

Photospheric and Sub-photospheric Horizontal Flows in Active Regions

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Why to study sub-surface flows?

Precise knowledge of sub-surface flows is crucial to understand the **long-term variability of the Sun**. For dynamo models, observations spanning, at least, 11 to 22 years are required.

Space Weather Forecast ...

Sub-surface weather (SSW) may provide important clues, at least several days in advance, before any major eruption, e.g. flares (Work by Komm & co-workers in last decade).

Questions to be addressed in this talk:

- ✓ How well we can infer flows near surface?
- ✓ Is there temporal variation in sub-surface flows beneath active regions during their passage across the solar disk?
- ✓ How different flows are depending upon the morphology of active regions?

Determination of Flows

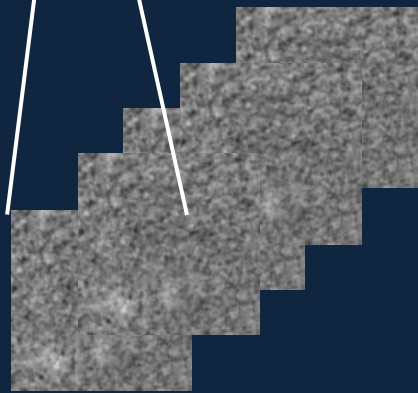
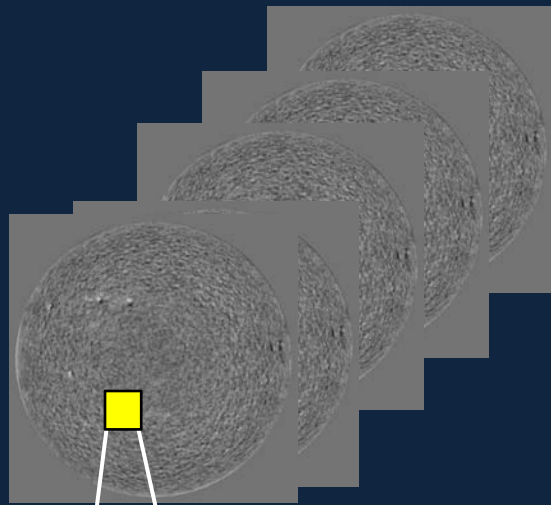
Sub-photospheric flows

- calculated using local helioseismic technique of ring-diagrams

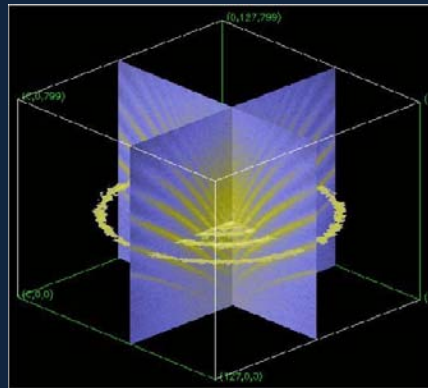
Photospheric flows

- calculated using local correlation tracking (LCT) method

Ring-diagram Technique a quick recap



3D-FFT



Velocity (V_x & V_y) as a function of depth

Inversion

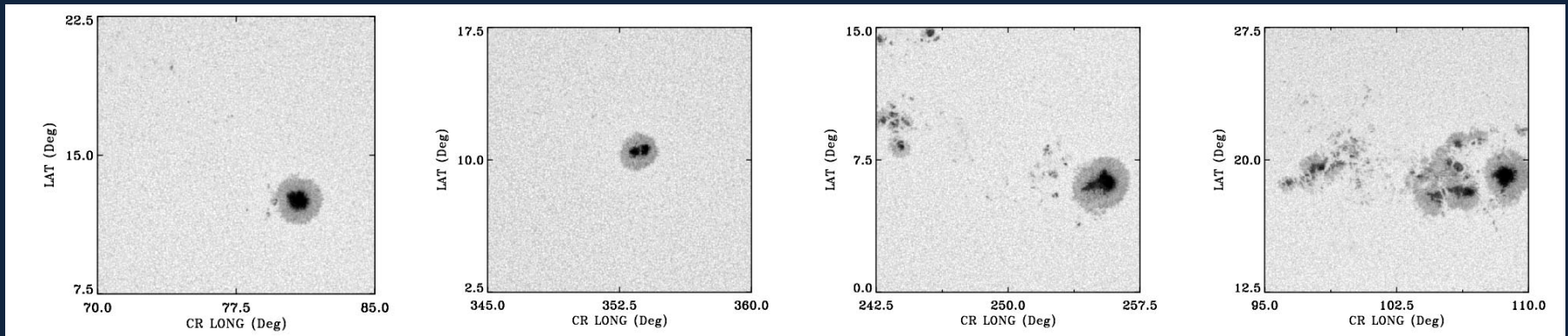
Mode parameters:
Frequency, Line width,
Amplitude, Background,
Velocity (U_x & U_y)

Peak Profile Model

Question:

- ✓ How well we can infer flows near surface?
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- ✓ How different flows are depending upon the morphology of active regions?

Photospheric Flows - Data Selection



AR 11092

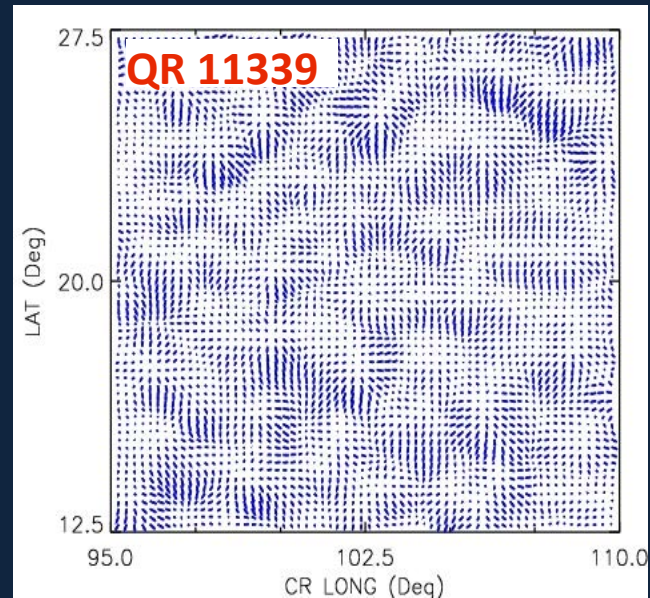
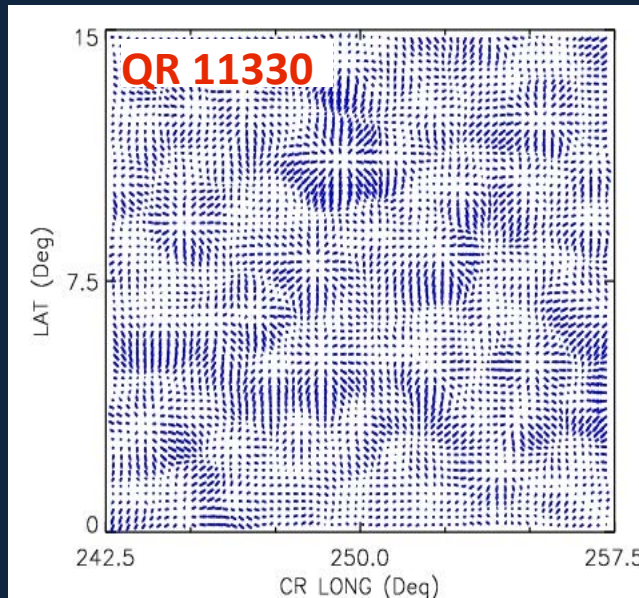
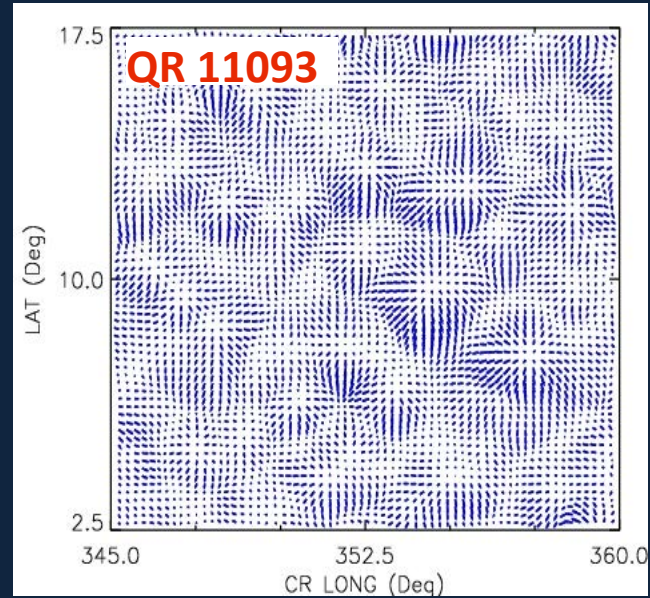
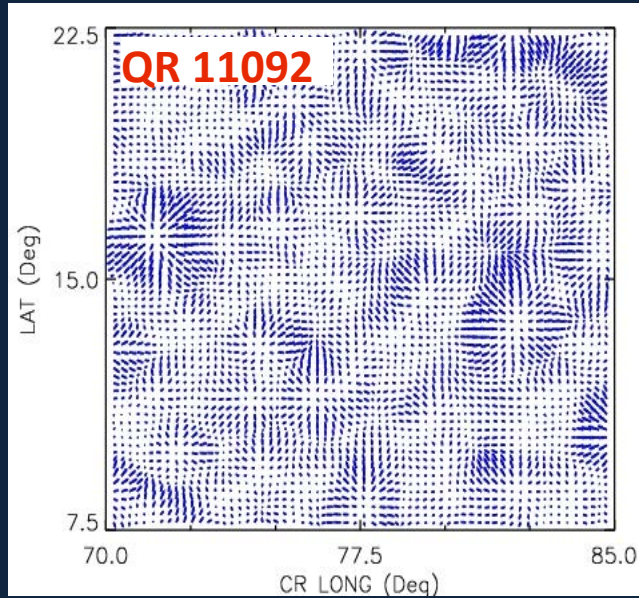
AR 11093

