On the use of ionosonde profiles in the Electron Density Assimilative Model (EDAM)

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Abstract

Ground based measurements of slant total electron content (TEC) can be assimilated into ionospheric models to produce 3D representations of ionospheric electron density. The Electron Density Assimilative Model (EDAM) has been developed for this purpose. Previous tests using EDAM and ground based data have demonstrated that the information on the vertical structure of the ionosphere is limited in this type of data. However, information regarding the profile peak below the F2 layer can be obtained by assimilating data from ionosondes into EDAM. EDAM assimilations, focused on the Republic of South Africa (RSA) have been run for periods in November 2008 and February/March 2009. For each run three datasets will be ingested: only GPS TEC data; only ionosonde data: GPS TEC data and ionosonde data.

1. Introduction

Comprehensive, global and timely specifications of the earth's atmosphere (particularly refractivity profiles of the troposphere and ionosphere) are required to ensure the effective operation, planning and management of many radio frequency systems. One way of providing ionospheric refractivity information is to employ an ionospheric data assimilation system. Such systems can produce 3D images of the ionosphere using data provided by a range of measurement techniques such as GPS receivers and ionosondes.

The Electron Density Assimilative Model (EDAM) has been developed by QinetiQ [Angling and Cannon, 2004; Angling and Khattatov, 2006; Angling et al 2008] to assimilate disparate ionospheric measurements (including ground and space based total electron content (TEC) measurements, height profiles from ionosondes and incoherent scatter radars and electron density data from in-situ sensors) into a background ionospheric model. This model is currently provided by IRI2007 (Bilitza and Reinisch, 2008). EDAM exploits optimal data assimilation techniques that have been developed in the meteorological community over the past few decades. The philosophy has been to design a system that will operate on a single PC, which will continue to provide physical results with very sparse data and from which products can be derived for a range of RF systems.

The assimilation is based on a weighted, damped least mean squares estimation. This is a form of minimum variance optimal estimation (also referred to as best linear unbiased estimation, BLUE) that provides an expression for an updated estimation of the state (known as the analysis) that is dependent upon an initial estimate of the state (the background model), and the differences between the background model and the observations (Menke, 1989). The error covariance matrices of the background model and the observations are also used to control the relative contributions of the background and the observations to the analysis:

$$\mathbf{x_a} = \mathbf{x_b} + \mathbf{K}\left(\mathbf{y} - H\left(\mathbf{x_b}\right)\right) \tag{1}$$

$$\mathbf{K} = \mathbf{B}\mathbf{H}^{\mathbf{T}}\left(\mathbf{H}\mathbf{B}\mathbf{H}^{\mathbf{T}} + \mathbf{R}\right)^{-1} \tag{2}$$

where $\mathbf{x_a}$ is the analysis, $\mathbf{x_b}$ is the background model, $\mathbf{K}$ is the weight matrix, $\mathbf{y}$ is the observation vector, $\mathbf{B}$ is the background error covariance matrix, and $\mathbf{R}$ is the error covariance matrix of the observations [Rodgers, 2000]. H is the non-linear observation operator that relates the measurements to the state. The operator is non-linear because, in EDAM, the background model is comprised of the log of the ionospheric electron density. $\mathbf{H}$ is the Jacobian, whose elements are given by the partial differentials of the observation operator evaluated at the background model.

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The assimilation is conducted using a magnetic coordinate system that remains fixed in space with respect to the sun. An assimilation time step of 15 minutes has been used and the electron density differences between the voxels of the analysis and the background model are propagated from one time step to the next by assuming persistence combined with an exponential decay. The time constant for this decay is set at 4 hours. Thus, if the data feed is interrupted, the analysis will decay back to the background model.

This paper will present results from a test campaign based on data from November 2008 and February/March 2009 and makes use of the four station Digisonde network in the Republic of South Africa (RSA). Three of these stations are assimilated into EDAM, whilst the fourth provides the truth data used for verification of EDAM. The testing replicates that undertaken by McNamara et al [2011] with the Utah State Global Assimilative Ionospheric Model (GAIM) [Thompson, et al., 2006].

2. Test Scenario

EDAM will be operated between November 16th and November 30th 2008 and between February 11th and March 11th 2009. For each time interval three assimilation runs will be conducted using different input data: assimilation of just GPS TEC data, assimilation of just ionosonde data, and assimilation of both ionosonde and ground based TEC data.

