The solar wind's geomagnetic impact and its Sun–Earth evolution

Predictive models for space weather and for the Parker Solar Probe orbit

PhD defense by
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Thursday, 1 November 2018, 14:00
Seminarraum Astrophysik (SR 17, F 05.104)

Two topics

Title

The solar wind's geomagnetic impact and its Sun–Earth evolution

–

Predictive models for space weather and for the Parker Solar Probe orbit

Two topics

Study 1

The solar wind's geomagnetic impact – Predictive models for space weather

Two topics

Study 1

The solar wind's geomagnetic impact – Predictive models for space weather

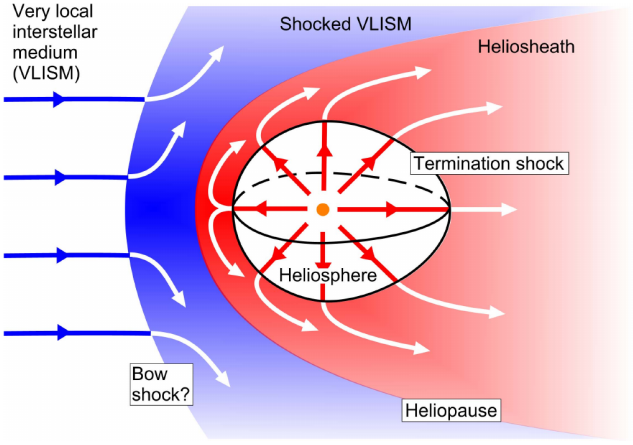
Study 2

The solar wind's Sun–Earth evolution – Predictive models for the Parker Solar Probe orbit

Solar wind

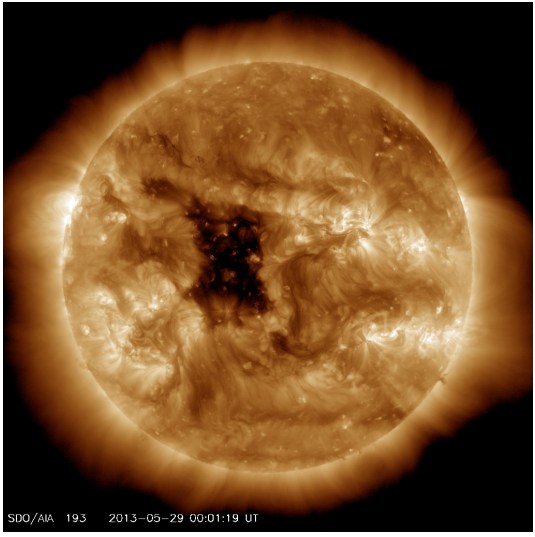
Credit: Miloslav Druckmüller, Peter Aniol, Shaddia Habbal, 2017

Solar wind



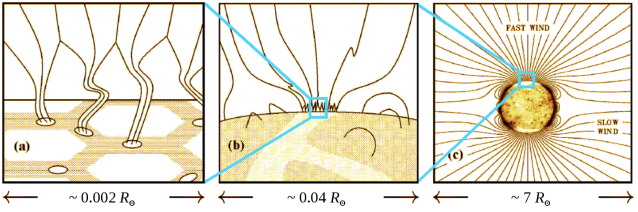
Credit: Owens & Forsyth (2013, Fig. 9)

Solar wind



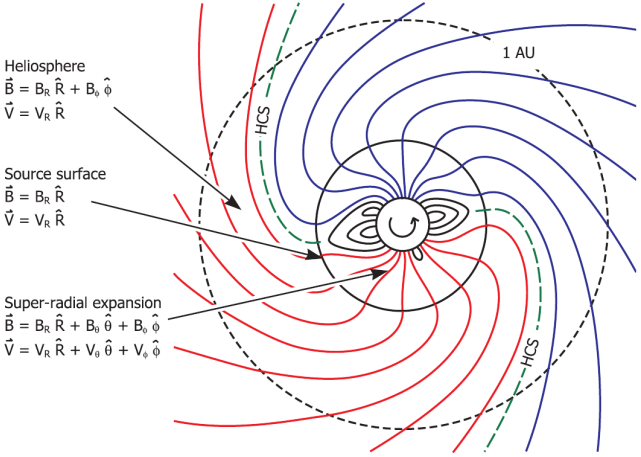
Credit: NASA/SDO and the AIA, EVE and HMI science teams

Solar wind



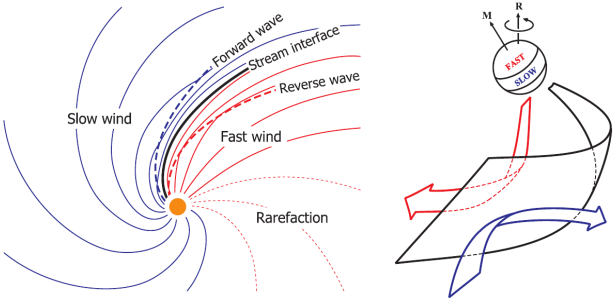
Courtesy of S. R. Cranmer

Solar wind



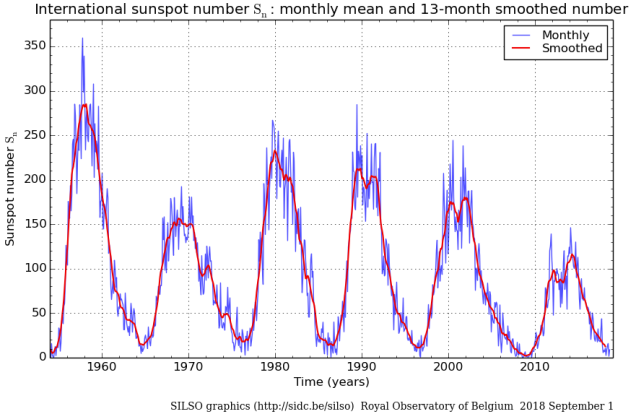
Credit: Owens & Forsyth (2013, Fig. 1), adapted from Schatten et al. (1969, Fig. 1)

