# Information Theory and Space Weather

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This lecture will describe the contribution that the use of tools from *Information Theory* can give to the science of Space Weather.

## 1 Core part of the lecture

Everything relies on the fact that quantities can be defined, based on the concept of Shannon Entropy [1], that are able to capture the "correlation" between two (or more) dynamic processes interacting, to all orders. Instead, the traditional cross-correlation functions only encode the linear interaction level. The use of such information quantities may be of help in the study of Space Weather dynamics, both in terms of understanding the fundamental mechanisms, and of defining prediction or early warning tools.

We will start from the definition and physical meaning of Shannon Entropy for classical systems, and introduce the concepts of mutual information between two dynamic processes $X$ and $Y$. Then, the time-delayed mutual information $M_{X,Y}(\tau)$ and transfer entropy $T_{X\to Y}(\tau)$ are defined [2], in order to introduce the idea of dynamic binding and causal relationship. Their conceptual and practical meanings and differences are studied, and the difficulties of producing numeric tools from them discussed.

Results about those quantities, all focussed on the study of Space Weather (see [3], [4] and [5]), will be presented, illustrating concretely how the tools introduced may be used. Future development of this line of research, namely "Information Space Weather" will then be illustrated, and an outlook will be given about modification and refinements of these tools [6].

## 2 Generalized part of the lecture

The lecture will be concluded with a more theoretical subject, suitably focussed on the Space Weather dynamics, but ranging in a wider context, that of the role of entropy-like quantities in dynamics. In particular, the problem of fluctuation-dissipation mechanisms will be discussed [7], and the not-so-intuitive behaviour of entropy in space plasma turbulence will be discussed [8].

*Time duration of the lecture*: 2 to 4 hours.

*Background culture*: mathematics of a scientific university course (physics, mathematics or engineering). However, fundamental properties of probability and/or differential operators, useful in the discussion, will be re-introduced if necessary. Questions, comments and discussions suggested by the students will be welcome.

*Didactical support*: viewgraphs of the lecture will be provided in electronic format. Also, a pdf file including the text of the lecture, as conceived before the school, will be given. The text will be updated with exercises and discussions after the school, if necessary.

## References


[1] Shannon, C.E. (1948), *A mathematical theory of communication*, Bell Syst. Tech J., **27**,379.

[2] Schreiber, T. (2000), *Measuring information transfer*, Phys. Rev. Lett., **85**, 461.

[3] Materassi, M., A. Wernik, and E. Yordanova (2007), *Determining the verse of magnetic turbulent cascades in the Earth's magnetospheric cusp via transfer entropy analysis: Preliminary results*, Nonlinear Process. Geophys., **14**, 153.

[4] Materassi, M., L. Ciraolo, G. Consolini, N. Smith, *Predictive Space Weather: an information theory approach*, Advances in Space Research **47** (2011), pp. 877-885, doi:10.1016/j.asr.2010.10.026.

[5] De Michelis, P., G. Consolini, M. Materassi, R. Tozzi, *An information theory approach to storm-substorm relationship*, Journal of Geophysical Research, vol. **116**, A08225, doi:10.1029/2011JA016535, 2011.

[6] Materassi, M., G. Consolini, N. Smith, *Mutual information and dynamics*, in preparation.

[7] Gallavotti, G., E. G. D. Cohen, *Dynamical ensembles in non-equilibrium statistical mechanics*, Physical Review Letters, **74**, 14 (1995).

[8] Klimontovich, Yu. L., *Turbulent motion and the structure of chaos: a new approach to the statistical theory of open systems*, Kluwer Academic Publishers, Springer (1991).