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REPLY TO L. J. LANZEROTTI: SOLAR WIND RAM PRESSURE CORRECTIONS AND AN ESTIMATION OF THE EFFICIENCY OF VISCOUS INTERACTION

Bruce T. Tsurutani[1], Walter D. Gonzalez[2], Frances Tang[3],
Yen Te Lee[4], Masaki Okada[5], Daniel Park[1,6]

Lanzerotti (1992) has pointed out that there was a central United States outage of the AT & T L4 line (Anderson et al., 1974) and significant satellite solar cell damage associated with the August 4 - 5, 1972 magnetic storm, even though the storm was not classified as a great storm (peak $D_{ST} \leq -249$ nT). Lanzerotti quotes a value of D_{ST} of only - 125 nT for the August 5 event. Anderson et al. (1974) speculated that the geomagnetic disturbance may have been caused by large magnetopause currents which were highly distorted (displaced to much lower latitudes). This effect was due to unusually high solar wind speeds.

In determining the storm intensity (ring current energy), care should be taken to remove the effects of the Chapman - Ferraro current, particularly when the ram pressure of the solar wind stream is exceptionally high (Gonzalez et al., 1989; 1992). The August 1972 event had the highest solar wind velocity ever detected near Earth by direct spacecraft measurements ($V_{SW} > 1500$ km s^{-1}). Cliver et al. (1991) speculate that the peak solar wind velocity (the plasma instruments were saturated) was probably about 2170 km s^{-1}.

If one assumes a solar wind speed of ~ 2000 km s^{-1} and uses Anderson et al.'s (1974) argument that the magnetopause was pushed in to 5 R_e, then one can calculate the necessary solar wind density for pressure balance. A value of ~ 23 cm^{-3} is obtained. The well-established empirical relation between solar wind ram pressure and the equatorial field associated with the magnetopause current (Burton et al., 1975; Gonzalez et al., 1989) is:

$$DCF = 0.2\, V_{sw} \sqrt{n}\ \ 10^{-1}$$

where V_{sw} is measured in km s^{-1}, n in cm^{-3} and DCF (Disturbance Corpuscular Flux) in nT. The field associated with the closer location of the magnetopause current is + 170 nT. Thus, the August 5, 1972 storm ring current peak intensity could have been -295 nT, placing the event in the great storm category. This could also explain the strong ionospheric heating that was observed during this event.

Figure 1 gives the (uncorrected) D_{ST}, AE and Kp indices for the period August 3-13, 1972. The vertical dashed lines indicate storm main phase onsets. These occur at ~ 03 UT day 217, ~ 22 UT day 217, ~ 15 UT day 218 and ~ 03 UT day 222. The first three storm onsets occur within the two days that Lanzerotti discusses.

Because continuous 1 AU interplanetary magnetic field and plasma data are not available, we show the Pioneer 10 magnetic field at a distance 2.2 AU from the Sun (Figure 2). The spacecraft is at a solar longitude of - 43° relative to the Earth (positive angles are in the direction of the orbit of the planet). Assuming a peak solar wind speed of ~ 2000 km s^{-1}, the radial propagation delay from 1 AU to 2.2 AU is 1 day, 1 hour. The corotation delay is ~ - 3.0 days. The magnetic field contains four primary features which are indicated by vertical dashed lines in the Figure. There is a fast forward shock at ~ 15 UT day 219, a second forward shock at ~ 22 UT day 219 and a reverse shock at ~ 15 UT day 222. These have been discussed in detail by Smith (1976). A fourth feature is an abrupt discontinuity that occurs at ~ 0850 UT day 220, changing the field from a southward orientation to a large northward direction. A second discontinuity found only in the northward component occurs at ~ 1340 UT on the same day. After this time, the field is large and without waves or discontinuities, indicating they are part of a driver gas (Tsurutani et al., 1988). The field is strongly northward throughout the driver (CME).