Solar wind



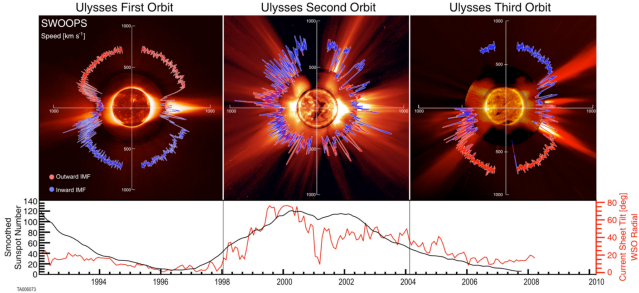
Credit: Owens & Forsyth (2013, Fig. 7); right panel adapted from Pizzo (1991, Fig. 2)

Solar wind



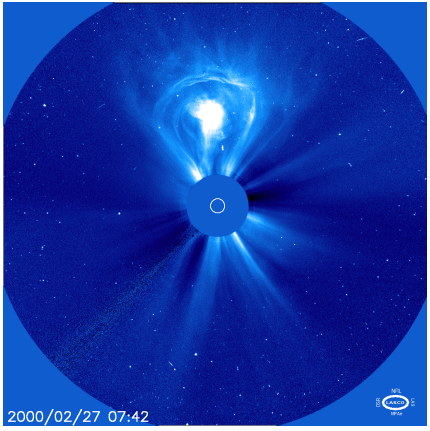
Credit: SILSO data/image, Royal Observatory of Belgium, Brussels, 2018

Solar wind

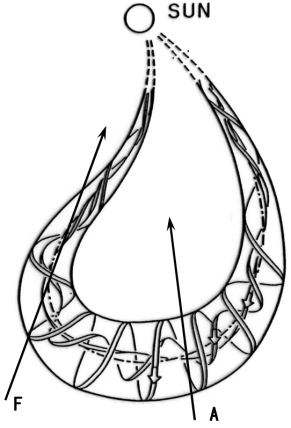


Credit: McComas et al. (2008a, Fig. 1)

Solar wind

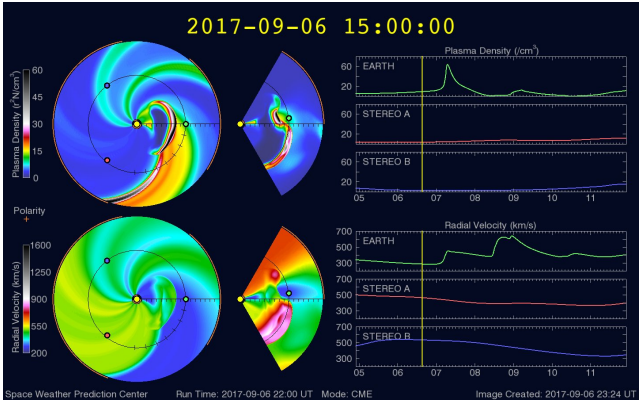


Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA



Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

Solar wind



Credit: SWPC: WSA-Enlil Solar Wind Prediction. NOAA National Centers for Environmental Information

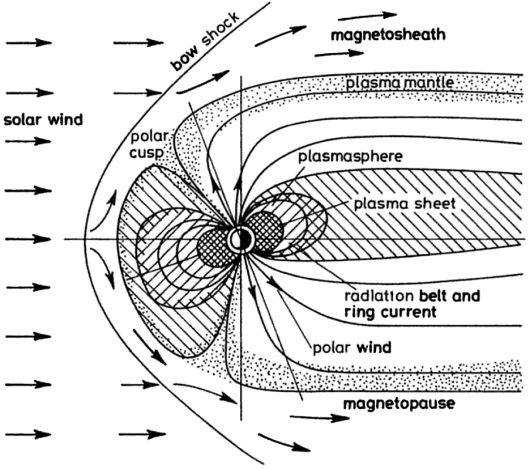
Geomagnetic impact of the solar wind

images...

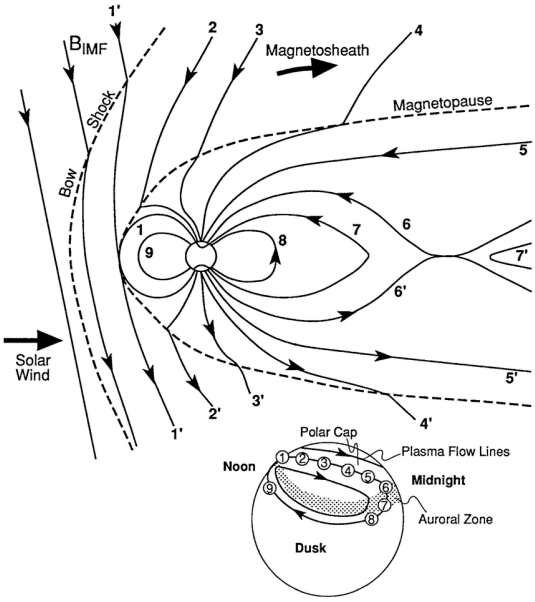
Geomagnetic impact of the solar wind

Aims

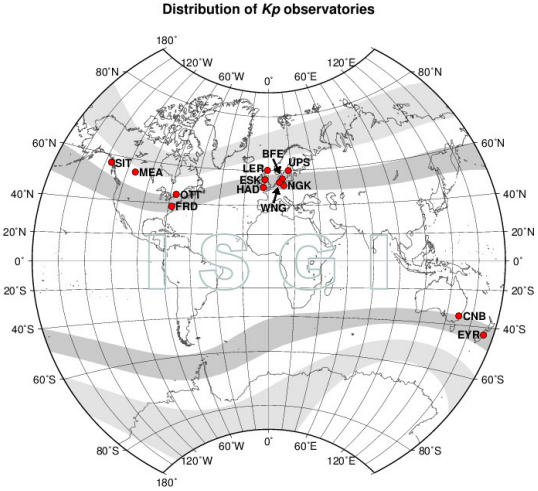
Empirical relations to predict the Kp index from solar wind electric field and from CME and stream velocity



