Thermospheric densities for the Swarm satellite mission

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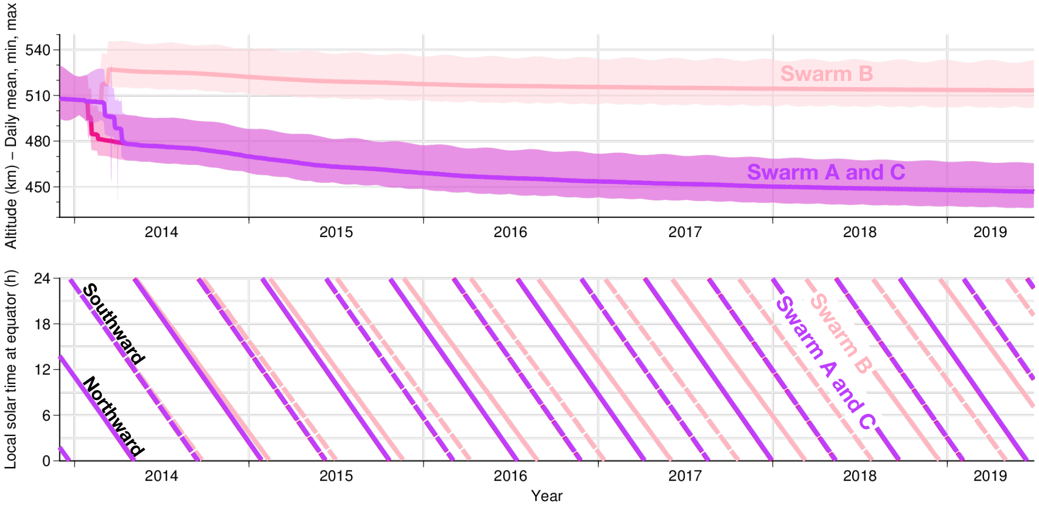
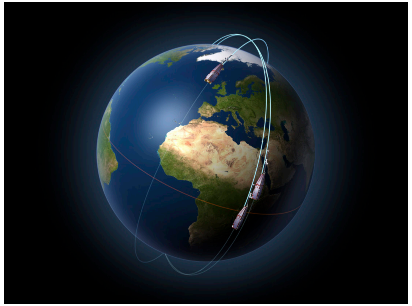
The Swarm mission – orbit

The Swarm mission consists of 3 identical satellites in near polar low Earth orbits and therefore can deliver highly valuable thermospheric density information.



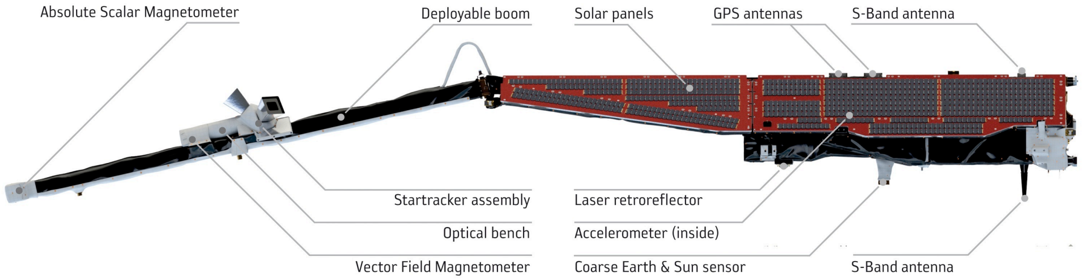
Evolution of the Swarm satellite orbits in altitude and local time



The Swarm constellation:
- a side-by-side lower pair (A & C)
- a higher flying satellite (B)

The Swarm mission - payload

- The Swarm satellite payload includes an **accelerometer** and **GPS** receiver for thermospheric density retrieval
- The Swarm accelerometers have issues, but the GPS data have high quality
- Therefore an alternative GPS-based approach is implemented to derive:
    - **total non-gravitational** accelerations → to correct and augment accelerometer data to derive high-resolution densities (Swarm-C only)
    - **aerodynamic** accelerations → to derive lower-resolution thermospheric densities (all Swarm satellites)



The Swarm satellite payload

Acceleration processing strategy

Total non-gravitational accelerations:

- extended Kalman filter approach with DLR/GSOC GHOST s/w
- undifferenced ionosphere-free GPS carrier phase & code observations and AIUB CODE final GPS ephemeris and 5s clocks
- state-of-the art gravitational models used
- smooth empirical accelerations recover the non-gravitational signal

Aerodynamic accelerations:

- state-of-the art models for solar radiation pressure, Earth albedo and infrared radiation (CERES)
- Swarm 15-plate macro model with surface properties for absorbed, diffusely or specular reflected radiation
- smooth empirical accelerations recover the aerodynamic signal
  → especially important during solar minimum conditions!

