Towards a Standardised Satellite Maneuver Log Dataset

Leveraging Data from IDS for Space Domain Awareness Model Validation and Machine Learning Applications

Lara Amusan

PhD Student | Orbit Lab | Civil, Environmental & Geomatic Engineering | UCL

IDS Workshop | Wiesbaden | June 2026

What is Space Domain Awareness (SDA)?

Understanding the space environment: **what objects are in orbit, where they are, and what they are doing for space safety.**

From precision to the bigger picture

SDA takes a broader look across the entire catalogue of orbiting objects, because managing collision risk and long-term sustainability requires understanding of the environment as a whole.

Science, Industry and Policy

SDA sits at the intersection of all three. This creates differences in how willingly data is shared. Some data is freely available, some is restricted, and some are simply not routinely exchanged.

Satellite maneuver data is one area where **greater sharing would benefit the entire community.**

Why Satellite Maneuvers Matter

Space Traffic Management

Detecting when a satellite maneuvers and distinguishing them from drag or space weather is essential for understanding satellite behavior and improving conjunction assessment for collision avoidance

Pattern of Life

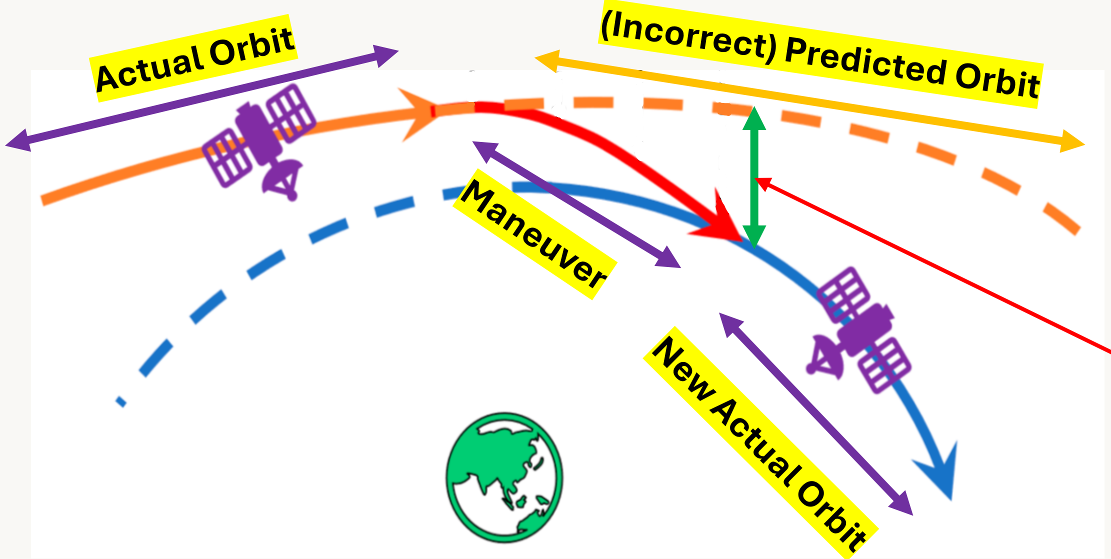
Detecting maneuvers across fleets builds a picture of operator behavior: station-keeping frequency, collision avoidance responses and space weather reactions

The Problem

No official, large maneuver dataset exists to validate detection algorithms, so studies often validate against a handful of real maneuver data, and ML methods need quality labelled data, making this a gap in resources

The Cost of a Missed Maneuver

EXAMPLE OF A MISSED SATELLITE MANEUVER CAUSING INCORRECT ORBIT PREDICTION



Source: Qin, Z. *et al.* (2023) 'BDS Orbit Maneuver Detection Based on Epoch-Updated Orbits Estimated by SRIF', *Remote Sensing*, 15(10), p. 2558. Available at: https://doi.org/10.3390/rs15102558

Maneuvers are part of satellite force modelling

A satellite maneuver = a deliberate change in a spacecraft's speed, direction, or orbit using onboard thrusters.

