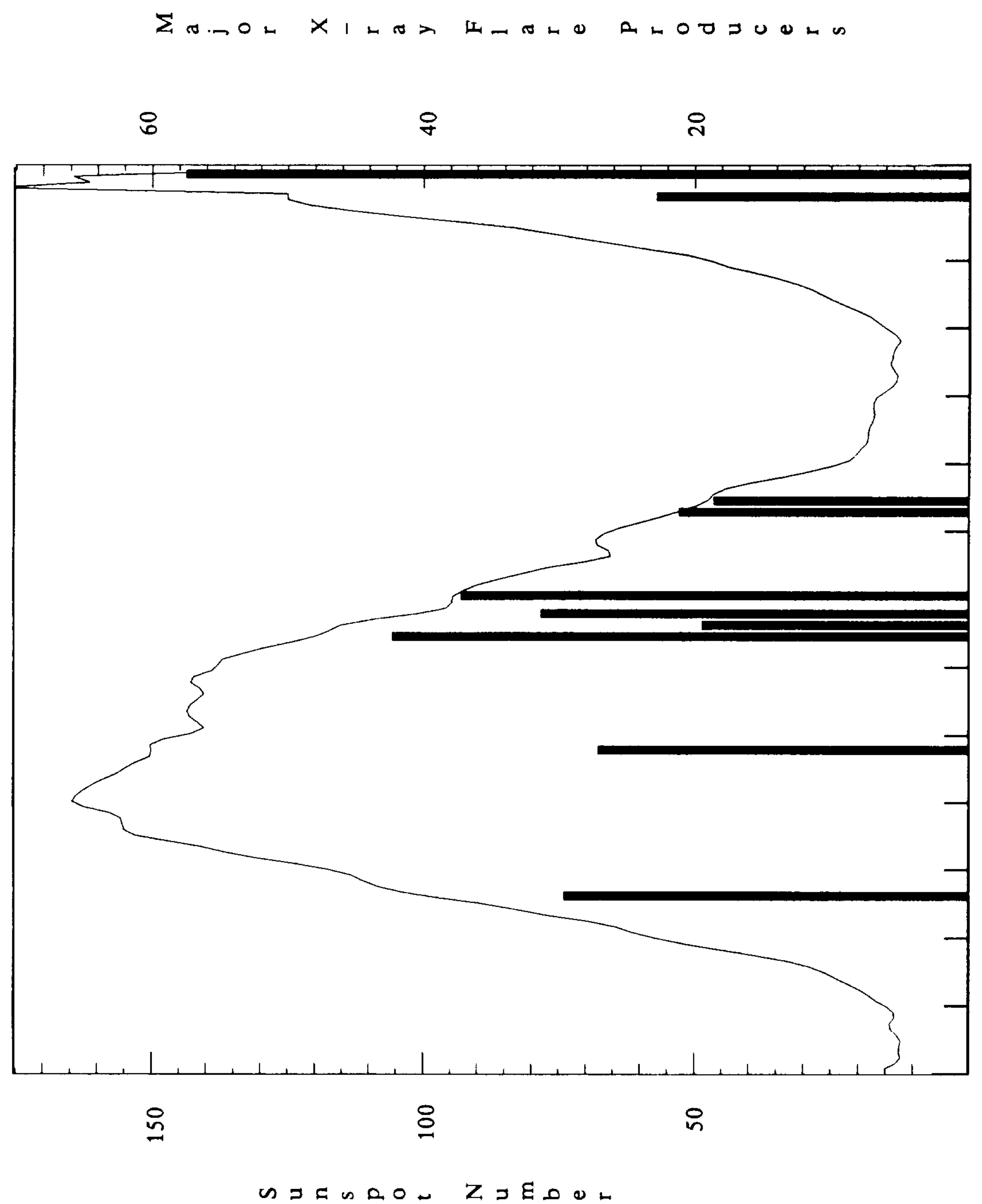

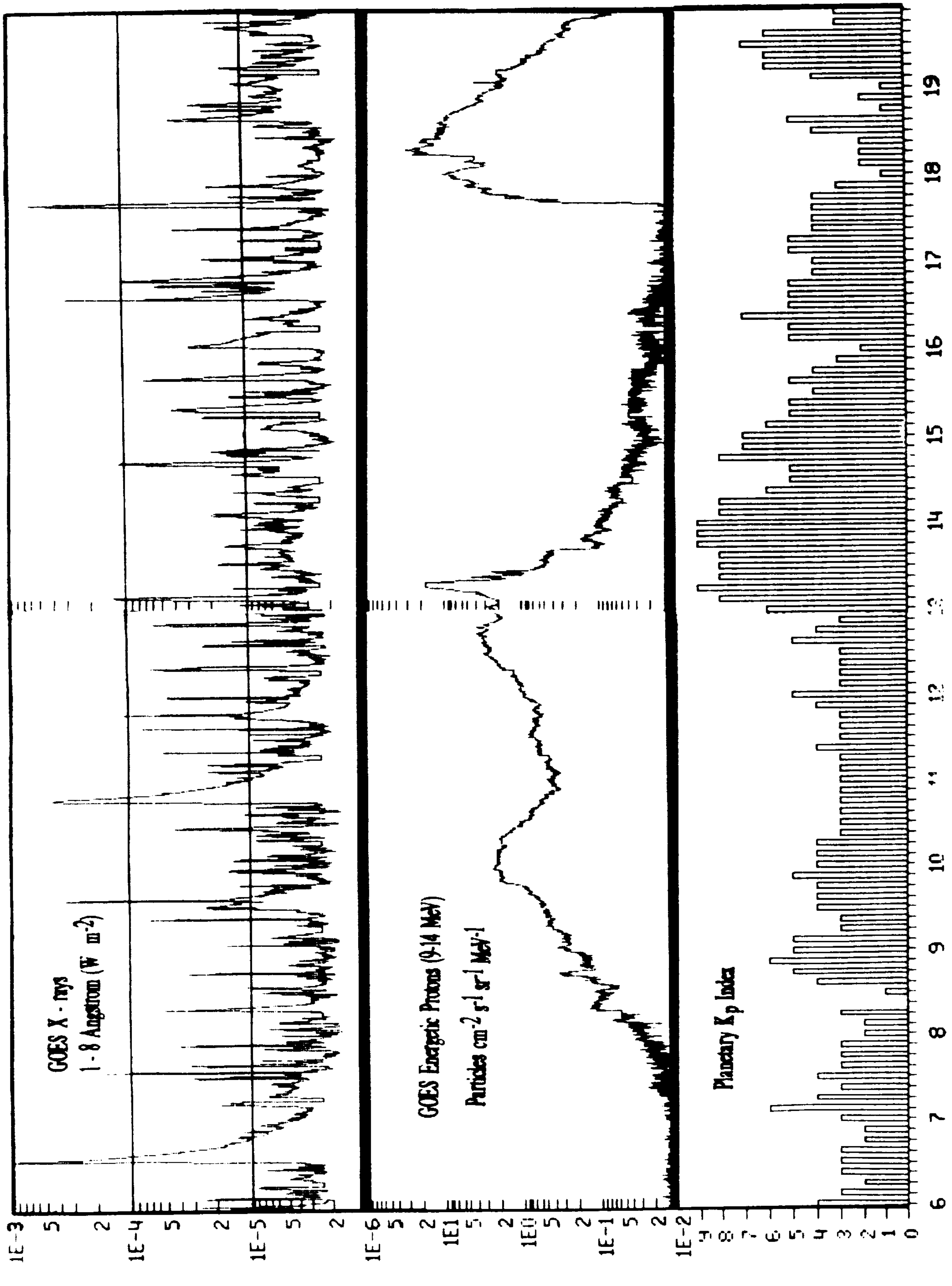

GOES X - rays
1 - 8 Angstrom (W m-2)
GOES Energetic Protons (9-14 MeV)
Particles cm-2 sr-1 s-1 MeV-1
Planetary Kp Index
