NOAA/TIROS AND GOES OBSERVATIONS OF GALACTIC AND SOLAR COSMIC RAYS OVER A SOLAR CYCLE

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ABSTRACT

Correlations between solar activity and atmospheric processes have been investigated for more than 30 years, and the reality of the strong correlations found has been well accepted. However, it remains problematic to establish mechanisms capable of coupling the physical manifestations of solar variability to the lower atmosphere. There has been to date a lack of long-term satellite measurements of particles of sufficient energy to penetrate the Earth's atmosphere. The NOAA Space Environment Laboratory has maintained energetic particle detectors on board both the NOAA/TIROS and GOES series of satellites. These instruments monitor the flux of energetic protons to energies greater than about 800 MeV. Measurement of particles above 350 MeV began October 1978, and continue to date. The instruments are briefly described, along with the current program to reduce the data. The goal is to provide a data base that will help to assess the significance of variations of atmospheric and ionospheric properties due to energetic particle precipitation.

INTRODUCTION

Many authors have proposed cosmic rays and their variations as the mediator or carrier of solar variability since Ney [1] examined the relationship between cosmic rays and the weather in 1959. The suggestion is attractive because there have been established correlations of atmospheric phenomena and cosmic ray variations on time scales ranging from days, through solar cycles, to centuries.[2,3] Recent studies by Labitzke [4] and Labitzke and van Loon, [5] demonstrating the solar cycle relationship of northern hemisphere stratospheric temperatures and pressures that depend on the phase of quasi-biennial oscillation of the equatorial stratospheric winds, have served to stimulate inquiry in this area. In a recent paper, Tinsley et al. [6] address the hypothesis that cosmic rays and solar energetic particles of energy 100 to 1000 MeV are the principal mediators of solar variability. They conclude that the hypothesis is supported on at least two grounds: first, the mentioned close correlations on all three time scales (days, solar cycle, and century), and secondly, that opposite tropospheric responses are observed for Forbush decreases as for solar flare responses. They further note the lack of appropriate long-term measurements over this energy range. It is the purpose of this note to present the development of a data base of observations over this energy range extending back to 1978.

DATA RESOURCES

The Space Environment Laboratory (SEL) of the National Oceanic and Atmospheric Administration (NOAA) maintains monitoring instruments aboard both the GOES series of geosynchronous orbiting satellites, and the NOAA/TIROS series of low-altitude, Sun-synchronous, polar-orbiting satellites.

The Space Environment Monitor (SEM) package on the GOES satellites is comprised of three sensor assemblies: the X-Ray Sensor (XRS) which measures the whole-Sun X-Ray emission between .5 and 8 Angstrom, a Magnetometer assembly which measures the local vector magnetic field, and the Energetic Particle Sensor (EPS) which measures the energetic particle population at geostationary orbit. The EPS consists of several silicon detector assemblies which initially covered the range from .6 MeV to several hundred MeV. Beginning with GOES-4 in 1982, a Cerenkov Telescope called the High Energy Proton and Alpha Detector (HEPAD), was added. However, satellite and instrument failures prevented HEPAD data acquisition until the launch of GOES-6 in 1983. The HEPAD measures protons in an energy range from about 370 to greater than 800 MeV, and with less certainty, alpha particles in the range from about 600 to greater than 850 MeV/nucleon. The half angle acceptance cone of the HEPAD is 34°, with a geometric factor of about .9 cm^2 sr. The GOES spacecraft are spinning at about 100 rpm, with their rotation axis approximately parallel to the Earth'. Since the HEPAD looks out orthoganally to the rotation axis and the spin rate is much higher than the data accumulation rate (4 s.), it represents a reasonably omnidirectional detector, covering the equatorial half of the unit sphere.

The energetic particle instruments of the NOAA/TIROS series also consist of several detector assemblies: the Total Energy Detector (TED) measures the differential and total energy flux of .3 to 20 keV electrons and protons, the Energetic Particle Sensor (EPS) assembly contains independent particle telescopes separately covering the range from >30 to >300 keV for electrons and the range of 30 keV to > 2.5 MeV for protons, and a set of large aperture silicon detectors for the energy range of >16 MeV to >80 MeV. Further, the TIROS-N and NOAA-6 satellites EPS also contain a HEPAD that is nominally identical to that of the GOES (EPS), except that it looks radially outward from the Earth. These instruments have been described by Seale and Bushnell[7]. A brief summary of the data coverage of these instruments is given in Table I.