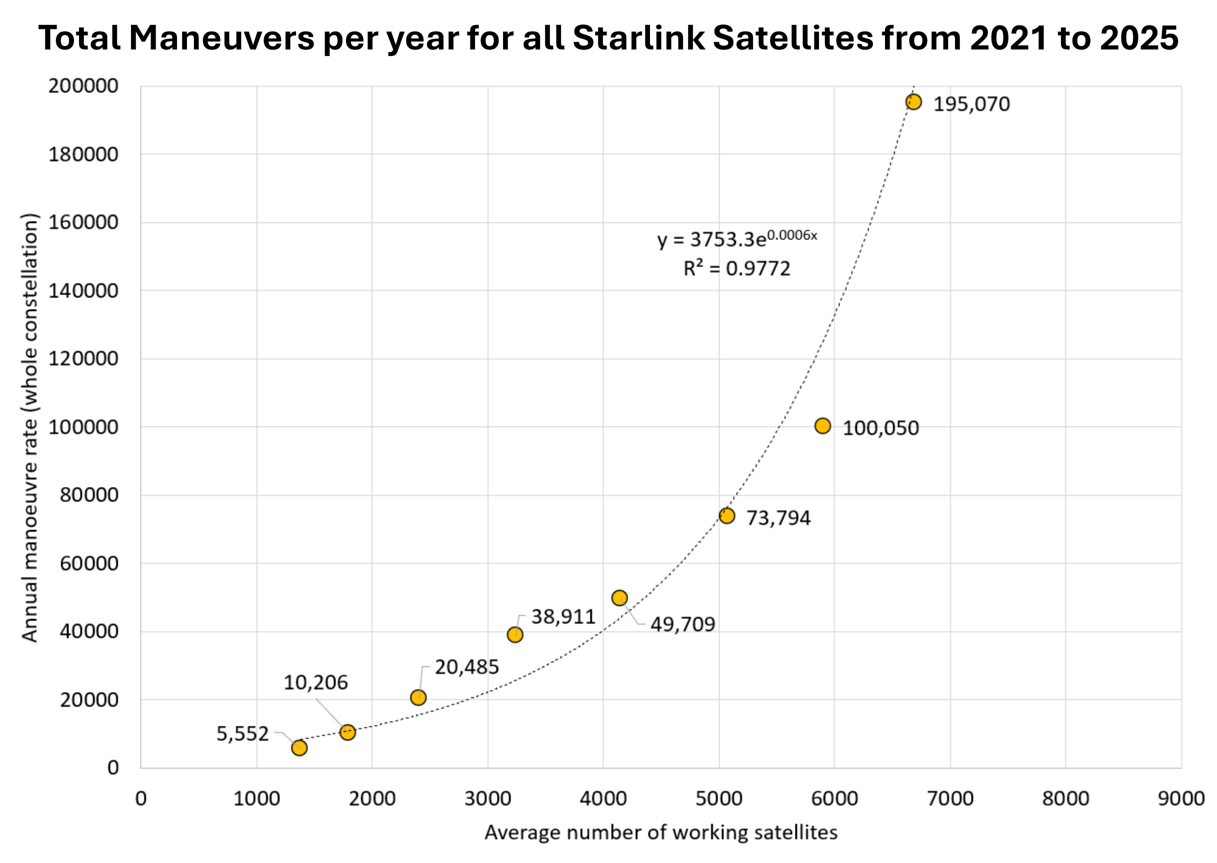
Not accounting for this in satellite force modelling leads to error in the predicted orbit that increases over time.

Discrepancy errors can reach to over 100s of km in under a week

The Consequence

Missed maneuvers lead to missed collision warnings or maneuver false alarms, both of which compromise space traffic management.

More Satellites, More Maneuvers



Source: Lewis, H. (2025) 'Starlink Manoeuvre Update July 2025', *LinkedIn*, 2 July. Available at: https://www.linkedin.com/pulse/starlink-manoeuvre-update-july-2025-hugh-lewis-utkhe/

We are seeing a sharp increase in:

- Satellites
- Satellites that can maneuver

= More maneuvers at an increasing rate (as on the right)

SDA aims to understand the broader space environment, which is growing at an increasing rate. Collecting and understanding maneuver data will become more important.