Van den IJssel et al, Thermosphere densities derived from Swarm GPS observations, ASR, 2020

Density processing strategy - 1

GPS+accelerometer derived densities:

- Merge accelerometer observations with GPS-derived accelerations

  Siemes et al, Swarm accelerometer data processing from raw accelerations to thermospheric neutral densities, EPS, 2016
- Substract modeled radiation pressure acceleration using panelized satellite model to derive aerodynamic accelerations

Spacecraft geometry and aerodynamic modelling:

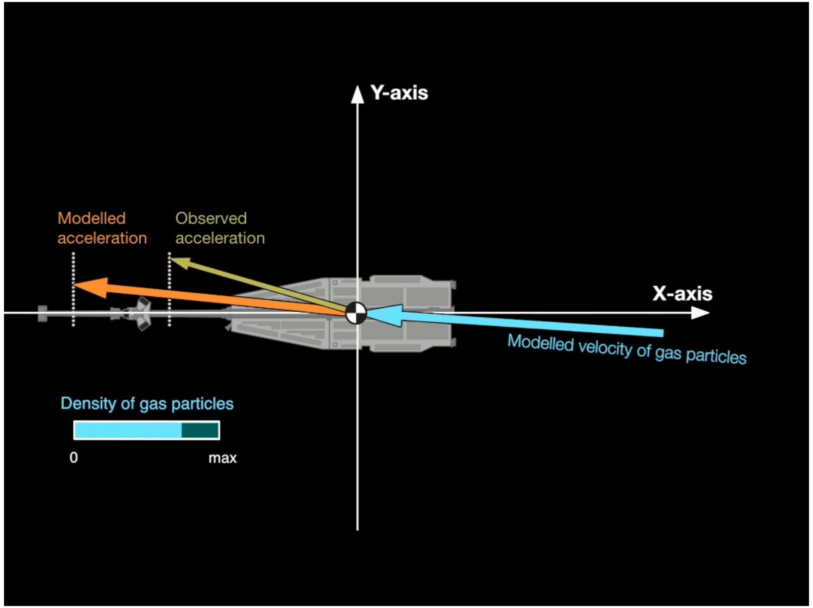
- High-fidelity satellite geometry model
- SPARTA rarefied gas-dynamic model with accommodation coefficient 0.93

March et al, High-fidelity geometry models for improving the consistency of CHAMP, GRACE GOCE and Swarm thermospheric density data sets, ASR, 2019
March et al, CHAMP and GOCE thermospheric wind characterization with improved gas-surface interactions modelling, ASR, 2019

Density processing strategy - 2

Density retrieval approach:

- Calibrated accelerations in Y- and Z-direction are unavailable → no winds!



Doornbos et al, Neutral Density and Crosswind Determination from Arbitrarily Oriented Multiaxis Accelerometers on Satellites, J Spacecr Rockets, 2010

Current status of density products

GPS-derived Level 2 products (all Swarm satellites):

