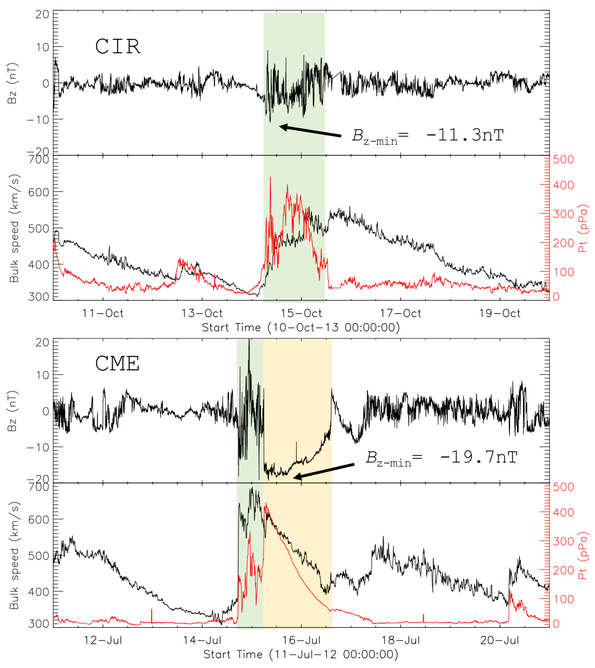
SODA, an ESA-SWE pilot study to predict space weather effects on LEO satellites

M. Temmer[1], S. Krauss[2], L. Drescher[1], S. Kroisz[1], B. Suesser-Rechberger[2], S. Behzadpour[2], T. Mayer-Guerr[2]
[1] Institute of Physics, University of Graz, [2] Institute of Geodesy, Graz University of Technology

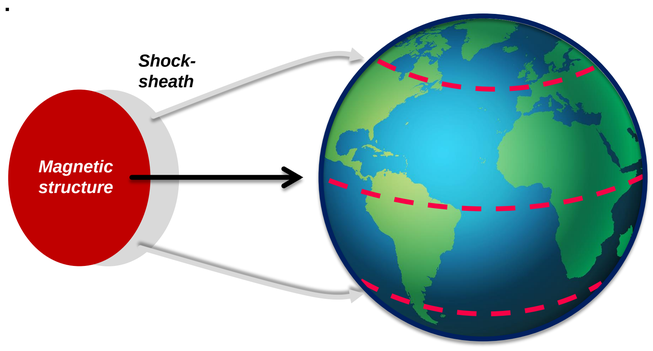
Introduction

- Geomagnetic storms have the capability to trigger atmospheric disturbances and subsequently influence the trajectories of Earth orbiting satellites.
- The key element of SODA (Satellite Orbit DecAy) is to develop a forecasting model to predict the expected impact of solar events on satellite missions like Swarm or GRACE-FO.
- Thermospheric densities are estimated based on scientific data, such as kinematic orbit information or accelerometer measurements.
- SODA is based on a joint analysis and evaluation of solar wind plasma and magnetic field measurements at L1 from the ACE and DSCOVR satellites as well as thermospheric neutral mass densities.
- By taking into account the varying propagation speeds of CME's and the response time of the thermosphere, the lead time for the expected maximum orbit decay will be up to one day.

In-situ measurements and the impact at Earth



- Geomagnetic effects are related to the B_z component of magnetic field structures (CME, CIR/SIR) and variations.
- Compression regions from SIR/CIRs and the shock-sheath component of a CME (green shaded areas) cause similar (weak) effects in the thermospheric density enhancements.
- The strong magnetic field in the flux rope causes major geomagnetic effects.
- Cascade of reactions in the magnetosphere (substorms), ionosphere $\left(\frac{dB_z}{dt}\right)$, thermosphere (satellite drag), GIC, …
- Differences in the magnetospheric response between ICMEs and shock-sheath regions (e.g., [2],[3]).

