CHAMP, GRACE, GOCE and Swarm Thermosphere Density Data with Improved Aerodynamic and Geometry Modelling

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CHAMP, GRACE, GOCE and Swarm thermosphere density data with improved aerodynamic and geometry modelling

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Introduction

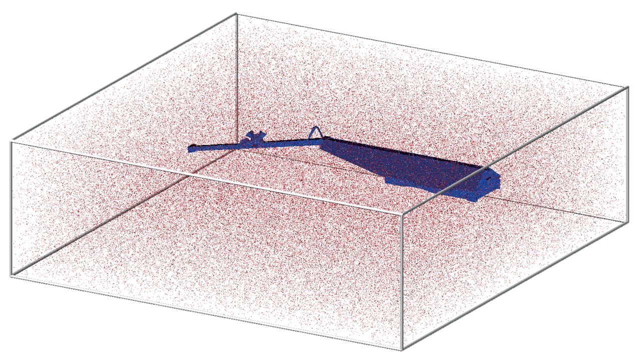
Since 2000, accelerometers on board of the CHAMP, GRACE, GOCE and Swarm satellites have provided high-resolution thermosphere density data, improving knowledge on atmospheric dynamics and coupling processes in the thermosphere-ionosphere layer.

Most of the research has focused on relative changes in density. Scale differences between datasets and models have been largely neglected or removed using ad hoc scale factors. The origin of these variations arises from errors in the aerodynamic modelling, specifically in the modelling of the satellite outer surface geometry and of the gas-surface interactions. Therefore, in order to further improve density datasets and models that rely on these datasets, and in order to make them align with each other in terms of the absolute scale of the density, it is first required to enhance the geometry modelling. Once accurate geometric models of the satellites are available, it will be possible to enhance the characterization of the gas-surface interactions and the satellite aerodynamic modelling.

Methodology

Through detailed high fidelity 3-D CAD models and Direct Simulation Monte Carlo (DSMC) computations, flow shadowing and complex concave geometries can be investigated. This was not possible with previous panels method, especially because of the low fidelity geometries and the inability to model shadowing effects. The panel method consists of the application of Sentman's equations to a simplified geometry model. A number of flat panels describe the entire structure of the satellite. Normal vectors and areas of each panel give the fundamental information needed to retrieve aerodynamic coefficients. This geometry and aerodynamic modelling turned out to have a large influence on derived densities, particularly for satellites with complex elongated shapes and protruding instruments and beams.

The geometry and aerodynamic modelling have been enhanced with the DSMC approach and the accelerometer data have been reprocessed leading to higher fidelity density estimates. In particular, the *Stochastic PArallel Rarefied-gas Time-accurate Analyzer* (SPARTA) simulator from SANDIA Laboratories has been used for the aerodynamic modelling. The collisions between atmospheric particles and satellite outer surfaces are simulated within a fixed domain. Pressures and shear stresses associated to each surface element are computed and processed to retrieve force coefficients.



