Análisis de la dinámica fotosférica a granescala durante el ciclo solar 24

Analysis of large-scale photospheric dynamics during the solar cycle 24.

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***Resumen*— El análisis de los movimientos propios de la fotosfera solar ha sido empleado por varios autores para el estudio de la dinámica del plasma solar a varias escalas espaciales y temporales. Este trabajo, en particular, está enfocado en el estudio de movimientos verticales, con el fin de realizar un análisis estadístico de los mapas de flujo para caracterizar algunos aspectos dinámicos del plasma fotosférico a lo largo de la evolución temporal del Sol. Para llevar a cabo este análisis se utilizó un conjuntos de imágenes obtenidas por el instrumento HMI (Helioseismic and Magnetic Imager) a bordo de la misión SDO (Solar dynamics observatory) a las que se le aplicaron algoritmos de seguimiento de correlación local (LCT, por sus siglas en inglés) que permiten la identificación de zonas de convergencia y divergencia del plasma en ciertos intervalos temporales durante el ciclo solar 24, cubriendo de esta forma momentos de alta y baja actividad solar. El estudio nos da razón de los movimientos meridionales mostrando que en latitudes bajas el flujo de emergencia saliente ocupó un mayor porcentaje de área, mientras que en latitudes cercanas a los polos cambia el comportamiento, es decir los flujos entrantes ocupan una mayor área.**

***Palabras clave*— Física solar, Granulación, Fotosfera, Dinámica, Flujos Meridionales, Técnicas de correlación local.**

***Abstract*— The analysis of the movements of the solar photosphere has been used by several authors to study the dynamics of solar plasma at various spatial and temporal scales. This work, in particular, is focused on the study of vertical movements, in order to perform a statistical analysis of the flow maps to characterize some dynamic aspects of the photospheric plasma along the time evolution of the Sun. To carry out this analysis, we used a set of images obtained by the HMI instrument HMI (Helioseismic and Magnetic Imager) aboard the SDO mission (Solar Dynamics Observatory) to which local correlation tracking algorithms (LCT) were applied. they allow the identification of areas of convergence and divergence of the plasma at certain time intervals during the solar cycle 24, thus covering moments of high and low solar activity. The study gives us the reason for the meridional movements showing that in low latitudes the outgoing emergency flow occupied a higher percentage of area, while in the latitudes near the poles the behavior changes, that is, the incoming flows occupy a greater area.**

***Key Word* — Solar physics, Granulation, Photosphere, Dynamics, Meridional Flows, Local Correlation Tracking.**

I. INTRODUCTION

The Sun presents a cycle of activity of approximately 11 years during which the solar disk undergoes changes in its surface known as photosphere. Observationally, this cycle is related to the variation in the number of sunspots, as well as to the dynamics and solar activity. In the literature, authors such as Hathaway et al., 2002 have related this activity to the emergence of large-scale granular cells from the sub-photo-spherical layer to the photosphere. The analysis of own movements in the photosphere has been widely used by several authors to study the dynamics of solar plasma at various spatial and temporal scales, e.g. November & Simons, 1989.

High resolution observations have shown that the solar photosphere is a non-uniform region formed by multiple structures that are constantly evolving at different spatial and temporal scales. A large part of the observational studies, especially of the solar surface, have been dedicated to the analysis of plasma flows in granular structures, which have different scales, such as granulation, mesogranulation and superanulation.[8]

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This work, in particular, is focused on Supergranulation structures, which are strong coupling by convection, very stable, with a half-life of 20h and with a size of 30 Mm approx. (see review). The existence of supergranulation in almost all the solar disk (in contrast to magnetic structures) and its great temporal stability make supergranulation an excellent tracer for the correlation technique that was used. [5]

Another type of large-scale plasma flows is the Meridional Convective Flows, they are flows of material along the meridian lines of the sun, which on the surface go from the equator to the poles and from the poles to the equator below the surface [See figure]. In general, they are slow flows, on the surface they have a speed of approximately 20m / s but below they are even slower (2m / s) because the material has a higher density. (See Figure 1) For more information about meridional flows characteristics please see [6] and reference in there.

