Energetic Electron Injection Signatures Observed by GPS at High Magnetic Latitudes

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ABSTRACT

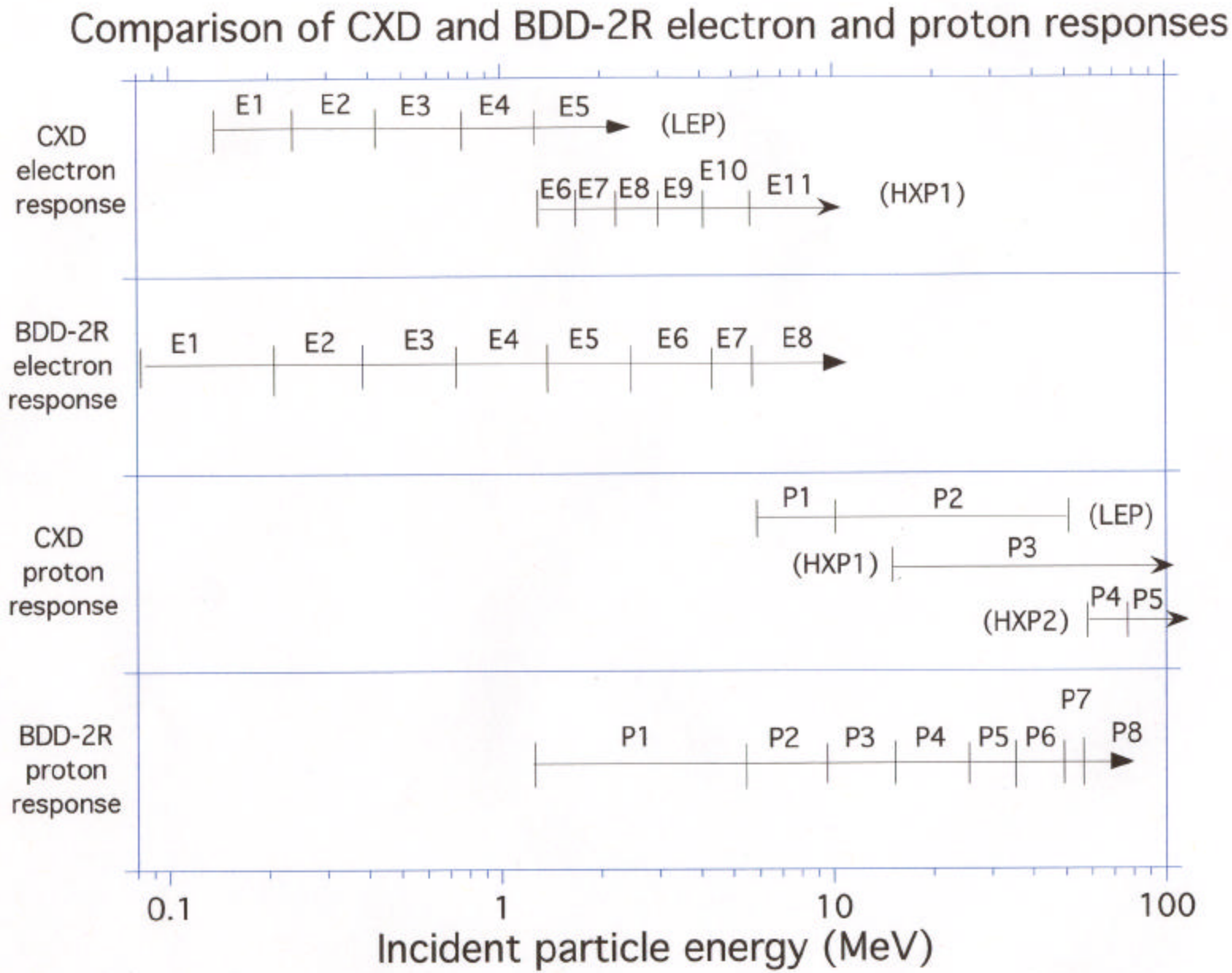
Energetic particle measurements continue to be expanded on the GPS constellation with the commissioning of two new instruments on recent GPS launches NS41 and NS54. These new instruments (BDD-IIR, CXD) now measure energetic electrons from ≈ 100 keV to several MeV, extending GPS capabilities beyond in situ monitoring of radiation dose received by satellite components, to now include sensitivity to a portion of the population responsible for spacecraft charging. Indeed, the lower energy channels respond to a range of energies commonly associated with substorm injections (≈ 20 to ≈ 300 keV). We report here on the first measurements of energetic electron injection signatures (> 100 keV) with these instruments, many of which occur outside the trapping boundary for these energies. We investigate the relationship of these high latitude injections to other injection observations on the LANL geosynchronous satellites, POLAR and CLUSTER, and to other traditional indicators of substorm activity.

INTRODUCTION

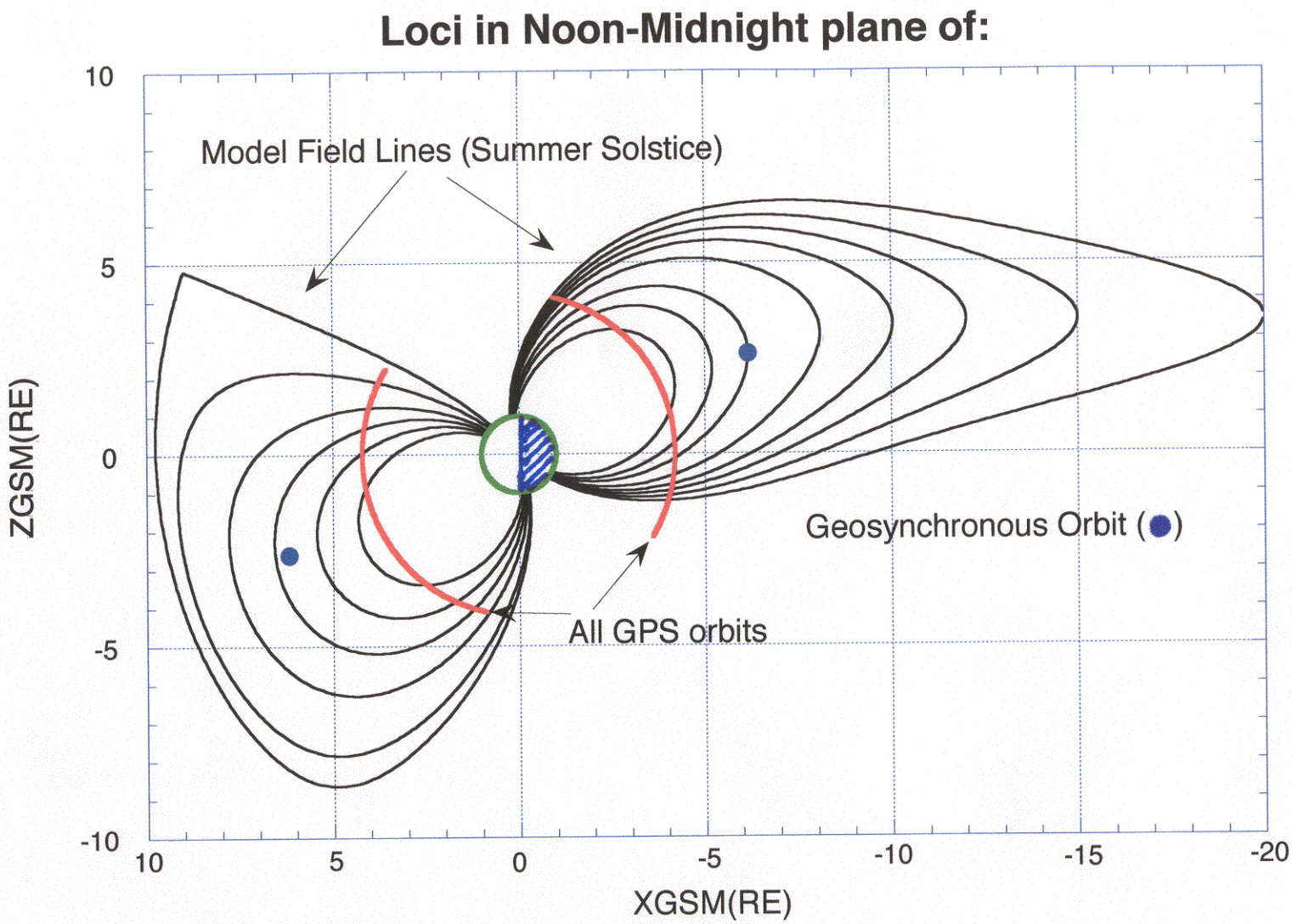
- 396 NS54 CXD injections identified for March through October, 2001

