Pre- Development Tests for Space Elevator

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Abstract

This paper explores the challenges inherent in operationalizing a space elevator within the dynamic expanse of space. Critiquing the limitations of current transient data collection methods, such as rockets, we contend that these approaches may inadequately capture the nuanced environmental conditions essential for a space elevator's success, especially considering the influence of rotating magnetic fields. Proposing a paradigm shift, our hypothesis advocates for continuous data collection through a dedicated mechanism—a deployment tether with sensors—operating 24/7 at various altitudes. This proactive approach, initiated well in advance, lays the groundwork for subsequent developments in space elevator construction. By addressing the deficiencies of transient collectors, deploying sensors on the initial tether during construction, and emphasizing continuous data acquisition, this research aims to enhance our understanding of the dynamic space environment, informing design decisions critical to the space elevator's resilience and adaptability throughout its operational trajectory.

1. Introduction

The journey from the Earth's surface to a height of 100,000 kilometers into space constitutes a considerable odyssey, traversing various strata of the Earth's atmosphere and the outer realms of space, each distinguished by unique environmental conditions. With a swift approximate speed of 350 kilometers per hour, we navigate through these zones, spending varying durations in each. Understanding how these zones impact our systems, particularly the well-being of cargo and personnel, necessitates a comprehensive examination of their nature. To facilitate accurate data gathering, we emphasize the importance of employing In-Situ Stationary data collection methods over In-Situ Transient approaches, such as rockets flying through these environments. In the pursuit of a thorough examination, we categorize these environments into three distinct levels:

- Level -1: 0 to 500 km [Until Exosphere]
- Level -2: 600 to 12,000 km [LEO & MEO]
- Level -3: 12,000 to 100,000 km [GEO +]

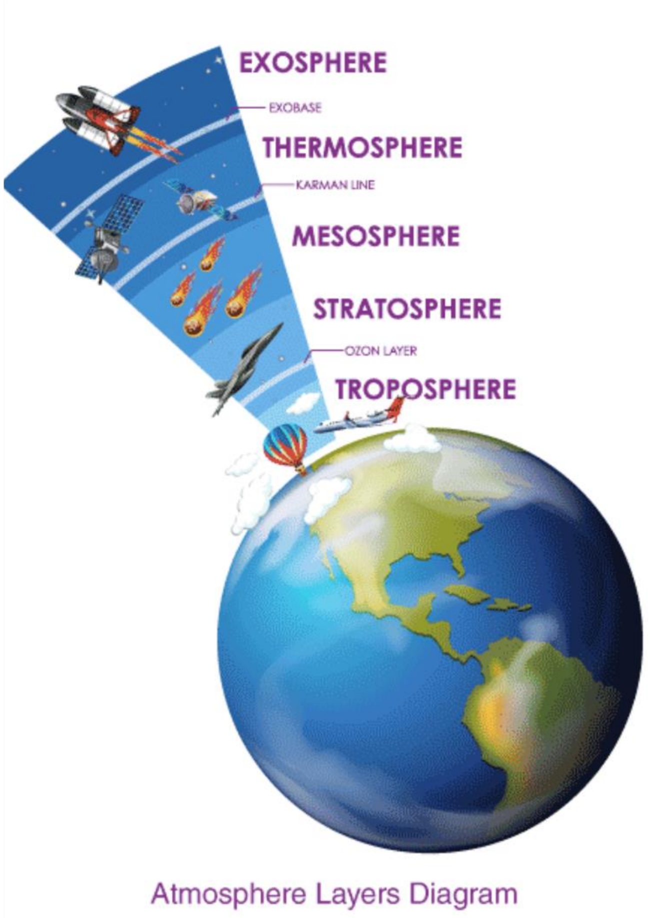

Figure 1.0

2. Level -1 [0 to 500 km]

The most crucial part of our elevator journey starts here, it's also the most turbulent and hazardous place our climber will cross through. In order to cross this level with maximum efficiency and safety. We need to understand it first-

1. Troposphere (0-12km): The troposphere is the layer closest to the Earth's surface and is where weather phenomena occur. It contains approximately 75% of the total atmospheric mass. As you go higher within

the troposphere, the temperature generally decreases with altitude due to the decrease in pressure. 12-50km is the boundary between the troposphere and the next layer, the stratosphere. The tropopause marks a region where the temperature generally stops decreasing and starts to stabilize.

2. Stratosphere (12-50km to about 85km): In the stratosphere, the temperature increases with altitude due to the presence of the ozone layer, which absorbs ultraviolet (UV) radiation from the Sun. The ozone layer helps protect life on Earth by absorbing harmful UV radiation. Commercial airplanes often fly in the lower stratosphere. 50-85 km is the boundary between the stratosphere and the mesosphere. At the stratopause, temperatures start to decrease again.
3. Mesosphere (50-85km to about 100km): The mesosphere is characterized by a significant drop in temperature with increasing altitude. It's also the layer where meteors burn up upon entering the Earth's atmosphere. 85-100 km marks the transition between the mesosphere and the next layer, the thermosphere. Temperatures reach their lowest in the mesosphere, often reaching -100 degrees Celsius (-148 degrees Fahrenheit) or even colder.
4. Thermosphere (100km to 500km): The thermosphere is characterized by extremely high temperatures, but the air is so thin that it wouldn't feel hot if you were to be there, as there would be very few molecules to transfer heat. This is where the International Space Station (ISS) orbits the Earth. In this layer, the temperature can increase significantly due to absorption of intense solar radiation.
5. Exosphere (approximately 500km and beyond): The exosphere is the outermost layer of the Earth's atmosphere, gradually transitioning into space. Molecules in the exosphere are extremely sparse and can escape the Earth's gravitational pull, essentially becoming part of space.

