Atmospheric Drag in Satellite Swarms

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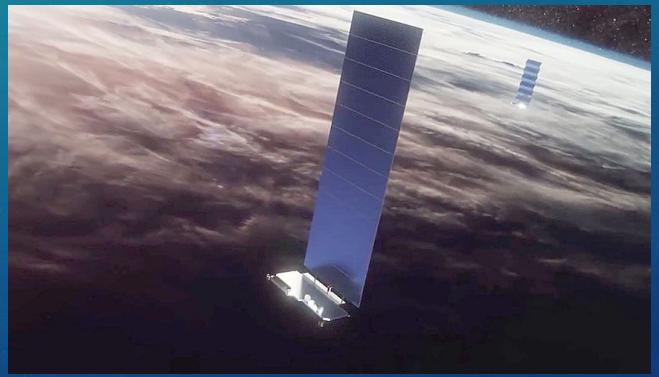
What is a CubeSat?

- As technology improves, it reduces in size and becomes more efficient
- Satellites follow this rule, and have gone from the size of buses to the size of tables
- CubeSats exist in mega-constellation swarms, where they all work together and function as a unit



Normal CubeSat conditions

- The CubeSat swarms usually travel through Low Earth Orbit (LEO), and experience a normal amount of atmospheric drag

- This is accounted for in their design and orbit, which we calculate first before adding the drag force model into the picture

Solar Weather

- As the Sun goes through its part of the cycle where it is active, sometimes it releases Coronal Mass Ejections(CMEs)
- When these CMEs hit Earth, they have big impacts on the atmosphere and its properties

Video courtesy of Rees Tucker, SWx TREC

Effects on Atmosphere

- The increased amount of particles and energy affect the whole atmosphere
- For the purposes of the research, we studied the Thermosphere where the CubeSat swarms reside
- The CMEs generates stormy conditions and causes the Thermosphere to increase in density.

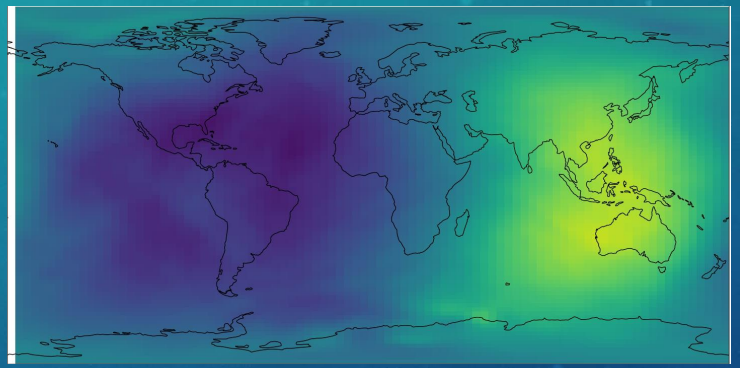
Effect on Satellites in Thermosphere

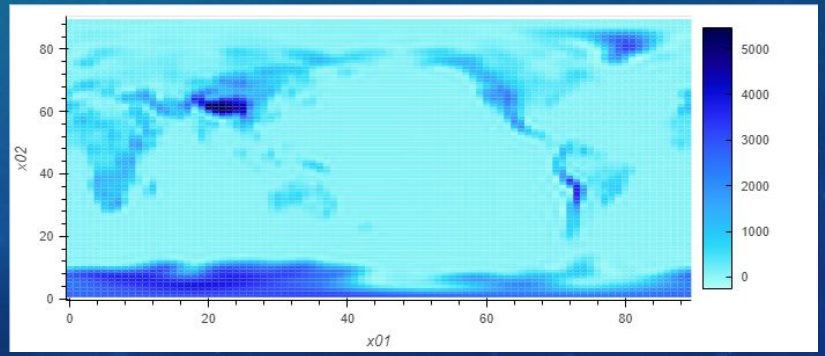
- As the density and other properties of the Thermosphere change, the drag acceleration increases on the CubeSats
- Their orbits begin to decay, they start to lose elevation, and their position becomes unpredictable

Video courtesy of Rees Tucker, SWx TREC

WAM-IPE

- We used the Whole Atmosphere Model (WAM), Ionosphere Plasmasphere Electrodynamics (IPE). Only using WAM for purposes of research
- This WAM is a Physics based model run during the 2003 geomagnetic storm
- Each cell in 3D array has information regarding density, particle ratios, and temperature
- Using the WAM output, we are able to create an operational forecasting model





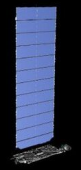
Orbit Propagator

- To calculate the properties of the CubeSats, we download the updated Two Line Element (TLE) data
- We ran the TLE through a TLE propagator, which is a computer program that is used to compute the position, velocity, and acceleration of an earth-orbiting satellite
- After we figured out our initial starting point and speed, we switch to a numerical propagator so we can add the force model

Force Model

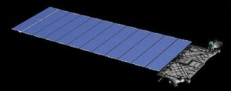
- To calculate the drag, we created a function that takes in variables from the conditions of the CubeSat
- This includes the position (in ECEF coordinates), the velocity, the density, the temperature, the ratio of molecules, and the angle relative to the sun
- Based in this information, we can figure out the geometry and orientation of the CubeSat as it travels through storm conditions and experiences drag

On station, brightness is driven by antennas since the satellite is in the "shark-fin" configuration during sunset and sunrise.