1E-3
1E-4
1E-5
1E-6
1E1
1E0
1E-1
1E-2
6
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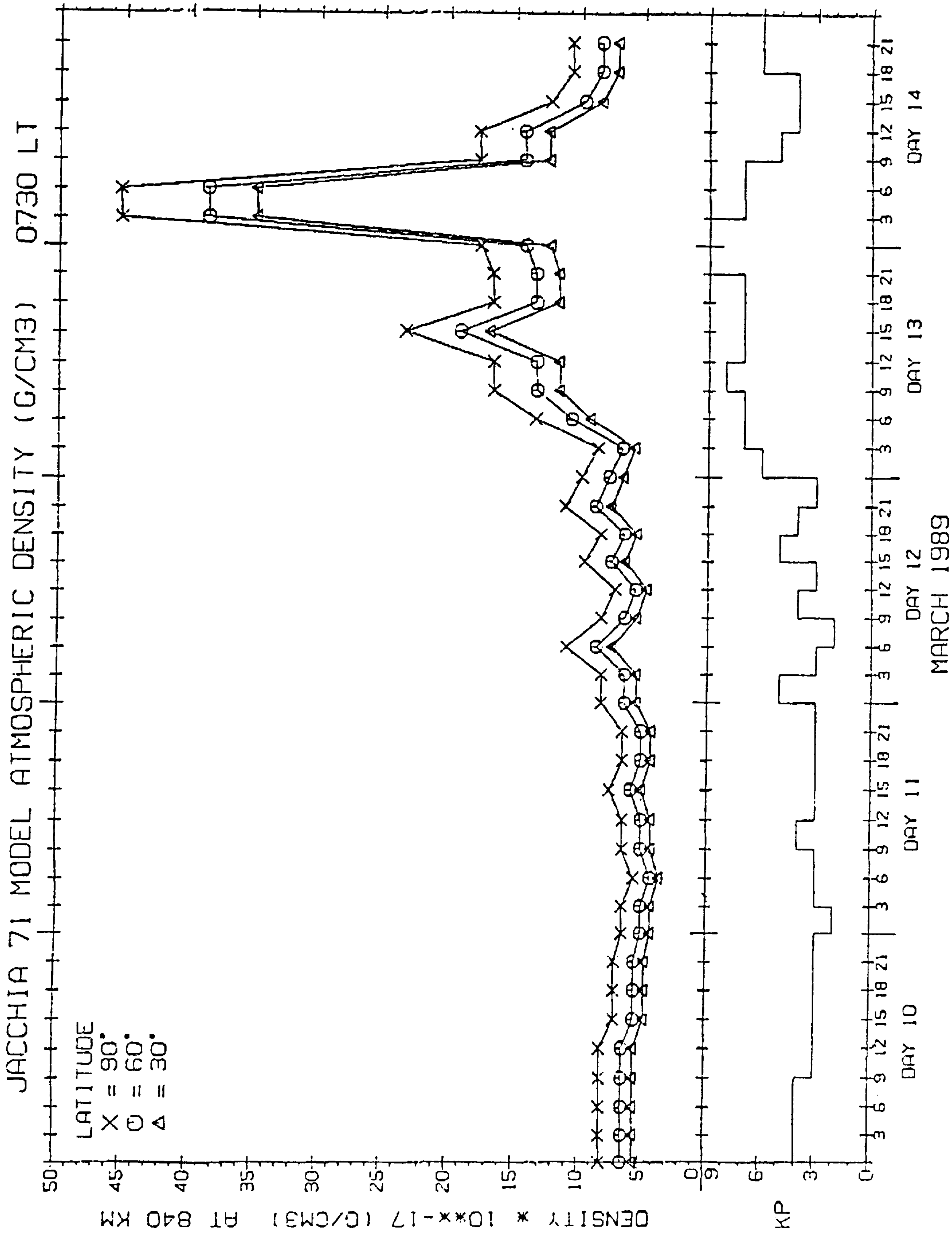
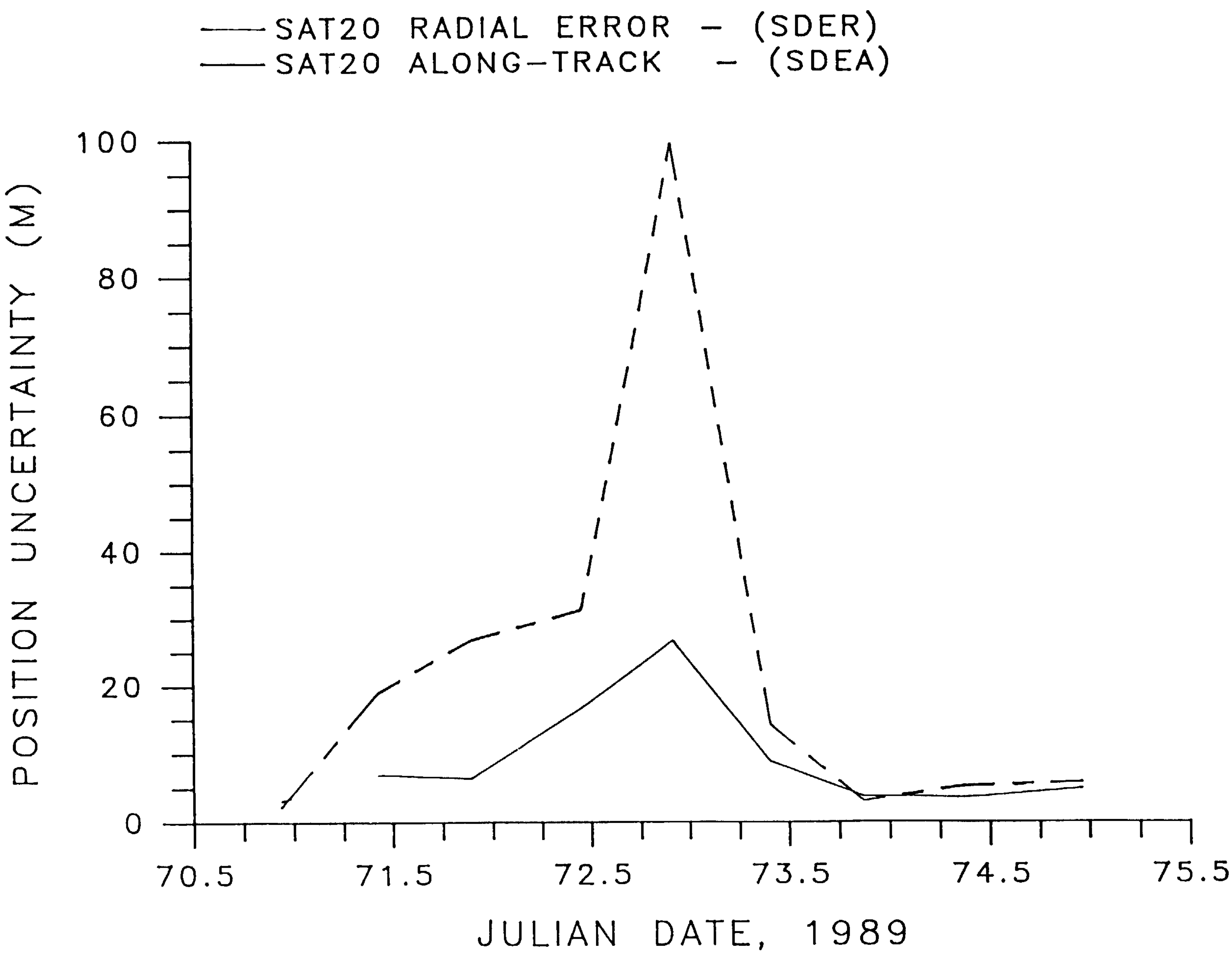
