POLITECNICO MILANO 1863 | DEPARTMENT OF AEROSPACE SCIENCE AND TECHNOLOGY

Operational Long-Term Assessment of Periodic Satellite Conjunctions

05.06.2026 I Achraf Mizmizi, Camilla Colombo, Sean Hannon

European Research Council
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Introduction

- CDM traffic is increasing over the last years.
- Many alerts are driven by recurrent encounters with catalogued objects.
- Alert peaks can rapidly increase operators workload.
- Early pattern detection supports long-term conjunction awareness.

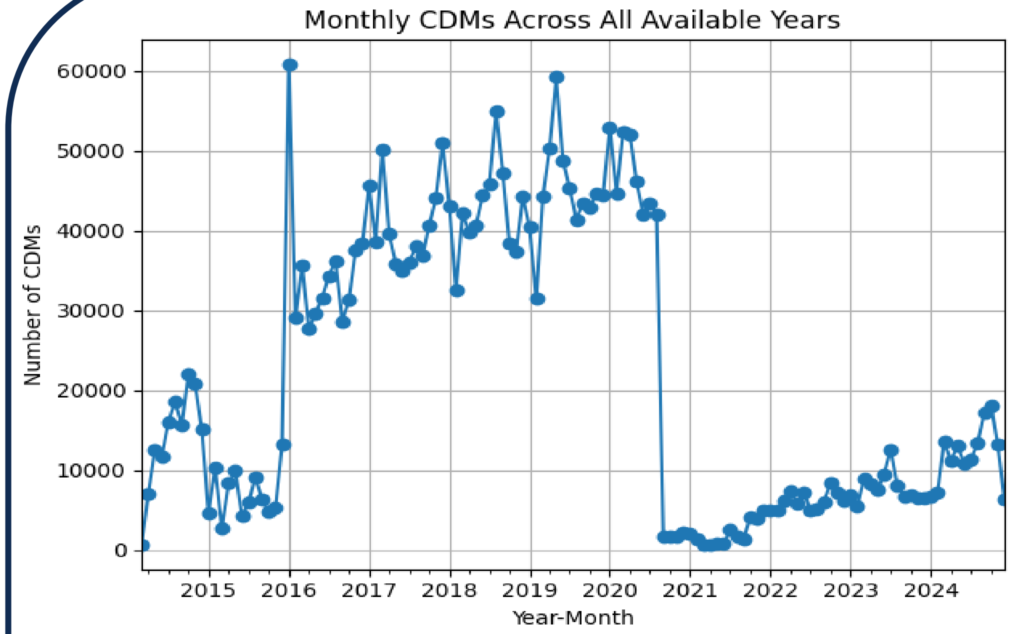


Figure A

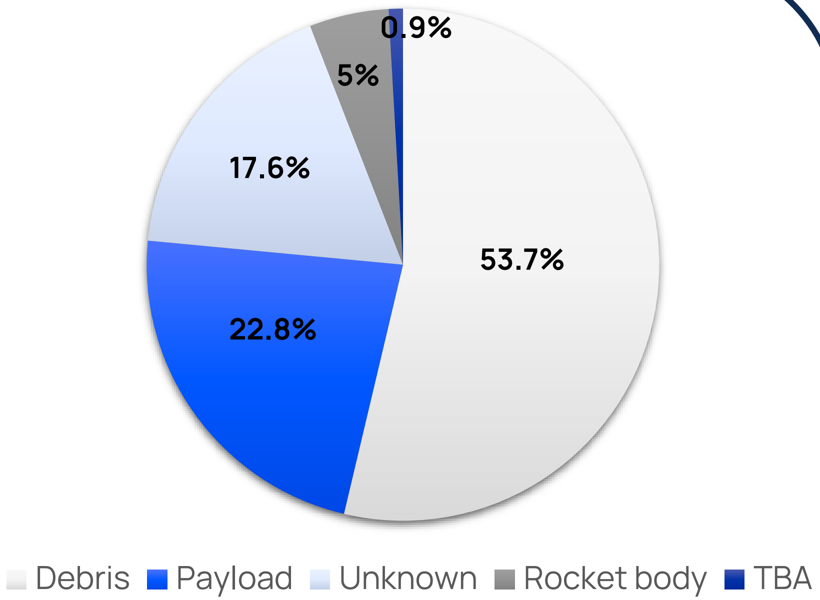


Figure B

The plots were produced by GMV France and GMV Romania within the ESA Orbital Neighbourhood Awareness project, using a CDM data dump provided by ESA. Figure A shows the monthly CDM evolution from 2014 to 2025 for ESA missions only, while Figure B shows the distribution of encountered object types.

Orbital Neighbourhood Awareness Project

SPIRE

The ambition of the ORBITHOOD project is to provide long-term awareness of the orbital neighbourhood: identifying how surrounding objects may affect a target satellite, how that satellite may affect nearby orbits, and when conjunction activity may become operationally demanding.

- Fragmentations events
- Manoeuvre prediction
- Anomaly detection
- Constellation crossing
- Periodic encounters

Periodic Encounters

CDM dataset analysis

Many alerts repeatedly involve the same object pairs.

