Lecture 12
The Importance of Accurate Solar Wind Measurements

May 24, 2000

B_z, Flows and Pressure in the “Equatorial” Plane

ACE 1112 UT

WIND 1114 UT

Electric Potential

kV
The Approach

- Magnetospheric studies usually are based on a single solar wind monitor.
- We propagate the solar wind from the observation point (usually the L1 point) to Earth by using the observed velocity and assuming that there are no changes along the way.
- We assume that the solar wind is homogeneous across the width of the magnetosphere.
Characterizing the Solar Wind Parcels that Interact with the Earth

• It has been recognized for a long time that simple propagation of the solar wind from a distant monitor to the Earth was flawed.

• How well the IMF observed upstream actually represents the solar wind that interacts with the Earth depends on the separation of the spacecraft perpendicular to the Sun-Earth line.
  – Crooker et al., [1982] good correlation for $d_{\perp}<50R_E$ if the variance in the solar wind is large—good correlation for $d_{\perp}<20R_E$ if the variance is small.
  – Collier et al., [1998; 2000] have quantified the percentage of time two monitors observed good correlation as a function of $d_{\perp}$. A good correlation was >80%.
Characterizing the Solar Wind Parcels that Interact with the Earth 2

\[ \% \text{ time} = 32\% \left[ -\frac{(d_\perp - 10R_E)}{L_\perp} \right] \]

where \( L_\perp = 41R_E \).

- The Collier formula indicates at good correlations are found only 25\% of the time for spacecraft with \( d_\perp \sim 30R_E \).
- Richardson and Paularena [2001] found evidence for scale lengths perpendicular to the flow of 45R_E the IMF, 70R_E for the speed and 100R_E for the density.
- The radial scale length is 400R_E.
- The entire potential difference across the magnetosphere only requires 3-4R_E [Burke et al., 1999].
- Since this is much smaller than the typical IMF scale length perhaps transverse variations in the solar wind are not too important for the magnetosphere.
Propagating the Solar Wind

• Weimer et al., in a series of papers suggested that by calculating a phase front the estimate of the time to propagate from L1 to the Earth could be improved.

• Two methods have been used over the past couple of years.
  – MVAB-0 – calculated the minimum variance direction constrained such that the average field along the minimum variance direction is zero. (Haaland et al., [2006]; and an equivalent approach by Bargatze et al., [2005])
    • For a set of magnetic field measurements: The eigenvectors of
      \[ M_{ij} = \langle B_i B_j \rangle - \langle B_i \rangle \langle B_j \rangle \] give the maximum, intermediate and minimum variation of the field components.
  – Cross product – take the vector cross product of average magnetic field vectors upstream and downstream of the discontinuity.
Calculating the Phase Fronts

- Red give phase fronts calculate from MVAB-0 and blue uses the cross product method. (Weimer and King, 2008)
Pick the Best Method at Each Time

- Where there is disagreement use the method closest to the trend.
Predicted Lags

- Top – convection delay; bottom – delay using combined method.
- Separation (227.3\(R_E\), 5.4\(R_E\), 14.4\(R_E\))
Spacecraft Orbits on May 24, 2000  
(Ashour-Abdalla, 2008)

• Four solar wind monitors were available throughout most of the interval.

• ACE was at the L1 point at $x=220 R_E$, $Y=25 R_E$ and $Z=-20 R_E$

• Wind was moving toward the Earth about $60 R_E$ upstream, at noon and in the equator.

• IMP-8 was duskward of noon, about $30 R_E$ upstream and $20 R_E$ below the ecliptic.

• Geotail was at noon and crossed the bow shock during the interval.
ACE Solar Wind Observations During the May 23-24, 2000 Magnetic Storm

• A magnetic cloud passed the Earth on May 23-24, 2000.
• The solar wind dynamic pressure exceeded 30nPa.
• A moderate storm (Dst~ -150nT) resulted.
• We have divided our analysis into two intervals
  – 2200UT May 23 to 0600UT May 24. The main body of the cloud passed the Earth.
  – 0900UT to 1500UT May 24. The magnetosphere was engulfed in the wake of the cloud.
Solar Wind and IMF Observations from Wind, ACE and IMP-8 - First Interval, May 23 and 24, 2000

Wind Observations MFI
ACE Observations Were Shifted by 31:32 min.
IMP-8 Observations Were Shifted back 9:34 min.