Data from these instruments are received by the SEL's Space Environment Services Center in real or near-real time, and a synopsis of some of the data is provided in the SESC weekly publication, *Preliminary Report and Forecast of Solar Geophysical Data*. More complete data sets are archived

Table I
Summary Energetic Particle Data Description

GOES EPS		
Protons:	7 Differential energy channels	0.6 < E < 500 MeV
Alphas:	6 Differential energy channels	3.8 < E < 500 MeV
Electrons:	1 Integral channel	E > 2 MeV
NOAA/TIROS TED		
Protons:	11 Differential energy channels	.30 < E < 20 keV
Electrons:	3 Integral electron channels	.30 < E < 20 keV
NOAA/TIROS MEPED		
Protons:	8 Differential energy channels	.03 < E < 215 MeV
Electrons:	11 Differential energy channels	>30, >100, >300 keV
HEPAD (Common to the GOES-6, TIROS-N, and NOAA-6 satellites)		
Protons:	3 Differential channels	370 < E < 800 MeV
	1 Integral channel	E > 800 MeV
Alphas:	1 Differential channel	600 < E < 800 MeV/n
	1 Integral channel	E > 800 MeV/n

with the National Geophysical Data Center, Boulder, Colorado for dissemination to the scientific community.

Satellite observation of energetic protons up to the order of 100 MeV have been available from the GOES sensors and from a number of other satellite data sets for a number of years. For example. Armstrong et al.[8] have presented a useful survey of interplanetary cosmic ray integral fluxes for the years 1963–1982, up to E >60 MeV. But corresponding long-term observations in the energy range encompassing those of solar cosmic ray ground-level events has been lacking. The HEPAD data emphasized here had not previously been available, and represent an extended data source in an energy regime of meteorological significance. Figure 1 illustrates the principal proton data availability from the sensors aboard the GOES and NOAA/TIROS satellites since the beginning of HEPAD data acquisition in November 1978.

DISCUSSION

Most studies concerning the relationship of galactic and solar energetic particles to atmospheric dynamics, chemistry, and meteorological phenomena have relied primarily upon data from Neutron Monitors. Such detectors have provided the only long-term monitoring of the Galactic Cosmic Ray flux, and its sporadic admixture of energetic solar particles. Unfortunately, Neutron Monitors principally monitor the energy range between 1 and 10 GeV and further represent relatively small angle detectors because of atmospheric collimation and geomagnetic field effects. Their calculated asymptotic cones of acceptance can be as small as 10°.[9] Neutron Monitor measurements represent a surrogate for the near-Earth energetic particle populations and their spectra in the energy range of 100–1000 MeV, the energy range most responsible for the ionization and its variation in the lower stratosphere and troposphere.[10] The GOES and NOAA/TIROS, for the first time, provides a consistent data base over this important energy range for the order of a solar cycle.

GOES-6 data for the geophysically active period from July through December 1989 have been reduced. In Figure 2, the hourly averages of the GOES-6 measurements of the integral fluxes >370 MeV and >800 MeV are compared to hourly pressure-corrected neutron monitor relative count rates from Deep River (Lat. 46.1° ; W. Long. 77.5° ; Cutoff = .6 GV) (National Geophysical Data Center, 1990), and Apatity (Lat. 67.3° ; E. Long. 33.2° ; Cutoff = 1.02 GV) (personal communication: M.A. Shea, 1990), for the period July 1 to December 31, 1990. Note that factor of 2–3 increases in the >370 MeV fluxes occurring on April 25 (Day 206), August 13 (Day 225), and November 15 (Day 319) are just discernable at Deep River or Apatity. These events represent a significant variation to tropospheric ionization rates. The hardest event of this period occurred on September 29 and 30 (Days 272,3), and it was reported[11] that this was the first time the red warning light of the Concorde SST dose-rate monitor had lit, indicating a rate in excess of 10 mrem/hr. There were seven Concorde flights on that day between Paris[11] or London[12] and the U.S. all of which reported total doses in excess of background levels.