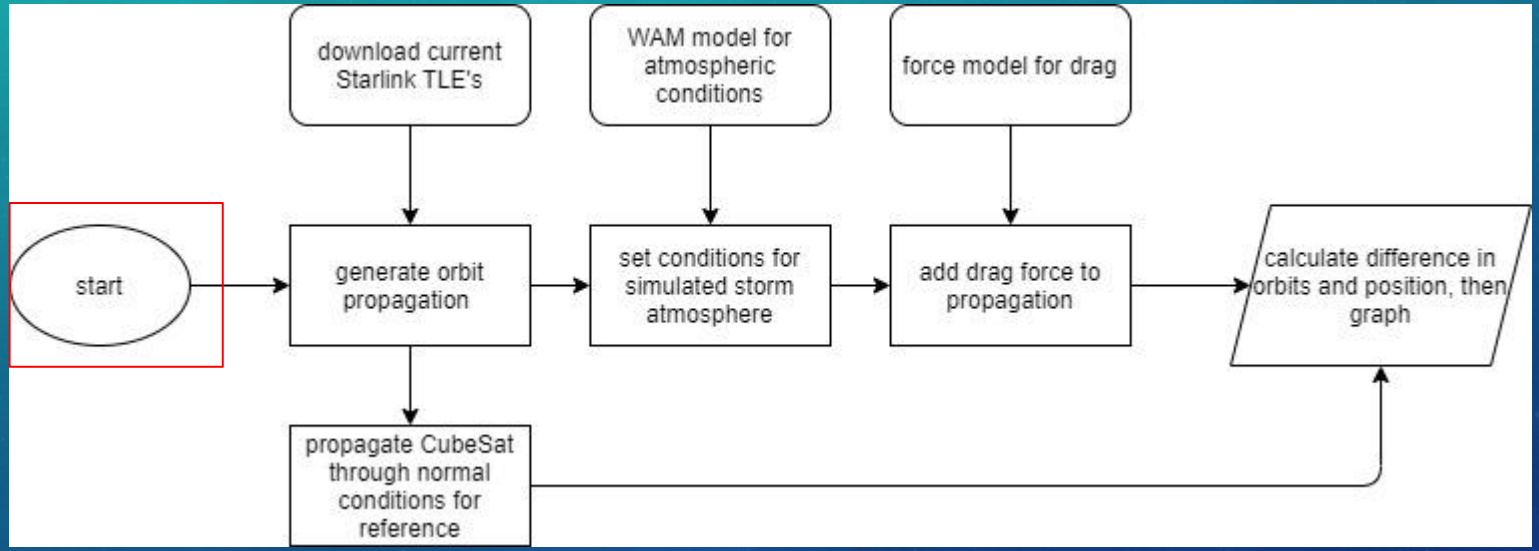
SHARK-FIN

During orbit raise, brightness is driven by the "open book" configuration for thrusting and drag and sunlight reflects off both the antenna and array.