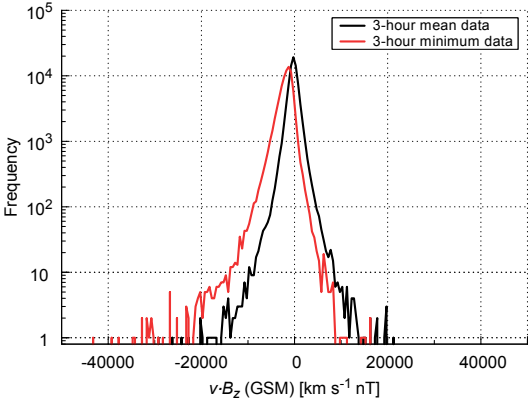
Credit: Davies (1990, Fig. 2.12)

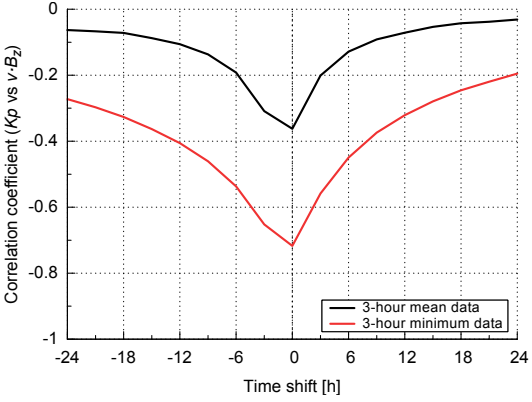


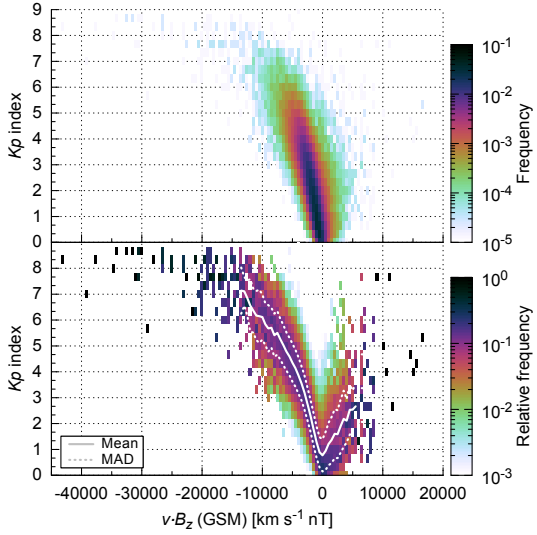
Credit: Hughes (1995, Fig. 9.11)

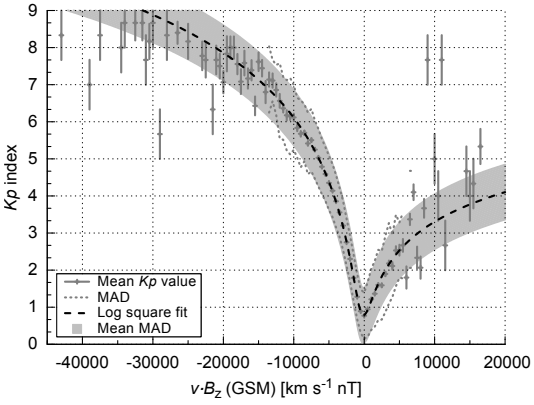


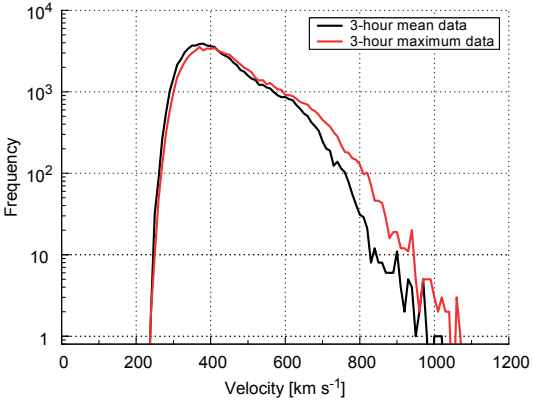
Courtesy of International Service of Geomagnetic Indices (ISGI), 2013

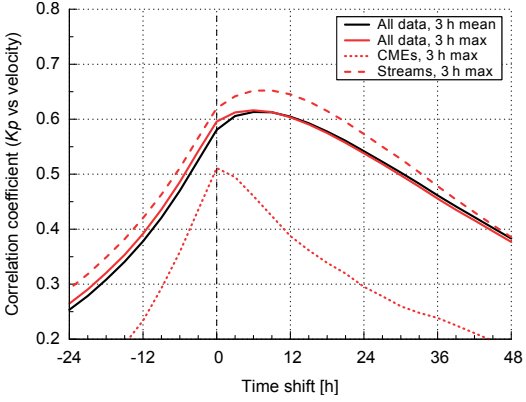

3-hour mean data
3-hour minimum data
Frequency
10^5
10^4
10^3
10^2
10
1
-40000
-20000
0
20000
40000
$v \cdot B_z$ (GSM) [km s^{-1} nT]

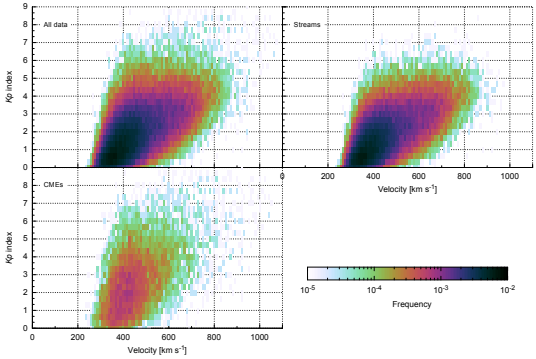

Correlation coefficient (Kp vs $v \cdot B_z$)
0
-0.2
-0.4
-0.6
-0.8
-1
-24
-18
-12
-6
0
6
12
18
24
Time shift [h]
3-hour mean data
3-hour minimum data