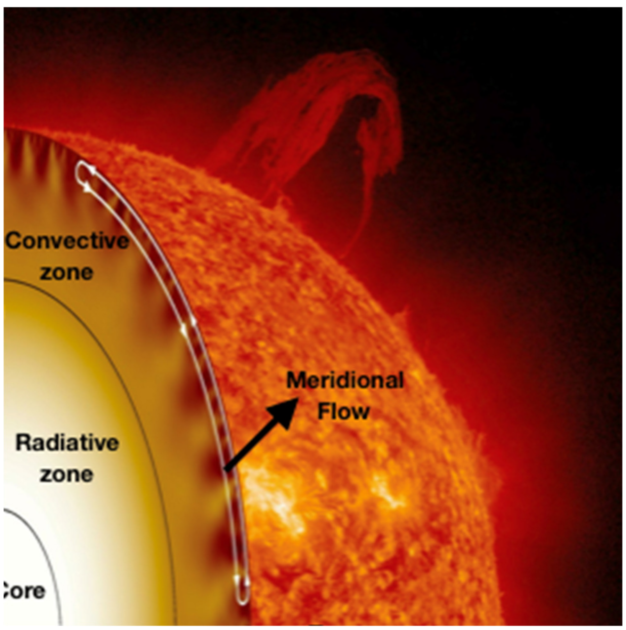

Fig 1. Meridional Convective Flow. Taken from [3]

Different techniques of local correlation have been used for the analysis of these structures. The first time a local correlation technique was used was by November and Simon (1988). The LCT (Local Correlation Tracking) algorithm is based on the detection of the best correlation of intensities between two consecutive images by means of a Gaussian correlation; in this case it has as purpose to study the solar dynamics with the flows inside super granular cells (Fig 3). For each pixel in the first image, a small correlation window is chosen and compared to a somewhat displaced window of the same size in the second. A displacement vector is then defined as a difference in the coordinates of the centers of both windows when the best match is found. The velocity vector is calculated from this displacement and the time delay between two images.

Because the sun is a sphere, the velocities obtained with the LCT algorithm must be corrected with a reference coordinates system located on the surface of the sun. (See [11],(2))

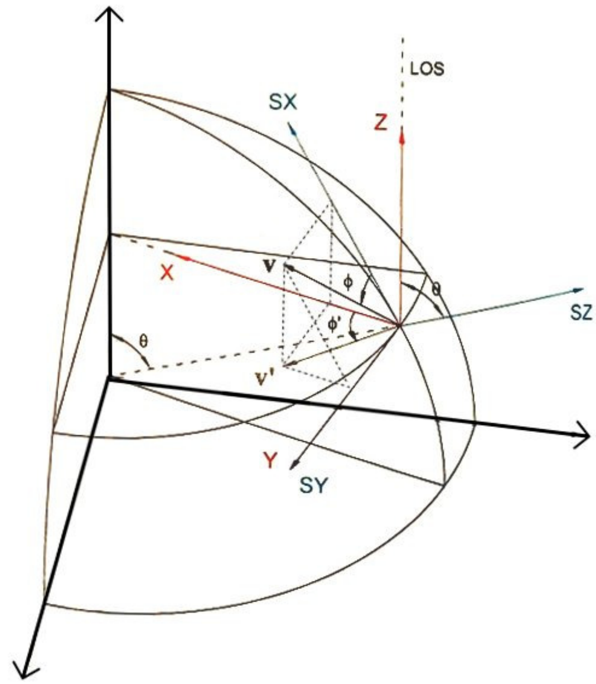

Fig 2. Diagram displays the coordinate system used during the coordinate's transformation. Taken from [10] where a detailed description can found.

II. DATA PROCESSING

The images were acquired from the HMI instrument on board the SDO mission, in FITS format, with a cadence of 45 seconds and a pixel resolution of 0.504 arcsec. The time interval studied is 90 minutes every Tuesday from 2011 to 2015 using Continuum Data (FeI 6173Å) [7]. The average number of images obtained in each time interval is 121, this value varies since in some days HMI presented instrumental errors in the data collection and therefore there were fewer images or some of them had to be discarded.

The data comes in a level 1.5 so no primary preparation of these should be done, however re-dimensioning processes were performed because the FITS data is large, rotation was performed because the images obtained from the instrument are rotated approximately 180º, transformation of coordinates to Heliographic Stonyhurst coordinates since the original coordinates of HMI are Helio-Projectives[10]. The software used for these processes has been written in the Python programming language and the specialized SunPy solar data analysis library has been used [9], as well as for the development of the LCT algorithm in python. [1]