This is why a large repository of maneuver data is needed

The Aim & Uses

Aim:

Build a publicly available dataset of historical satellite maneuver logs, harmonising multiple sources into a single standardised format

Uses:

Cross Validation

A collection of ground truth maneuver data with a unified format could improve cross validation of detection models

Shared Resource

Creates an open resource of shared multi-source data for the community, encouraging collaboration

Training Dataset

Machine Learning models thrive on large, quality data. Ground truth data can help to enhance these ML datasets

Future Constellation Scaling

As satellite operators scale/increase launches, the community would benefit from a shared exchange of maneuver data

The Bigger Picture

Maneuver log data posted on IDS already produces exactly what's needed, but it's not widely used in Space Domain Awareness (SDA) yet

What IDS Provides

- Well-structured, consistent maneuver logs maintained as part of the POD chain
- 14 satellites across different altitudes
- 20+ years of temporal depth
- Regularly updated through operator collaboration

Downstream Value for SDA

- Clearest and most extensive structured source of cooperative maneuver data found
- Currently used mainly for arc segmentation. This poses a secondary potential
- Including IDS as the baseline multiplies the value of data that already exists

Same data, different purpose: Originally to account for maneuvers during POD, whilst SDA uses them to find maneuvers

The Current Landscape

Currently no established dataset for sharing or comparing maneuver information across operators

However, there have been efforts that contribute towards this

Orbital Data Sites/Centres

- Sites like Space Track, created for space situational awareness
- Operators share ephemeris including planned maneuvers for conjunction assessment
- But this does not necessarily lead to shared maneuver records

CCSDS Maneuver Standard

- Consultative Committee for Space Data Systems recommends how to include maneuvers in orbit data messages (section 502.0-B-3)
- Adoption for standardised records is limited in practice

A Benchmark Dataset

- Paper in 2023 from Shorten et al. proposes and shares a benchmark dataset containing maneuver data.
- Covers 15 satellites across 2 sources to create a robust and fixed benchmark
- A multi-source, extensible and standardised dataset enables greater comparison and modelling efforts

Source: Shorten, D.P. *et al*. (2023) 'Wide-scale Monitoring of Satellite Lifetimes: Pitfalls and a Benchmark Dataset', *Journal of Spacecraft and Rockets*, 60(6), pp. 2003–2007.

The Gap

Without a requirement to make maneuver data homogeneous, there hasn't been the incentive to compile it, despite the potential benefits

The Compilation Effort (so far)

9 Data Sources	**86** Satellites (LEO and MEO)	**20+** Years of Data

- IDS is a reference, but the dataset combines multiple sources into one unified format
- All sources publicly available, some required direct inquiry with operators and services
- Data comes in different formats with varying detail: **the work is aligning with uniform headers, formats, and units**

Data Harmonisation

Transforming heterogeneous maneuver data sources into a consistent dataset

Source A – IDS Format (for satellite Sentinel 3A for maneuver performed on 11/12/2025)

Beginning of maneuver Year	Beginning of maneuver Day of Year	Beginning of maneuver Hour	Beginning of maneuver Minute	End of maneuver Year	End of maneuver Day of Year	End of maneuver Hour	End of maneuver Minute	Maneuver Type	Maneuver Parameter Type	Number of burns	Median Date of maneuver Year	Median Date of maneuver Day of Year	Median Date of maneuver Hour	Median Date of maneuver Minute	Median Date of maneuver Second	Boost Duration (s)	Delta V 1 (m/s) (radial)	Delta V 2 (m/s) (along track)	Delta V 3 (m/s) (cross track)	Acceleration 1 (10-6m/s2)	Acceleration 2 (10-6m/s2)	Acceleration 3 (10-6m/s2)	Delta Acceleration 1 (m/s)	Delta Acceleration 2 (m/s)
2025	345	8	5	2025	345	8	18	N/A	6	1	2025	345	8	11	55.33	7.35E+02	8.72E-11	2.77E-02	1.48E+00	1.19E-07	3.76E+01	2.01E+03	0.00E+00	0.00E+00

Source B – ESA Format (for satellite Swarm-B for maneuver performed on 16/05/2017)

Date	Time (UTC)	Duration (s)	Delta V Magnitude (m/s)	Delta V along (m/s)	Delta V cross (m/s)	Delta V radial (m/s)	Purpose
16/05/2017	00:51:12	95	0.02	-0.02	0	0	Collision Avoidance

Data Harmonisation

Transforming heterogeneous maneuver data sources into a consistent dataset

Source A – IDS Format (for satellite Sentinel 3A for maneuver performed on 11/12/2025)