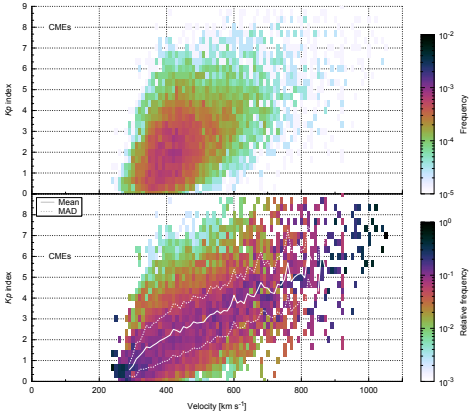

Kp index
Frequency
Relative frequency
Mean
MAD
v·B_z (GSM) [km s^-1 nT]

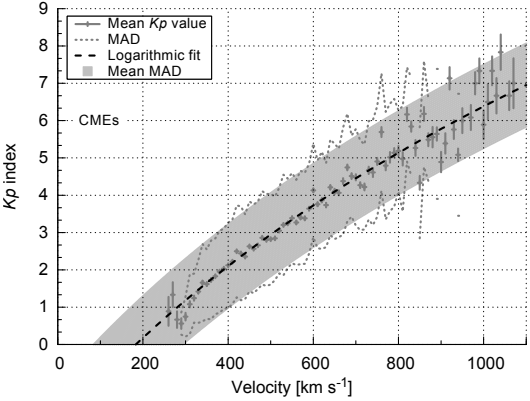

Kp index
Mean Kp value
MAD
Log square fit
Mean MAD
v·B_z (GSM) [km s^-1 nT]

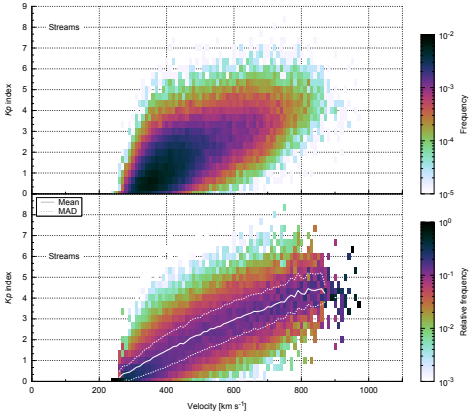

3-hour mean data
3-hour maximum data
Frequency
Velocity [km s-1]
10^4
10^3
10^2
10
1
0
200
400
600
800
1000
1200

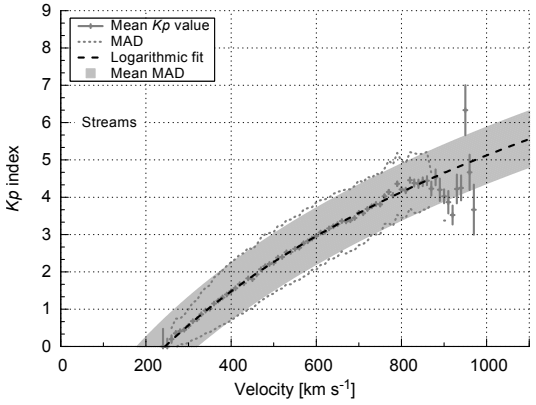

All data, 3 h mean
All data, 3 h max
CMEs, 3 h max
Streams, 3 h max
Correlation coefficient (Kp vs velocity)
Time shift [h]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
-24
-12
0
12
24
36
48

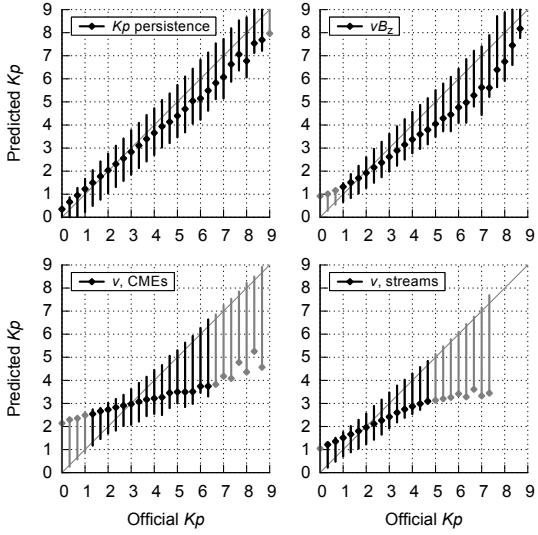

All data
Streams
CMEs
Kp index
Velocity [km s⁻¹]
Frequency
10⁻⁵
10⁻⁴
10⁻³
10⁻²

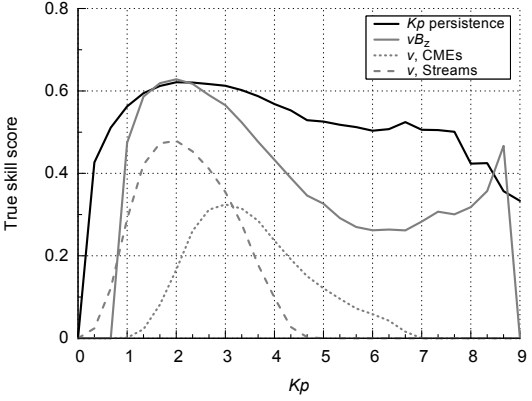

CMEs
Kp index
Frequency
Mean
MAD
CMEs
Kp index
Relative frequency
Velocity [km s-1]

