ON THE RELATIVE INTERCALIBRATION OF SOLAR WIND DETECTORS

C. T. Russell and S. M. Petrinec
Institute of Geophysics and Planetary Physics
University of California, Los Angeles, CA, USA, 90024-1567

ABSTRACT

We have intercompared simultaneous or suitably lagged solar wind measurements from the Faraday cup on IMP-8 and the electrostatic analyzers on IMP-8 and ISEE-3. The densities are in fairly good agreement (within 20%) for the most frequently observed solar wind velocities and temperatures but can be much different elsewhere. These differences can range over a factor of 2 and can be important for abnormal but very interesting periods in the solar wind.

1. INTRODUCTION

The International Magnetospheric Study (IMS) from 1977-1979 provided us with an unprecedented opportunity to study the magnetosphere. There were the geosynchronous and near geosynchronous spacecraft such as GOES and SCATHA; the eccentric orbiters ISEE 1 and 2 which probed from deep in the magnetosphere out into the solar wind; and both IMP-8 and, for some of the time, ISEE-3 monitoring the solar wind. The extent of the available data have allowed us for the first time to attempt not just qualitative studies of the magnetosphere but also quantitative investigations, such as determining the size of the magnetosphere as a function of the dynamic pressure of the solar wind [Petrinec et al., 1991] and the change in the magnetic field on the surface of the Earth as a function of the change in the square root of dynamic pressure [Russell et al., 1992]. In order to maximize the amount of data used in these studies it is desirable to use data from all available solar wind instruments and it is wise to check to see that they have all the same calibration. It is the purpose of this paper to report on the significant differences between instruments found when such a comparison is performed. A preliminary report has been published [Russell and Petrinec, 1992]. This paper reviews this preliminary report and adds further information about the differences found in this study.

2. IMP-8 LANL VERSUS MIT

There are four main sources of solar wind data during the IMS: two instruments measuring solar wind ions on IMP-8, a Faraday cup provided by MIT and an electrostatic analyzer provided by LANL, and two instruments on ISEE-3, both electrostatic analyzers provided by LANL, one measuring electrons and one ions. No comprehensive description of either of the IMP instruments has been published in the two decades since their launch. The ISEE-3 instruments are described in the article by Bame et al. [1978]. It has long been known that there is a slight difference in the average density measured by each of these instruments. This is illustrated in Figures 1a) and 1b) which show the density measured at IMP by the LANL instrument versus that measured simultaneously by the MIT instrument. The data used are 5-minute averages of the best fit moments of the distribution functions provided by the original investigators, the MIT moments being from a model fit and the LANL moments from a numerical integration. The 5-