Beginning of maneuver Year	Beginning of maneuver Day of Year	Beginning of maneuver Hour	Beginning of maneuver Minute	End of maneuver Year	End of maneuver Day of Year	End of maneuver Hour	End of maneuver Minute	Maneuver Type	Maneuver Parameter Type	Number of burns	Median Date of maneuver Year	Median Date of maneuver Day of Year	Median Date of maneuver Hour	Median Date of maneuver Minute	Median Date of maneuver Second	Boost Duration (s)	Delta V 1 (m/s) (radial)	Delta V 2 (m/s) (along track)	Delta V 3 (m/s) (cross track)	Acceleration 1 (10-6m/s2)	Acceleration 2 (10-6m/s2)	Acceleration 3 (10-6m/s2)	Delta Acceleration 1 (m/s)	Delta Acceleration 2 (m/s)
2025	345	8	5	2025	345	8	18	N/A	6	1	2025	345	8	11	55.33	7.35E+02	8.72E-11	2.77E-02	1.48E+00	1.19E-07	3.76E+01	2.01E+03	0.00E+00	0.00E+00

Source B – ESA Format (for satellite Swarm-B for maneuver performed on 16/05/2017)

Date	Time (UTC)	Duration (s)	Delta V Magnitude (m/s)	Delta V along (m/s)	Delta V cross (m/s)	Delta V radial (m/s)	Purpose
16/05/2017	00:51:12	95	0.02	-0.02	0	0	Collision Avoidance

Source B – ESA Format, Now Aligned with IDS

Beginning of maneuver Year	Beginning of maneuver Day of Year	Beginning of maneuver Hour	Beginning of maneuver Minute	End of maneuver Year	End of maneuver Day of Year	End of maneuver Hour	End of maneuver Minute	Maneuver Type	Maneuver Parameter Type	Number of burns	Median Date of maneuver Year	Median Date of maneuver Day of Year	Median Date of maneuver Hour	Median Date of maneuver Minute	Median Date of maneuver Second	Boost Duration (s)	Delta V 1 (m/s) (radial)	Delta V 2 (m/s) (along track)	Delta V 3 (m/s) (cross track)	Acceleration 1 (10-6m/s2)	Acceleration 2 (10-6m/s2)	Acceleration 3 (10-6m/s2)	Delta Acceleration 1 (m/s)	Delta Acceleration 2 (m/s)
2017	129	0	51	2017	129	0	52	Collision Avoidance	6	N/A	N/A	N/A	N/A	N/A	N/A	9.50E+01	0.00E+00	-2.00E-02	0.00E+00	N/A	N/A	N/A	N/A	N/A

Toward a Future Framework

Aligning with CCSDS 502.0-B-3 maneuver parameter standards

CCSDS OCM maneuver parameters section

Maneuver Parameters (Repeat for each maneuver)			
COMMENT	(see 7.8 for formatting rules)		O
MAN_EPOCH_IGNITION	Epoch of ignition (see 7.5.10 for formatting rules)		O
MAN_DURATION	Maneuver duration (If = 0, impulsive maneuver)	s	O
MAN_DELTA_MASS	Mass change during maneuver (value is < 0)	kg	O
MAN_REF_FRAME	Reference frame in which the velocity increment vector data are given. The user must select from the accepted set of values indicated in 3.2.4.11.		O
MAN_DV_1	1st component of the velocity increment	km/s	O
MAN_DV_2	2nd component of the velocity increment	km/s	O
MAN_DV_3	3rd component of the velocity increment	km/s	O

'O' = optional item

IDS Log – Original Format

Beginning of maneuver Year	Beginning of maneuver Day of Year	Beginning of maneuver Hour	Beginning of maneuver Minute	End of maneuver Year	End of maneuver Day of Year	End of maneuver Hour	End of maneuver Minute	Maneuver Type	Maneuver Parameter Type	Number of burns	Median Date of maneuver Year	Median Date of maneuver Day of Year	Median Date of maneuver Hour	Median Date of maneuver Minute	Median Date of maneuver Second	Boost Duration (s)	Delta V 1 (m/s) (radial)	Delta V 2 (m/s) (along track)	Delta V 3 (m/s) (cross track)	Acceleration 1 (10-6m/s2)	Acceleration 2 (10-6m/s2)	Acceleration 3 (10-6m/s2)	Delta Acceleration 1 (m/s)
2025	345	8	5	2025	345	8	18	N/A	6	1	2025	345	8	11	55.33	7.35E+02	8.72E-11	2.77E-02	1.48E+00	1.19E-07	3.76E+01	2.01E+03	0.00E+00

