Initial Results of the Advanced European electron density (Ne) Assimilation System (AENeAS)

S. Elvidge* and M. J. Angling

SERENE, University of Birmingham, Birmingham, B15 2TT, UK.
(E-mail: s.elvidge@bham.ac.uk)

ABSTRACT

This paper presents the initial results of the Advanced European electron density (Ne) Assimilation System (AENeAS) which is a new ionosphere/thermosphere assimilation model being developed at the University of Birmingham, UK. AENeAS is a physics-based data assimilation model which uses a local ensemble transform Kalman filter (LETKF). The model assimilates electron density virtual height profiles from ionosondes and TEC measurements from GNSS receivers. The paper will describe the latest version of AENeAS and plans for its future development.

The LETKF is an ensemble Kalman filter variant first described by *Hunt et al.* [1]. The LETKF combines the transform ensemble Kalman filter (ETKF) [2] with the local ensemble Kalman filter (LEKF) [3]. The localization in the LEKF allows the analysis to be performed around each grid point and in parallel. Each of these individual analyses are combined to form the global analysis. The ETKF uses ensemble perturbation matrices, where the ensemble mean (or some other control) is removed from each ensemble member. The distance from the control to the ensemble member provides information about the spread of the ensemble, from which one can estimate the model covariances. The LETKF results are equivalent to the LEKF [4] results but are calculated in a more efficient manner, similar to the ETKF. The equations governing the LETKF are similar in form to that of the classic Kalman filter:

$$\begin{aligned}
\widetilde{\boldsymbol{A}} &= [(k-1)\boldsymbol{I} + (\boldsymbol{H}\boldsymbol{X}_b)^T\boldsymbol{O}^{-1}\boldsymbol{H}\boldsymbol{X}_b]^{-1}, \\
\boldsymbol{K} &= \boldsymbol{X}_b\widetilde{\boldsymbol{A}}(\boldsymbol{H}\boldsymbol{X}_b)^T\boldsymbol{O}^{-1}, \\
\boldsymbol{A} &= \boldsymbol{X}_b\widetilde{\boldsymbol{A}}(\boldsymbol{X_b})^T, \\
\overline{\boldsymbol{x}_a} &= \boldsymbol{K}(\boldsymbol{y}_o - \boldsymbol{H}\overline{\boldsymbol{x}_b}), \\
\boldsymbol{X}_a &= \boldsymbol{X}_b\left((k-1)\widetilde{\boldsymbol{A}}\right)^{\frac{1}{2}},
\end{aligned}$$

where $\boldsymbol{H}$ is the observation operator, $\boldsymbol{O}$ the observation covariance matrix, $\boldsymbol{y}_o$ the observation vector, $\boldsymbol{A}$ the analysis error covariance matrix and k the size of the ensemble. The matrix $\boldsymbol{X}_b$ is the background perturbation matrix where each column of the perturbation matrix is an ensemble member with the ensemble mean removed.

Like any Kalman filter the LETKF requires a background model. AENeAS is designed in such a way that the background model is easily interchangeable. Currently the background model is provided by the Thermosphere Ionosphere Electrodynamics General Circulation Model (TIE-GCM) [5]. However, the maximum altitude modelled by TIE-GCM is between 500 – 700 km (depending on solar conditions). Since AENeAS is designed to provide ionospheric parameters such as the total electron content (TEC) an NeQuick [6] topside is fitted above these heights.

Initially, AENeAS is designed to assimilate electron density virtual height profiles from ionosondes and TEC measurements from GNSS receivers. The modular design allows new data types to be easily added as the model is developed.

References

1 Hunt, B.R. *et al.* Efficient data assimilation for spatiotemporal chaos: A local ensemble transform Kalman filter. *Physica D: Nonlinear Phenomena*, 2007, 230 (1-2), pp. 112–126. DOI: 10.1016/j.physd.2006.11.008

2 Bishop, C.H. *et al.* Adaptive Sampling with the Ensemble Transform Kalman Filter. Part I: Theoretical Aspects. *Monthly Weather Review*, 2001, 129, pp. 420–436.

3 Ott, E. *et al.* A local ensemble Kalman filter for atmospheric data assimilation. *Tellus*, 2004, 56, pp. 415–428.

4 Ott, E. *et al.* Exploiting Local Low Dimensionality of the Atmospheric Dynamics for Efficient Ensemble Kalman Filtering. 2002.

5 Richmond, A.D. *et al.* A thermosphere/ionosphere general circulation model with coupled electrodynamics. *Geophysical Research Letters*, 1992, pp. 601–604.

6 Nava, B. *et al.* A new version of the neQuick ionosphere electron density model. *Journal of Atmospheric and Solar Terrestrial Physics*, 2008, 70 (15), pp. 1856–1862. DOI: 10.1016/j.jatsp.2008.01.015

Acknowledgements

AENeAS is being developed as part of the QinetiQ Mitigation of Ionospheric Effects Phase 4 project, funded through the Dstl Space programme via the Cyber and Information Systems division. Access to the latest version of TIE-GCM was provided by Ben Foster and NCAR.

Key words: Ionosphere, Model, Data Assimilation