OPEN BOOK

Flowchart for Propagation



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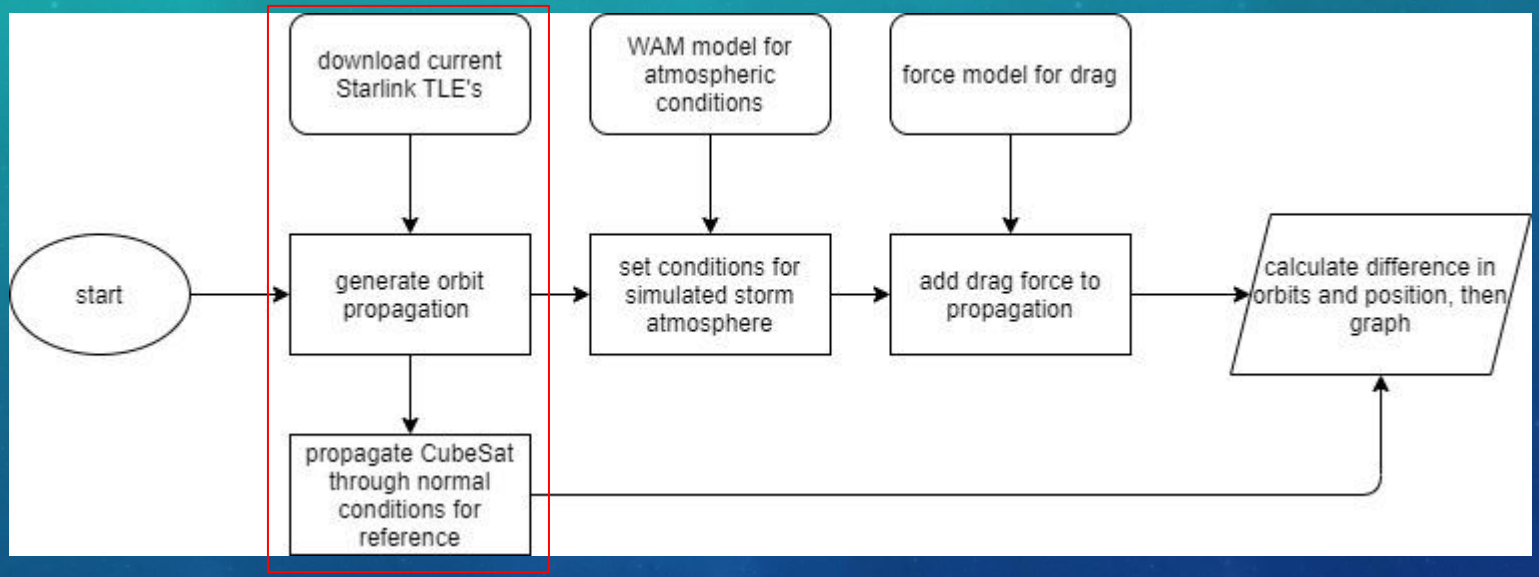

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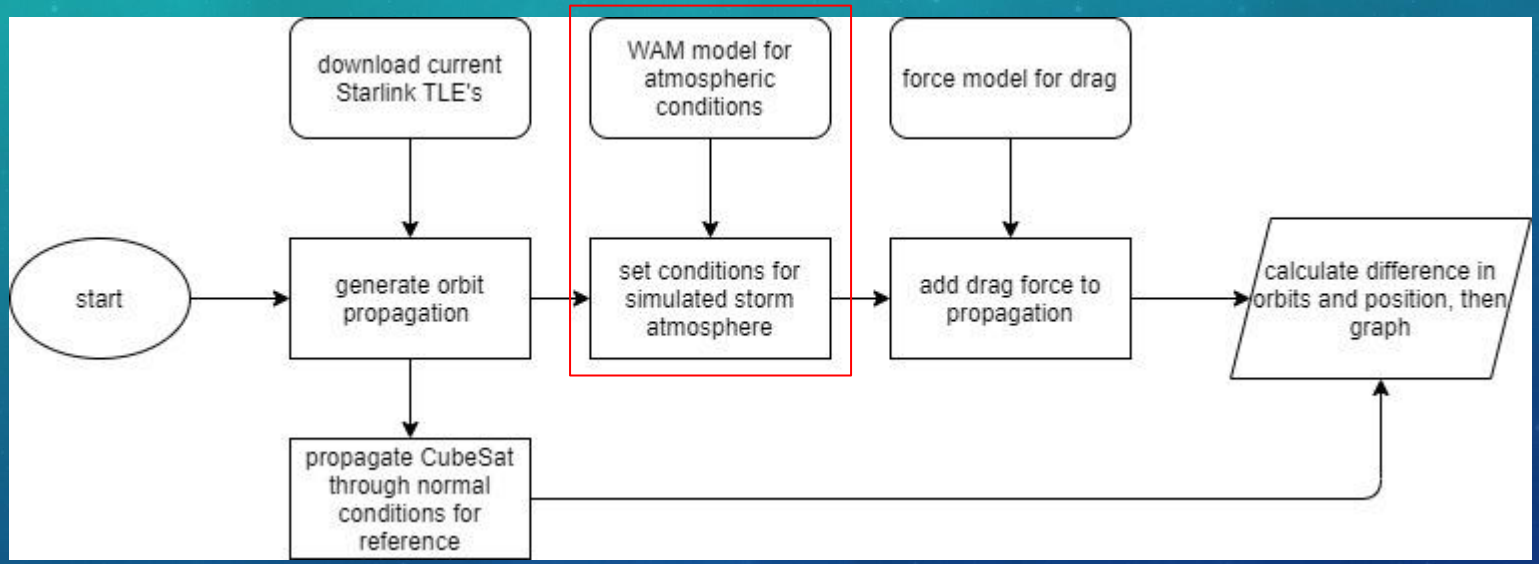