The ground based TEC data will be obtained from GPS receiver sites distributed in the RSA and across the wider southern hemisphere. Where available, differential code biases (DCBs) from the Centre for Orbit Determination in Europe (CODE) will used to provide calibrated TEC. Otherwise, the station DCBs will be determined by EDAM itself as part of the assimilation process. The four Digisonde stations used in the test are shown in Figure 1. Of these four stations, Hermanus will be used solely to provide the ground truth data.

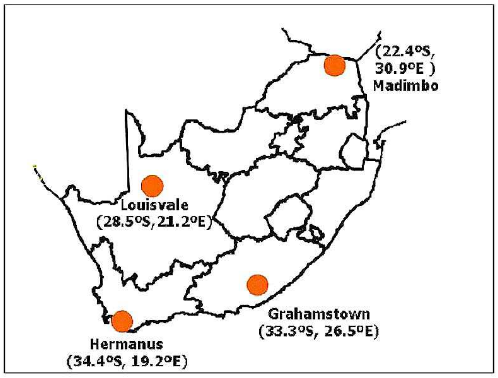
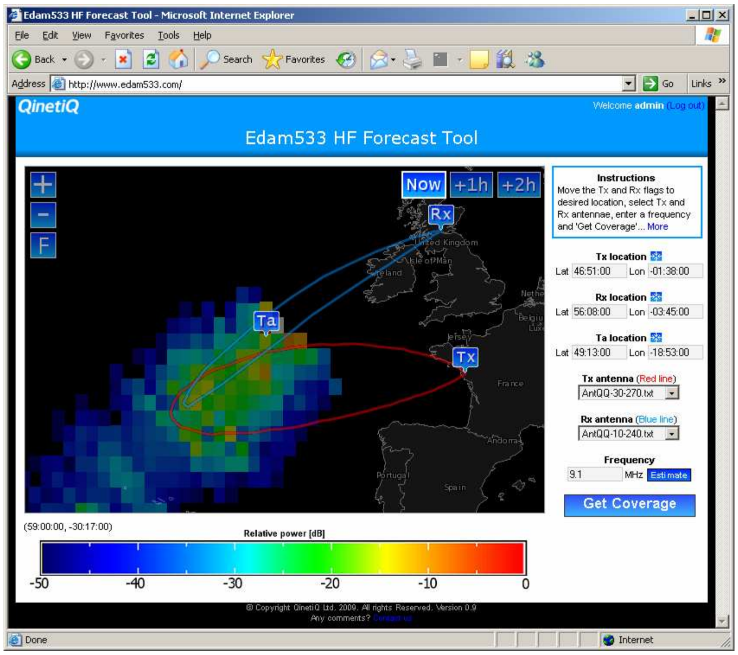


Figure 1. Map of RSA showing the locations of the four ionosondes. Reproduced from [McNamara et al., 2011]

3. Discussion

EDAM can be used to provide real time estimations of HF propagation conditions [Angling et al., 2008] (Figure 2). However, the performance of such tools is limited by the accuracy of EDAM's representation of the bottomside electron density profile. It is also clear that there is limited information on the vertical profiles in ground based TEC data. Consequently, other data sources, such as ionosondes, have a key role to play to constraining the bottomside shape.

A previous study [Angling and Jackson-Booth, 2010] has demonstrated that by assimilating both GPS and ionosonde data, EDAM displays both low TEC and low foF2 residuals. This is achieved by modifying the ionospheric slab thickness. The current study extends the analysis by using a wholly independent ionosonde station to provide a truth data set. Results will be presented that compare the EDAM vertical profiles with those provided by the Hermanus ionosonde. Furthermore, the results will be compared to those provided by McNamara et al. [2011] so that the EDAM performance can be considered with respect to GAIM.



Instructions
Move the Tx and Rx flags to desired location, select Tx and Rx antennae, enter a frequency and 'Get Coverage'... More

Tx location
Lat 46:51:00 Lon -01:38:00

Rx location
Lat 56:08:00 Lon -03:45:00

Ta location
Lat 49:13:00 Lon -18:53:00

Tx antenna (Red line)
AntQQ-30-270.txt

Rx antenna (Blue line)
AntQQ-10-240.txt

Frequency
9.1 MHz Estimate

Get Coverage

Figure 2. Example output from the EDAM533 HF coverage tool.

4. Acknowledgements

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