

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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Prof. Dr. Andreas Tilgner

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

1 Solar wind

2 Geomagnetic impact of the solar wind

3 Solar wind model for the inner heliosphere

4 End matter

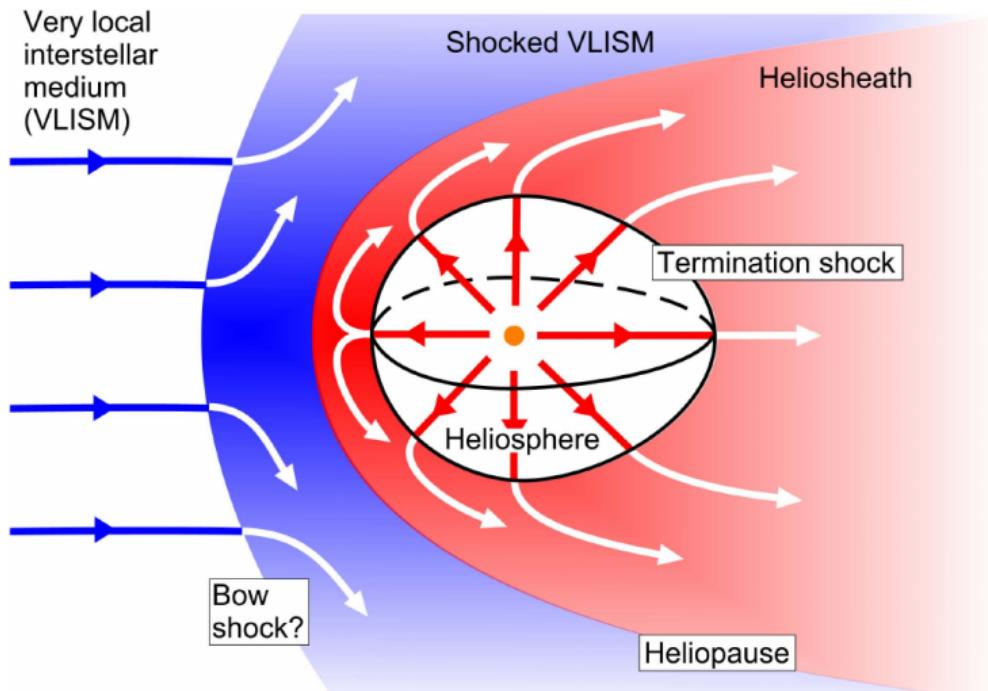
Solar wind



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

- flow of magnetized plasma
- consists of electrons, protons and 5% helium

Solar wind



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

Solar wind

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Geomagnetic impact of the solar wind

A horizontal row of 20 red circles, evenly spaced, used as a visual element in the page header.

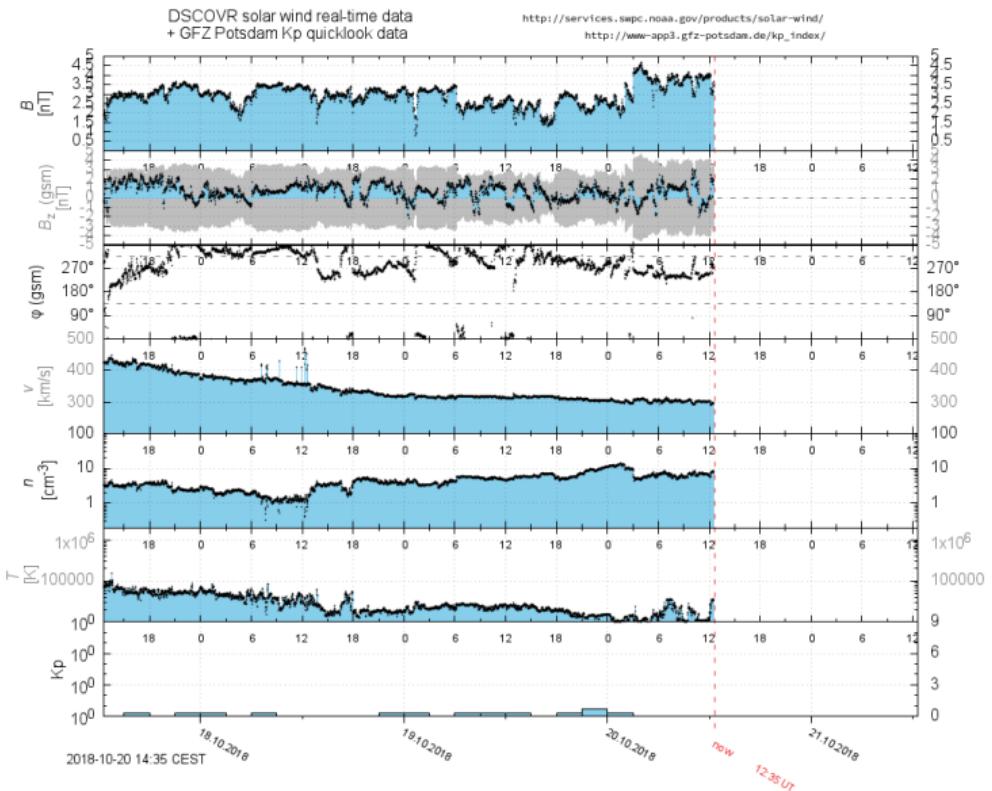
Solar wind model for the inner heliosphere

End matter

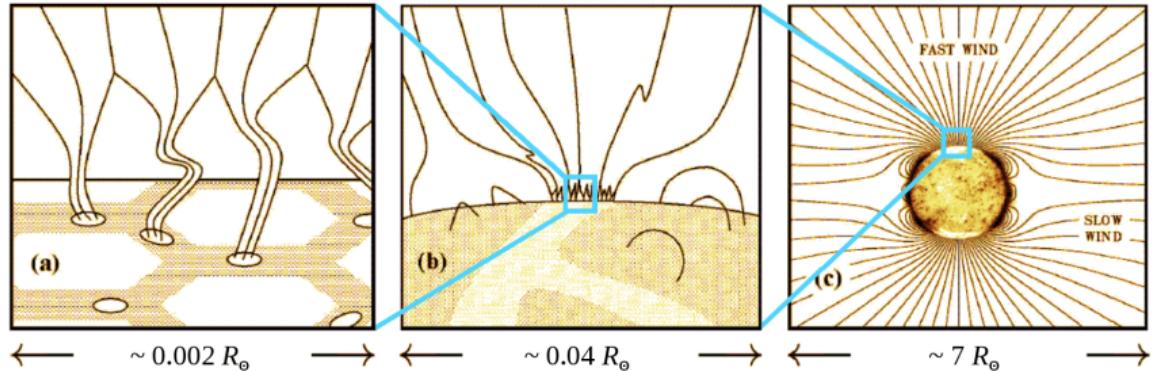
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References

Solar wind

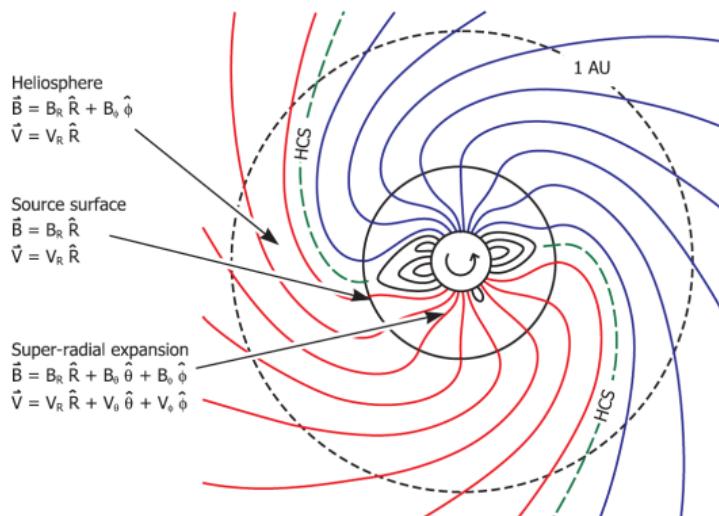


Solar magnetic field



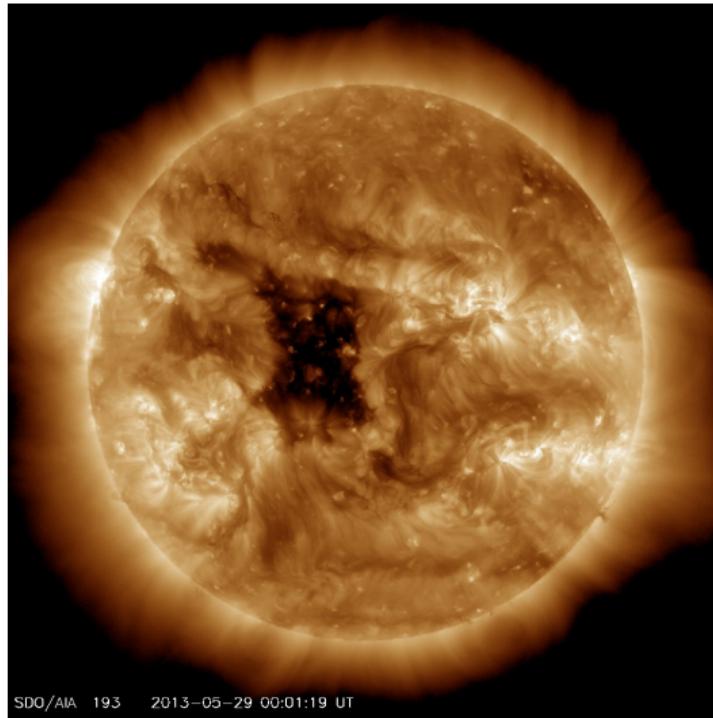
Courtesy of S. R. Cranmer

Solar magnetic field



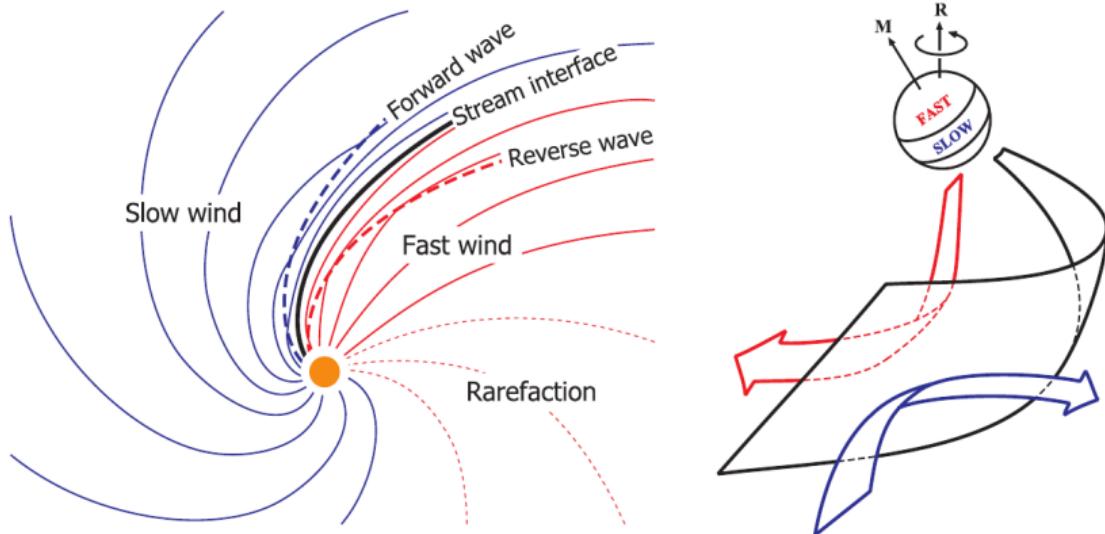
Credit: Owens & Forsyth (2013, Fig. 1), adapted from Schatten et al. (1969, Fig. 1)

Slow and fast solar wind



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

Slow and fast solar wind



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

Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

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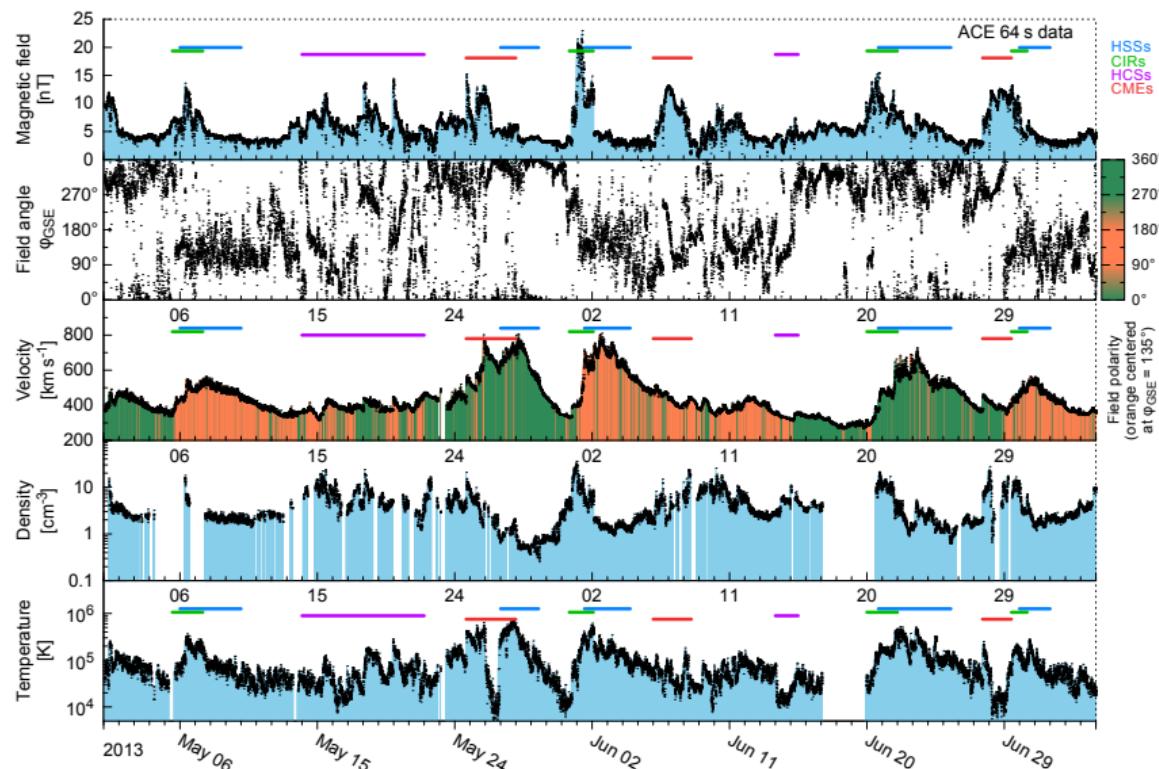
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References

