SmallSat SSC21-IX-02

# Improved Orbital Propagator Integrated with SGP4 and Machine Learning

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HYPER GIANT INDUSTRIES

# INTRODUCTION

## Why accurate orbital prediction?

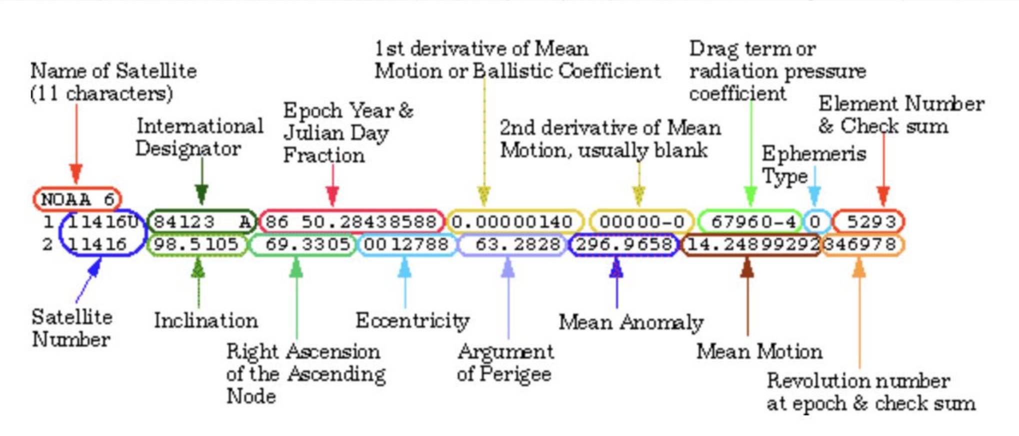
Benefits

- Better mission operation planning, and prioritization
- Facilitate mission autonomy
- Improve space situational awareness
- Improve collision avoidance

# CURRENT APPROACH

## SGP4 (Simplified General Perturbation Model- 4)

### Data- TLE (Two-Line Element)



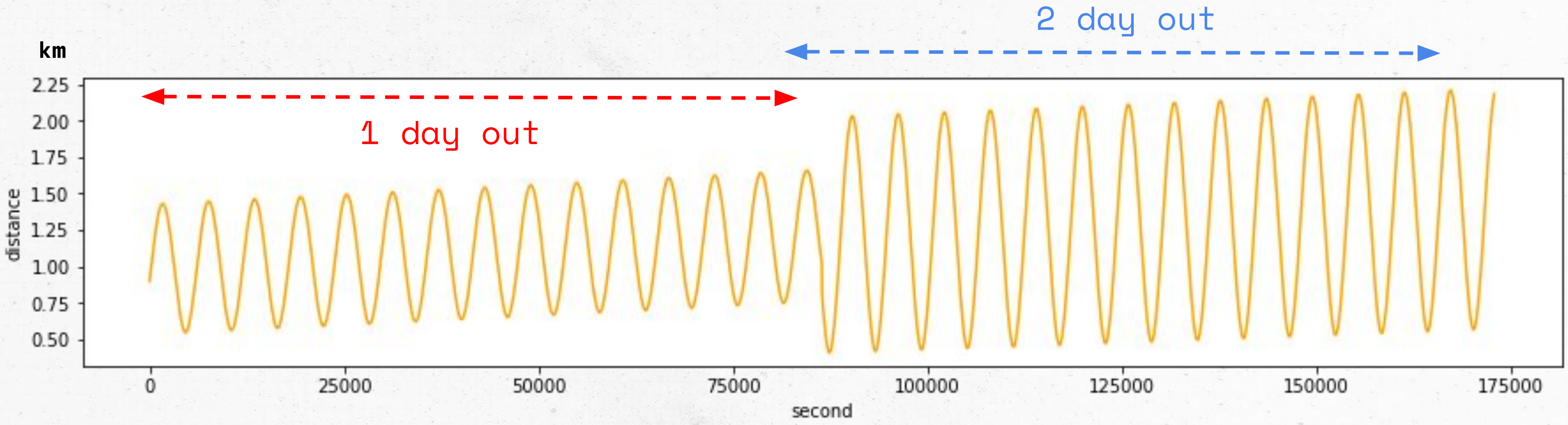

Source: NASA

### Limitations

- Only considers the main perturbing effects
- Low Earth Orbit (LEO) objects → distance error: **1-3 Km** each day