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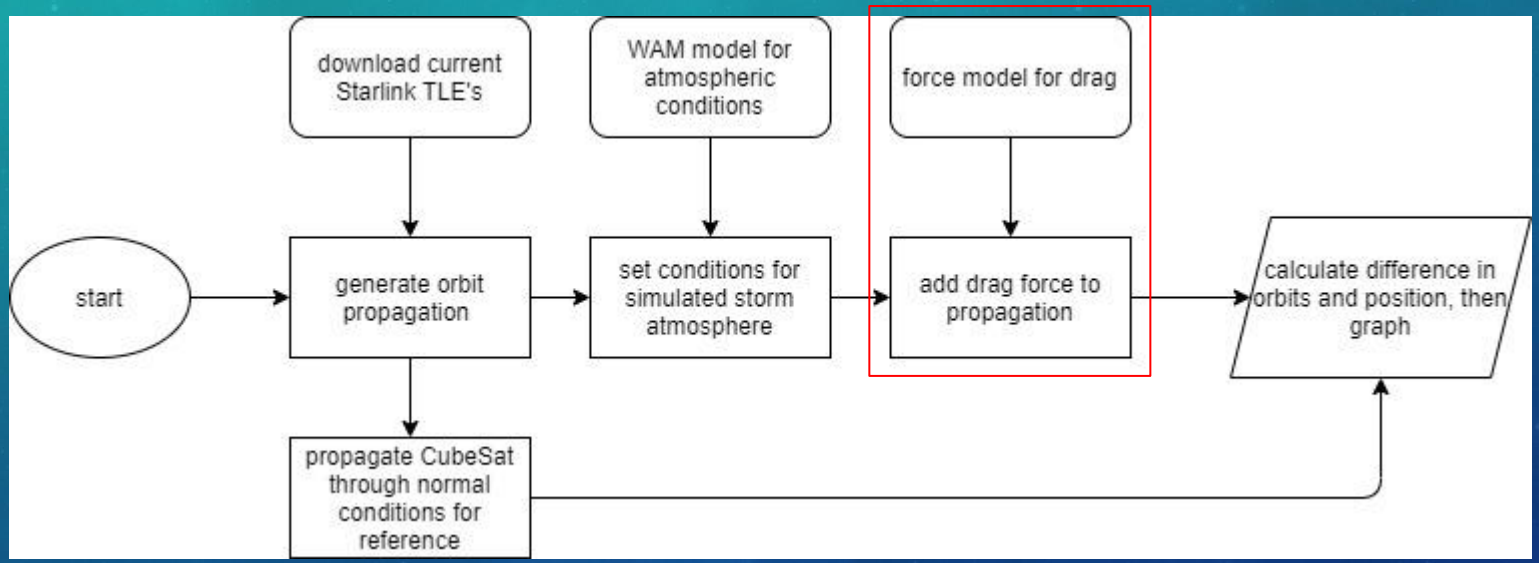

