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S3TOC OPERATIONS CENTRE

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Should I stay or should I go?

Machine Learning applied to Conjunction Analysis

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IAC-22,A6,2,4,x71184 – 20th September 2022

Agenda

- Introduction
- Objectives
- Risk level change prediction
- State vector propagation improvement
- Conclusions

Introduction

- Crowded LEO environment
  - Increase of close approach events frequency
- S3TOC research activities for resource optimization
- Research aimed at reducing time devoted to conjunction analysis
- Two independent studies are proposed:
  - Risk level change prediction
  - State vector propagation improvement

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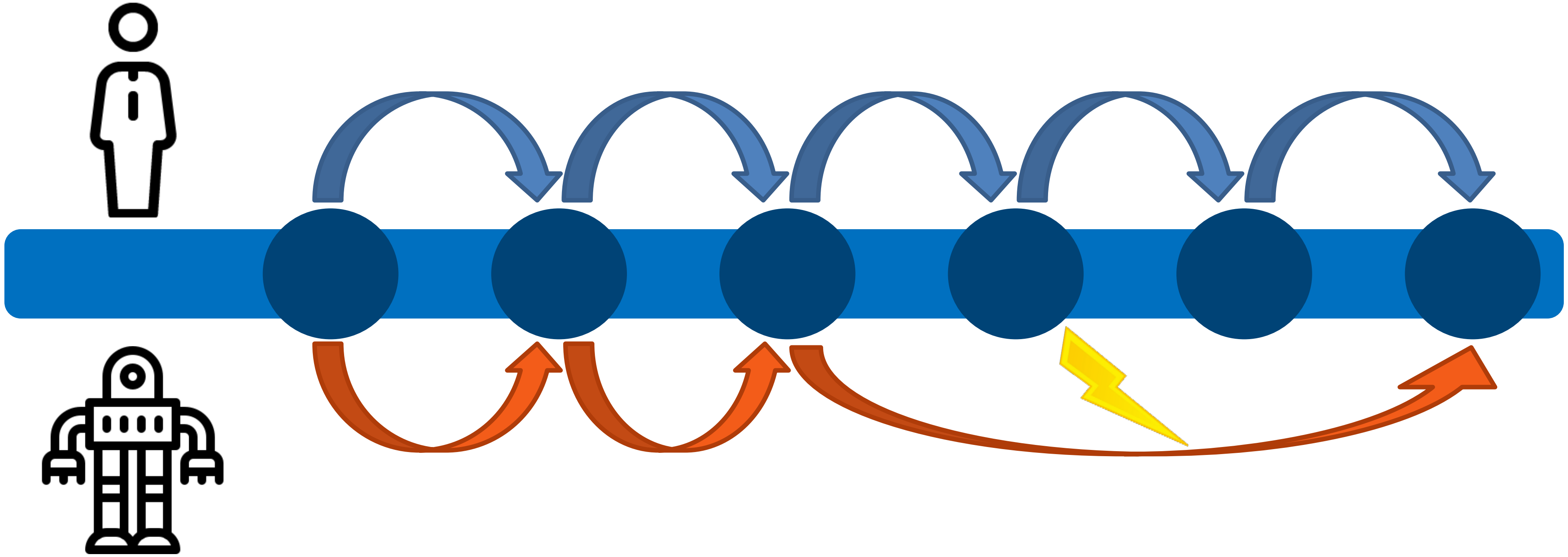
Objectives

- Explore the **applicability of ML** technologies to CA services
- **Improve** event monitoring **accuracy**
- **Accelerate** event resolution and **decrease** operator **workload**



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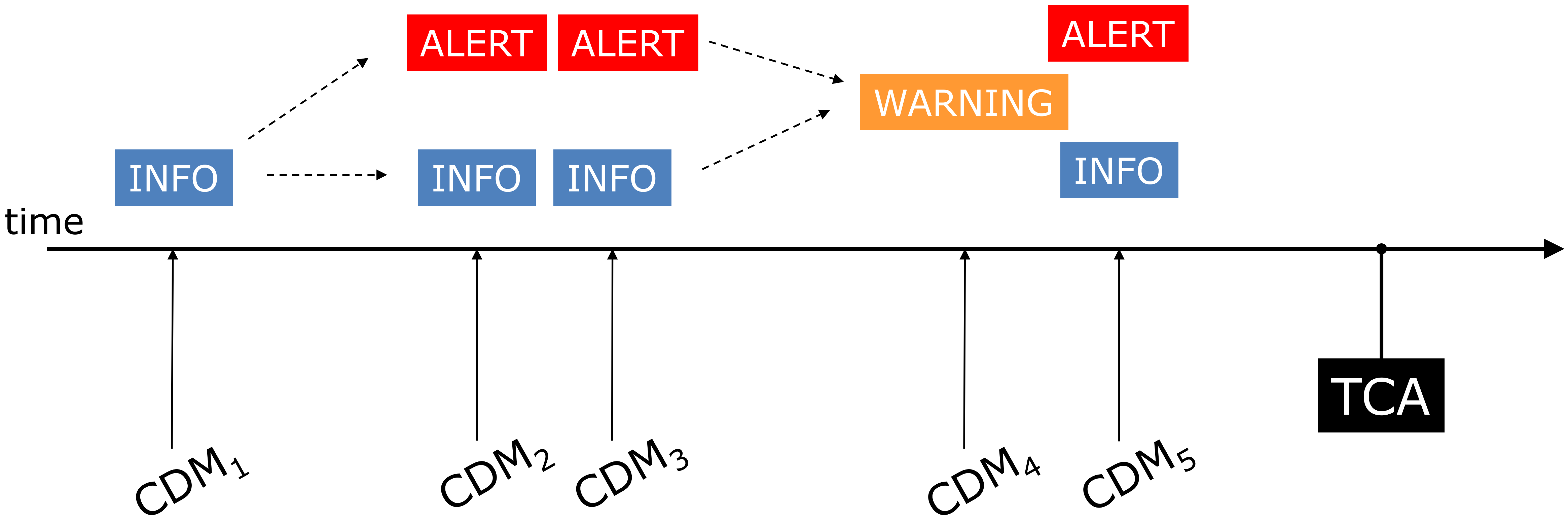
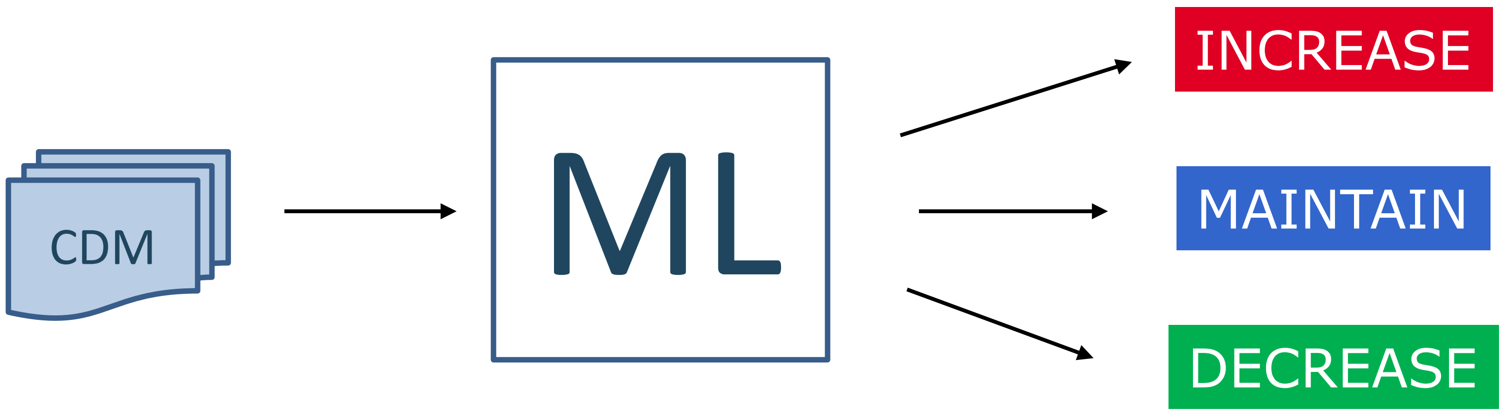
Risk level change prediction

