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Development of an operational prototype for the determination of the thermospheric density on the basis of a thermosphere-ionosphere coupling model (TIK)

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1. Introduction

With respect to the determination and propagation of the trajectories of LEO satellites or debris, the thermospheric drag is of particular importance, since it is the most important deceleration effect at that altitudes in the equation of motion. Today, the calculation of the thermospheric drag is usually carried out by empirical thermosphere models such as the Jacchia-Bowman model (JB2008), the NRLMSISE model or the Drag Temperature Model (DTM2013). The project TIK will analyse and apply the relation between the thermosphere and the ionosphere to improve the estimation of both the neutral and the electron density using the inherent coupling. TIK will also introduce the use of data assimilation techniques using physical models which utilize the coupling between the thermosphere and the ionosphere (TI).

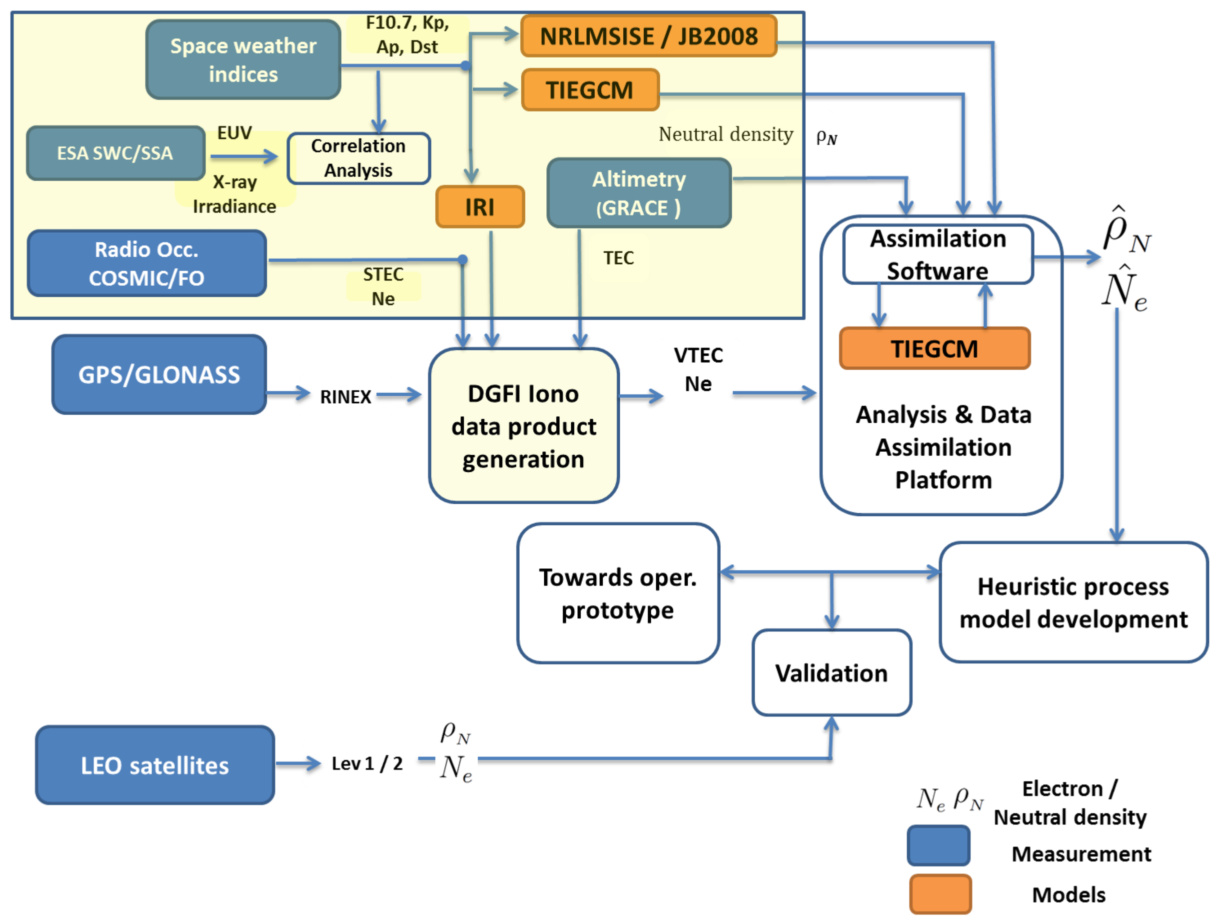
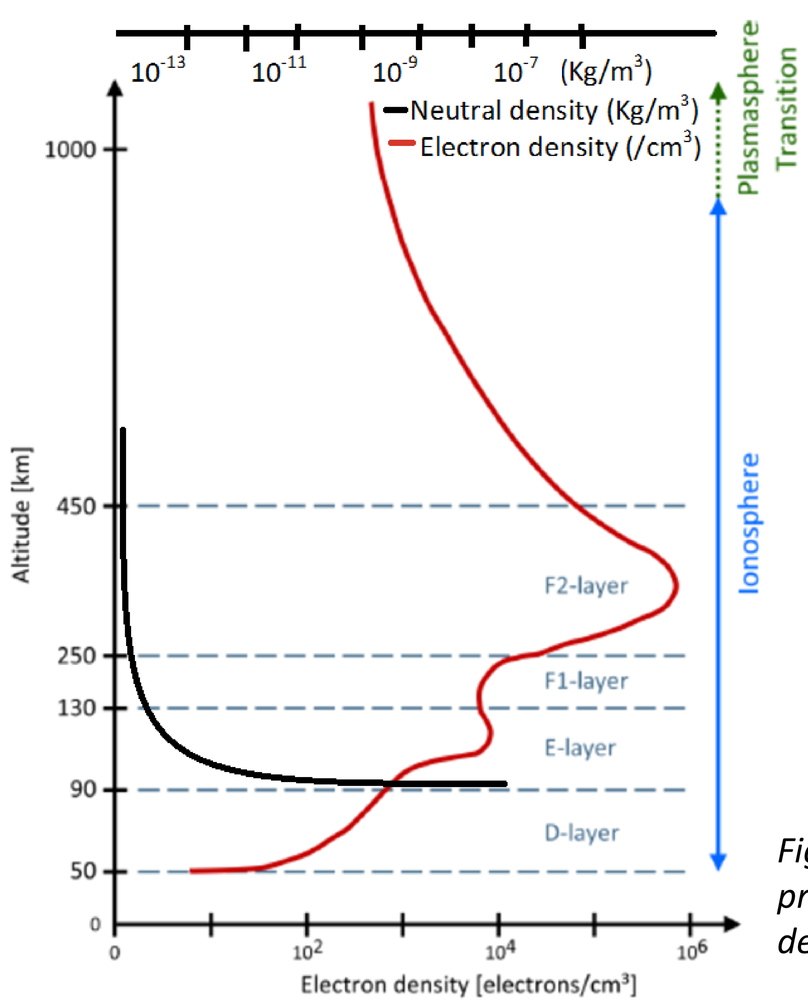


