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Solar wind prediction for the Parker Solar Probe orbit

Near-Sun extrapolations derived from an empirical solar wind model based on Helios and OMNI observations

M. S. Venzmer and V. Bothmer

University of Goettingen, Institute for Astrophysics, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

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ABSTRACT

Context. In view of the planned near-Sun spacecraft mission Parker Solar Probe (PSP) (formerly Solar Probe Plus) the solar wind environment for its prime mission duration (2018–2025) and down to its intended closest perihelion (9.86 solar radii) is extrapolated using in situ data. The PSP mission will be humanity's first in-situ exploration of the solar corona of a star. Visiting this yet uncharted region is of special interest, because it will to help answer hitherto unresolved science questions on the heating of the solar corona and the source and acceleration of the solar wind, its structure and dynamics and the acceleration of and solar energetic particles. PSP is currently scheduled for launch in mid 2018. The solar wind extrapolation of this study is performed within the project CGAUSS (Coronagraphic German And US Solar Probe Survey) which is the German contribution to the PSP mission as part of the Wide field Imager for Solar PRobe (WISPR). Within the CGAUSS project the solar wind environment is extrapolated down to the closest perihelion of 9.86 solar radii distance to the Sun using in situ solar wind data. from the German-US Helios 1 and 2 space probes, including 1 AU data from various satellites compiled in the NASA/GSFC OMNI solar wind database.

Aims. We present the development of an empirical solar wind model for the inner heliosphere which is derived from Helios and OMNI in situ data. The German-US space probes Helios 1 and Helios 2 flew in the 1970s and observed solar wind in the ecliptic within heliocentric distances of 0.29–0.98 AU. The OMNI database at NASA's Space Physics Data Facility (SPDF) consists of multi-spacecraft intercalibrated in situ data obtained near 1 AU. The solar wind model is used together with sunspot number predictions to estimate the frequency distributions of major solar wind parameters PSP will encounter during its mission.

Methods. The established model covers the solar wind's magnetic field strength and its plasma parameters proton density, velocity and temper- ature. Their individual frequency distributions are represented with lognormal functions. In addition, we also consider the velocity distribution's bi-componental shape, consisting of a slower and a faster part. The model accounts for solar activity and for solar dis- tance dependency by shifting of these lognormal distributions nicht klar. We take into account dependencies on compile functional relations to solar activity by correlating and fitting the frequency distributions with the sunspot number (SSN), using almost five solar cycles of OMNI data. Further, based on the combined data set from both Helios probes, the parameters' frequency distributions are fitted with respect to solar distance to obtain exponential dependencies. Finally, by combining the found solar cycle and solar distance relations, we obtain a simple dynamical solar wind model for the inner heliosphere, confined to the ecliptic region.

Results. The inclusion of SSN predictions and the extrapolation to the PSP perihelion region enables us to estimate the solar wind environment for the PSP's planned trajectory during its prime mission duration 2018--2025. The estimated solar wind values at PSP's nearest perihelion are: ... Their values vary up to 0.0000 %, arising only from differing amplitude assumptions for the next solar cycle.

Key words. solar wind – sun: heliosphere – sun: corona

1. Introduction

Almost at the same time From observations of cometary tail fluctuations (ref.) Biermann (1951) (Kometenschweife und solare Korpuskularstrahlung) inferred the presence of a continuous flow of particles from the Sun. With his theoretical solar wind model Parker (1958) formulated the existence of the solar wind even before the first satellites measured it in-situ in 1962 (ref. Neugebauer1966, Mariner 2 Observations of the Solar Wind, 1, Average Properties).

The idea of a space mission flying through the solar corona dates back to the founding year of NASA in 1958 (ref.). Since then several space missions like Helios 1 and 2, and Voyager 1 and 2 have measured the solar wind in situ at a wide range of heliocentric distances, in the case of Voyager 1 as far away as 138 AU, having even left the heliospause into interstellar space (ref. Gurnett2013). Ulysses was the unique probe that orbited the Sun out of the ecliptic plane and thus could retrieve solar wind measurements from the poles of the Sun (ref.). So far, Helios 2 made the nearest in situ solar wind measurements ever at a distance as close to the Sun as 0.29 AU, closely followed by Helios 1 with 0.31 AU.

The Parker Solar Probe (PSP), with a planned launch date in mid 2018, will reach after six years in 2024 a distance of 9.86 RS, i.e. 0.0459 AU. This distance will be achieved through seven Venus gravity assists with orbital periods of 88--168 days. In its prime mission time 2018--2025 PSP provides 24 orbits with perihela inside 0.25 AU.