Solar wind

In-situ example



Solar wind
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Geomagnetic impact of the solar wind
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Solar wind model for the inner heliosphere
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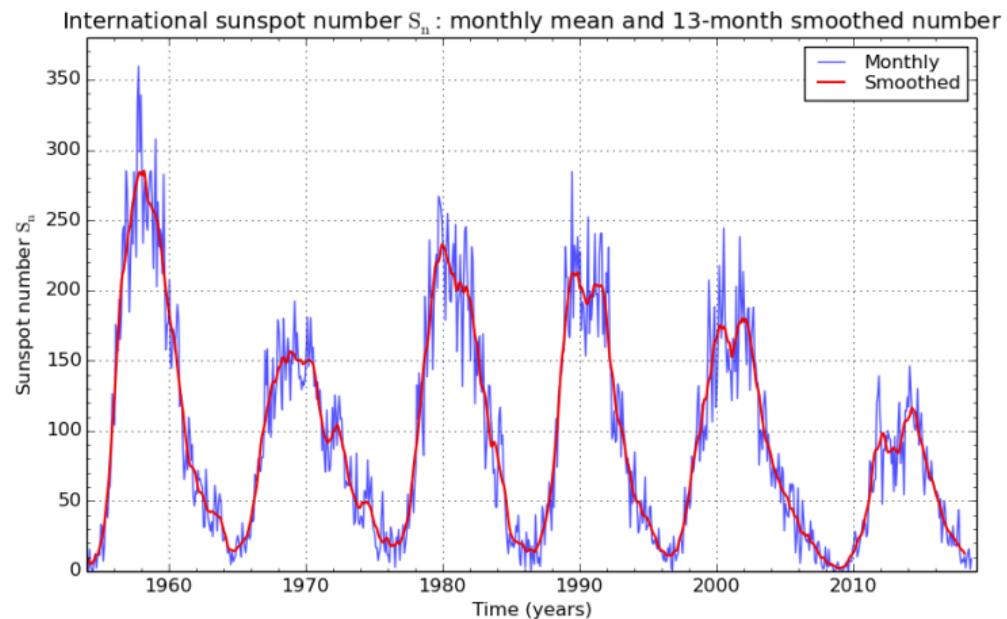
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References

Solar activity

Sunspots

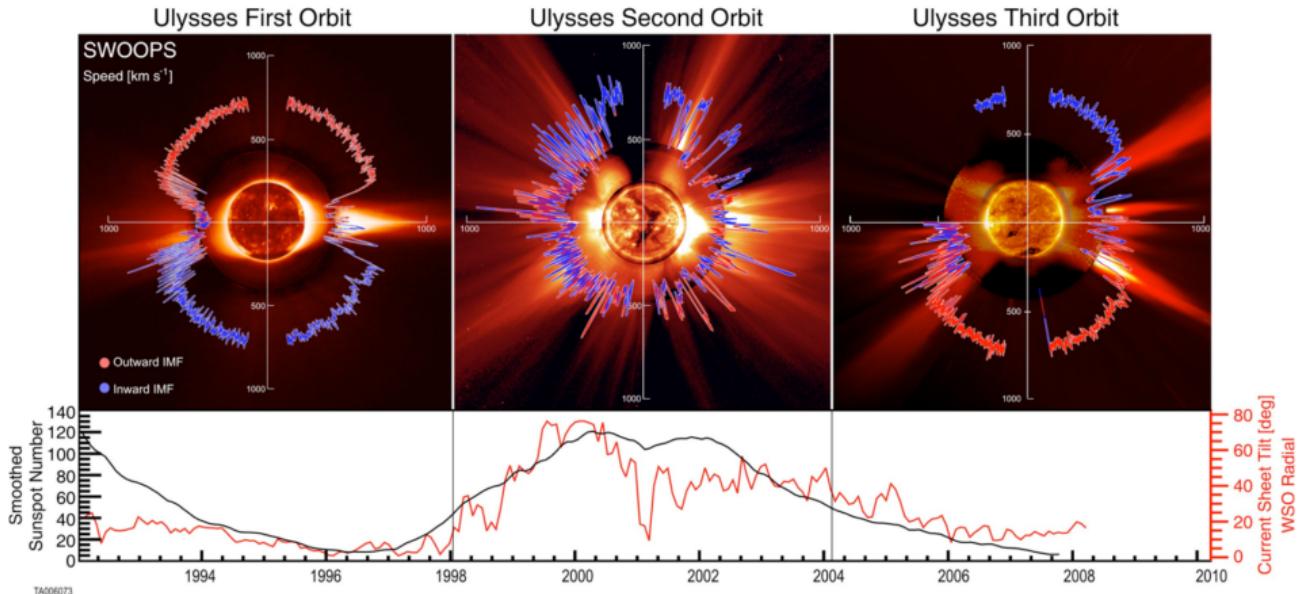
Solar activity



SILSO graphics (<http://sidc.be/silso>) Royal Observatory of Belgium 2018 September 1

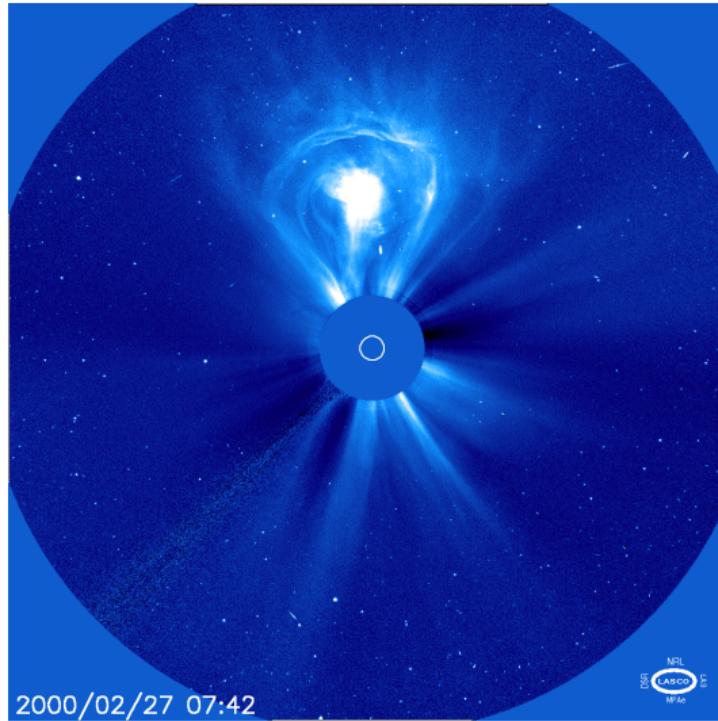
► Magnetic butterfly diagram

Solar activity



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

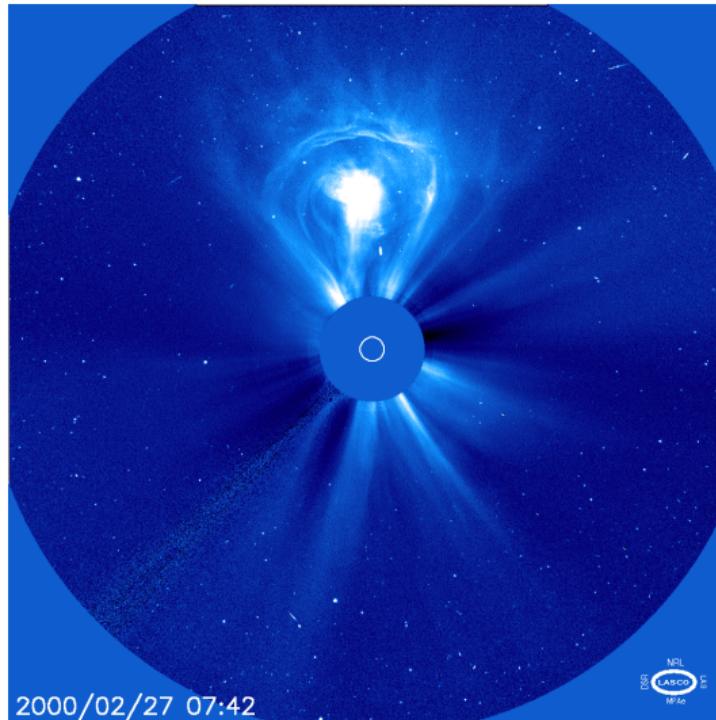
Coronal mass ejections



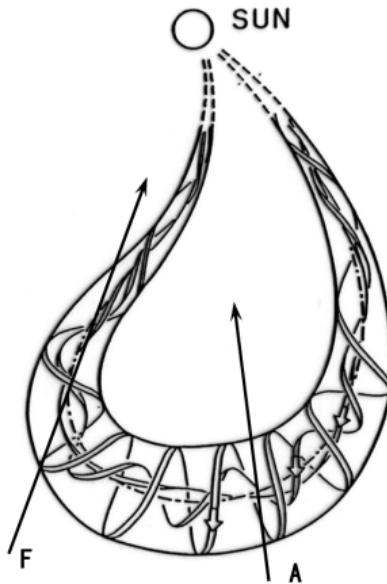
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Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA

Coronal mass ejections

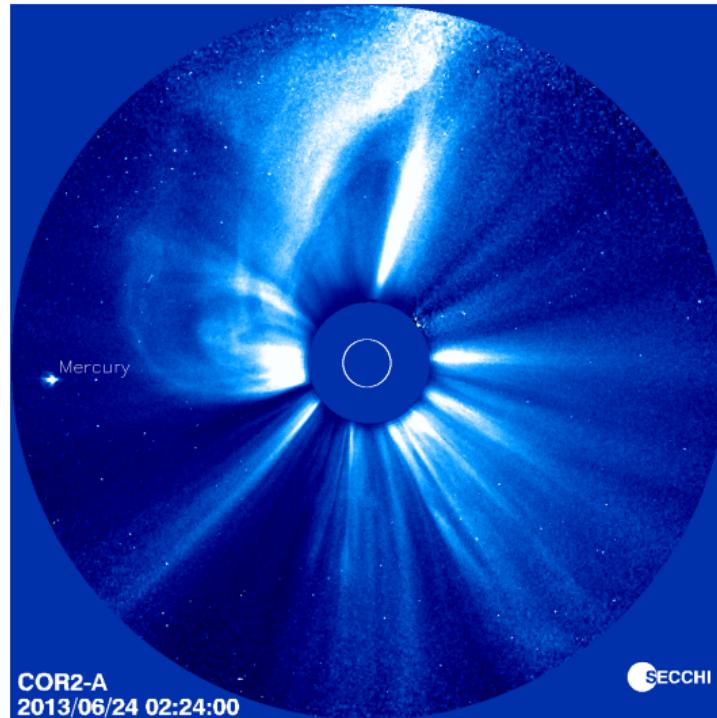


Courtesy of SOHO/LASCO consortium. SOHO is a project of international cooperation between ESA and NASA

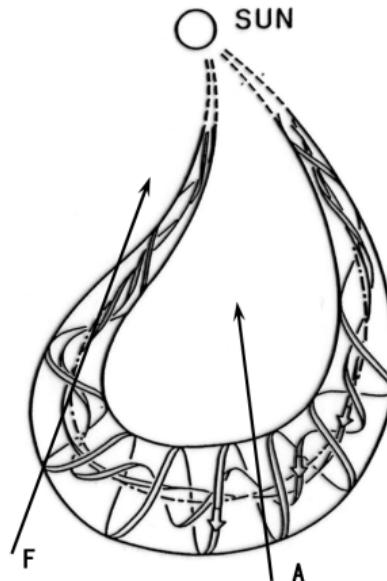


Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

Coronal mass ejections

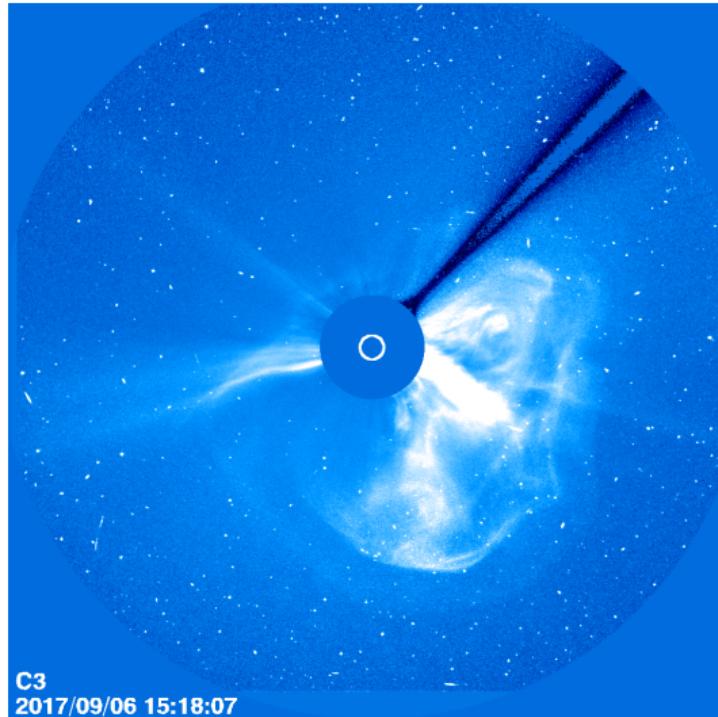


Courtesy of STEREO/COR2 consortium (NASA)



