Solar velocity field determined tracking coronal bright points

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1. Introduction
2. Data
3. Methods of data reduction
4. Results and comparisons
5. Discussion and conclusions
6. Acknowledgements
Introduction

Two concepts:

• Solar velocity field
• Coronal bright points
Solar velocity field

- Solar differential rotation
  \[ \Omega = A + B \sin^2 \psi + C \sin^4 \psi \]
- Residual rotation velocity / torsional oscillations,
  \[ \Delta \omega_{rot} = \Delta \nu_{rot} \]
- Meridional motions, \( \omega_{mer} = \nu_{mer} \)
- Correlation \( \Delta \omega_{rot} \) and \( \omega_{mer} \)
- Reynolds stress, \( Q = \langle \Delta \omega_{rot} \cdot \omega_{mer} \rangle \)
- Large scale motions, \( L > 50000 \text{ km} \)
- Random walk, diffusion of magnetic elements
Coronal bright points

- magnetic tracers associated with bipolar magnetic features; 1/3 of them lie over ephemeral regions (new emerging regions of magnetic flux) and the remaining 2/3 lie above cancelling magnetic features (consisting of opposite polarity fragments that approach and disappear)
- Skylab, Yohkoh, **SOHO**, TRACE, Hinode, **SDO**
Agenda

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Data: SOHO/EIT, SDO/AIA

- Solar and Heliospheric Observatory (NASA/ESA), EIT (1998-2006, EUV, Fe XV, 28.4nm, 6h, 2.6")
  - Interactive (dataset 1 < 11 images, dataset 2 < 24 images)
  - Automatic (3 images)
- Solar Dynamics Observatory (NASA), AIA (two days 2011, EUV, soft X, 10 min, 0.6")
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Methods of data reduction

- Measured positions -> heliographic coordinates -> latitudinal and longitudinal velocity components
  - Daily shift method
  - Tracing, linear least square fit
- Filters (0.85 R, 8 < \( \omega \) < 19 °/day, -4 < \( v_{\text{mer}} \) < 4 °/day, ... )
- Synodic rotation rates -> siderereal rotation velocities (Skokić et al., 2014)
- Height correction (Roša et al., 1998; Brajša et al., 2004)
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Solar differential rotation – SOHO/EIT

Brajša et al. (2004)
Solar differential rotation – SOHO/EIT

Wöhl et al. (2010)
Meridional motions - SOHO/EIT

- Up to ≈ 10 m/s
- However, errors of the same order of magnitude
- Results are dependent on the method
- Cycle dependence: larger velocity in minimum of activity (Hathaway & Rightmire, 2010)

SOHO-EIT: Vršnak et al. (2003), interactive

Hathaway & Rightmire (2010)
Meridional motions – SOHO/EIT

automatic method, \( v_{mer} \sim 10 \text{ m/s} \)
Meridional motions – SOHO/EIT

Non-axisymmetric motions (October - November 1999), deg/day
1 deg/day = 140 m/s
(interactive method)
Torsional oscillations – SOHO/EIT

automatic method, $\Delta v_{\text{rot}}$ in m/s
Reynolds stress SOHO/EIT

- Interactive method
- Correlation of the velocity components of sunspots: sign and amount consistent with the observed solar differential rotation (Ward, 1965)
- Similar results obtained later with sunspots (Howard & Gilman, 1986) and CBP (Vršnak et al., 2003)
- Latitude dependent
- New research needed to obtain more reliable results
Velocity correlations – SOHO/EIT

Automatic method

Velocity correlation, $v_{\text{mer}} = (-0.003 \pm 0.001) \Delta v_{\text{rot}}$

Reynolds stress, $\sim -100 \text{ (m/s)}^2$, min. at $b \approx 20^\circ$
SDO/AIA: 19.3 nm

2 days, \( \sim 50,000 \) measurements, segmentation algorithm
SDO/AIA: 19.3 nm
SDO/AIA: 19.3 nm
Proper motions of CBPs, min. 10 measurements
Velocity errors

SDO/AIA

meridional

rotational
SDO/AIA

Differential rotation  
(Sudar et al., 2014a)

\[
\begin{align*}
A &= 14.47 \pm 0.10 \\
B &= 0.6 \pm 1.0 \\
C &= -4.7 \pm 1.7 \\
\end{align*}
\]

\[
\begin{align*}
C &= 0 \\
A &= 14.62 \pm 0.08 \\
B &= -2.02 \pm 0.33
\end{align*}
\]
SDO/AIA: meridional motions
SDO/AIA: rotation velocity residual
Reynolds stress,
$v_{mer} = (-0.06 \pm 0.03) \Delta v_{rot}$

$Q \sim -5000 \text{ m}^2/\text{s}^2$
Absolute velocities and lifetimes

- SOHO/EIT, 1998-1999, interactive method (Brajša et al., 2008)
Absolute velocities and lifetimes

- SDO/AIA (1-2 January 2011)
Random walk model

SOHO/EIT (Brajša et al., 2008)
• lifetime $\approx 12-60\text{h}$
• $v_{\text{abs}} \approx 50-70 \text{ m/s}$
• mean free path $\approx 3000-15000 \text{ km}$
• diffusion coefficient of random walk, $D \approx 150-250 \text{ km}^2/\text{s}$

SDO/AIA
• lifetime $\approx 4-25\text{h}$
• $v_{\text{abs}} \approx 100-250 \text{ m/s}$
• mean free path $\approx 3000-8000 \text{ km}$
• diffusion coefficient of random walk, $D \approx 200-250 \text{ km}^2/\text{s}$

\[ D = \frac{\langle r^2 \rangle}{4\tau}. \]
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Sunspot groups: Extended Greenwich

- Meridional motions (Sudar et al., 2014b)
Sunspot groups: Extended Greenwich

- Correlation: \( v_{mer} = (-0.0804 \pm 0.0017) \cdot \Delta v_{rot} [m/s] \)
Sunspot groups: Extended Greenwich

- Reynolds stress, $\approx -2000 \text{ (m/s)}^2$, min. at $b \approx 30^\circ$
Reynolds stress: comparison with theoretical models

Canuto et al. (1994)
SDO: other efforts

- Lorenc et al. (2012): manual, semi-automatic method (similar to our SOHO/EIT interactive method)
- Dorotovič et al. (2014), Shahamatnia et al. (2014): improvement of that method; still not fully automatized
- In a general agreement with our results
Tracking magnetic elements, Hinode: Iida (2014)

\[ K(\tau) = \frac{1}{4} \frac{\partial L(\tau)^2}{\partial \tau} \]
Tracking magnetic elements, Hinode: Iida (2014)

1. Consistent with previous results
2. Smaller than global evaluation

\[ K(\tau) = \frac{1}{4} \frac{\partial L(\tau)}{\partial \tau} \]

Global Surface Transport

Our result!
Conclusions

- Coronal bright points are excellent tracers for the determination of the solar velocity field
- Good spatial and temporal coverage, localized structure
- Possibility to:
  - Study solar rotation on the monthly basis
  - Use CBPs for tracking magnetic elements
- SOHO, Hinode, SDO
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