Magnetic Mapping to Determine Sources of Solar Wind at Solar Max

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Solar MHD Conference, Santa Barbara, January 2002

Neugebauer et al. (JGR, to appear 2001) used two-step mapping to determine sources of solar wind sampled by ACE & Ulysses

Here, Describe "Bootstrap" technique for validating mapping procedure & Show details for 3 Carrington Rotations analyzed in Neugebauer et al.

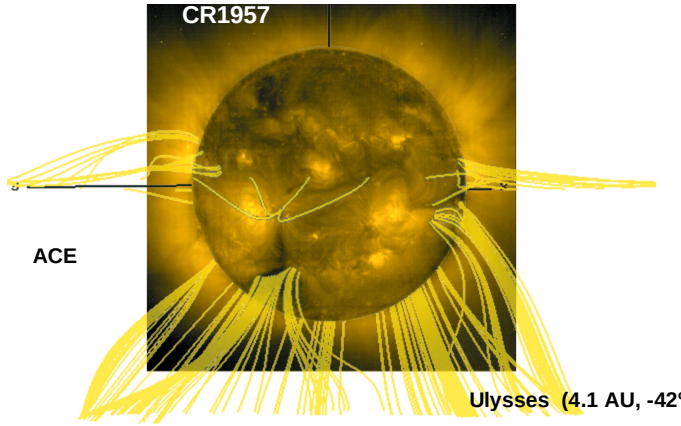
Bootstrap Technique

- Does the open flux predicted by the PFSS magnetic model agree with the observed coronal holes? **YES**
- Does the polarity predicted at the spacecraft agree with the measured polarity? **Usually***
- Does the solar wind data show source boundaries where model predicts source boundaries? **YES**

*** For Ulysses poleward of 60º, polarities do not agree. We did not map & analyze the solar wind data for these rotations.**

1

Mapping of Solar Wind from Ulysses and ACE from Source Surface to Sun



Results from Neugebauer et al (2001) Study

- *Find ACE and Ulysses solar wind near maximum activity maps to both mid-latitude coronal holes (CH) and active regions (AR)*
  - *Many equatorial coronal holes are in unipolar regions trailing active regions*
  - *AR source implies temporary coronal holes within active regions*
- *For Carrington rotations studied, no wind mapped to small polar coronal holes and no wind was as fast as wind seen by Ulysses at solar minimum*
- *Source boundaries with no polarity change show many characteristics of sector boundaries, e.g., plasma sheet, dip in entropy, magnetic hole*
- *Statistical studies showed little differences between coronal hole and active region wind except for $O7^+/O6^+$ ratio (somewhat lower for CH)*

2

Two Stage Mapping Procedure

1. "Ballistic" mapping from spacecraft to Source Surface at R_{SS} = 2.5 R_{Sun}
   ⇒ *Assumes wind flows radially from source surface to spacecraft at velocity measured at spacecraft*

2. Map wind from Source Surface to photosphere following field lines
   ⇒ *Field lines computed from potential field source surface (PFSS) model*
   ⇒ *Assumes solar wind follows magnetic field lines from photospheric source to source surface at R_{SS} = 2.5 R_{Sun}*

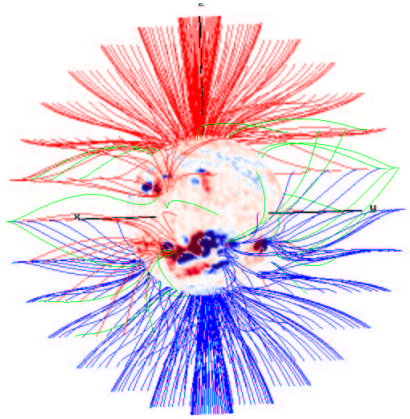
Details of Potential Source Surface Model

- *We use Kitt Peak synoptic magnetograms (1° resolution in latitude & longitude)*
  - *Assume B radial at the surface*
  - *No polar field correction applied*
  - *Compute potential field magnetic field on grid with nr=101, ntheta=151 and nphi=256*