# Example: Dove 3 Sat- Planet

## NORAD ID: 39429- Error (distance: prediction - actual)



# IMPROVEMENT

**Hybrid model = SGP4 + Machine Learning (ML)**

- Use ML to model SGP4 distance error patterns
- Two ML estimators: Auto-Encoder and Random Forest
- Auto-Encoder to learn the embeddings of historical TLE propagation
- Random Forest to learn the trend of historical embedding vectors
- Treat distance errors as waveforms

→ use modeled error waveform to make correction to SGP4 propagation

# TESTING OBJECTS

## 3 LEO objects

- NORAD: 27845- **QuakeSat** (Research CubeSat by Stanford)
- NORAD: 20774- **COSMOS 2098** (Satellite Payload)
- NORAD: 23975- **PEGASUS DEB** (Satellite Debris)

→ no propulsive capability

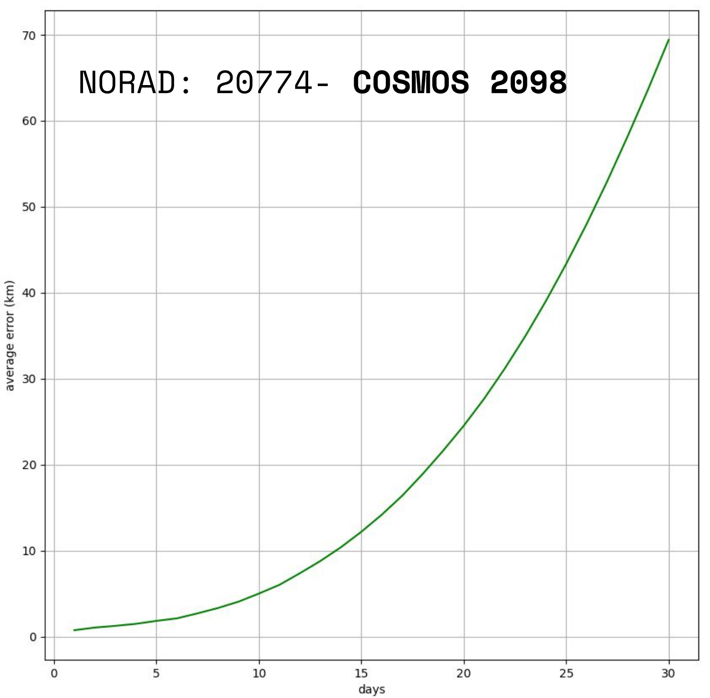
→ TLE data collected via Space-Track API

→ all 3 objects have ~ 20 years daily TLE

# SGP4 ERROR

**Average distance error 1-30 days out; period Jan 2020- June 2020**

Daily TLE with SGP4 propagation to 24 hours




→ consider as valid pseudo-observation

→ assume as ground truth

Distance error

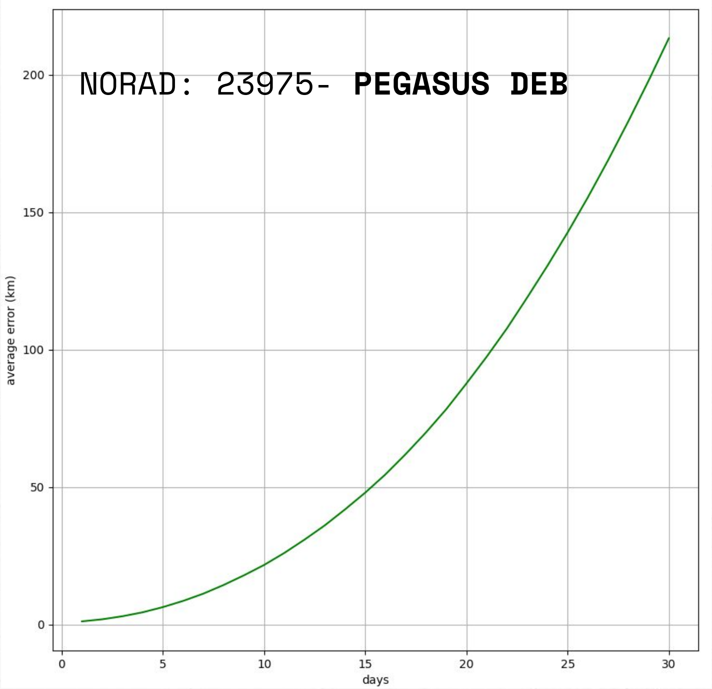
- 15 days out- 12 km
- 30 days out- 70 km

