8. Summary

The scientific objective of this study, being part of the German contribution Coronagraphic German and US Solar Probe Plus Survey (CGAUSS) to the Wide field Imager for Solar Probe (WISPR), is to model the solar wind environment for the Parker Solar Probe mission (formerly Solar probe Plus) to be launched mid 2018 as.

For this purpose we derived lognormal representations of the frequency distributions' shapes of the four key solar wind parameters magnetic field strength, proton velocity, proton density and proton temperature for the near-Earth solar wind OMNI data, and the Helios 1 and 2 data obtained over the solar distance range 0.29–0.98 au. The dependencies of these frequency distributions on the solar activity cycle, as measured by the international sunspot number, and on radial distance to the Sun were modeled with analytical relations and then extrapolated to the Parker Solar Probe orbit, taking into account predictions of the sunspot number. With the resulting CGAUSS empirical solar wind model for PSP the following main results for the bulk solar wind parameters and estimations for their solar wind median values at PSP's first perihelion in 2018 at a solar distance of 0.16 au and for PSP's closest perihelion in 2024 at 0.046 au (9.86 RS) are obtained:

- The dependency of the magnetic field strength median value on solar activity and radial distance is
  $B_{med}(ssn, r) = (0.0131\ nT \bullet ssn + 4.29\ nT) \bullet r^{-1.66}$. (12)
  This approximation starts to reveals uncertainties of about 20 % in the distance range below 20 RS distance from the Sun.
- The estimated magnetic field strength values for PSP's first and closest perihelion are 87 nT and 943 nT.
- The radial dependencies of the median velocity values for slow and fast solar wind are

  $v_{slow}(r) = 363\ km\ s^{-1} \bullet r^{0.099}$ and (13)

  $v_{fast}(r) = 483\ km\ s^{-1} \bullet r^{0.099}$. (14)

  These relations appear valid to distances of above about 20 RS solar distance, before below they overestimate the actual solar wind velocities obtained from remote measurements.
- The calculated proton velocity values for PSP's first and closest perihelion are 340 km s^{-1} and 290 km s^{-1}.

- The share of their frequency distributions to the overall solar wind distribution is depending on solar activity, as measured by the international sunspot number their balance was found to be c(ssn) = 0.00180 ssn + 0.64. At solar minimum with sunspot numbers around 0 the slow wind contributes to about 64% to the overall solar wind distribution and dropping to 28 % at solar maximum conditions with sunspot numbers around 200.

– The median density relation is found to be

$n_{med}(ssn, r) = 0.0038\ cm^{-3} \bullet ssn + 4.50\ cm^{-3} \bullet r^{-2.11}$. (15)

This relationship seems valid throughout the full PSP orbital distance range, even down to about 8 RS.

- The estimated proton density values for PSP's first and closest perihelion are 4015 cm^{-3} and 9733 cm^{-3}.

– The derived correlation function for the median temperature is

$T_{med}(ssn, r) = (197\ K \bullet ssn + 57\ 300\ K) \bullet r^{-1.10}$. (16)

Around PSP's perihelion this relationship seems to provide too high proton temperature values in comparison to coronal measurements.

- The estimated proton temperature values for PSP's first and closest perihelion are 503 000 K and 1 930 000 K.

The overestimation limitations of the extrapolated velocity and temperature values at distances below 20 Rs indicate the occurrence of solar wind acceleration and heating processes, which PSP will thus be able to directly measure these processes as planned.

The results of the modeled solar wind environment will be useful to help optimize the WISPR and in situ instrument science plannings and PSP mission operations. This also applies for the Heliospheric Imager (SoloHI) (Howard et al. 2013) and the in situ instruments on board the Solar Orbiter spacecraft.

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ABSTRACT

Context. The Parker Solar Probe (PSP) (formerly Solar Probe Plus) mission will be humanity's first in situ exploration of the solar corona with a closest perihelia at 9.86 solar radii distance to the Sun. It will help answer hitherto unresolved questions on the heating of the solar corona and the source and acceleration of the solar wind and solar energetic particles. The scope of this study is to model the solar wind environment for PSP's unprecedented distances during its prime mission phase during the years 2018–2025. The study is performed within the project Coronagraphic German And US Solar Probe Survey (CGAUSS) which is the German contribution to the PSP mission as part of the Wide field Imager for Solar PRobe (WISPR).

Aims. We present an empirical solar wind model for the inner heliosphere which is derived from OMNI and Helios data. The German-US space probes Helios 1 and Helios 2 flew in the 1970s and observed solar wind in the ecliptic up to within heliocentric distances of 0.29–0.98 au. The OMNI database consists of multi-spacecraft intercalibrated in situ data obtained near 1 au and provides data for over more than five solar cycles. The international sunspot number (SSN) and its predictions are used to derive the dependencies of the solar wind parameters on solar activity and to forecast its properties for the PSP mission.

Methods. The frequency distributions for the solar wind key parameters magnetic field strength, proton velocity, number density and temperature of the OMNI and Helios data are represented by lognormal functions. In addition, we consider the solar wind velocity distribution's bi-componental shape, consisting of a slower and a faster part. Functional relations to solar activity are compiled with use of the OMNI data by correlating and fitting the frequency distributions with the SSN. Further, based on the combined data set from both Helios probes, the parameters' frequency distributions are fitted with respect to solar distance to obtain power law dependencies. Thus Based on the analysis of the OMNI and Helios data sets an empirical solar wind model for the inner heliosphere confined to the ecliptic region is derived, accounting for solar activity and for solar distance through adequate shifts of the lognormal distributions. Finally, the inclusion of SSN predictions and the extrapolation to PSP's perihelion enables us to estimate the solar wind environment for PSP's planned trajectory during its mission duration. From the found relationships of the functions with solar activity the solar wind parameter frequency distributions are fitted with power law dependencies. Finally, through extrapolation the empirical solar wind model for the PSP orbit and its expected phase of the sunspot cycle is obtained.

Results. The CGAUSS empirical solar wind model for PSP yields dependencies of the solar wind parameters median values on solar activity and radial distance. The estimated for the solar wind median values for PSP's first perihelion in 2018 at a solar distance of 0.16 au are 87 nT, 340 km s−1, 4015 cm−3 and 503 000 K. and The estimates for PSP's closest perihelia, beginning in 2024 at 0.046 au (9.86 RS), are 943 nT, 290 km s−1, 9733 cm−3 and 1 930 000 K. Though, the modeled velocity and temperature values below 20 RS appear overestimated in comparison with existing observations. Thus, PSP is expected to directly measure solar wind acceleration and heating processes below 20 RS as planned.

Key words. solar wind – sun: heliosphere – sun: corona, Parker Solar Probe