Interpretation

some object pairs remain in orbital configurations that favour recurrent close approaches.

Objective

Develop a methodology to predict repeated close encounters over a six-month horizon.

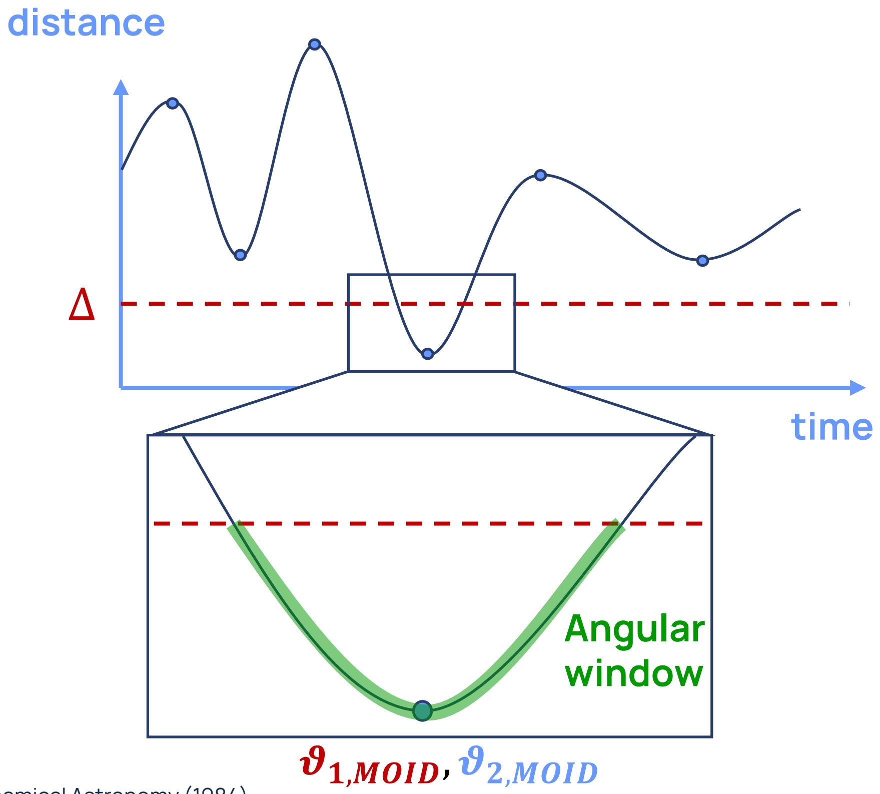
Methodology Overview: Triple Loop Filter

The proposed method prioritises fast analytical screening over full-catalogue propagation: for a selected target satellite, each catalogued object is analysed pair by pair through a sequence of filtering steps.

Perigee-apogee filter — Check whether the radial ranges are compatible [1].

MOID filter — Identify algebraically the possible close approach regions [2].

Time-window filter — Verify whether both objects reach those regions at the same time [3].



The time-window filter can be extended over a six-month horizon.

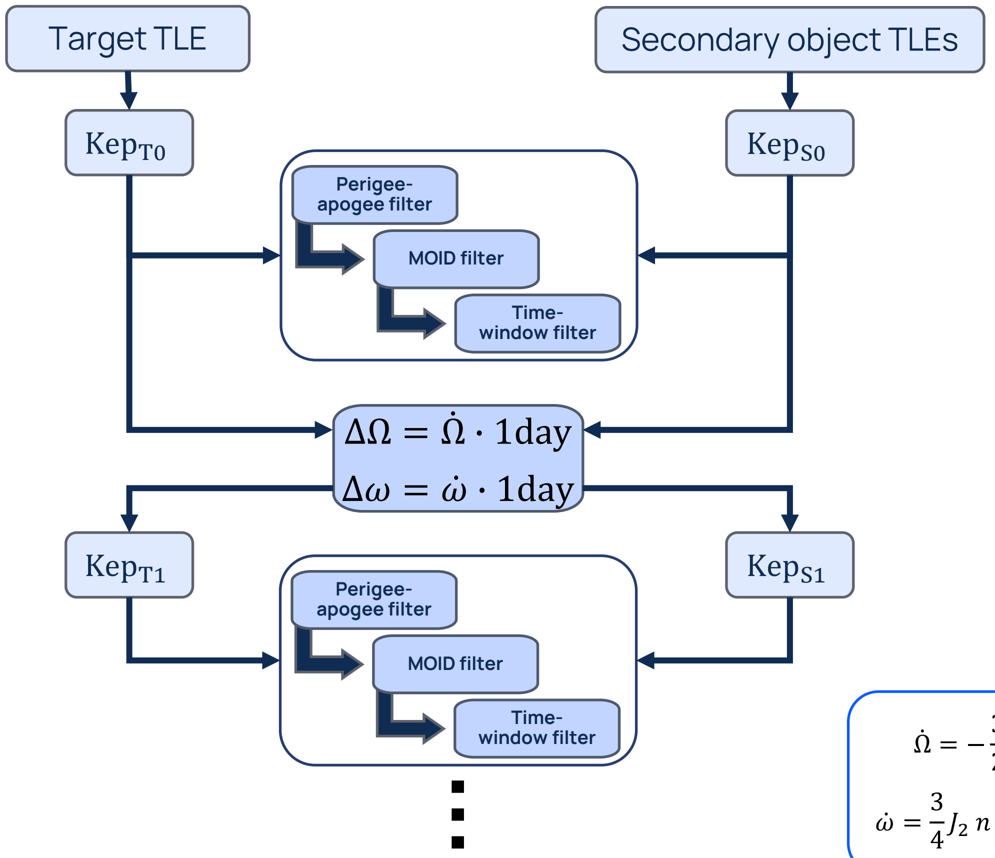
1. Hoots, F. R., Crawford, L. L., and Roehrich, R. L., An analytic method to determine future close approaches between satellites., Celestial Mechanics and Dynamical Astronomy (1984).
2. Gronchi, G. F., An algebraic method to compute the critical points of the distance function between two Keplerian orbits., Celestial Mechanics and Dynamical Astronomy (2005).
3. Romano, M., Muciaccia, A., Trisolini, M., Colombo, C., Di Lizia, P., Di Cecco, A., and Salotti, L., Puzzle software for the characterisation of in-orbit fragmentations., in 8th European Conference on Space Debris, ESA/ESOC.
4. Alfano, S., and Finkleman, D., On selecting satellite conjunction filter parameters., Acta Astronautica (2014).
5. Ottoboni, F., Muciaccia, A., and Colombo, C., Reconstruction of in-orbit breakup events over the short term., Acta Astronautica (2026).