→ Both dispersive and nondispersive injections included
→ Classified by size
→ Local time and static(T89 model) L-value (L ~ 4 – 16) determined
→ Likelihood of detection vs injection location evaluated and tabulated
→ Correlation between larger injections and geosynchronous injections evaluated and graded by quality
→ Location of larger injections plotted and identified by correlation quality

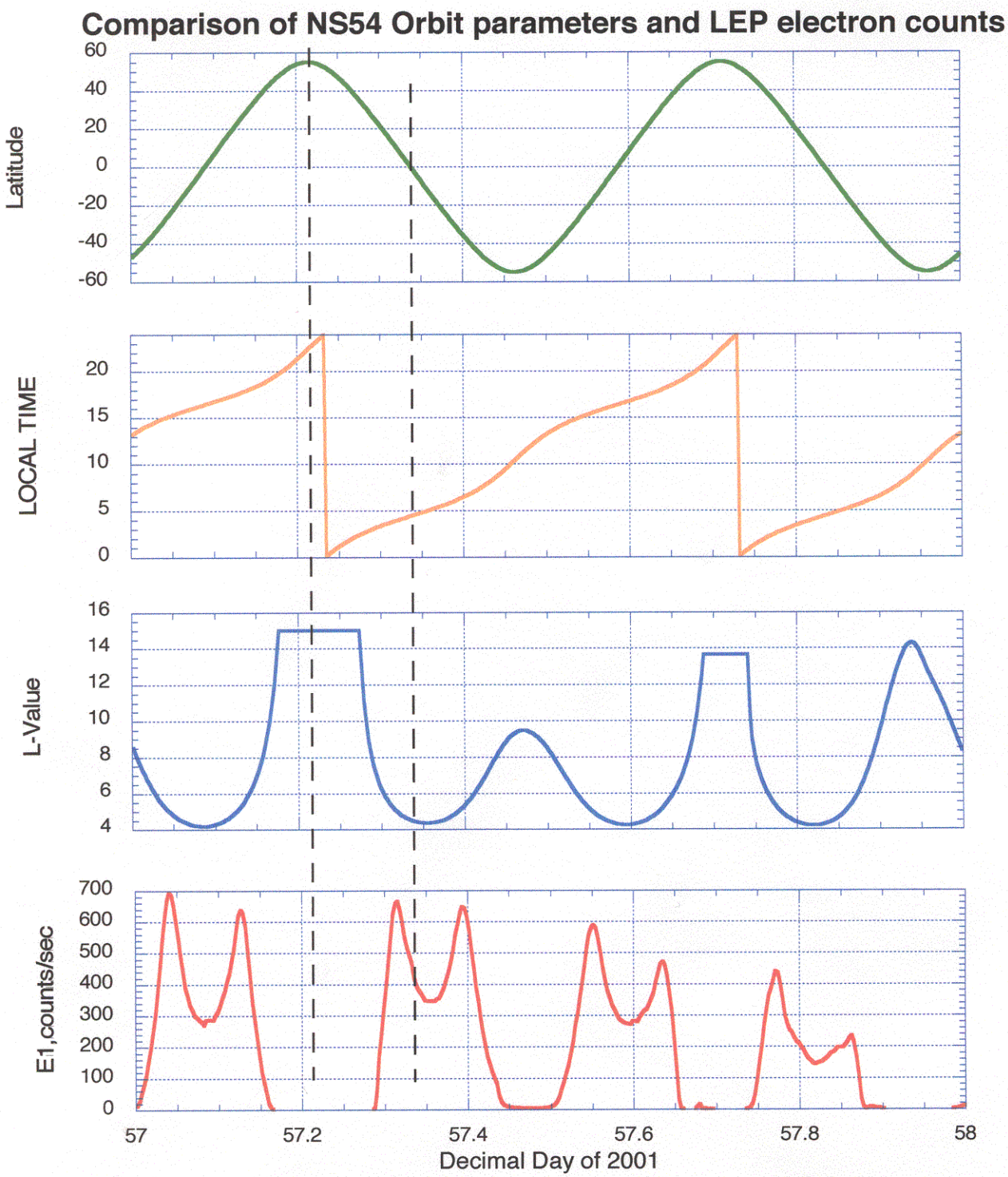
- Some examples of injection measurements on POLAR, CLUSTER, AND BDD-IIR on NS41 are also presented