IDS Log – Mapped to CCSDS Standard

COMMENT	MAN_EPOCH_IGNITION	MAN_DURATION	MAN_DELTA_MASS	MAN_REF_FRAME	MAN_DV_1	MAN_DV_2	MAN_DV_3
Source: File obtained from IDS	2025-12-11T08:05:00	735.468	N/A	RSW	8.72E-14	2.77E-05	1.48E-03

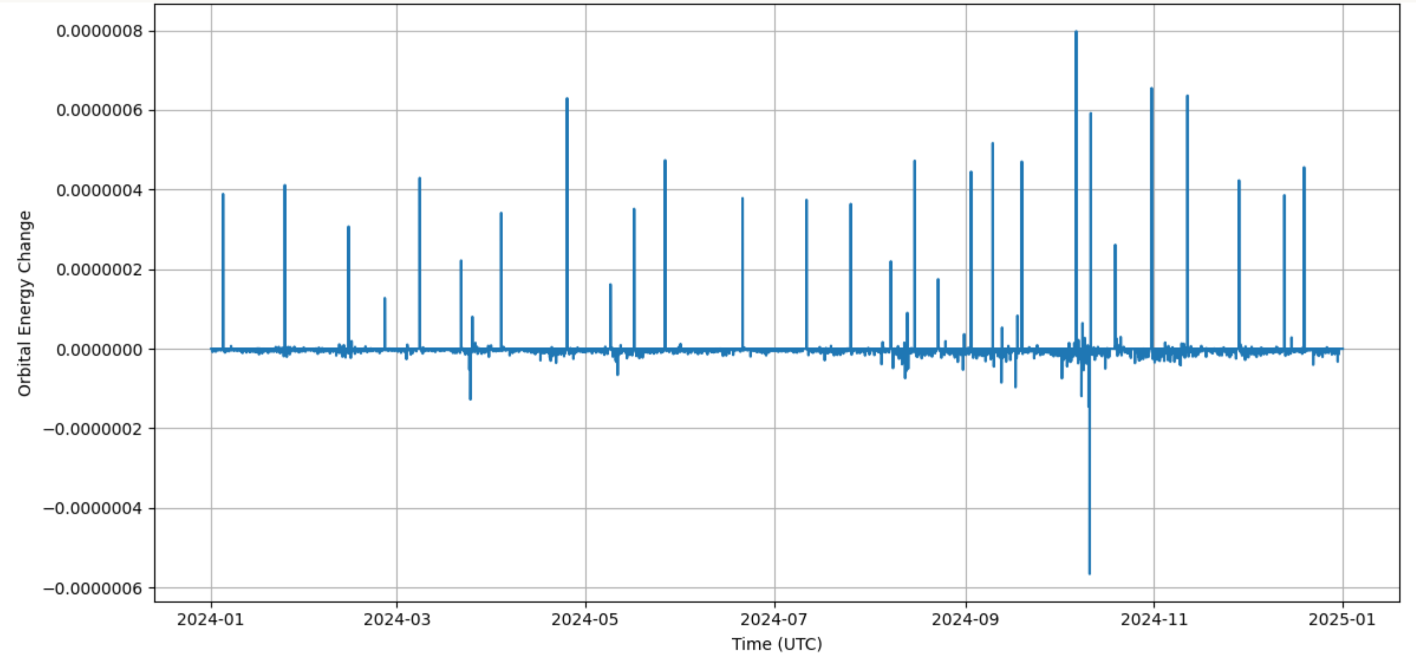
Not claiming to establish an official standard/dataset

Which would require official bodies/formal review. The aim here is to produce a valuable tool (data harmonization) and product (dataset) that aligns with existing standards and invites community feedback to shape its direction.