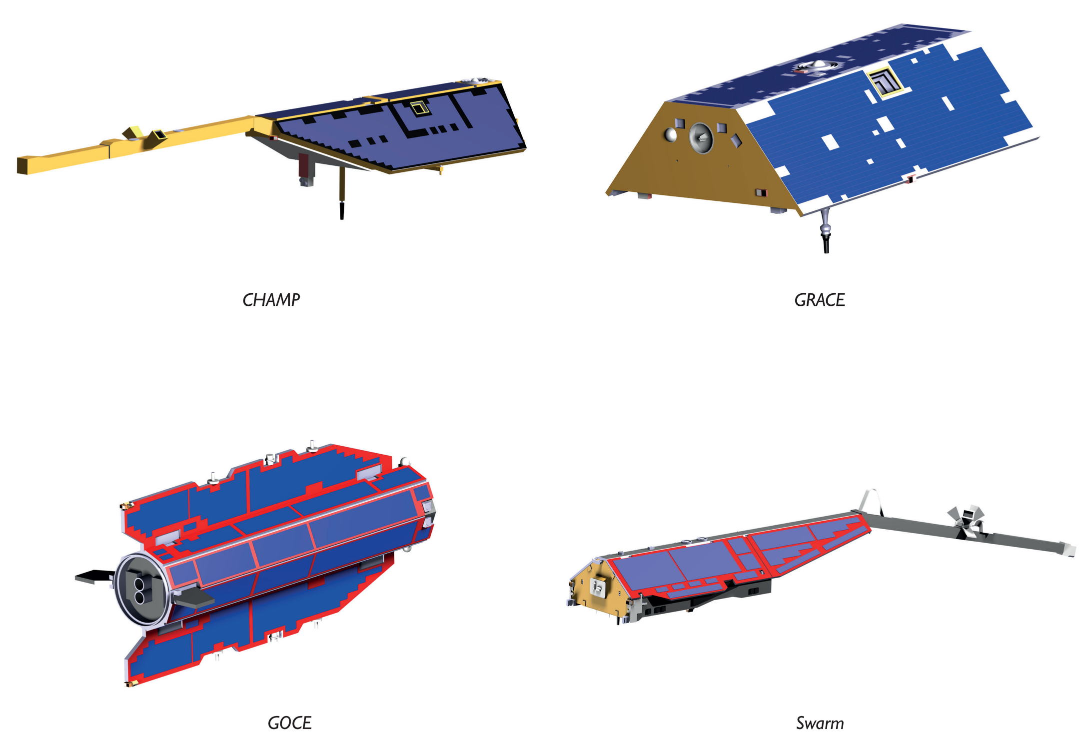
Representation of the SPARTA simulation domain for Swarm satellite.

Aerodynamic datasets from this processing are obtained as output. Afterwards, these datasets are processed by the *Near Real-Time Density Model* (NRTDM) developped by Doornbos at TU Delft. Accelerometer data have been processed with Panels and SPARTA methods. The results are provided in the following sections.

Geometry Modelling

In order to improve previous panel geometries for CHAMP, GRACE, GOCE and Swarm, new geometries have been designed with *CATIA V5 R21*.

These geometries have been the inputs for SPARTA DSMC simulations. Several attitude configurations have been simulated in order to describe all the possible flight configurations during mission lifetime.



Satellite geometry models designed with *CATIA V5 R21*.

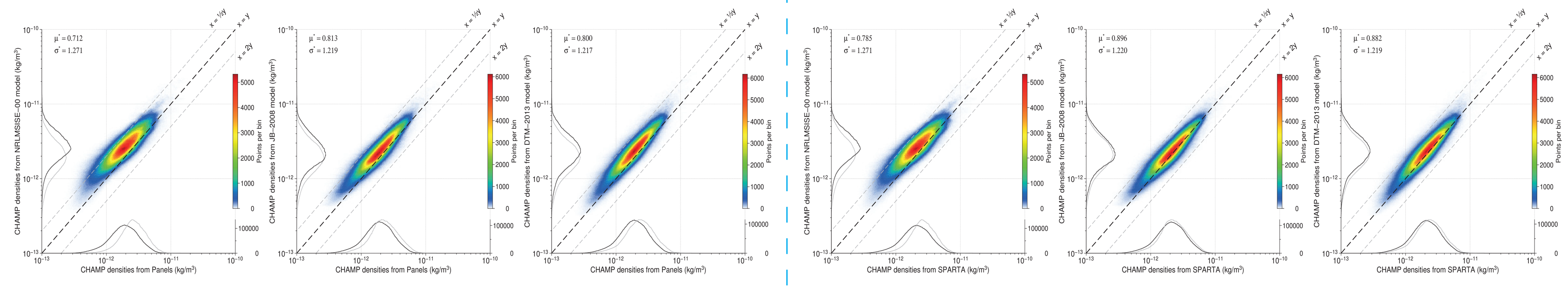
For panels and SPARTA results, which are provided in the following section, a fully diffusive energy accommodation coefficient and a wall temperature of 400 K have been adopted.