Figure 1: The data flow within TIK towards the development of an operational prototype by means of satellite measurements and other models



- Figure 3 shows the height dependency of the electron density and neutral density within the thermosphere -ionosphere
- In the ionosphere, different layers have to be considered for parameterization. The neutral density profile shows an exponential decay
- For the electron density modelling, a multi-layer Chapman profile approach will be used within TIK:

$$N_e(h) = N_e^D(h, N_m^D, h_m^D, H^D) + N_e^E(h, N_m^E, h_m^E, H^E) + N_e^{F1}(h, N_m^{F1}, h_m^{F1}, H^{F1}) + N_e^{F2}(h, N_m^{F2}, h_m^{F2}, H^{F2}) + N_e^P(h, N_0^P, H^P)$$

Figure 3: Representation of a typical electron density profile and the ionosphere layers along with the neutral density profile in the thermosphere

2. Accelerometer and thermosphere models

- Goal: representation of the thermospheric density as a function of the ionospheric electron density
- Accelerometer measurements on-board low-Earth orbit satellites are directly related to the atmospheric drag acting on the satellite
- Calibration of the accelerometer data and improved modeling of the radiation pressure of the Sun and the Earth or the drag coefficient
- The empirical thermosphere models provide rather different values during strong solar activity. Coupled TI processes have to be considered