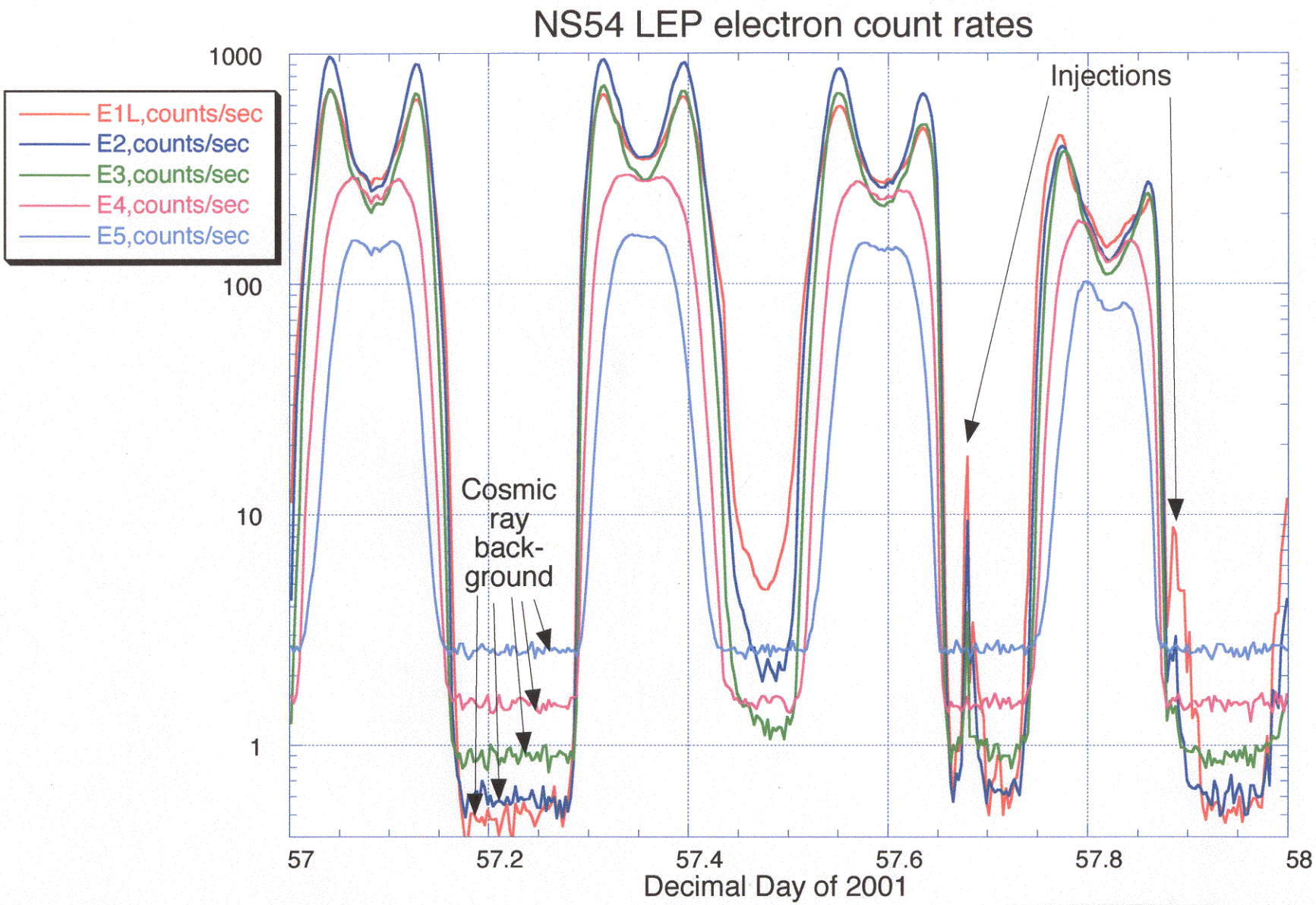
The BDD-2R instrument on NS41 and the CXD instruments (LEP, HXP1, HXP2) on NS54 cover similar ranges of incident electron and proton energies. The electron injections are observed chiefly in the low energy channels of the BDD-2R and the LEP.



The GPS orbit is circular of radius 4.2 R_E and inclined at an angle of 55 degrees to the geographic equator. Consequently, it intersects field lines that cross the magnetic equator over a wide range of distances from the earth.

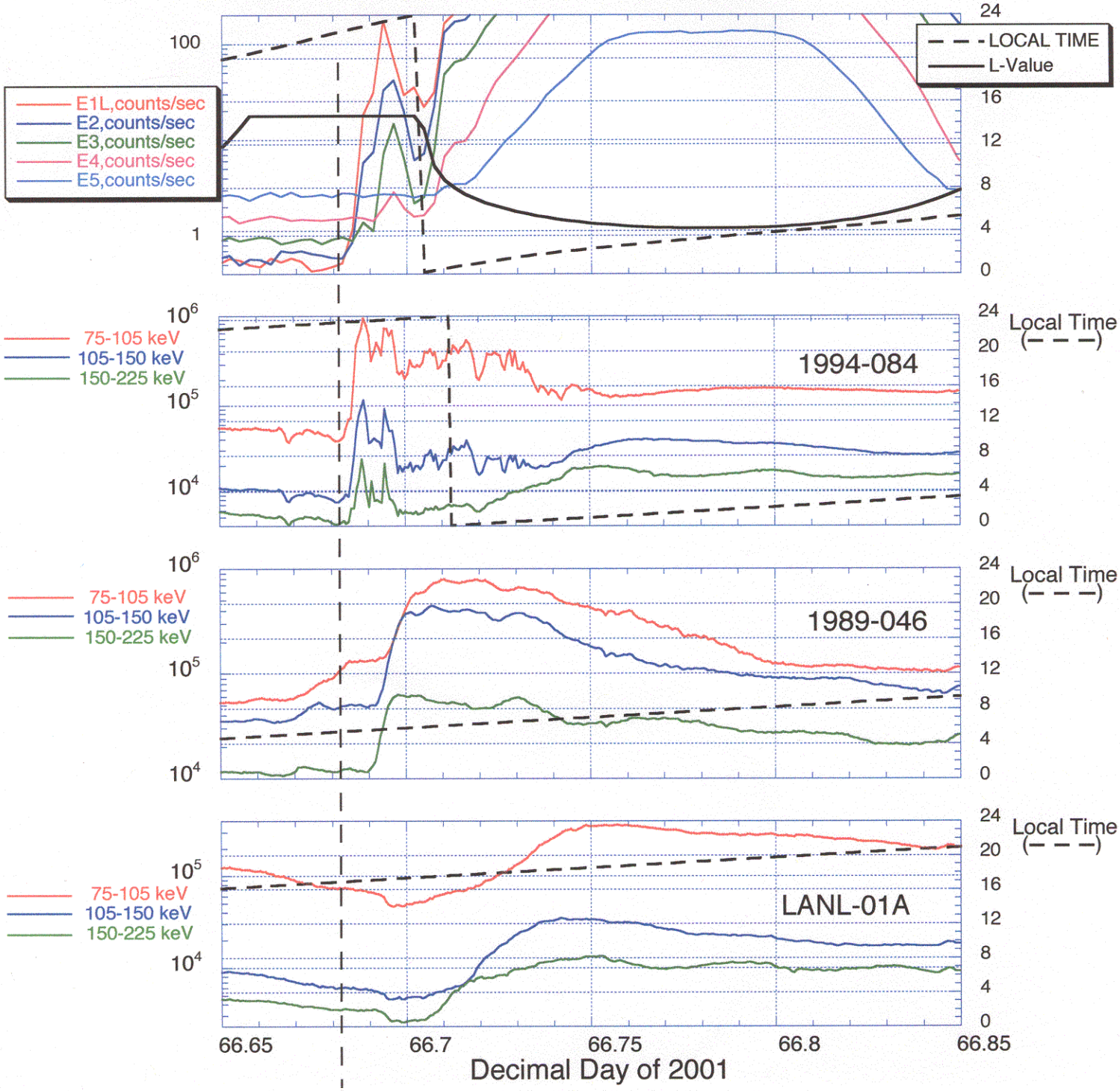


The GPS orbit has a period of 12 hours, so that it passes through the heart of the radiation belt four times per day. The model L-value of the satellite location is set to an upper bound wherever the model field line (Tsyganenko 1989) that passes through the satellite reaches farther than 18 R_E from the Earth.