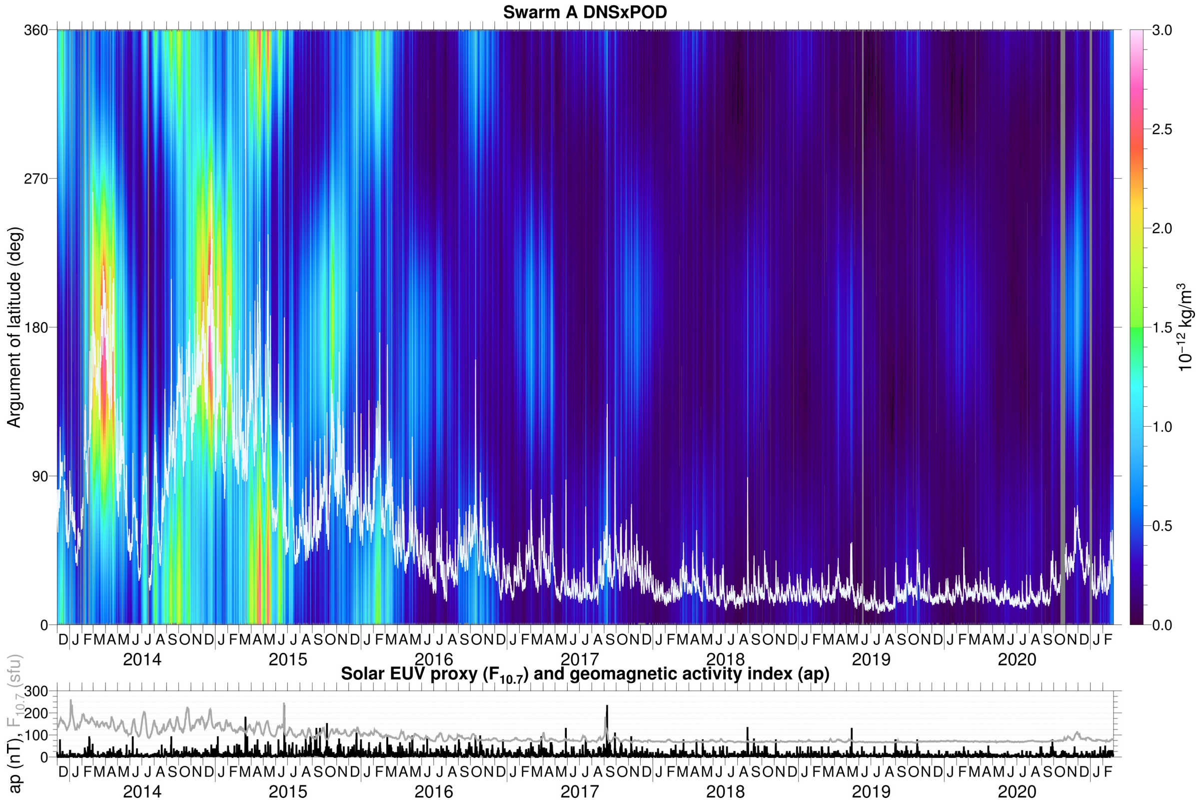
- **ACCxPOD** → total non-gravitational & aerodynamic accelerations (30 s sampling)
- **DNSxPOD** → densities & orbit mean densities (30 s sampling)
- **DNSxVAL** → quality report

Accelerometer Level 2 products (Swarm-C only):

- **ACCxCAL** → calibrated along-track accelerations (1 s sampling) (calibrated by IfE Leibniz Universität Hannover)
- **DNSxACC** → high-resolution densities (10 s sampling)
- **TDAxVAL** → quality report

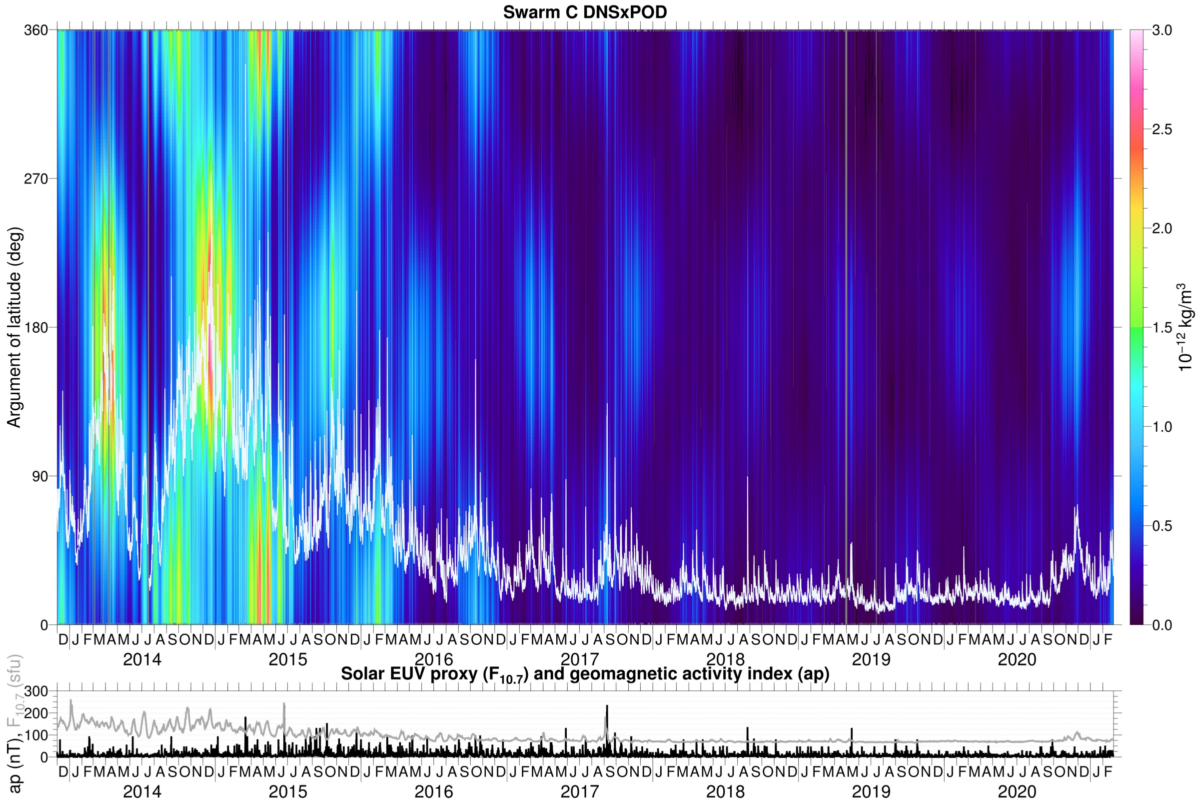
Daily 24 h products that are nominally delivered in monthly batches.