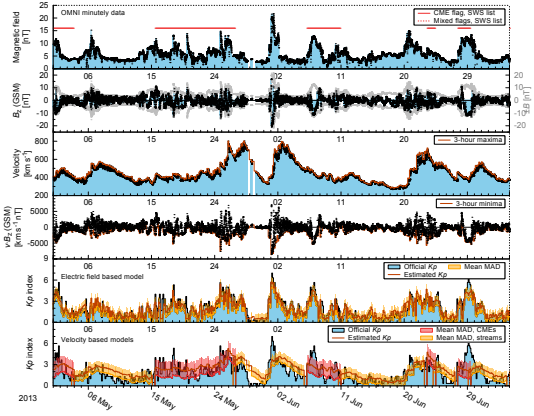

Mean Kp value
MAD
Logarithmic fit
Mean MAD
CMEs
Kp index
Velocity [km s-1]

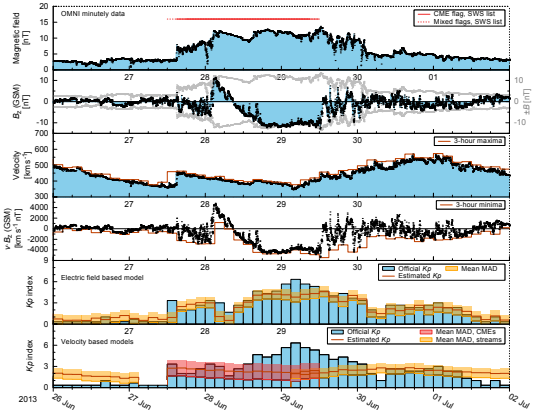

Streams
Kp index
Frequency
Mean
MAD
Streams
Kp index
Relative frequency
Velocity [km s-1]

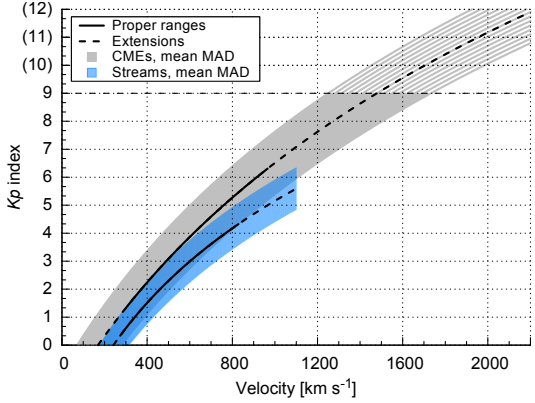

Mean Kp value
MAD
Logarithmic fit
Mean MAD
Streams
Kp index
Velocity [km s-1]


Kp persistence
vBz
v, CMEs
v, streams
Predicted Kp
Predicted Kp
Official Kp
Official Kp


Kp persistence
vBz
v, CMEs
v, Streams
True skill score
Kp


OMNI minutely data
CME flag, SWS list
Mixed flags, SWS list
Magnetic field [nT]
B_z (GSM) [nT]
B_T [nT]
3-hour maxima
Velocity [km s^{-1}]
3-hour minima
$v \cdot B_z$ (GSM) [km s^{-1} nT]
Official Kp
Estimated Kp
Mean MAD
Electric field based model
Kp index
Mean MAD, CMEs
Mean MAD, streams
Velocity based models
2013
06 May
15 May
24 May
02 Jun
11 Jun
20 Jun
29 Jun


OMNI minutely data
CME flag, SWS list
Mixed flags, SWS list
Magnetic field [nT]
B_z (GSM) [nT]
B_t [nT]
3-hour maxima
Velocity [kms^{-1}]
3-hour minima
$v \cdot B_z$ (GSM) [kms^{-1} nT]
Official Kp
Estimated Kp
Mean MAD
Electric field based model
Kp index
Mean MAD, CMEs
Mean MAD, streams
Velocity based models
2013
26 Jun
27 Jun
28 Jun
29 Jun
30 Jun
01 Jul
02 Jul


(12)
(11)
(10)
9
8
7
6
5
4
3
2
1
0
Kp index
Proper ranges
Extensions
CMEs, mean MAD
Streams, mean MAD
0
400
800
1200
1600
2000
Velocity [km s-1]

Results

Predictive Kp models based on relations with

- solar wind electric field proxy (vB_z)
- velocity of CME-associated flows (v_{CME})
- velocity of solar wind streams (v_{stream})

Conclusions

- The processing of 3-hour extrema of high time resolution data captures short-term geoeffective magnetic features that are neglected when averaging over 3-hour intervals
- The isolated treatment of CMEs and streams is beneficial to the prediction accuracy of Kp
- The prediction models perform well for their limited input information

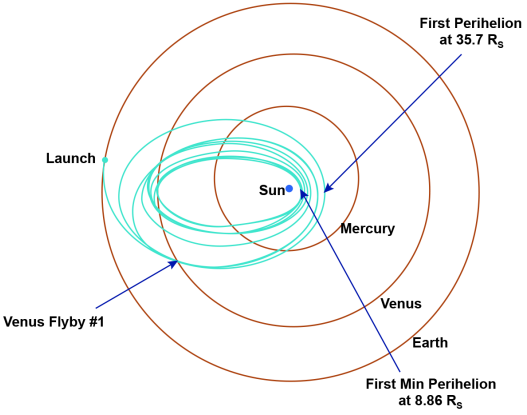
Sun–Earth evolution of the solar wind

images...

