Interactions Between Magnetic Activity and Large-Scale Subsurface Flows

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How does Ring Analysis work?
Overview of Solar Subsurface Weather (SSW)
The interaction of SSW and active regions
Global versus Local Helioseismology

**Local Techniques:** Ring Analysis, Time-Distance Helioseismology, Acoustic Holography
Local Helioseismology: *Ring-Diagram Analysis*

- Analyze acoustic wave fields over mosaic of tracked localized regions (each $15^\circ$ square)
- Measure anisotropic frequency splittings of local $f$ and $p$ modes in power spectra
- Invert splittings to deduce flows with depth
Ring Analysis Kernels

- RLS – Optimizes the fit to the data
- OLA – Optimizes the shape of the inversion kernel
Ring-Diagram Dense-Pack Flow Inversion

SUBSURFACE FLOWS FOR TWO SUCCESSIVE DAYS

Magnetic Field Patterns Underlayed (Red-Green)
Solar Subsurface Weather

Synoptic Average of the Daily Maps

April 2002
Synoptic Mapping of SSW over Full Rotation

7.1 Mm DEPTH

Global Patterns of SOLAR SUBSURFACE WEATHER
7-day Averages of Ring-Diagram Inversions
Synoptic Maps of Two Successive Rotations

1997
7.1 Mm

CRCR 1923
CRCR 1922

16 Jun 97, CR 1923, Depth = 7.10 Mm, 7 day avg, 21 May 97

20 May 97, CR 1922, 7 day avg, 24 Apr 97

30 m/s Carrington Longitude
SSW Flows Changing as Cycle Progresses

Depth = 7.1 Mm

29 Apr 99 CR 1948

16 Jun 97 CR 1923

CRCR 1948
CRCR 1923

03 Apr 99 21 May 97

30 m/s Carrington Longitude
Varying Pattern of Meridional Cells

**2003**

**NORTH:**

**DOUBLE CELL**

**2002**

**POLEWARD FLOW NEAR SURFACE**

**2001**

**REVERSED FLOW AT DEPTH**

**2000**

**1999**

**MULTI-ROTATION AVERAGES**

**1998**

**SOUTH:**

**SINGLE CELL**

**2003**

**10 days**

**2002**

**2001**

**1999**

**1998**

**Latitude (degrees)**

**Depth (M/m)**

**20 m/s**

**SOUTH**

**NORTH**
SSW and Active Regions

- The flows are generally faster in active regions.
- Near the surface active regions are zones of convergence.
- At depths greater than 10 Mm many active regions are zones of intense outflow.
- The RLS and OLA inversions agree well.
Evolving SSW Near Active Complexes

FLOW EVOLUTION OVER THREE DAYS
STREAMING FEATURES STRENGTHEN AND CONVERGE TOWARD ACTIVE REGION
Average the meridional flow over longitude (140 – 160 degrees) time (4 days)

- The transition occurs at different depths for different latitudes.
- The transition is poorly resolved by the inversion; it could be sharper.
Active Region Differences

01 Feb 2002  CR 1985

13 Nov 2003  CR 2009

Carrington Longitude

Latitude

30 m/s

Depth = 14.0 Mm

CR 2008  18 Oct 2003

A
Future Goals for SDO

- How small a spatial resolution can the ring analysis technique achieve?
- Can properties of the rings other than the frequencies and displacements be used to deduce physical properties? (p-mode line shape, power anisotropies, etc.)
- Can information from neighboring tiles be used in a single 3-D inversion? (optimal tiling schemes? achievable horizontal resolution?)
• Clear interplay between SSW flows and magnetic fields.
• Major AR exhibit prominent inflows in upper 7 Mm, outflows below ~ 10 Mm.
• Finer scale flows achievable with time-distance (and improved ring techniques) are needed to assess the structure of the inflows and outflows.
Evolving Mean Zonal and Meridional Flows

Propagating Zonal Bands
Varying Meridional Cells
Close-in Views \textit{Apr 2001} \textit{FOUR DAYS}
Close-in Views  Mar 2001  FOUR DAYS

Mar 2001

EIT
Fe XII
195 Å

7 Mm

16 Mm

FOUR DAYS
Equatorial Coronal Hole  *Feb-Mar 02*

*MAJOR CORONAL HOLES EXPECTED IN DESCENDING PHASE*
Close-in View: Coronal Hole  Mar 2002

EIT 284

Depth = 7 Mm

Depth = 12 Mm
Mean Flows and Field Effects

Weighted Average

7.10 Mm

1996
Time-Distance & Ring-Diagram Comparisons

Hindman et al.
SSW in Apr 2002
Synoptic Mapping of SSW in *Apr 2002*

10.2 Mm Total Interp

24 Apr 2002   CR 1988   10.2 Mm   7 day avg   29 Mar 2002

Carrington Longitude

Latitude

30 m/s
Synoptic Mapping of SSW in *Apr 2002*

10.2 Mm Fluctations

CR 1988

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30 m/s

Carrington Longitude
Time-Distance: Flows Within Active Region

NOAA 9393, 2001.04.26_20:00, d=6.4 Mm

Kosovichev, Duvall & Zhao