→ **Benchmark**

# SGP4 ERROR

## Average distance error 1-30 days out; period Jan 2020- June 2020

Daily TLE with SGP4 propagation to 24 hours




→ consider as valid pseudo-observation

→ assume as ground truth

Distance error

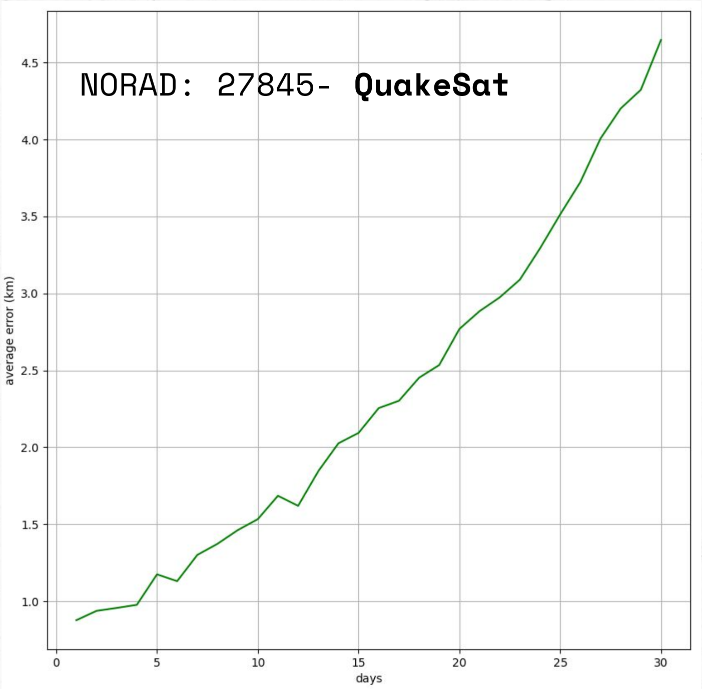
- 15 days out- 50 km
- 30 days out- 210 km

→ **Benchmark**

# SGP4 ERROR

**Average distance error 1-30 days out; period Jan 2020- June 2020**

Daily TLE with SGP4 propagation to 24 hours




→ consider as valid pseudo-observation

→ assume as ground truth

Distance error

- 15 days out- 2 km
- 30 days out- 5 km

→ **Benchmark**

# ML FRAMEWORK & WORKFLOW

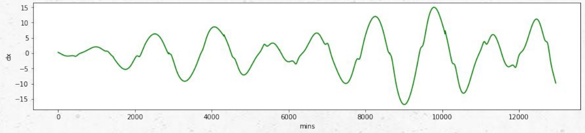
~ 1,000
daily TLE

TLE

SGP4

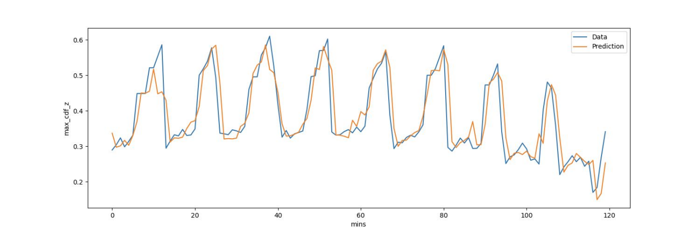
Propagate
30 days

Position error:
x, y, z
(30 days out)




Auto-Encoder

Encode embedding
vectors
(time-series)