Use Case 1: Algorithm Validation

Sentinel-3A maneuver detection validated against IDS logs

SENTINEL 3A ORBITAL ENERGY CHANGE (2024)

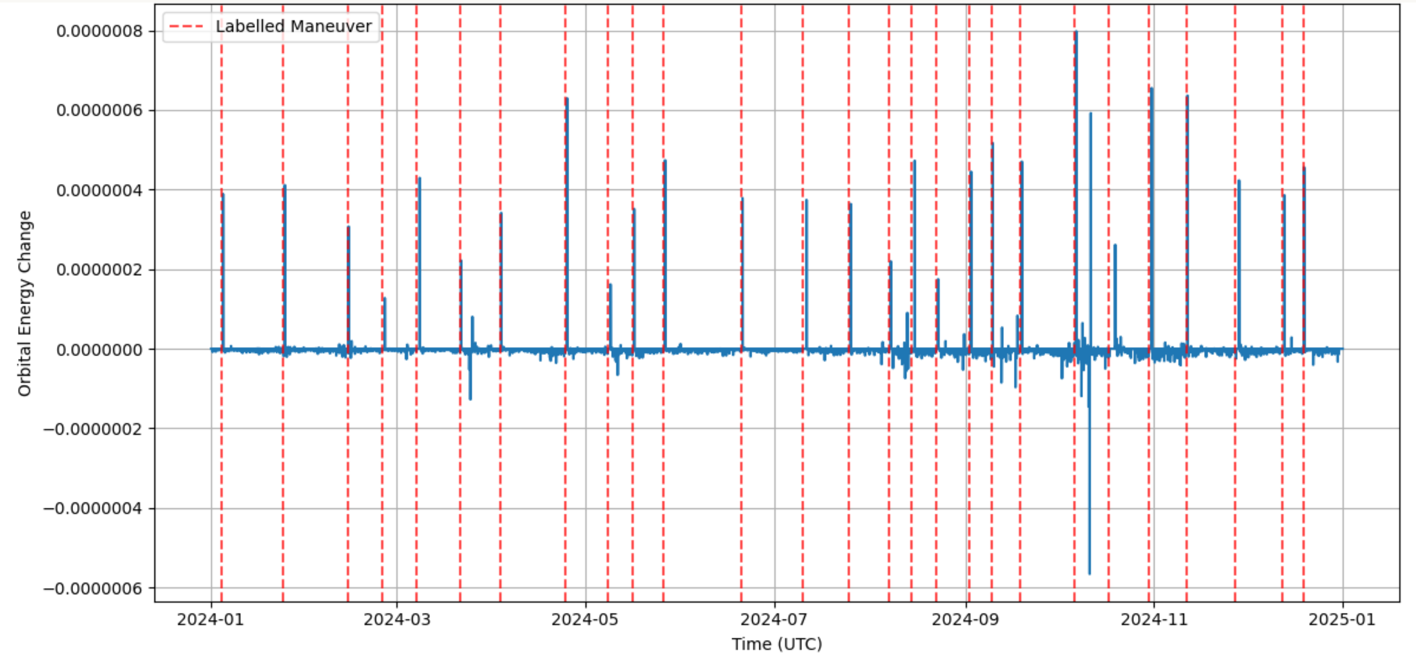


- Algorithm uses TLE data + SGP4 to detect sudden changes in orbital energy

Use Case 1: Algorithm Validation

Sentinel-3A maneuver detection validated against IDS logs

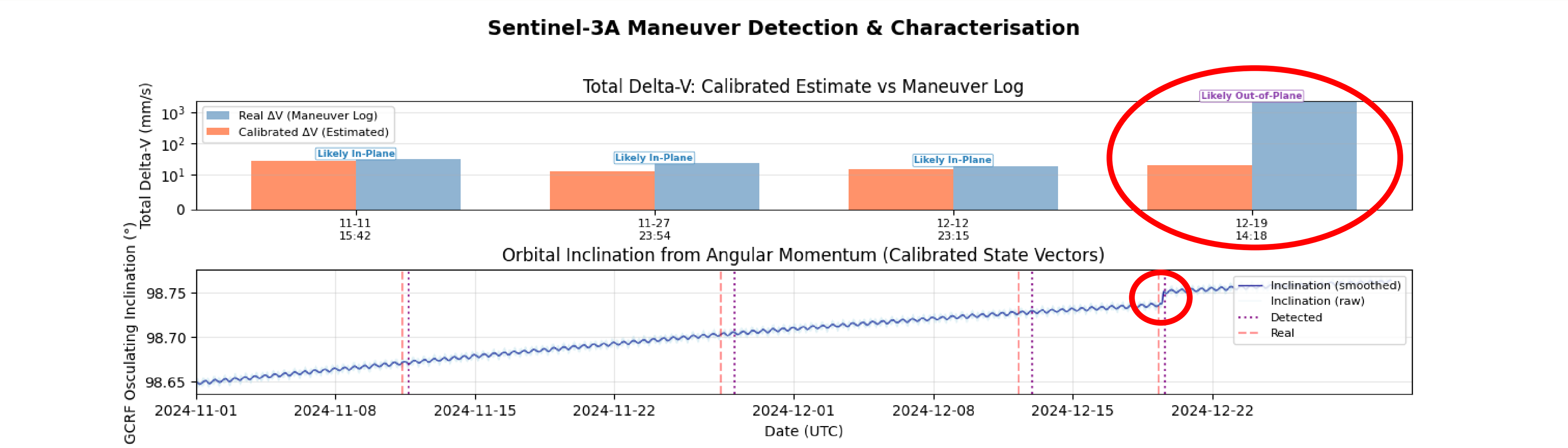
SENTINEL 3A ORBITAL ENERGY CHANGE (2024)