Swarm-A GPS-derived densities



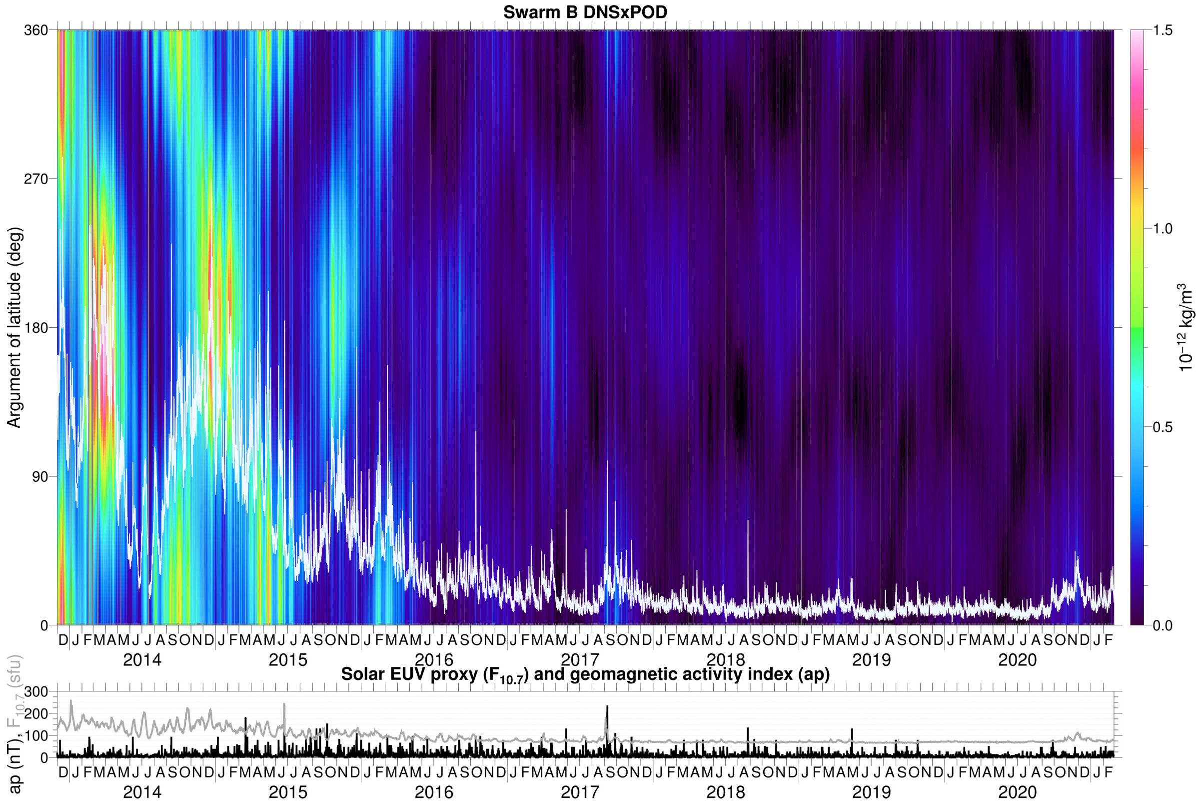
Time series of estimated density for Swarm-A (top), and solar activity proxy $F_{10.7}$ and geomagnetic index *ap* (bottom). The white line indicates the mean orbit density.