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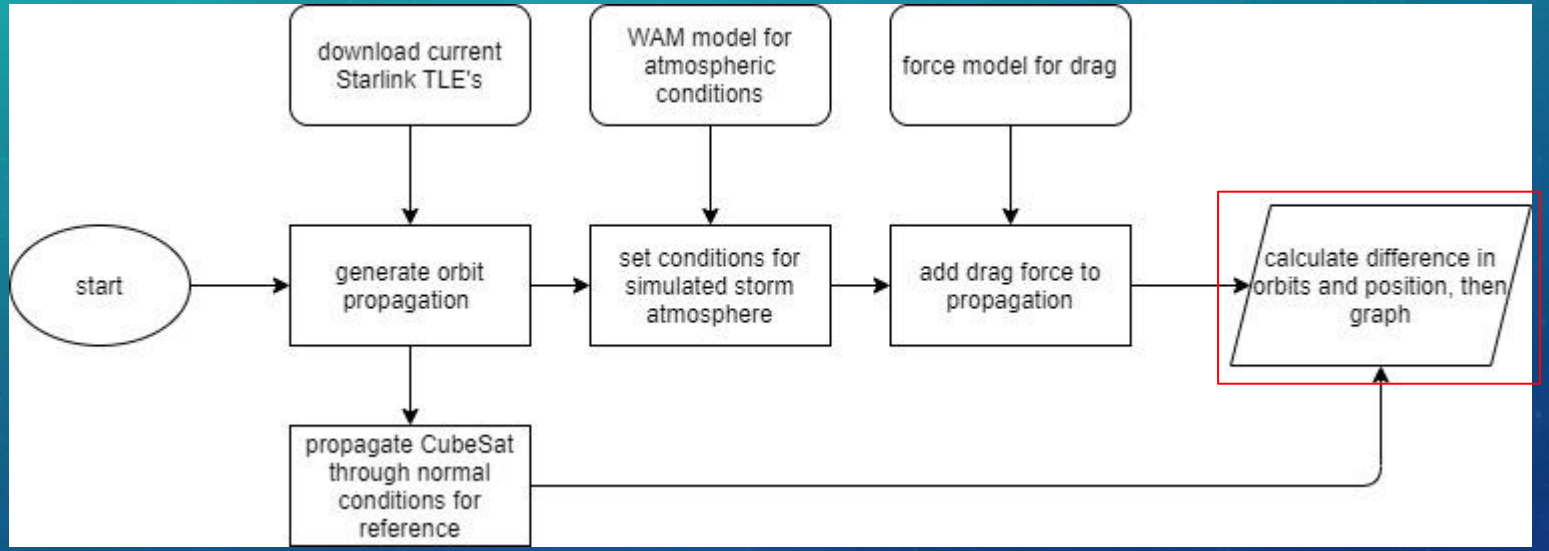
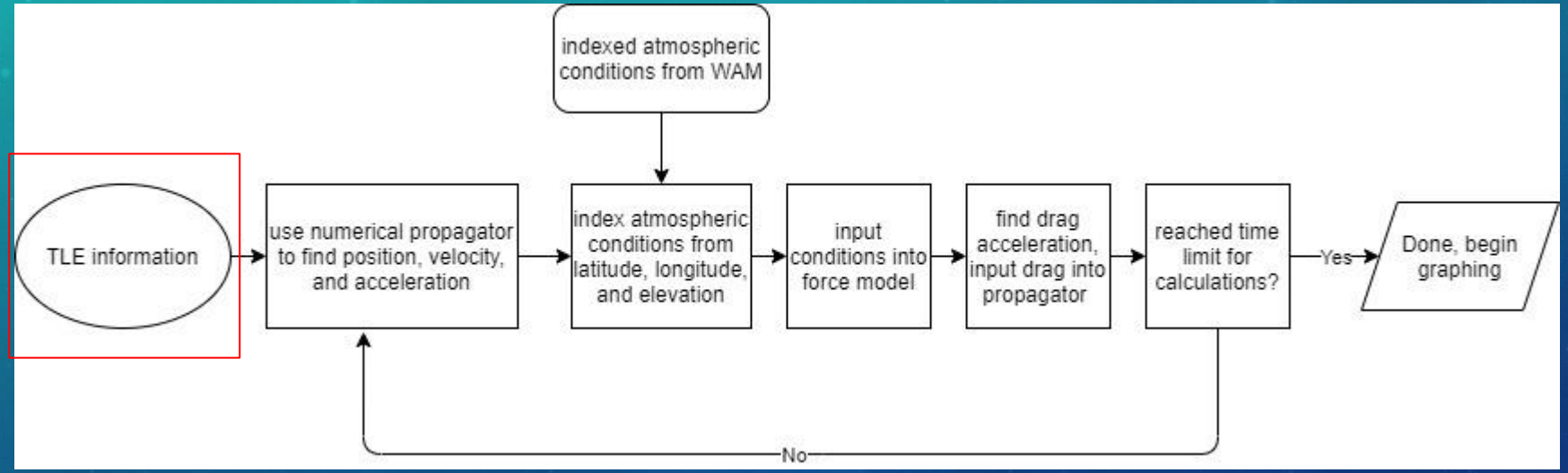


Flow Chart for Force Model



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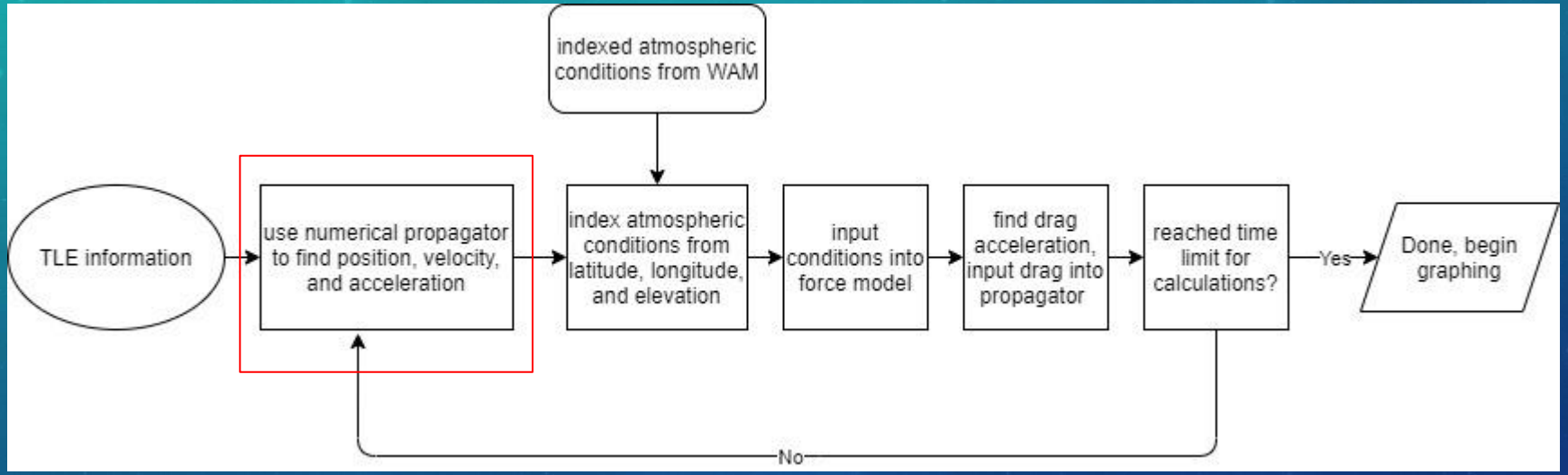