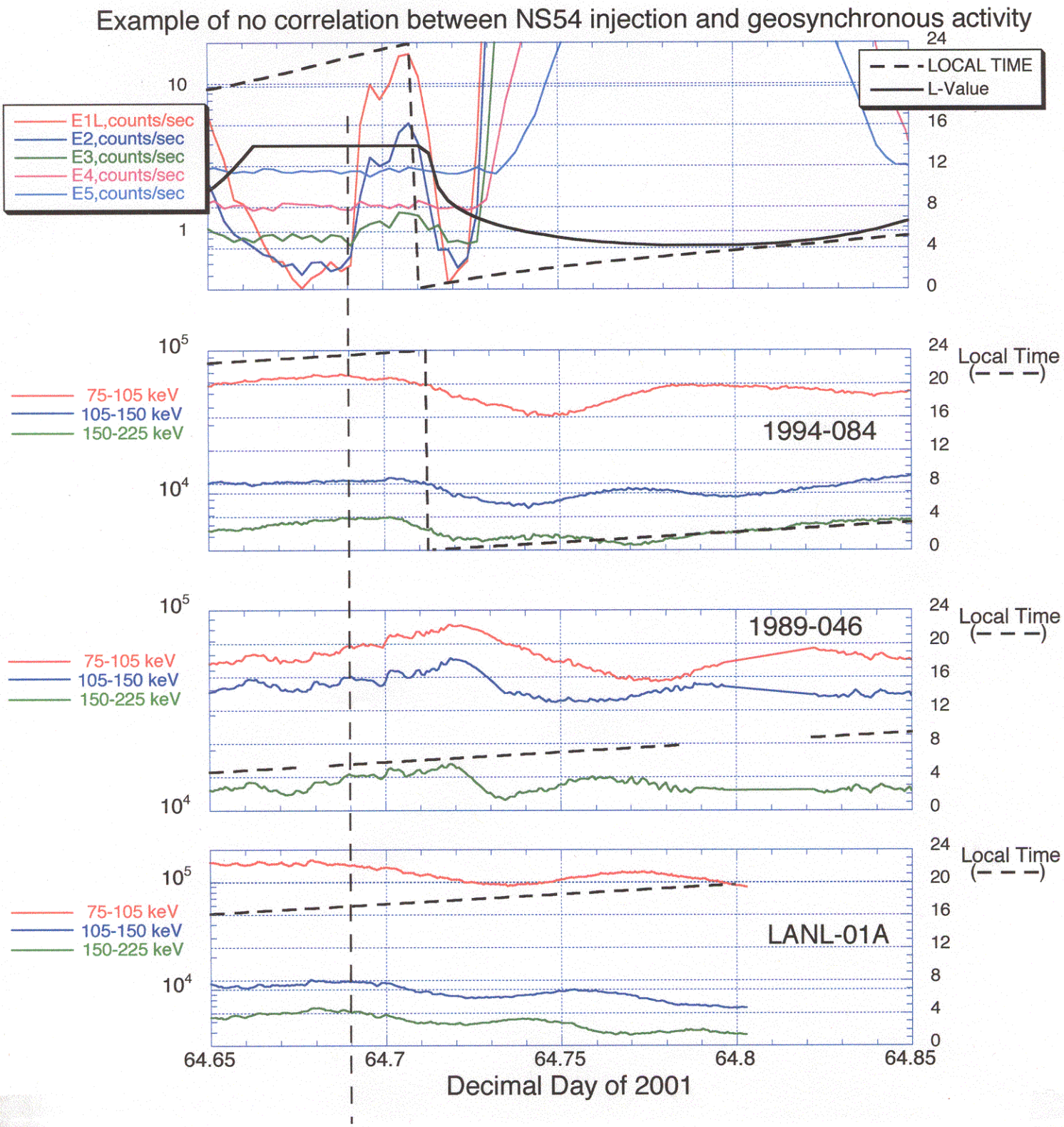


An example of one day's data collection on the low energy particle (LEP) sensor of CXD, showing two injections. On the average, about one injection per day is observed. (The double-humped radiation belt profile is observed whenever the maximum of the radiation belt, for a given energy channel, is further from the Earth than the satellite is when it crosses the magnetic equator.)

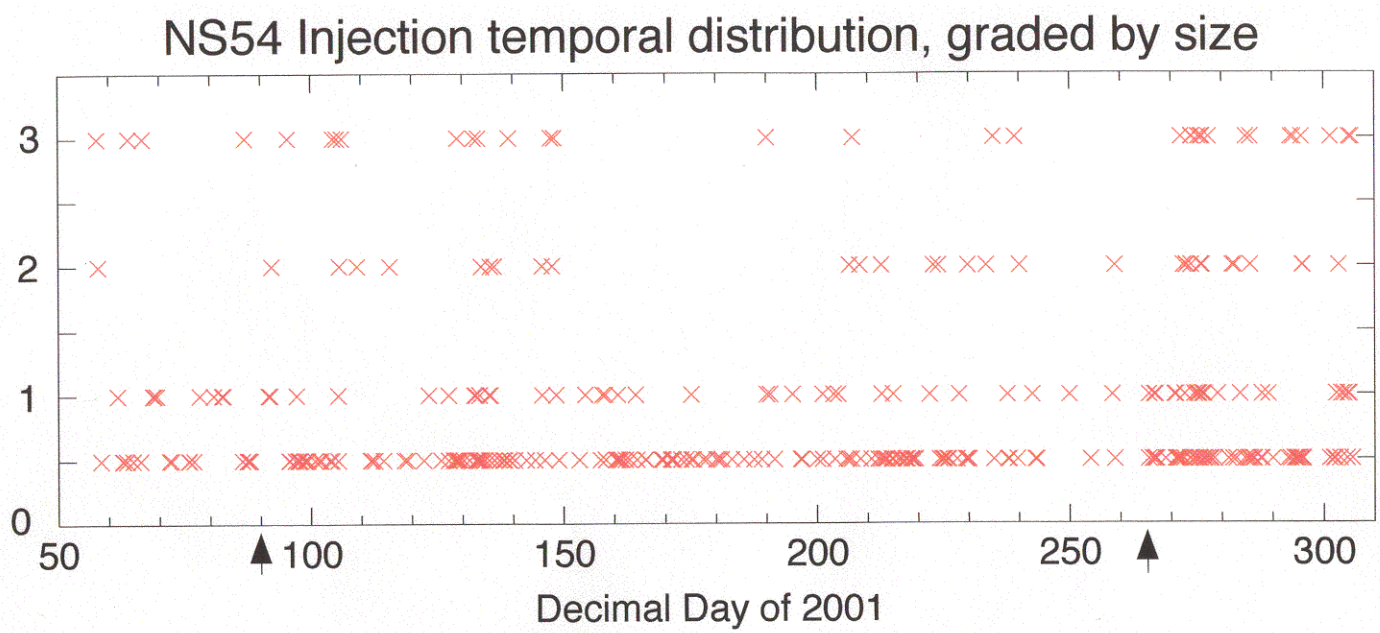
Example of good correlation of NS54 injection with geosynchronous injection



An example of good time correlation between an injection detected at NS54 and a confirmed substorm injection on three geosynchronous satellites. The energy-dispersed signals on the two geosynchronous satellites located away from local midnight confirm the substorm injection near local midnight. Note the near simultaneity of the injections on NS54 and 1994-084, even though NS54 is located on a high L field line.