AR 11330

AR 11339

AR #	LAT (Deg)	CR LON (Deg)	Date	MAI (G)	MAI (G) (Quiet)
11092	15.0	77.5	20100803	40.8	0.98
11093	10.0	352.5	20100810	28.7	1.09
11330	12.5	10.0	20111028	119.5	1.02
11339	20.0	102.5	20111107	168.0	1.40

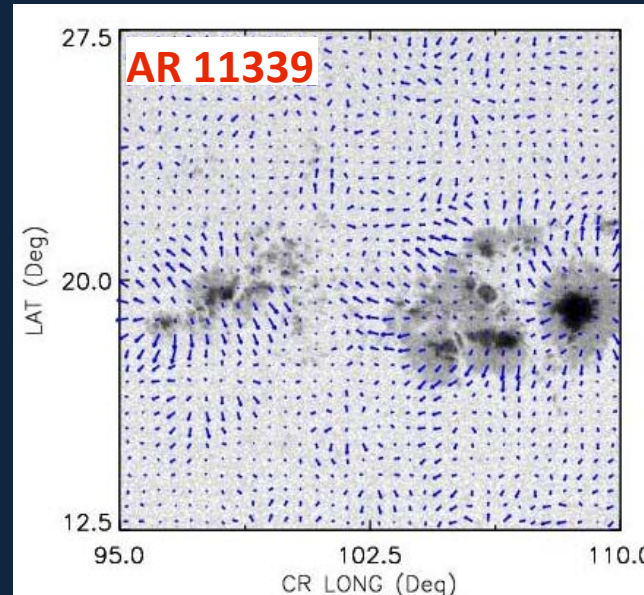
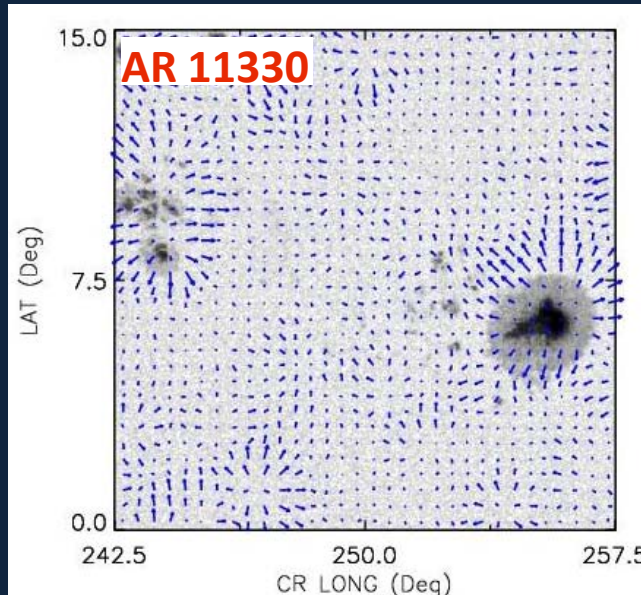
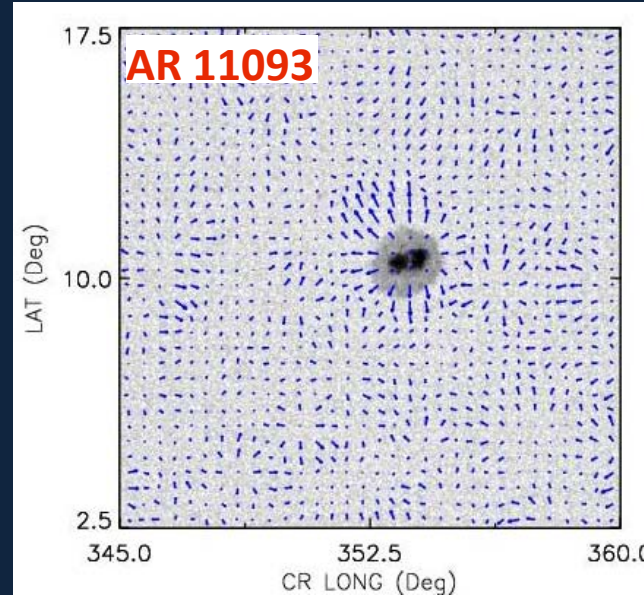
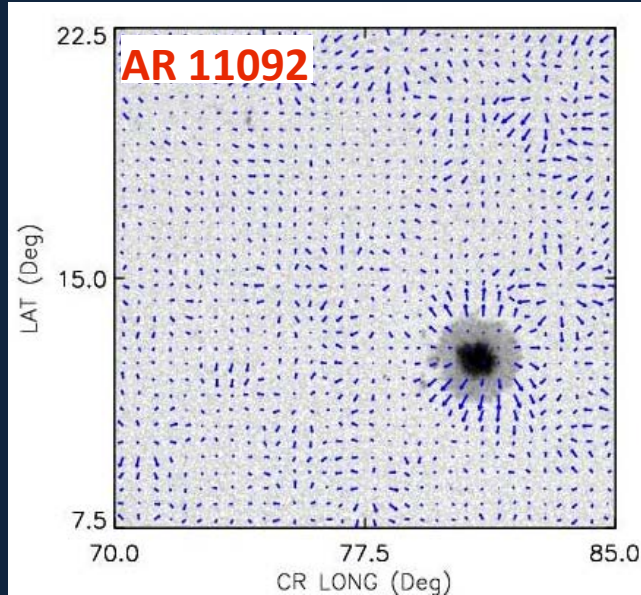
Photospheric Flows from LCT



Steady flows averaged over 1440 minutes.

QR:
Supergranular flows can be clearly seen.

Photospheric Flows from LCT



Steady flows averaged over 1728 minutes. ;

QR:
Supergranular flows can be clearly seen.

AR:
Strong outflows (moat flow) from sunspots which is consistent with earlier studies.

Small inflows are also seen in the umbra

Near-surface Flows from LCT and Ring-diagram Methods

In order to compare flows obtained from two methods, and due to the limitations of ring-diagram method,

Flows calculated from the LCT were binned down to the same grid for comparison.

We created a mosaic of tiles of $7.5^\circ \times 7.5^\circ$ spaced by 2.5° in each direction for each active region.

We calculated sub-surface flows from ring-diagram method in the depth range of 0.5 - 1.4 Mm using

- fitted velocities of f-modes
- inverted horizontal flows.