Figure 3 compares the hourly neutron monitor rates as before for Deep River and Apatity with 5-minute averaged values of the >370 MeV and >800 MeV integral fluxes measured by GOES-6 on September 29 and 30, 1989. Additionally, the heavy dots on the lower panel (>800 MeV) denote the total doses reported from the dosimeters carried on the above-referenced Concorde flights on September 29. Their nominal flight altitude is about 59,000 ft (18 km, the upper troposphere). While it is fortuitous that the magnitude of the dosages approximate the >800 MeV flux, it is not fortuitous that the time profiles should be reasonably congruent. As noted previously, the ionization and its variation at tropospheric heights is dominated by the particle fluxes in the 100–1000 MeV energy range. It is concluded that the GOES and NOAA/TIROS instruments, particularly with the inclusion of the HEPAD, for the first time provides an appropriate record of galactic and solar energetic particle fluxes and their variation to more critically examine the variation of ionization of the lower atmosphere, and its relationship to the chemical, electrical and meteorological dynamics of Earth's atmosphere.

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12. Reported by Capt. Peter Horton, Concorde Flight Technical Manager, London Heathrow Airport, Hounslow, England, October 1989.

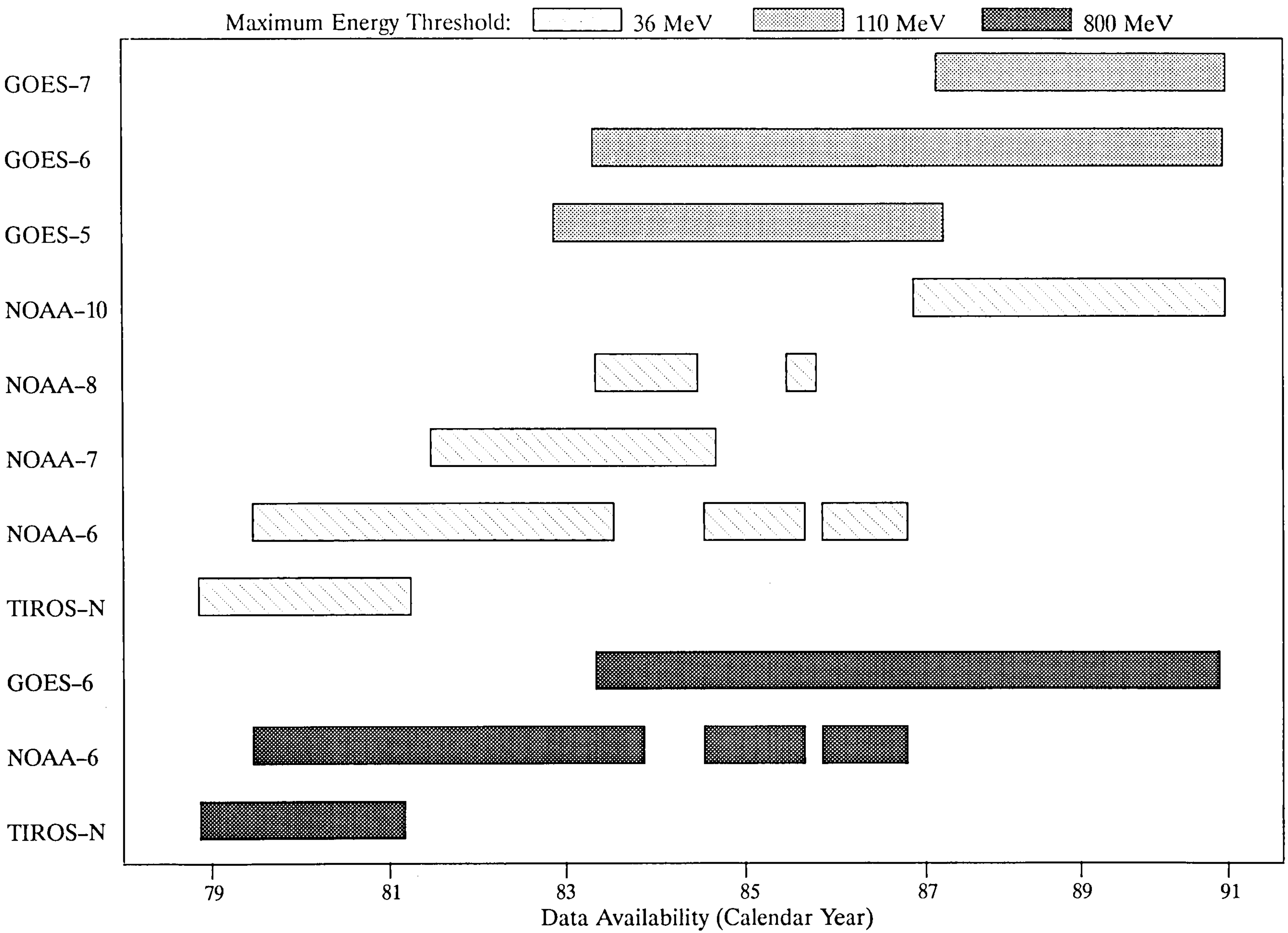

Figure 1. Bar graph of principal proton data availability from the detectors aboard the GOES and NOAA/TIROS satellites since October 1978, when HEPAD data collection began.