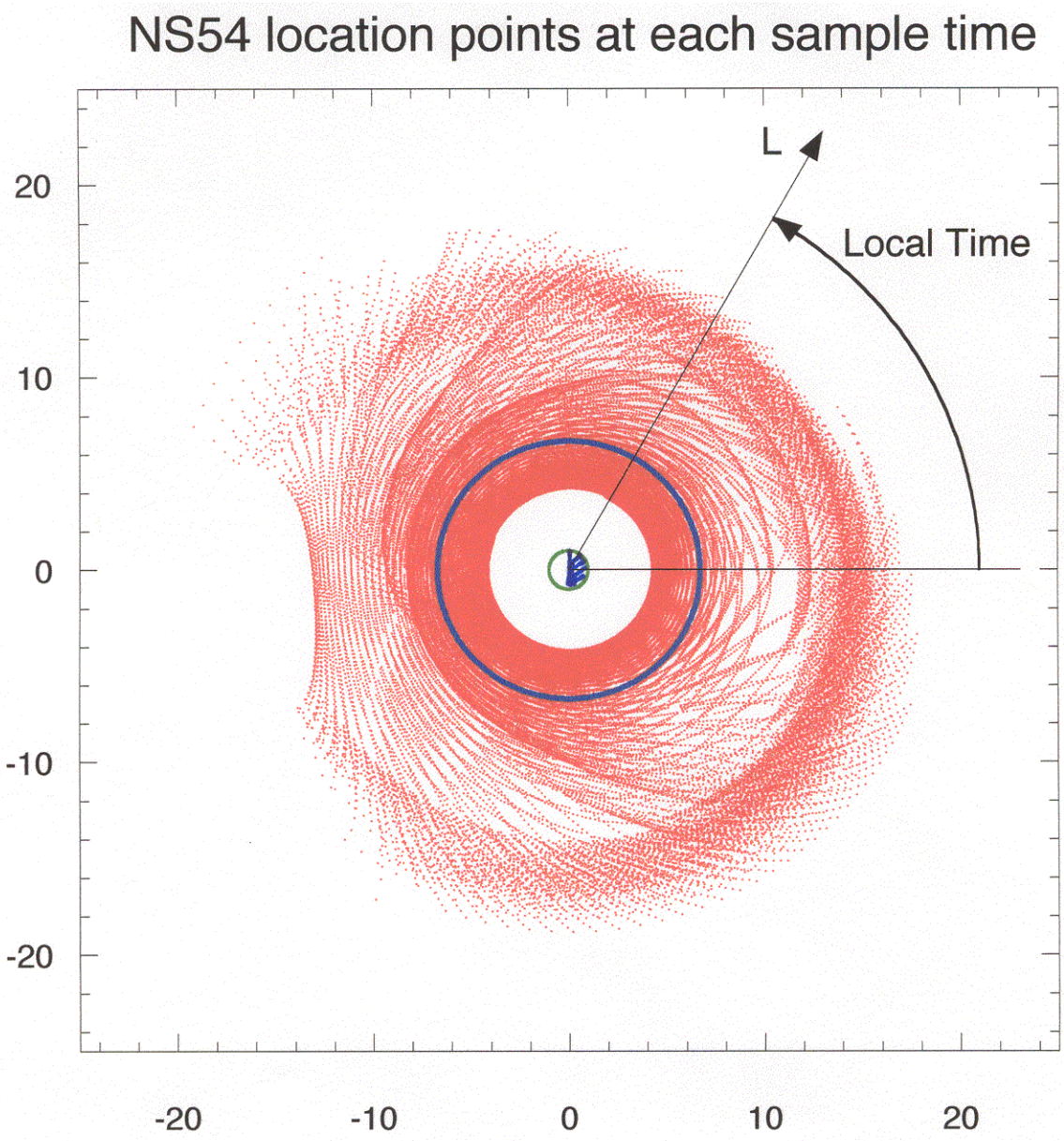
An example of no observed correlation between an injection detected at NS54 and activity at three geosynchronous satellites. It is possible that this injection did not propagate all the way to geosynchronous altitude, since it was detected on NS54 at L > 14.