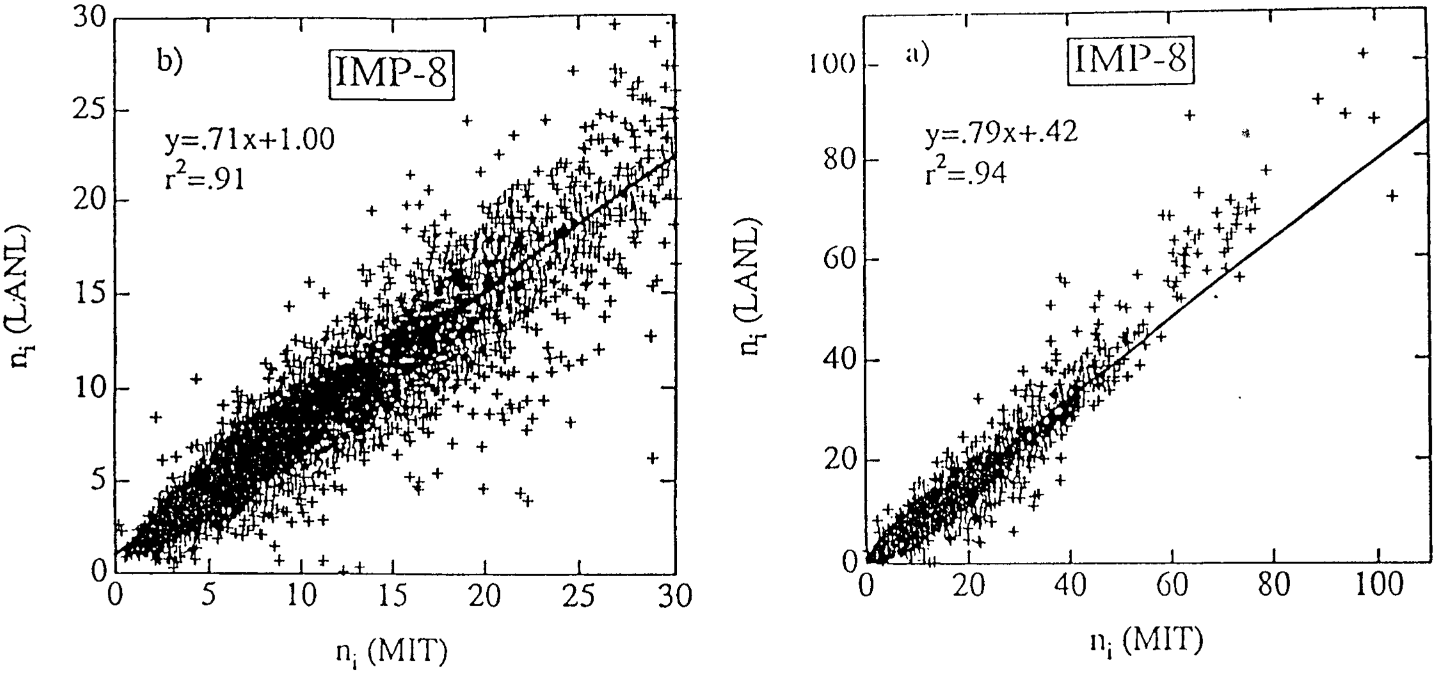

Fig. 1. Density measured simultaneously by the two IMP-8 solar wind experiments during the 1978 to 1980 period during which the ISEE-3 solar wind experiment ion was operating. a) Left panel shows full range of density measured. b) Right panel shows the same data but restricted to 0-30 cm^{-3}. Least square fits and correlation coefficients for the points shown in each panel.

minute averages of the MIT data were calculated at NSSDC and of the LANL data were calculated at UCLA. Figure 1a shows the comparison over the full range of densities encountered. Figure 1b shows the comparison for densities from 1-30 cm^{-3}, more typical solar wind values. Table 1 gives the parameters of the best least square fit straight line for each of 4 study intervals: the period in late 1978 after ISEE-3 was launched; two six month intervals in 1979; and the period early in 1980 when ISEE-3 ion data were still available. We see that the correlation is strong between the two measurements but that the slope is variable.

TABLE 1. Least Squares Fits Between MIT and LANL Densities

Year	Number of Points	Slope	Intercept	Correlation Coefficient
1978	1802	0.71	0.96	0.98
1979.0	8521	0.77	0.65	0.94
1979.5	6829	0.82	0.10	0.98
1980	179	0.74	0.28	0.98

There are several possible causes for such variability. First, one or the other of the instruments could have aged. We do not believe this is the answer because the slope does not change monotonically. Second, one or the other of the instrument may have a "density" calibration