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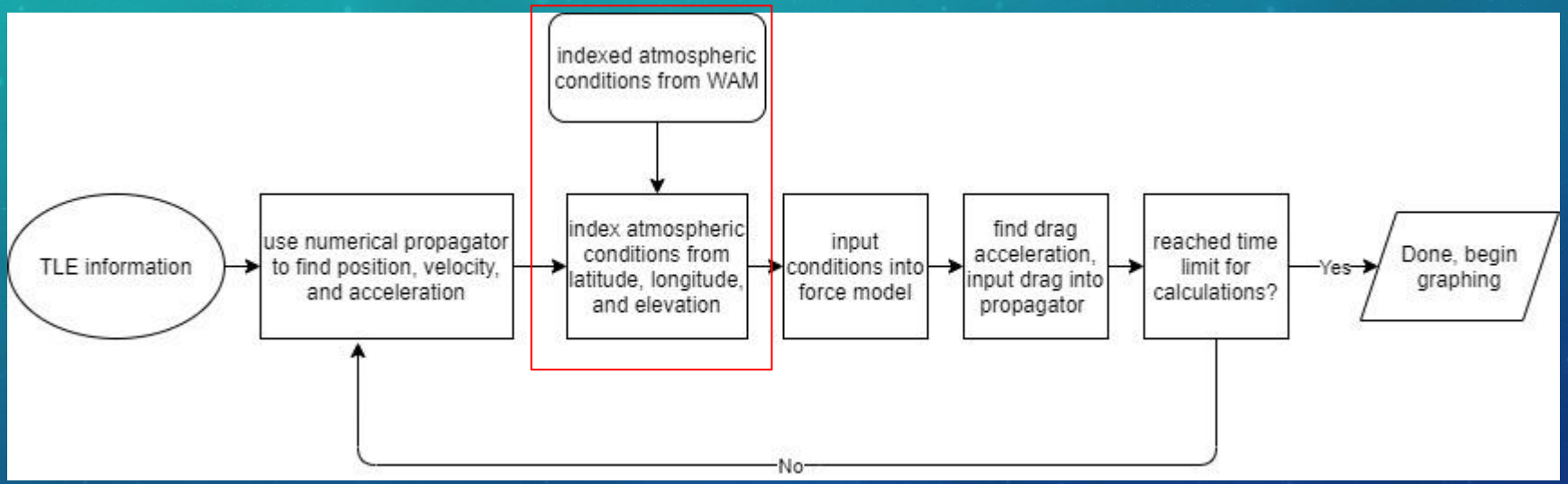

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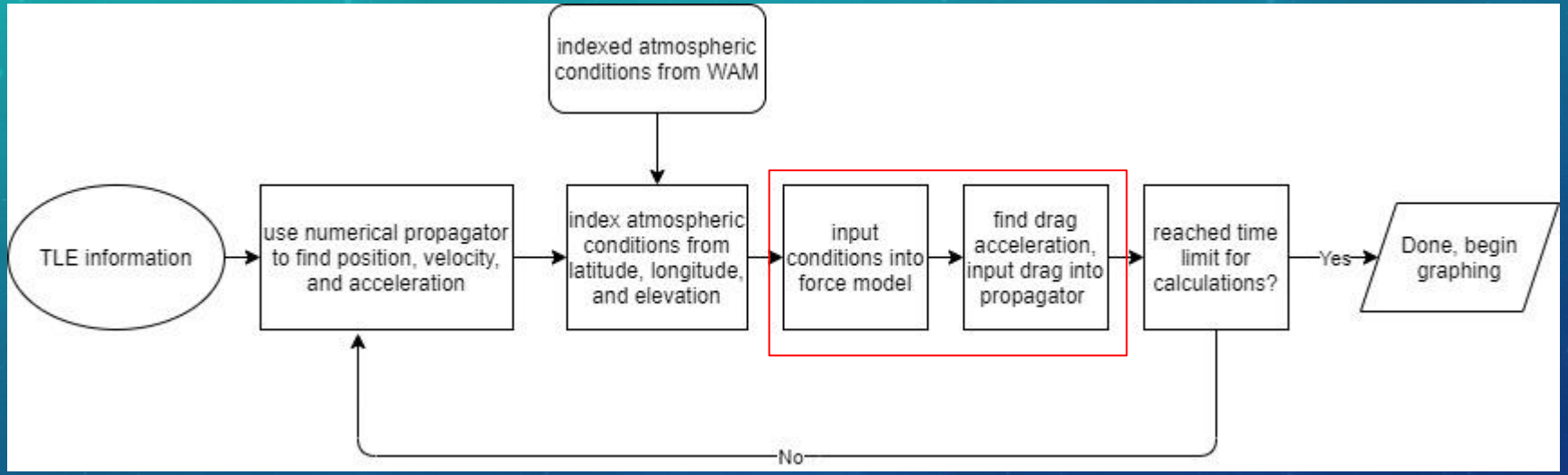