Methodology Overview: Triple Loop Filter

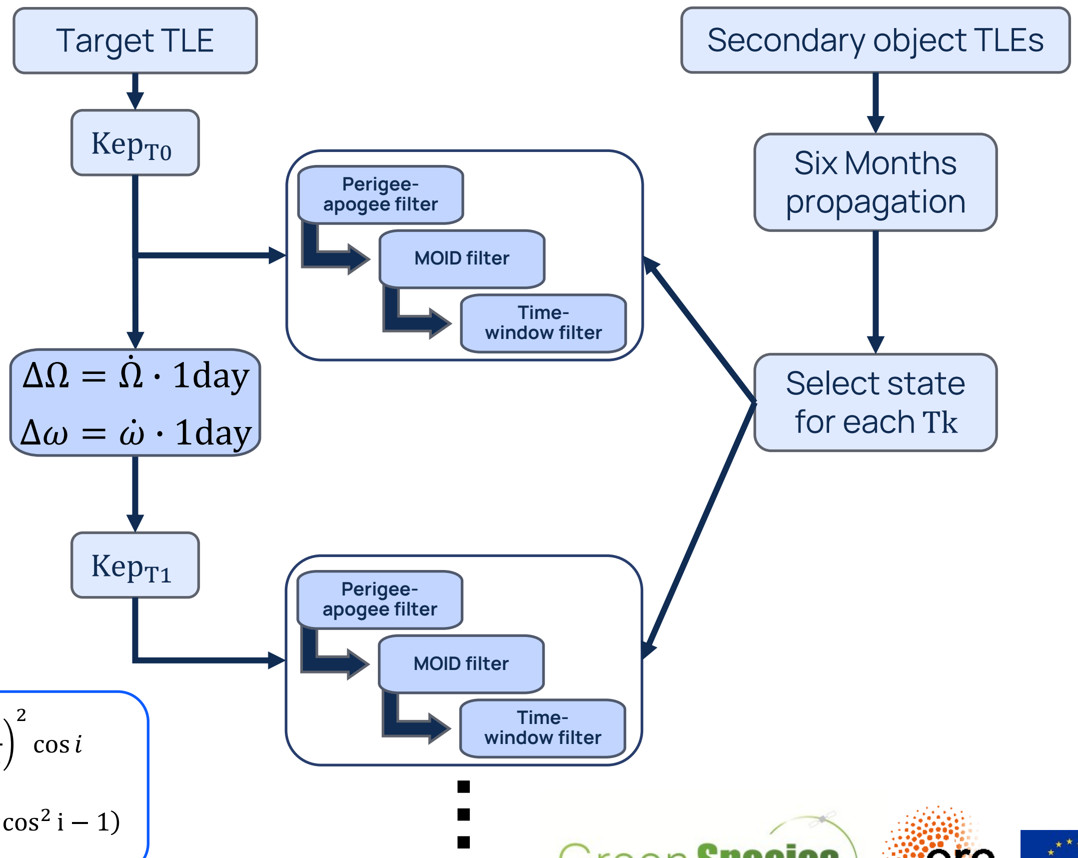
The time-window filter can be extended over a six-month horizon.

However, over this time scale the orbital geometry is not fixed, the relative configuration between the two orbits evolves with time.