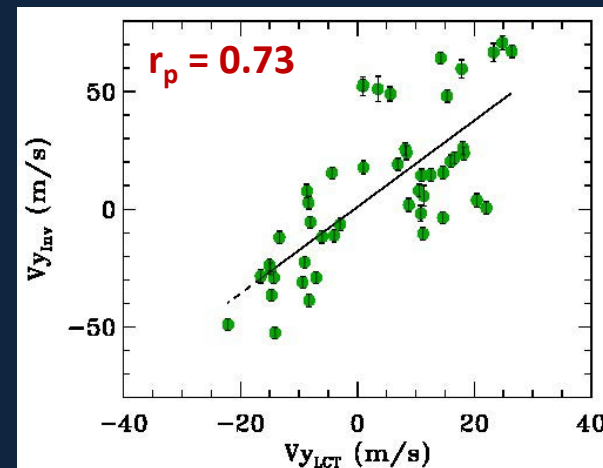
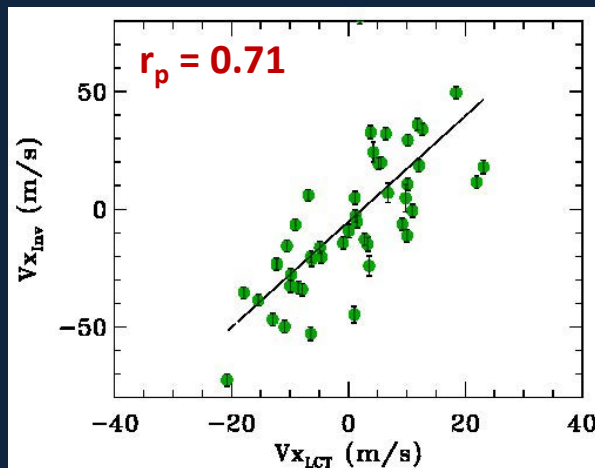
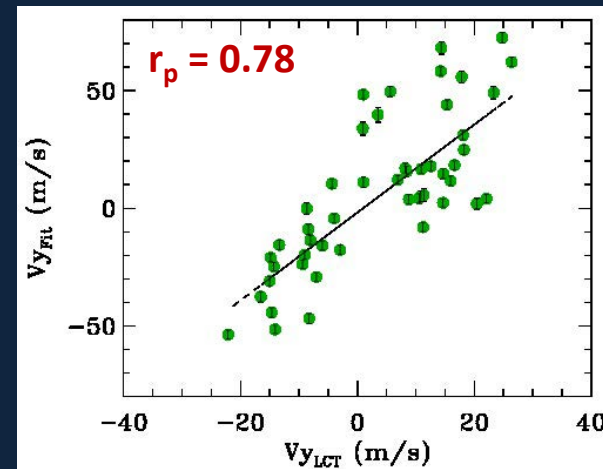
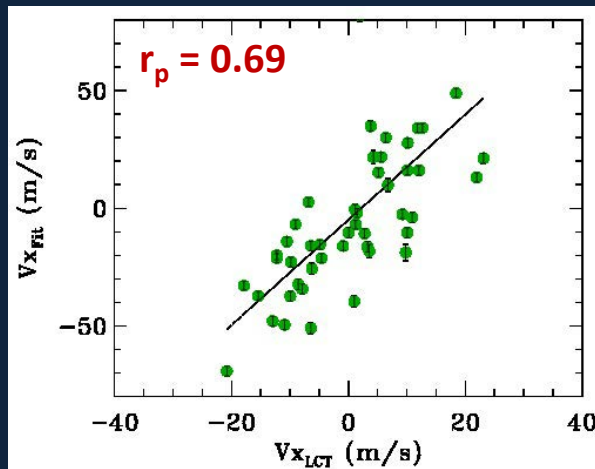
Near-surface Flows from LCT and Ring-diagram Methods

AR 11339

Zonal Component

Meridional Component

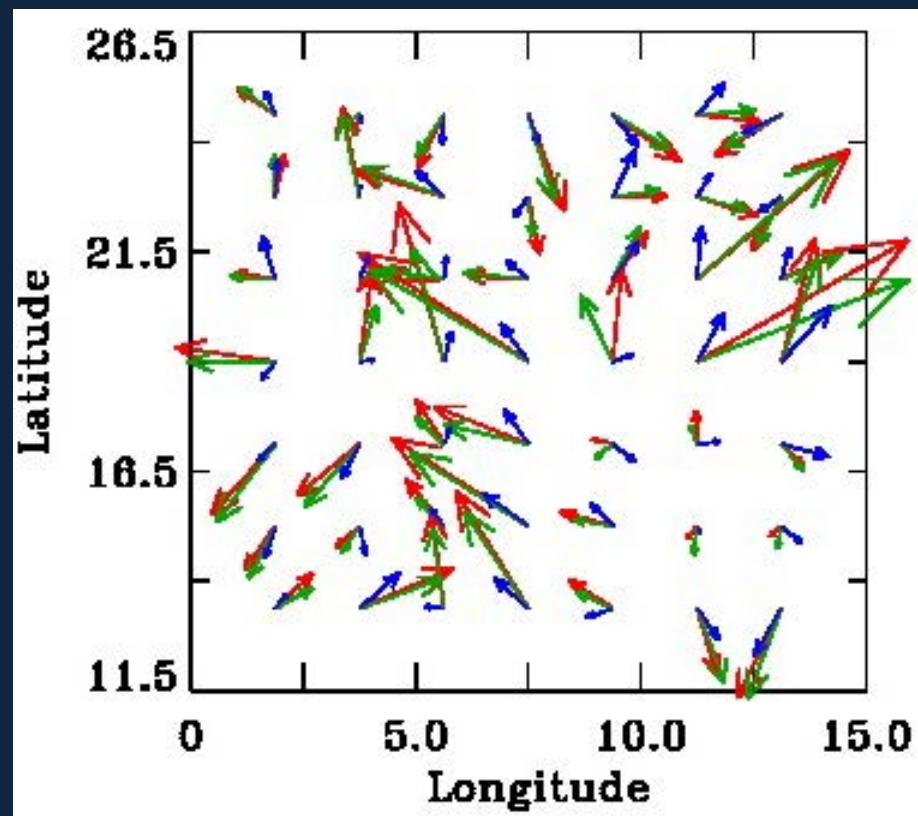
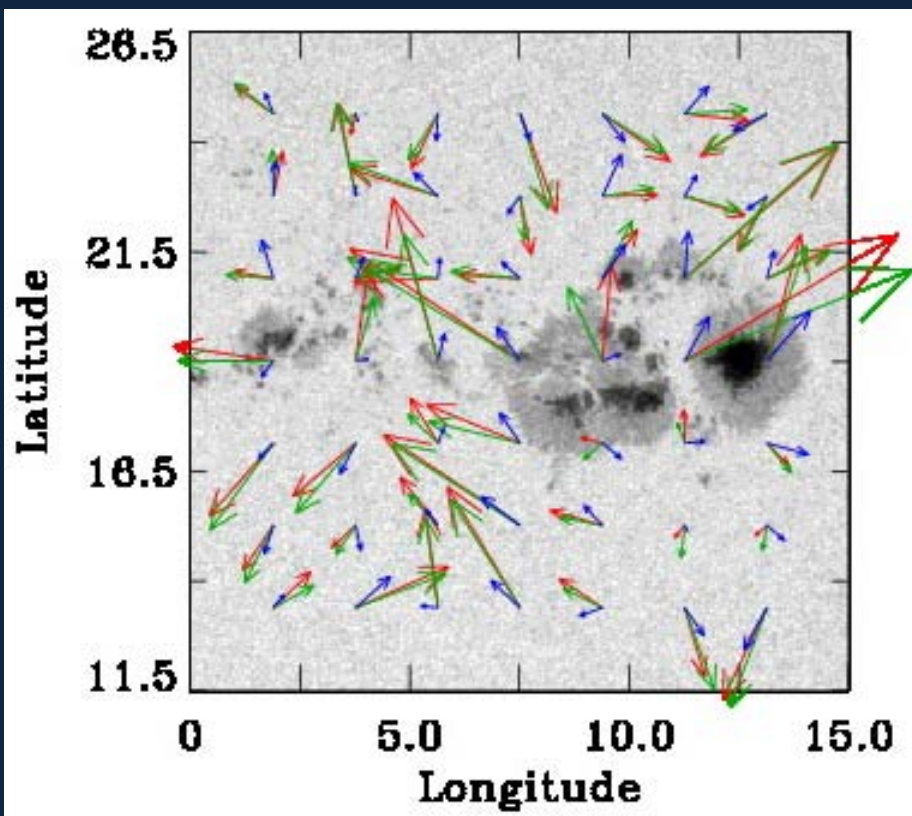
From Helioseismology
Fitted
Inverted