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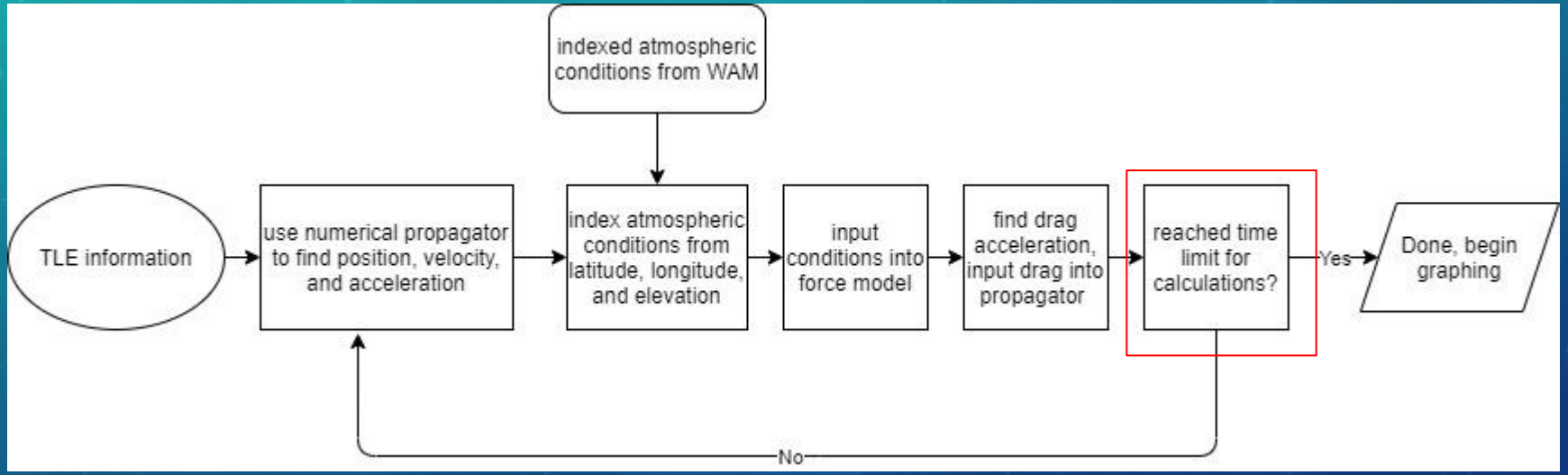
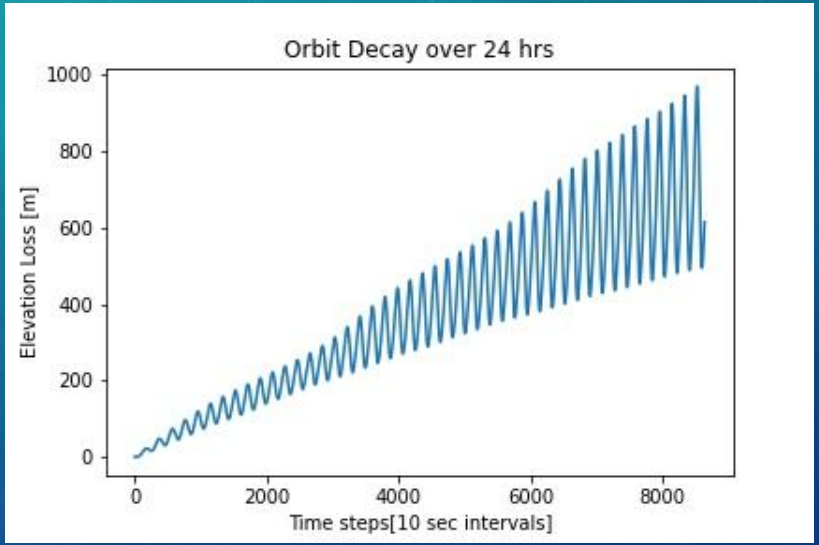


Orbit Decay

- Over 24 hr interval, simulated orbit decayed roughly .75 km, with the elevation constantly fluctuating