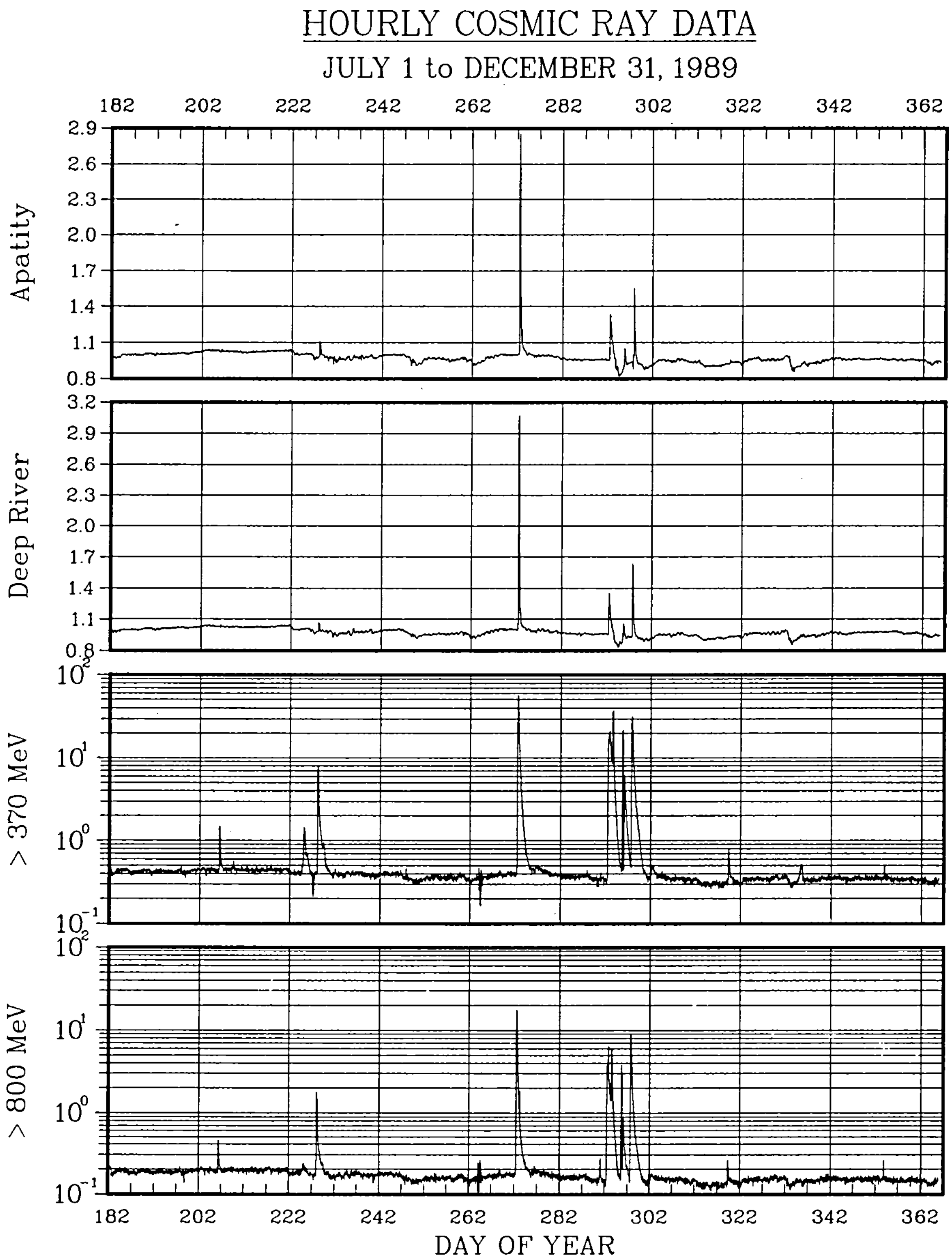

Figure 2. Hourly normalized data averages of the Deep River and Apatity Neutron Monitors with the corresponding hourly averages of the >370 MeV and >800 MeV integral proton fluxes (protons/cm^2 s sr) measured by the GOES-6 HEPAD for the period July 1 to December 31, 1989.

