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Comparative testing of empirical, data assimilation and physics-based ionospheric/thermospheric models

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1. Introduction

There are a wide range of ionospheric/thermospheric models in active use and development around the globe, utilizing a number of modelling techniques. The ionospheric models can be split into three main categories: empirical, data assimilation and physics-based.

To gain an insight into the success of the various model types at specifying the ionosphere, two things are required: (1) common testing scenarios and (2) model metric(s).

Shim et al. [1] conducted one of the first published comparisons of the three model types. Model results for NmF2 (peak density of the F2 layer), hmF2 (Height of the peak of the F2 layer) and vertical drifts, were compared with observational data from incoherent scatter radars (ISRs), for nine different test scenarios. However, the test scenarios were all of a relatively short time frame; only ranging from one to two and a half days. The time-step was set to 15 minutes, and therefore a fairly small number of data points were used in the calculation of the metric statistics.

This paper compares the three model types for a longer test study (one month, September 2011). It also provides a preliminary test of the suitability of using physics-based background models for data assimilation schemes.

2. Models

A short description of each model used in this test, and a reference for more information, can be found below:

- **IRI-2007**: An empirical monthly median model, widely used due to relative ease, speed and generally acceptable level of validity [2].
- **EDAM**: A data assimilative model, using a variation of minimum variance optimal estimation to update its background model (currently provided by IRI-2007) [3].
- **GPSII**: A data assimilative model which uses Tikhonov regularization to combine data and background model [4].
- **mNeQuick**: A data assimilation version of the NeQuick 2 model, providing real time 3D specifications of electron densities [5].
- **TIE-GCM**: A non-linear 3D physics-based model of the thermosphere/ionosphere system which solves the continuity, energy and momentum equations at each time step [6].
- **GITM**: A physics-based 3D global thermosphere/ionosphere model that solves the full Navier-Stokes equations for density, velocity and temperature for a number of components at each time step [7].

3. Testing Scenario

The analysis interval for the present study is the whole of September 2011. The study concentrates on observations from the four Digisondes in the Republic of South Africa (RSA), situated at Grahamstown, Hermanus, Louisvale and Madimbo (Figure 1). foF2, hmF2 and h(0.8foF2) (height of 80% the foF2 value) have been used to test the models.

Data from the Grahamstown Digisonde and GNSS data from Sub-Saharan Africa was assimilated. The remaining RSA Digisondes were used to test the models. Results from the Hermanus station are presented here.

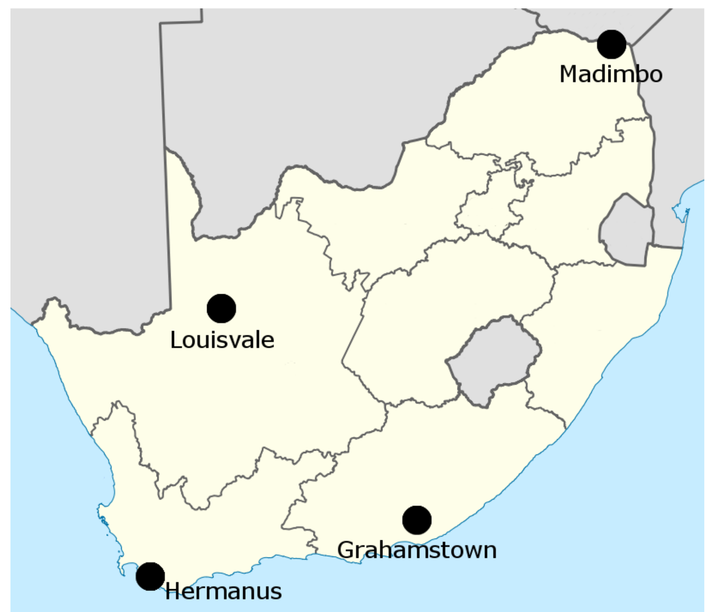

Figure 1: Locations of the four RSA Digisondes.

