MHD Rossby waves and the analogy between solar magnetic activity and the Earth's weather

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The Solar magnetic activity is believed to be a result of a dynamo process operating in the interior of the Sun, most likely in the Tachocline region where strong large scale toroidal fields are believed to exist. Although aspects of the spatio-temporal behavior of the axissymmetric component, such as the butterfly diagram, are well understood in terms of dynamo theory, the non axis-symmetric is much less understood.

In the last decade, theoretical, numerical and observational efforts, have pointed out to the role of Rossby waves as an organizing principle for solar magnetic field particularly relevant to the understanding of non axis-symmetric phenomena such as preferred active longitudes, activity nests and the spatial distribution and migration of active regions and coronal holes.

Rossby waves have long been recognized as a crucial mechanism for understanding Earth's atmospheric and oceanic phenomena, such as weather and climate patterns. In Particular, they are believed to organize weather patterns via the so-called teleconnection mechanism (i.e. the coupling between weather patterns on remote regions of the globe). These waves result from the principle of conservation of potential vorticity, and is expected to occur in any rotating astronomical body where fluids are present.

In the Sun's interior, where strong magnetic fields are believed to exist, Rossby waves are expected to be modified by magnetic forces such that they become a hybrid between hydrodynamic Rossby waves and Alfvén Waves, resulting in two different modes, a prograde and a retrograde one [1,2].

Here, we will utilize information theory to quantify the degree of organization of globally observed photospheric magnetic fields and relate it to the action of MHD Rossby waves. Magnetic field synoptic maps obtained from Helioseismic and Magnetic Imager (HMI) and Michelson Doppler Imager (MDI) instruments ranging from 1996 and 2022 are used here, in order to characterize their degree of organization as a function of latitude. The Shannon entropy and the mutual information are utilized, respectively, as measures of degree of organization and coupling.

Our results (see [3]), depicted in Figure 1, show how the Shannon entropy of the longitudinal distribution of the magnetic fields calculated for each latitude evolve in time. It becomes clear that it follows the well known butterfly-diagram. Estimation of the drift velocities of the longitudinal magnetic field profiles match those of the phase velocities of Solar Rossby waves.

During the talk, we will review the theory of hydrodynamic and magnetohydrodynamic Rossby waves, and explore the analogy between solar magnetic activity and Earth's weather.

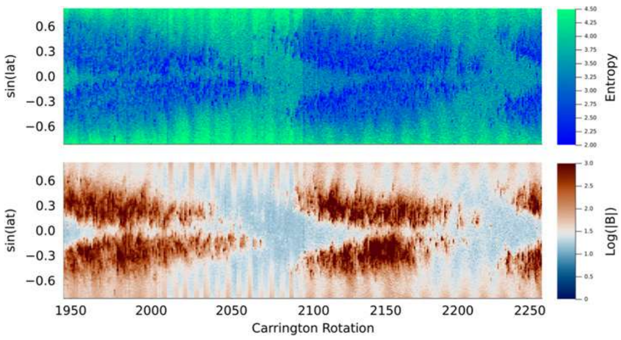

Figure 1: Butterfly diagram representing the entropy calculated over the longitudinal distribution of magnetic fields as a function of the latitude (top), compared with the butterfly diagram derived by the (unsigned) magnetic flux. Reproduced from [1].

References

[1]Raphaldini, B., Teruya, A. S., Raupp, C. F., & Bustamante, M. D. (2019). Nonlinear Rossby wave–wave and wave–mean flow theory for long-term solar cycle modulations. The Astrophysical Journal, 887(1), 1.

[2]Raphaldini, B., Dikpati, M., McIntosh, S., & Teruya, A. S. W. (2024). Spectra of solar shallow-water waves from bright point observations. Astronomy & Astrophysics, 692, A102.

[3] Raphaldini, B., Dikpati, M., & McIntosh, S. W. (2023). Information-theoretic Analysis of Longitude Distribution of Photospheric Magnetic Fields from MDI/HMI Synoptic Maps: Evidence for Rossby Waves. The Astrophysical Journal, 953(2), 156.