From surface features (LCT)

Near-surface Flows from LCT and ring-diagram methods

AR 11339



Fitted Inverted LCT

Questions:

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Sub-photospheric Flows - Data Selection

AR #	LAT (Deg)	CR LON (Deg)	Dates	CR #	Data Source
10923	-4.0	5.9	2006 Nov 12 - 15	2016	GONG
10930	-4.0	9.5	2006 Dec 09 - 12	2017	GONG
11158	-20.0	35.07	2011 Feb 11 - 16	2108	HMI

Evolution of AR 10923 and AR 10930

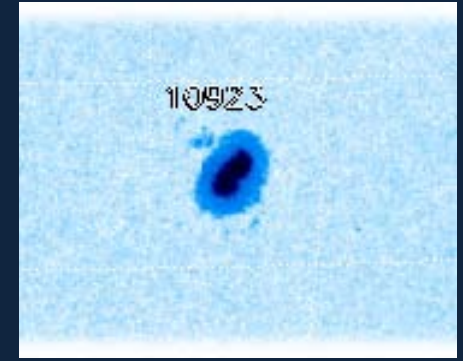
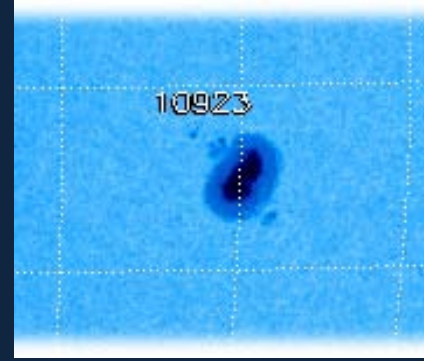
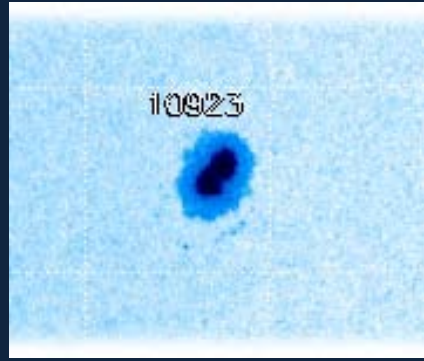
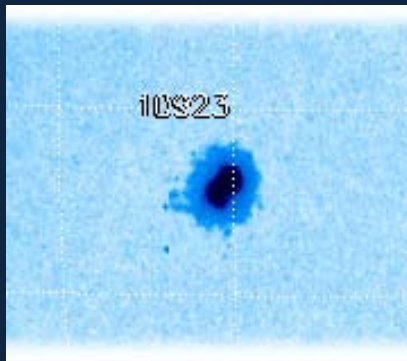
Day 1

Day 2

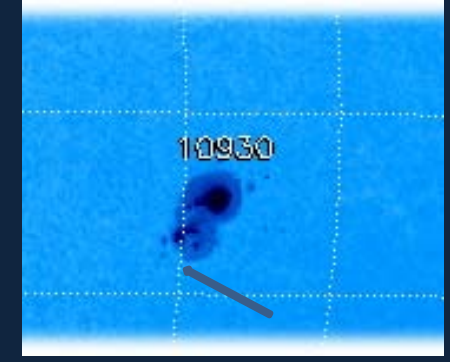
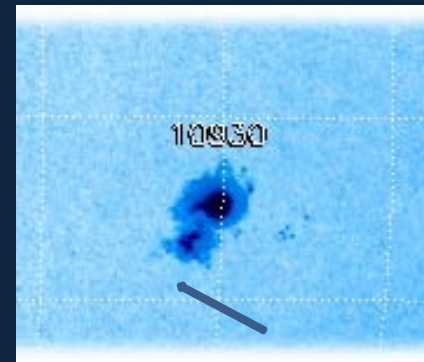
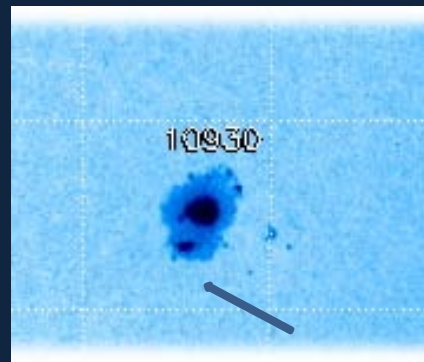
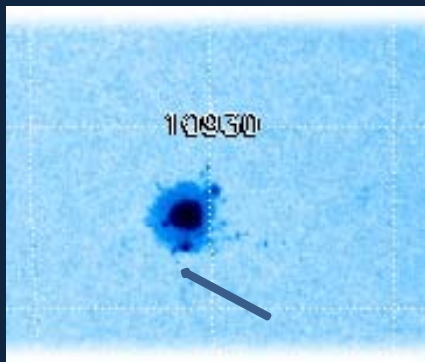
Day 3

