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Probabilistic Forecasting for RF Systems using an Ensemble of Ionospheres

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The increasing use of ensemble approaches for modelling the ionosphere (for example the ensemble Kalman filter) provides the opportunity for producing probabilistic forecasts of radio frequency (RF) systems. Ensemble methods rely on having a set of independent realizations of the ionosphere (ensemble members) which are used to describe the statistical nature of the ionospheric state (for example the electron density). However, the forecasted ensemble members do not necessarily describe a probability distribution function; rather, they are simply a finite set of deterministic forecasts. Further assumptions about the statistical properties of the ensemble are therefore required. For example, it could be assumed that the ensemble members are directly drawn from some underlying distribution. However, in the absence of any evidence that this assumption is valid, the ensemble members should first be converted into a suitable probability distribution function. This can be done by one of three methods (Figure 1):

a) Consider the ensemble members to be delta function. Then assume that the proportion of ensemble members showing a certain event defines the probability (a frequentist interpretation).
b) Replace the delta functions with a continuous function which characterizes the uncertainty in the ensemble member. Sum these ‘dressed’ ensemble members to form a probability distribution function.
c) Fit a suitable a distribution to the ensemble members, and then the individual members can be assumed to be random samples of that distribution.

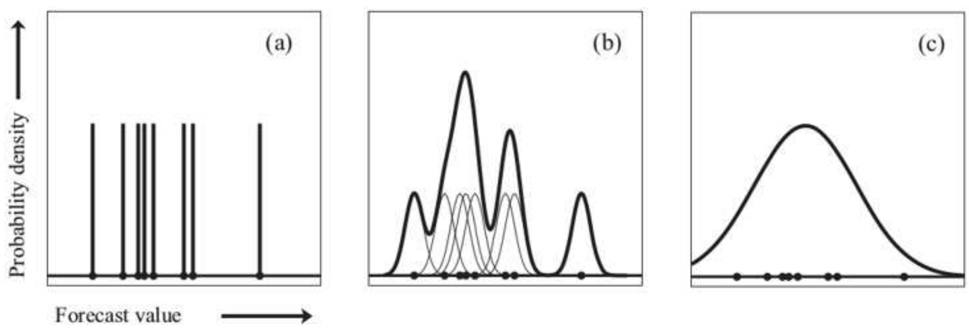

Figure 1. Methods for converting ensemble members to probability distribution functions [1].

Using electron density ensemble members from the Advanced Ensemble electron density (Ne) Assimilation System (AENeAS) [2] this paper will demonstrate two examples of how converting ensemble members to probability distribution functions can be used for probabilistic forecasting. The first example is for a high frequency (HF, 3-30 MHz) single site location system, and combines uncertainties in the estimated direction of the received signal with that of the ionosphere to provide a probability distribution of the target location. Secondly, the AENeAS ensemble is used to estimate the probability distribution function of the time rate of change in h’F. This is the minimum virtual height of an F region ionogram and can be used as a proxy for $\boldsymbol{E} \times \boldsymbol{B}$ drift [3]. Therefore, it can be used to provide a probabilistic estimate of the likelihood of scintillation occurring at a given location.

1. Jolliffe, I. T., and D. B. Stephenson (Eds.) (2011), “Forecast Verification: A Practitioner’s Guide in Atmospheric Science”, 2nd ed., Wiley-Blackwell.
2. Elvidge, S. & Angling, M. J., (2018) “Using the Local Ensemble Transform Kalman Filter for Upper Atmospheric Modelling”, *Journal of Space Weather and Space Climate.*
3. Anderson, D. N. and R. J. Redmon (2017), “Forecasting scintillation activity and equatorial spread F”, *Space Weather*, 15(3) 495-502.