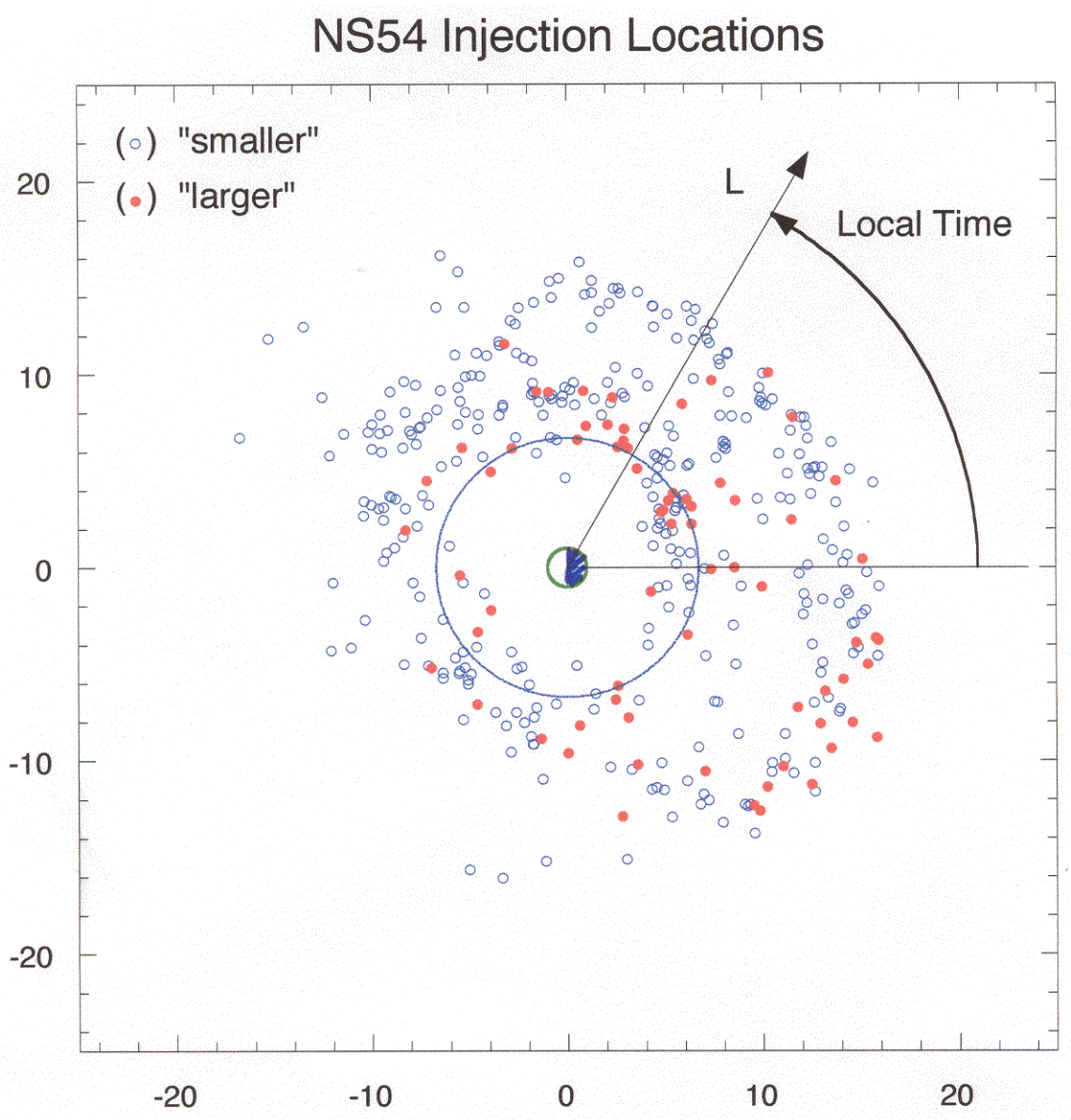
The "larger" injections, grades 2 and 3, are defined as having more than 5 counts/sec at their maximum in the LEP E1 channel, well above the cosmic ray background of 0.5 counts/sec in E1. The "smaller" injections, grades 0.5 and 1, are defined as having less than 5 counts/sec at their maximum, but must be clearly distinguishable above the statistical background fluctuations.

Unusual structures that are clearly distinguishable on the wings of the radiation belt profile are also labeled as injections for this study. These occur at the smaller L values, typically less than 8 to 10 on any given pass.

For the 254 days of this study 70 larger injections and 326 smaller injections were identified. Note that the larger injections occur more frequently around the equinoxes(see arrows on the plot), similar to substorm injections.



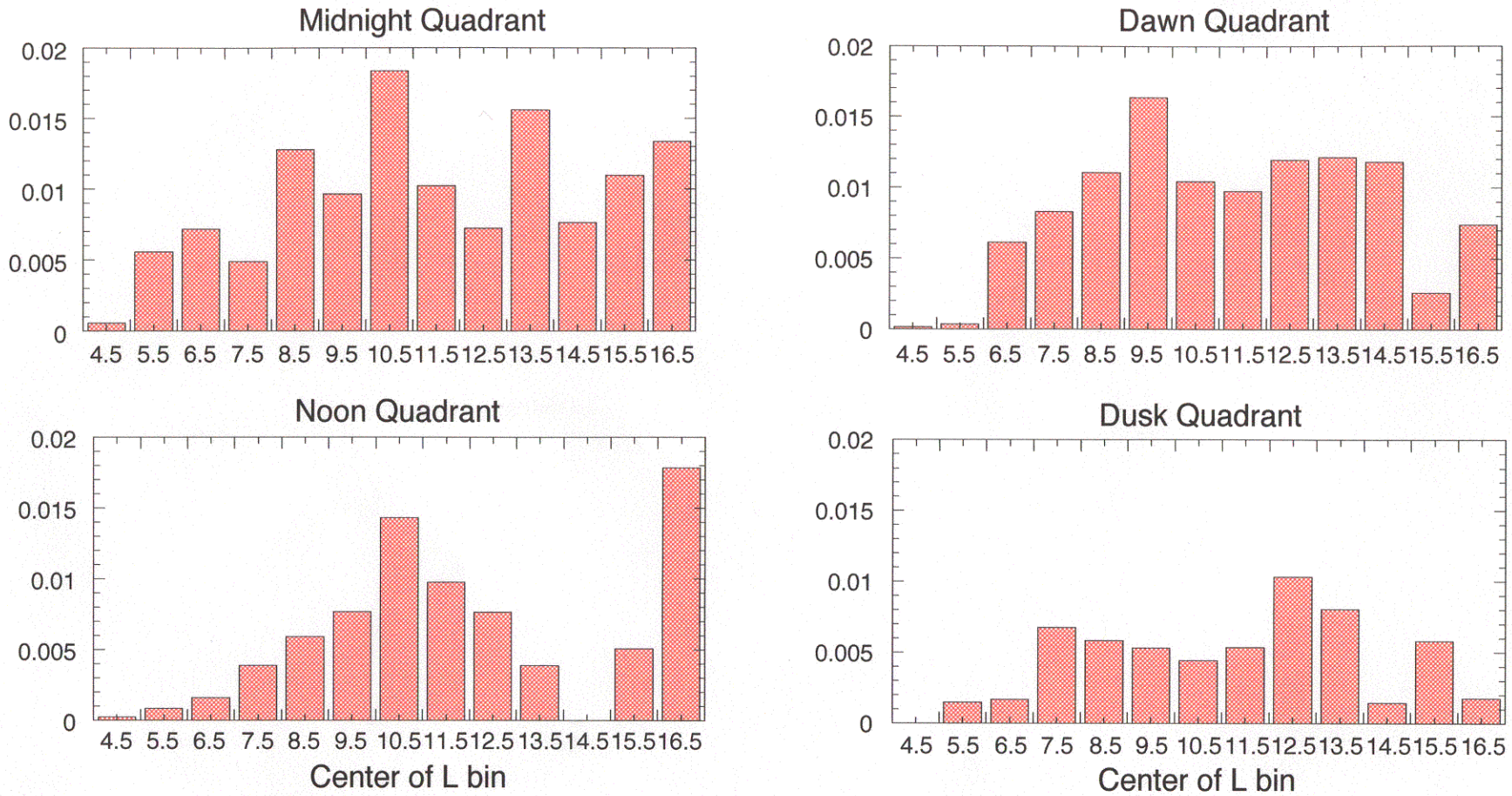
NS54 location at the time of each 4 minute sample for the 254 days of the March – October, 2001, period. The radial distance from the center of the Earth corresponds to the L value of the field line that passes through the satellite at the sample time. The geosynchronous orbit is indicated in blue.



Injections are detected out to the largest L-values of the satellite location and correlate to some degree with the likelihood for NS54 to be at that location (see previous figure).