Active vs Active



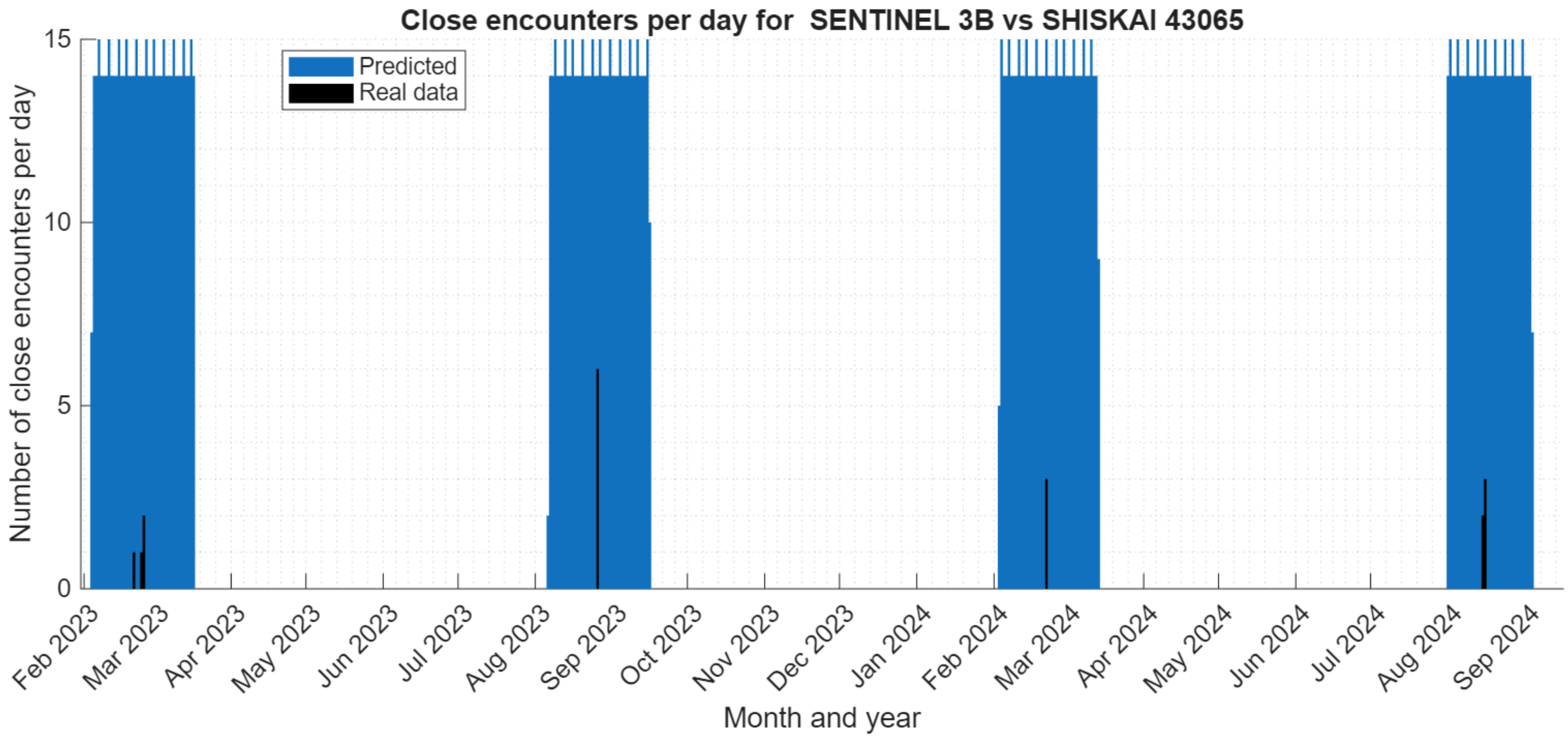
Active vs Inactive



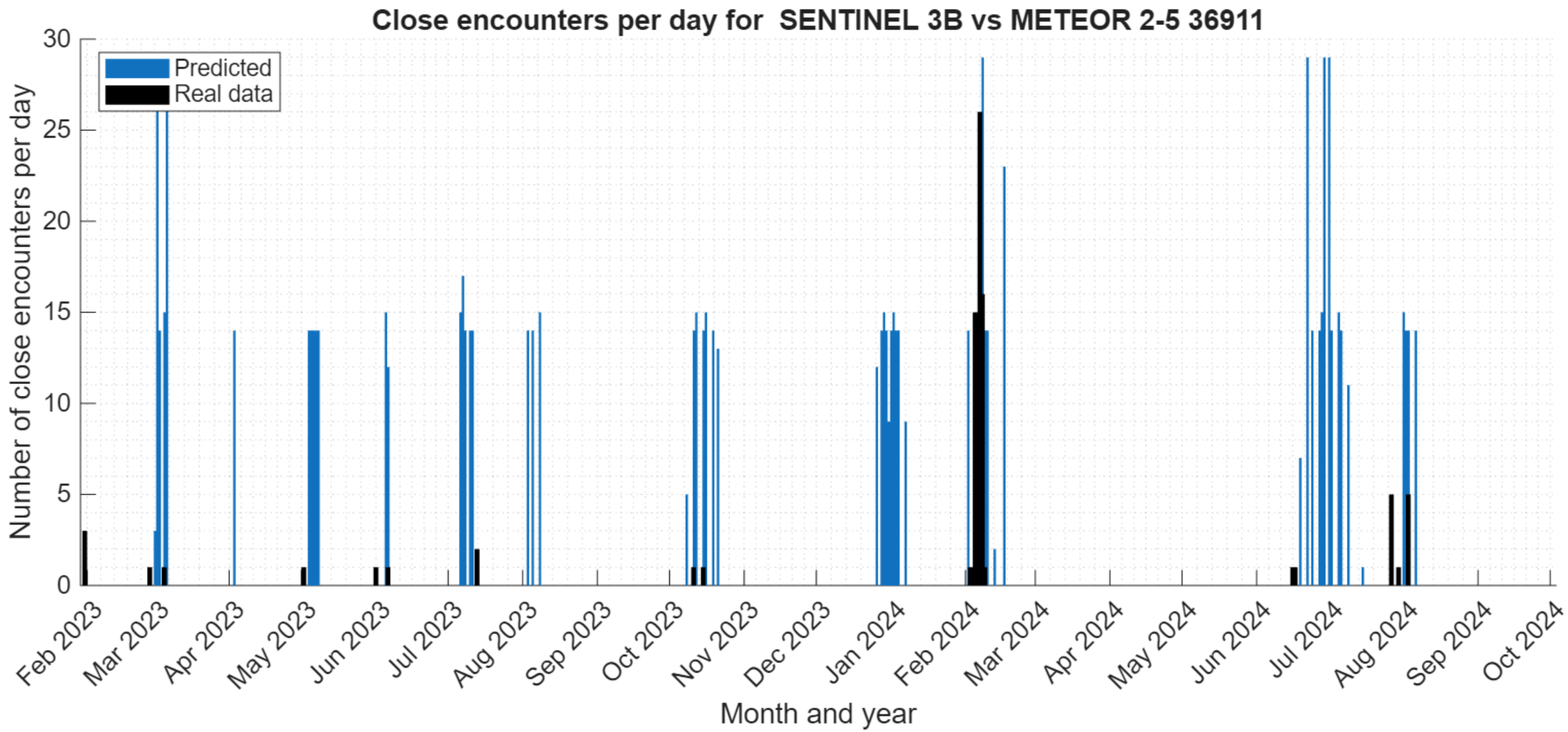
$$\dot{\Omega} = -\frac{3}{2} J_2\, n \left(\frac{R_E}{a(1-e^2)}\right)^2 \cos i$$

$$\dot{\omega} = \frac{3}{4} J_2\, n \left(\frac{R_E}{a(1-e^2)}\right)^2 (5\cos^2 \mathrm{i} - 1)$$

Validation, Active vs Active: Sentinel 3B vs Shiskai