Description



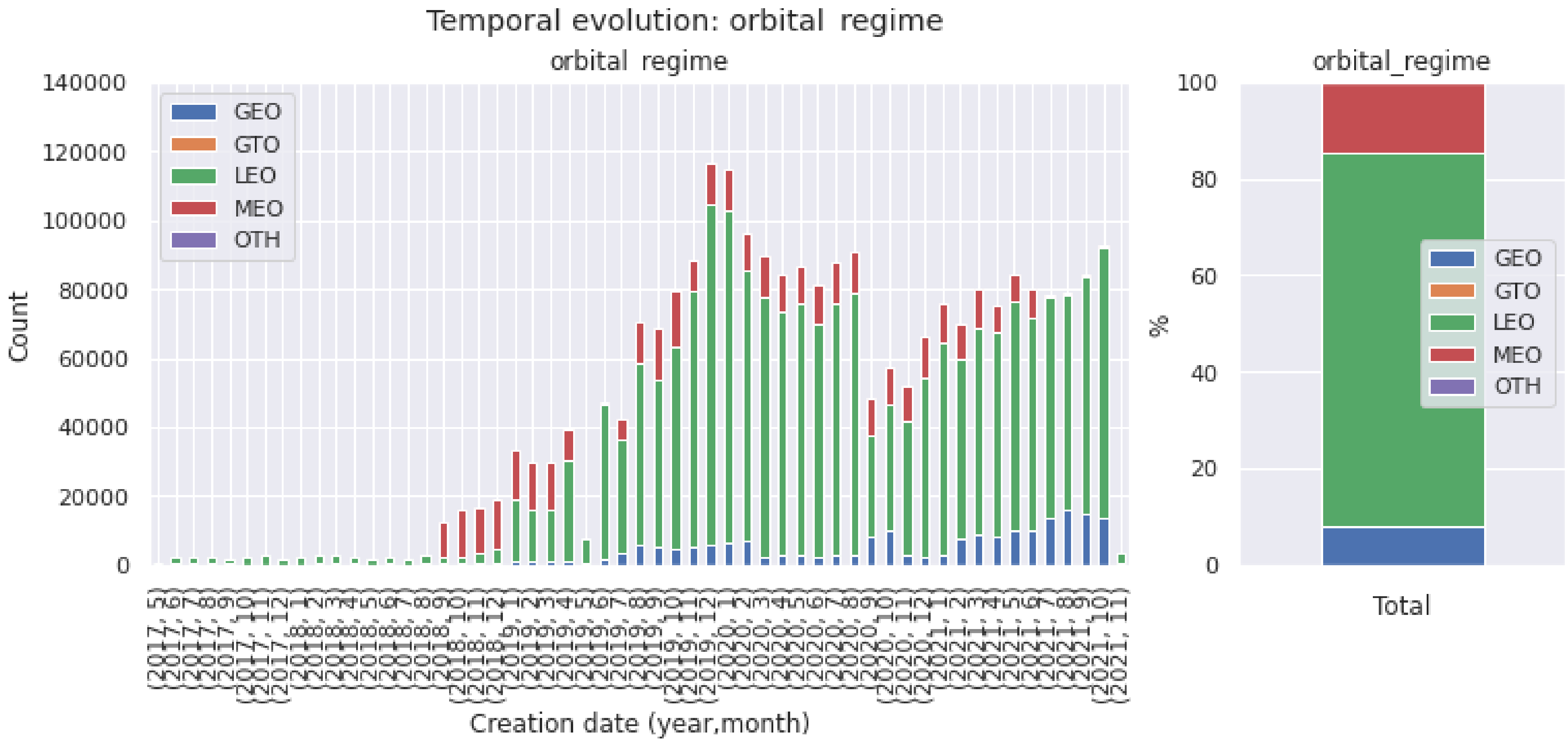
Objective



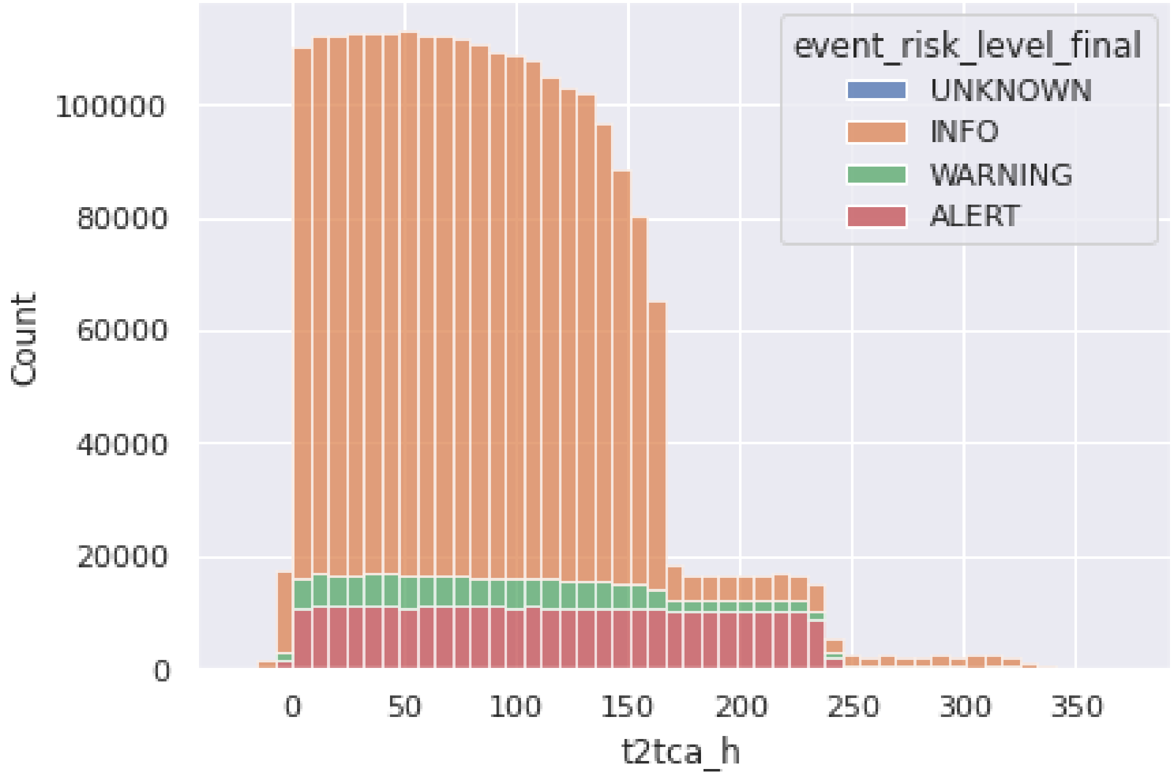
- Predict the probability of the CA event changing its risk level in the future

Dataset

- 1.8 million CDMs
- Median of 8 CDMs per event
- From May 2017 to Nov 2021

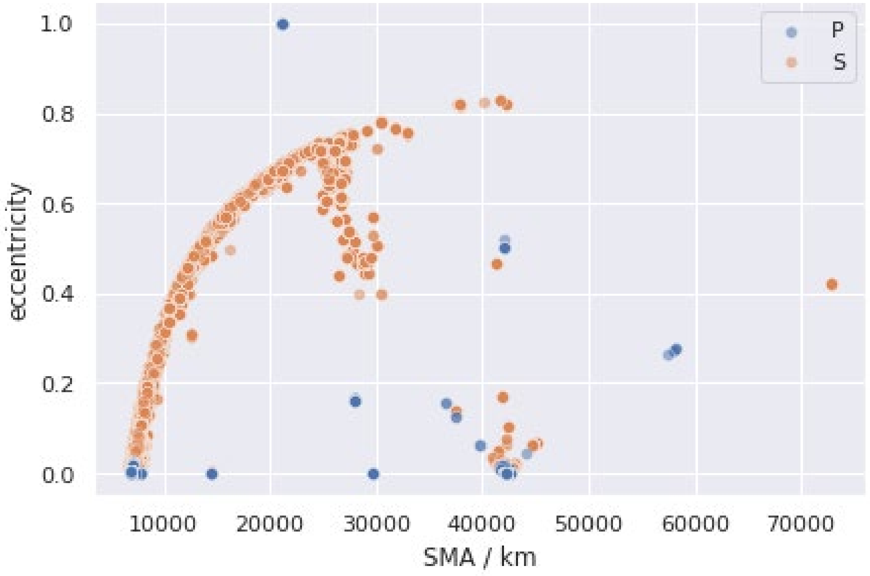


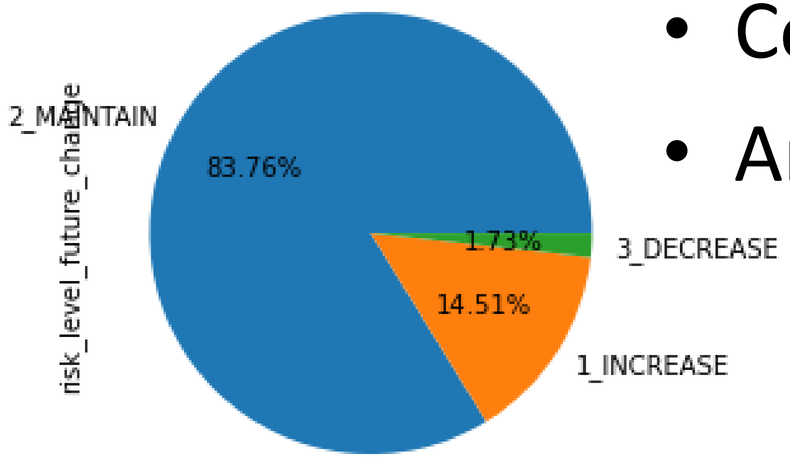
