Sun’s Magnetic Pole

Judith de Patoul, Bernd Inhester and Robert Cameron

MPS Solar Group Seminar

Katlenburg-Lindau, February 7, 2012
On the Earth:
- The magnetic pole is the point where the large scale field is perpendicular to the surface.

On the Sun:
- Can we define such a point on the Sun?
- Can we measure its location?
- Which information can it provide us?
Solar plumes trace the field lines

We can use them to find the location of the solar magnetic pole.
1. Observation of the temporal evolution of the 3D axis of plume.

2. Identification of the Sun’s magnetic pole.

3. Comparison of the observations with an open magnetic flux model.

4. Discussion: What can we learn from this?
Data from 1st of April 2007 to 31st of May 2008

- **Wavelength**: 171Å
- **Pixel resolution**:
  - STEREO/EUVI: 1.6 arcsec/pixel
  - SOHO/EIT: 2.5 arcsec/pixel
- **Separation angles**:
  - EUVI-A & EUVI-B: 6.08° – 49.94°
  - EUVI-B & EIT: 1.89° – 24.04°
  - EUVI-A & EIT: 4.21° – 25.90°
- **Preprocessing**:
  - secchi_prep.pro
  - eit_prep.pro
**Observation**

STEREO/EUVI-A (171 Å) on 1-Nov-2007 at 00:06:00 UT

Cosmic ray hits removal + Contrast enhancement

Judith de Patoul et al.
Katlenburg-Lindau, 2011
**Hough-wavelet Transform:**

\[
HW(\rho, a, \theta) = \int_{\mathbb{R}^2} I(x) \frac{1}{a} \psi^{MH} \left( \frac{\mathbf{u}_\theta \cdot x - \rho}{a} \right) dx,
\]

where \(\theta \in [-\pi/2, \pi/2]\), \(\mathbf{u}_\theta = (\cos \theta \ \sin \theta)\),
\(\rho \in [-\rho_{\text{max}}, \rho_{\text{max}}]\), and \(a \in \mathbb{R}_0^+\)
**Hough-wavelet Transform:**

\[
HW(\rho, a, \theta) = \int_{\mathbb{R}^2} I(x) \frac{1}{a} \psi_{MH}^{\rho} \left( \frac{u_\theta \cdot x - \rho}{a} \right) dx,
\]

where \( \theta \in [-\pi/2, \pi/2] \), \( u_\theta = (\cos \theta \ \sin \theta) \), \(\rho \in [-\rho_{\text{max}}, \rho_{\text{max}}] \), and \( a \in \mathbb{R}_0^+ \)

**Image Space** \((x, y)\)

**Hough-wavelet Space** \((\rho, a = 1.0, \theta)\)
IDENTIFICATION OF THE MAGNETIC POLE

Hough-wavelet Transform:

\[ HW(\rho, a, \theta) = \int_{\mathbb{R}^2} I(x) \frac{1}{a} \psi^{MH}(\frac{u_\theta \cdot x - \rho}{a}) \, dx, \]

where \( \theta \in [-\pi/2, \pi/2] \), \( u_\theta = (\cos \theta \ \sin \theta) \), \( \rho \in [-\rho_{\text{max}}, \rho_{\text{max}}] \), and \( a \in \mathbb{R}_0^+ \)

Image Space \((x, y)\)

Hough-wavelet Space \((\rho, a = 5.5, \theta)\)

Judith de Patoul et al.
Katlenburg-Lindau, 2011
**Hough-wavelet Transform:**

\[
HW(\rho, a, \theta) = \int_{\mathbb{R}^2} I(x) \frac{1}{a} \psi_{MH}^{\mathbf{u}_\theta} \left( \frac{\mathbf{u}_\theta \cdot x - \rho}{a} \right) \, dx,
\]

where \( \theta \in [-\pi/2, \pi/2] \), \( \mathbf{u}_\theta = (\cos \theta \sin \theta) \),
\( \rho \in [-\rho_{\text{max}}, \rho_{\text{max}}] \), and \( a \in \mathbb{R}_0^+ \)

---

**Image Space** \((x, y)\)

**Hough-wavelet Space** \((\rho, a = 14.5, \theta)\)
Hough-wavelet Transform: Solar plumes

1. Image Space \((x, y)\)

2. Mapping in \((s_r, s_\phi)\)-coordinate

\[
(x, y) \rightarrow (r, \phi) \quad \begin{cases} 
    r = \sqrt{x^2 + y^2} \\
    \phi = \arctan(x/y)
\end{cases}
\]

\[
(r, \phi) \rightarrow (s_r, s_\phi) \quad \begin{cases} 
    s_r = (r - r_c)/\Delta r \\
    s_\phi = \phi/\Delta \phi
\end{cases}
\]