- *Uncertainty of mapping: ±5-10° at source surface, but smaller at photosphere (unless near source boundary)*

3

CR 1934
Open Flux from Magnetic Model



Mapping of field lines from source surface to solar surface
(lines uniformly spaced at R_{SS} = 2.5 R_{Sun})

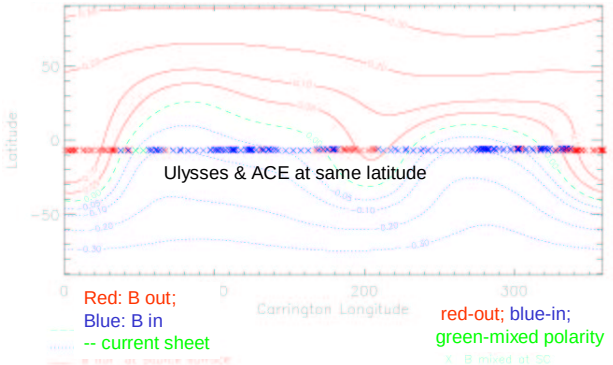
Most flux from polar coronal holes

Days 77-104 of 1998, Ulysses at 5.4 AU

Some active region flux warps current sheet
(see --- green line below)

Ulysses and ACE footpoints on Source Surface

Good agreement between observed and predicted polarity for ACE & Ulysses



Red: B out;
Blue: B in
-- current sheet

red-out; blue-in;
green-mixed polarity

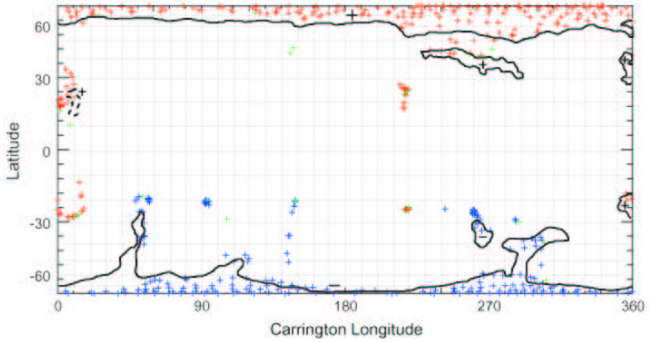
4

CR 1934: Mapping to Solar Source

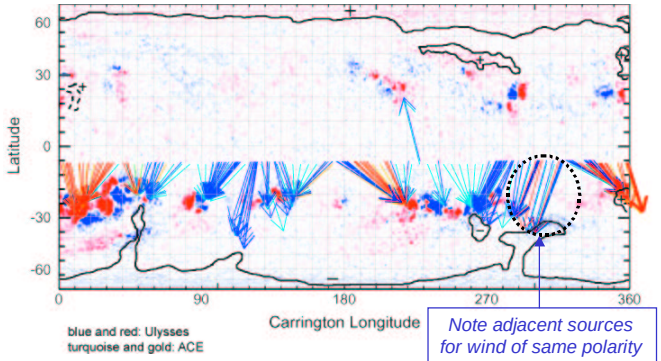
Open Flux from Models (+) agrees very well with Observed Coronal Holes Observed in He 10830 Å

Small open flux regions in model may be too small to seen in 10830

NSO/KP He I 1083 nm Coronal Hole Map: Carrington Rotation 1934



Mapping of ACE and Ulysses footpoints from source surface to photosphere



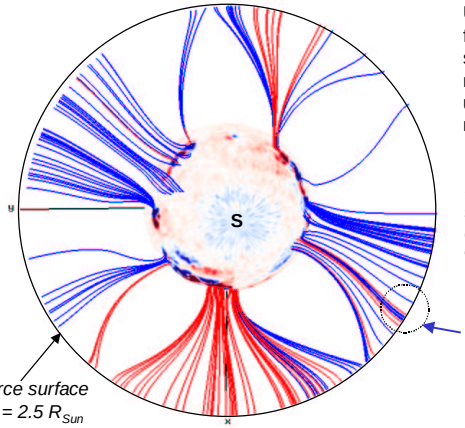
blue and red: Ulysses
turquoise and gold: ACE