Swarm-C GPS-derived densities



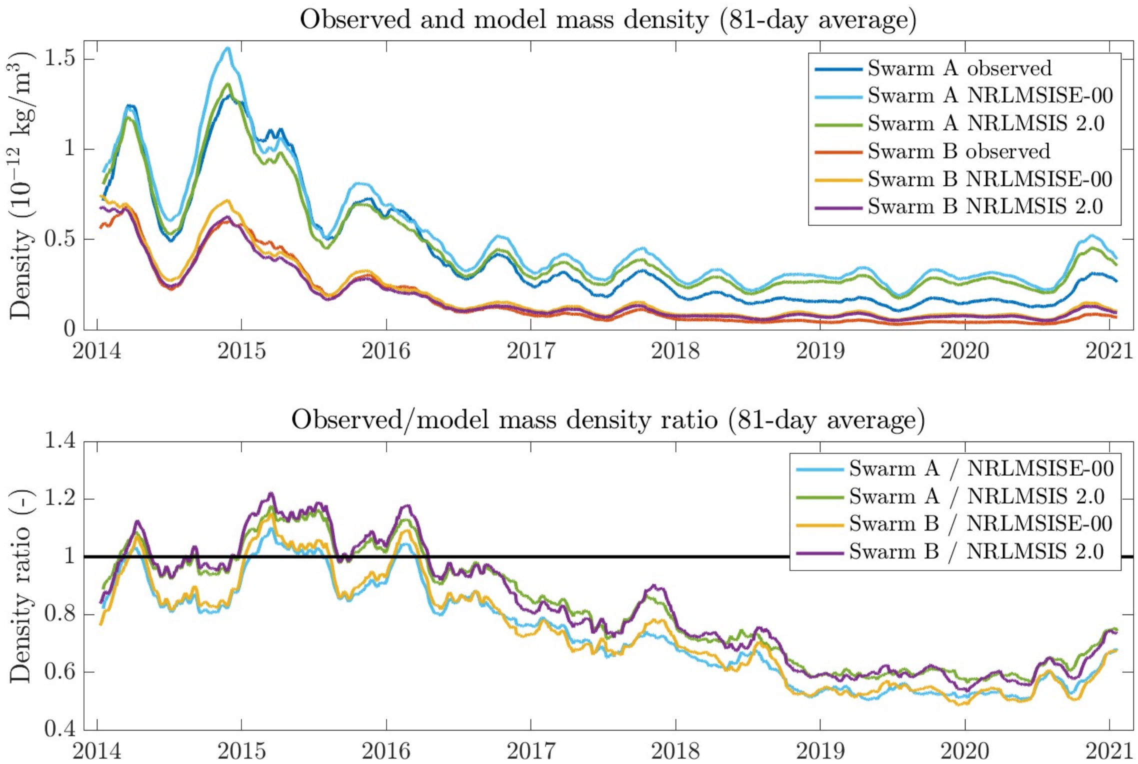
Time series of estimated density for Swarm-C (top), and solar activity proxy $F_{10.7}$ and geomagnetic index *ap* (bottom). The white line indicates the mean orbit density.