It is worthwhile to attempt a qualitative comparison using this complete and continuous field data set. The initial phase onset of the first magnetic storm in Figure 1 is most certainly related to the first shock passage. The main phase storm onset occurs within a few hours after the onset of the initial phase (shock compression). There is a considerable amount of north-south fluctuations in the sheath immediately behind the first shock (Figure 2). Presumably, the B_s component is responsible for the (peak) $D_{ST} = -118$ nT storm and AE ≅ 2000 nT auroral zone activity.

The second and third storms were probably caused by the southward fields following the second shock and the southward fields after the discontinuity at ~ 0850 UT day 220. These events would be in close correspondence if the solar wind radial velocity was 1020 km s^{-1} at this time. This is in reasonably good agreement with the measured Pioneer 9 velocity at 0.8 AU (Mihalov et al., 1974) and shock speed calculations (Smith, 1976). The fourth major storm starting at ~ 0700 UT day 222 may be associated with southward fields that occur after the completion of the passage of the driver gas (CME). Again, the Earth-Pioneer 10 delay time is comparable to the radial plus corotation delays.

One particularly interesting feature is the intense northward fields during this complex interplanetary event. This occurs at Pioneer 10 from ~ 13 UT day 220 to ~ 11 UT day 221. If one considers the corotation delay in addition to the radial propagation delay of the solar wind event (assuming the $V_{sw} \cong$ 550 km s^{-1} measured by Pioneer 9, 45° east of the Earth's solar longitude it is found that the driver gas should reach the Earth and Pioneer 10 within a half-day of each of other (assuming that the driver gas longitudinal extent covers both the Earth and Pioneer 10). Correspondingly, we note from Figure 1 that there is a ~ 24 hour interval centered on ~ 06 UT day 221 where AE is less than ~ 100 nT and Kp is quite low.

This event gives us a unique opportunity to calculate the solar wind energy transfer when magnetic reconnection is presumably not occurring or is occurring at a low rate. Extrapolating from Pioneer 9 data from a measured plasma density of ~ 3 cm^{-3} and a velocity of ~ 600 km s^{-1} on 6 August, one gets a solar wind energy flux of ~ 0.36 ergs cm^{-2} s^{-1} at 1 AU. The stand-off distance of the magnetopause is ~ 11.6 R_e for the given ram pressure, and the cross-sectional area for the magnetosphere, ~ 1.7 x 10^{20} cm^2. Thus, the solar wind energy flux impinging on the magnetosphere is ~ 0.6 x 10^{20} ergs s^{-1}.

Akasofu (1981) has approximated the magnetospheric output parameter U_T :

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[1] Jet Propulsion Laboratory, California Institute of Technology
[2] Instituto Nacional de Pesquisas Espaciais
[3] California Institute of Technology
[4] Yen Te Lee, Lockheed Aircraft Company
[5] Kyoto University
[6] University of California, Irvine

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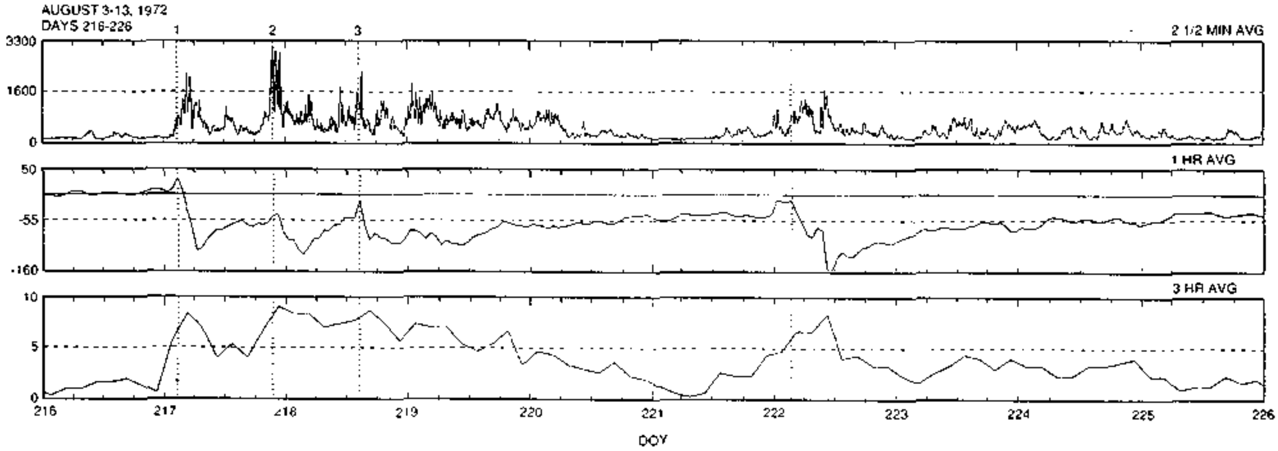