Dataset: 19 features



- a, e, i of P/S
- Time to TCA
- Area P/S
- CDM originator
- Operational status P/S

Dataset: 19 features





- Angle P and S orbital planes
- Miss distance
- Relative speed
- Covariance in B-plane
- Angle pos. and vel.

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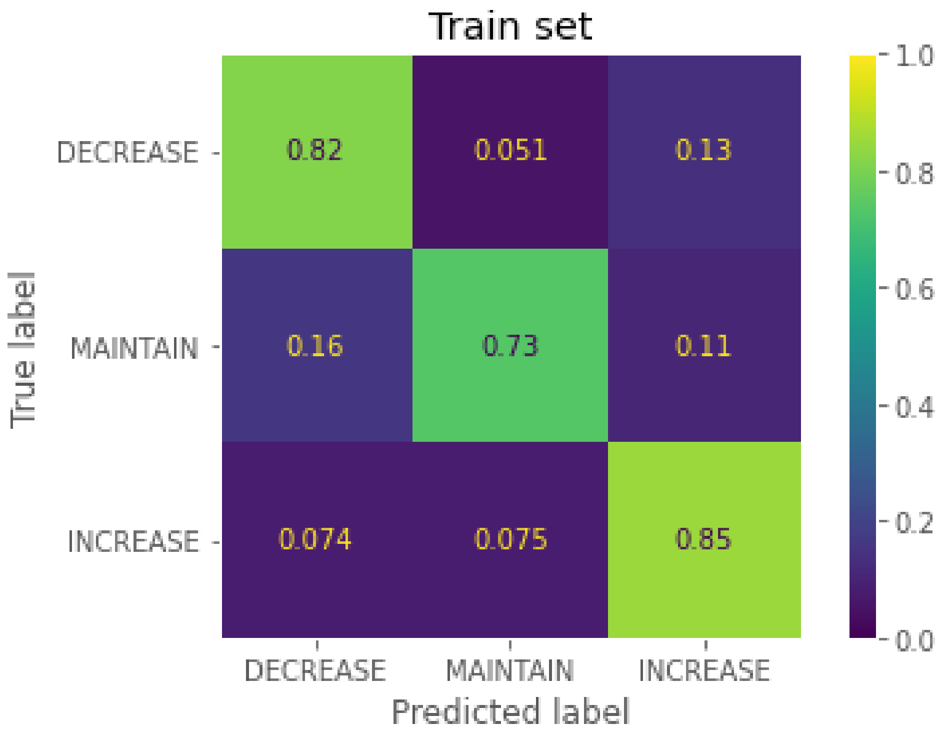
Methodology

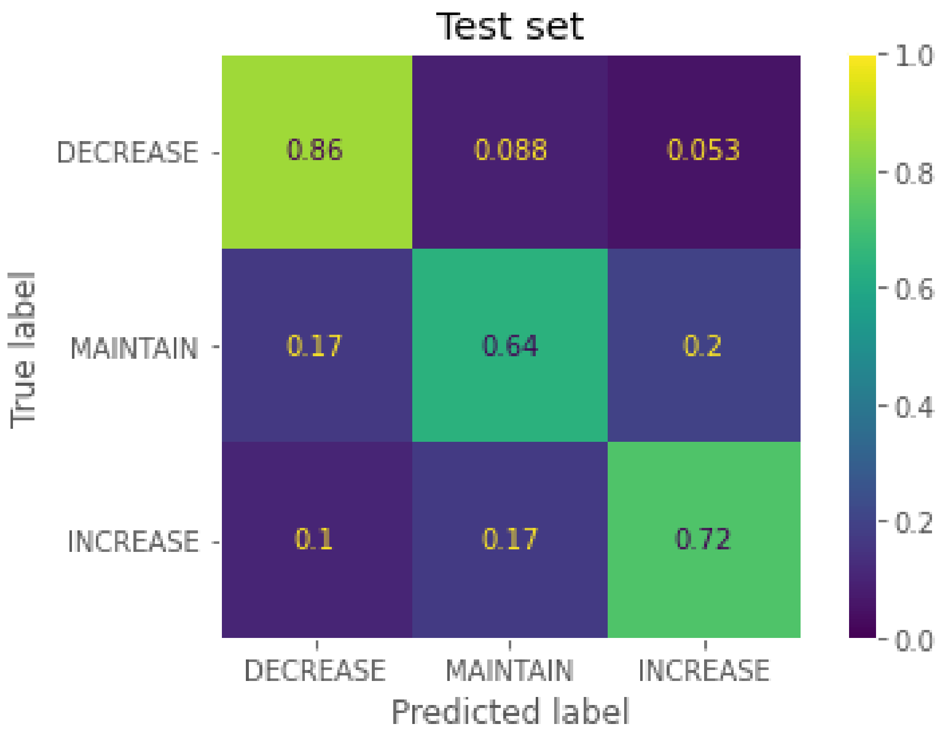
- Ensemble learning based on decision trees:
  - Random forest (RF), Extremely randomized trees (ERT), gradient boosting (GB)
- Robust scaling based on interquartile range (IQR)
- Unbalanced dataset → upsampling for training set
- Test set: from March 2021 to Nov 2021 (24%)

- **Automatic hyperparameter search** → LightGBM

Results



Train set
True label
DECREASE
MAINTAIN
INCREASE
0.82
0.051
0.13
0.16
0.73
0.11
0.074
0.075
0.85
DECREASE
MAINTAIN
INCREASE
Predicted label
1.0
0.8
0.6
0.4
0.2
0.0

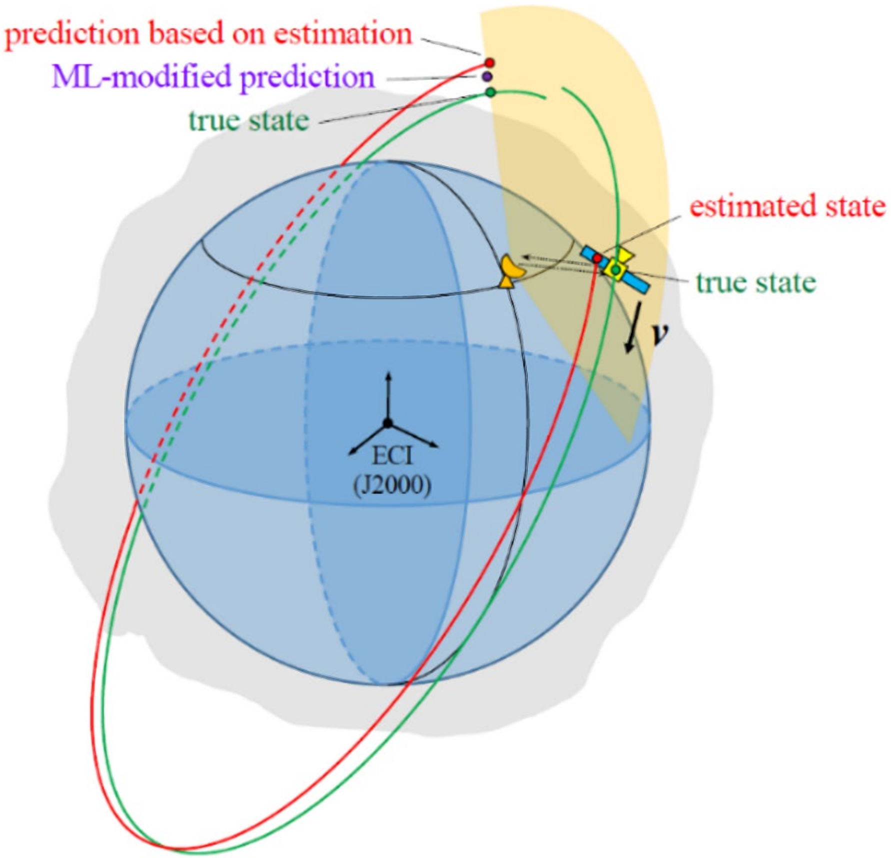


Test set
True label
DECREASE
MAINTAIN
INCREASE
0.86
0.088
0.053
0.17
0.64
0.2
0.1
0.17
0.72
DECREASE
MAINTAIN
INCREASE
Predicted label
1.0
0.8
0.6
0.4
0.2
0.0

State vector propagation improvement

Objective

- Apply a correction to a propagated state.
- Each CDM contains the state at TCA.
- The algorithm generates a correction.



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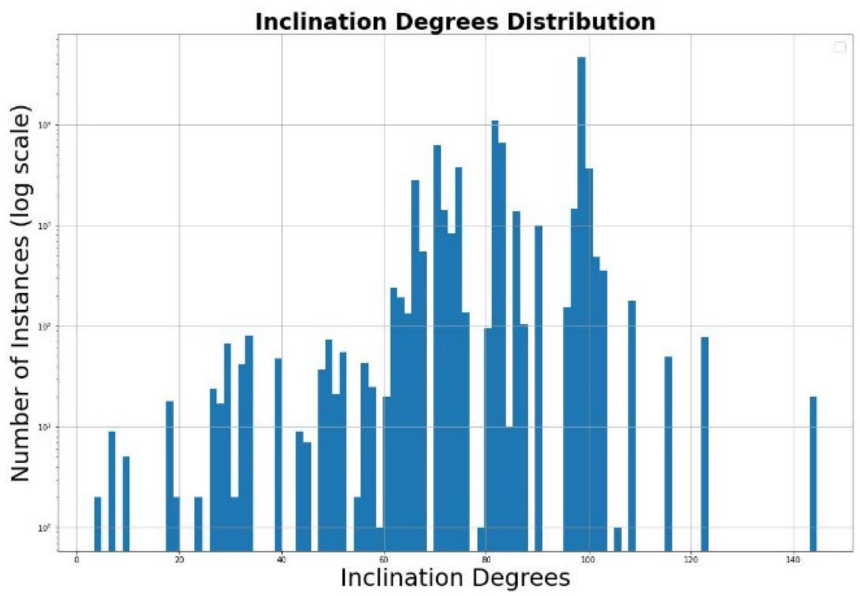
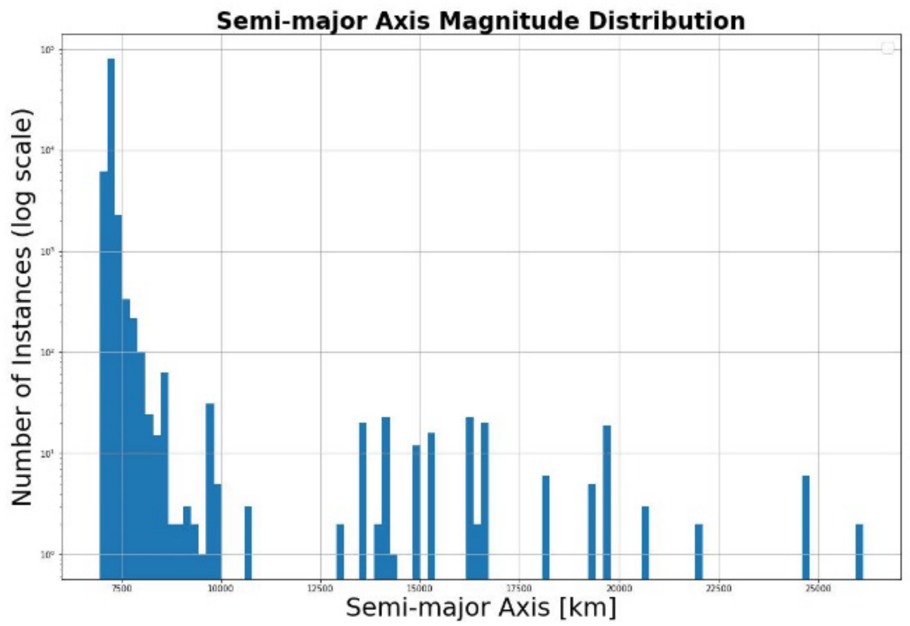
Dataset

- ~150.000 CDMs from EUSST O/O users
- Only secondary objects
- Primaries on polar orbits





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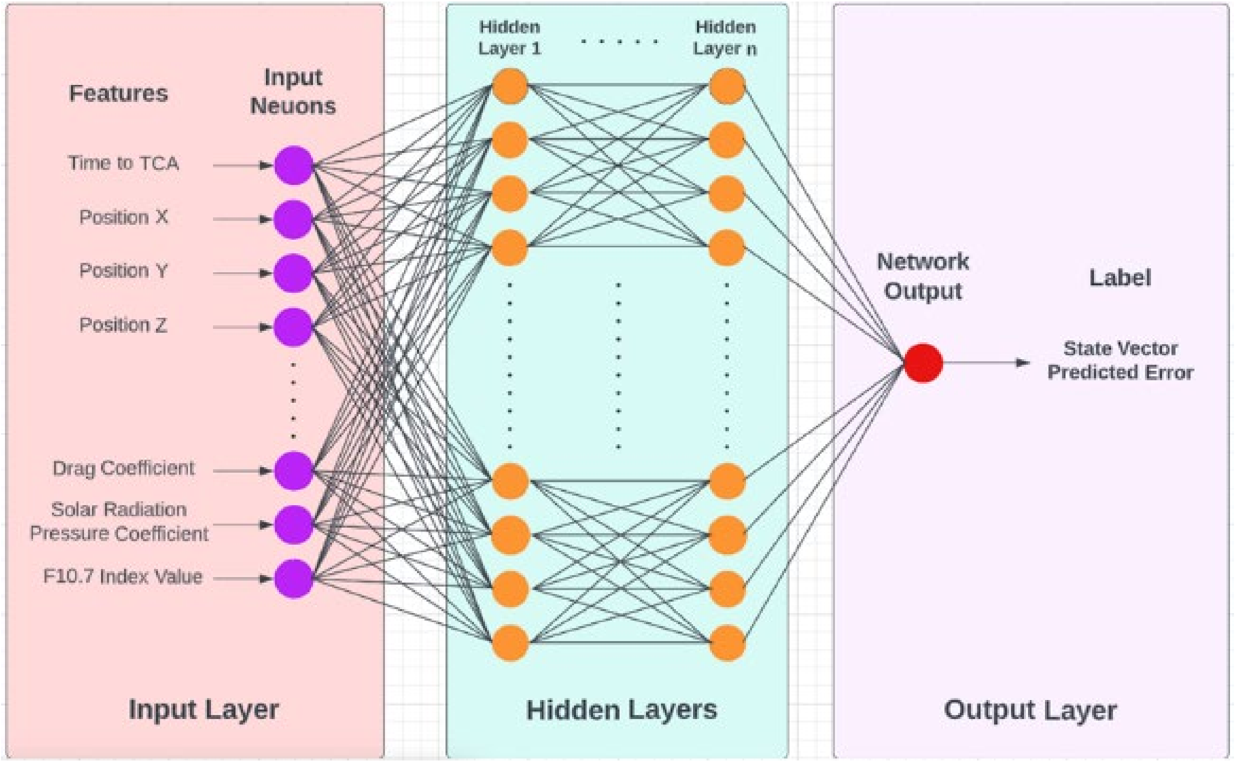
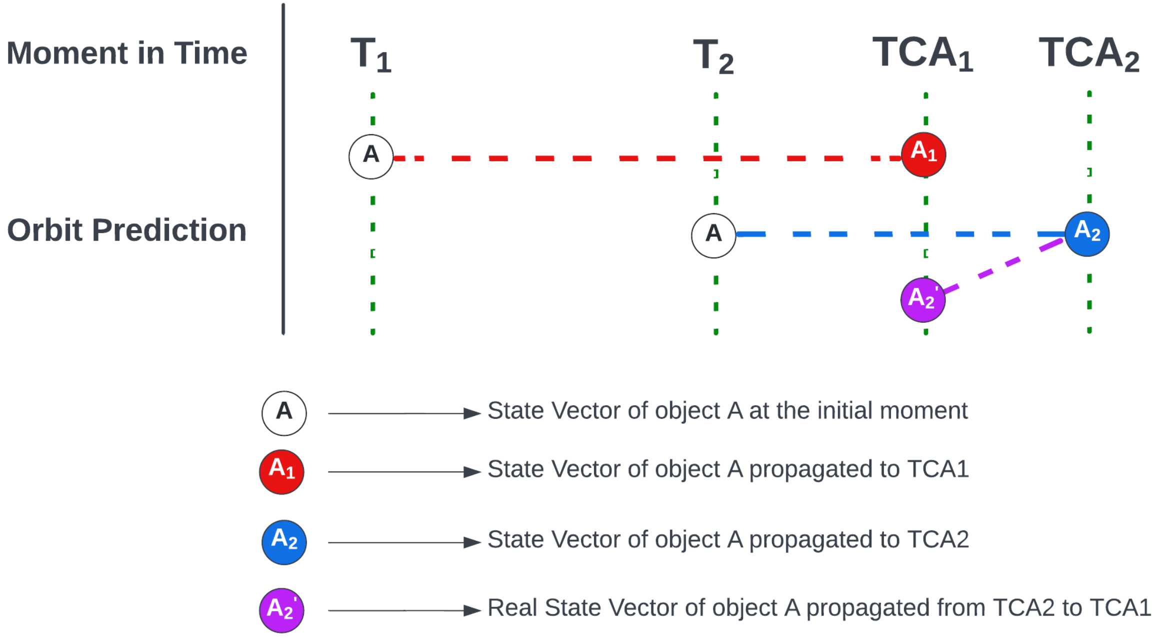
Methodology

- Single CDM approach
- State vector of last CDM as true value
- Inputs from CDM + F10.7 index
- Feedforward deep neural network



Methodology

- State vector in last CDM (A_2) propagated to TCA of input CDM (TCA_1)



Results

- Results are tested on 30% of the data
- The error of the corrected value is projected to a RTN reference frame
- Results are compared against a baseline
- Baseline is best knowledge at prediction time (i.e., no correction)

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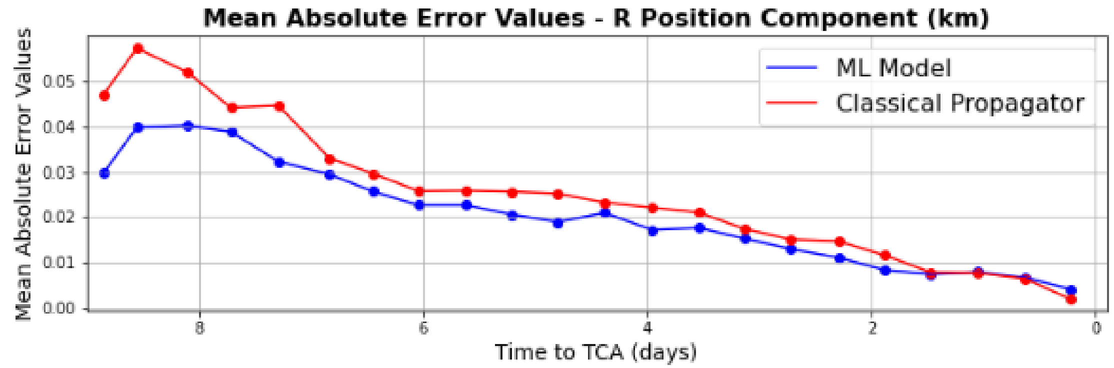
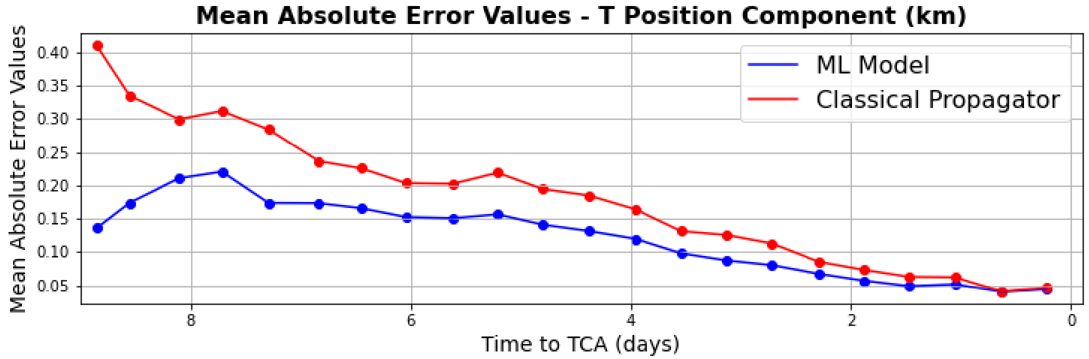
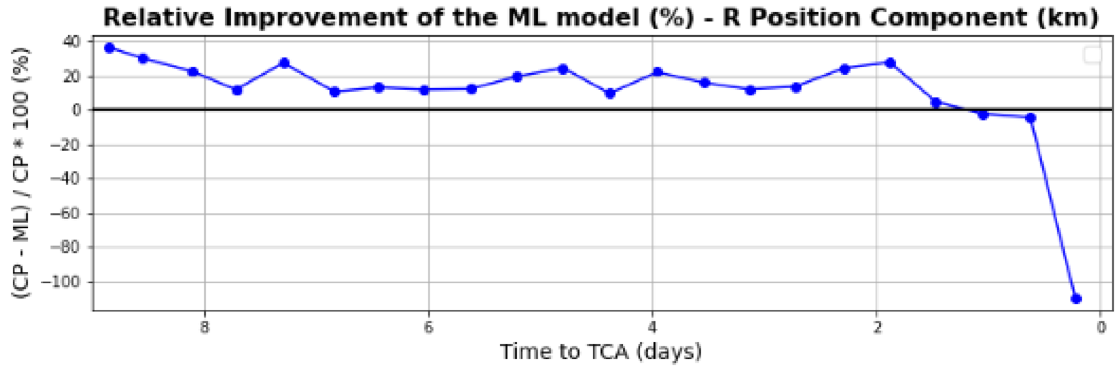
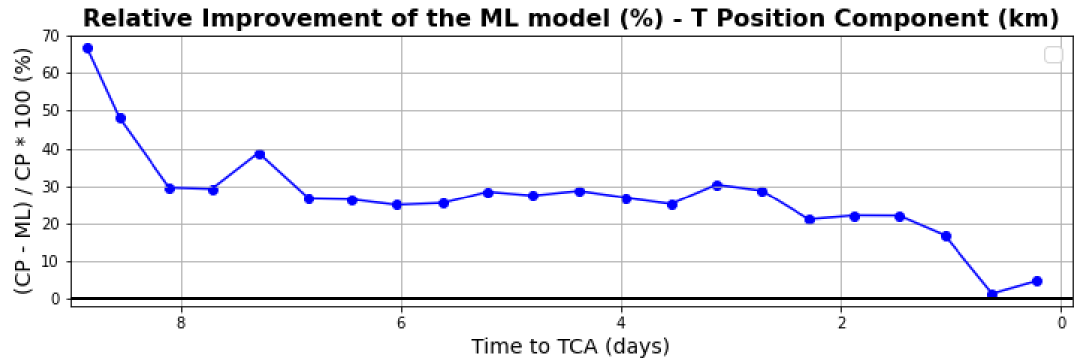
Results









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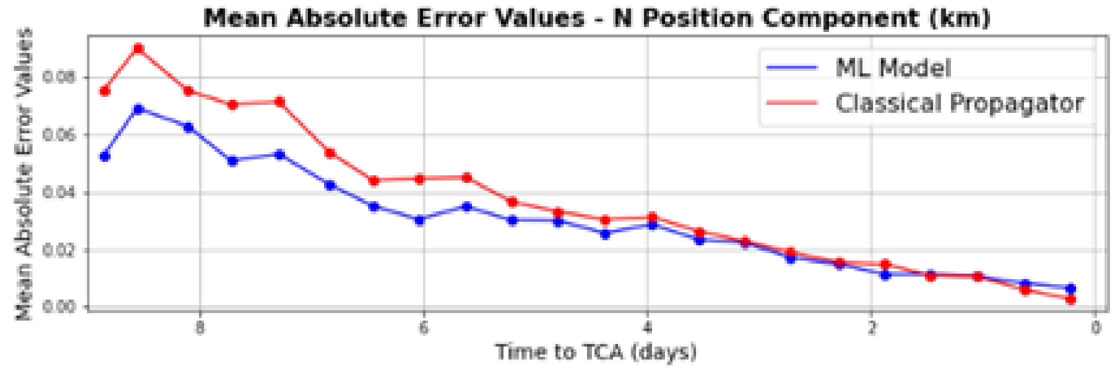
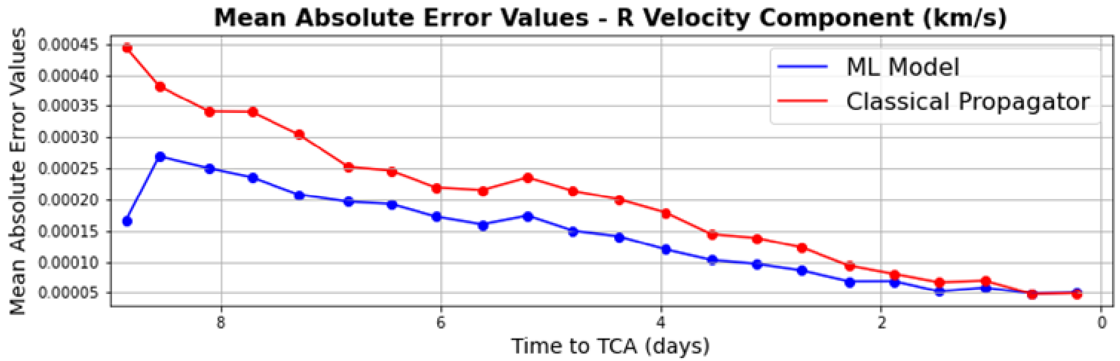
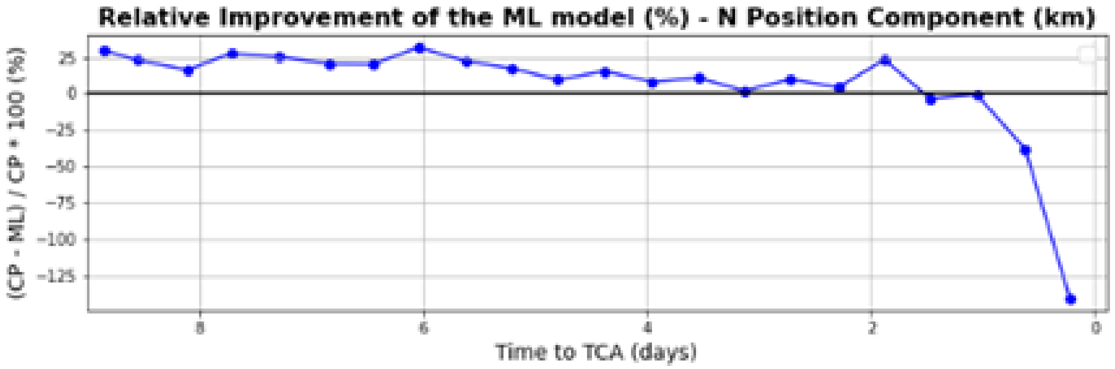
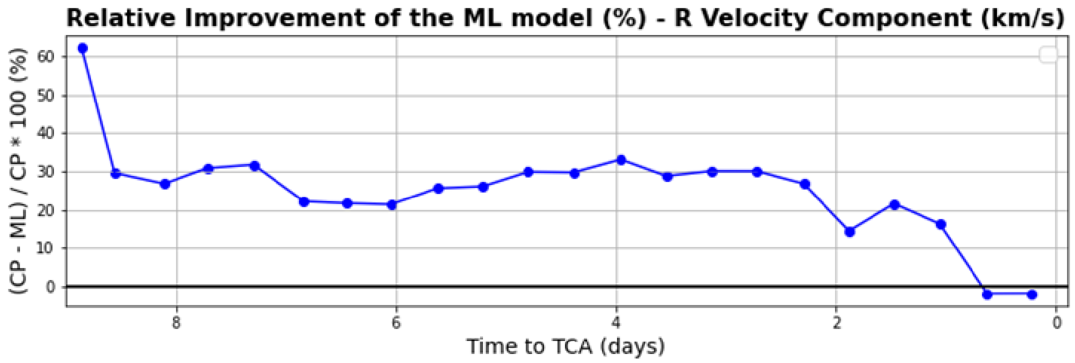
Results

