**The Spire TEC Environment Assimilative Model (STEAM); a new 4D ionospheric data assimilation model using Spire radio occultation data**

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The ionosphere can affect a wide range of radio frequency (RF) systems operating below 2 GHz. One option for mitigating these effects is to produce assimilative models of the ionospheric density from which products can be derived for specific systems. Such models aim to optimally combine a background model of the ionospheric state with measurements of the ionosphere. This approach is analogous to the use of numerical weather prediction in the meteorological community, and has been evolving for ionospheric use for the last 10 to 15 years.

Published research has demonstrated to the utility of this approach [i.e. *McNamara et al.*, 2013; *Elvidge et al.*, 2014]. However, obstacles to providing effective data products remain due to the sparseness of ionospheric data over large parts of the world and the timeliness with which data is available. Spire is working to overcome these issues through the use of its large, and growing, constellation of satellites (Figure 1), that can measure Total Electron Content (TEC) data in both zenith looking and radio occultation (RO) geometries and its large ground station network that will allow low data latency.

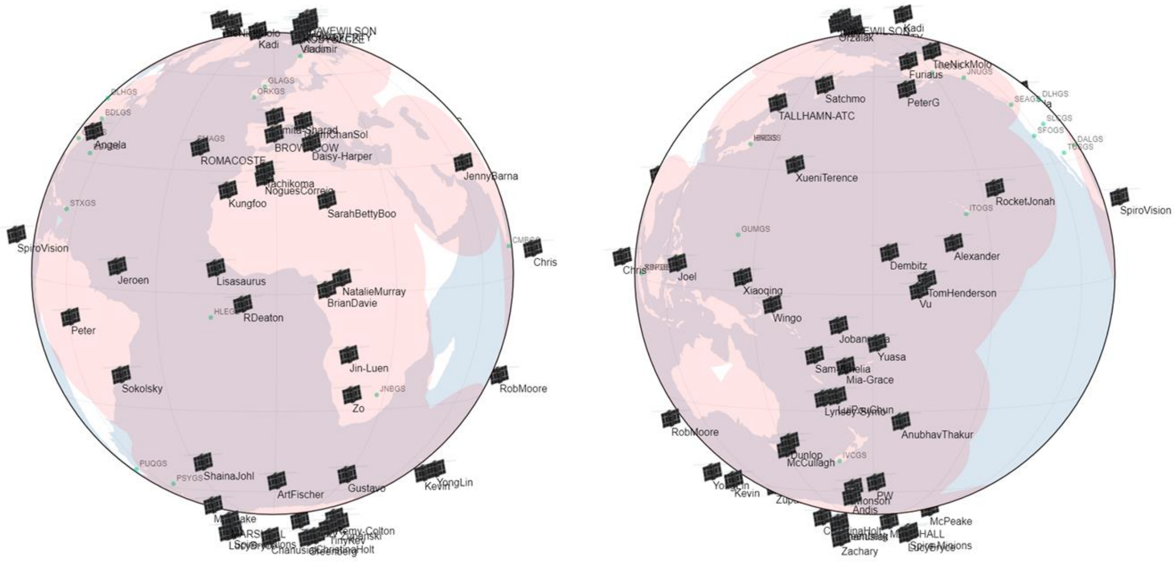


*Figure 1. Snapshot of Spire satellite constellation*

The Spire data will be combined with an innovative data assimilation model (the Spire TEC Environment Assimilative Model, STEAM) to provide accurate and actionable ionospheric products. Data assimilation is required to overcome the limitations and assumptions of the traditional Abel Transform analysis of RO data (i.e. spherical symmetry; transmitter and receiver in free space and the same plane) and to effectively combine RO data, topside data, ground based GNSS data, and other sources of ionospheric information (i.e. ionosondes).

STEAM uses a 4D Local ensemble transform Kalman Filter (LETKF) [*Hunt et al.*, 2007; *Elvidge and Angling*, 2018]. As with other ensemble methods [*Evensen*, 2009], the LETKF uses an ensemble of models to approximate the background error covariance matrix. However, the LETKF provides a more efficient way to solve the ensemble KF equations than the ensemble KF. Furthermore, 4D operation permits the use of data with varying latency. Localisation means that grid points are only modified by data within a local volume; this restricts spurious long-range spatial correlations and means that the ensemble only has to span the space locally. The LETKF transforms the problem into ensemble space which makes each grid point independent, resulting in an algorithm that is highly parallelisable.

This paper will describe the data collection and processing chain, the data assimilation model, and plans for the ongoing development of the combined system.

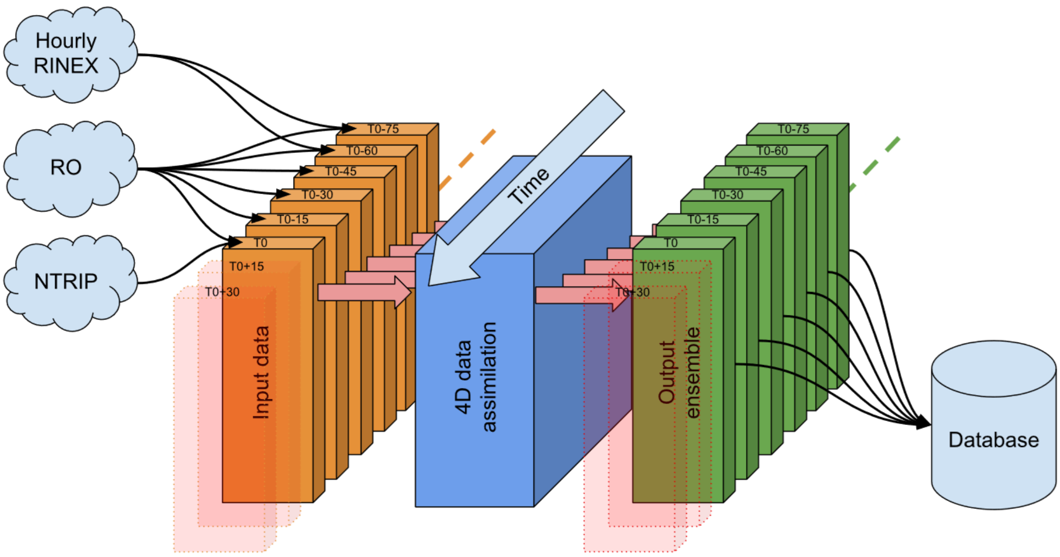


*Figure 2. Cartoon showing how data with different latencies is packaged and used to drive the 4D data assimilation model*

**References**

Elvidge, S., and M. J. Angling (2018), Using the Local Ensemble Transform Kalman Filter for Upper Atmospheric Modelling, *J. Sp. Weather Sp. Clim.*, *Submitted*.

Elvidge, S., M. J. Angling, and B. Nava (2014), On the use of modified Taylor diagrams to compare ionospheric assimilation models, *Radio Sci.*, *49*(9), 737–745, doi:10.1002/2014RS005435.

Evensen, G. (2009), *Data Assimilation, the Ensemble Kalman Filter*, 2nd ed., Springer-Verlag Berline Heidelberg.

Hunt, B. R., E. J. Kostelich, and I. Szunyogh (2007), Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter, *Phys. D Nonlinear Phenom.*, *230*(1–2), 112–126, doi:10.1016/j.physd.2006.11.008.

McNamara, L. F., M. J. Angling, S. Elvidge, S. V. Fridman, M. A. Hausman, L. J. Nickisch, and L.-A. McKinnell (2013), Assimilation procedures for updating ionospheric profiles below the F2 peak, *Radio Sci.*, *48*(2), doi:10.1002/rds.20020.