Background: synoptic magnetogram (Kitt Peak)
Arrows: tail is footpoint as source surface & head is footpoint at photosphere

Note adjacent sources for wind of same polarity Small AR by CH Day 104

5

CR 1934
Ulysses Mapping from Source Surface to Photosphere



Ulysses solar wind footpoints on source surface (R_{SS} = 2.5 R_{Sun}) mapped to solar surface using PFSS magnetic model (Step 2)

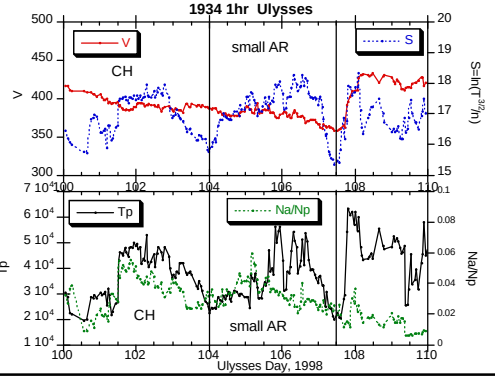
Solar wind from different source regions on Sun clearly identified by "bunching" of field lines

Adjacent sources for wind of same polarity Small AR by CH Day 104

source surface
R_{SS} = 2.5 R_{Sun}

Source Boundary is Evident in SW Data

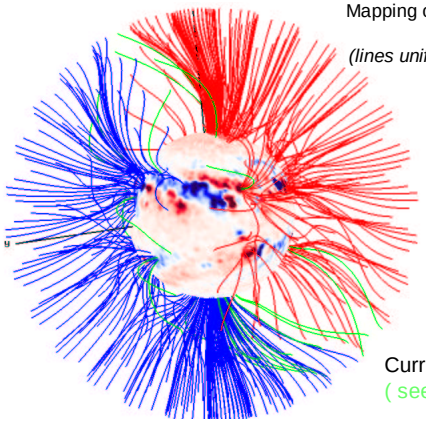
Best Marker is Entropy Dip ($S=T^{3/2}/n$)



6

CR 1946
Open Flux from Magnetic Model

Mapping of field lines from source surface to solar surface
(lines uniformly spaced at R_{SS} = 2.5 R_{Sun})



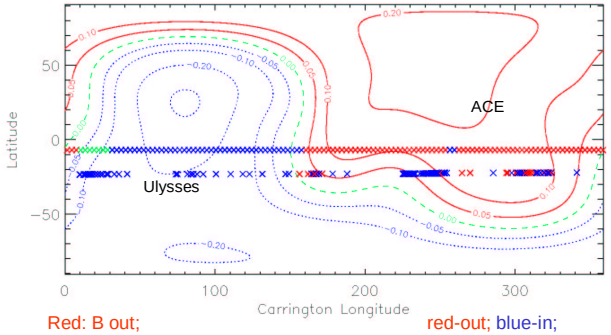
Open flux from polar coronal holes and equatorial regions

Days 39-66 of 1998, Ulysses at 5.1 AU

Current Sheet Quite Warped
(see --- green line below)