WIND Observations SWE
ACE Observations Were Shifted by 31:32 min.
IMP-8 Observations Were Shifted back 9:34 min.

Universal Time (Hours)
Solar Wind and IMF Observations from Wind, ACE and IMP-8 – Second Interval, May 24, 2000


A Digression on Correlation

- The *cross correlation* of two time series \( a \) and \( b \) is defined by
  \[
  c_k = \frac{1}{N + M - 1} \sum_p a_p b_{k+p}
  \]
  where \( k \) is the *lag*, \( N \) and \( M \) are the lengths of the time series.

- The sum is over all \( N+M+1 \) possible products.

- An *autocorrelation* is a cross correlation of a time sequence with itself.
  \[
  \phi_k = \frac{1}{2N - 1} \sum_p a_p a_{k+p}
  \]

- The *correlation coefficient* is equal to the cross correlation normalized to give one when the two time series are identical (perfectly correlated).
  \[
  \psi_k = \frac{\sum_p a_p b_{k+p}}{\sqrt{\sum_p a_p a_p \sum_p b_p b_p}}
  \]

- \( \psi_k \) is 1 for perfect correlation and -1 for anticorrelation.
**Cross Correlation Between ACE and Wind B<sub>Z</sub>**

- The ACE data have been shifted 31:32 minutes with respect to Wind.
- The cross correlation is >.95 with <2min additional shift.
- The small shift may be due to changes in solar wind velocity between the two spacecraft.
Cross Correlation Between ACE and Wind $B_Z$ Second Interval.

- The cross correlation is $<0.7$ with no dominant peak.
- Delays of 2 hours are as good as zero.
- The differences are not in the propagation scheme.
Peak Cross Correlations in IMF Bz Between ACE, Wind and IMP-8 Observations

- Peak cross correlations were calculated over 2 hour running intervals.
- Cross correlations are larger during the first interval.
- Cross correlations in first interval improved with averaged data.
- Best cross correlations occur between IMP-8 and Wind
- Cross correlations during the second interval are not improved by averaging.
- Similar results were found with up to 30 minute averages.

No Smoothing

Ten Minute Running Averages
Peak Cross-correlations in Dynamic Pressure Between IMP-8, ACE, and Wind Observations

- Low cross-correlations for all three combinations when the data with no smoothing are used.
- In general the IMP-8 and Wind observations agree best.
- Averaging improves the cross-correlations for the first interval (especially IMP-8 and Wind early during the large pressure increase).
- The cross-correlations during the pressure increase in the second interval become worse.

No Smoothing

Ten Minute Running Average
Organizing the Results

• The magnetosphere is a complex time dependent three-dimensional structure.

• The “equator” is a twisted surface located above the GSE equator on the dawn side and below it on the dusk side.

• The cross section varies with $X$ and time.

• It’s cross section depends on the history of the solar wind and the resulting dynamics.

• Needed to develop a way to organize the results.
Displaying the Results

• The plasma sheet is the maximum pressure surface.

• The color spectrogram gives the north-south component of B.

• The white arrows show the flow.

• The contours give the thermal pressure.
B$_z$, Flows and Pressure in the “Equatorial” Plane

May 23, 2000
May 24, 2000

$B_z$, Flows and Pressure in the "Equatorial" Plane

ACE 0132 UT

WIND 0132 UT

Electric Potential

kV
May 24, 2000

$B_z$, Flows and Pressure in the “Equatorial” Plane

ACE 0230 UT

WIND 0230 UT

Electric Potential

kV
May 24, 2000

$B_z$, Flows and Pressure in the “Equatorial” Plane

ACE 0330 UT

WIND 0330 UT

Electric Potential

kV
May 24, 2000

$B_z$, Flows and Pressure in the “Equatorial” Plane

ACE 1112 UT

WIND 1114 UT

Electric Potential

kV
May 24, 2000

$B_z$, Flows and Pressure in the "Equatorial" Plane

ACE 1128 UT

WIND 1130 UT

Electric Potential

$kV$

0 18 24

0 18 24
May 24, 2000

$B_z$, Flows and Pressure in the “Equatorial” Plane

ACE 1228 UT

WIND 1230 UT

Electric Potential

kV

X(RE)

Y(RE)