Data Assimilation Modelling of the Thermosphere

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ABSTRACT

This paper describes the use of the Advanced Ensemble electron density (Ne) Assimilation System (AENeAS) [1] in nowcasting and forecasting the thermosphere. AENeAS is a physics-based data assimilation model of the coupled ionosphere-thermosphere system. The model can assimilate electron density true height profiles from ionosondes, total electron content measurements from global navigation satellite system receivers, radio occultation observations and derived neutral densities from satellite accelerometers using the local ensemble transform Kalman filter (LETKF).

Forecasting the neutral density within the thermosphere has become useful for predicting the orbit of Low Earth Orbit (LEO) satellites. As more spacecraft are launched LEO is becoming increasingly populated. Knowledge of the thermosphere enables better predictions of where spacecrafts and debris will be enabling better collision prevention. Orbit propagation can be used to test the total neutral densities predicted by a variety of atmospheric models. This study uses the propagator Orekit running with the empirical models NRLMSISE-00 and DTM 2000 and a simple exponential description of the atmosphere to test the reliance on the model atmosphere.

In the future this study will be expanded by including the neutral density output from AENeAS.

1 INTRODUCTION

Low Earth Orbit (LEO) is becoming increasingly populated with spacecraft and debris. For efficient collision mitigation the location of these objects needs to be tracked and their future positions calculated using orbit propagation. Several different forms of propagation exist. For satellites in LEO the largest uncertainty in orbit prediction arises from the drag felt by the spacecraft as it moves through the thermosphere. This drag force is proportional to the thermospheric density. Therefore, to accurately model a spacecraft trajectory it is crucial to know the state of the thermosphere.

This study looks at the effect of using different atmospheric models with the orbit propagator Orekit [2]. To perform the comparisons positional data from Swarm-A has been used. Swarm [3] is a trio of satellites launched by ESA to map the Earth's magnetic field. All three are in near polar orbit. Swarm-A has an inclination of 87.35 degrees and had an initial altitude of 462 km. The three satellites are fitted with Global Navigation Satellite System (GNSS) receivers enabling their location to be accurately tracked.

2 MODELS

To calculate the orbit propagation caused by atmospheric drag an estimation of the neutral density is needed. This can be provided by a model of the upper atmosphere. Traditionally empirical models have been used. These can provide an accurate global average of thermospheric conditions. Physics-based data assimilation models provide the potential of improving the spatial resolution provided by these predictions. Such physics-based data assimilation models require large amounts of computational power preventing their operational uses before. The models tested in this study are described below.

- Simple exponential atmosphere - models the atmosphere as an exponential decrease in density as altitude increases.
- NRLMSISE-00 - is an empirical model which calculates the neutral atmosphere from the surface to the lower exosphere [4].
- DTM-2000 - a semi-empirical model describing the temperature, density and composition of the Earth's atmosphere [5].
- AENeAS - The Advanced Ensemble electron density (Ne) Assimilation System is a physics-based data assimilation model of the coupled ionosphere thermosphere system [1]. This model is yet to be tested but it is hoped that it will provide a good prediction of the density and add the ability to use the satellite tracking data as an input into the assimilation to further improve the predictions.

3 RESULTS

Orekit has been run for a period of 24 hours on 4th September 2019. This is a day of low solar activity with a mean DST index of -19. To start the propagation Orekit has been given the initial position and velocity of Swarm-A. This is then propagated forward for 24 hours using

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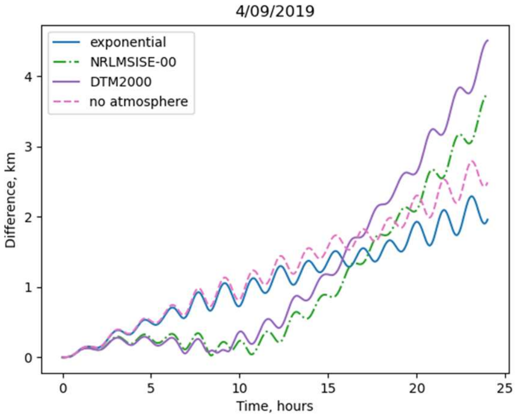