Day 4

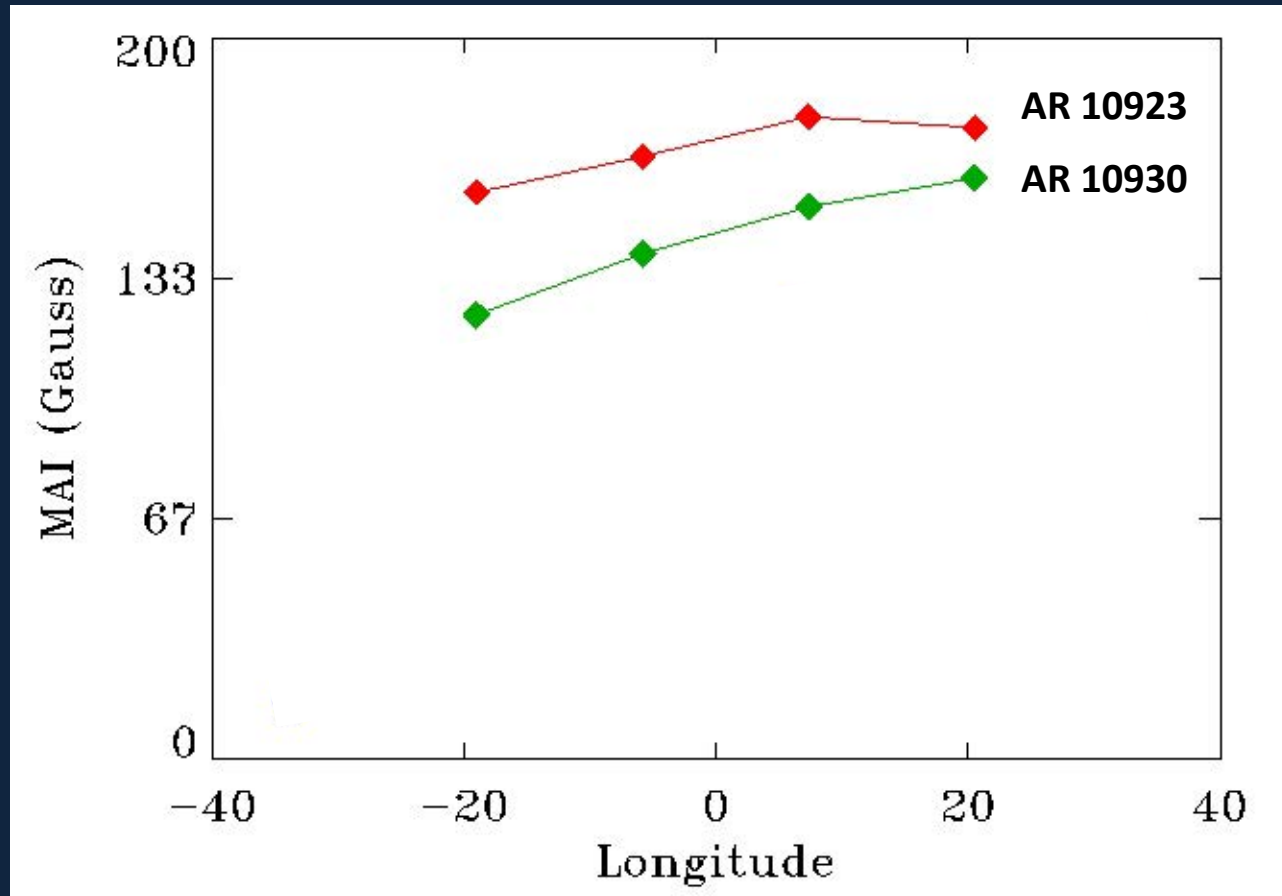
AR 10923



AR 10930

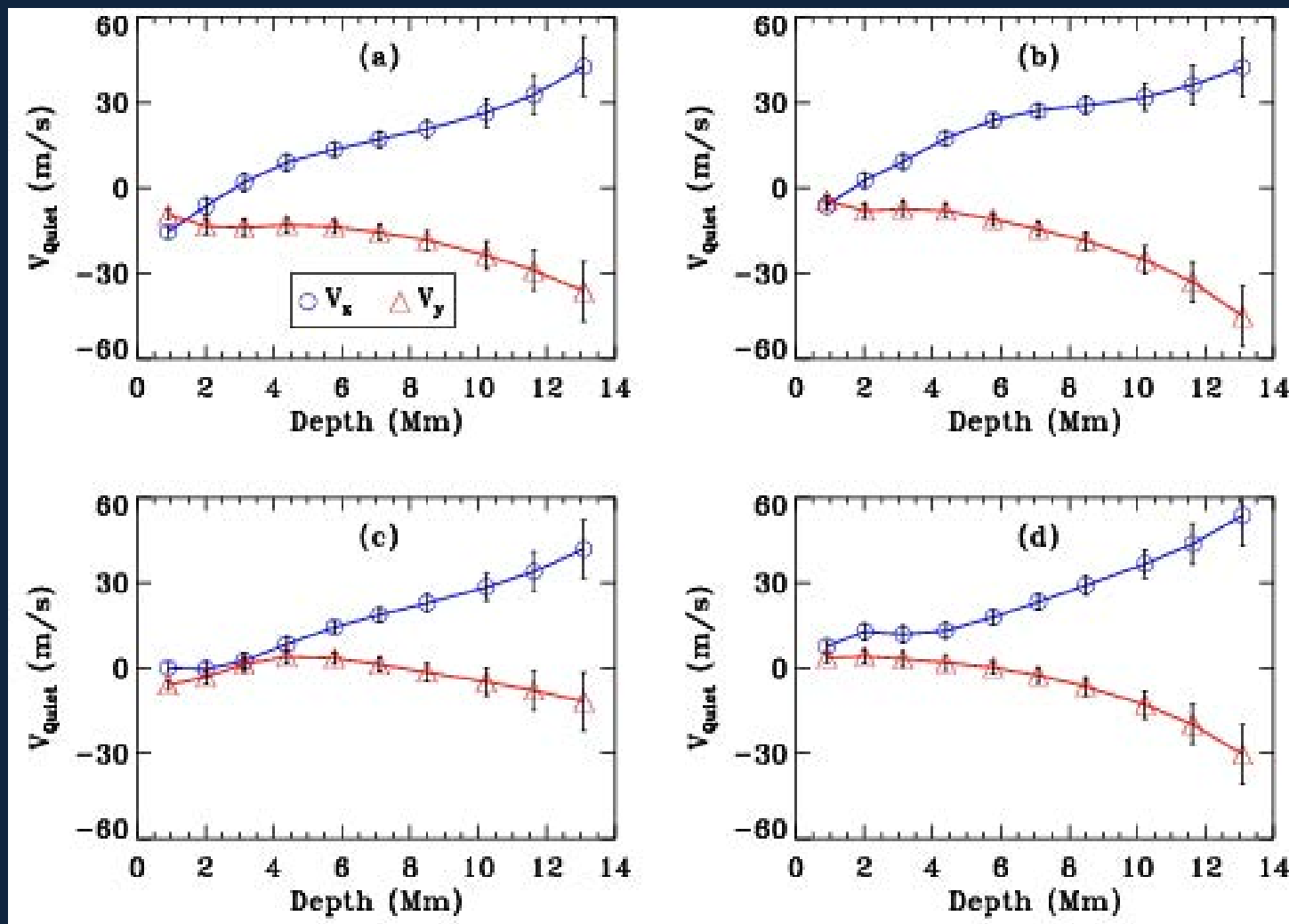


Magnetic Activity Index for AR 10923 & AR 10930



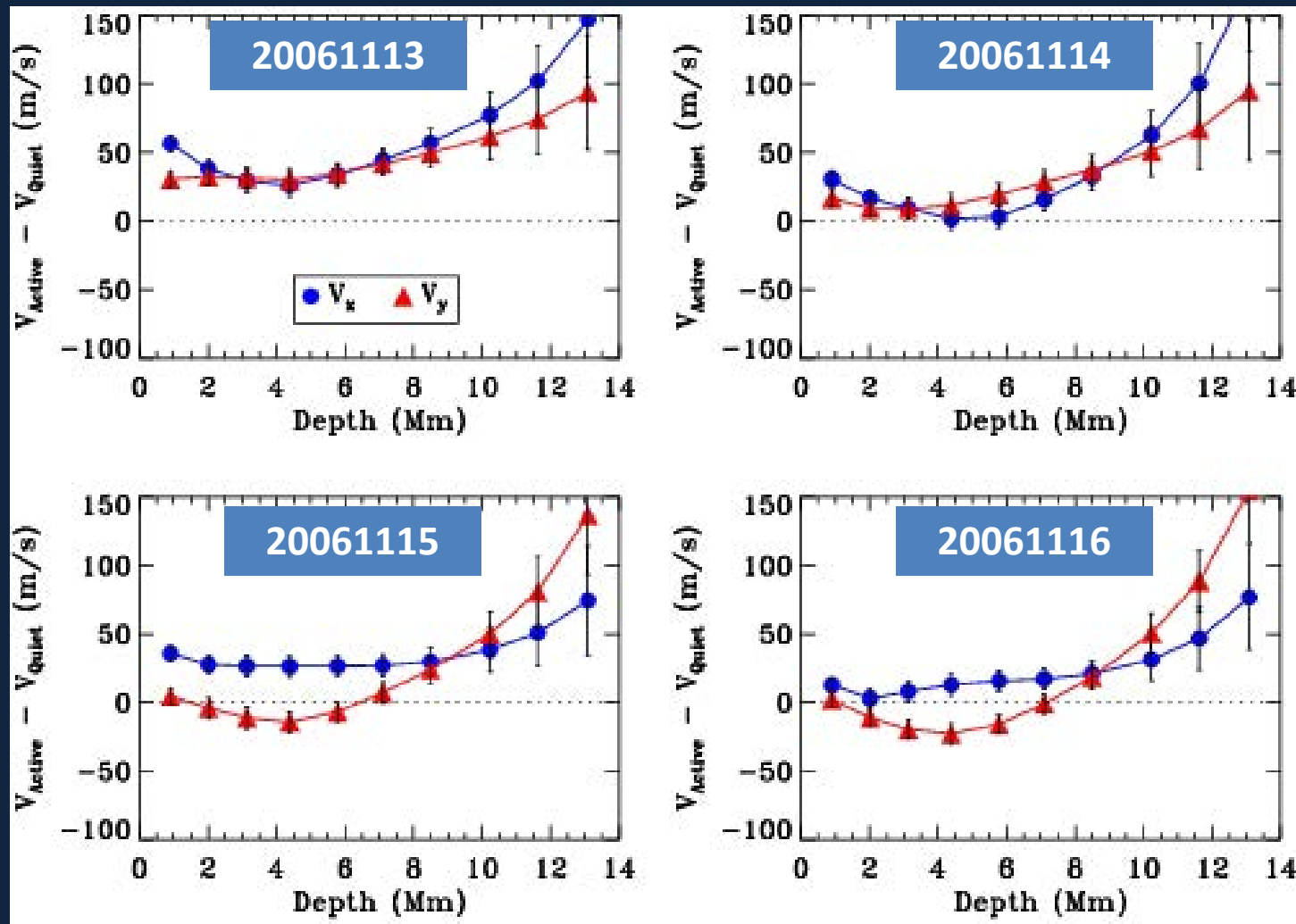
Depth and Temporal Variations of Velocity Components

Quiet Regions



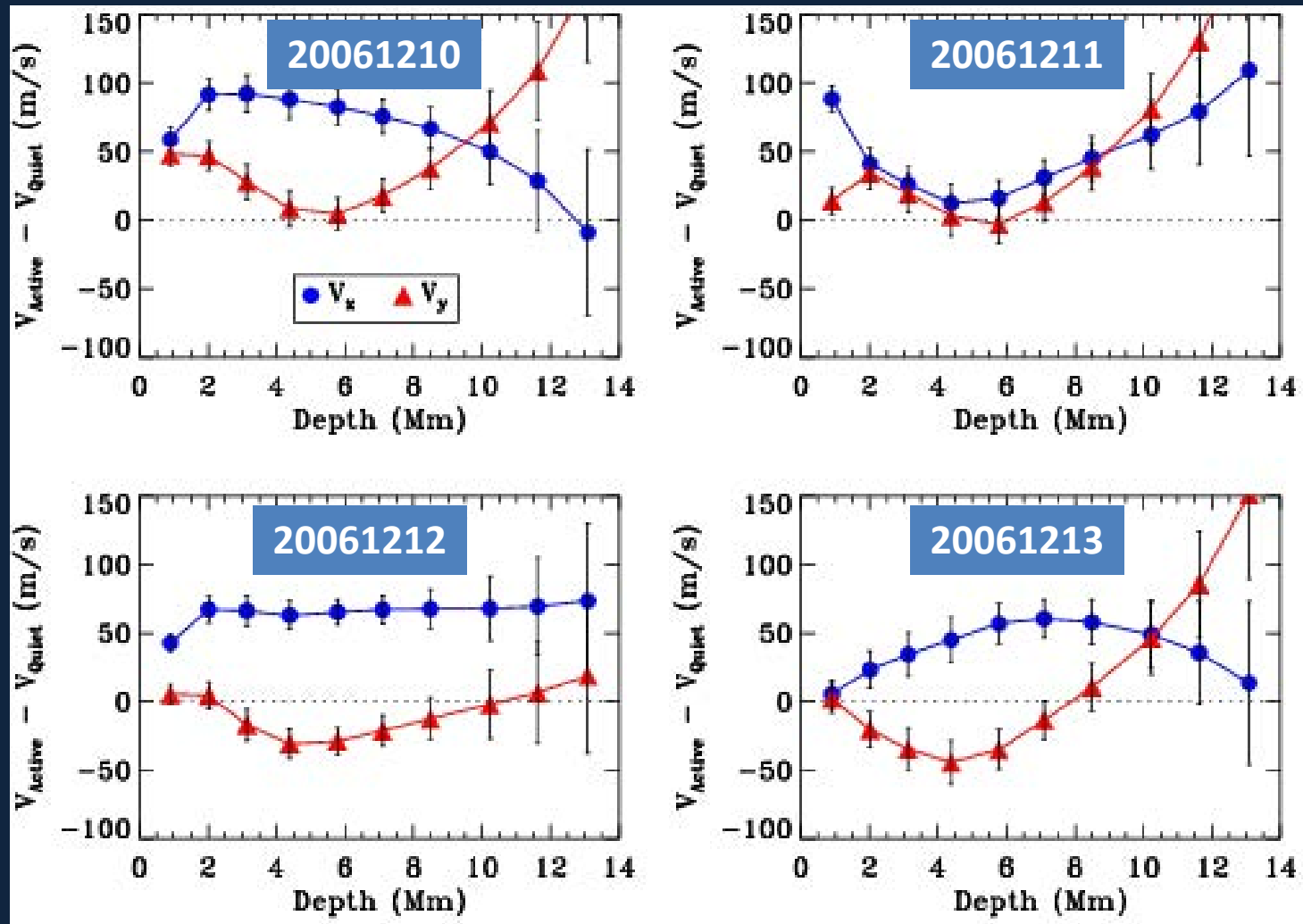
Depth and Temporal Variations of Velocity Components

AR 10923



Depth and Temporal Variations of Velocity Components

AR 10930



Another Example Evolution of AR 11158

Feb 11

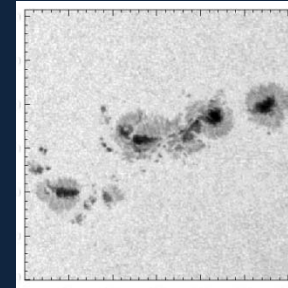
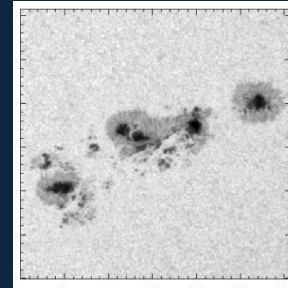
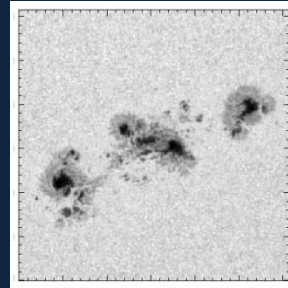
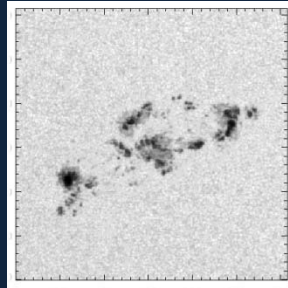
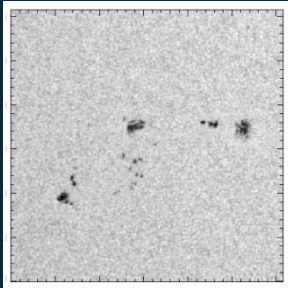
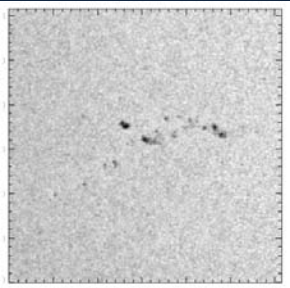
Feb12

Feb13

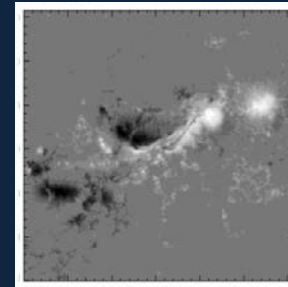
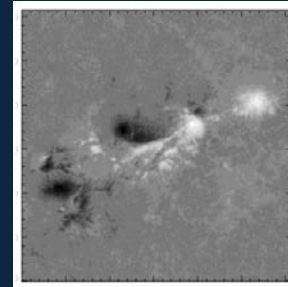
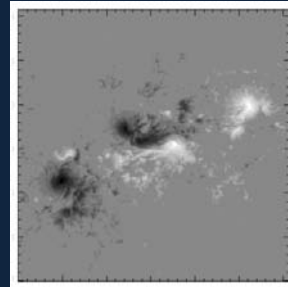
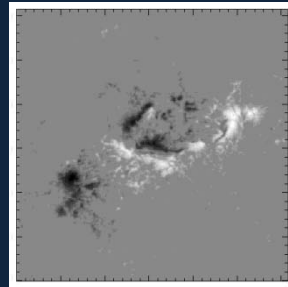
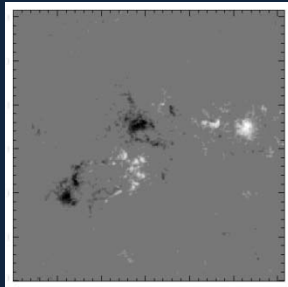
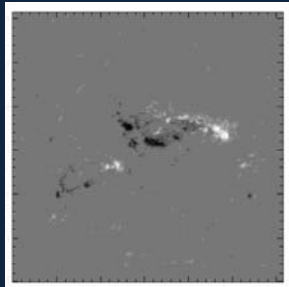
Feb14

Feb15

Feb16



Continuum



Magnetogram

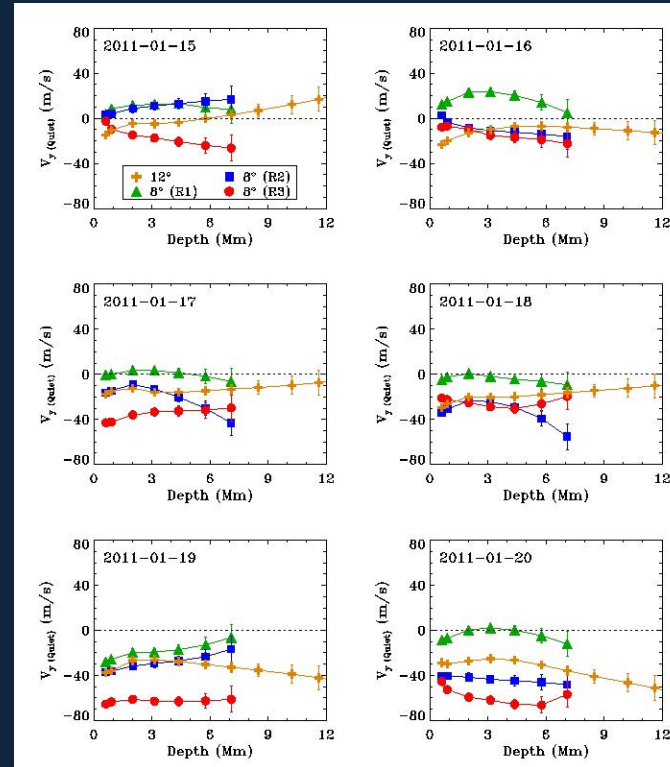
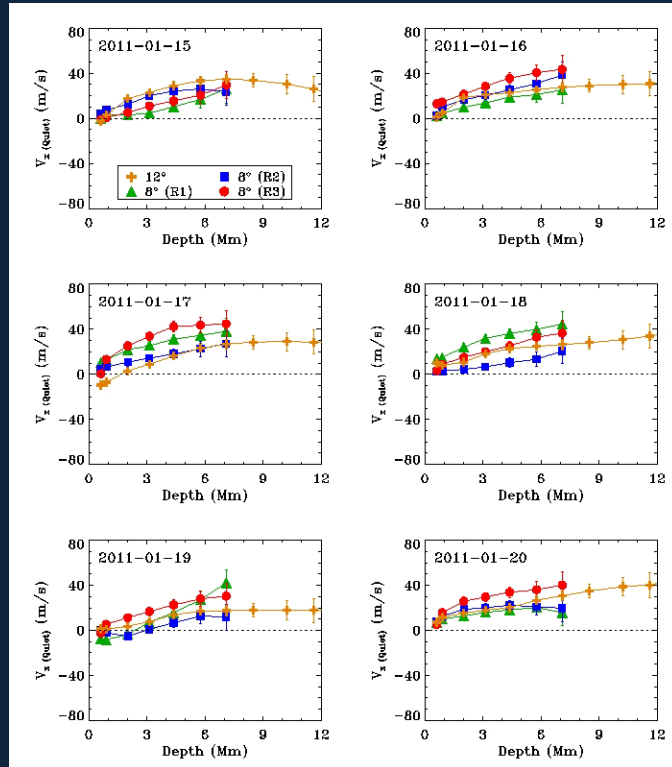
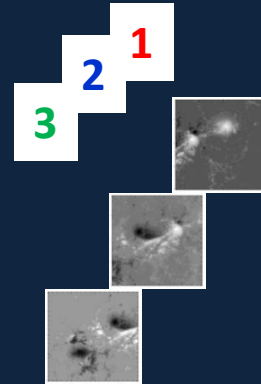
Depth and Temporal Variations of Velocity Components

QR 1158

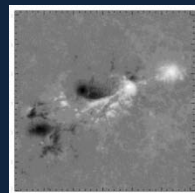
Zonal Component

Meridional Component

8° Tiles



12° Tile



Jain et al. 2014, in preparation

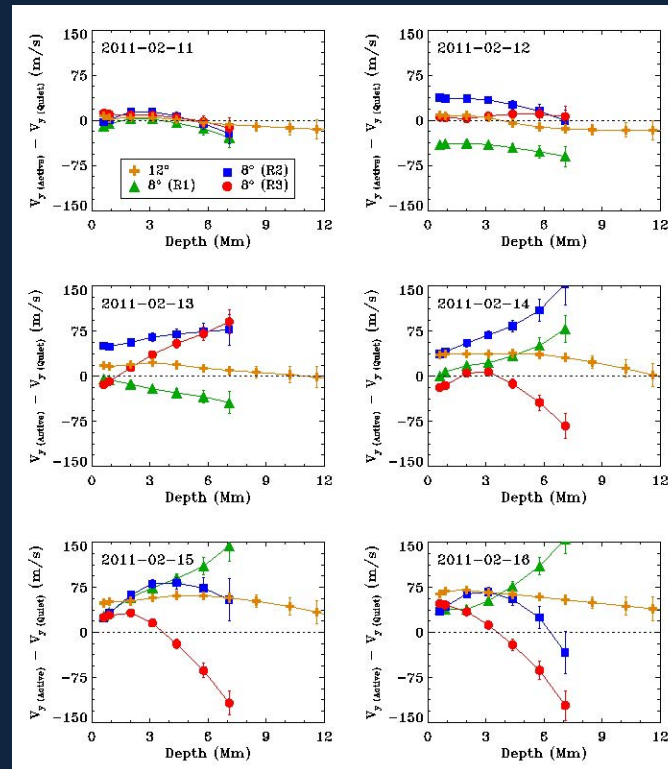
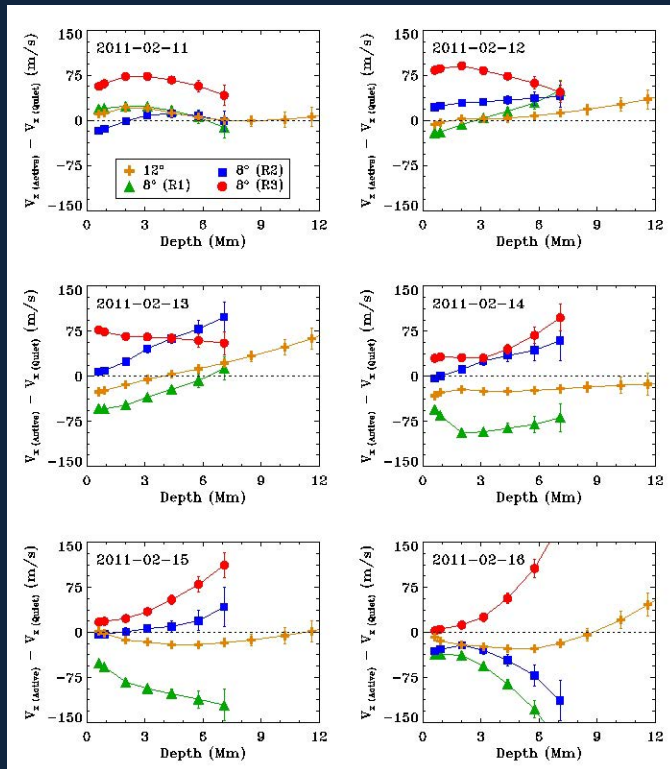
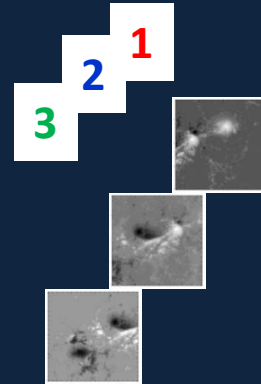
Depth and Temporal Variations of Velocity Components