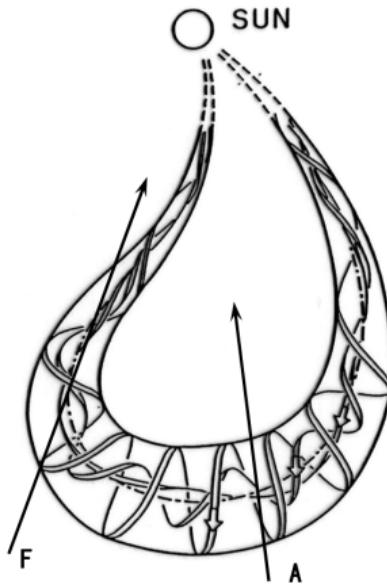
Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

Coronal mass ejections



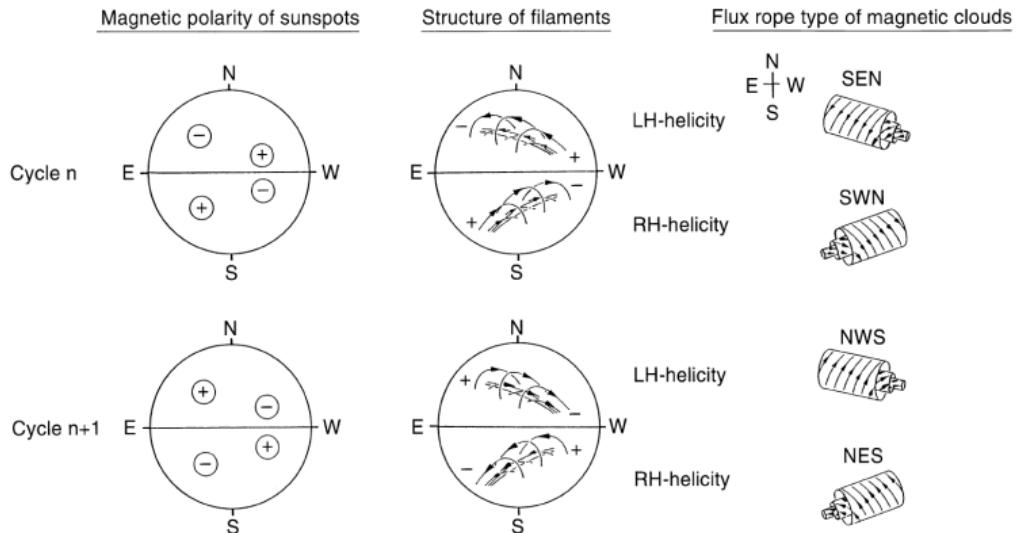
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Courtesy of SOHO/LASCO consortium; SOHO is a project of international cooperation between ESA and NASA



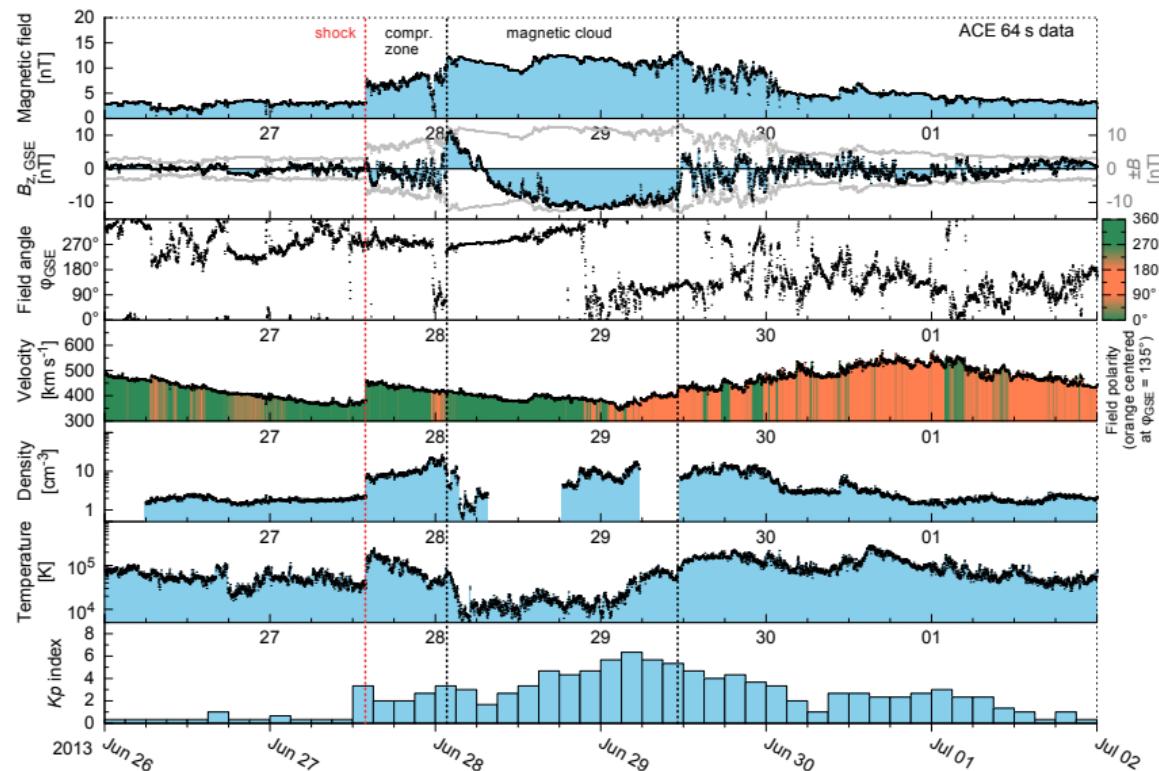
Credit: Marubashi & Lepping (2007, Fig. 1, panel (a))

CME orientation

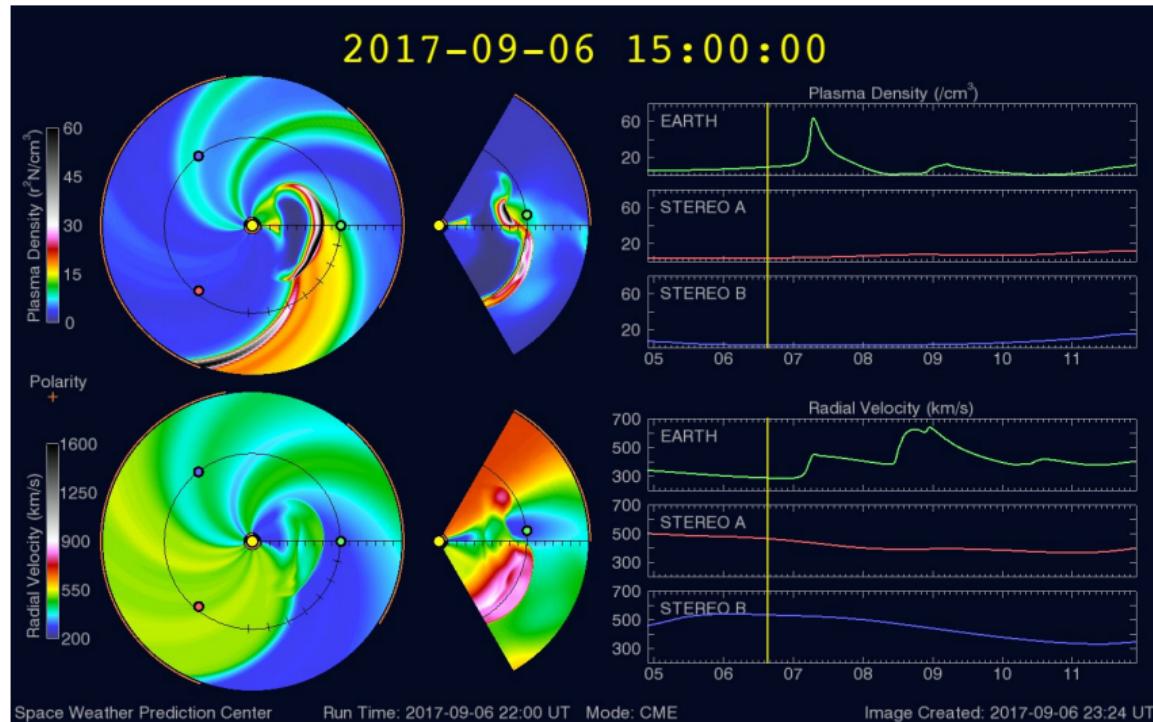


Credit: Bothmer & Schwenn (1998, Fig. 18)

In-situ CMEs



Solar wind and CME forecast



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

1 Solar wind

2 Geomagnetic impact of the solar wind

3 Solar wind model for the inner heliosphere

4 End matter

Solar wind
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Geomagnetic impact of the solar wind
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Solar wind model for the inner heliosphere
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References

Geomagnetic impact of the solar wind

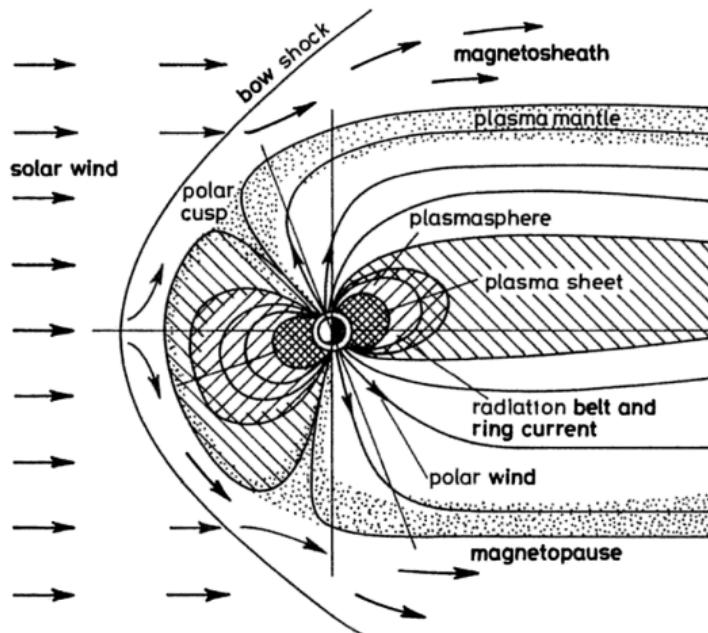
images...

Geomagnetic impact of the solar wind

Aims

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

Magnetosphere



Credit: Davies (1990, Fig. 2.12)

Solar wind
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Geomagnetic impact of the solar wind
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Solar wind model for the inner heliosphere
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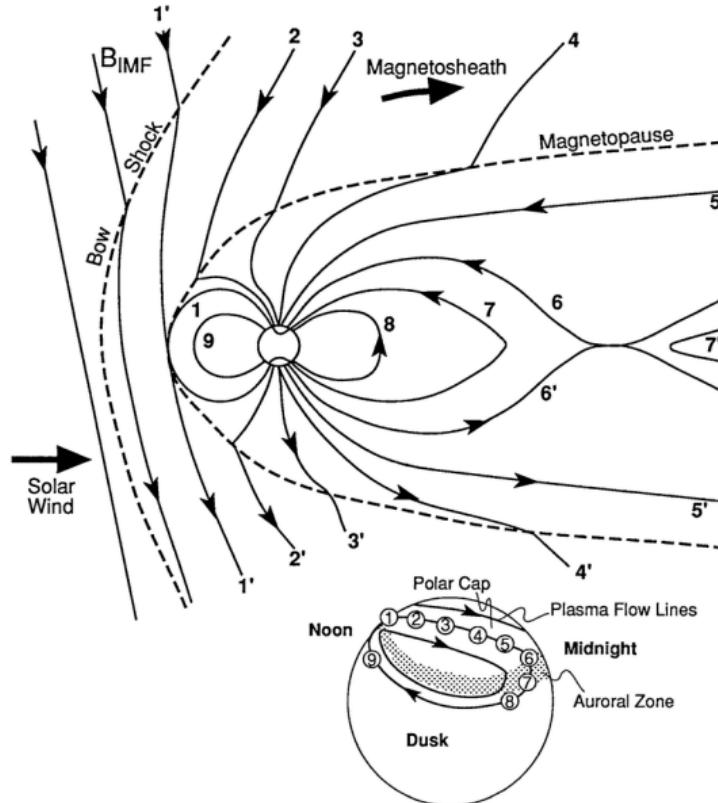
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References

Magnetosphere

4 interaction mechanisms

Magnetosphere



Credit: Hughes (1995, Fig. 9.11)

Solar wind
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Geomagnetic impact of the solar wind
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Solar wind model for the inner heliosphere
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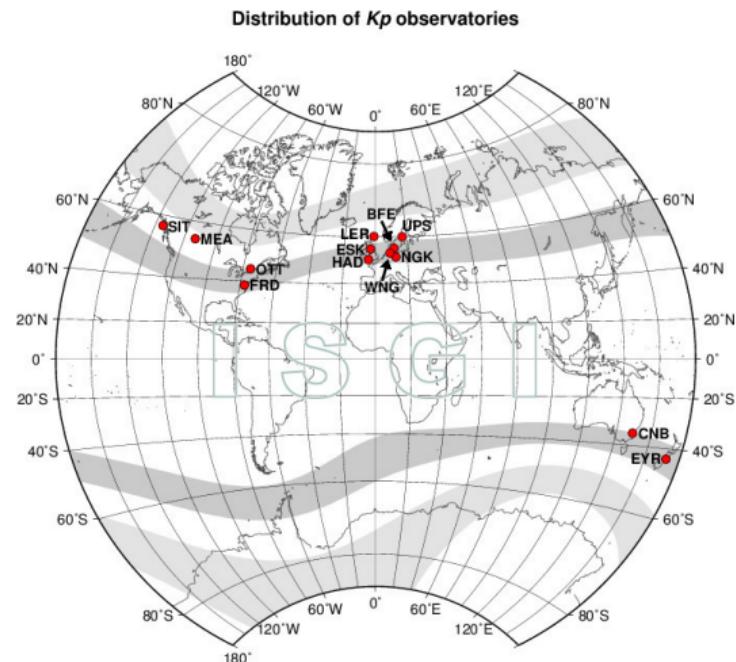
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Magnetosphere

4 factors for merging flux rate

K_p index

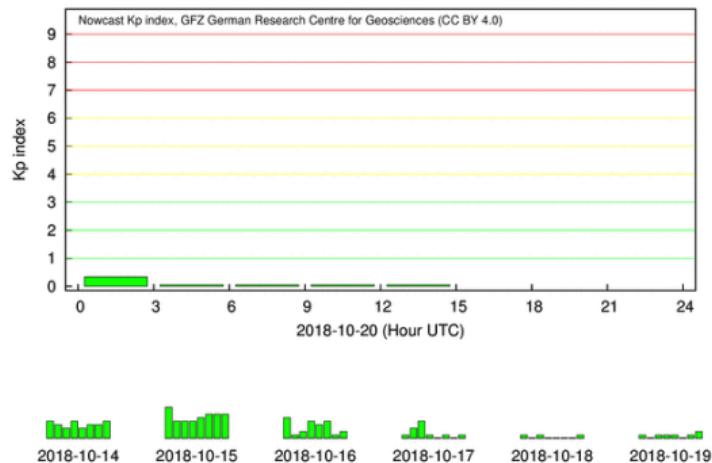
13 observatories...