Figure 2 The orbit of the Swarm satellite has been propagated for 24 hours on the 4th September 2019 using Orekit for three of the models in this study and without an atmospheric perturbation for comparison.

numerical propagation. The position predicted has been compared to the satellites recorded position, the difference between these two points has been plotted in Fig 1. For the first 15 hours the performance of the propagation run with the empirical models NRLMSISE-00 and DTM2000 show a greater agreement to the recorded position than the simpler exponential model or running without atmospheric perturbation. After this the agreement diverges and by 20 hours the difference is larger than when no atmospheric perturbation is applied to the propagation.

3.1 Satellite Frame

Fig 1 plots the Euclidean distance between propagation and recorded positions. To extract the direction of this difference it has been converted into the satellite centred radial, cross-track, in-track (RCI) frame. This frame is described in Fig 2. This transformation has been performed for each of the four propagations shown in Fig 1. The results of this are shown in Fig 3. In all cases the largest difference is seen in the in-track direction.

4 CONCLUSION

This preliminary study shows that the atmospheric model used in orbit propagation influences the accuracy of the prediction. Fig 1 shows that the addition of an empirical model to provide thermospheric density estimates can improve an orbit prediction. Fig 3 shows these differences split into RCI-frame with the largest difference seen in the in-track direction meaning the predicted position is too far ahead or behind. For the two empirical models NRLMSISE-00 and DTM2000 at approximately 10 hours the satellite's predicted position moves from being behind the recorded to in front. From around this time the position starts to deviate steeply. Beyond 15 hours this divergence causes the estimation to become less accurate than that performed with a simple exponential atmosphere.

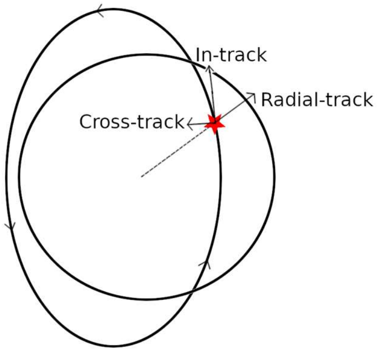

Figure 1 The radial, in-track, cross-track frame is a satellite centred frame. Where the axes are orientated with respect to the satellite's motion.

The next step for this study is to create an interface between Orekit and the data assimilation model AENeAS. This will test the difference between using an empirical and physics-based data assimilation models.

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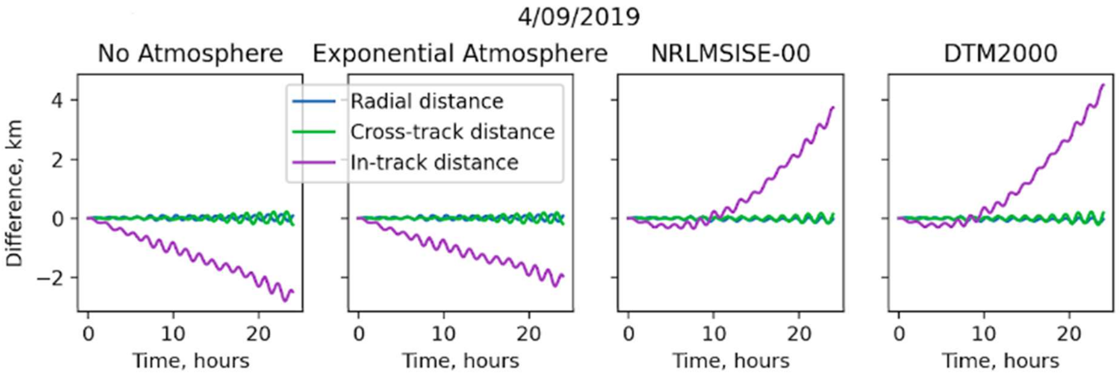

Figure 3 The propagation seen in Figure 2 has been split into radial, in-track and cross track components. The largest difference is seen in the in-track direction.