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The application of dynamic time warping to understand correlation distances in the ionosphere

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Extended Abstract

Ionospheric measurements are often spatially sparse and unevenly distributed. This means that ionospheric mapping algorithms have to apply a correlation distance to interpolate across observation gaps.

In reality the ionosphere is dynamic and to maximize information from spaced observations this aspect should also be taken into account. This problem is most prominent when the ionosphere contains features that move across a region; features such as such as travelling ionospheric disturbances (TIDs) or polar cap patches. In such cases a stationary snapshot of the ionosphere would have a rather small horizontal correlation distance related to the scale size of the feature but, when a feature is moving, information is lost if consecutive time steps are not considered. This problem has been partly addressed by the development of time-dependent assimilation algorithms for the polar cap ionosphere, but has not been fully addressed for tracking the movement of TIDs.

In motion tracking the analogy is that of an object crossing the field of view - since it is the same object in each frame the correlation distance across each individual frame is not as meaningful as the correlation of a structure moving across the 2D images in consecutive frames.

A simple method to track TIDs at spatially separated sites is to use cross-correlation. However, this assumes a constant velocity and shape of the wave between observation sites, which may not be true because of (i) observation geometry (ii) changes in the wave characteristic as it propagates. Cross-correlation also suffers from signals' DC bias and trend dissimilarities, an effect that could not be entirely eliminated in the observations considered in this paper.

Here a new technique called Dynamic Time Warping is applied to the tracking of TIDs in the time domain. The Dynamic Time Warping algorithm uses dynamic programming to evaluate the similarity of a temporal structure in two or more data streams. It establishes a search space, populated by a distance or correlation measure of each individual data point in one signal to each data point in the other, producing an optimal alignment between them. The key advantage of this method is that it offers a reliable estimate of comparison between time sequences, even if the signals suffer from continuously changing shape deformations of the temporal structures from one data sequence to the other. In the case of TID evaluation the new algorithm could produce far more accurate estimates of movement than the cross-correlation procedure, as it does not assume a constant velocity or shape of the wave as it is observed from different observation sites.

The technique is applied to track the velocity and direction of TIDs across a small region (sub-100 km) of New Mexico during January 2014. Further application of the technique in North America and Europe show the applicability to larger regions.

The paper develops a new approach to understanding correlation distances in the ionosphere that allows for both spatial and temporal changes simultaneously. This has useful implications for ionospheric specification for navigation and surveillance applications, where the best instantaneous estimate of the ionosphere (usually the electron density) is required from a set of sparsely distributed observations.