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

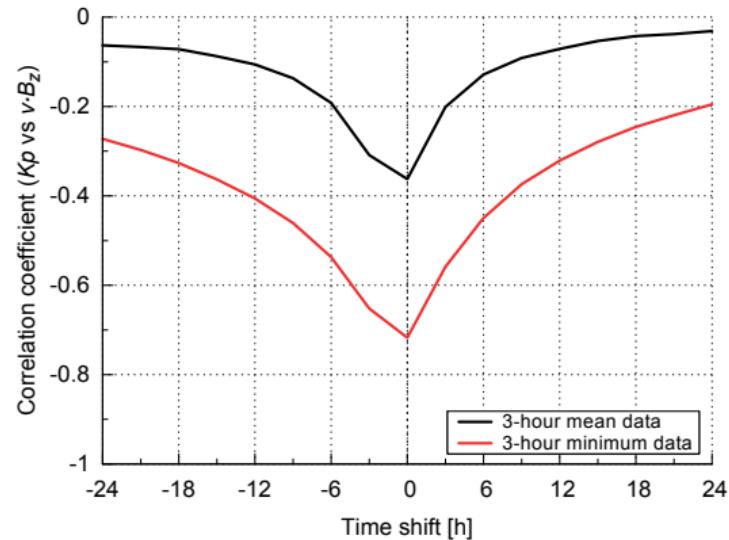
K_p index

Quicklook K_p



Credit: GFZ Potsdam, 2018

Solar wind electric field



Solar wind
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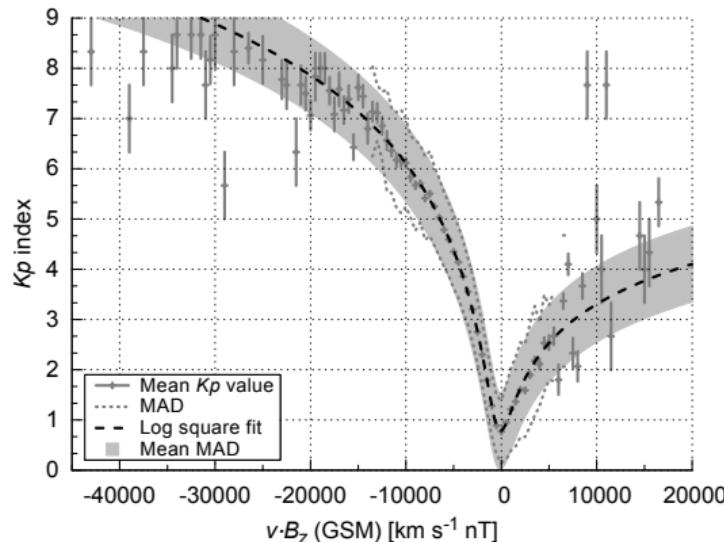
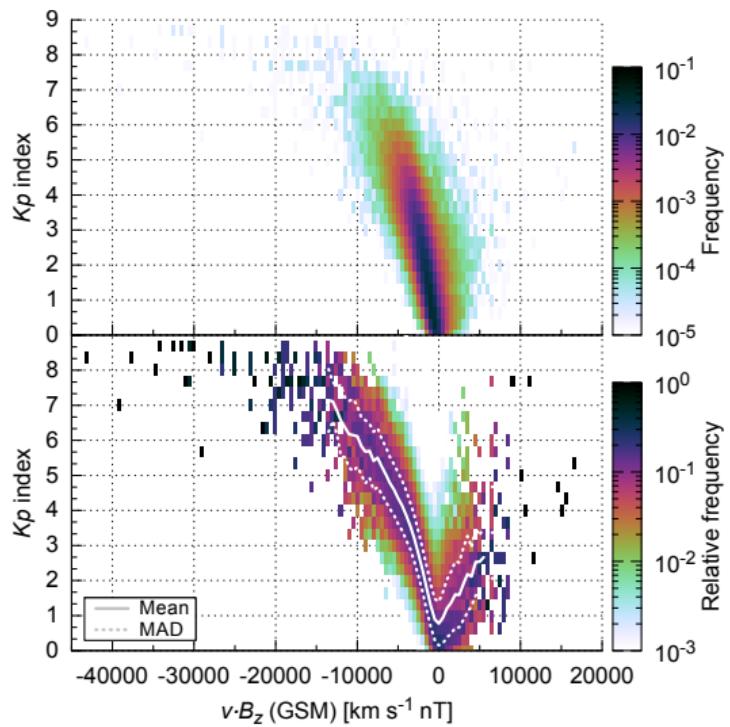
Geomagnetic impact of the solar wind
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Solar wind model for the inner heliosphere
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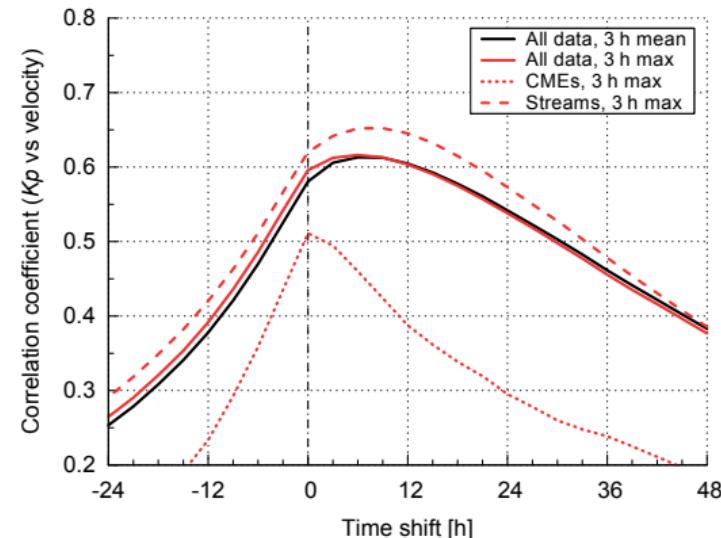
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Solar wind electric field



Solar wind velocity



Solar wind
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Geomagnetic impact of the solar wind
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Solar wind model for the inner heliosphere
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References

Solar wind velocity

CME – stream separation
Solar Wind Structures list

Solar wind
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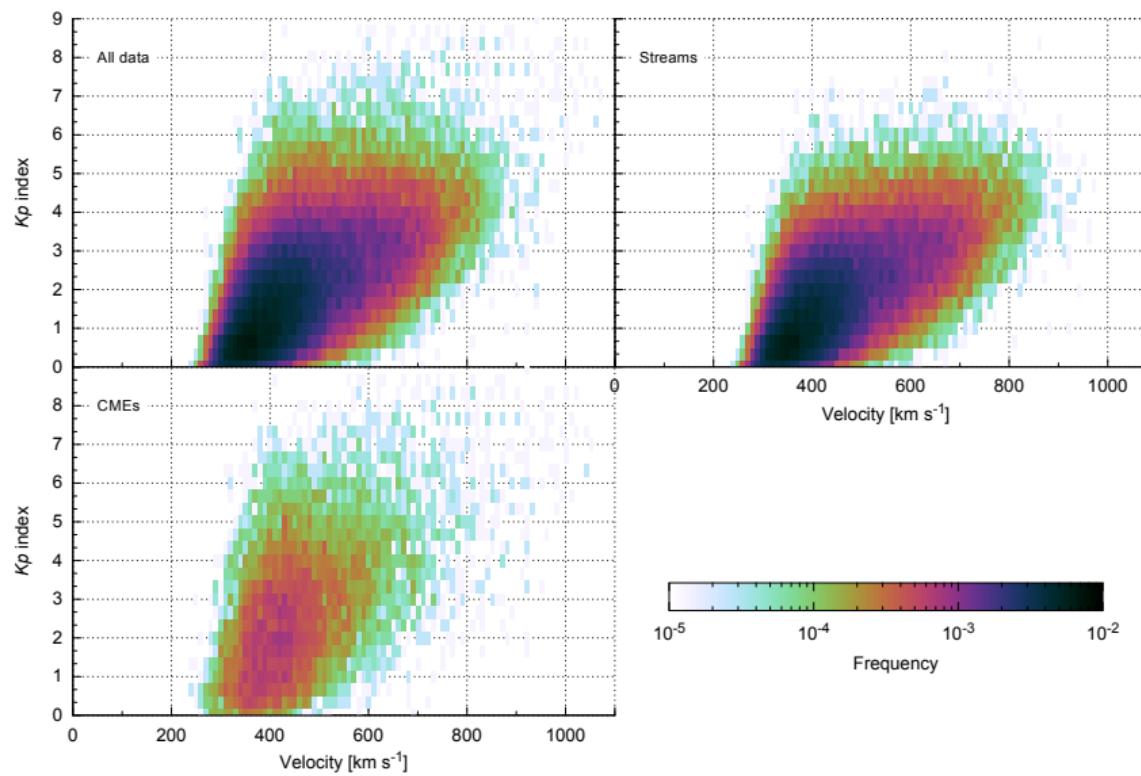
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References

Solar wind velocity



Solar wind

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Geomagnetic impact of the solar wind

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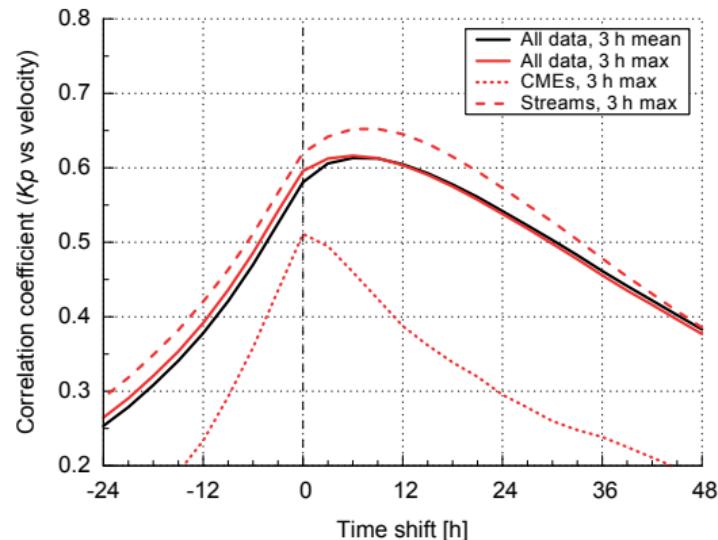
Solar wind model for the inner heliosphere

