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A novel technique to identify scale-dependent lags and application to ionospheric science

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The ionosphere is a dynamical system exhibiting nonlinear couplings with the other "spheres" characterizing the geospace environment. Such nonlinearity manifests also through the non-trivial, scale-dependent, time delays in the cause-effect chain characterizing the Solar Wind-Magnetosphere-Ionosphere coupling.

The present study uses the Intrinsic Mode Cross Correlation (IMXC): a novel scale-wise signal lag measurement, conceived to possibly identify scale-dependent lags [1]. The method performance is evaluated first on known artificial signals and then applied to ionospheric data, mainly in situ electron density from Swarm constellation. The IMXC relies on non-linear non-stationary signal decomposition provided by the novel Multivariate Fast Iterative Filtering (MvFIF) technique [2], which identifies the common scales embedded in the signals. The lags are then obtained scale-wise, enabling the identification of the lag dependence on the involved spatio/temporal scales for the artificial data set (even in presence of high levels of noise), and to estimate them in a real-life signal.

As the first real-life scenario assuming cause-effect relationship, we use the closely separated measurements of the European Space Agency's Swarm Alpha (A) and Charlie (C) satellites [3] with identical Langmuir probe instruments sampling the ionospheric plasma density in the topside ionosphere. The latitudinal orbital separation between Swarm A and C is about 8.8 s between the two satellites. By using IMXC technique, we can extract the 8.8 s seconds lag from the electron density measurements, as demonstrated in a case event.

As an example of an additional application to demonstrate the usability of the technique in the Space Weather context, we evaluate lags of the intensifications in the common scales between the electron density measurements and the field-aligned current measurements from Swarm FAC dataset again by comparing the leading and trailing satellite (Swarm A-C pair) in the high latitude regions. This can pave the way to future uses of this technique in contexts in which the causation chain can be hidden in a complex, multiscale coupling of the investigated features.

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