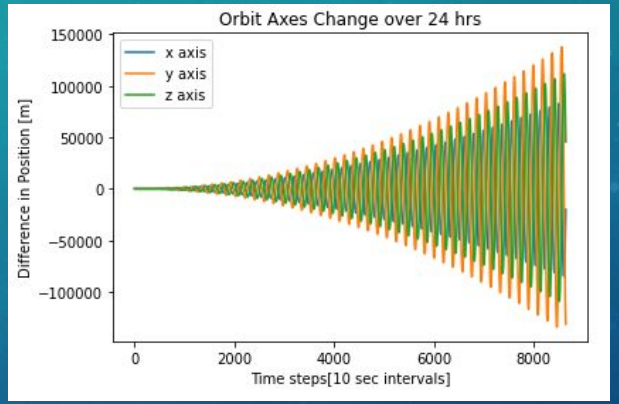
- The elevation becomes very difficult to track as it is changing very quickly

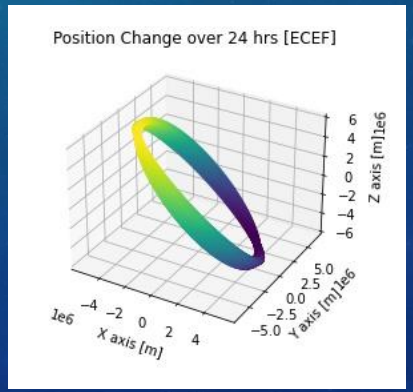


Change in Position

- We also observe a change in every axis (in ECEF coordinates), so its position at any one time becomes very difficult to know

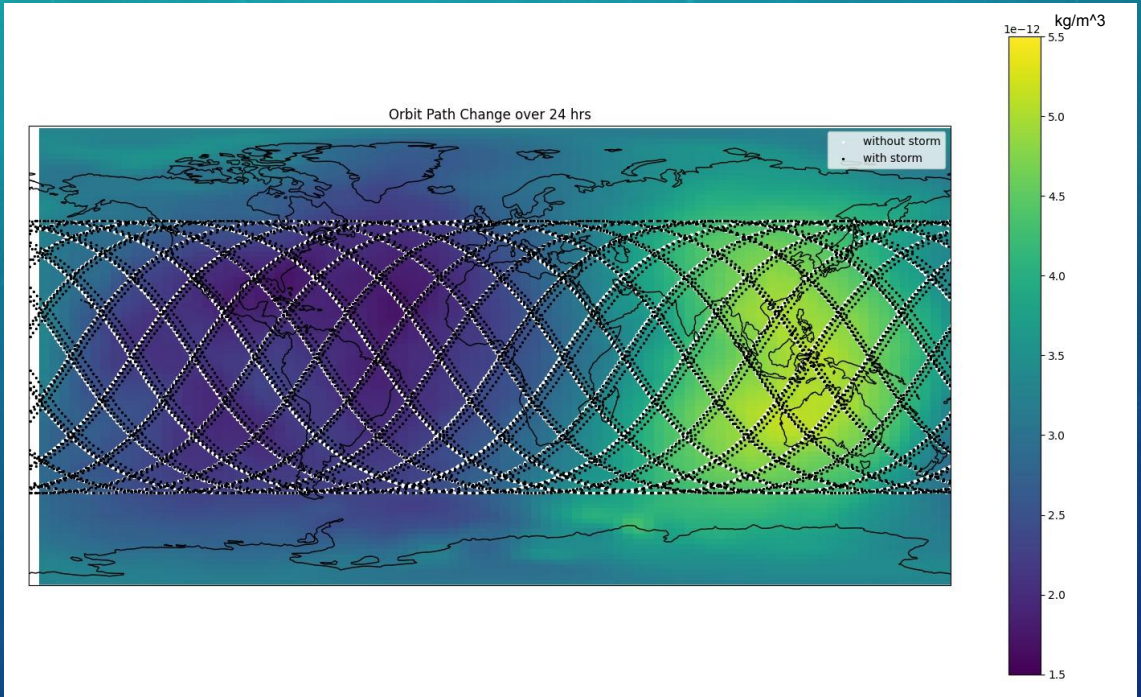
- The difference between normal conditions and those during a storm can be as large as 150 km after 1 day in any direction





CubeSat Path Difference

- Drag is exaggerated by x50 to show how path differs



Conclusions

- Atmospheric drag from geomagnetic storms has serious impact on mega-constellations in orbit
- This research shows the importance of incorporating physics-based atmospheric density into orbital propagation models
- If we do incorporate it, we could reduce (or eliminate) the number of satellites lost during large geomagnetic storms.

Future

- Use WAM to forecast and simulate a 4D model with time variability
- Run multiple simulations at a time
- Create a more dynamic model for greater accuracy

Thank you for your time

- Any questions?