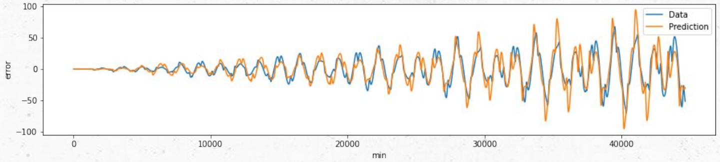



Random
Forest

Learn the trend of
historical
embedding vectors

Predict next time step of
embedding vector

Decode embeddings to error
waveform




Make
correction
to
SGP4
predictions

# RESULTS

NORAD: 20774 COSMOS 2098

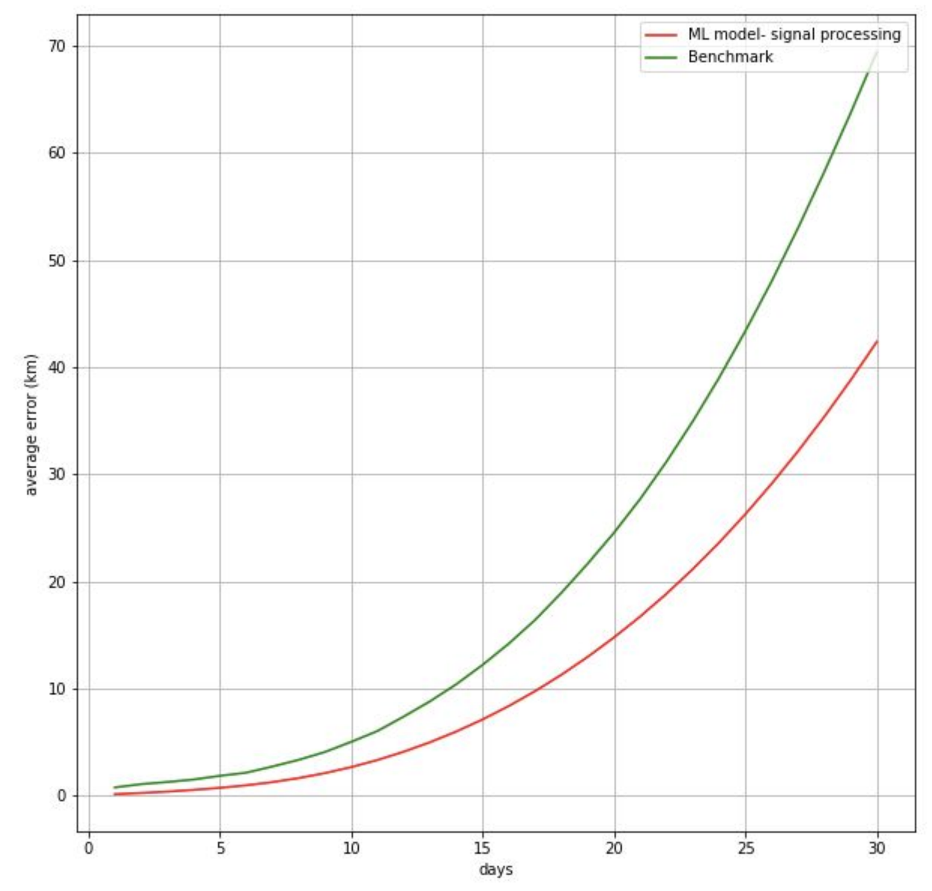
Training ~1,000 daily TLE

Validate ~120 daily TLE

→ 30% Error reduction

Distance error improvement

- 15 days out: 12 km → 8 km
- 30 days out: 70 km → 45 km



# RESULTS

NORAD: 23975 PEGASUS DEB

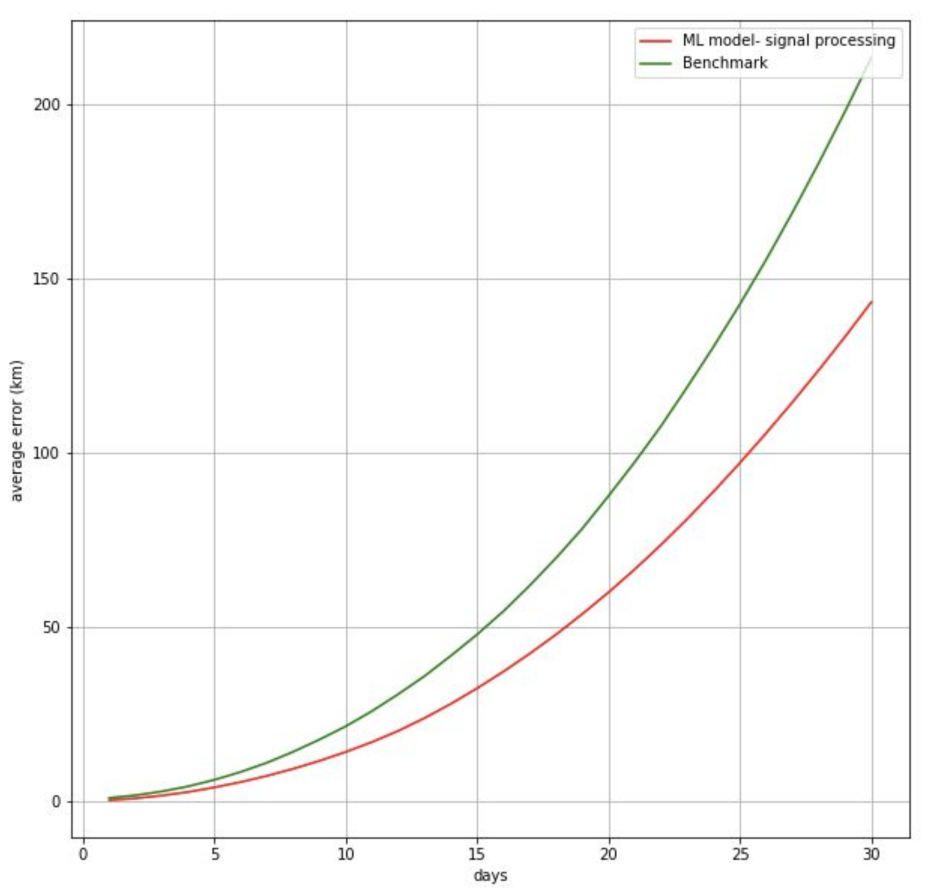
Training ~1,000 daily TLE

Validate ~120 daily TLE

→ 30% Error reduction

Distance error improvement

- 15 days out: 50 km → 35 km
- 30 days out: 210 km → 150 km



# RESULTS

NORAD: 27845 QuakeSat

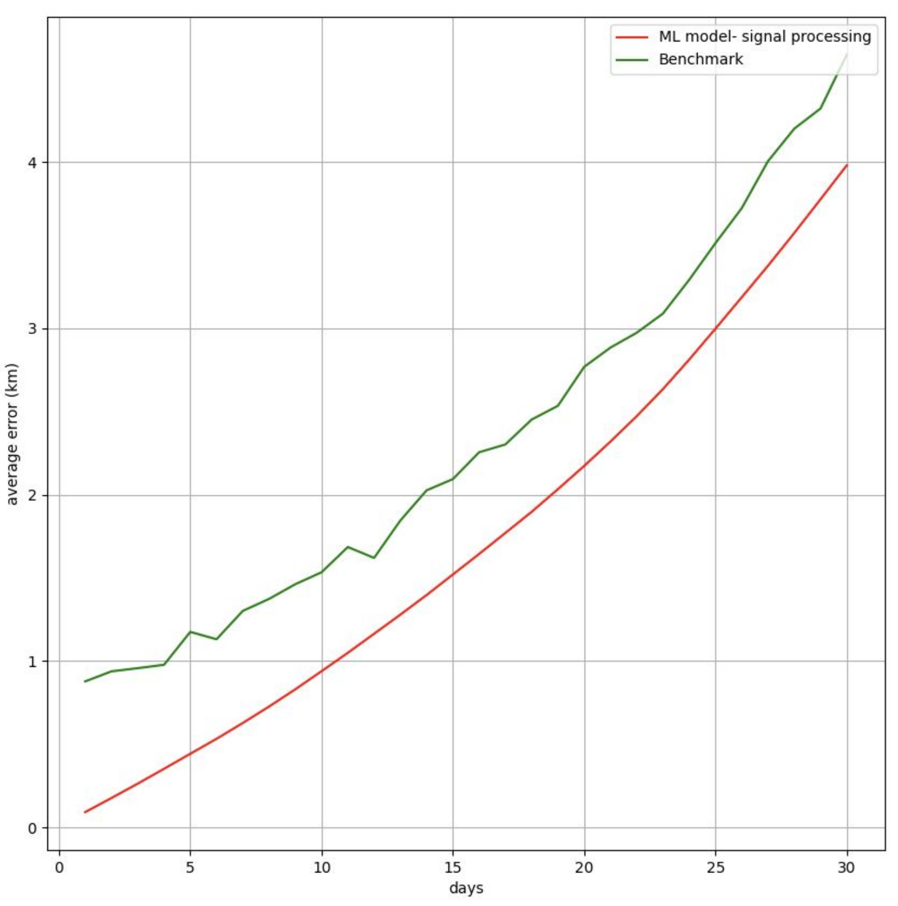
Training ~1,000 daily TLE

Validate ~120 daily TLE

→ 25% Error reduction

Distance error improvement

- 15 days out: 2 km → 1.5 km
- 30 days out: 5 km → 4 km



# DISCUSSION

## Hybrid model: SGP4 + ML error correction

- Time-series orbital error patterns can be modeled by ML
- Beat SGP4 benchmark by 25-30% with test cases

- Limitations: need at least 3 years of TLE data

  → can be overcome by creating synthetic orbital data with similar objects in orbit

# POTENTIAL APPLICATIONS

**This hybrid model can easily be packaged into software tool.**

- Better ground station bandwidth forecast
- Better AOS (acquisition of signal) and LOS (loss of signal) prediction
- Better mission planning and optimization
- Measuring ground station reliability
- Improve satellite trajectory design
- Facilitate collision risk analysis