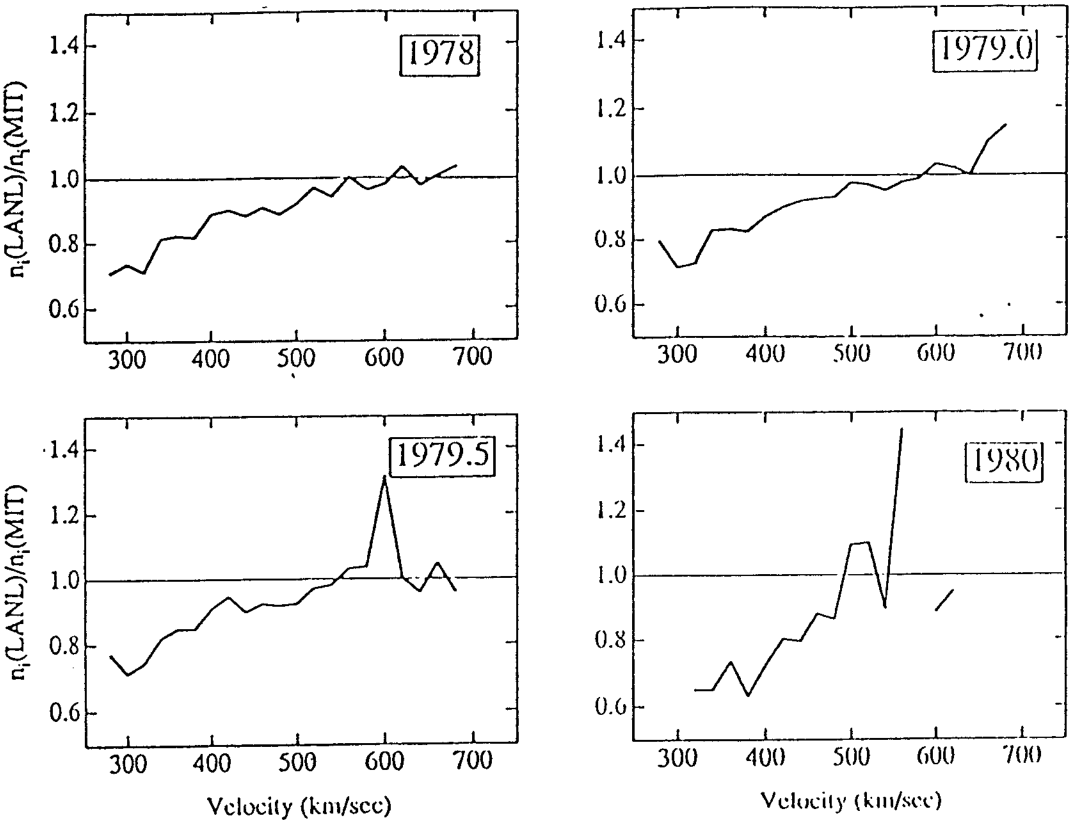

Fig. 2. **Ratio of density observed by the IMP-8 electrostatic analyzer (LANL) to that observed by the Faraday cup (MIT) over the period studied in Figure 1. a) August-December 1978. b) January-June 1979. c) July-December 1979. d) January-February 1980.**

factor that is a function of some other parameter in the solar wind such as temperature or velocity. Figures 2 a-d show the ratio of the LANL electrostatic analyzer (ESA) densities to the MIT Faraday cup (FC) densities. We see a clear dependence of the median density ratio on velocity in each of the four study periods.

The intercalibration factor, however, may also depend on other conditions. Since the solar wind ion temperature is well correlated with the ion velocity the correlation found in Figures 2 a-d may be due to ion temperature effects, or velocity effects or both. To check whether ion temperature does help order the data, we plot in Figure 3 a contour plot of the relative density versus the ion temperature and velocity as measured by the ESA. The ion temperature used here is the weighted average of the perpendicular and parallel temperatures. This definition differs from our previous work [Russell and Petrinec, 1992] which contains a slight error but is qualitatively correct. To create this plot we have found the average density ratio in bins determined by ion velocity and temperature and then drawn contours of the resulting ratios. Since the contours are vertical, the ion temperature has a major role in ordering the intercalibration difference. There is slight dependence on velocity. Moreover, the intercalibration varies more than a factor of 2 from low ion temperatures to high. Figure 4 shows the number of data points in each bin used in creating Figure 3.