Relative to the "smaller" injections the "larger" injections show some preference for occurrence at large L in the pre-midnight quadrant, and at small L in the post-midnight quadrant.

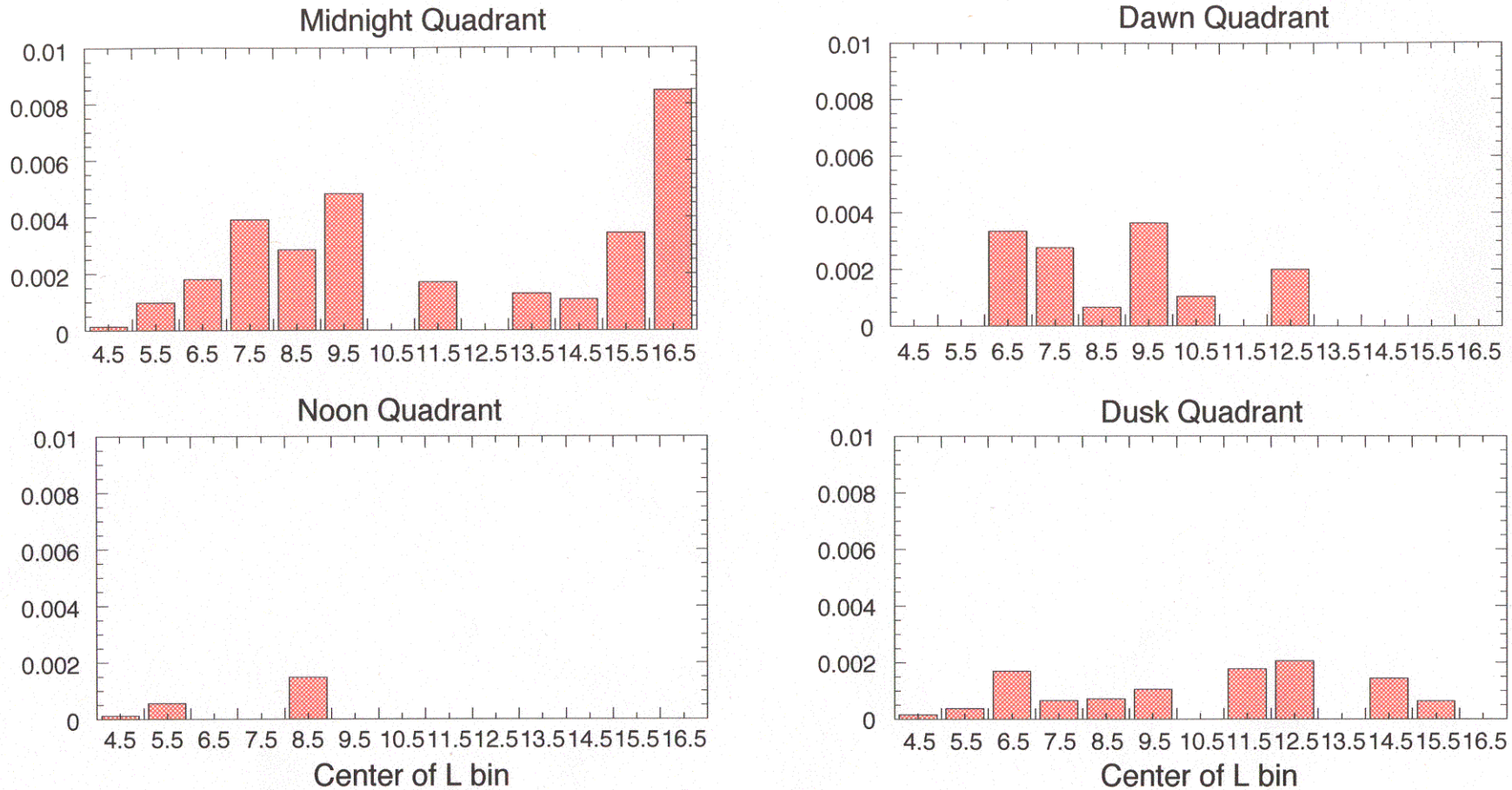
NS54 Injections (all grades) per Sample – Quadrant-resolved and Binned by L-value



For the midnight- and dawn-centered quadrants the probability of detecting an injection within the 4- minute measurement window increases with L up to the L bin center 8.5. Thereafter, it remains roughly constant at a level of about 0.01 out to the L bin center of 16.5, which corresponds to the approximate maximum extent in L of the NS54 orbit.

On average, it is about twice as likely to detect an injection (of any grade) in the midnight or dawn quadrants than it is in the noon or dusk quadrants.

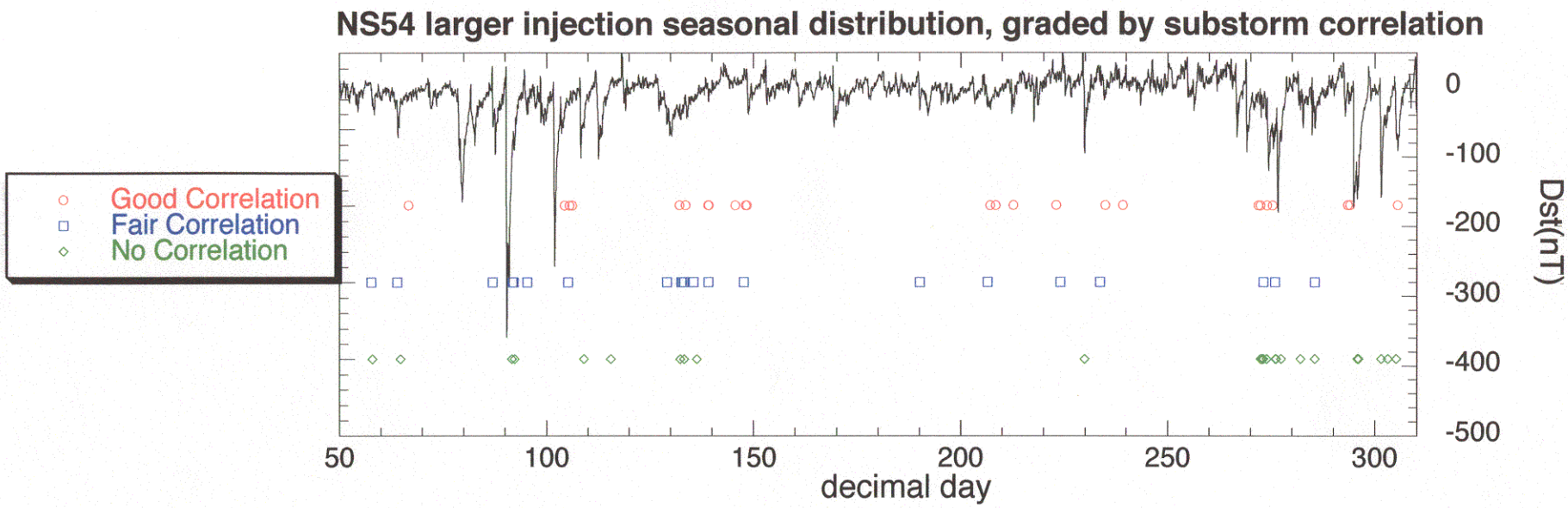
NS54 "Larger" Injections per Sample – Quadrant-resolved and Binned by L-value



Comparison of Mean (L=4-17) Probabilities of Injection Detection in a 4-minute NS54 Sample

	Midnight Quadrant	Dawn Quadrant	Noon Quadrant	Dusk Quadrant
All Inj.	.0095	.0083	.0061	.0045
"Larger" Inj.	.0023	.0010	.00017	.00082

The "larger" injections favor the nightside over the dayside considerably more strongly than do the group of all injections (dominated by the more numerous smaller injections).