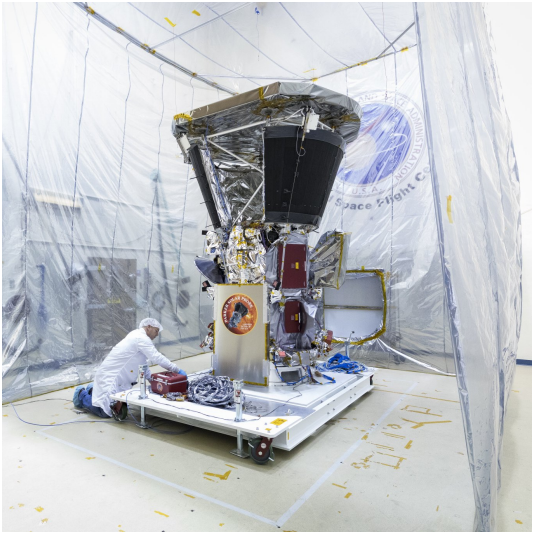
Sun–Earth evolution of the solar wind

Aims

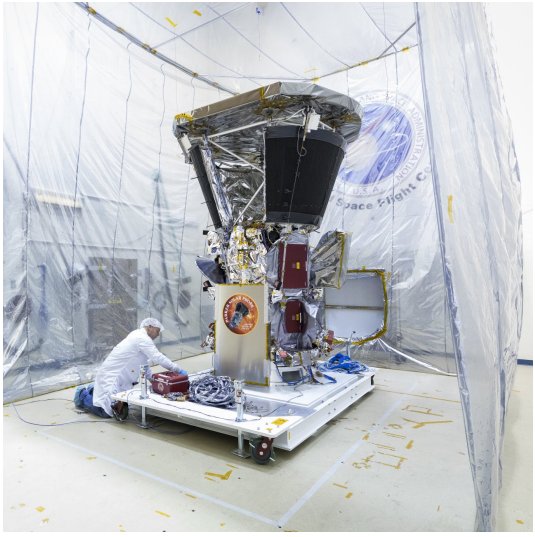
Solar wind model for the inner heliosphere and prediction of the near-Sun environment for the PSP orbit



Credit: NASA/Johns Hopkins APL, 2018

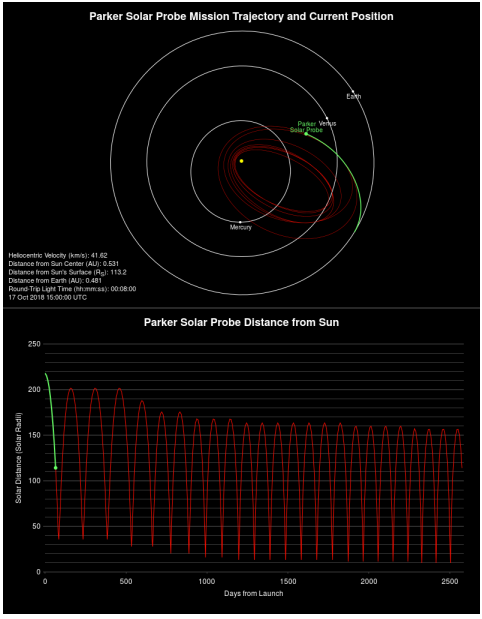


Credit: NASA/Johns Hopkins APL/Ed Whitman, 2017

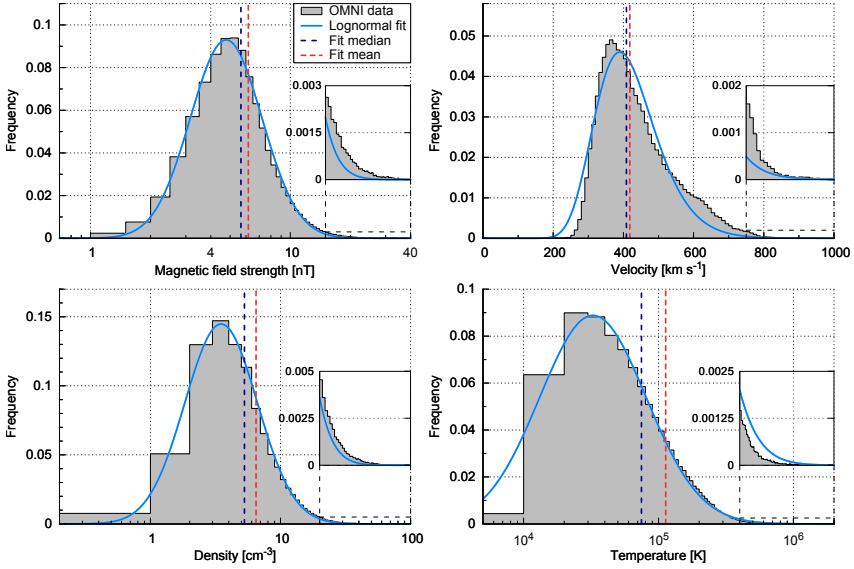


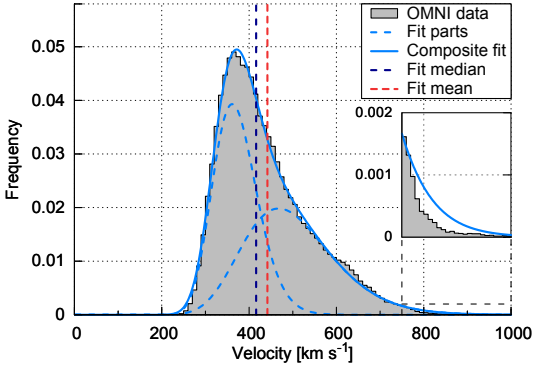
Credit: NASA/Johns Hopkins APL/Ed Whitman, 2017

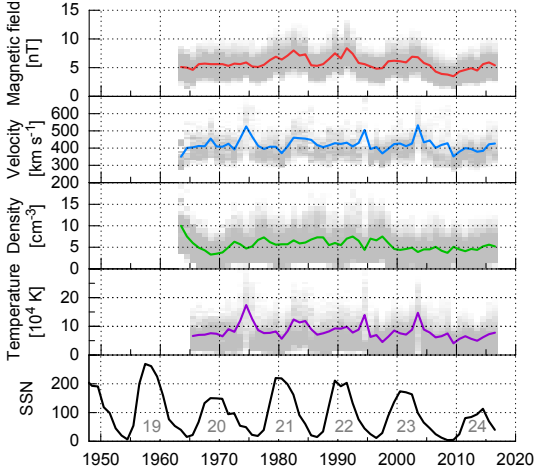
Credit: NASA/Johns Hopkins APL/Ed Whitman, 2018

