Optimizing the Time-Lag Estimate between Spacecraft for Recurring Solar Wind Structures

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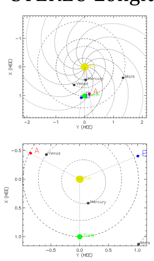
EGU2018-9885

Abstract

One may use the longitudinal coverage of different spacecraft assets, or the same asset over sequential Carrington Rotations, to study the solar wind behavior and evolution from long-lived large-scale solar structures (coronal holes, active regions). The STEREO observatories are ideally suited for these longitudinal studies. Since commissioning in 2007, the two STEREO spacecraft (A, B) drifted away from the Earth by 22.5° per year, in opposite directions. Since solar conjunction in 2015, the STEREO spacecraft began drifting back toward the Earth. The early mission included the declining phase of Cycle 23, while the recent observations cover the same phase for Cycle 24. These orbital and cycle phase circumstances present unique conditions for studying the persistence of solar wind parameters over various delta solar longitudes during solar minimum conditions. Prior solar wind persistence studies during solar minimum estimated about 2-3 days robustness (e.g., Opitz et al. 2009 and references therein), although this result depends upon the type of solar wind structure being studied. Here we look at intervals during the declining phase of Cycle 23 (early mission) and Cycle 24 (post solar conjunction), when solar winds emanating from long-lived coronal-hole structures are observed both at STEREO and at near-Earth assets (OMNI2). The observations have been selected for similar solar latitudes but temporal separation in solar longitude, to observe how well the time-lag estimate being used aligns the solar wind structures.

Introduction

STEREO Longitudes, Then and Now

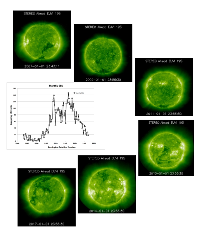


Early Orbit. Earth-STA-STB separations were initially very close, with the Earth-ST longitudinal angle gradually increasing by ~22.5° per year. Orbit shown for July 1, 2007, with Earth-STA separation at ~10°, Earth-STB separation ~6°.

Post Conjunction. Earth-STA separation is currently 118° (April 10, 2018), and gradually closing (~ 22.5° per year). Earth-STB separation is currently 111°, gradually closing by ~22.5° per year.

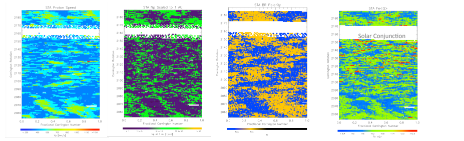
(Communications were lost with STB in October 2014, and recovery efforts are underway.)

Different Solar/SW Features Separated in Longitude During Cycle Phase



Solar features, such as coronal holes (CH), active regions (AR), and the heliospheric current sheet and plasma sheet (HCS, HPS), change over the sun spot cycle.

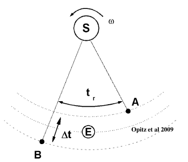
This means the solar wind and interplanetary conditions also change. Coronal Hole associated High Speed Streams and Stream Interface Regions (SIRs) are more prevalent near Solar minimum conditions, while Interplanetary Coronal Mass Ejections (ICMEs) are more prevalent near Solar maximum conditions.



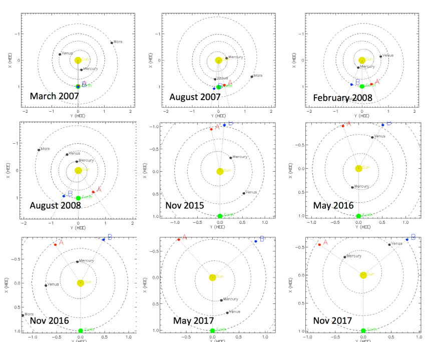
A data organization by Carrington Rotation Number, where each CRN represents one solar rotation, is useful to see large-scale, long-lived solar wind structures. Above, various solar wind in-situ parameters (Vp, Np, Br polarity, and Iron Charge State) are organized by the STA CRN. The last solar minimum clearly shows two sets of recurring high-speed solar wind (from mid-latitude coronal holes) with uni-direction magnetic field and low Fe<Q>. These are preceded by high density ridges (SIRs). However, one also sees an apparent drift in the location of the solar wind structures within successive CRNs. This drift is, in part, due to the differential rotation of the Sun. The CRN is defined for the mid-latitude Sun (near 26°), while the in-situ measurements are taken in the ecliptic plane (+/- 7° latitude). (And, the solar source could be at other latitudes!)

Methodology

- Event Selection To minimize the influence of latitudinal effects on the solar structures contributing to the solar wind, periods have been identified that, when the STA trajectory is projected to Earth's longitude, the STA and Earth have similar solar latitudes. This increases the probability of having the solar wind originate from the same solar structure, with similar solar latitudinal rotation rates. This does not take into account potential temporal evolution of the solar wind source, nor the inclusion of transient phenomena.

