MULTI-WAVELENGTH OBSERVATIONS OF VORTEX-LIKE FLOWS IN THE PHOTOSPHERE FROM GROUND-BASED **AND SPACE-BORNE TELESCOPES**

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ABSTRACT

In this work we follow a series of papers on high-resolution solar observations (Balmaceda et al. 2009, Balmaceda et al. 2010, Vargas Dominguez et al. 2011, Palacios et al. 2012, Vargas Domínguez et al 2015, Cabello et al., in preparation), utilizing several long multi-wavelength data series. These were acquired from both ground-based (SST) and space-borne (Hinode), thus obtaining high-cadence and high resolution data, including SOT-SP data, in a joint campaign of the Hinode Operation Program 14, in Sept 2007. Diffraction-limited SST data, taken in G-band and G-cont, were restored by MFBD, whilst Hinode obtained multispectral data from SOT-FG in CN, Mg II, Ca II and also SP in Fe I lines. In these series we have thoroughly studied vortex flows and their statistical occurrences, horizontal velocities by means of local correlation tracking (LCT), divergence and vorticity; but we also have studied bright point statistics and magnetic field intensification, clearly highlighting the importance of the smallest-scale magnetic element observations.

Telescope	Obs.	Series #	Time [UT]	Duration [minutes]	Number of images	Cadence [sec]	FOV [″]
SST	G-band	1	08:47-09:07	19	76	15	68.5×68.5
		2	09:14-09:46	32	128	15	68.5×68.5
II:d.	CN	1	09.40 00.20	40	70	25	10.2×74.1

Table 1 Characteristics of the time series acquired from ground-based and spacecraft facilities.





Observations of magnetic elements in the quiet Sun internetwork (ASPC, 2009) Balmaceda, J. Palacios, I. Cabello, V. Domingo Magnetic, Mgl CN 1.00 1.05 1.10 1.15 1.20 1.2 Figure 1. Properties of magnetic elements. Left: Distribution of magnetic flux density measured for each feature. Values in Gauss are obtained following Figure 1. From top to bottom rows: sequences of unsigned LOS magnetograms, Chae et al. (2007). Middle: Size distribution. Right: Lifetime (minutes) for integrated Stokes V profile and LOS velocity, respectively. the magnetic elements lasting more than 3 minutes Max |V|/I; integrated V (from -29 to +29 pm); LOS-velocity G-band 0. 5 0.20 0.25 0.30 0.35 0.40 0.4 .02 0.05 0.08 0.11 0.14 0.1 Figure 2. Distribution of properties of BPs detected in CN bandhead. Un 0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.8 1.0 1.2 1.4 1.6 1.8 2 0.00 0.02 0.04 0.06 per panel, left: Lifetime (minutes) of each fea scaled intensities measured for the BPs detected Figure 3. Properties of BPs observed in G-band. Left: Distribution of Bottom panel, left: Area distribution. Right: scaled intensities of BPs. Center: Area distribution. Right: Diameter distribution Evidence for small-scale magnetic concentrations dragged by vortex photospheric plasma (A&A, 2010) L. Balmaceda, S. Vargas Domínguez, J. Palacios, I. Cabello and V. Domingo Ca II F Fig. 1. Quasi-simultaneous observations showing the evolution of a quiet sun region on 29 September 2007. From top to bottom: Mg I magne-Fig. 3. Map of horizontal velocities (FWHM 1".0). The length of

Observations of Vortex Motion in the Solar Photosphere Using Lines of Long (J. 2012) Judith Palacios, Laura A. Balmaceda, Santiago Vargas Domínguez, Iballa Cabello, and Vicente Domingo





Figure 3. Left panel: Stokes I profiles. Right panel: abnormal V Stokes profiles.

Three-lobed Stokes V: a hint for gradients. Plausible convective collapse

Evolution of Small-Scale Magnetic Elements in the Vicinity of Granular-Sized Swirl Convective Motions (Sol. Phys., 2015)

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ty field and vortex structure

BPs intensities

Magnetic field intensification



CN

Figure 7 Sequence of contrasted SST/G-band images for both time series s1 and s2 showing the evolution of the studied quiet-Sun region on 29 September 2007. Frame at 09:08 UT (in gray-scale) corresponds to a Hinode/CN image that covers the gap between s1 and s2 during the SST observation, with black contours outlining the negative magnetic polarity area. These frames display the average image over four-minute intervals and the time stamps correspond to the initial time. The top-left frame shows the location of five regions of nterest (colored dots). The white arrow in frame at 08:48 pointing to the center of a convective vortex motion detected in the FOV is included for reference. Boxes in black (top sequence) and gray (bottom sequence) extract a common FOV. Case 1 (at 09:20) and Case 2 (at 09:32) stand for the analysis of plausible convective collapse events shown in Figure 9. The locations displaying an intensification of BPs are encircled in white.



Figure 9 Detected cases of plausible convective-collapse events in *Hinode* data on 29 September 2007. Fo every case the temporal sequence of LOS Doppler velocities (upper row) and magnetic signal (lower row) are simultaneously shown in false-color maps. Encircled in white are regions displaying redshifts accompanied by an intensification in the magnetic field. Stokes-V profiles are correspondingly plotted for these regions (from the subpanel holding the white circumference to the following four panels), along with magenta and blue lines indicating the nominal wavelengths.

for each interval, respectively. BPs are detected in all filtergrams and are co-spatial with the magnetic concentrations observed in magnetograms Spatial scales in both axis are in arcsec and correspond to solar coordinates (FOV $\sim 6'' \times 5''$). The black box at 09:04 UT shows the FOV covered by the SP in Fig. 2. Encircled in white in G-band frames at 08:48, 08:52, and 08:56 UT is the location of the detected vortex (Sect. 3.3) for reference

togram, G-band, CN, Ca II H. Every panel displays the average image over 4-min intervals and the time stamps correspond to the initial time



represents the normalized divergence field The solid/dotted boxes extract the FOV covered by the sequences of images in Figs. 1 and 2, respectively, as labeled.

the black arrow at coordinates [0, 0] corresponds to 1.5 km s⁻



Fig. 4. Temporal evolution of the magnetic centroid for both

Fig.2. From top to bottom: magnetic field strength and LOS velocity single maps obtained by inverting SP data. The FOV covered is shown in the left lower panel. Positive/negative V_{LOS} values correspond to upward/downward velocity directions. Encircled region in V_{LOS} map at 08:44 UT displays a strong downflow appearing just before the formation of the vortex. Note that the displayed evolution of the region is longer in time here than in Fig. 1 and the FOV smaller as framed by the black box at 09:04 UT in the same figure



atistical properties of small-scale convective vortex-like motions in a quiet Sun region (MNRAS, 2011) juez, J. Palacios, L. Balmaceda, I. Cabello and V. Domingo



Horizontal velocities and divergence and vorticity for G-band series sl (red), s2 (blue), both (black).







median(s1)=1692.0

median(s2)=1477.0



Figure 4 Horizontal velocities for different time intervals covering the G-band series s1. The upper-left ma ed for the whole duration of the series against the background of vertical velocities in false c he ROI is framed in a black box with the same FOV $(6'' \times 5'')$ as that in Figures 1 and 7. The other maps at e time intervals as labeled with background rage images. The length of the yellow horizontal bar at coordinates [0, 0] in every map co

s1, $\Delta t = 19$ minutes (black) and four-minute interval averages Δt_1 (green), Δt_2 (yellow), Δt_3 (blue), Δt_4 (cyan), and Δt_5 (red). Statistics of velocities are computed in a region including the vortex. The upper panel plots the mean velocity magnitudes in the histogram for the different intervals, where Δt_{vortex} (horizontal dotted line) and $\Delta t_{\rm FOV}$ (horizontal black line) represent the mean velocity computed in the box framing the vortex and in the whole FOV in the top left panel in Figure 4, respectively (see text for details).



corresponding colored dots in the top-left panel in Figure 7. The two vertical shadowed areas highlight the time periods of the plausible convective collapse events (cases 1 and 2) analyzed in Figure 9 that correspond to the location of the dark-blue and black dots in the first panel in Figure 7 and encircled in white in the same 09:22 09:24 09:26 09:28 09:30 09:32 09:34 09:35 09: time [UT

Figure 10 Evolution of peak magnetic-field strength [B], red squares] and maximum redshifted LOS petty (black diamonds) for case 1 (from \approx 09:21 to 09:27 UT) and case 2 (from 09:33 to 09:38 UT) in the encircled in white in Figure 9. Note that the bright point that corresponds to case 1 is already visible Figure 8 Normalized intensity profiles for selected locations in different series of images. First three rows at the leftmost part of the plot. Two important downflows at 09:21 and 09:33 UT and a peak in the magnetic (from top to bottom) from the analysis of Hinode/BFI (CN and Ca II H) and NFI (magnetic field in Mg I) data, field at 09:30 UT are displayed (see text for details) and the last row from SST data. The vertical solid lines separate the two time series s1 and s2 in SST/G-band data with the seven-minute gap in between. Dot-dashed blue and black curves correspond to the locations of

Methods

MFBD: image restoration process, mainly applied to ground-based images. Method from Löfdahl 1996 and 2002.

LCT: (Local Correlation Tracking, November & Simon 1988; Molowny-Horas & Yi 1994) is a key technique to infer horizontal velocities, flow shapes and for further calculation of divergence and vorticity. It also provides estimation of vertical velocities.

BP detection: to distinguish BPs from granular fragments, with segmentation and recognition. We have used two methods: MLT4 (Bovelet & Wiehr, 2007); and Sánchez Almeida (2004).

Centroids: method to calculate the center of gravity of various structures; in this case, in Mgl magnetograms.

Inversion and weak-field approximation: the inversion code LILIA (Socas Navarro, 2001) and weak-field approximation (as in d'egli Innocenti, 1992) for inferring magnetic flux densities.

Main results

-Magnetic elements, CN, G-band BPs properties:

Magnetic elements have a typical area of 0.1 sq-arcsec, and lifetime of 5-10 min. CN BP typical size is 0"27, and median intensity is 1.05; while G-band BP typical diameter is 0"14 and median intensity of 1.1. Surface coverage for CN is 0.22%, while 0.26% for G-band.





-Average divergence and vorticity values. Vortex occurrence is about 1.5 ·10-3 /Mm² · min; density values of 3 ·10⁻² /Mm². Horizontal velocities are about 0.5 km/s; however, this mean value increases when vortices increase the circulation. Vortex mean radius is 250 km. Vortex downflow speed is about 0.5 km/s. -Magnetic field intensification: We have observed some cases of plausible magnetic field intensification followed by supersonic downflow up to 7 km/s.

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