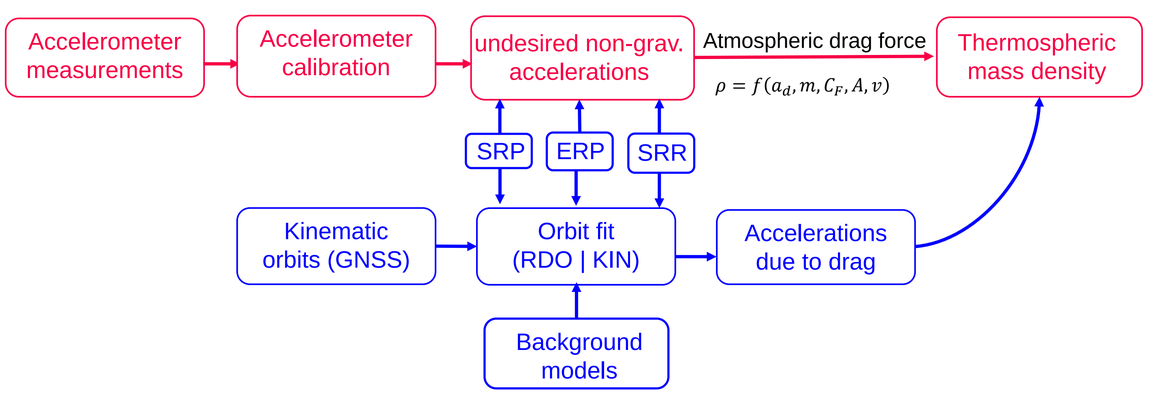


- Shock-sheath at polar regions, magnetic flux rope has increased effects at equatorial regions; CME and CIR-driven storms different [1].

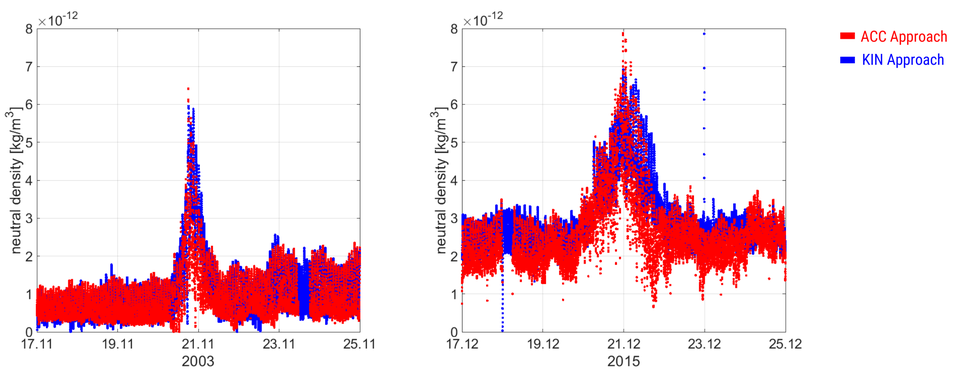
Neutral mass density estimation

Two approaches were implemented for the density estimation process

- ACC: Based on accelerometer observations suitable for the satellite missions CHAMP, GRACE, GRACE-FO1.
- KIN: Based on kinematic orbit information, applicable for satellites equipped on-board GNSS receivers [6].



Process flow for neutral mass density estimation [5,7].



Comparison between the density solutions based on ACC and KIN approach for GRACE at the beginning (left) and end of the mission (right) lifetime.

