Two-point observations of solar wind parameters

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Abstract

For a number of years ACE has been the only spacecraft situated at the first Lagrangian point (L1) measuring the solar wind just before it impacts Earth’s magnetosphere, acting as our lone watchman in the Earth-impacting portion of solar wind flow. In 2016, DSCOVR, the replacement for ACE became operational, situated in a complimentary orbit around L1, doubling the number of measurement points in the upstream wind. The aim of this project is to take advantage of the pair of similar solar wind observing spacecraft we currently have access to, by investigating the typical scale sizes of structures in the solar wind that impact the magnetosphere.

1 Introduction

The advent of the space age has made it possible for man to observe the vast space between the sun and the Earth by means of satellites equipped with sensors to measure and antennas to transmit observations to Earth. The solar wind is the plasma flowing out from the Sun, impacting Earth’s magnetosphere and causing various negative impacts on technology. Monitoring this outflow from the Sun is important to understand and predict the interaction between the magnetised solar wind plasma and the Earth’s magnetic field enabling us to take mitigating actions against the effects of space weather on technological systems that are critical for humanity. In order to continuously monitor the solar wind before it reaches Earth satellites are placed in to orbit around the first Lagrangian point: a location about 0.01 AU from Earth toward the Sun, where the gravitational force between two bodies effectively cancel.

Since its launch in 1996, the Advanced Composition Explorer (ACE; http://www.srl.caltech.edu/ACE/ace_mission.html) has been the main, and later only, point of observation in the upstream solar wind. ACE measures plasma particle, flow, density and magnetic field quantities that enable scientists to characterise the incoming plasma and its frozen-in magnetic field. It’s replacement, the Deep Space Climate Observatory (DSCOVR; https://www.nesdis.noaa.gov/content/dscovr-deep-space-climate-observatory) satellite was launched in 2015 and became fully operational in July of 2016 when the American National Oceanographic Atmospheric Administration (NOAA) switched their solar wind data feed to DSCOVR from ACE. Since then both ACE and DSCOVR has continued to provide quality data from their respective orbits around L1.

The aim of this project is to take advantage of this unique opportunity to observe the incoming solar wind at two points near L1. Several research questions, summarised below, could be explored. The aim is not to fully answer all of these questions, but to touch on some of them. The implication, and opportunity afforded by this project, is that there is definite scope to continue with this project beyond Honours level to MSc and even PhD research.

The research questions to be explored are summarised below.
1. **Is ACE and DSCOVR separated far enough from each other to measure meaningfully different parcels of solar wind plasma?** We want to know how the distance between the two spacecraft compares with the typical structures and length scales we are interested in measuring in the solar wind plasma. For example, in the ambient solar wind the differences between measurements at ACE and DSCOVR may be relatively large due to small spatial-scale structures dominating, but large passing structures like coronal ejecta may form a coherent disturbance larger than the scale defined by the distance between the two spacecraft.

2. **How does the observed flow vectors, and the differences between them, compare with our current models of solar wind flow near the Earth?** It is important to evaluate current understanding of the models that we rely on to predict solar wind flow. Would having two observation points provide more information than just relying on one measurement point?

3. **Can we differentiate between direct-hit and glancing blow CMEs?** When coronal mass ejections erupt from the Sun we do not know for sure if they will impact the magnetosphere directly, not at all, or with a glancing blow. Having two points of measurements upstream of Earth may enable us to distinguish between direct hit and glancing blow CME’s. Can we use ACE and DSCOVR observations to predict the severity of CME impact?

4. **Are there fluid-dynamical quantities we care to measure that needs two points of observation?** Can we calculate the spatial correlation of solar wind turbulence from two point measurements (ACE and DSCOVR)? The aim is to repeat some of the work done by [1] with ACE and DSCOVR.

## 2 Special Requirements

This project is heavily focussed on data analysis and time series modelling and as such some proficiency in computer programming is expected. These are valuable and highly transferable skills that will be useful regardless of eventual career path chosen.

The student is expected to download, read, and interact with data in a programming language such as Python, Matlab or R. Intermediate proficiency in computer programming is expected. The student will of course be assisted in the writing of programs where necessary, but will have to do the bulk of this work him/her self.

## 3 Example Roadmap

1. Collect and read data from ACE and DSCOVR, including the position of the spacecraft in GSE coordinates.

2. Plot solar wind plasma and magnetic parameters on the same axis, attempt to explain some of the differences seen.
   - Are the differences constant or do they vary? Are the differences a function of the s/c distance from the Sun, or distance between each other?

3. Find interesting CME, or coronal hole signatures in data and explore and explain the differences seen in the two sets of measurements.

4. Compute quantities such as scale lengths, fractal dimension, etc. using two point measurements and compare with quantities from single-point measurements.
4 Introductory example: getting data and plotting it

4.1 Data

Spacecraft position and solar wind data found at CDAweb https://cdaweb.sci.gsfc.nasa.gov/. Select the ACE and DSCOVR spacecraft, with no data type selections made to see all available data sets from all onboard instruments. Position data is in the following two data sets:

- AC_OR_SSC: ACE GSE Positions @ 12 min resolution - SSC/SSCWeb (NASA’s GSFC) [Available Time Range: 1997/08/25 17:48:00 - 2018/03/26 23:36:00]

The list of interesting data sets for ACE and DSCOVR are in table 1.

<table>
<thead>
<tr>
<th>Data</th>
<th>ACE</th>
<th>DSCOVR</th>
</tr>
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<tbody>
<tr>
<td>IMF</td>
<td>AC_XX_MFI</td>
<td>DSCOVR_H0_MAG</td>
</tr>
<tr>
<td>SW plasma speed</td>
<td>AC_XX_SWE</td>
<td>DSCOVR_H1_FC</td>
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<td>SW plasma particle density</td>
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<tr>
<td>Position</td>
<td>AC_OR_SSC</td>
<td>DSCOVR_ORBIT_PRE</td>
</tr>
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</table>

4.2 Sample plots

Let’s plot an event. Select the period 20–25 June 2016 to capture the geomagnetic storm that commenced on 22 June 2016. Figure 1 shows the solar wind velocity components in GSE coordinates and Fig. 2 the IMF components in GSE. Figure 3 shows the near earth region with the earth at origin, moon (magenta squares) and both spacecraft position and $V_{sw}$ vector (scaled by ×1000).

Figure 1: ACE and DSCOVR solar wind velocity components in GSE coordinates.
Figure 2: ACE and DSCOVR interplanetary magnetic field components in GSE coordinates.

Figure 3: Near-Earth environment in GSE coordinates with Earth at the origin (red star), the moon (magenta squares) and the ACE (blue) and DSCOVR (orange) spacecraft showing measured $V_{sw}$ vectors at each position. The vectors are colour-coded to run from blue to red, implying that ACE orbits in clockwise direction and DSCOVR in the counter-clockwise direction, when viewed from Earth.
References