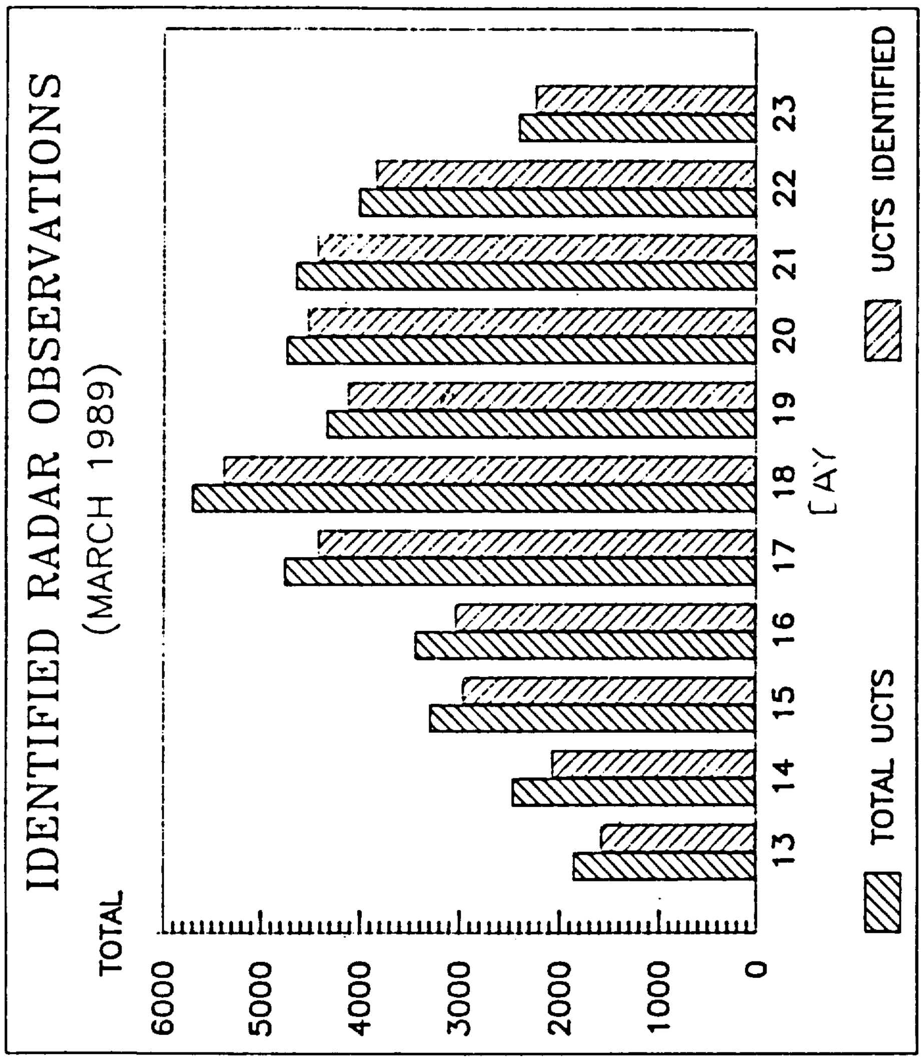
March 1989


JACCHIA 71 MODEL ATMOSPHERIC DENSITY (G/CM3) 0730 LT
LATITUDE
X = 90°
Θ = 60°
Δ = 30°
DENSITY * 10**-17 (G/CM3) AT 840 KM
KP
DAY 10
DAY 11
DAY 12
DAY 13
DAY 14
MARCH 1989

13 MAR89 SOLAR FLARE – RMS POSITION ERROR




IDENTIFIED RADAR OBSERVATIONS
(MARCH 1989)
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3000
2000
1000
0
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19
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22
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TOTAL UCTS
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