SODA service – storm induced orbit decay

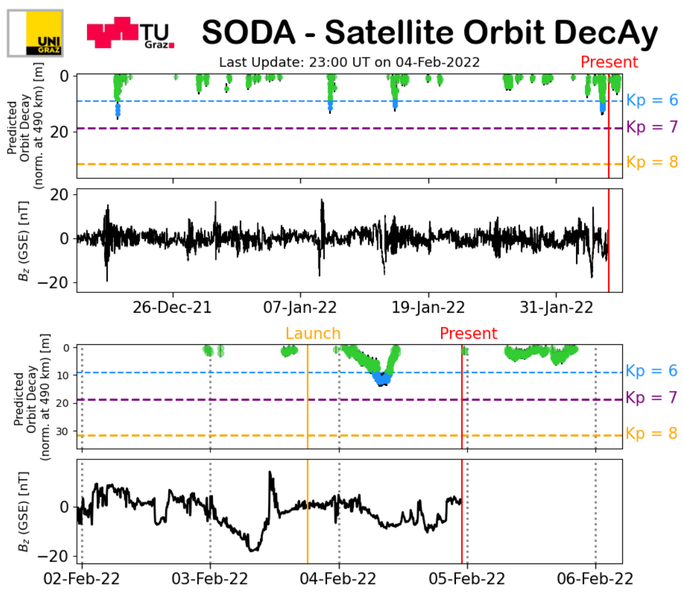
Storm induced orbit decay is expressed by the time derivative of the semi-major axis a [5].

$$\frac{da}{dt} = -\Delta\rho \frac{C_F A}{m} \sqrt{GM\bar{a}} \cdot \psi(e)$$

density increase | ballistic coefficient | gravity parameter | mean semi-major axis | eccentricity function

Access:
https://swe.uni-graz.at/index.php/services/esa-space-safety-services

- SODA uses automatized data download and script execution for ACE and DSCOVR near-real-time data.
- SODA applies the minimum B_z relation for the orbit decay as derived in [4,5].



The plot shows the satellite orbit decay at 490 km and the Bz component measured at L1 for the past 50 days and 72 hours as well as the expected orbit decay for the next 30 hours. Period comprises the "Starlink Event" in 2022.

Summary

- SWEETS is an FFG national project (878876) under which the SODA tool was developed.
- For the next portal release, planned in autumn 2022, SODA plans to become part of the I-ESC for forecasting ionospheric disturbances.
- We currently run a validation campaign with data from TU Graz to validate our product.
- Other services from University of Graz run under S-ESC (flare and filament detection) and H-ESC (solar wind and CME propagation models) for solar and heliospheric weather warnings and predictions.

Acknowledgments

The authors acknowledge financial support by the Austrian Research Promotion Agency (FFG) in the framework of the Austrian Space Application Program (ASAP 16, Project SWEETS, 878876).

References

[1] **Borovsky** J.E. et al. (2006): Differences between CME-driven storms and CIR-driven storms. *J Geophysical Res: Space Physic, 111*.

[2] **Huttunen** K.E.J et al. (2005): Properties and geoeffectiveness of magnetic clouds in the rising, maximum and early declining phases of solar cycle 23. *Ann Geophys, 23*.

[3] **Kilpua** K.E.J. et al. (2017): Coronal mass ejections and their sheath regions in interplanetary space, *Living Reviews in Solar Physics, 14*.

[4] **Krauss**, S. et al.(2018): Multiple satellite analysis of the Earth's thermosphere and interplanetary magnetic field variations due to ICME/CIR events during 2003–2015. *J Geophysical Res: Space Physics, 123*.

[5] **Krauss**, S. et al. (2020): Exploring thermospheric variations triggered by severe geomagnetic storm on 26 August 2018 using GRACE Follow-On data. *J Geophysical Res: Space Physics, 125.*

[6] **Suesser-Rechberger**, B. et al. (2022): Improved precise kinematic LEO orbits based on the raw observation approach, *ASR, 69.*

[7] **Vielberg**, K., & **Kusche**, J. (2020): Extended forward and inverse modeling of radiation pressure accelerations for LEO satellites. *J of Geodesy, 94.*

Contact

Manuela Temmer
manuela.temmer[at]uni-graz.at
Sandro Krauss
sandro.krauss[at]tugraz.at

SWEETS SODA

Living Planet Symposium, 23-27 May 2022, Bonn, Germany