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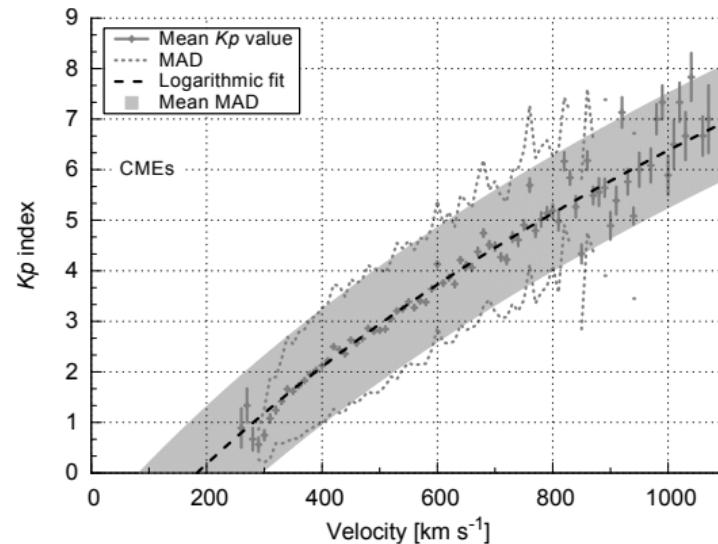
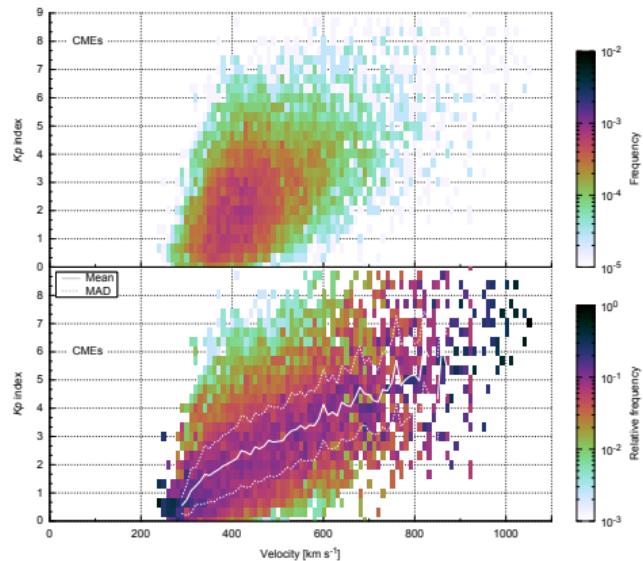
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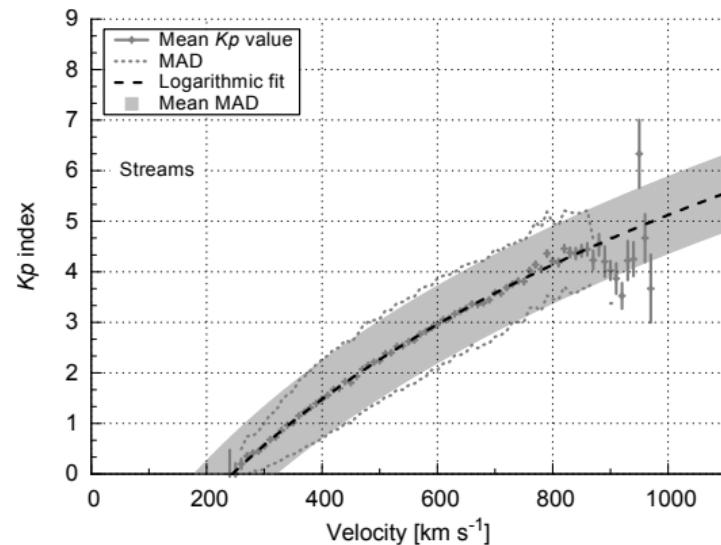
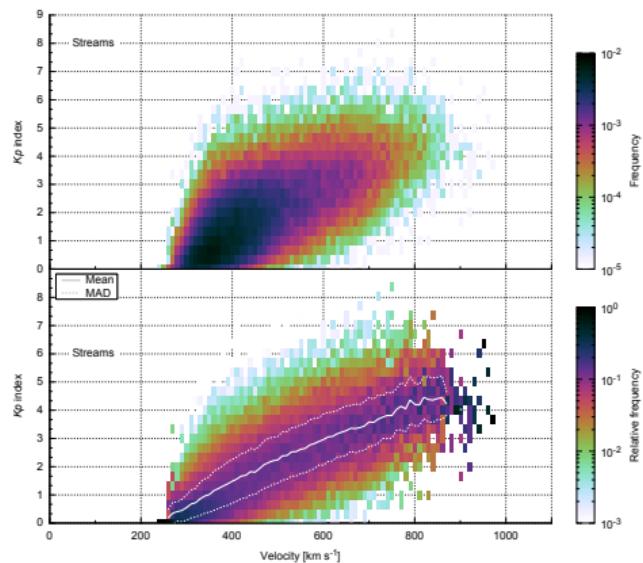
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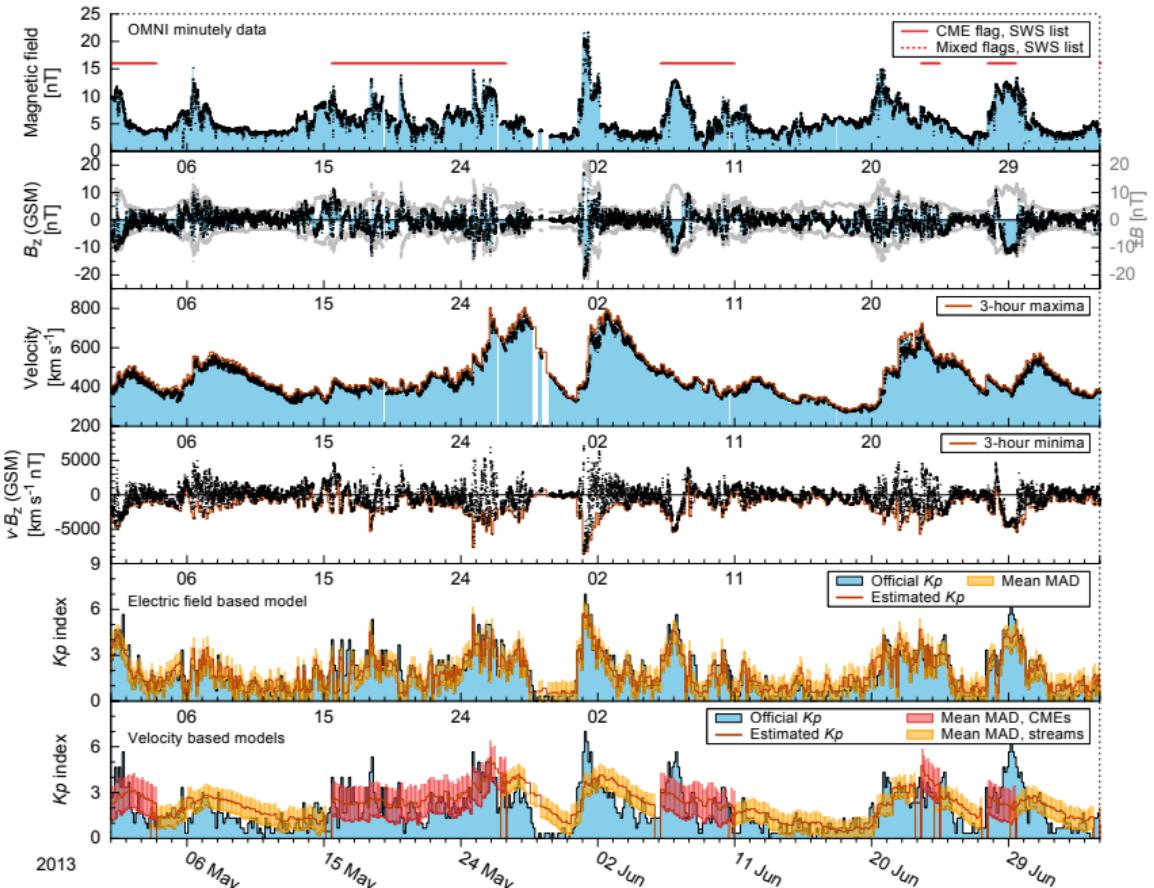


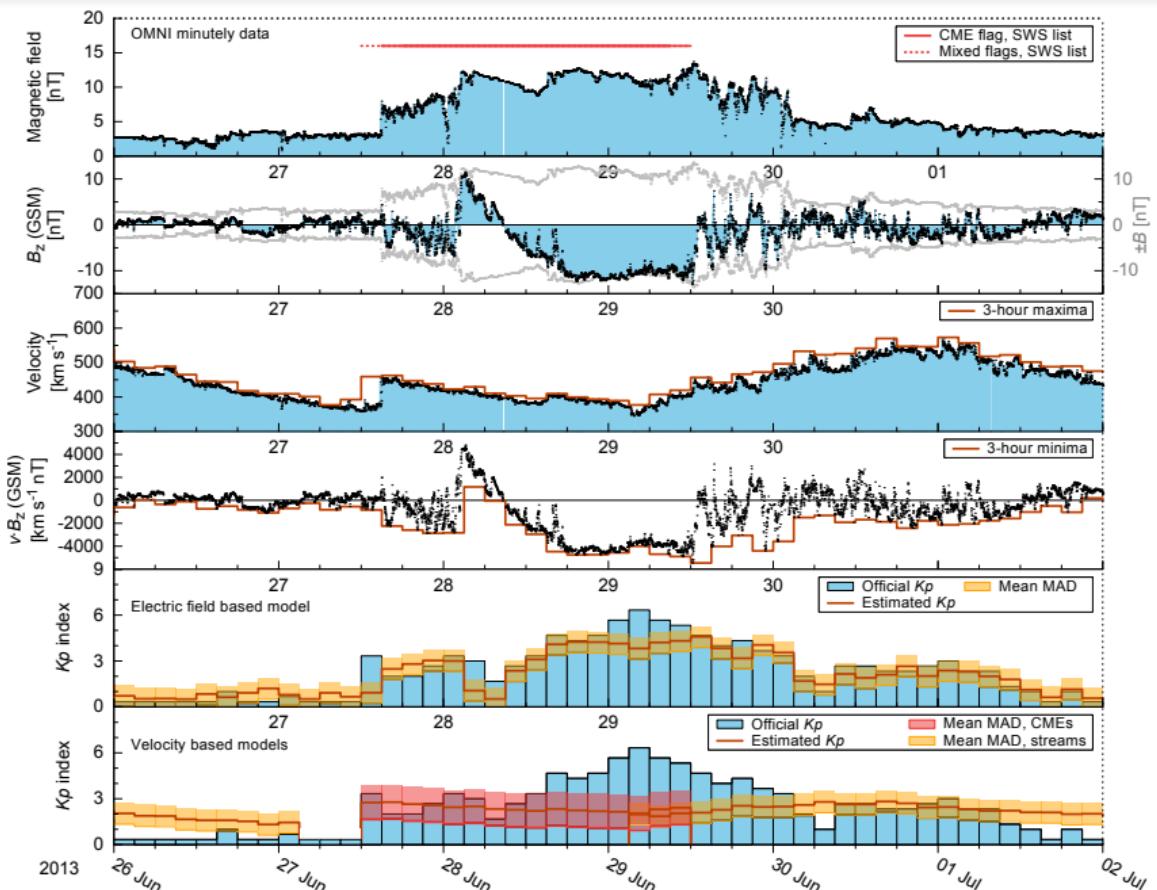
CME velocity

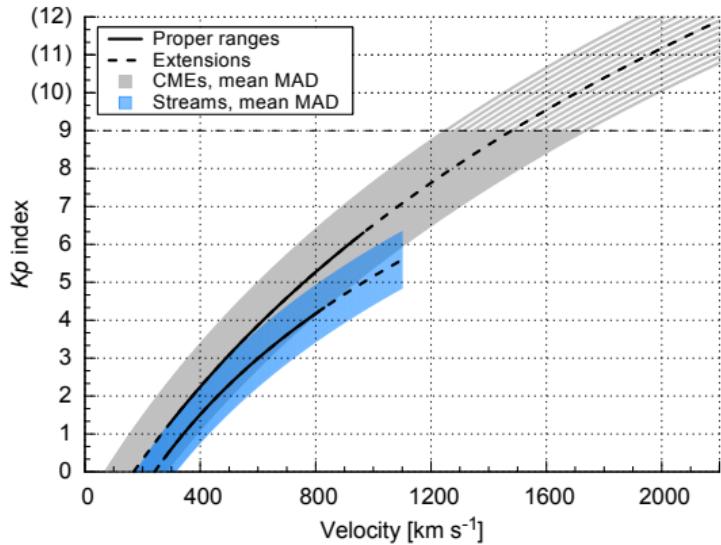


Stream velocity









Results

Predictive K_p 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 K_p
- The prediction models perform well for their limited input information

» Prediction performance

1 Solar wind

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Sun–Earth evolution of the solar wind

Solar wind measured in-situ throughout the heliosphere – except near-Sun

Sun–Earth evolution of the solar wind

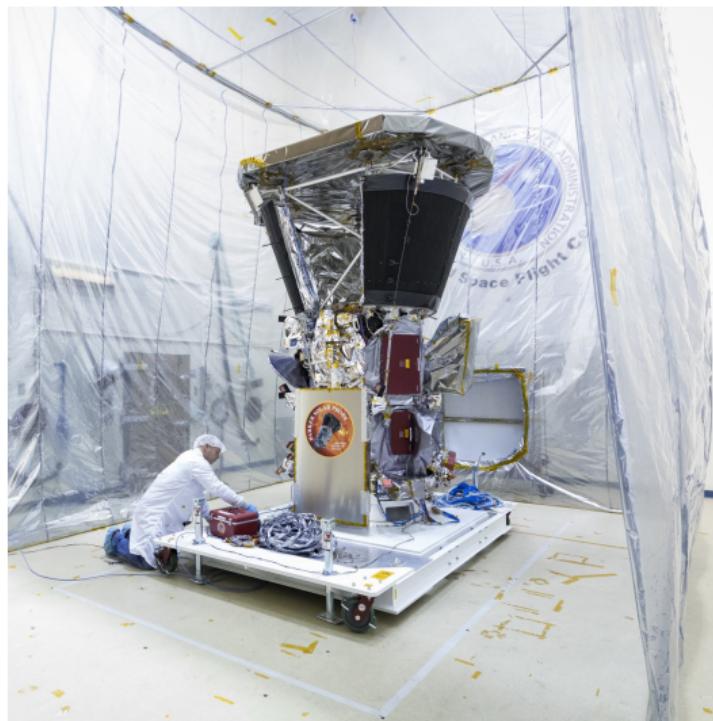
special scientific interest:
coronal heating
solar wind acceleration

Sun–Earth evolution of the solar wind

Aims

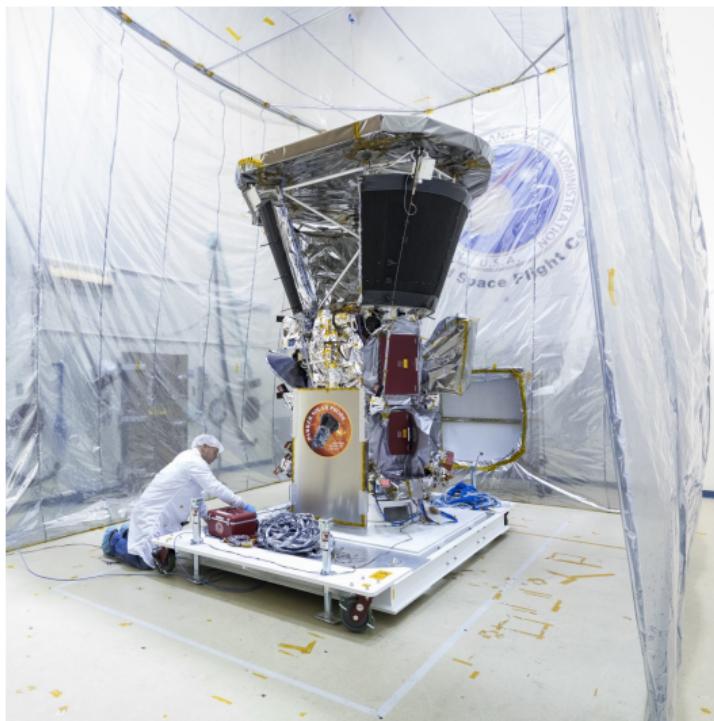
Solar wind model for the inner heliosphere and prediction of the near-Sun environment
for the PSP orbit