Validation, Active vs Inactive: Sentinel 3B vs Meteor 2-5



Application to Constellations-Crossing Scenarios

Following the promising results obtained for periodic encounters, the approach was extended to constellation-crossing scenarios involving:

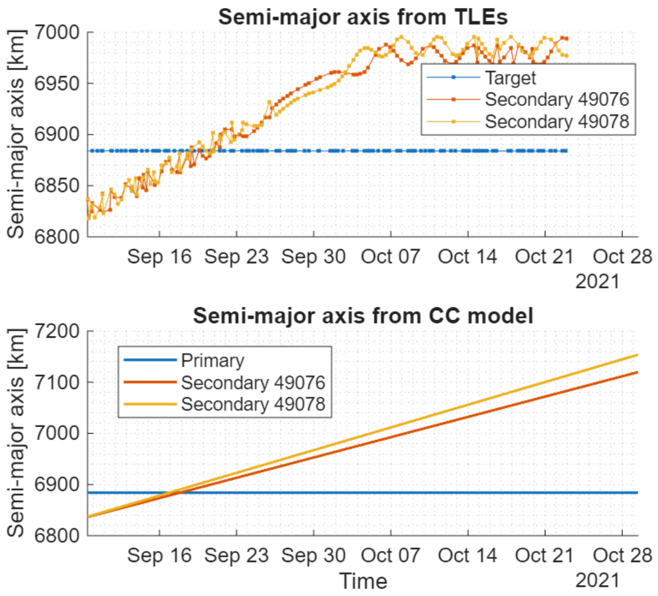
Crossing of a constellation shell by a manoeuvring satellite