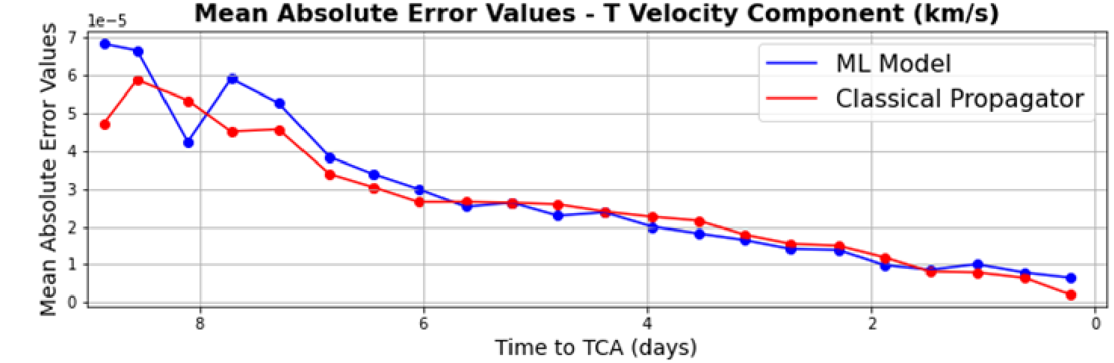

Mean Absolute Error Values - N Position Component (km)
Mean Absolute Error Values
0.08
0.06
0.04
0.02
0.00
ML Model
Classical Propagator
8
6
4
2
0
Time to TCA (days)

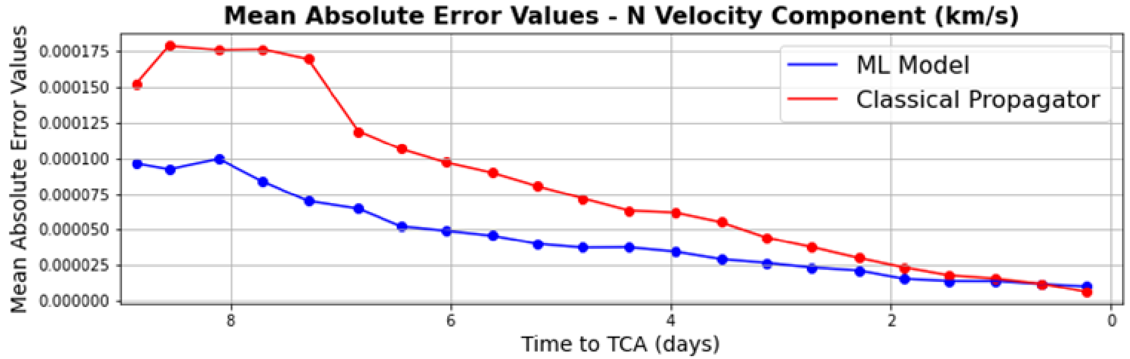

Mean Absolute Error Values - R Velocity Component (km/s)
Mean Absolute Error Values
0.00045
0.00040
0.00035
0.00030
0.00025
0.00020
0.00015
0.00010
0.00005
ML Model
Classical Propagator
8
6
4
2
0
Time to TCA (days)

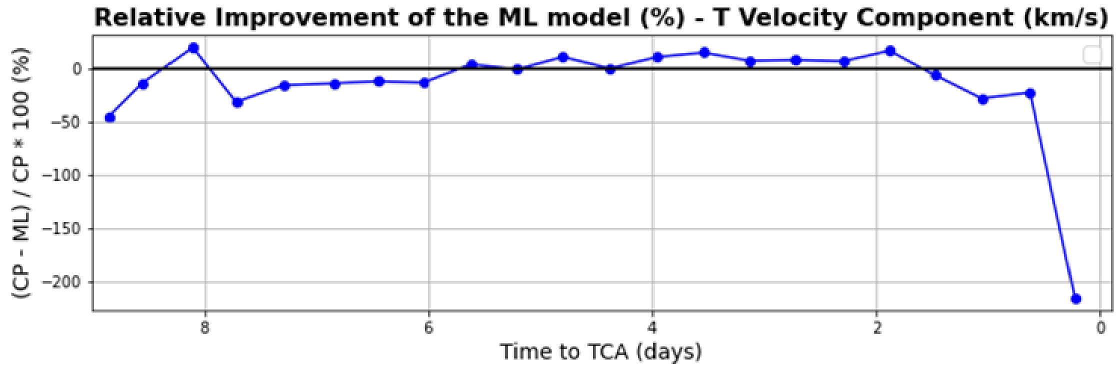

Relative Improvement of the ML model (%) - N Position Component (km)
(CP - ML) / CP * 100 (%)
25
0
−25
−50
−75
−100
−125
8
6
4
2
0
Time to TCA (days)

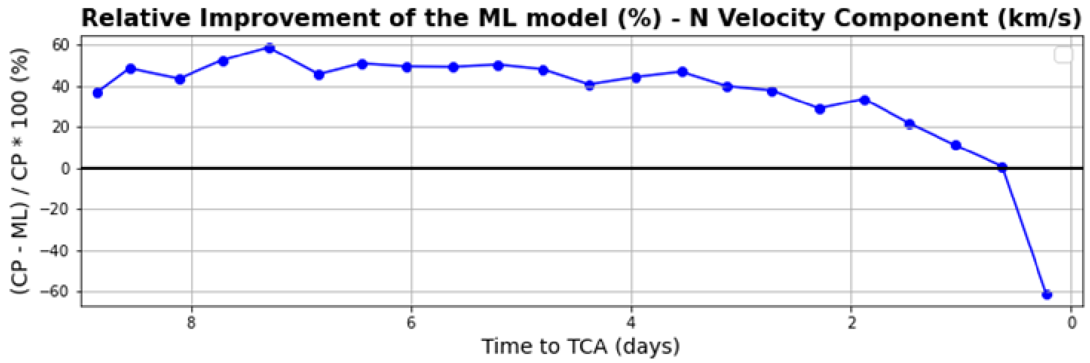

Relative Improvement of the ML model (%) - R Velocity Component (km/s)
(CP - ML) / CP * 100 (%)
60
50
40
30
20
10
0
8
6
4
2
0
Time to TCA (days)

Results









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Conclusions

- Machine learning can provide meaningful value to SSA operations
- Applicability has been proven and both tasks tackled successfully in research activities with actual operational data

- Continued deployment must be closely monitored
- Additional studies outside the used dataset are required

THANK YOU VERY MUCH !

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Daniel Lubián Arenillas (daniel.lubian@deimos-space.com)

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