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It will be humanity's first space probe flying through the solar corona, providing the first in-situ measurements of the coronal and near-Sun solar wind plasma and magnetic field parameters and the properties of solar energetic particles, as well as their structures and dynamics.

The key PSP science objectives are to "trace the flow of energy that heats and accelerates the solar corona and solar wind, determine the structure and dynamics of the plasma and magnetic fields at the sources of the solar wind, and explore mechanisms that accelerate and transport energetic particles" (ref.1 NASA STDT report, ref.2 Fox et al 2015). To achieve these goals, PSP has four scientific instruments on board: FIELDS for the measurements of magnetic fields and AC/DC electric fields, SWEAP for the measurements of flux of electrons, protons and alphas, ISIS for the measurement of solar energetic particles and WISPR for the measurement of coronal structures (ref. to each instrument paper).

The Wide field Imager for Solar Probe (WISPR) will contribute to the science goals by deriving the 3D structure of the solar corona through which the in-situ measurements are made to determine the sources of the solar wind. It will provide density power spectra over a wide range of structures, e.g., streamers and pseudostreamers, equatorial coronal holes, for determining the roles of turbulence, waves, and pressure-balanced structures in the solar wind. It will also measure the physical properties, such as speed and density jumps, of SEP-producing shocks and their CME drivers as they evolve in the corona and inner heliosphere (ref. Vourlidas et al., 2016).

CGAUSS (Coronagraphic German And US Solar Probe Survey) is the German contribution to the PSP mission as part of the Wide field Imager for Solar PRobe (WISPR). One of the objectives of the CGAUSS project is to extrapolate the solar wind environment down to the closest perihelion of 9.86 Rs distance to the Sun in order to optimize the WISPR and PSP science operations. To achieve that goal this study uses for this approach in situ solar wind data from the US-German Helios 1 and 2 space probes and 1 AU data from various satellites compiled in the NASA/GSFC OMNI solar wind database.

This paper examines the variations of the bulk solar wind frequency distributions, considers solar activity and extrapolates these distributions to the near-Sun region.

In section 2 we …, in section will …

2. Solar wind environment

As a baseline we treat the solar wind primarily as a proton plasma, because the average helium abundance is only about 4.5 % and in slow wind at solar cycle minimum even less than 2 % (Feldman et al. 1978; Schwenn 1983; Kasper et al. 2012). Neglecting heavier ions, the electron and mass density can then be derived ….

The characteristic behavior of a magnetized plasma is deter- mined by its *density*, *temperature and magnetic field strength* *(ref.)*. Furthermore, the bulk flow *velocity* is the parameter which makes the plasma a 'wind'. For this study we define the solar wind envi- ronment through these four major solar wind parameters a, b, c, d. Quantities like flux densities, mass flux and plasma beta can directly be derived from those four parameters (ref.).

Generally, two types of solar wind are observed in the heliosphere, as slow and fast streams (ref. Neugebauer 1966, Schwenn (19xx), McComas et al. (19xx)). Fast streams are found to originate from coronal holes as Ulysses polar measurements revealed (ref.). whereas The origin of slow wind is a subject of controversial discussions because several sources are closed magnetic structures in the solar corona, such as Schwenn (19xx) has even reported the possibility of four types of solar wind depending on the phase of the solar cycle/activity.

The solar wind velocity is the defining parameter of the two types of solar wind. Slow solar wind has typical speeds of < 400 km/s and fast solar wind has speeds > 600 km/s (ref. s. Buch Schwenn1990, p. 144). Their different compositions and characteristics indicate different sources and generation processes (ref. in McGregor et al. 2011b). Their occurrence frequency varies strongly with the solar activity cycle and their interactions lead to phenomena such as stream interaction regions (SIRs) and for quasi-stationary coronal source regions to co-rotating interaction regions (CIRs, ref. Buch über CIRs).

Superimposed on Embedded in the slow and fast solar wind streams are coronal mass ejections (CMEs, ref.). Their frequency in near 1 AU measurements varies between almost zero during solar cycle minima ~~up to a daily rate of about 0.5 during times of solar maximum (Richardson & Cane 2012). This study averages over these internal solar wind structures.~~

Since one cannot know which specific solar wind type or struc-ture PSP will encounter at a given point in time during its mission, we extrapolate the parameters' probability distributions from existing solar wind measurements.

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Our approach is to get an analytical representation of the frequency distributions' shapes, their solar activity dependence and their solar distance scaling. We get the parameters' frequency distributions and solar activity dependence from near-Earth solar wind and sunspot number (SSN) time series with a duration of almost five solar cycles and their distance dependency from solar wind measurements of more than half a solar cycle, covering more than two third of the distance to the Sun (0.29–0.98 au).

[...]