Satellite Density Data Improvements

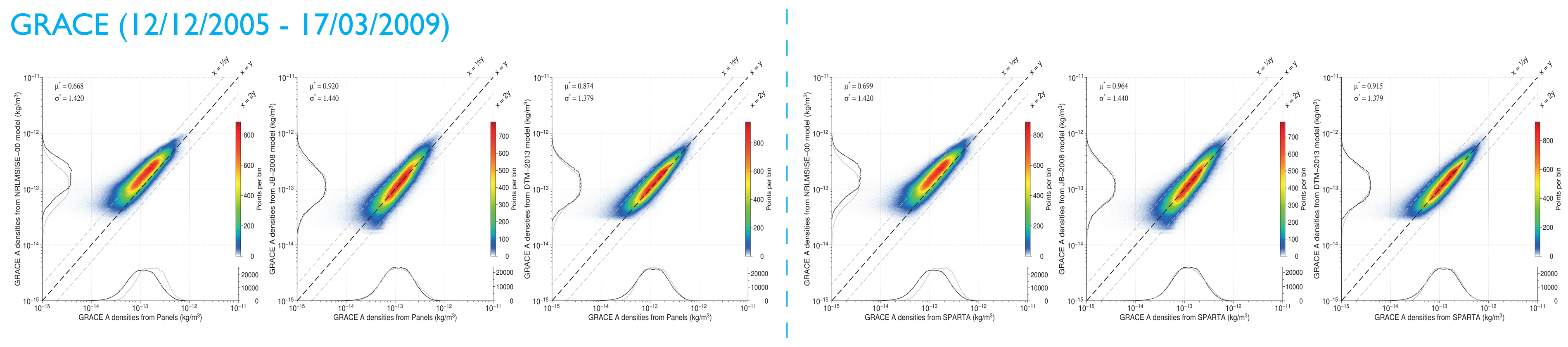
Within this section, the densities obtained with Panels and SPARTA aerodynamic models have been compared with three atmospheric models (NRLMSISE-00, JB-2008 and DTM-2013). The results are available for CHAMP, GRACE, GOCE and Swarm missions for some specific periods which are listed below.

Panels	SPARTA

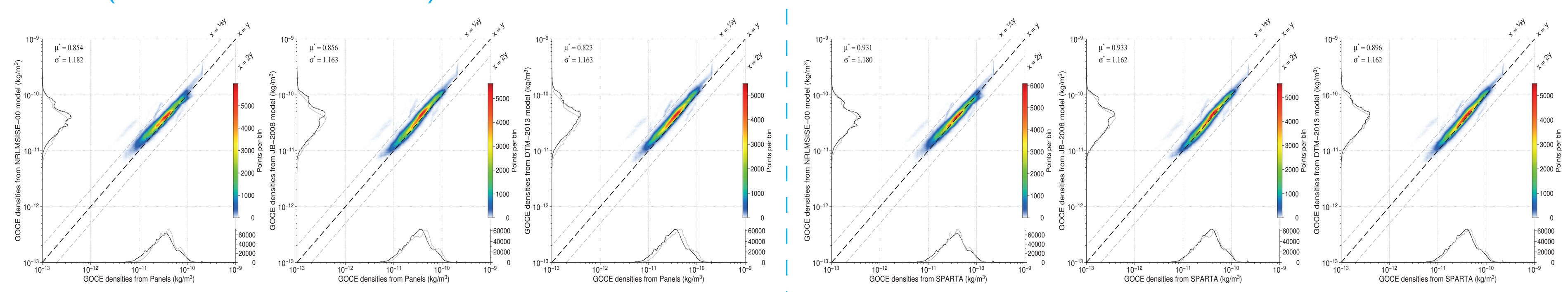
CHAMP (07/11/2002 - 31/12/2008)



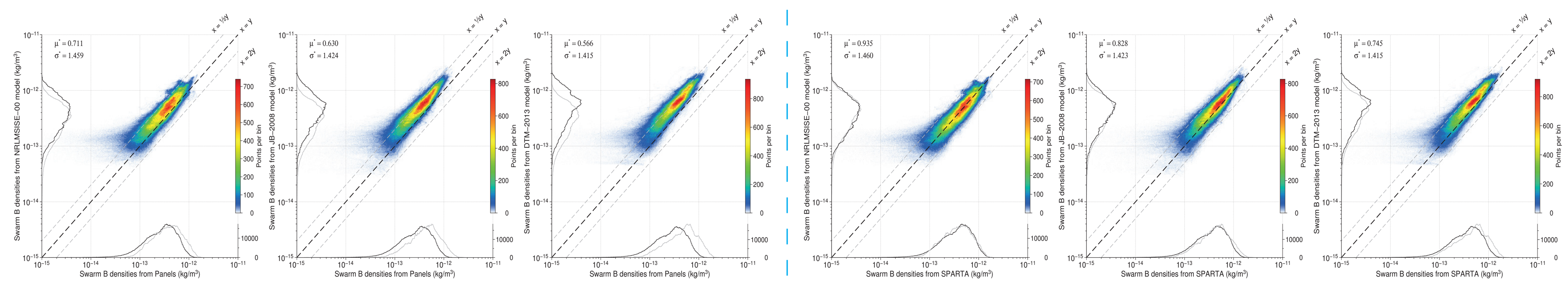
GRACE (12/12/2005 - 17/03/2009)



