Realistic Modeling of Multi-Scale MHD Dynamics of the Solar Atmosphere

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Realistic 3D radiative MHD simulations open new perspectives for understanding the turbulent dynamics of the solar surface, its coupling to the atmosphere, and the physical mechanisms of generation and transport of non-thermal energy. Traditionally, plasma eruptions and wave phenomena in the solar atmosphere are modeled by prescribing artificial driving mechanisms using magnetic or gas pressure forces that might arise from magnetic field emergence or reconnection instabilities. In contrast, our 'ab initio' simulations provide a realistic description of solar dynamics naturally driven by solar energy flow. By simulating the upper convection zone and the solar atmosphere, we can investigate in detail the physical processes of turbulent magnetoconvection, generation and amplification of magnetic fields, evolution of MHD waves, and plasma eruptions. We present recent simulation results of the multi-scale dynamics of quiet-Sun regions, and energetic effects in the atmosphere and compare them with observations. For the comparisons we calculate synthetic spectropolarimetric data to model observational data from SDO, Hinode, and the BBBSO New Solar Telescope.

**SolarBox code**
- 3D rectangular geometry
- Fully compressible, fully compressible
- Fully coupled radiation solver
- LTV using a spatially distribution function bisection
- Raytracing treated by Feautier method
- Up to 2 iterations in each angular quadrature
- KNC dark initialized EOS
- 4th order finite difference
- 4th order high-order line integration
- LES
- 5th order simulation systems (subfluence models)
- Compressible Boussinesq model
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**Basic equations**

- Conservation of mass
- Conservation of energy
- Conservation of momentum
- Conservation of magnetic flux

**Structure of the flow dynamics**

- Magnetic fields as function of depth below the photosphere.
- Horizontal snapshot of a fraction of the computational domain in the solar disc center. Different stages of a flow ejection. Black chromosomes. Global view of a fraction of the computational domain. Topology of the magnetic field lines above the photosphere. Time-difference between snapshots is 10s. White circle shows the location of a probe for studying the evolution of the Stokes profile shape. Square-root of the power spectral density of the Fourier transform of the Stokes profile I(λ) of Fe I 6173Å. The spectra reveal the line asymmetry, interesting variations in the form of 'running-wave' perturbations across the line with time - reflecting the turbulent magnetic fields. It is important to model the observational and data analysis procedures and calculate observables using the synthetic line profiles. Combination of p-value and diagnostic to achieve a realistic description of solar dynamics.

**Conclusions**

- Realistic 3D hydrodynamical simulations allow us to investigate important links between solar dynamics and the physical and radiative properties of solar conditions. This is achieved via the realistic description of the chromospheric and coronal dynamics. The internal dynamics of the solar atmosphere are driven by solar energy flow. The primary topology of the dynamo-generated magnetic field is represented by compact magnetic structures. It is important to model the observational and data analysis procedures and calculate observables using the synthetic line profiles. Combination of p-value and diagnostic to achieve a realistic description of solar dynamics. The chromospheric and coronal dynamics are strongly correlated with the stratification of the vertical magnetic field at the photosphere. The significance of the magnetic field is shown at the bottom of the photosphere.