Swarm-B GPS-derived densities



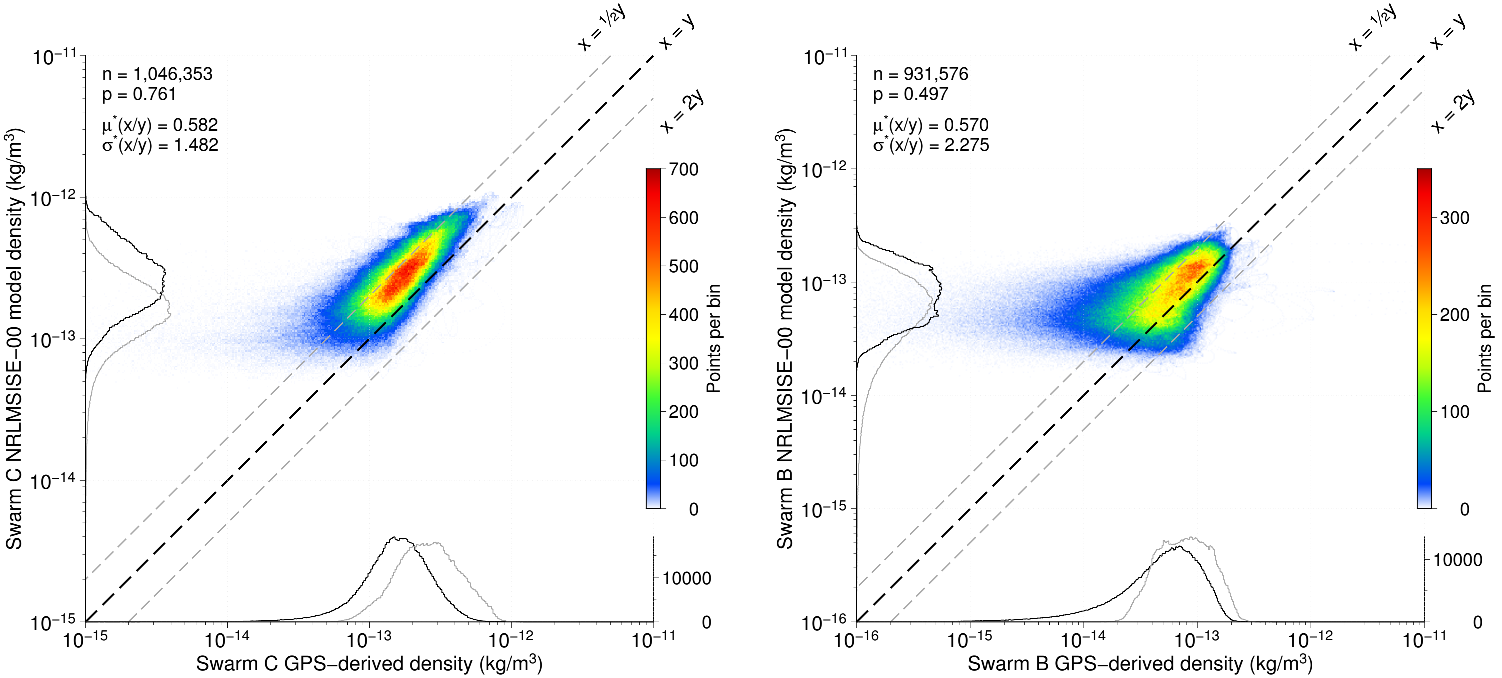
Time series of estimated density for Swarm-B (top), and solar activity proxy $F_{10.7}$ and geomagnetic index *ap* (bottom). The white line indicates the mean orbit density.