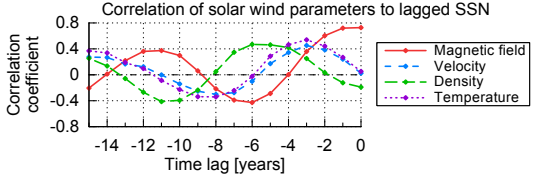

Parker Solar Probe Mission Trajectory and Current Position
Earth
Parker Solar Probe
Venus
Mercury
Heliocentric Velocity (km/s): 41.62
Distance from Sun Center (AU): 0.531
Distance from Sun's Surface (R_S): 113.2
Distance from Earth (AU): 0.481
Round-Trip Light Time (hh:mm:ss): 00:08:00
17 Oct 2018 15:00:00 UTC
Parker Solar Probe Distance from Sun
Solar Distance (Solar Radii)
250
200
150
100
50
0
0
500
1000
1500
2000
2500
Days from Launch

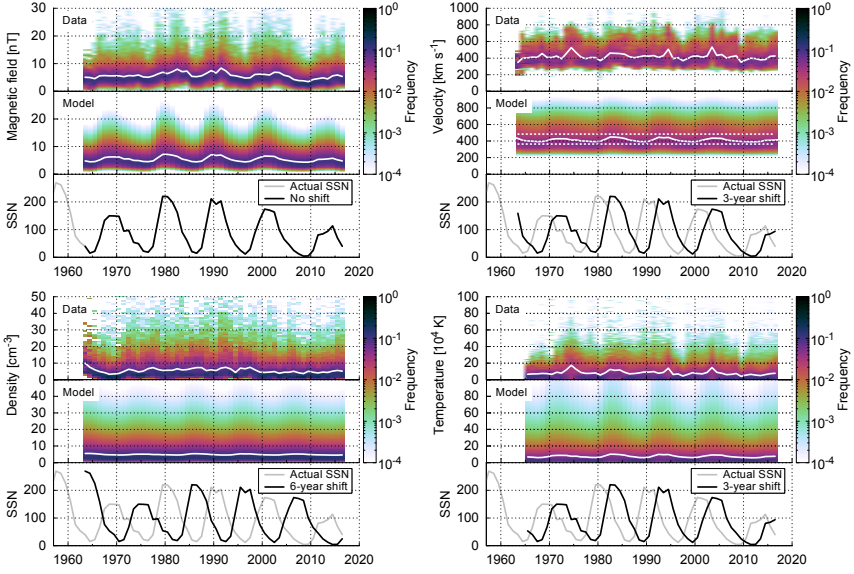
Credit: NASA

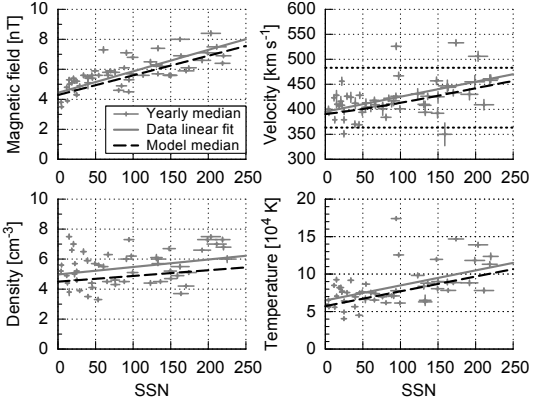

OMNI data
Lognormal fit
Fit median
Fit mean
Frequency
Magnetic field strength [nT]
Velocity [km s^{-1}]
Density [cm^{-3}]
Temperature [K]

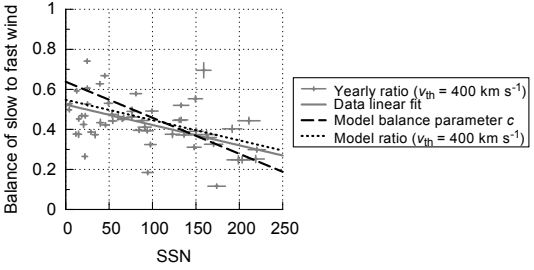

OMNI data
Fit parts
Composite fit
Fit median
Fit mean
Frequency
0.05
0.04
0.03
0.02
0.01
0
0.002
0.001
0
0
200
400
600
800
1000
Velocity [km s^{-1}]

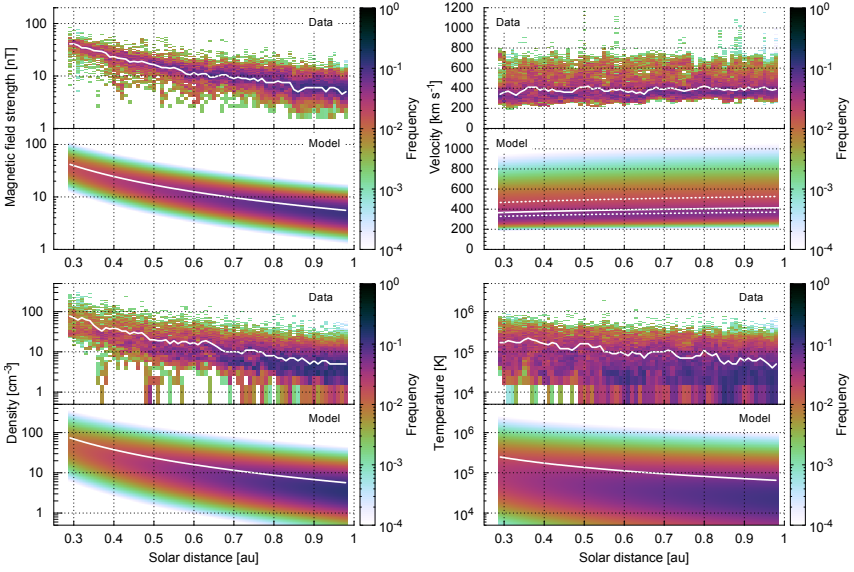

Magnetic field [nT]
Velocity [km s^{-1}]
Density [cm^{-3}]
Temperature [10^4 K]
SSN
19
20
21
22
23
24
1950
1960
1970
1980
1990
2000
2010
2020