Fig. 1 The four magnetic storms of the August 1972 event. The dashed vertical line indicate the main phase onsets.

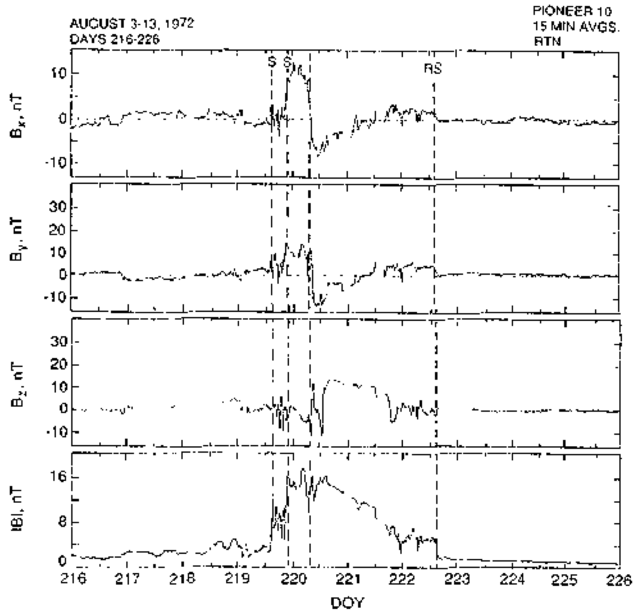

Fig. 2 The Pioneer 10 interplanetary magnetic field data at 2.2 AU from the Sun. Four regions of southward IMF are identified. Of particular interest is an interval of northward directed fields from ~ 13 UT day 220 to ~ 11 UT day 221.

$$U_T = U_O + U_J + U_A$$

where U_O is the ring current input, U_J the ionospheric Joule heating rate and U_A the energy dissipation rate of auroral particle precipitation. He approximated $U_J + U_A$ as = 3 AE x 10^{15} erg s^{-1}. During this quiet interval, AE was less than 40 nT for 2 consecutive hours near the peak of the quiet period. Using this value, $U_J + U_A \cong 1.2$ x 10^{17} erg s^{-1}. We find little or no D_{ST} energy contribution. Thus, if we compare the U_T value to the estimate of the available solar wind energy flux, we find the efficiency of energy injection into the magnetosphere is ~ 2.0 x 10^{-3}.

This value should be contrasted to the efficiency for solar wind energy transfer during magnetic reconnection events. During intense substorms and magnetic storms, the efficiency for magnetic reconnection is about ~ 5 - 10% (Weiss et al., 1992 and Gonzalez et al., 1989, respectively). Thus, "viscous interaction" during intense northward IMF events is about 50 to 100 times less efficient (this number could be less if there is substantial energy deposition over the polar caps).

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Bruce T. Tsurutani, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109

Walter D. Gonzalez, Instituto Nacional de Pesquisas Espaciais, Sao Jose dos Campos, Sao Paulo, Brazil

Frances Tang, California Institute of Technology, Pasadena, California 91125

Robert Lee, Lockheed Aircraft Service Company, Ontario, California 91761

Masaki Okada, RASC, Kyoto University, Uji, Japan

Daniel Park, University of California at Irvine

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