Reducing Errors in Atmospheric Density Modelling Using a Multi-Model Ensemble

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Introduction

NASA predicts that, by 2030, orbital collisions could become frequent enough to cause a cascade, known as the *Kessler Syndrome* [1]. This has the potential to make space exploration and the use of low Earth orbit (LEO) satellites impossible. Preventing the Kessler Syndrome requires new techniques for both object removal and atmospheric density modelling, since drag due to atmospheric density is a key parameter in satellite orbit predictions. Given the region of interest (i.e. the thermosphere), atmospheric densities, and therefore orbital drag estimations are often driven by space weather.

For this study three atmospheric density models have been used: NRLMSISE-00 [2], TIE-GCM [3], and GITM [4]. NRLMSISE-00 is an empirical density model, whereas GITM and TIE-GCM are physics based models. The models are driven using standard geophysical indices; i.e. F10.7, which is the solar flux at a wavelength of 10.7 cm at the Earth's orbit and is used as a proxy for solar output; and Kp and Ap, which indicate the severity of the magnetic disturbances in near-Earth space.

Testing Scenario

The time period chosen for this study was August 28th to September 1st 2009; i.e. during solar minimum. At solar minimum the impact of the solar input parameters on the models is relatively small, and thus other internal and external dynamics dominate the evolution of the ionosphere-thermosphere densities. This particular time period was chosen since it included a geomagnetic storm which took place on August 30th, when the Ap reached a high of 67. The performance of each model was compared against the derived density fields obtained from CHAMP [5]. The models were run with a 30 minute time step and the observational data from the CHAMP satellite was restricted to the closest matching time for comparison.

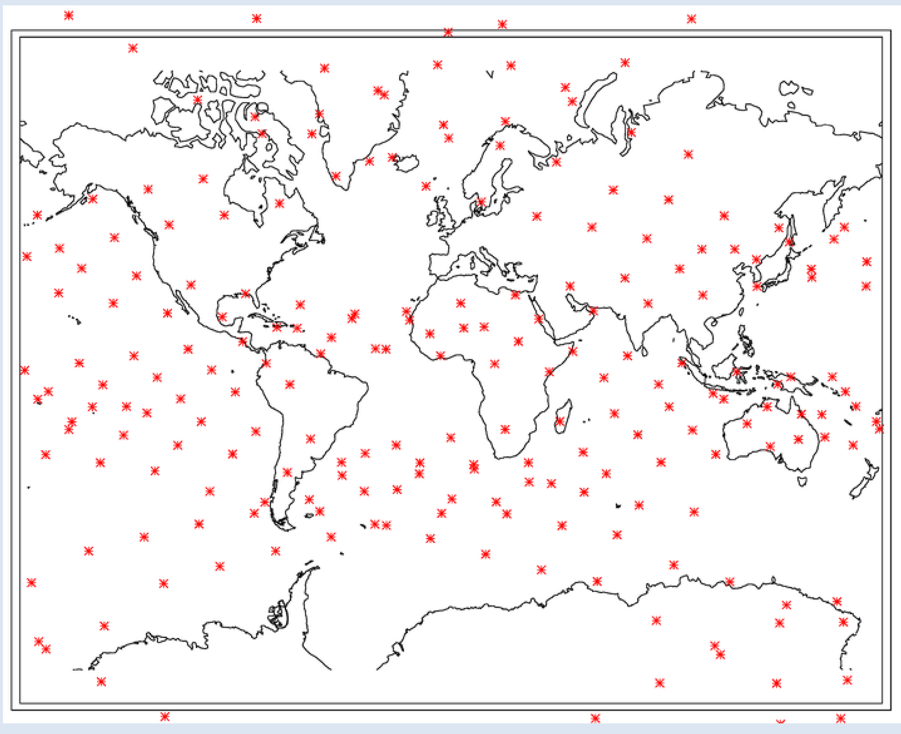

Figure 1: Reported CHAMP positions.

Methodology

Multi-model ensembles (MMEs) are widely used in atmospheric and climate modelling. There are a number of difficulties in constructing a MME; not least that observational data is often not available for all the model parameters, thus making it difficult to assess model performance. One way to resolve this problem is to not take model performance into account and use an equally weighted average. Such methods have been shown to increase model skill [6].

An equally weighted MME has been constructed from NRLMSISE-00, TIE-GCM and GITM results (green line in top panel of Figure 2). The MME has then been used, every six hours, to provide the initial conditions for forecast runs of TIE-GCM.