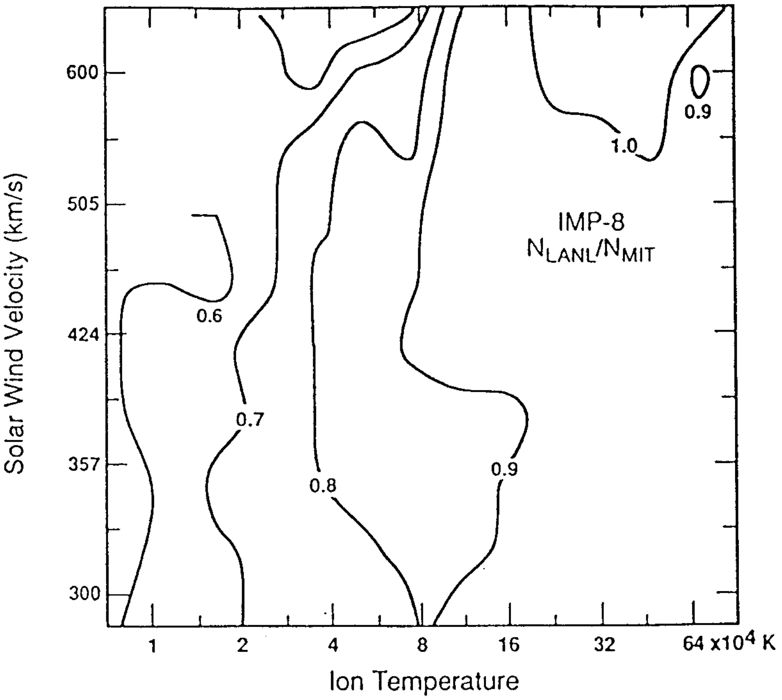

Fig. 3. Contour plot of the solar wind ion density ratio on IMP-8 versus the LANL solar wind velocity and temperature. Data are binned in logarithmically spaced bins in ion velocity and temperature and the resulting average density ratios contoured. In the upper left hand corner where the flow is fast and the ions cold, the LANL detector registers only half the density that the MIT detector sees.

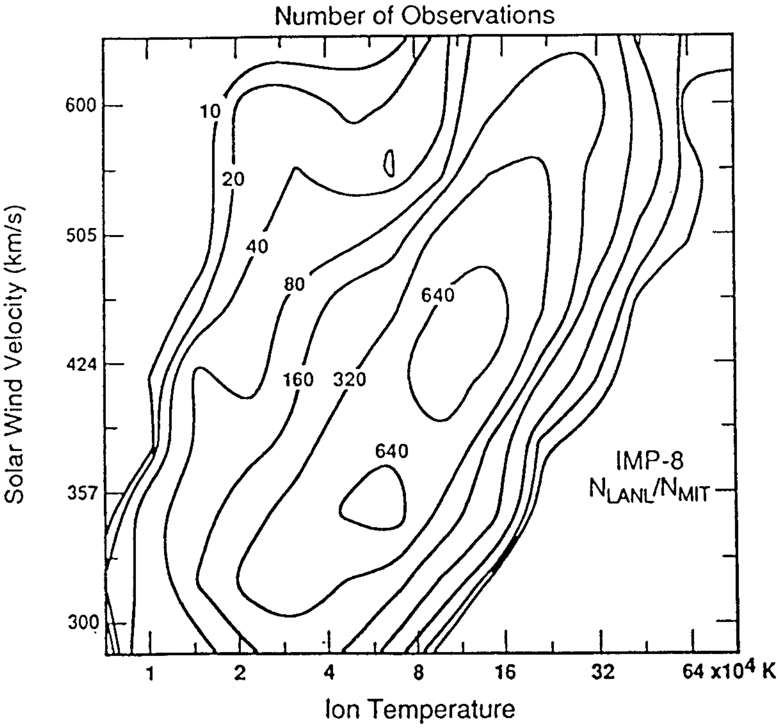

Fig. 4. Contour map of the number of observations of simultaneously measured 5-minute averages of the solar wind detectors on IMP-8 in the period studied in Figure 3. Identical bins were used as in Figure 3.

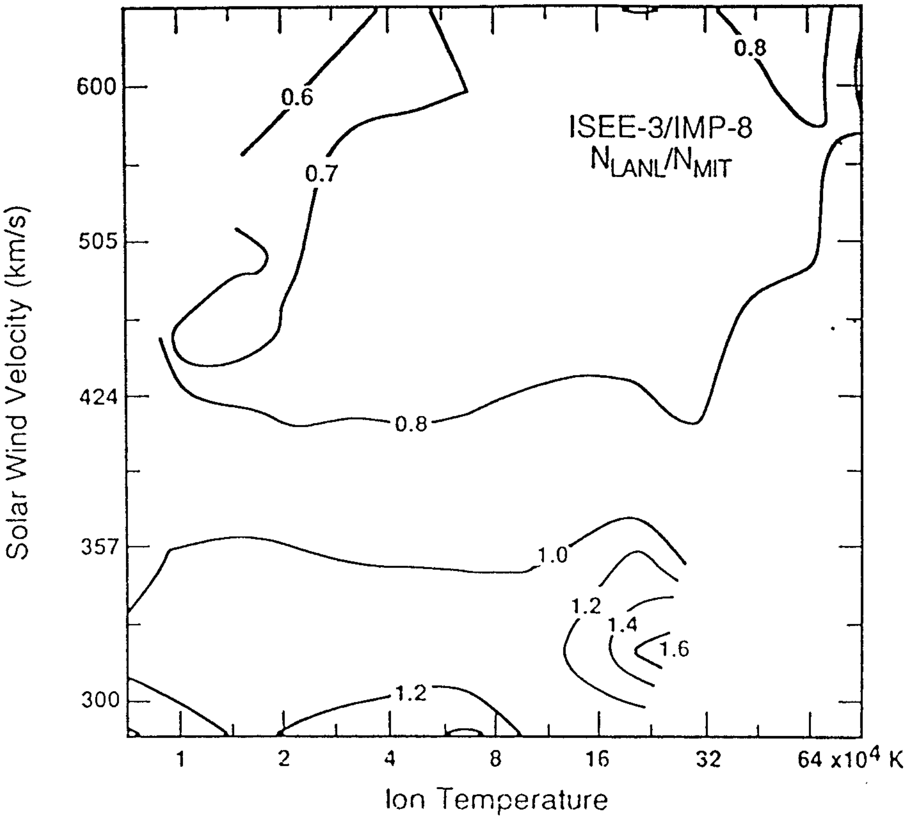

Fig. 5. Contour plot of the solar wind ion density ratio between the LANL electrostatic analyzer on ISEE-3 to the MIT Faraday cup. The variations of this density ratio with solar wind ion velocity and temperature is quite different than that shown in Figure 3.

3. ISEE-3 VERSUS IMP-8

Although it is tempting to attribute the differences between the MIT and LANL densities on IMP-8 to some inherent differences between the responses of Faraday cups and electrostatic analyzers, this does not appear to be the case. As illustrated in Figure 5, the two electrostatic analyzers have quite different responses relative to the Faraday cup. For the ISEE-3 ESA the differences are not simply a function of ion temperature but vary with both ion temperature and velocity. Figure 6 shows the number of data points in each bin used in creating Figure 5.

4. DISCUSSION

We should emphasize that the three instruments examined agree within about 20% in the range of most common solar wind velocity and temperature. However, the lack of agreement during abnormal solar wind conditions is troublesome because the abnormal solar wind conditions are often the most interesting. One would hope that our understanding of the solar wind interaction with the Earth had become sufficiently quantitative that we could now test the accuracy of these instruments by monitoring the position of the magnetopause for example. The magnetopause position is determined by several factors including the compression factor inside the magnetopause and the divergence of the streamlines in the magnetosheath. Furthermore, the southward component of the IMF and the strength of the ring current affect the magnetopause

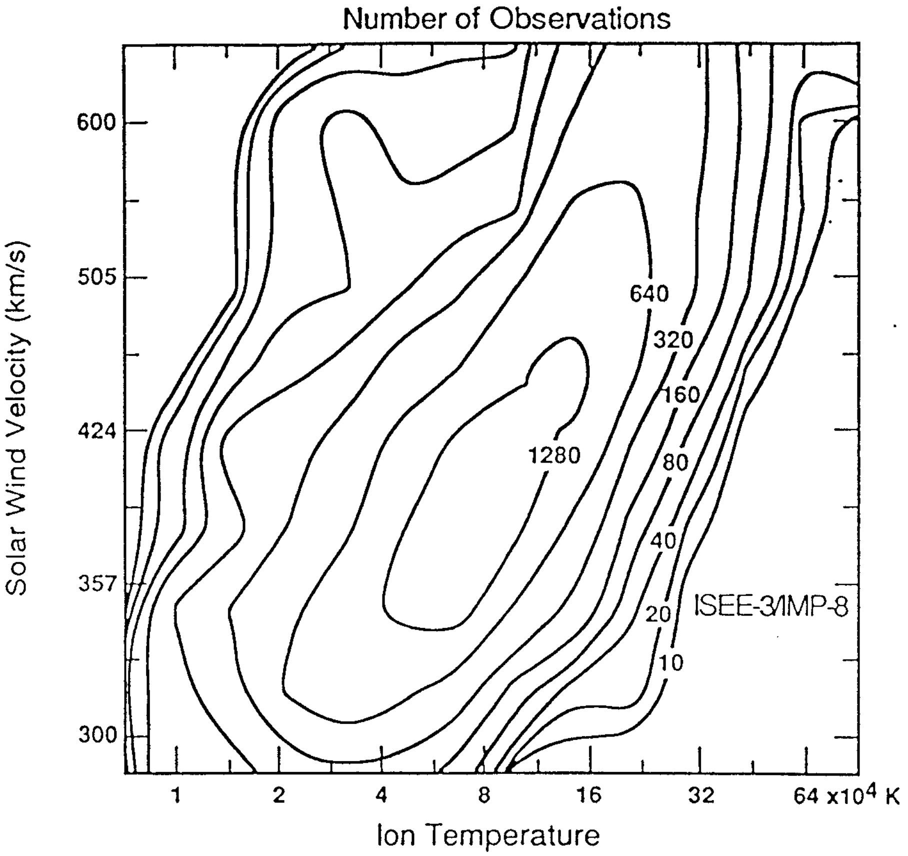

Fig. 6. Contour map of the number of observations of simultaneously measured 5-minute averages of the solar wind from the Faraday cup on IMP-8 for the period studied in Figure 4. Identical bins were used as in Figure 5.

position [Petrinec and Russell, 1992]. Still, we may be able to use the magnetopause position, if the sample is large enough, because the observations suggest there are differences in the magnetopause location using the data from the different solar wind instruments.

Figure 7 (top) shows the location of the magnetopause as a function of $(\rho v^2)^{-1/6}$ as measured by ISEE-3. Here the mass density includes the observed amount of Helium. When the IMF is northward theory and observation agree almost precisely . When the IMF turns southward the magnetopause moves inward about 1 R_E at all pressures. When this test is repeated for the IMP-8 Faraday cup (bottom) there is not so much agreement and the effect of the southward magnetic field is less well defined. However, the scatter is large especially for ISEE-3 and the differences between the slopes and theory are not significant, nor are the absolute positions of the northward curves significantly different. Thus we cannot yet provide an improved absolute calibration.

5. CONCLUSIONS AND RECOMMENDATIONS

We conclude that the density calibration of at least 2 of the 3 solar wind instruments used for supporting studies during the IMS have temperature and or velocities dependencies that have not been removed in the data processing. The density calibration variations across the temperature and velocity range of the solar wind is over a factor of two. This is a significant variation that could stymie some quantitative solar wind-magnetosphere interaction studies. We urge all those

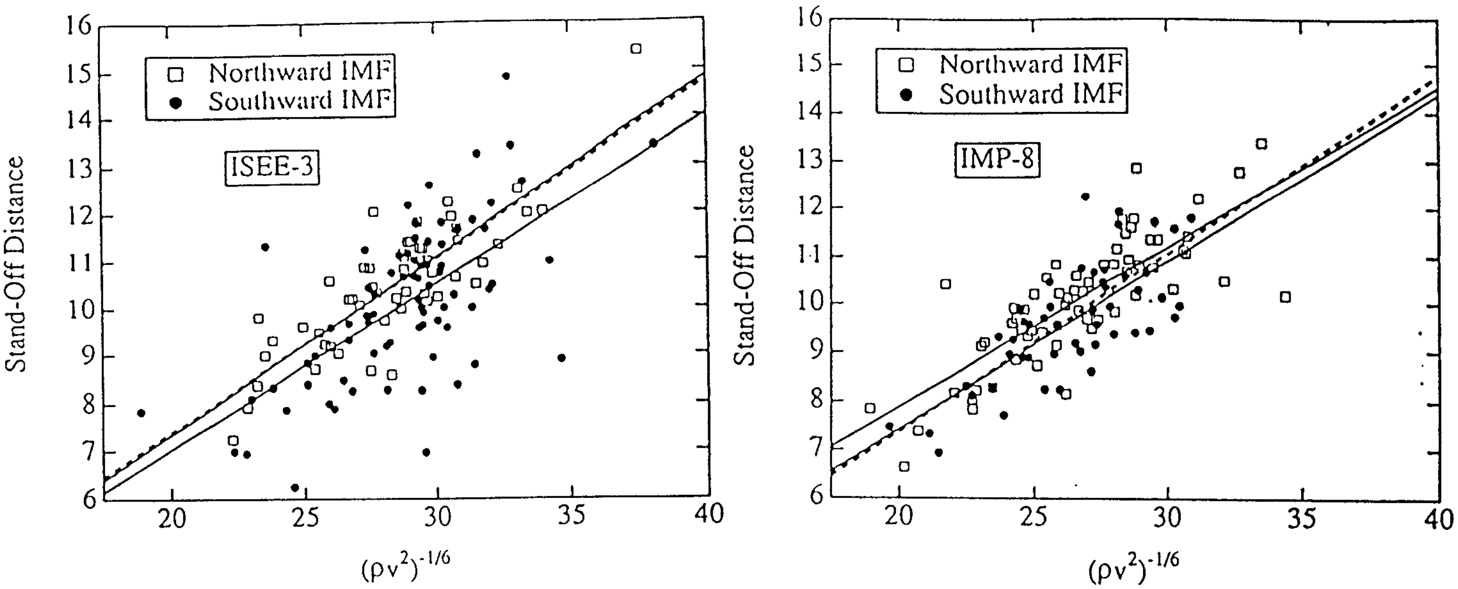

Fig. 7. The location of the magnetopause as a function of the inverse sixth root of solar wind dynamic pressure. The dashed line gives the theoretical location assuming an inelastic solar wind and divergence of the stream tubes about the magnetosphere. The two solid lines are fits to the magnetopause position for northward (upper) and southward (lower) IMF. The left panel shows the ISEE-3 data and the right panel LANL IMP-8 data. The ISEE-3 mass density used includes the observed amount of helium while the IMP-8 includes only a statistical (16%) increase for the helium content of the solar wind.

concerned to attempt to determine better calibrations for these three instruments, to prepare a new set of solar wind parameters for the community and to publish comprehensive descriptions of these instruments including discussions of their calibration procedures.

6. ACKNOWLEDGEMENTS.

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