Parker Solar Probe

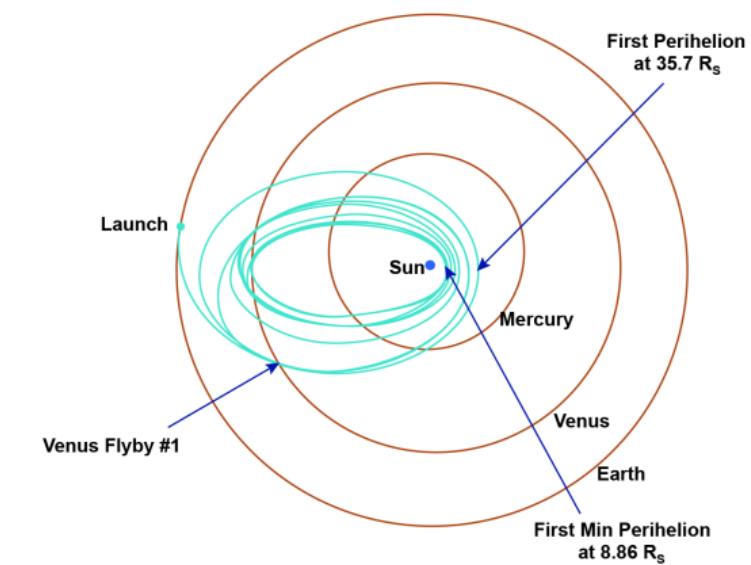


Credit: NASA/Johns Hopkins APL/Ed Whitman, 2017

Parker Solar Probe



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



Credit: NASA/Johns Hopkins APL, 2018

Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

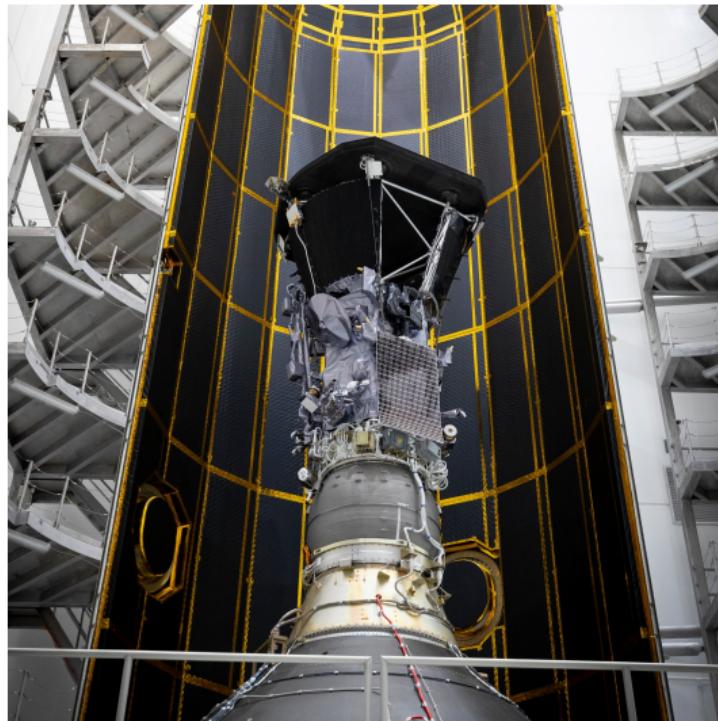
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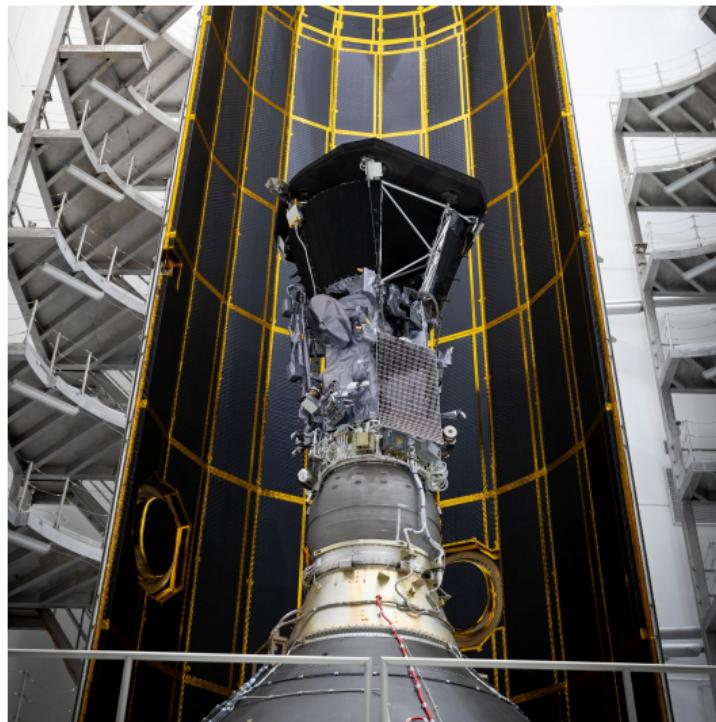
References

Parker Solar Probe



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

Parker Solar Probe



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

launch date, Venus flyby, first perihelion

Solar wind
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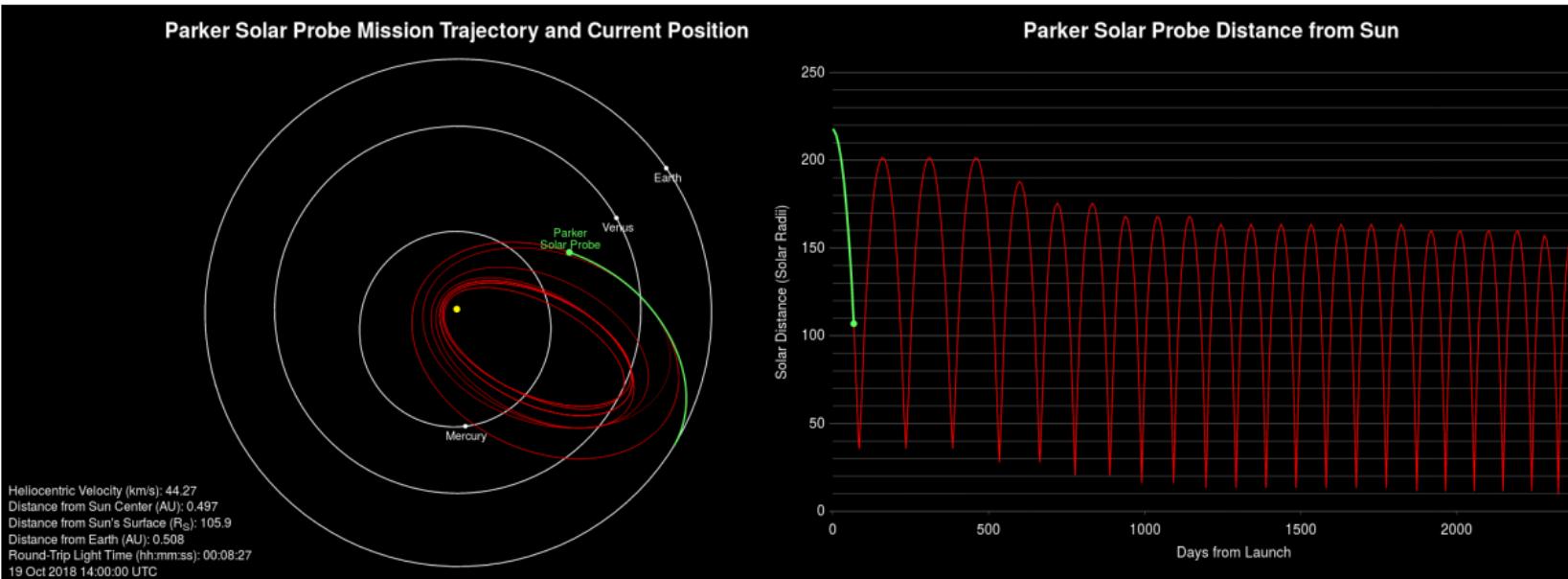
Geomagnetic impact of the solar wind
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Solar wind model for the inner heliosphere
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References

PSP's current position



Credit: NASA

Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

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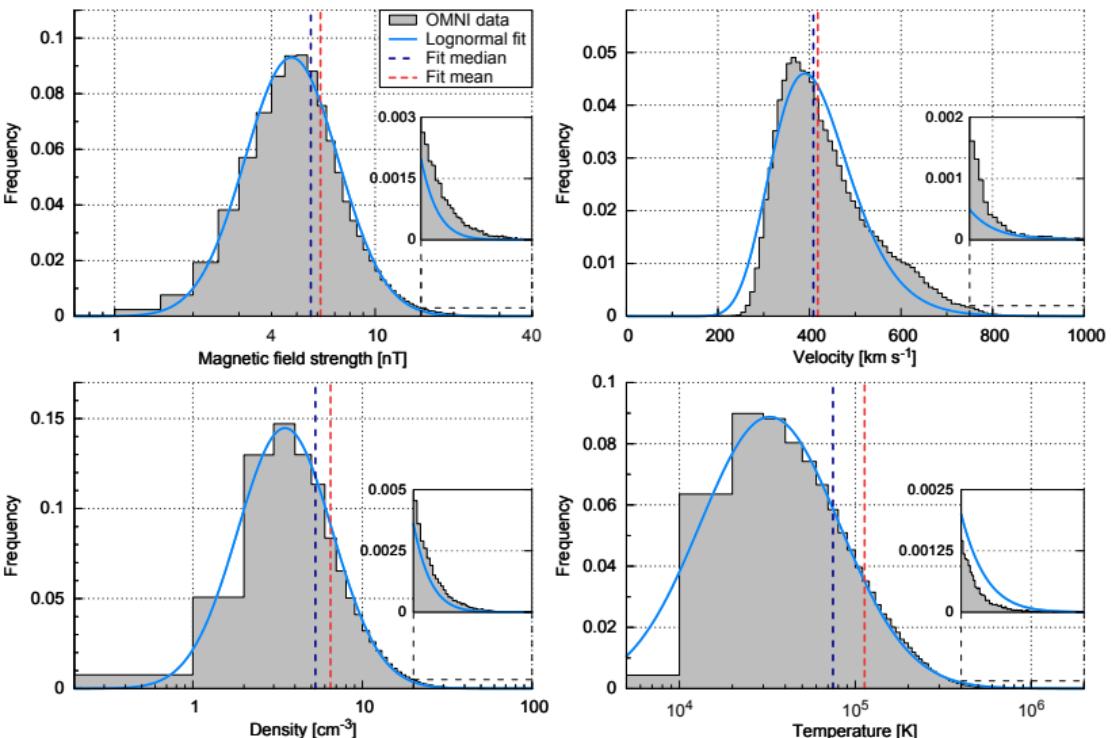
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References