3. Hough-wavelet Space \((\rho, a, \theta)\)

4. Hough Space \((\rho, a_M, \theta)\)
Hough-wavelet Transform: Results

- Pre-processed Image:

- Hough Space \((\rho, a_M, \theta)\):

  (J. de Patoul et al., 2011)
MAGNETIC POLE & MAGNETIC OPENING

plume peaks are aligned along an inclined line
\[ \theta = u \rho + v \]

Magnetic Opening \( \iff \) Variation of the slope \( u \):

- \( |u| \sim 0 \)
- \( |u| > 0 \) after 45°
- \( |u| >> 0 \) after 90°

Magnetic Pole location \( \iff \) Variation of the intercept \(-v/u\):

- \( -v/u < 0 \)
- \( -v/u = 0 \) after 90°
- \( -v/u > 0 \) after 180°
Magnetic Opening – Slope \( u \)

Data from 1st of April 2007 to 31st of May 2008

North pole:

South pole:
**MAGNETIC POLE – INTERCEPT \(-v/u\)**

Data from 1st of April 2007 to 31st of May 2008

North pole:

\[
\text{intercept } -\frac{v}{u} < 0
\]

South pole:

\[
\text{intercept } -\frac{v}{u} = 0
\]

\[
\text{intercept } -\frac{v}{u} > 0
\]
Sun’s open magnetic flux and the heliospheric current sheet: Robert Cameron et al.; J. Jiang, R. Cameron et al., 2010

Judith de Patoul et al. Katlenburg-Lindau, 2011

Sun’s Open Magnetic Flux Model

From 2007-10-21 to 2007-11-18

Radial field $B_r$

Azimuthal field $B_{\theta}$

Polar field $B_{\phi}$

Open and closed field

(Sun’s open magnetic flux and the heliospheric current sheet: Robert Cameron et al.; J. Jiang, R. Cameron et al., 2010)
From 2007-10-21 to 2007-11-18

Open and closed (white/black) field lines:

Field line inclinations: \( \arctan \left( \frac{B_\theta}{B_r} \right) \):
For each rotation angle, we produce synthetic plumes:
SYNTHETIC PLUME RECONSTRUCTION

→ See movie
MAGNETIC POLE & MAGNETIC OPENING IDENTIFICATION

■ Pre-processed Image:

■ Hough Space \((\rho, a_M, \theta)\):

Judith de Patoul et al. Katlenburg-Lindau, 2011
Magnetic Opening – Slope $u$

Model – North pole:

Observation – North pole:

Data from 21st of October 2007 to 18th of November 2007

Judith de Patoul et al.
Katlenburg-Lindau, 2011
MAGNETIC POLE – INTERCEPT $-v/u$

**Model – North pole:**

- $-v/u < 0$
- $-v/u = 0$
- $-v/u > 0$

**Observation – North pole:**

Data from 21st of October 2007 to 18th of November 2007

Judith de Patoul et al.
Katlenburg-Lindau, 2011

SUN’S MAGNETIC POLE
**MAGNETIC POLE – INTERCEPT $-v/u$**

**Model – North pole:**

Data from 21st of October 2007 to 18th of November 2007

**Radial field:**

Data from 21st of October 2007 to 18th of November 2007
We have identified:

- the solar magnetic pole’s location.
- the magnetic field opening at the pole.

What can we infer from the variation of these quantities?

- Tells us whether there is a flux emergence on (the back side of) the Sun.
- Can comment on the expansion factor of the field lines.
- Gives us a better constraint on the near polar meridional flows.
Thank you!
MAGNETIC OPENING – SLOPE $u$

**Model – South pole:**

Data from 21st of October 2007 to 18th of November 2007

**Observation – South pole:**

Data from 21st of October 2007 to 18th of November 2007

Judith de Patoul et al. Katlenburg-Lindau, 2011
MAGNETIC POLE – INTERCEPT \(-\nu/u\)

INTRODUCTION

OUTLINE

DATA

HWT

OBSERVATION

MODEL

RESULTS

CONCLUSION

Model – South pole:

Observation – South pole:

Data from 21st of October 2007 to 18th of November 2007

Judith de Patoul et al.

Katlenburg-Lindau, 2011

SUN’S MAGNETIC POLE
Magnetic Pole – Intercept $-\nu/\mu$

**Model – South pole:**

Data from 21st of October 2007 to 18th of November 2007

**Radial field:**

Data from 21st of October 2007 to 18th of November 2007