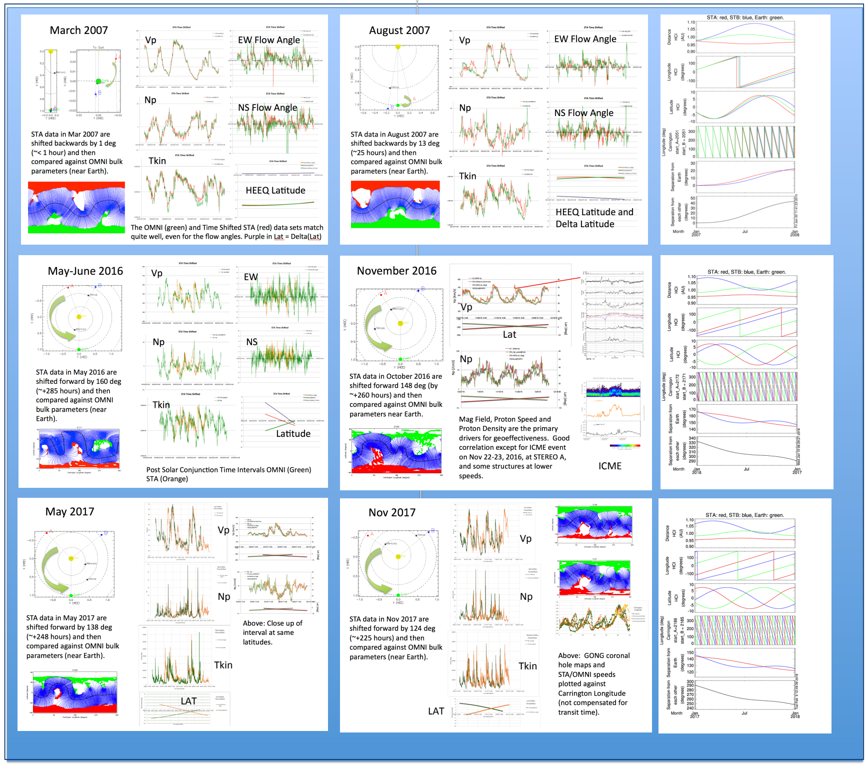


The technique for time shifting of the STA data to earth is similar to that used by Opitz et al. (2009), which took into account the longitudinal and radial separations of the spacecraft/planet. The distinction here is limiting the periods to the same latitude, and using the ST and Earth latitude to correct the solar rotation as given by Snodgrass (1990), for each minute of data covered in the interval of study.



Longitudinal separations for periods where the time-shifted STA and Earth had same solar latitudes. This criteria is met about twice a year.

Time-shifted Solar Wind Parameters (Not All Events Shown)



Summary

Finding a robust technique for aligning solar wind structures at different longitudes, latitudes, and radial distances is of scientific importance: e.g., for studying the evolution of solar wind structures such as SIRs (Jian et al.,2009; Simunac et al., 2009a; Conlon et al., 2015), and determining the quasi-stationary vs. transient nature of the HPS (Liu et al. 2014). There is also interest from a space weather forecast perspective. At 60° prior to Sun-Earth Line, solar wind structures at L5 will be sampled ~ 4 days prior arrival at the Sun-Earth line. Accuracy of L5 'forecasts' hence depend on the persistence of solar structures. In this manner, STB in the past acted as a test bed to check the robustness of L5 as a solar wind monitor, achieving relatively good correlations during the last declining phase (Simunac et al., 2009b; Turner and Li, 2011). One challenge is the temporal evolution of the structures on the Sun and the affect of 'sampling' different solar sources due to different solar latitudes of the in-situ spacecraft observations. Here we looked at case studies from the previous and current approaches to solar minimum where solar wind emanating from long-lived coronal-hole structures are observed both at STEREO A and at near-Earth assets (OMNI2). The observations are taken at similar solar latitudes and synoptic (Carrington) longitudes but temporally separated by hours to weeks. These present ideal conditions for studying the persistence of solar wind parameters over various delta longitudes, near minimum conditions. The next phase of the study to to quantify (e.g., through correlation coefficients) these results at similar latitudes and as the latitudes diverge.

Acknowledgements

Remote Images courtesy STEREO SECCHI (Howard) and SDO/AIA (Title). OMNI data courtesy NASA/GSFC's Space Physics Facility's ftp service. IMPACT Data (Luhmann). GONG data from NSO. Orbit data: https://stereo-ssc.nascom.nasa.gov/where.shtml PLASTIC NASA Grant NNX15AU01G at UNH.

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