AR 11158

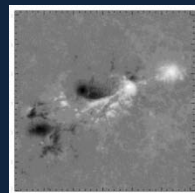
Zonal Component

Meridional Component

8° Tiles



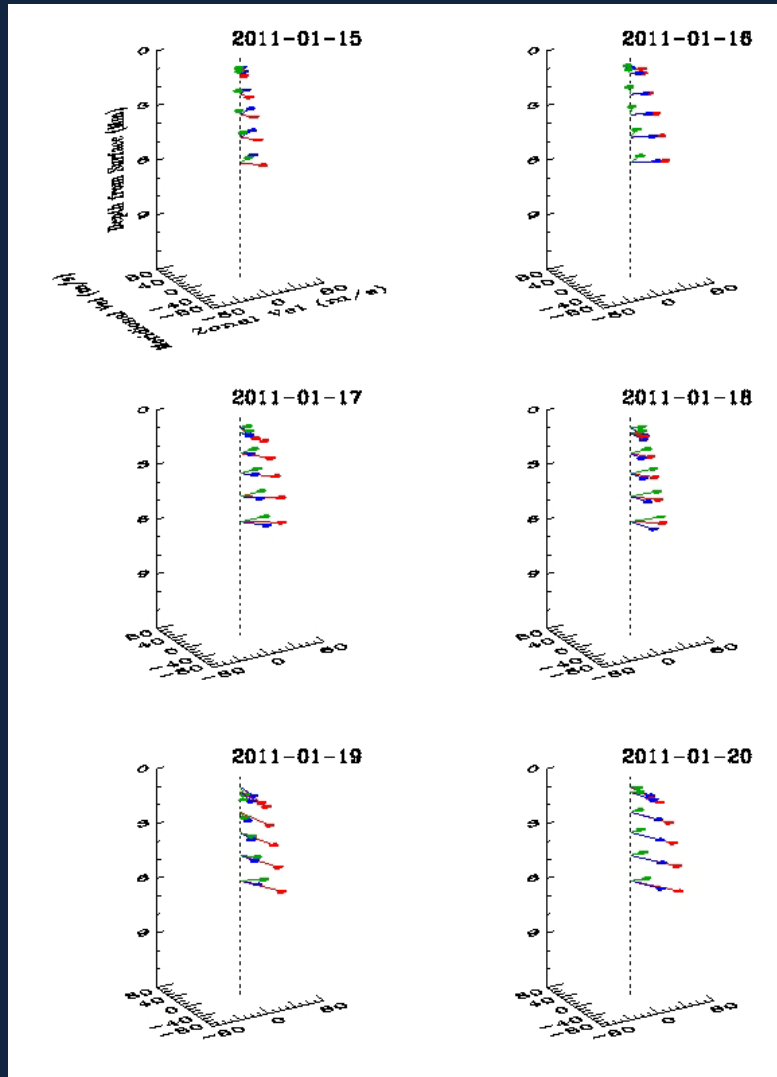
12° Tile



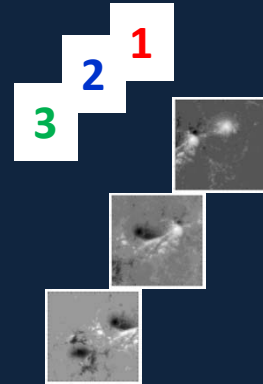
Jain et al. 2014, in preparation

Depth and Temporal Variations of Sub-surface Flow

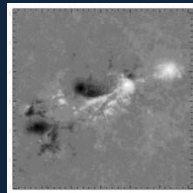
QR 11158



8° Tiles

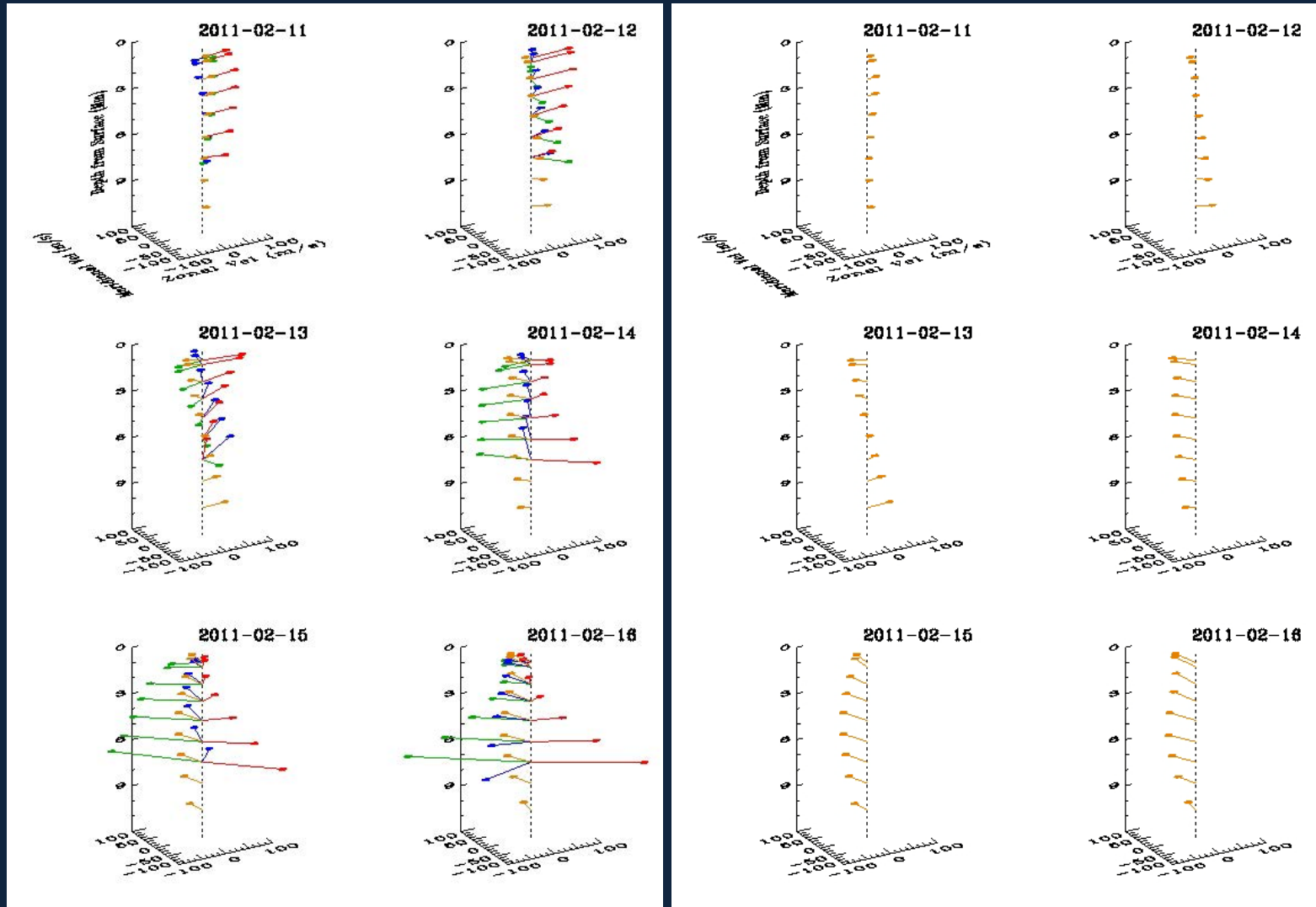


12° Tile

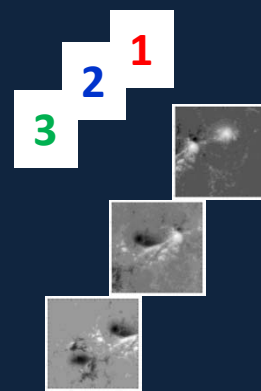


Depth & Temporal Variations of Sub-surface Flows

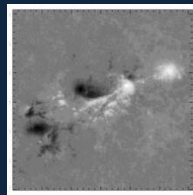
AR 11158



8° Tiles



12° Tile



Summary

- There is a strong correlation between photospheric and sub-photospheric flows near surface. This clearly indicates that despite the absorption of acoustic power in active regions, **the flows calculated using helioseismology techniques, e.g., ring-diagram technique, are reliable.**
- The horizontal velocity in active regions are larger than the quiet regions.
- The morphology of active regions plays an important role in their subsurface flows as they move across the disk.

We find significant temporal and depth variations in subsurface velocity beneath active regions with rotating sunspot (e.g. AR 10930 and 11158).

The temporal variation is small in active regions containing non-rotating sunspots (e.g. AR 10923).

- The small-region analysis of an active region with several rotating sunspots clearly indicates the presence of different horizontal velocity within the active region.....**this can be used to refine the flare forecasting capabilitiesspecially with the HMI high-spatial resolution data.**

Biggest Observed Active Region of Solar Cycle 24