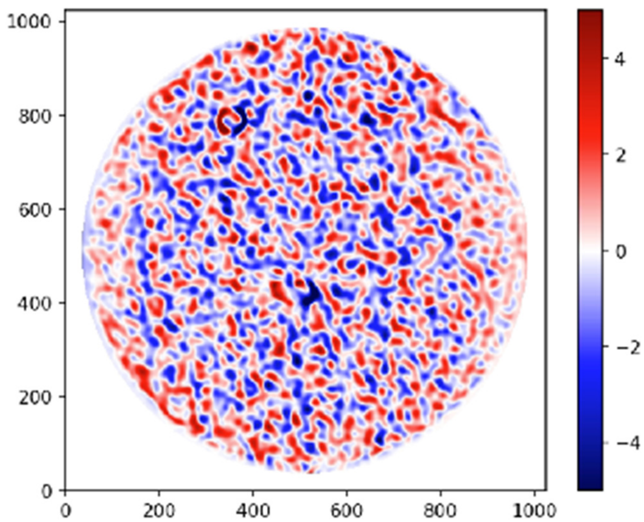

Fig 3. Vertical velocity flow map for the solar disk on 04-01-2011. The axes are in units of pixel and the velocity scale are in km/s. The blue color are incoming velocities and red color are outgoing velocities.

To carry out the LCT method, the correlation window (FWHM) chosen for this study is 40", equivalent to 80 pixels and therefore almost 80 Mm which is the average size of a supergranule. The pixel size after the rebining is 2.016 arcsec. The data for LCT are best shown in Table 1.

Parameter	Value
Correlation window	*40'' = 80 pix = 80 Mm*
Time interval	*90 min, ~121 images*
Pixel Resolution	*2.016 arcsec*
Cadence	*45s*

Table 1. Parameters for LCT.

III. ANALYSIS AND RESULTS

By performing the LCT process, the vertical flow rates of photospheric plasma were obtained through the years that make up the solar cycle 24. As the Sun is a sphere, a box was chosen in which the most reliable speeds are found, with coordinate values ranging from [-690,690] arcsec in both direction x and y, which is approximately between [-45,45] degrees of latitude as shown in Figure (4),(5).

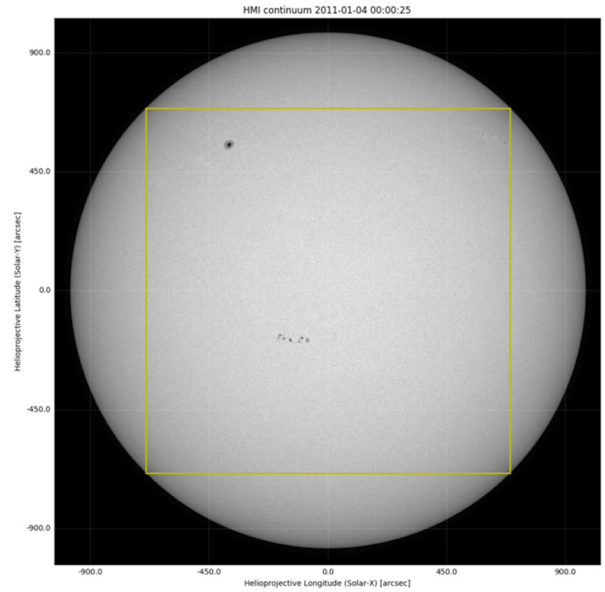

Fig 4. Continuum Image (FeI 6173Å) of the Sun taken on 2011-01-04, by HMI instrument onboard SDO. The yellow box shows the most reliable velocities.

By having a specific region, a complete statistical analysis was performed and by areas of the vertical plasma flow maps as shown in the figure (6). To obtain the divisions by areas, it was necessary to calculate contours that enclose regions with positive (ascending) speeds greater than 1 km/s and negative (descending) less than -1 km/s, finally the area enclosed in each contour was calculated.

In the figure (6) it is observed that in the first of the evolutions (Range in Y [-690, -554] arcsec) and the last one (Range in Y [554,690] arcsec), the negative velocities cover a greater percentage over the area of the selected region and as they approach the equator the positive begin to occupy a greater percentage. This result could be giving us information about the behavior of the large-scale meridional flows that occur in the Sun.

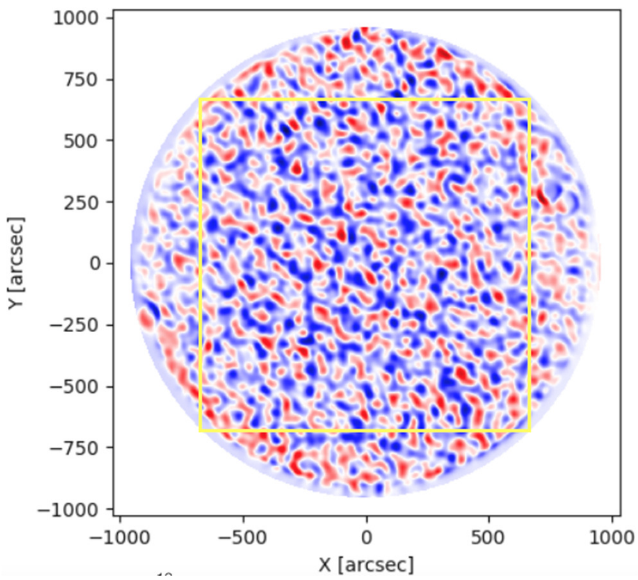

Fig 5. Flow map of vertical velocities using LCT algorithm on 29-03-2011. The yellow box shows the most reliable velocities.

The "systematic" vertical lines that appear in the figure (6), can be associated with errors in the calculations produced by these specific dates, since the data presented abnormalities caused by the HMI instrument.

IV. CONCLUSIONES

From the study of super granular structures, it was evidenced, by means of vertical velocity maps, that, at the global level of the Sun, approximately 20% of the solar disk area is covered with ascending flows of speeds higher than 1km / s. In the same way it happens for the descending flows with speeds lower than -1km / s. An error is obtained, in the calculation of the total area, of approximately 7% assuming circular emergencies.

By now, it can be said that the use of the local correlation technique gives us information about the dynamics of plasma at large scales and the latitudes in which changes in this dynamic are beginning to be evidenced. It is possible that it is also giving us information of the southern flows that happen in the sun since the positive speeds cover a greater percentage of area in latitudes near the equator, on the contrary, the negative speeds cover a greater percentage of area in the latitudes near the poles.

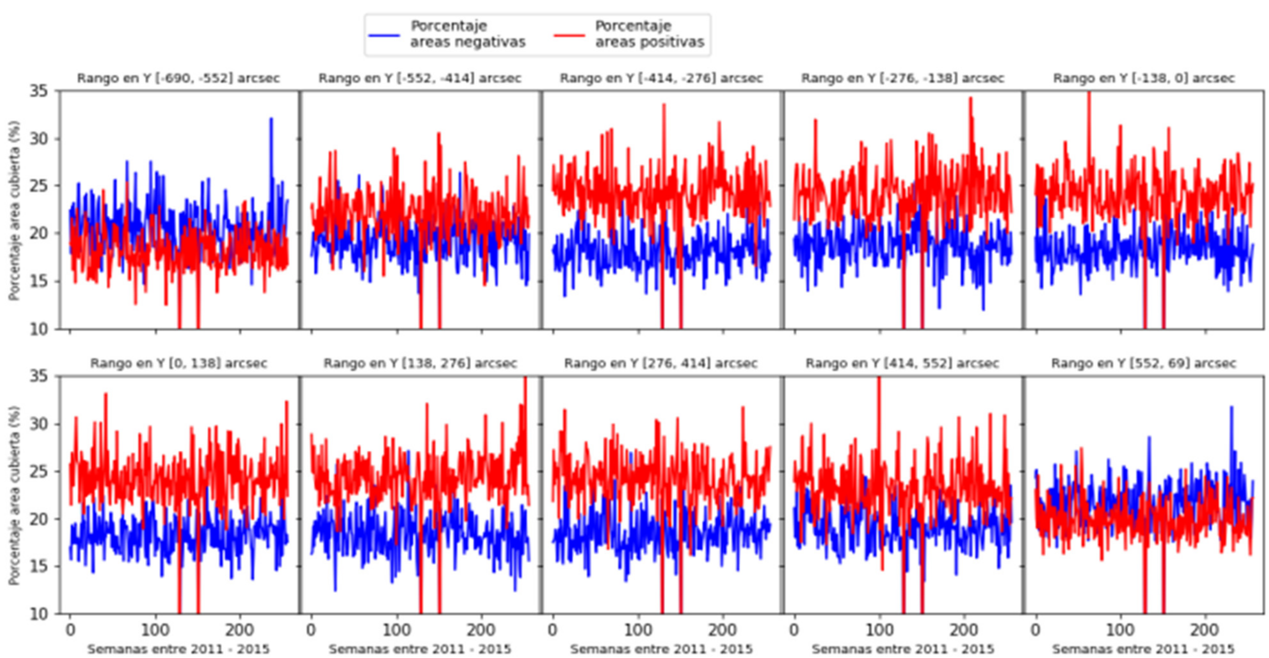

Fig 6. Statistical analysis of areas occupied by negative and positive vertical plasma flows at different latitudes.

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