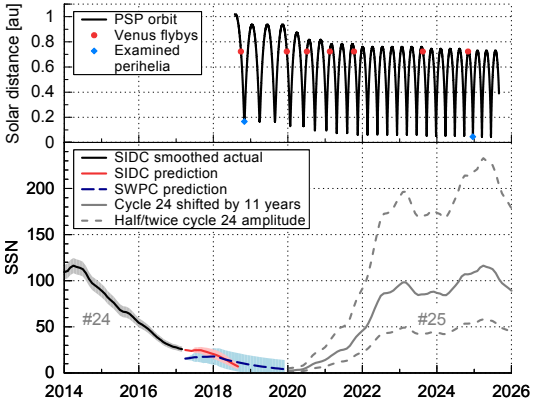

Correlation of solar wind parameters to lagged SSN
Correlation coefficient
Time lag [years]
Magnetic field
Velocity
Density
Temperature

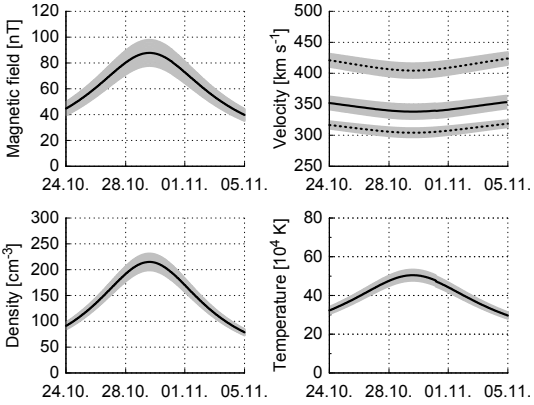

Data
Model
Magnetic field [nT]
Velocity [km s^{-1}]
Density [cm^{-3}]
Temperature [10^4 K]
Frequency
SSN
Actual SSN
No shift
3-year shift
6-year shift

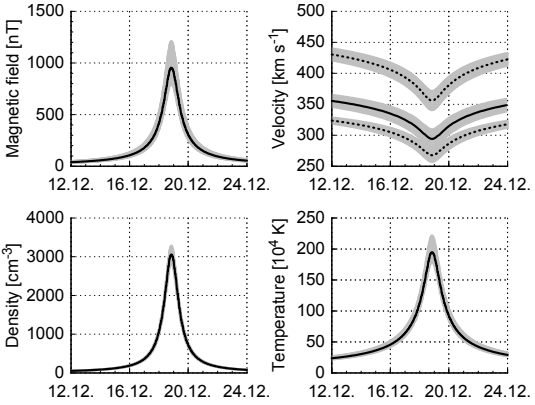

Magnetic field [nT]
Velocity [km s^{-1}]
Density [cm^{-3}]
Temperature [10^4 K]
SSN
SSN
Yearly median
Data linear fit
Model median

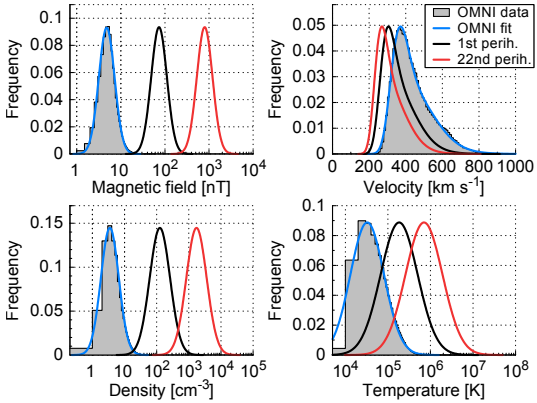

Balance of slow to fast wind
SSN
Yearly ratio (v_{th} = 400 km s^{-1})
Data linear fit
Model balance parameter c
Model ratio (v_{th} = 400 km s^{-1})


Data
Model
Magnetic field strength [nT]
Velocity [km s-1]
Density [cm-3]
Temperature [K]
Frequency
Solar distance [au]


Solar distance [au]
PSP orbit
Venus flybys
Examined perihelia
SSN
SIDC smoothed actual
SIDC prediction
SWPC prediction
Cycle 24 shifted by 11 years
Half/twice cycle 24 amplitude
#24
#25
2014
2016
2018
2020
2022
2024
2026


Magnetic field [nT]
Velocity [km s^{-1}]
Density [cm^{-3}]
Temperature [10^4 K]
24.10. 28.10. 01.11. 05.11.


Magnetic field [nT]
Velocity [km s^{-1}]
Density [cm^{-3}]
Temperature [10^4 K]
12.12. 16.12. 20.12. 24.12.


Frequency
Magnetic field [nT]
Velocity [km s^{-1}]
Density [cm^{-3}]
Temperature [K]
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Results

- Empirical solar wind model for the inner heliosphere
- Solar wind predictions for the PSP orbit

Conclusions

- Velocity discrepancy -¿ Solar wind is still being accelerated up to 20 $R_\odot$
- Temperature discrepancy -¿ Solar wind is still being heated up to 20 $R_\odot$

Thank you!

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first slide

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first slide

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Definition

A definition

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Sample frame title

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Examples

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Sample frame title

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Remark

Sample text

Important theorem

Sample text in red box

Sample frame title

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Remark

Sample text

Important theorem

Sample text in red box

Examples

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Two-column slide

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$$E = mc^2$$

- First item
- Second item

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Sample

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Remark

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Remark

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Important theorem

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