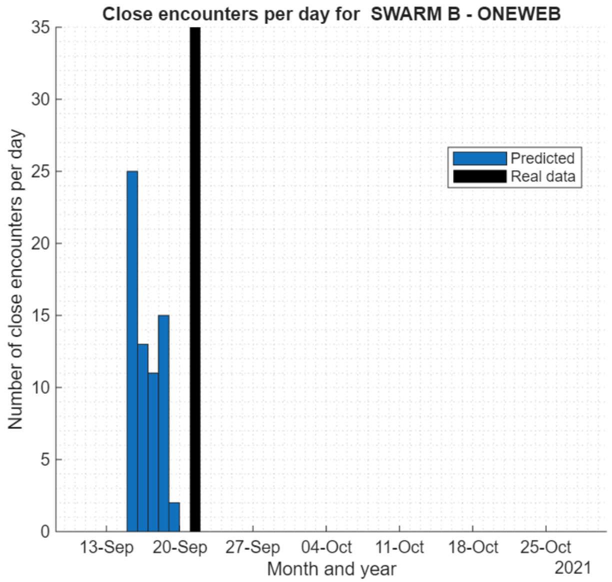
Manoeuvres performed within an existing constellation

Same pair-by-pair analytical screening as the periodic encounter analyser, but with an additional estimate of semi-major axis evolution.
For manoeuvring or crossing objects, the semi-major axis is modelled as:

$$\mathrm{a(t)} = \mathrm{a_0} + \dot{\mathrm{a}} \cdot \mathrm{t}$$

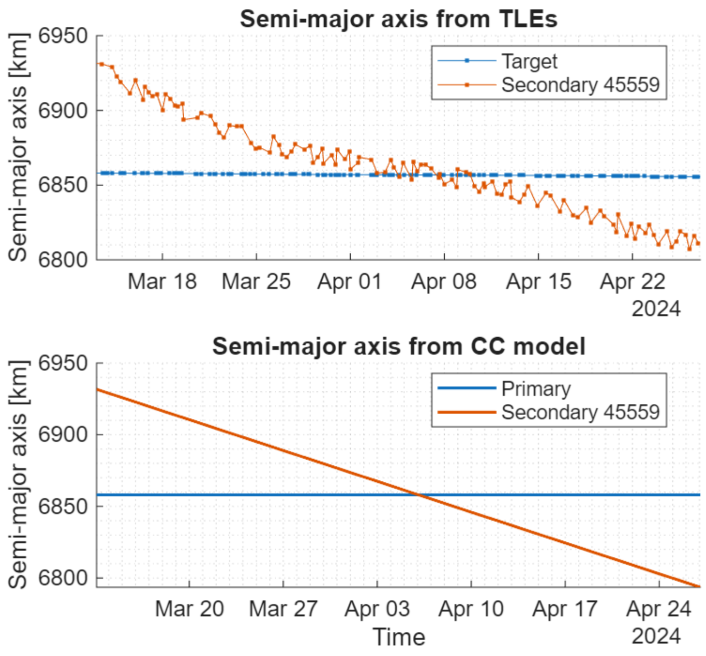
The rate $\dot{\mathrm{a}}$ is obtained by fitting a linear trend to 5 days aggregated TLE data.

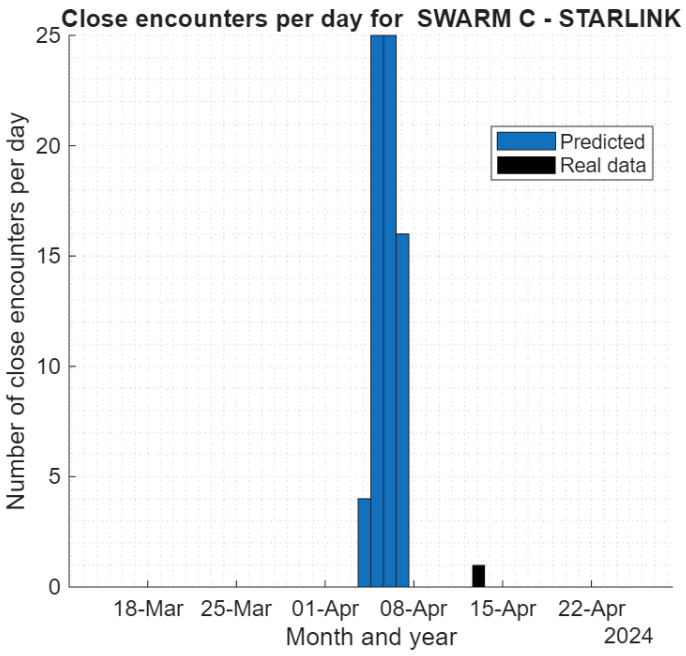




Using the initial semi-major-axis trend, the model predicts a cluster of close encounters around the expected crossing window.
The real CDM peak occurs a day later.

Application to Constellations-Crossing Scenarios





- The real CDM occurred on 14 April, while the method predicted the encounter window approximately one week earlier.
- The one-week offset is mainly caused by extrapolating the semi-major-axis drift rate from the first five days of data, while the actual Starlink de-orbiting rate changed later in the manoeuvre.

Conclusions

What Works

- Analytical screening reduces the number of catalogued objects by approximately 98.2%.
- The methodology is computationally efficient, especially for the Active vs Active case, requiring about 2 minutes for a six-month prediction horizon.
- Validation test cases show good temporal localisation of CDM activity peaks.
- The same screening logic can be adapted to constellation-crossing scenarios.