Ulysses and ACE footpoints on Source Surface

Good agreement between observed and predicted polarity for ACE & Ulysses



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-- current sheet

red-out; blue-in;
green-mixed polarity

CR 1946: Mapping to Solar Source

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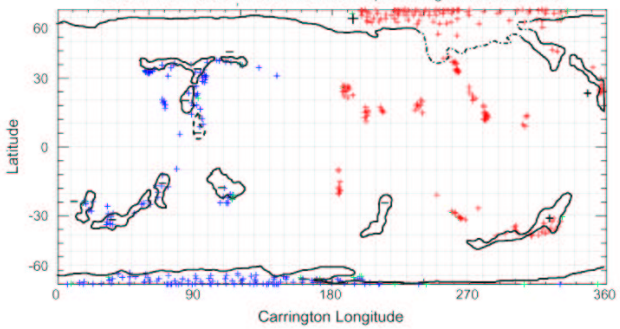
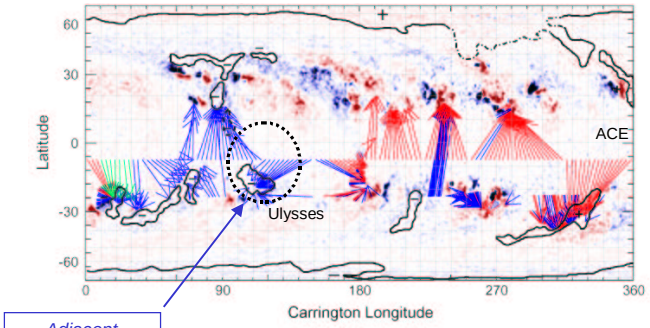
NSO/KP He I 1083 nm Coronal Hole Map: Carrington Rotation 1946



Mapping of ACE and Ulysses footpoints from source surface to photosphere



Adjacent sources for wind of same polarity CH by CH ACE Day 62

Background: synoptic magnetogram (Kitt Peak)
Arrows: tail is footpoint as source surface & head is footpoint at photosphere
Black lines: coronal holes from 10830 Å (Kitt Peak, K. Harvey)

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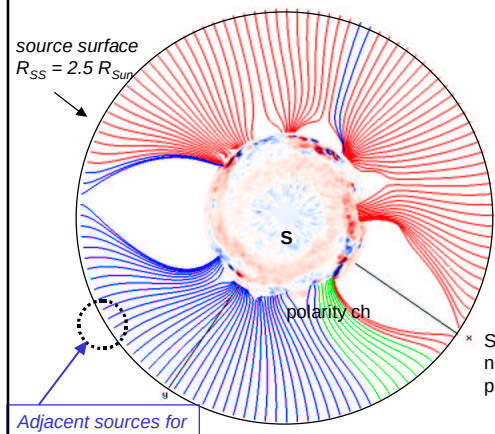
CR 1946
ACE Mapping from Source Surface to Photosphere



ACE solar wind footpoints on source surface (R_{SS} = 2.5 R_{Sun}) mapped to solar surface using PFSS magnetic model (Step 2)

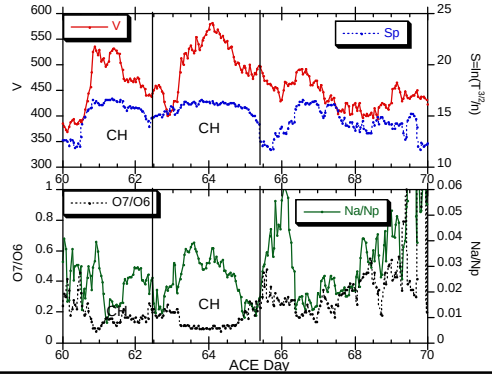
Solar wind from different source regions on Sun clearly identified by "bunching" of field lines

Source region changes not necessary marked by polarity change

Adjacent sources for wind of same polarity CH by CH ACE Day 62

Source Boundary is Evident in SW Data

Best Marker is Entropy Dip



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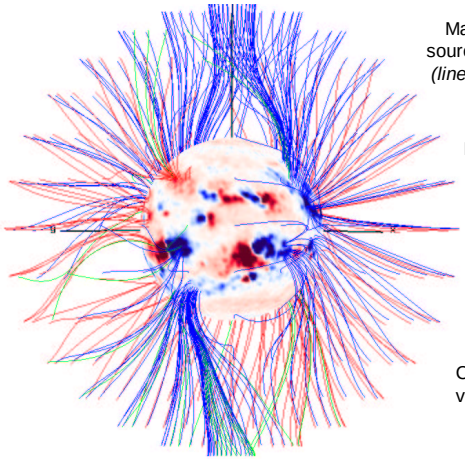
CR 1957
Open Flux from Magnetic Model