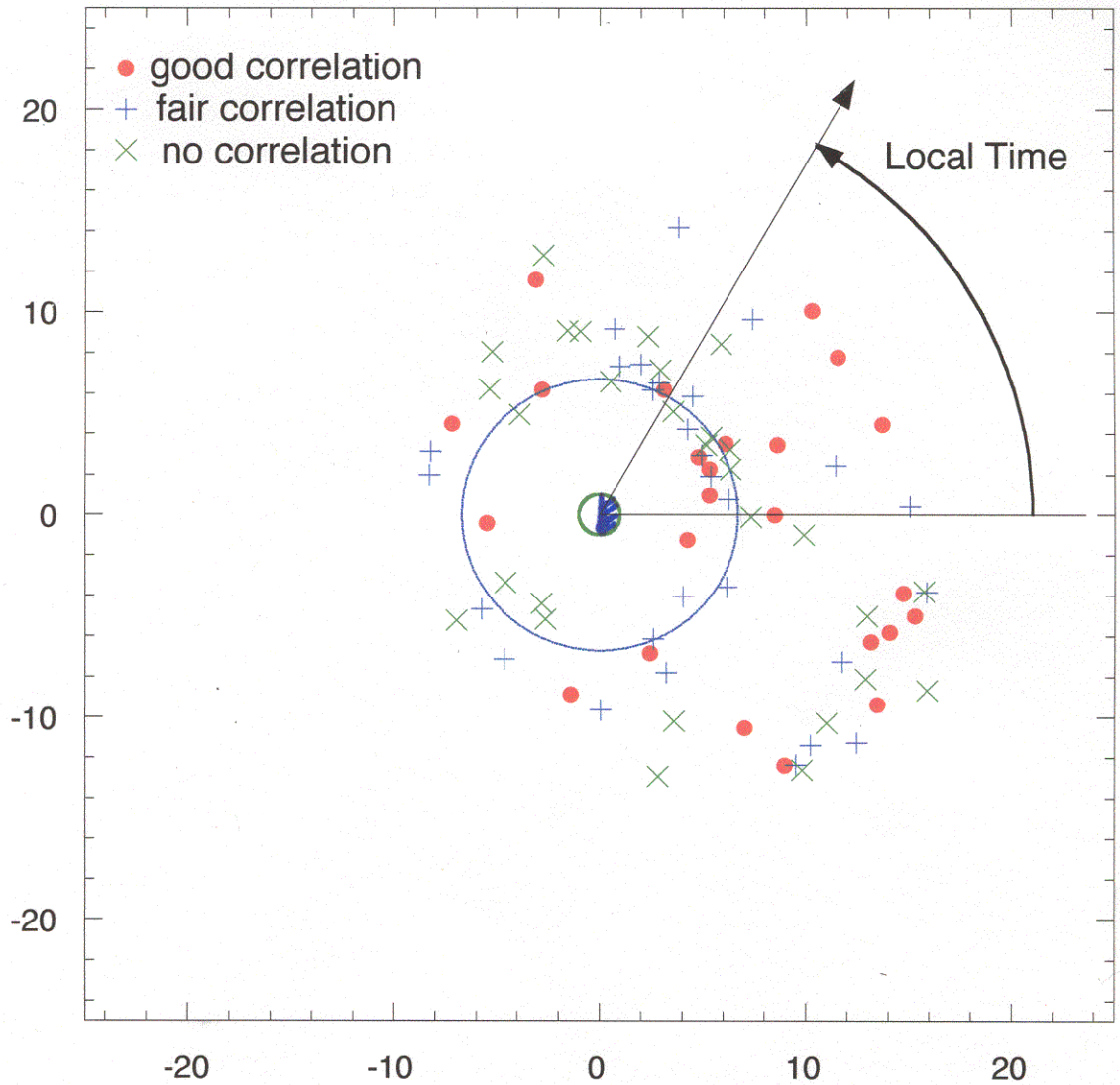


The 70 "larger" NS54 injections, graded by quality of correlation with geosynchronous substorms, are plotted versus decimal day, along with the Dst index.

The quality of the temporal correlation of these injections with identified substorm injection times (using geosynchronous satellite electron (LANL SOPA) and magnetometer (GOES 8 & 10) data) has been graded as follows: < 5 min = good correlation; 5 – 40 min = fair correlation; > 40 min = no correlation.

Note that the "no correlation" grade cases occur more often during times of magnetic storms.

Correlation of larger NS54 injections with substorm injections



NS54 location at the time of detection of each of the 70 "larger" injections for the 254-day period of March – October, 2001. The quality of the correlation of each injection with a geosynchronous substorm injection is indicated using three symbol types. The geosynchronous orbit is indicated in blue.

No clear differences are seen in the locations of these injections, as a function of the grade of the correlation.

Note that there are a significant number of these large injections detected near the geosynchronous L-value (≈ 6.7) that show <u>no correlation</u> with geosynchronous injections. (Some possible explanations are discussed below.)

Results Summary

- NS54 electron injections (all sizes) are about twice as likely to be observed in the midnight and dawn quadrants as in the noon and dusk quadrants (> three times as likely for the "larger" injections)
- About equal fractions of the 70 larger injections show "good", "fair", and "no" temporal correlation quality with identified geosynchronous substorm injections
- There is no obvious sorting of correlation quality by injection location, either in L or local time
- It is surprising that large injections with "no correlation" to geosynchronous injections are sometimes seen for NS54 at L = 6 – 7, since L ≈ 6.7 corresponds to geosynchronous orbit
- Possible reasons for this are:

  → The magnetic field line model calculations were done for kp=2, whereas the "fair" and "no" correlation injections occurred at a mean kp of 4 and the "good" correlation injections occurred at a mean kp of 3

  → Thus, the magnetic field mapping from the satellite to geosynchronous is more accurate for the cases where "good" correlation is observed

  → Furthermore, at higher kp there is a higher level of fluctuations in the geosynchronous particle fluxes, which can mask the identification of actual substorm injections
- Observations of such injections from multiple points (GPS, geosynchronous, POLAR, and CLUSTER) show the global nature of the "injection region", which may have implication for several substorm models