GPS-derived densities vs model



Ratio between observed and NRLSMISE model densities varies during the mission

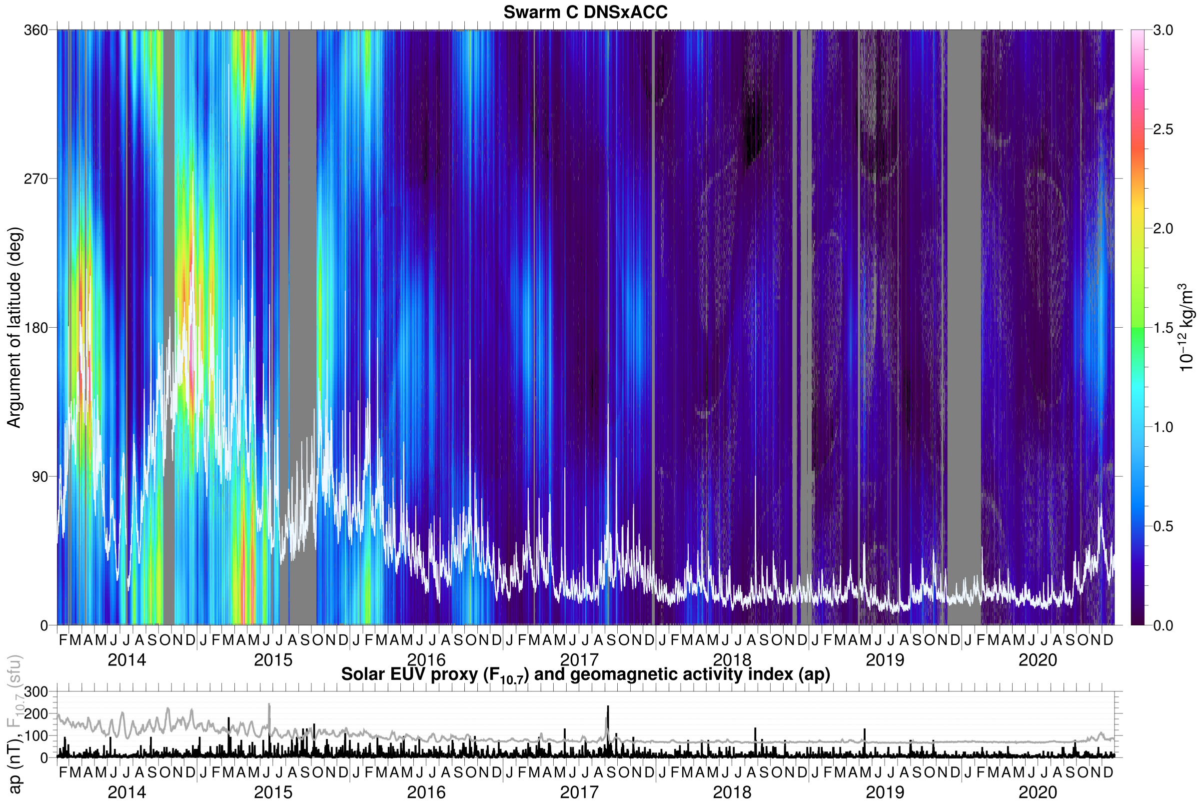
GPS-derived densities vs model



Estimated versus modeled densities for Swarm-C (left) and Swarm-B (right) for 2018

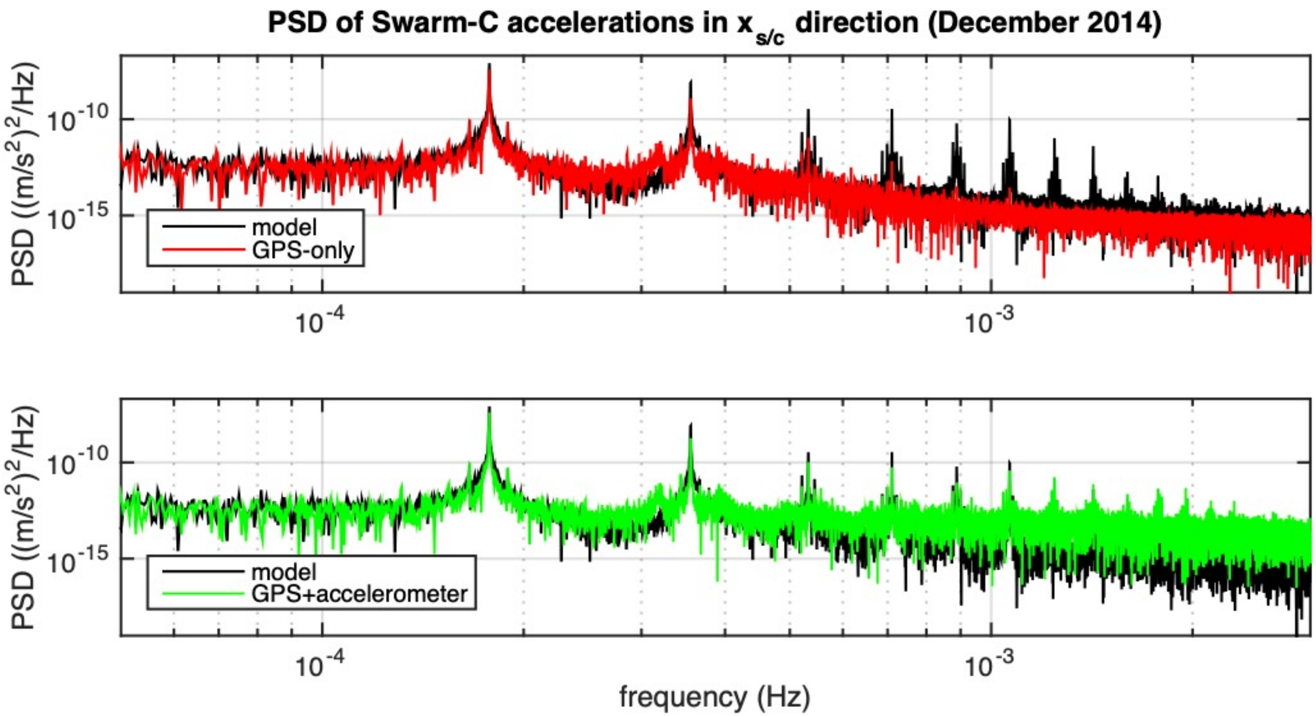
Larger density errors at low signal suggest remaining radiation pressure errors