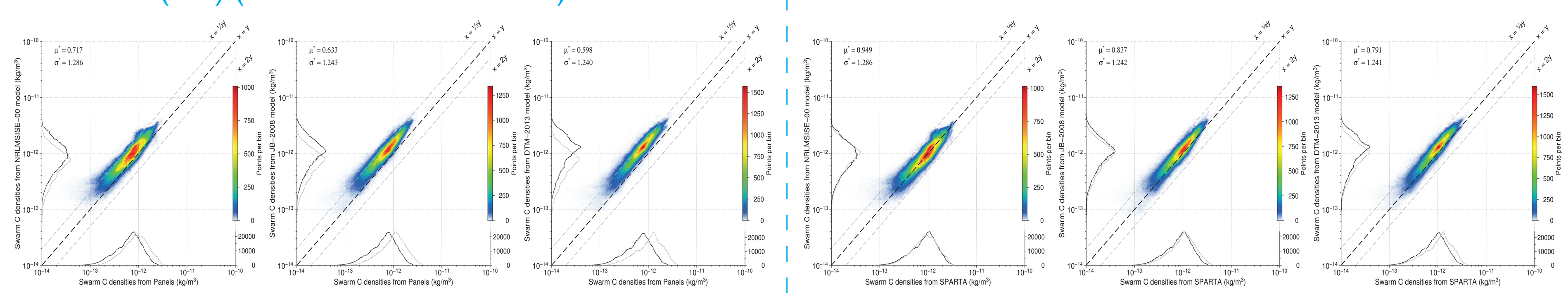
GOCE (01/11/2009 - 05/11/2013)



SWARM-B (19/07/2014 - 30/09/2016)



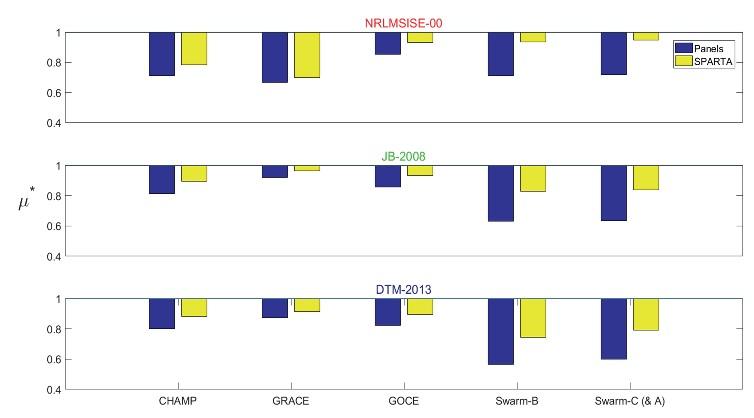
SWARM-C (& A) (19/07/2014 - 30/09/2016)



Results and Future Work

A general improvement can be found comparing the mean ratio (μ^*) between Panels and SPARTA models with the atmospheric models. New densities turned out to be higher, reaching a mean +11% for CHAMP, +5% for GRACE, +9% for GOCE and +32% for Swarm.

In the next months, further research is aimed at estimating Gas-Surface-Interactions (GSI) parameters and their influences on the thermospheric density datasets.



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- M.A. Gallis, J. R. Torczynski, S. J. Plimpton, D. J. Rader and T. Koehler, ***Direct Simulation Monte Carlo: The Quest for Speed***, Proceedings of the 29th Rarefied Gas Dynamics Symposium, Xi'an, China, July 2014.

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TU Delft

NWO Netherlands Organisation for Scientific Research