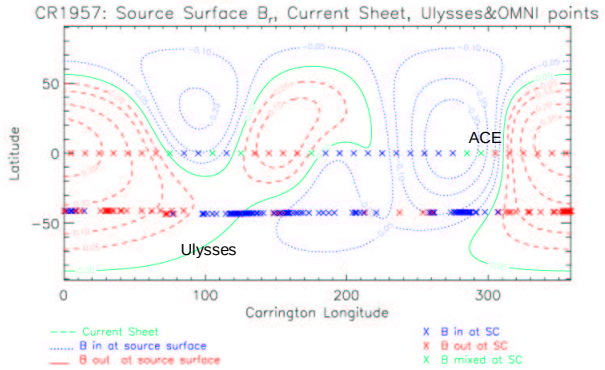
Mapping of field lines from source surface to solar surface *(lines uniformly spaced at R_{SS} = 2.5 R_{Sun})*

Days 339,1999 -1/2000
Ulysses at 4.1 AU

Most Open flux from equatorial regions

Flux over poles is from mid latitude regions

Current sheet quite warped; vertical in places



Good agreement between observed and predicted polarity for ACE & Ulysses

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CR 1957: Mapping to Solar Source

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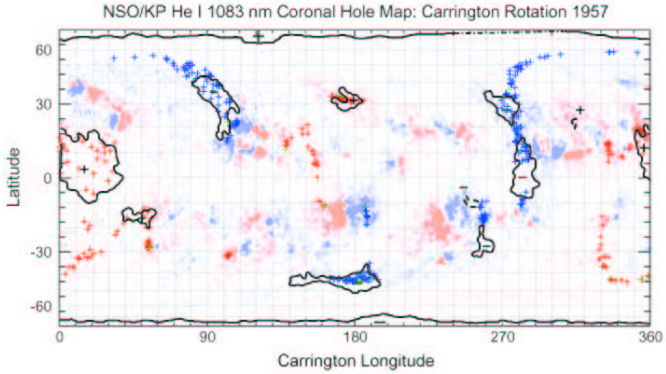

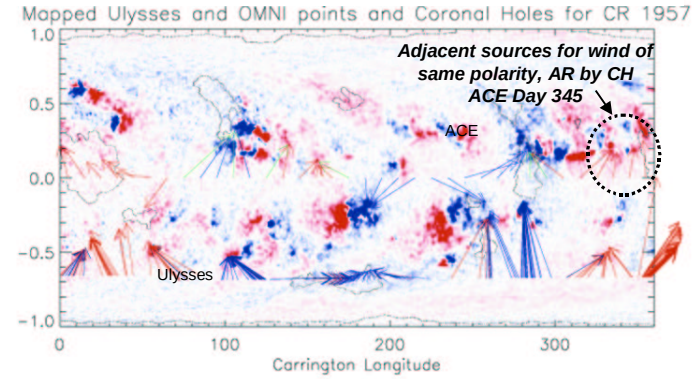

Background: synoptic magnetogram (Kitt Peak)
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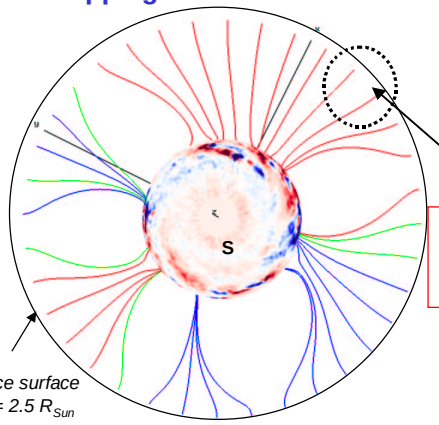
CR 1957
ACE Mapping from Source Surface to Photosphere



ACE solar wind footpoints on source surface (R_{SS} = 2.5 R_{Sun}) mapped to solar surface using PFSS magnetic model (Step 2)

Adjacent sources for wind of same polarity, AR by CH ACE Day 345

source surface R_{SS} = 2.5 R_{Sun}

Source Boundary is Evident in SW Data

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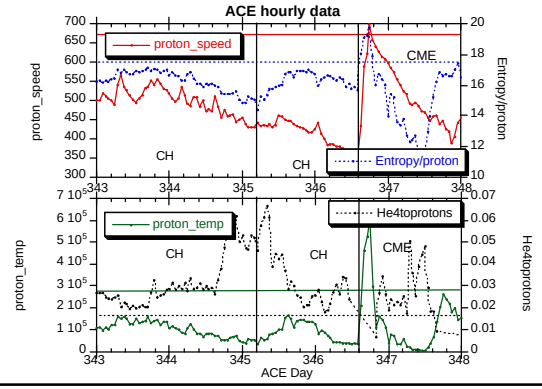

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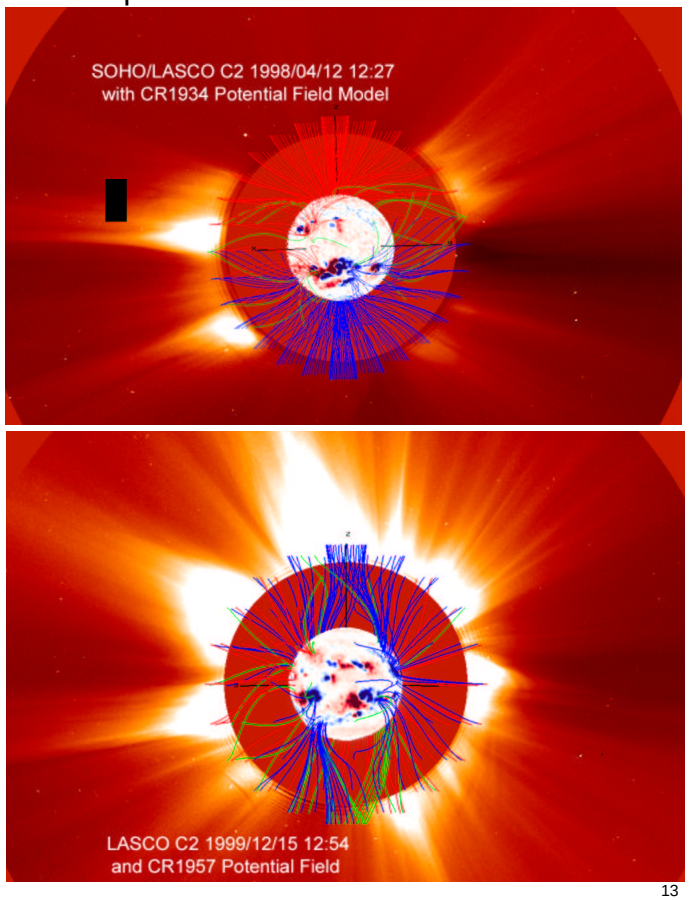
Comparison of CR1934 and CR1957



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Summary

We described bootstrap mapping technique used to determine solar source of solar wind sampled by ACE and Ulysses for Carrington Rotations analyzed in Neugebauer et al. 2001

- We tested the potential source surface model by comparing predicted open flux with observed coronal holes -- excellent agreement
- We tested the mapping by comparing the predicted magnetic field polarity with that observed at the spacecraft -- good agreement
- The mapping then predicts source regions boundaries
- We see whether the solar wind data itself shows evidence of a source region boundary (easiest marker is entropy S = ln) -- So far, we find evidence very close to predicted boundaries

Conclusion

Bootstrap modeling technique is valid and is an excellent tool for studying properties of solar wind from various sources

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