Swarm-C accelerometer densities



Time series of estimated density for Swarm-C (top), and solar activity proxy $F_{10.7}$ and geomagnetic index *ap* (bottom).
The white line indicates the mean orbit density.

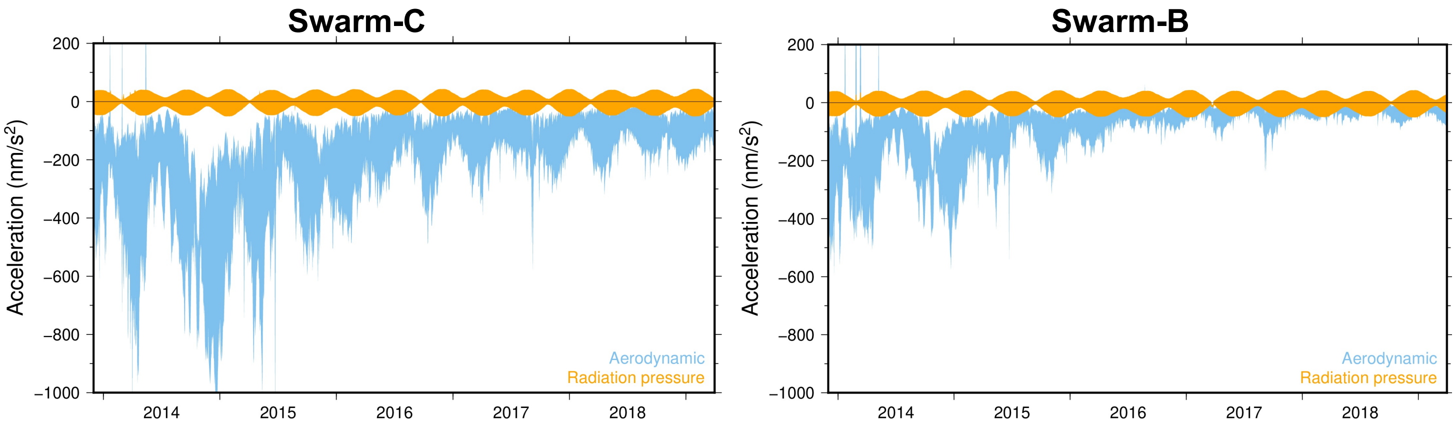
Swarm-C accelerometer densities



GPS-derived densities have ≈ 20 min temporal resolution
accelerometer densities also recover higher orbital frequency harmonics

Density products – future plans

- Use of improved accommodation coefficient (0.82 vs 0.93)
  March et al, Gas-surface interactions modelling influence on satellite aerodynamic and thermosphere neutral density, in prep.
- Further improve radiation pressure modeling (improve geometry & surface properties, add thermal reradiation modeling)



Time series of modelled aerodynamic and solar radiation pressure accelerations for Swarm

For recent altitudes and low solar conditions the SRP and aerodynamic signal is of similar magnitude for Swarm, therefore an accurate SRP modeling is even more important to derive accurate thermospheric densities.

Summary

- GPS-derived densities are available for all Swarm satellites
- Higher-resolution accelerometer densities are only available for Swarm-C
- All Swarm thermospheric densities are publicly available at:
  - the ESA Swarm website: ftp://swarm-diss.eo.esa.int
  - our thermospheric density database: http://thermosphere.tudelft.nl
- Very low solar activity affects the Swarm density accuracy, especially for the higher flying Swarm-B satellite
- Plans for further improvement include:
  - use of improved energy accomodation coefficient
  - use of high-fidelity satellite geometry & surface properties for solar radiation pressure modeling
  - addition of thermal reradiation modeling

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