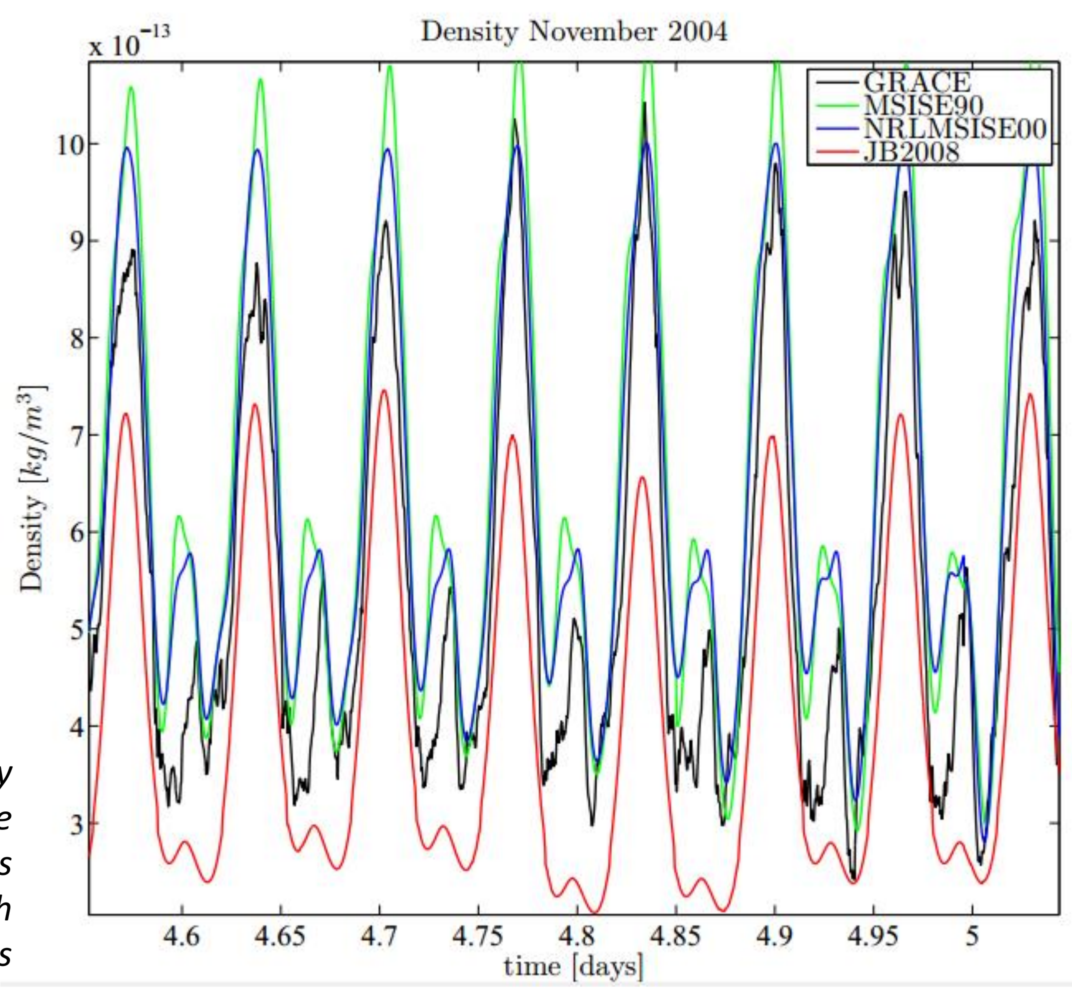


Figure 2: Neutral density measured along track of the satellite by accelerometers and comparison with thermosphere model values

3. Electron density modelling – parameterization

- As shown in Fig. 3 the ionosphere can be split into 5 **layers**, namely the *D*, *E*, F_1, F_2 layers and the plasmasphere P
- 14 **key parameters** (altogether 5 peak densities, 4 peak heights and 5 scale height parameters) have to be modelled and estimated from the observations [Liang (2017)].

$$\mathcal{K} = \{N_m^D, h_m^D, H^D, N_m^E, h_m^E, H^E, N_m^{F_1}, h_m^{F_1}, H^{F_1}, N_m^{F_2}, h_m^{F_2}, H^{F_2}, N_0^P, H^P\} = \{\kappa_1, \kappa_2, \ldots, \kappa_r, \ldots, \kappa_R\}$$

- We choose **B-Spline series expansion** for each key parameters, e.g. for the F_2 layer peak height parameter $h_m^{F_2}$ as

$$h_m^{F_2}(\varphi, \lambda, t) = \sum_{k_1=0}^{K_{J_1}-1} \sum_{k_2=0}^{K_{J_2}-1} d_{k_1,k_2}^{J_1,J_2}(t)\, N_{J_1,k_1}^2(\varphi)\, T_{J_2,k_2}^2(\lambda)$$

- For each key parameter κ_r a series expansion in terms of 2-D tensor products of the **polynomial B-splines** $N_{J_1,k_1}^2(\varphi)$ and **trigonometric B-splines** $T_{J_2,k_2}^2(\lambda)$ with level values J_1, J_2 and shift values k_1, k_2. The quantities $d_{k_1,k_2}^{J_1,J_2}(t)$ represent the time-dependent B spline coefficients.
- The **B-spline levels** J_1, J_2 can be chosen for each key parameter individually (depending e.g. on the spatial variability).