Current Limitations

- Strongly manoeuvre-driven scenarios, such as GEO operations, are not fully captured without explicit manoeuvre modelling.
- For constellation-crossing scenarios, the semi-major-axis drift rate should be updated repeatedly to account for changes in the manoeuvre profile.
- Active vs Inactive analyses remain computationally heavier, requiring about 2.5 minutes per inactive object in the current implementation.

The main value of the method is not to replace high-fidelity conjunction assessment, but to act as an early-warning layer. It can highlight when recurrent encounter activity is likely to concentrate, while the main limitations are linked to simplified orbital evolution and manoeuvre modelling.

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Thank you for your attention!

This research has received funding from the European Space Agency (ESA) activity “ORBITHOOD: Orbital Neighbourhood Awareness”; and from the European Research Council (ERC) under the European Union’s Horizon Europe research and innovation program as part of the GREEN SPECIES project (Grant agreement No 101089265)

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European Research Council
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Validation, Active vs Active: Sentinel 3B vs Shiskai

Figure A

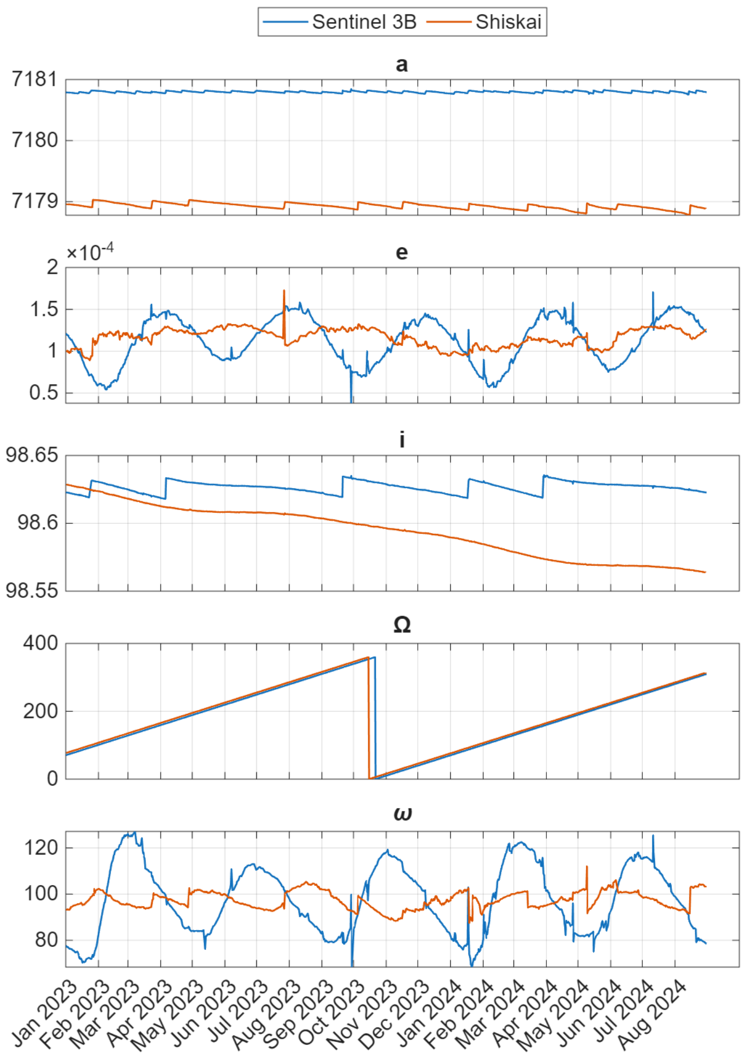
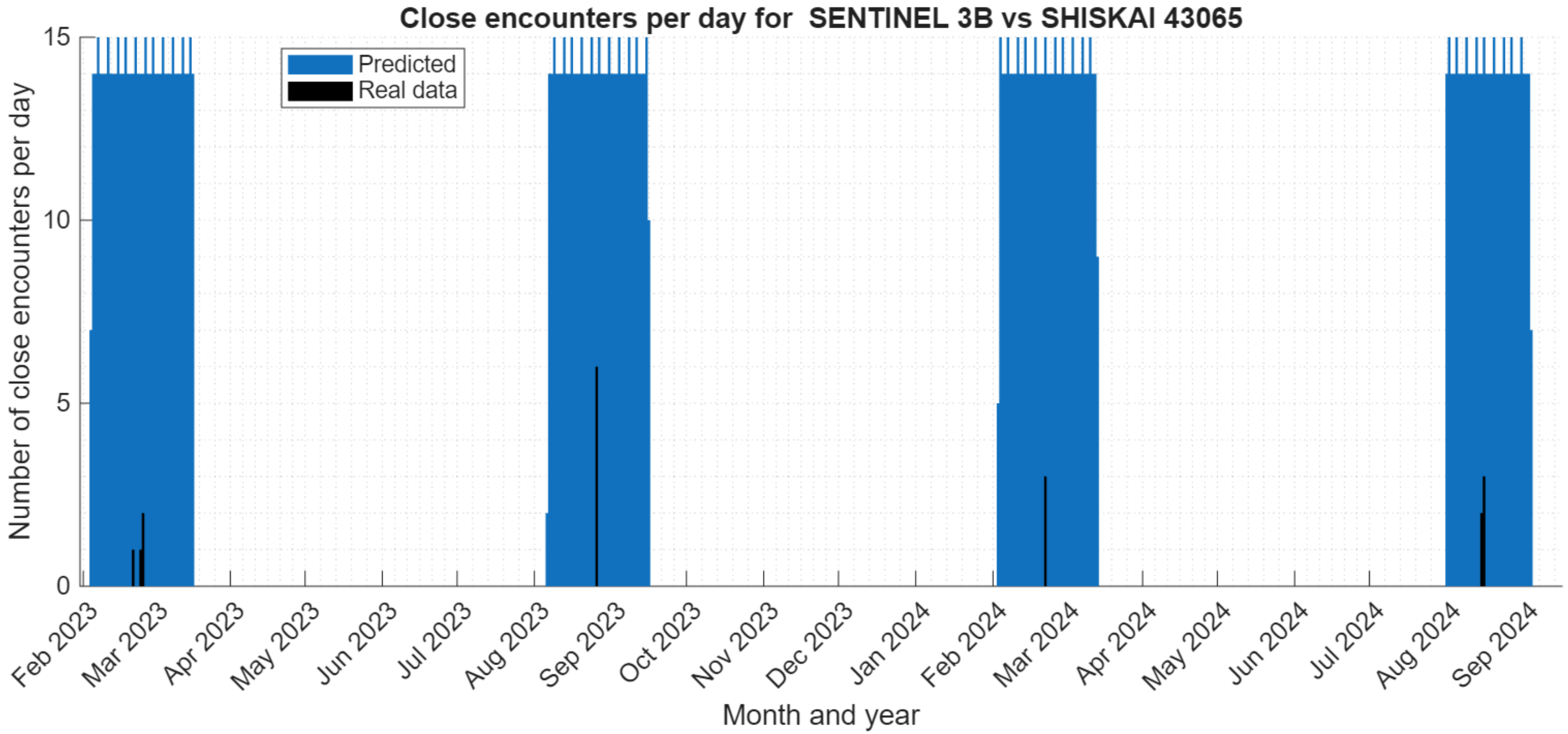