- Algorithm uses TLE data + SGP4 to detect sudden changes in orbital energy
- IDS logs provide definitive reference which enables precision, recall, and detection delay metrics
- Without ground truth detection performance cannot be objectively measured

Use Case 1: Algorithm Validation

Sentinel-3A maneuver detection validated against IDS logs



- Algorithm uses TLE data + SGP4 to detect sudden changes in orbital energy
- IDS logs provide definitive reference which enables precision, recall, and detection delay metrics
- Without ground truth detection performance cannot be objectively measured

Use Case 2: ML Training Data

SNIPPET OF LABELLED DATASET FOR EXAMPLE SATELLITE

	epoch_utc	x_km	vx_km_s	delta_orbital_energy	delta_sma_km	in_maneuver_window
6844	2024-01-04 07:01:42.001000+00:00	2311.892073	0.304626	-0.001306	-0.330527	0
6845	2024-01-04 07:02:12.001000+00:00	2319.962255	0.230221	-0.001406	-0.355862	0
6846	2024-01-04 07:02:42.001000+00:00	2325.783596	0.155593	-0.001501	-0.379828	0
6847	2024-01-04 07:03:12.001000+00:00	2329.350473	0.080815	-0.001590	-0.402452	0
6848	2024-01-04 07:03:42.001000+00:00	2330.659475	0.005961	-0.001673	-0.423322	0
6849	2024-01-04 07:04:12.001000+00:00	2329.709390	-0.068897	-0.001749	-0.442483	0
6850	2024-01-04 07:04:42.001000+00:00	2326.501215	-0.143686	-0.001818	-0.459853	0
6851	2024-01-04 07:05:12.001000+00:00	2321.038150	-0.218333	-0.001880	-0.475368	1
6852	2024-01-04 07:05:42.001000+00:00	2313.325593	-0.292765	-0.001934	-0.488977	1
6853	2024-01-04 07:06:12.001000+00:00	2303.371136	-0.366909	-0.001980	-0.500620	1
6854	2024-01-04 07:06:42.001000+00:00	2291.184552	-0.440694	-0.002019	-0.510330	1
6855	2024-01-04 07:07:12.001000+00:00	2276.777786	-0.514047	-0.002050	-0.518059	1
6856	2024-01-04 07:07:42.001000+00:00	2260.164944	-0.586898	-0.002073	-0.523804	1
6857	2024-01-04 07:08:12.001000+00:00	2241.362274	-0.659175	-0.002088	-0.527570	1
6858	2024-01-04 07:08:42.001000+00:00	2220.388152	-0.730808	-0.002095	-0.529373	1

Labelled Training Data

Maneuver records enable labelling of thrust periods which is essential for supervised learning

