INVESTIGATION OF SMALL SCALE TURBULENT MHD PHENOMENA USING NUMERICAL SIMULATIONS AND NST OBSERVATIONS

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Quiet Sun Region

Magnetic bright points & vortices in the solar photosphere

HMI/SDO

SOT/Hinode

TiO, NST/BBSO

TiO, IMaX/Sunrise
QUIT SUN REGION

Kitiashvili et al., 2010, 2011
VORTEX TUBES IN SIMULATIONS

Magnetic structures in a dynamo simulation

Brandenburg, A., Jennings, R. L., Nordlund, Å., Rieutord, M., Stein, R. F., Tuominen, I.

(Stein & Nordlund, 2000)

Kitiashvili et al., 2010

Shelyag et al., 2011

Steiner et al., 2010

Wedemeyer-Bohm et al, 2012
Our simulations show that the small-scale vortices representing whirlpool-type motions at intersections of the intergranular lanes may play important roles in the dynamics of the quiet-Sun and magnetic regions. The results indicate that the process of formation of small-scale magnetic structures and their accumulation into a large-scale magnetic structure is associated with strong vortical downdrafts developed around these structures. The resulting stable pore-like magnetic structure has the highest field strength of ∼6 kG at a depth of 1–4 Mm and ∼1.5 kG at the surface. It has a cluster-like internal structurization, and seems to be maintained by strong downdrafts converging around this structure and extending into the deep layers. The simulations show that these internal dynamics play a critical role in the magnetic self-organization of solar magnetic fields and formation of large-scale magnetic structures.
3D snapshot of the top part of the computational domain of MHD simulations with initial field $B_{z0} = 10$ G shows the penetration of convective vortex tubes (yellow isosurfaces) from the subphotosphere into the low and mid chromospheric layers. The horizontal wavy surface indicates the distribution of temperature at 6400 K, and corresponds to a photospheric layer. The vortex tubes (yellow isosurfaces) are shown for the enstrophy value of 0.0075 s$^{-2}$. The vertical slices in the back illustrate the vertical velocity distribution. Blue color corresponds to downflows; orange shows upflows.
VORTEX TUBE STRUCTURE ABOVE THE SOLAR SURFACE

Initial field Bz=10G

3D rendering of a vortex tube indicated by the arrow in the previous slide shows the relative distribution of the kinetic (blue isosurface) and current helicities (pink) for value \(-5000\) cm s\(^{-2}\). The gray–yellow isosurface shows the distribution of temperature \(T = 5800\) K.

Kitiashvili et al., 2012
Observations of the Vortical Structures in Chromosphere

(Wedemeyer-Böhm & Rouppe van der Voort, 2009)

Fig. 1. Temporal evolution of a swirl event as seen in close-ups of intensity maps in the wide-band (top row), Ca line wing (upper middle), Ca line core (lower middle), and Doppler shift (bottom). The columns from left to right show every other time step ($\Delta t = 18$ s). The black contours in the bottom row mark a zero Doppler shift. The grey scale of the Doppler shift is from $-5.5$ to $+5.5$ km s$^{-1}$ with negative values corresponding to blueshifts and thus upflows. The temporal evolution is presented in a movie provided as online material.
A quiet-Sun region observed in the TiO filter with the New Solar Telescope (NST) on August 3, 2010. Squares in panel a) show two subregions: subregion A without magnetic bright points, and subregion B with conglomerates of magnetic bright points concentrated in the intergranular lanes. In panel b), subregion B is shown in detail with overlapped velocity field derived by a Local Correlation Tracking (LCT) method.

Kitiashvili et al., Physica Scripta, 2012
**Turbulent Kinetic Energy Spectra of Solar Convection**

Effect of temporal averaging on the energy spectral density for the horizontal velocity fields in the simulations with an initial vertical field strength 10 G (panel a), and the horizontal velocities reconstructed by LCT from the TiO observations at NST/BBSO (b). Panel a shows also deviations of the energy spectra for the full resolution of the numerical data (12.5 km) and for the resolution degraded to the observational resolution (50 km). Each panel shows the kinetic energy spectra for the original data set without averaging (blue curves), and for the filtered data sets obtained using the sliding averaging (black and green curves), and 2-min and 5-min bin averaging (yellow and red-brown curves).

Kitiashvili et al., Physica Scripta, 2012
Observations of the Individual Acoustic Events

The average excess power ($v^2$) in the neighborhood of more than 2000 seismic events (Goode et al, 1998)

Intensity continuum of the averaged acoustic power. Blue, green and red colors correspond to 12, 20 and 32% of the maximum power (Bello González et al., 2010).
Excitation of Individual Acoustic Waves

Temporal evolution of density fluctuations (calculated as $\rho(t_{i+1}) - \rho(t_i)$) at the solar surface ($\tau \sim 1$) with cadence 30 s shows an example of acoustic wave excitation and radial propagation from a vortex source, representing the interaction of two vortices with the opposite-sign vertical component of vorticity, $\Omega_z$. Overplotted yellow circles indicate the approximate position of the wave front. Red and blue contours correspond to the magnitude of the positive (clockwise) and negative (counterclockwise) vertical vorticity.

Kitiashvili et al., 2011
Subsurface interaction of the vortices shown in at different stages: initial structure of the vortices, closing-up stage, and after partial annihilation. Solid and dashed isolines show the magnitude of the positive and negative vertical vorticity (s$^{-1}$).

Kitiashvili et al., 2011
Examples of acoustic waves propagation

Time-distance diagrams of the normalized density fluctuations show inclined ridges, corresponding to acoustic waves. The slope of the ridges corresponds to a mean speed of 7 – 14 km/s.

Kitiashvili et al., 2011
Wave propagation in subsurface layers

Acoustic waves propagation through the subsurface layers. The grayscale background shows the density difference, revealing a wave front (a dark diffuse region at ~3Mm) propagating into the interior. Blue and red isolines are positive and negative vertical vorticity contours.

Kitiashvili et al., 2011
CONCLUSIONS

- Recent progress in observational capabilities and numerical modeling provide unique high-resolution data with demonstrate complicated dynamics of turbulent flows and magnetic field. Realistic approach to numerical simulation, based on first physical principles and takes into account compressible fluid flow in a highly stratified medium, 3D multi-bin radiative energy transfer between fluid elements, real-gas equation of state, and ionization, and excitation of all abundant species, magnetic and effects of turbulence.

- The problem of excitation of acoustic waves by turbulent convection is one of the key questions in solar and stellar physics. We present new results of 3D radiative MHD simulations of the solar convection zone that reveal a strong connection between the wave excitation events and dynamics of vortex tubes, which are located mostly in the intergranular lanes. These whirlpool-like flows are characterized by very strong horizontal shear velocities (7 - 11 km/s) and downflows (~ 7 km/s), and are accompanied by sharp decreases of temperature, density and pressure at the surface. High-speed whirlpool flows can attract and capture other vortices, penetrate into low chromosphere.

- In this talk we present different aspects of small-scale turbulent dynamics of low atmosphere, sources of acoustic and shock waves, and comparison with observational results by New Solar Telescope at Big Bear Observatory.