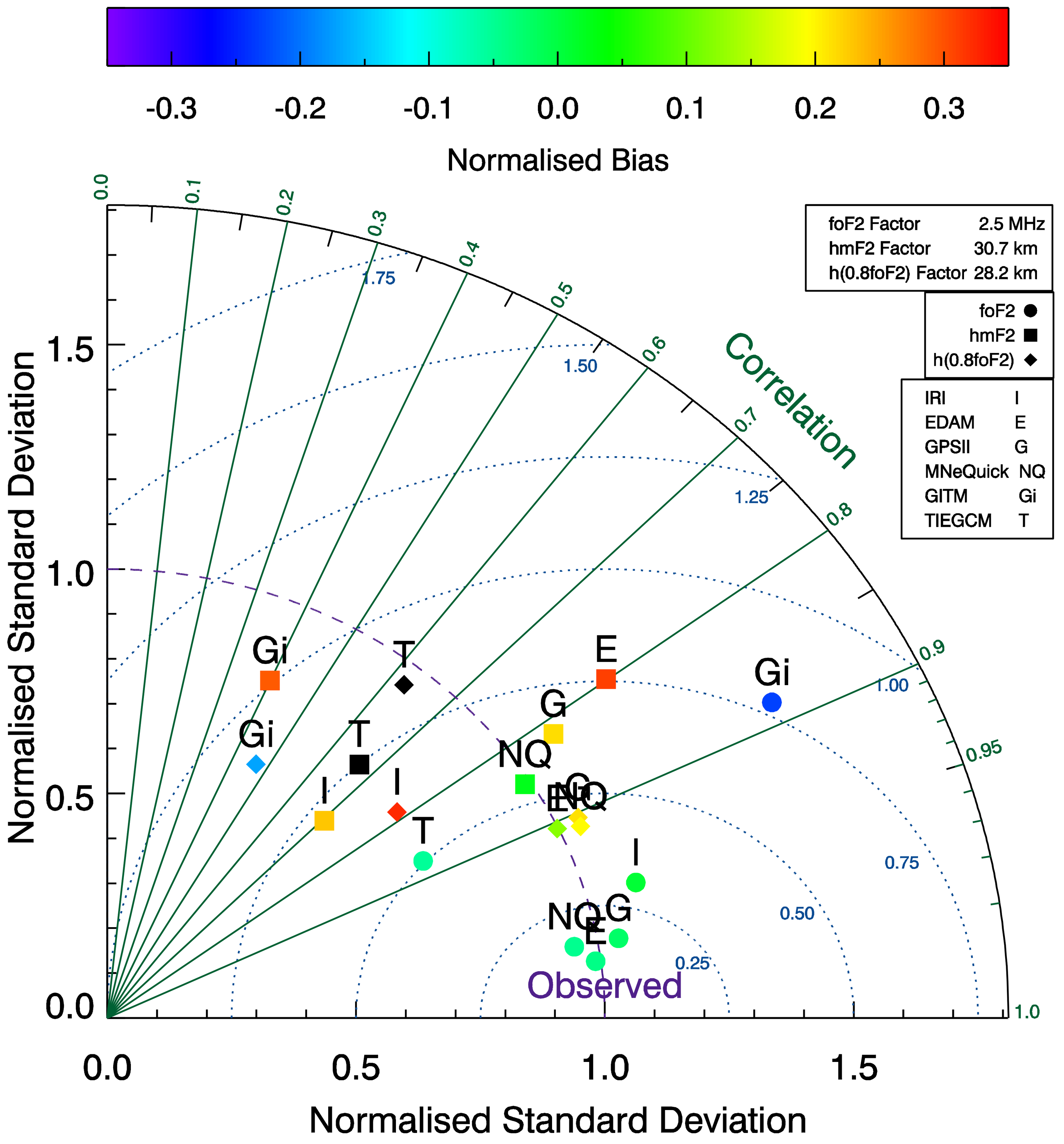

Figure 2. The test results for Hermanus shown in a modified Taylor diagram [8] for the September 2011 test study. Symbols in black exceed the colour scale.

4. Results & Conclusions

Figure 2 is the modified Taylor diagram [8] for the test data above the Hermanus ionosonde station, and gives a clear indication of model performance.

In terms of specifying foF2 the data assimilative models perform the best, as expected, and are comparable to each other. EDAM exhibits a better (normalized) standard deviation and correlation than GPSII and mNeQuick. IRI, the empirical model, also performs well, and only slightly worse than the assimilative models. TIE-GCM gives a standard deviation of less than unity, implying the model tends to underestimate the range of values for foF2, whilst GITM is greater than unity. However TIE-GCM has a smaller standard deviation of errors than GITM.

For hmF2 the model performance is more varied. mNeQuick performs the best, in terms of standard deviation and correlation, followed by GPSII (with slightly poorer correlation and a greater than unity standard deviation). Both models show no significant bias. Out of IRI, EDAM and TIE-GCM, EDAM has the best correlation, but with a greater than unity standard deviation. Its standard deviation of errors is very similar to TIE-GCMs. IRI has a slightly better standard deviation of errors, and shows no noticeable bias; however TIE-GCM has a large positive bias (off the colour scale at 30.8 km). Finally GITM performs poorest in terms of correlation with the observation and standard deviation of errors.

For h(0.8foF2) the assimilative models produce standard deviations close to the observation. They also perform similarly in terms of correlation and bias. The TIE-GCM result has a worse correlation and shows a positive bias. GITM however shows very little correlation with the observation and a negative bias. IRI gives a standard deviation less than unity but has a better correlation and mean square error than both TIE-GCM and GITM.

References & Acknowledgements

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