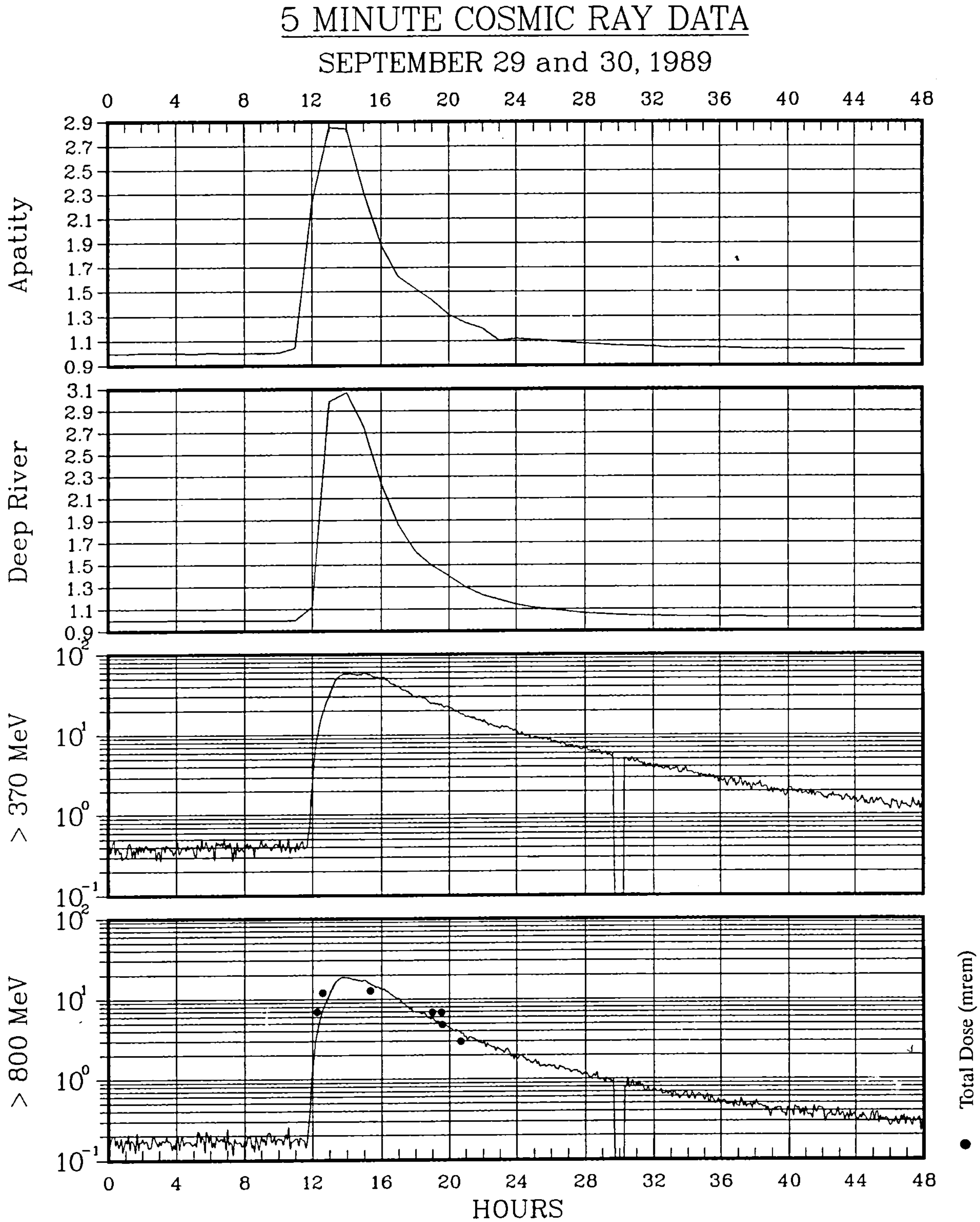

Figure 3. Hourly normalized data averages of the Deep River and Apatity Neutron Monitors with the corresponding 5-minute averages of the >370 MeV and >800 MeV integral proton fluxes (protons/cm² s sr) measured by the GOES-6 HEPAD for the solar cosmic ray event of September 29 and 30, 1989. The heavy dots in the figure indicate the total dose (mrem) measured by the Concorde SST's flights on September 29 (see text).