motivation

Frequency distributions



Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

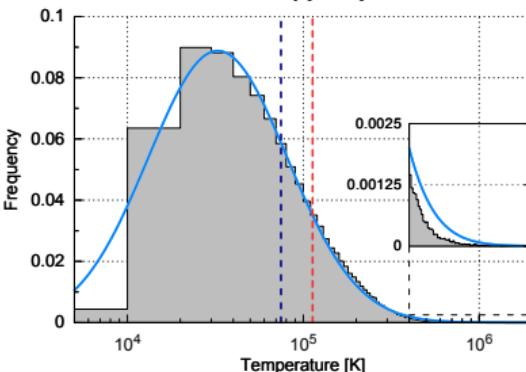
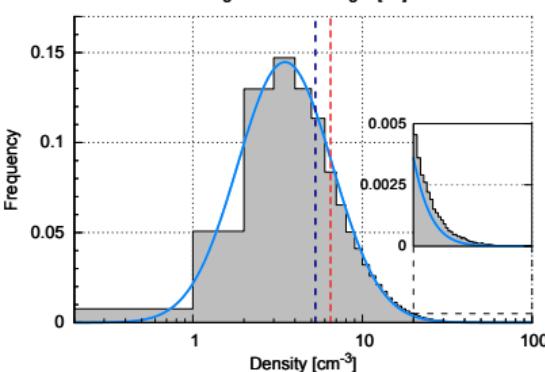
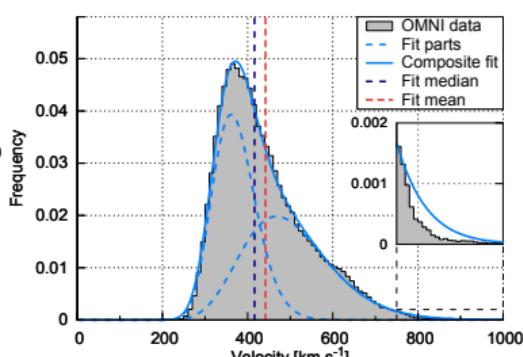
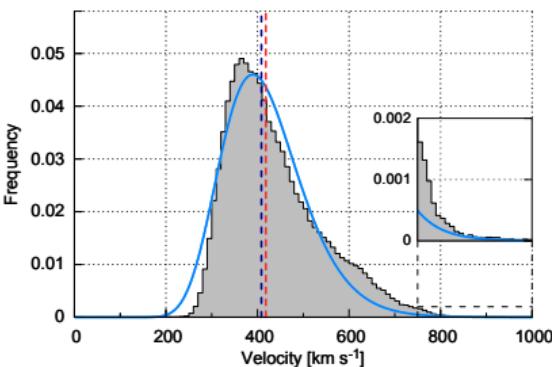
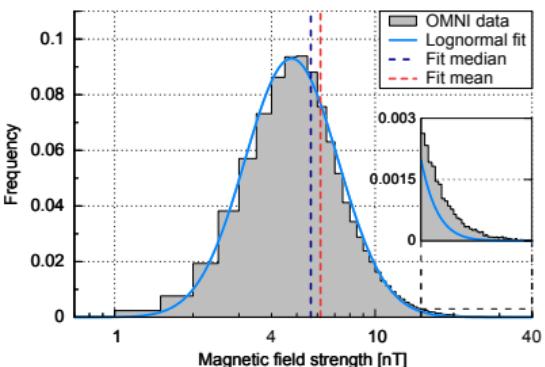
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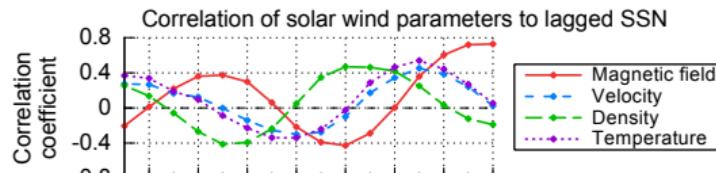
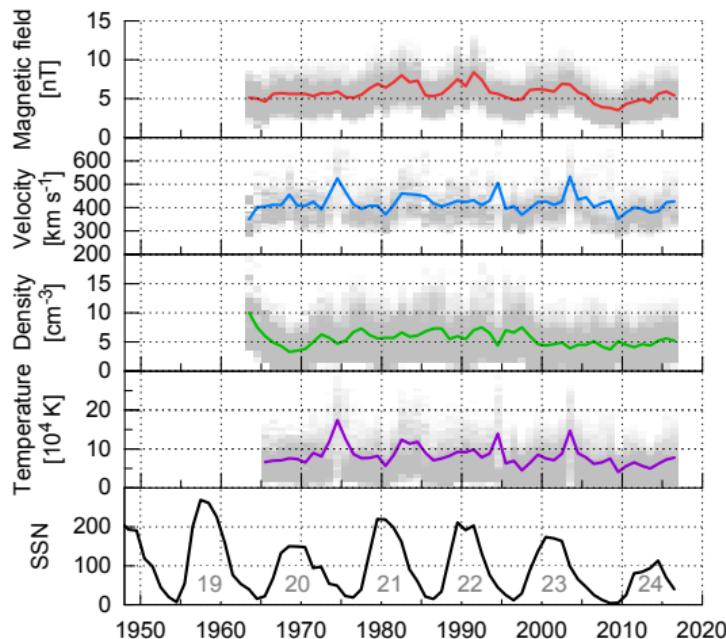
Frequency distributions



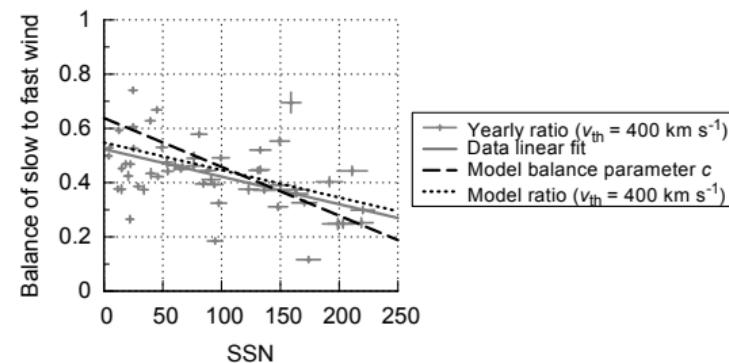
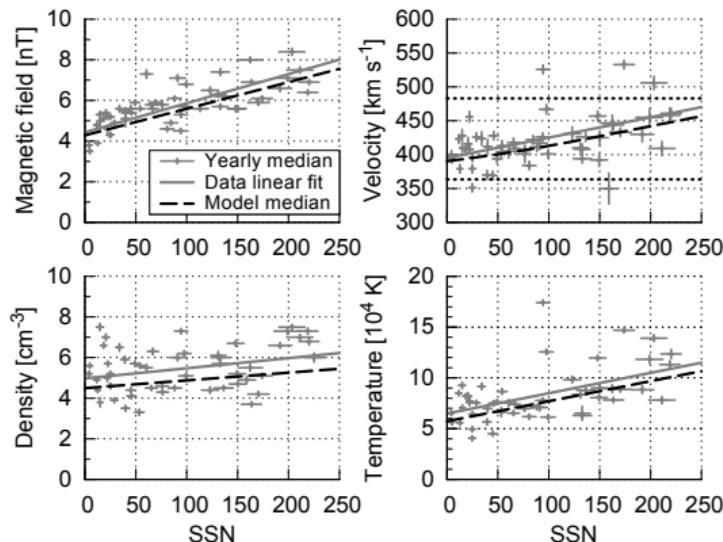
» Lognormal distribution



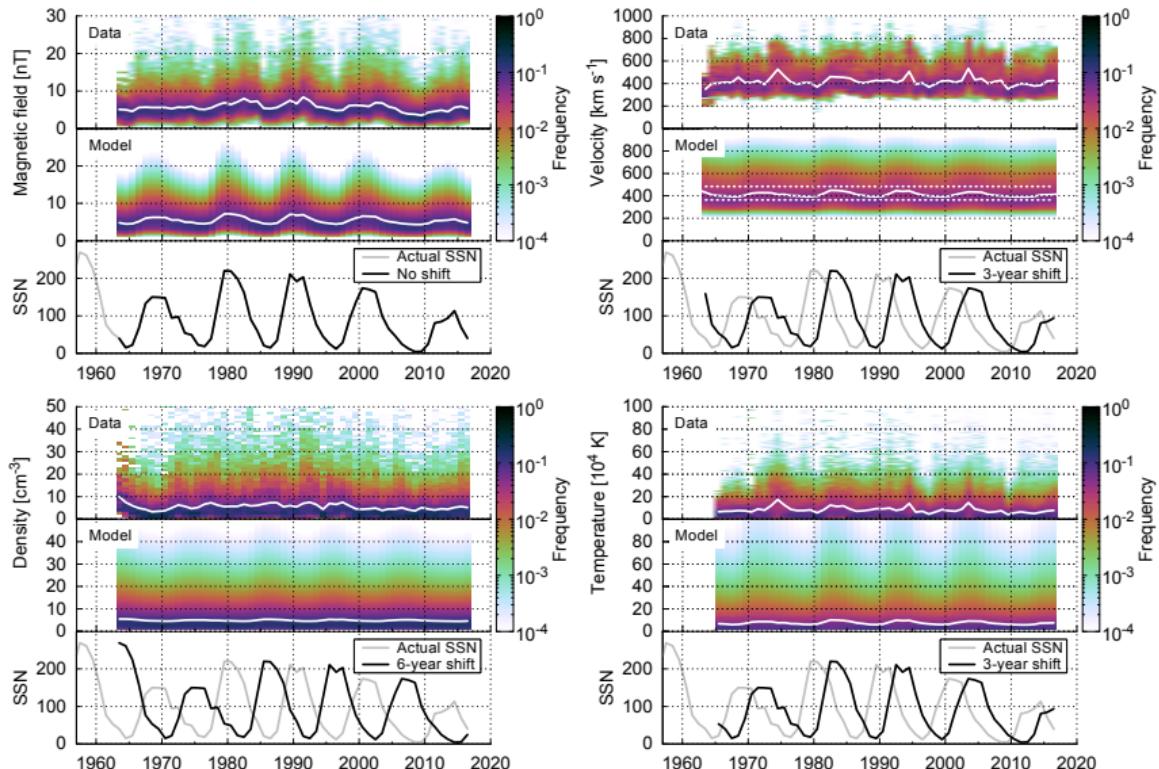
Sunspot number dependence



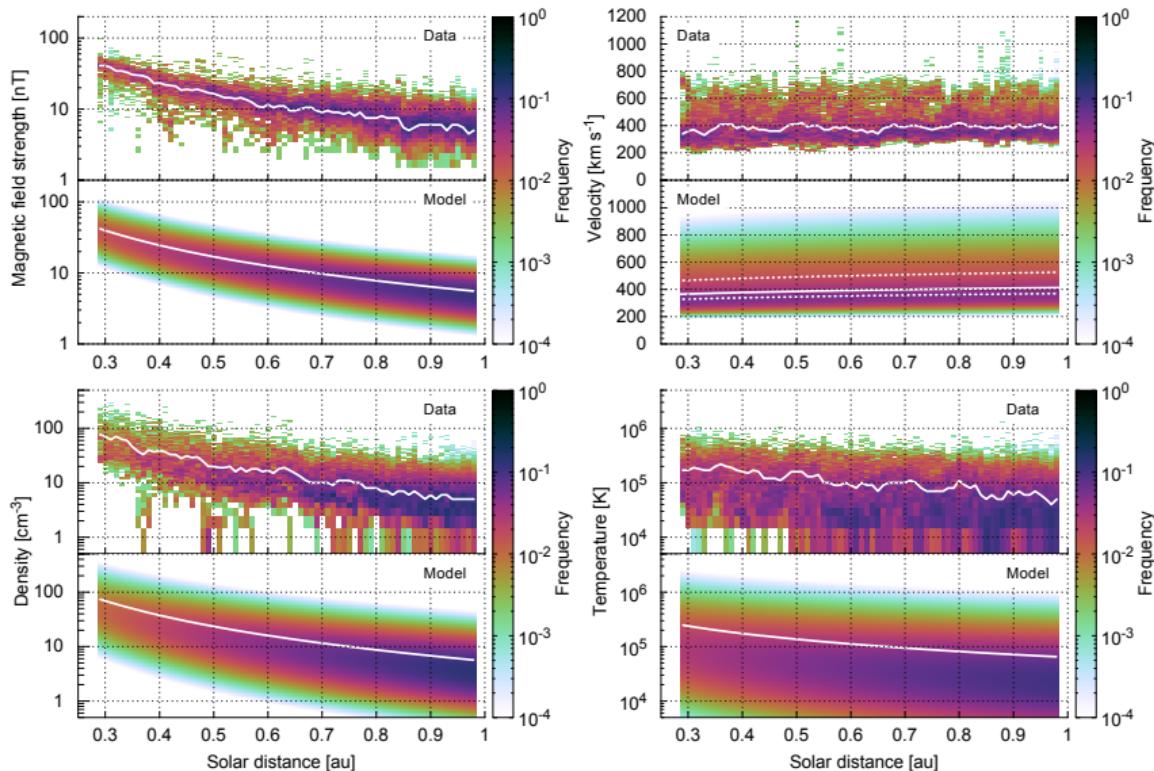
Sunspot number dependence



Sunspot number dependence



Solar distance dependence



Solar wind

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Geomagnetic impact of the solar wind

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Solar wind model for the inner heliosphere

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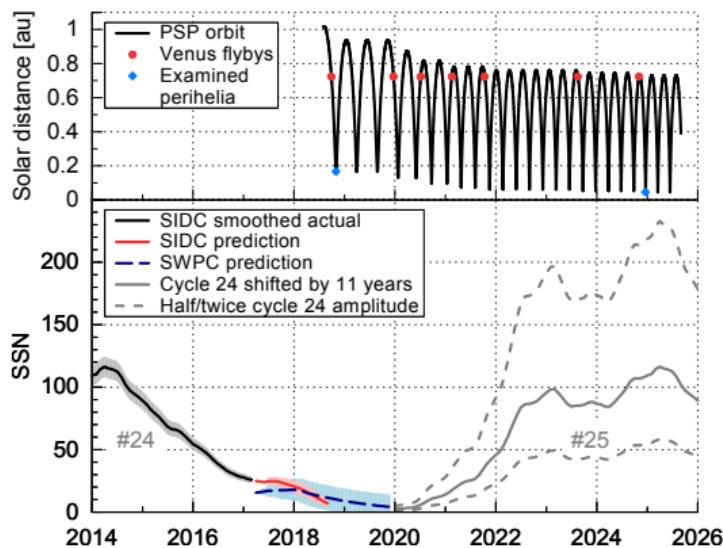
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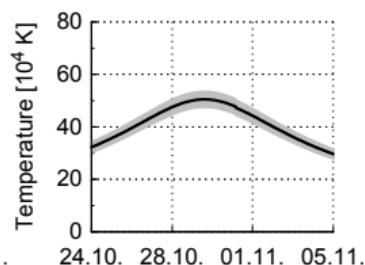
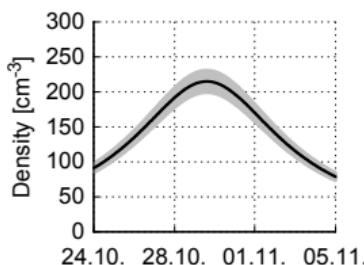
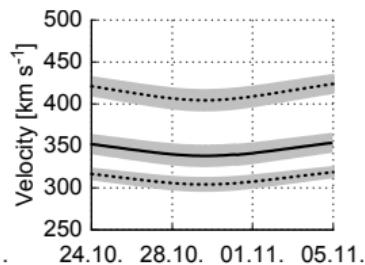
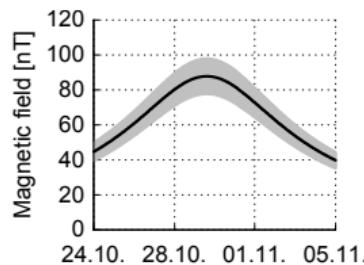
combine models, extrapolation