Figure B



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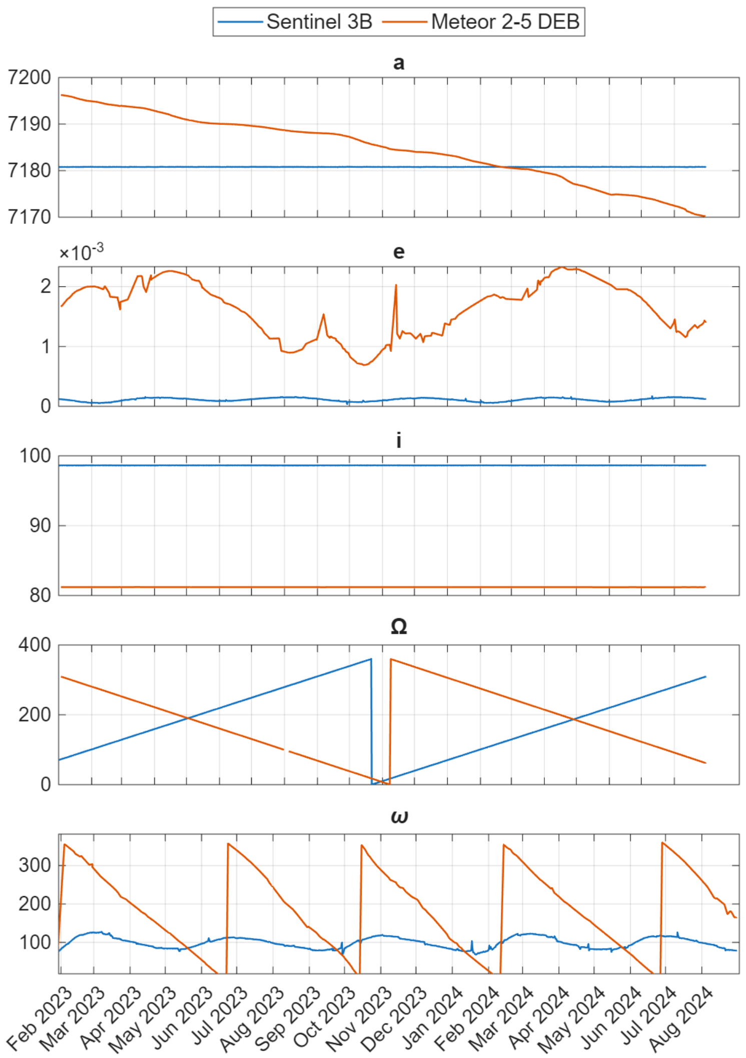

Figure B