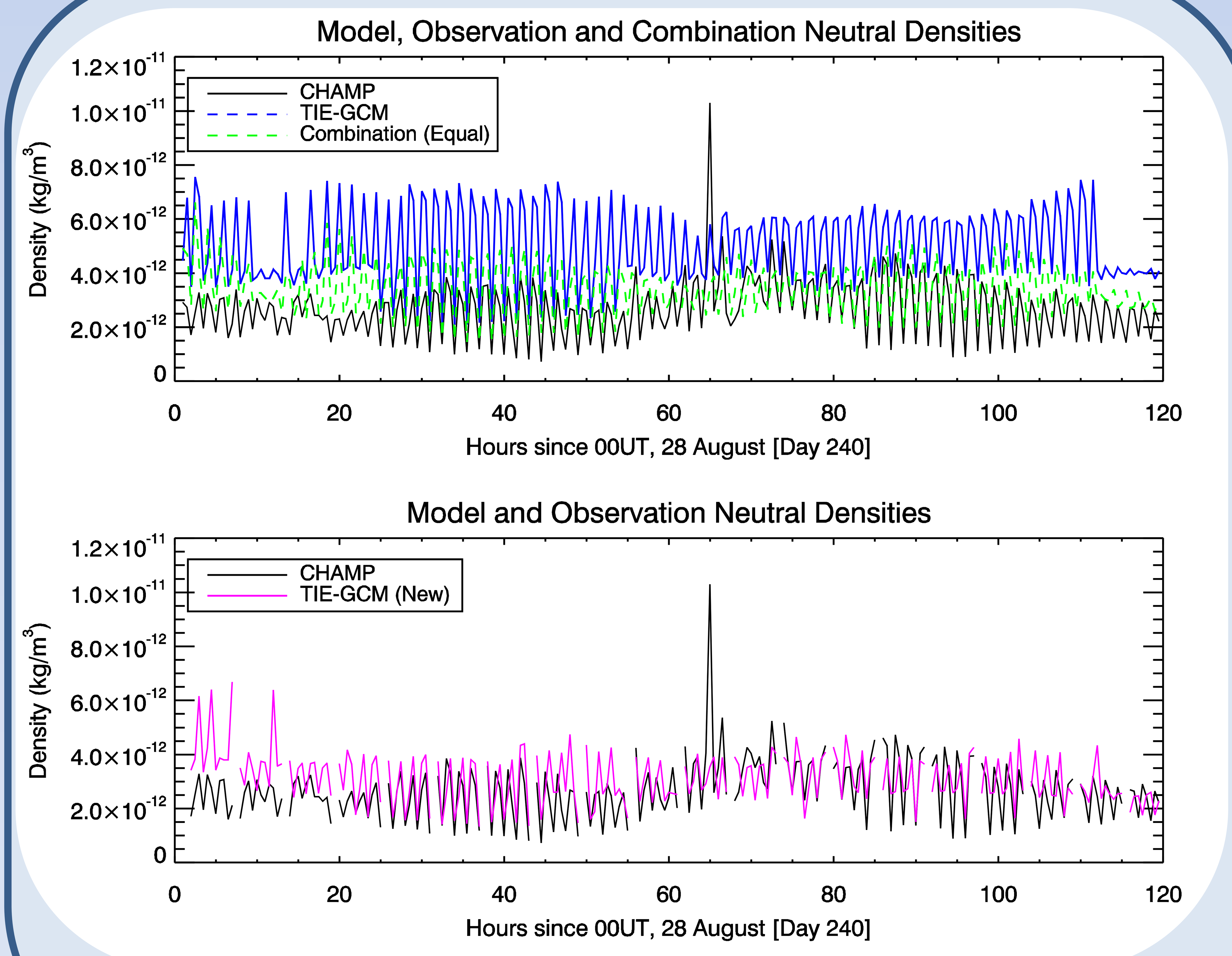

Figure 2: Top panel shows the neutral density from the CHAMP observations, from the original TIE-GCM run and the equal combination MME. The bottom panel shows the CHAMP observations and the forecast TIE-GCM output, using the MME as the initial condition every six hours.

Results & Discussion

The top panel of Figure 2 shows the standard TIE-GCM run (blue), the observation from CHAMP (black), and the equally weighted MME (green). The bottom panel shows the observation from CHAMP (black) and the forecast TIE-GCM run, using the MME to provide the initial conditions (purple).

The forecast TIE-GCM run (using the MME as the initial conditions every six hours) provides a clear improvement in RMS error compared to the standard run of TIE-GCM. Initially the forecast run is well above the observation, caused by the GITM 'spin up' time, along with the already large TIE-GCM and NRLMSISE-00 values. After ~20 hours this settles and, in particular, the post-storm period is modelled very accurately. Using the MME as the initial conditions for TIE-GCM offers a 55% reduction in the RMS error compared to the initial TIE-GCM run.

Acknowledgments & References

This research was conducted as part of the 3rd Space Weather Summer School, IMPACT project, at Los Alamos National Laboratory (LANL). More information is available at www.impact.lanl.gov. LA-UR-13-26825.

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