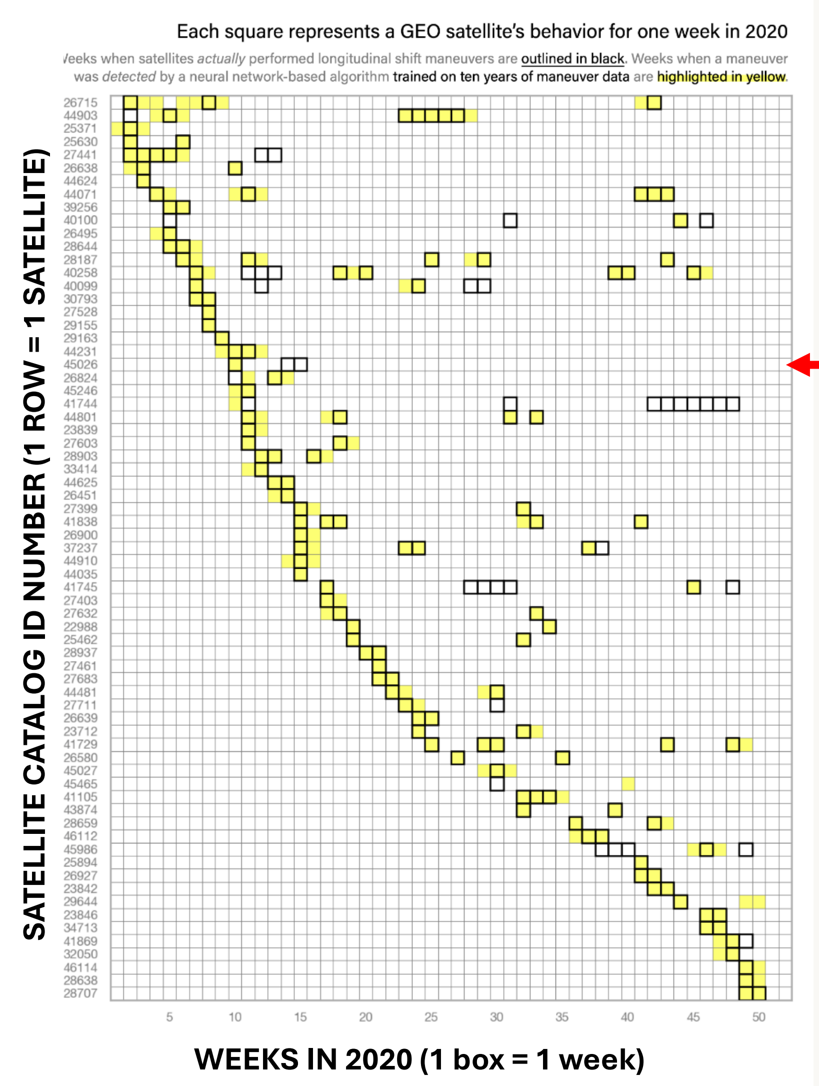
Diversity Prevents Overfitting

Multi-satellite, multi-orbit dataset avoids models learning only one satellite's behaviour

Beyond Detection

Understanding how and why satellites maneuver. Determining different types of maneuver

Use Case 3: ML Model Example From Roberts and Linares (2021)



Machine Learning for maneuver detection

In left example, labelled changes in satellite longitude shift rates are used in ML Neural Network model training data to identify maneuvers for 71 GEO satellites over 2020

ML Model Results: Yellow means predicted maneuver, thick black outline means actual maneuver took place

Performance Metrics (Total Average)		
Accuracy	**Recall**	**Precision**
99.7%	83.4%	27.1%

Benefits of using Machine Learning

Scalability & Generalisability

How a maneuver log dataset adds value

Provide more data to verify labelling physical changes as moments of maneuvers in training data and to verify and improve results

Source: Fig. 9 from Roberts, T. and Linares, R. (2021) 'Geosynchronous satellite maneuver classification via supervised machine learning'. In *Advanced Maui Optical and Space Surveillance Technologies Conference* (AMOS).

Summary & Considerations

What I'm Building

- A homogeneous, public dataset of satellite maneuver logs from multiple sources, anchored by maneuver data from IDS
- Serving as a cross-validation resource and option for ML training dataset for maneuver-related models

Current Considerations

- Formatting heterogeneity across sources (varying headers, reference frames, levels of detail)
- Time needed to communicate with data providers to understand acquisition methods and interpretations
- With more collaboration, the stronger the dataset becomes

Next Steps & Feedback

Next Steps

- Continue growing the dataset with additional sources
- Consolidate sources into an automated load and transform pipeline
- Apply the dataset to detection and classification models
- Continue sharing results across communities

Call for Feedback

- Feedback on feasibility and approach
- Potential additional data sources!
- Interest in collaboration or co-development
- Is this valuable to the IDS community?
- Project is in early stages. Any input will help shape its direction

Thank You

Lara Amusan
UCL | Orbit Lab
lara.amusan.18@ucl.ac.uk
LinkedIn: