IPS OBSERVATIONS OF THE SOLAR WIND SPEED OUT OF THE ECLIPTIC

by

W. A. Coles

and

B. J. Rickett

APPLIED PHYSICS & INFORMATION SCIENCE DEPARTMENT

UNIVERSITY OF CALIFORNIA, SAN DIEGO

LA JOLLA, CALIFORNIA 92093

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Abstract

Interplanetary scintillation (IPS) observations from 1971-1975 show that the average solar wind speed increases away from the solar equator, with a mean gradient of 2.1 km/s per degree. These results are compared with spacecraft observations over the $\pm 7^{o}$ attainable in the ecliptic and with those deduced from comet tails. The role of temporal variations, especially those caused by latitude dependent solar wind streams, is emphasized. This points to the need for extensive ecliptic and ground-based observations during an out-of-the-ecliptic spacecraft mission.

Introduction

The solar wind both in and out of the ecliptic can be studied from the earth by the method of Interplanetary Scintillations (IPS). The method was pioneered by Hewish and his colleagues, who deduced the solar wind speed from multiple station observations. In 1966 Dennison and Hewish (1967) found an increased speed out of the ecliptic, while in 1967 Hewish and Symonds (1969) found no such increase. Their multiple station observations then ceased. In this paper we report solar wind speeds deduced from 74 MHz IPS observations made at UC San Diego from May 1971 through to April 1975. The observing system was described by Armstrong and Coles (1972) and by Coles et al (1974). Results from 1972 were reported by Coles and Maagoe (1972). We will also mention briefly the relevance of IPS observations simultaneous with an out-of-the-ecliptic spaceprobe mission.

IPS Method

The scintillation signal is the sum of waves scattered along the line of sight from a given radio source. Most of the scattering occurs where the line of sight is closest to the sun, because of the steep decrease with solar distance in the strength of the electron density microstructure which causes IPS. For a spherically symmetric solar wind a weighting function can be defined and the IPS "mid-point" speed (Coles and Maagoe 1972) can be shown to be a spatial average of the solar wind speed centered on the point of closest approach. However, in the presence of solar wind streams spherical symmetry does not apply.

The effect of the spatial average through such streams has been investigated by comparing the IPS observation with those expected by mapping point observations made on the IMP-7 spacecraft out along the line of sight in question.

Harmon (1975) and Coles et al. (1975) demonstrated a close agreement between IPS "mid-point" speed and the IMP-7 data mapped to the point where the line of sight is closest to the sun. More detailed comparisons are in progress, investigating the precise form of the spatial weighting caused by streams. However, for the present purposes the comparison demonstrates that each IPS observation is representative of the solar wind speed at the point of closest approach.

Results

This effective observing point changes in solar latitude, longitude and radial distance as the sun rotates and the earth orbits the sun. Thus for radiosources not in the ecliptic, about two months of high solar latitude data can be obtained each year. The geometry, however, is such that the high latitudes occur together with small solar distances. The distance dependence can be separated out by studying the four ecliptic radio-sources, for which the latitude remains within 10^{0} of the equator; Figure 1 shows the solar wind speeds averaged into intervals of 0.1 AU in radial distance during 1971-1975. We conclude that there is no significant variation of average solar wind speed with radial distance between 0.4 AU. and 1.1 AU. Figure 2 shows a similar plot for all sources versus latitude and, because there is no radial distance dependence, it can be interpreted as showing the solar wind speed as a function of latitude. The vertical bars are ± 2 standard deviations in the average solar wind speed over latitude intervals indicated by the horizontal bars. The r.m.s. variation in a single speed observation is remarkably constant at about 120 km/s, showing no significant change with latitude. The vertical error bars are larger at high latitudes because there are fewer data points at high latitudes. (In a typical year, 300 observations from 0-10^{0}N decreasing to 25 observations from 50^0-70^{0}N). The major conclusion is that there is a systematic increase of solar wind seed with latitudes both north and south of the solar equator. This is evident in each year from 1971 through 1975 as well as in the grand average of all data. The average gradient is close to 2.1 km/s per degree of latitude. However, the curves are not quite symmetrical but centered near 10^{0}N, giving an apparently steeper gradient in the south than in the north. This asymmetry is only marginally significant and we are still checking for second order systematic errors which could cause this.

Discussion

Our observed latitude gradient must be compared with other data. As already mentioned,the Cambridge IPS observations detected a latitude gradient in 1966 but not in 1967. Whereas this could conceivably be influenced by solar cycle effects, it is more likely that the small number of observations at high latitudes is responsible. Their measurements included only about 30 days each year which corresponded to latitudes above 20^0; the long term average behavior could well be masked by the day-to-day and month-to-month variability found in the solar wind speed.

Spacecraft observations have been analyzed to look for effects due to the $\pm$ 7^0 latitude range available in the ecliptic (e.g. Hundhausen et al. 1971). Smith and Rhodes (1974) and Rhodes and Smith (1975) deduced large apparent gradients (10-15 km/s per degree) by comparing solar wind speeds observed near Earth (Explorer 33,34,35) and at Mariner 5. They analyzed data from nearly six solar rotations over latitude differences from 0^0 to 6^0. We suggest that a possible explanation of their large gradient over a few degrees of latitude comes from solar wind streams. From our IPS data it is clear that solar wind streams often exist for several solar rotations with steep latitude gradients near the equator (see for example the wide southerly stream in

Figure 13 of Coles et al. 1974). It is likely that such features contribute strongly to a six month average. Figure 2 shows that in 1972 the apparent gradient between ± 5^{o} was + 4 km/s per degree, while in 1973 the apparent gradient reversed to - 3 km/s per degree. The influence of steep latitude gradients from specific recurrent streams was probably the cause for such large values.

More difficult to reconcile are the results from comet tail observations. Brandt et al. (1975) have analyzed 678 comet observations spread over 75 years and conclude that the latitude gradient is - 0.9 ± 0.7 km/s per degree north or south; that is not significantly different from zero. Their observations are concentrated in the range 0^{o} to 50^{o}N (as are the IPS observations) and are scattered fairly well through the phases of the solar cycle. It would be of interest to see if the high latitude data were uniformly distributed over the phases of the solar cycle. Except for solar cycle effects we cannot suggest any simple explanation for the discrepancy; though long term systematic or random temporal variations could be responsible.

Conclusions

We have presented strong evidence that during 1971 through 1975 the average solar wind speed increased out of the equatorial plane giving an average gradient of 2.1 km/s per degree of latitude either north or south. Our observations show that stream and also slower variations can obscure the average latitude behaviour in the solar wind (as they do also for average properties in the ecliptic). In planning out-of-the-ecliptic spacecraft missions such changes must be expected. Jupiter "swing-by" missions would give 12-18 months at more than 30^{o} from the equator. During this time it will be important to maintain regular observations in the ecliptic in order to disentangle temporal and latitude effects. A continued program of IPS observations throughout the period would cover a range of longitudes and latitudes and further help build a picture of the spatial and temporal structure in the solar wind. In addition to the average latitude behaviour such joint observations would allow the latitude structure of individual streams to be explored.

Acknowledgements

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Figure Captions

Figure 1. Solar wind speeds from 1971-1975 measured within 10° of the solar equator, averaged into 0.1 AU intervals of radial distance. The vertical error bars are ± twice the standard deviation in the mean.

Figure 2. Solar wind speeds from 1971 through 1975 averaged into latitude intervals shown by the horizontal bars. Vertical bars are ± twice the standard deviation in the mean. The lower right graph is the overall average from the other five graphs.

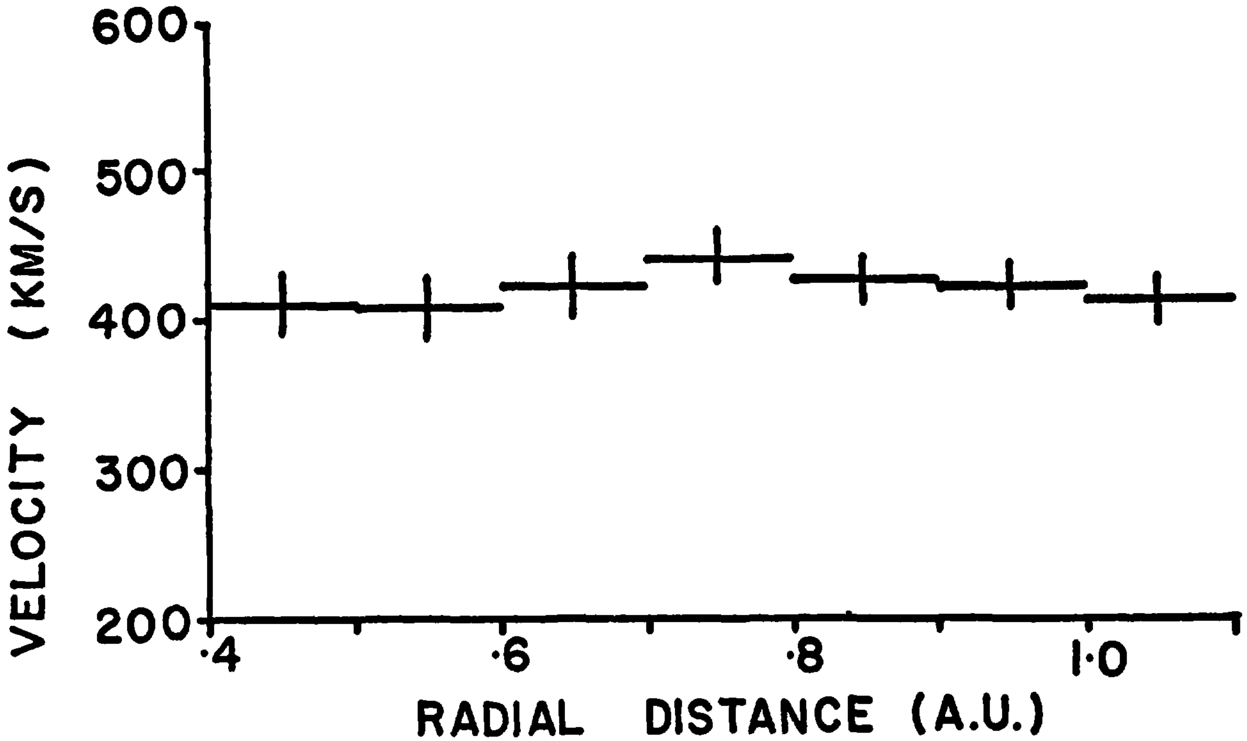
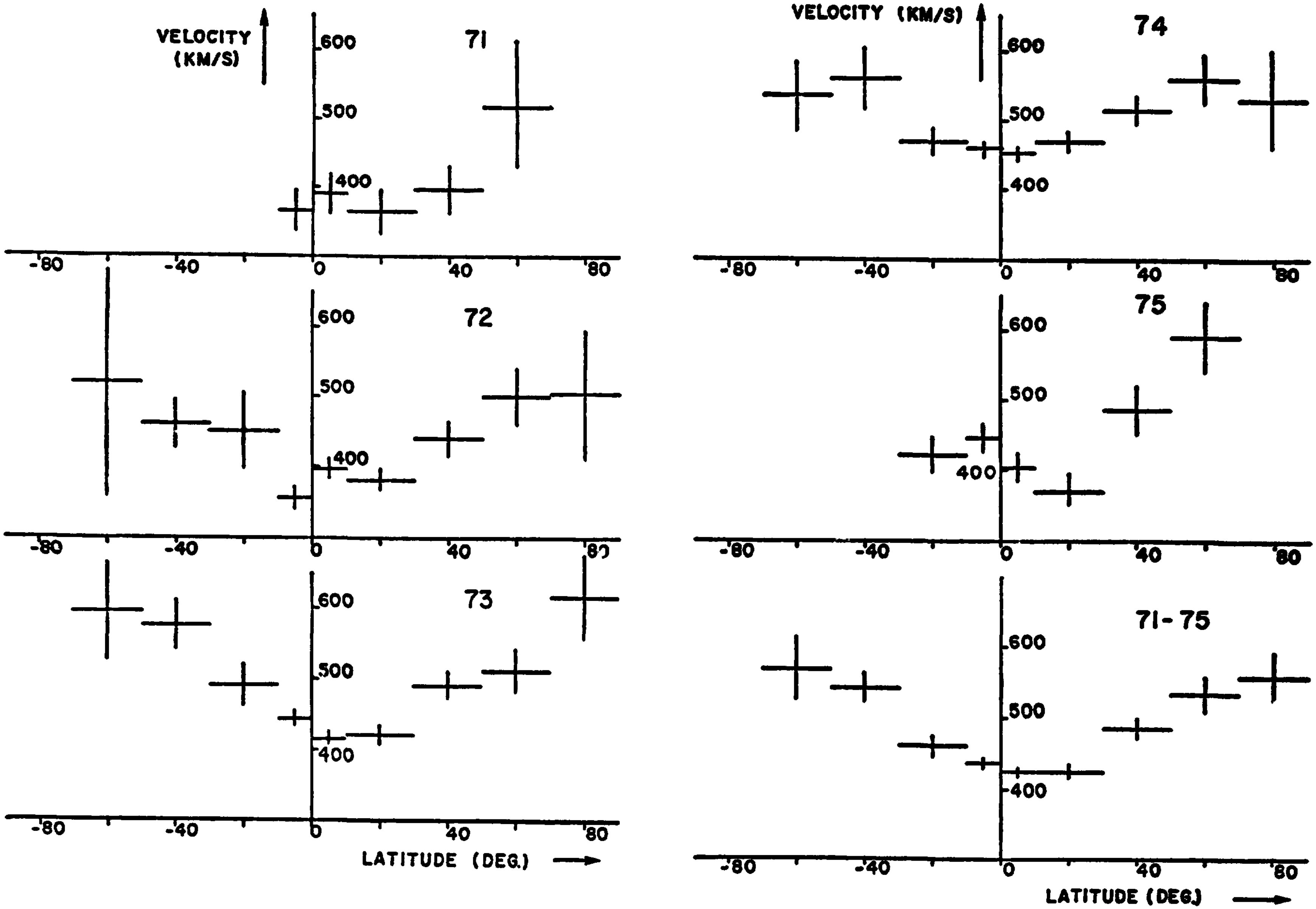


Figure 1.



VELOCITY (KM/S)
600
500
400
71
72
73
74
75
71-75
-80
-40
0
40
80
LATITUDE (DEG.)

Figure 2.