SSN prediction



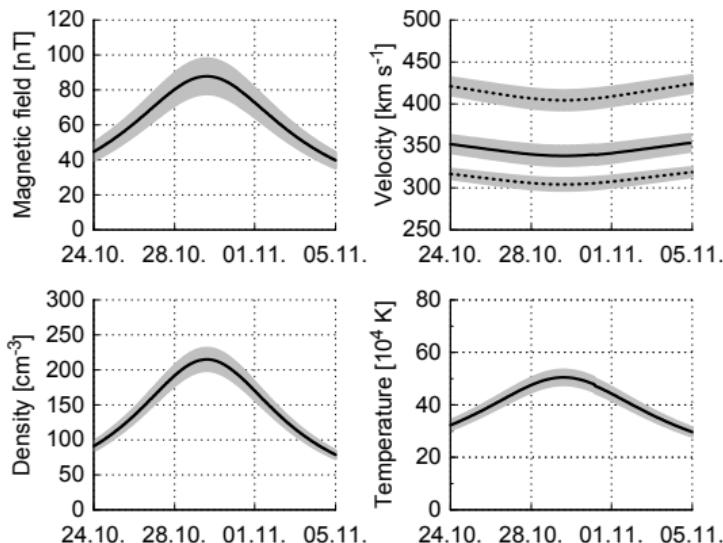
PSP orbit prediction

First perihelion ($9.86 R_{\odot}$)

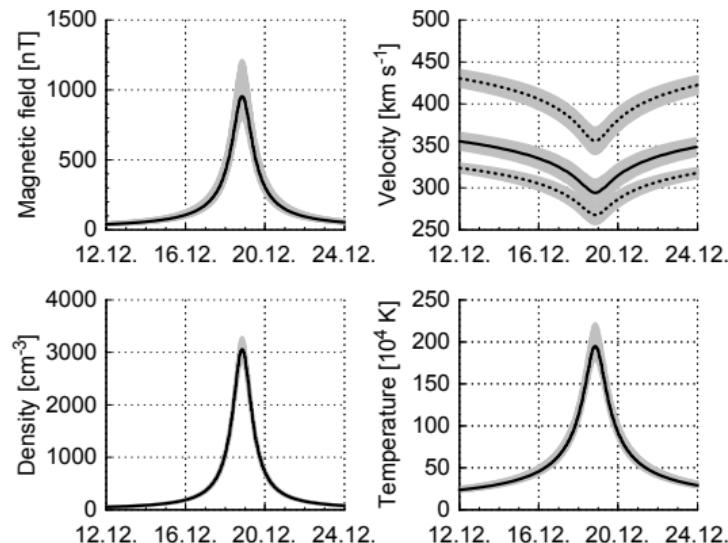


PSP orbit prediction

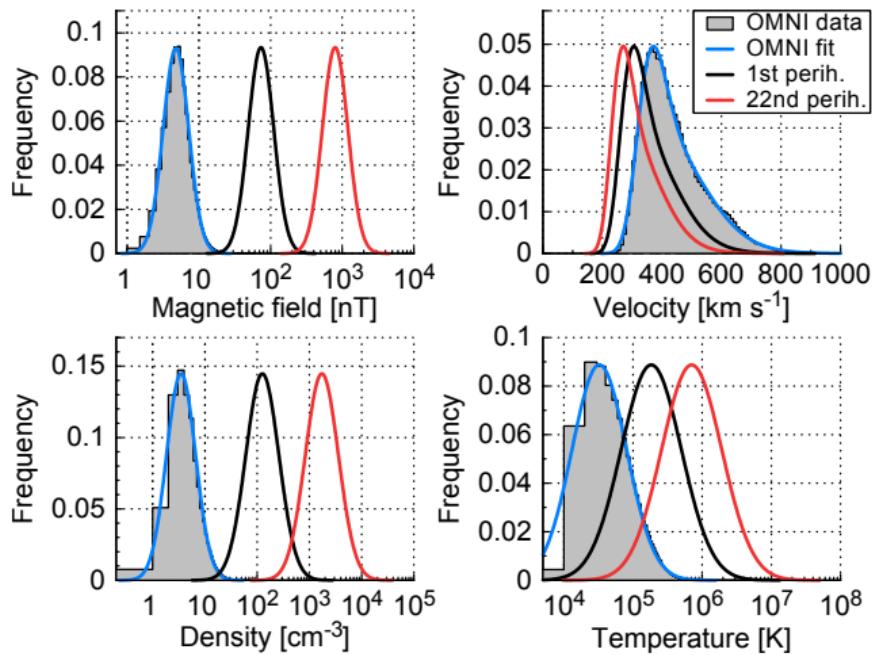
First perihelion ($9.86 R_{\odot}$)



First closest perihelion ($36.7 R_{\odot}$)



PSP perihelia prediction



Results

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

Conclusions

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

1 Solar wind

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4 End matter

Solar wind
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Geomagnetic impact of the solar wind
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Solar wind model for the inner heliosphere
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References

Thank you!

References |

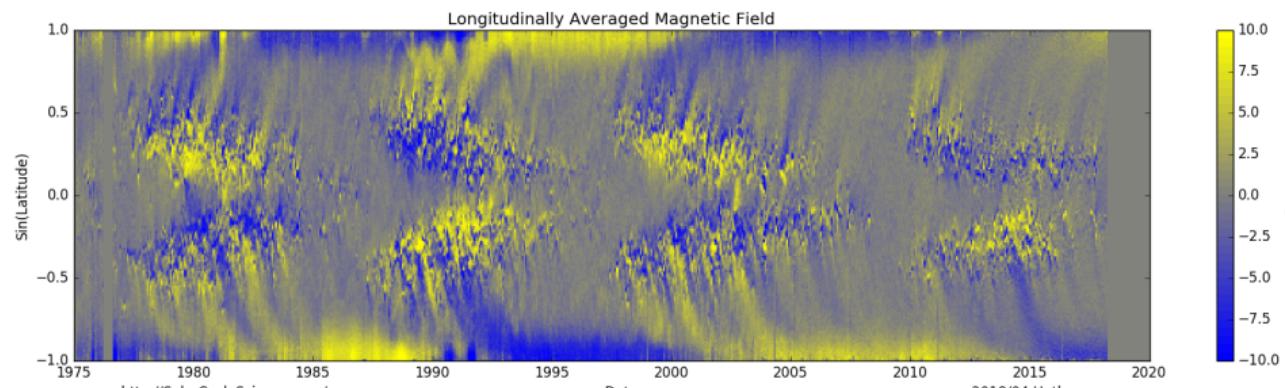
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5 Backup slides

- Solar wind
- Chapter2
- SW model

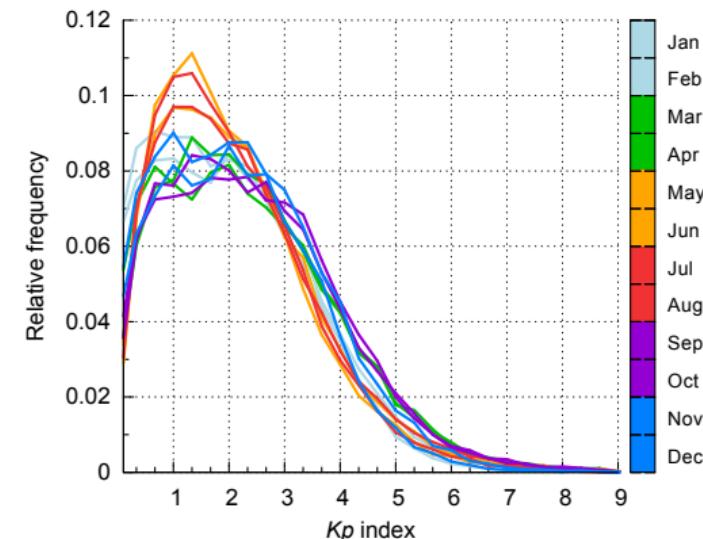
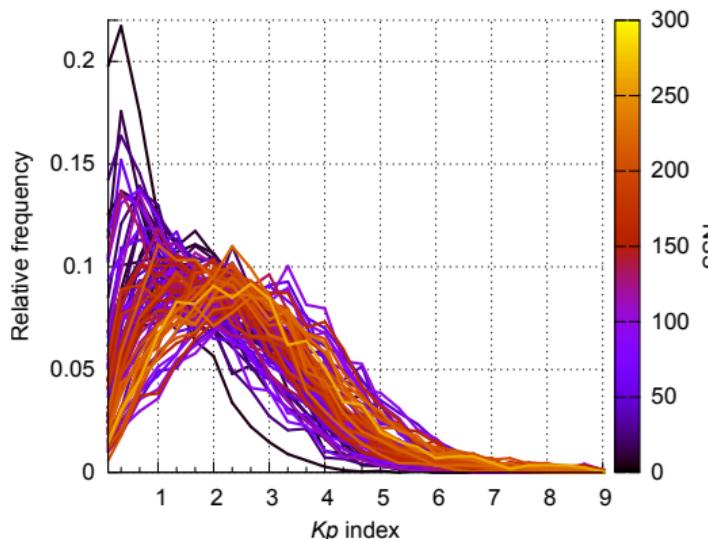
Solar activity

Magnetic butterfly diagram

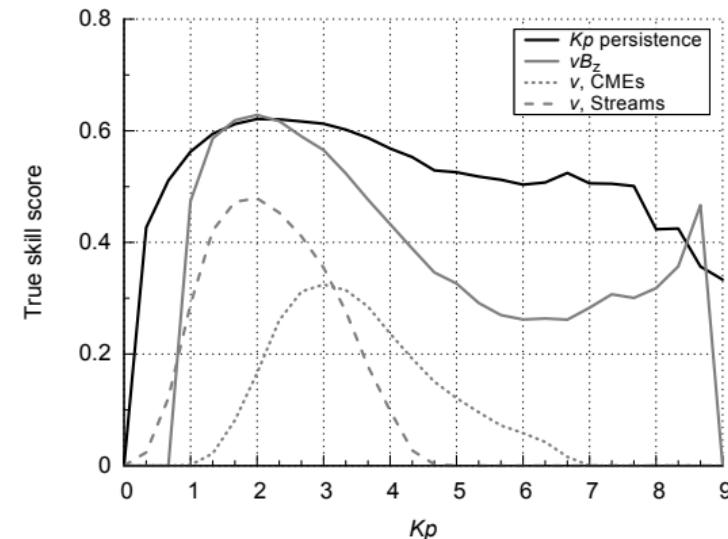
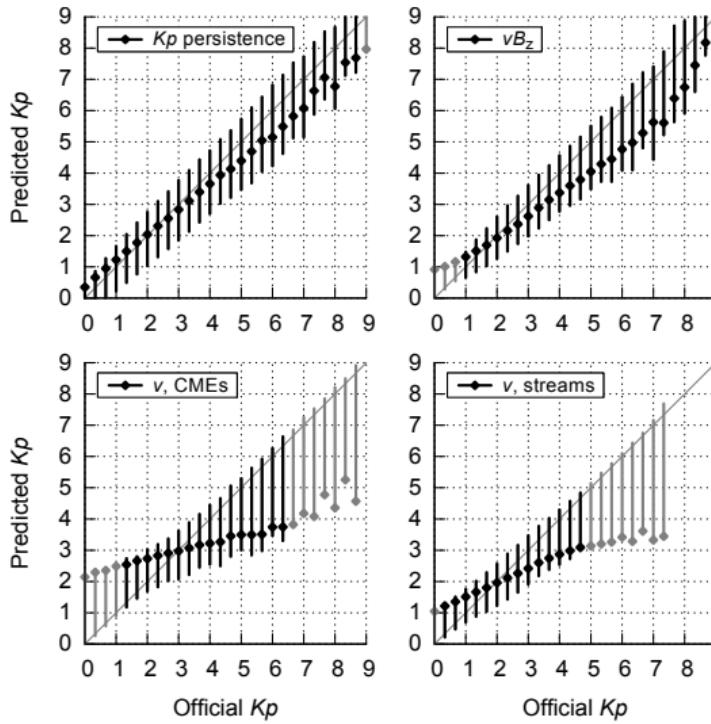


Courtesy of David Hathaway, Solar Cycle Science, 2018, updated version of Hathaway (2015, Fig. 17)

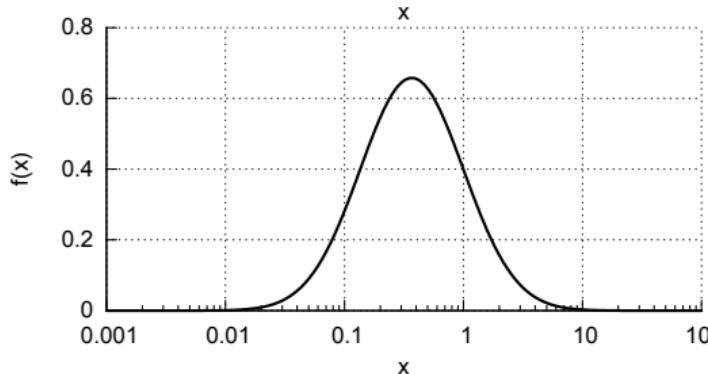
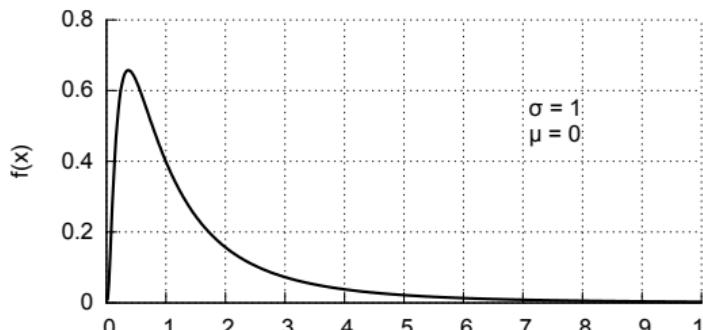
K_p long-term variations



Prediction performance



Lognormal distribution



Probability density function:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}x} e^{-\frac{(\ln x - \mu)^2}{2\sigma^2}}$$

Location (μ) and shape parameter (σ)