4. Data Assimilation – electron density and physics-based model

- The **initial state vector** of the TI system, containing the parameters of interest, namely the neutral, the ion and the electron density
- **Ensemble Kalman filtering** will be used for assimilating the high precision electron density model derived before into the physics-based model
- Development of a **heuristic model** of the thermospheric drag as a function of the electron density
- Development towards an **operational prototype** of the thermospheric density prediction for given conditions of space weather.

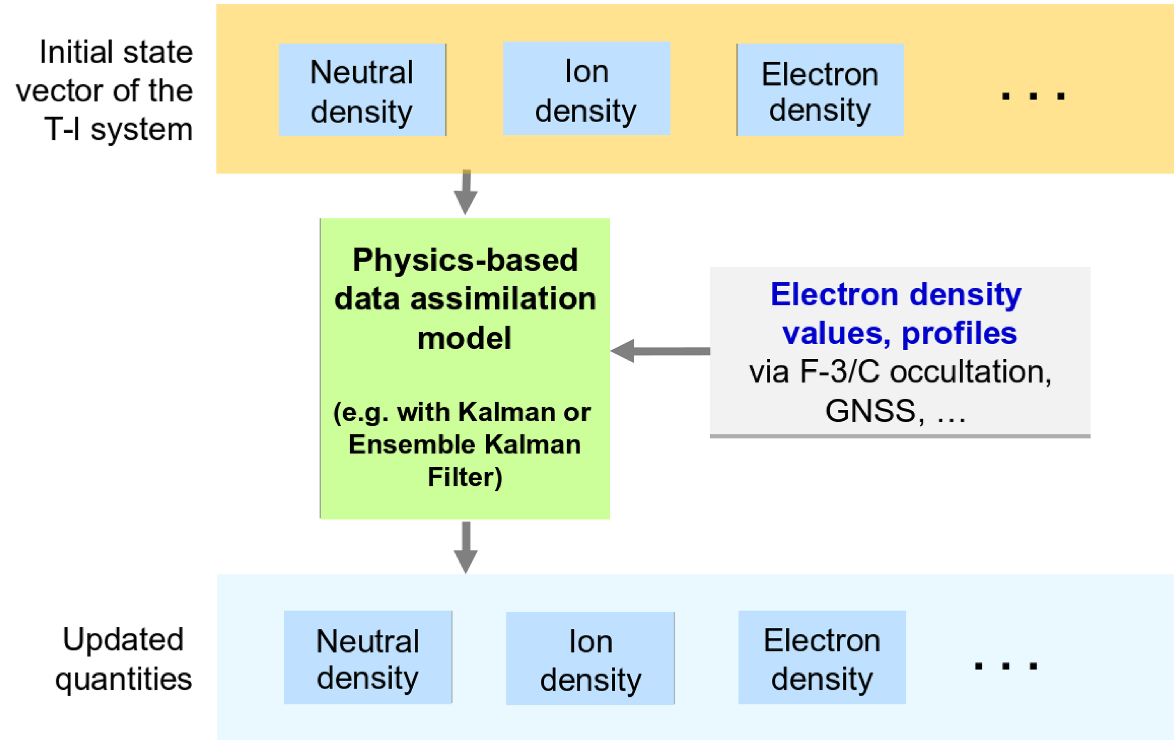


Figure 4: Data assimilation approach using the electron density model and the physics-based TI model

5. Summary of project goals

1. Development of a **global spatio-temporal model** to describe the **electron density** of the ionosphere and the plasmasphere
2. Development of a physical assimilation model to compute thermospheric densities using the data from the global electron density model
3. **Correlation analysis** to relate the thermospheric density to the electron density
4. Development of a **heuristic / empirical model** to describe the thermospheric density as a function of the electron density

Acknowledgements

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