2.1 Level -2 [600 – 12,000km]

Between 600 km and 12,000 km above the Earth's surface, you primarily traverse the exosphere and into regions where the Earth's magnetosphere is influential. Here are some general facts about this altitude range:

1. Exosphere (600 km to 10,000 km): The exosphere is the outermost layer of the Earth's atmosphere, and it is characterized by an extremely low density of particles. It's essentially where the atmosphere transitions into outer space. It contains very few particles, mainly hydrogen, helium, and other light gases. The density is so low that particles can travel hundreds of kilometers without colliding with one another. Since the density is so low, temperatures in the exosphere can be quite high when exposed to solar radiation.
2. Magnetosphere (extends beyond the exosphere): The magnetosphere is a region surrounding the Earth that is influenced by the planet's magnetic field. The magnetosphere is crucial for shielding the Earth from the solar wind, a stream of charged particles emitted by the Sun. It helps deflect and trap these particles, preventing them from directly impacting the Earth's surface.
3. Low Earth Orbit (LEO): Satellites in low Earth orbit, where altitudes typically range from about 160 km to 2,000 km, fall within this altitude range. They include Earth observation satellites, communication satellites, and scientific instruments like those on the International Space Station (ISS).
4. Medium Earth Orbit (MEO) and Geostationary Orbit (GEO): Satellites in higher orbits, such as MEO (2,000 km to 35,786 km) and GEO (approximately 35,786 km), are beyond the exosphere. MEO is often used for navigation satellites, while GEO is commonly employed for communication satellites.
5. Satellite Graveyard: In this altitude range, remnants of defunct satellites and other space debris may be found. Over time, defunct satellites in certain orbits can contribute to the growing issue of space debris.

Understanding these layers is crucial for space exploration and satellite deployment. The exosphere and magnetosphere are key regions that influence the behavior of satellites and play a role in shaping Earth's interactions with the solar wind and cosmic rays.

2.2 Level -3 [12,000 – 100,000km]

Beyond 12,000 km above the Earth's surface, you enter the realm of the Van Allen radiation belts and the outer reaches of the Earth's magnetosphere.

1. Van Allen Radiation Belts: The Van Allen radiation belts are regions of charged particles (predominantly electrons and protons) that surround the Earth, forming two concentric belts. These belts are primarily situated between about 1,000 km and 60,000 km above the Earth's surface.

The belts are a result of the Earth's magnetic field trapping charged particles from the solar wind.

2. Magnetosphere (Extended Region): The magnetosphere extends well beyond the Van Allen radiation belts, shaping the Earth's interactions with the solar wind. The magnetosphere continues to shield the Earth from the solar wind and cosmic rays in this region.
3. Geostationary Orbit (GEO): Satellites in geostationary orbit, approximately 35,786 km above the Earth, are commonly found in this altitude range. These satellites appear to be stationary relative to a specific point on the Earth's surface and are widely used for communication and weather monitoring.
4. Medium Earth Orbit (MEO): Some navigation satellites, such as those in the Global Positioning System (GPS), operate in medium Earth orbit, which extends from approximately 2,000 km to 35,786 km.
5. Bow Shock: As the solar wind encounters the Earth's magnetosphere, a bow shock is formed. This is the boundary where the solar wind is significantly slowed and deflected by the Earth's magnetic field.
6. Extended Aurora Zones: The interaction between charged particles in the solar wind and the Earth's magnetosphere contributes to the phenomenon of auroras, which may extend beyond the polar regions at higher altitudes.

Understanding the dynamics of these outer layers is essential for the safe operation of satellites, as well as for studying the Earth's interactions with the solar wind and cosmic radiation. Additionally, research in this region contributes to our understanding of space weather and its potential impacts on technology in space and on Earth.

3. The Hypothesis

1. In addressing the complexities of an operational space elevator within the inherently dynamic and intricate expanse of space, our research posits that the current methodology of data collection through transient means, such as rockets flying through designated regions, may not yield a comprehensive understanding of the ever-changing environmental conditions. The pivotal question arises: Can these transient collectors truly capture the authentic and nuanced information required for the successful operation of a space elevator, especially given the dynamic nature influenced by rotating magnetic fields?

2. We propose that for a profound and nuanced comprehension of the space environment, continuous data collection is indispensable. Our hypothesis asserts that deploying a dedicated and continuous data collection mechanism, specifically a deployment tether equipped with a suite of sensors, at various altitudes 24/7, will provide a more accurate representation of the dynamic space environment. This pioneering deployment tether, initiated well in advance of the space elevator's operational phase, acts as the foundational framework upon which subsequent developments, including tether climbers and additional tether structures, are built.

3. The inherent limitation of transient collectors, exemplified by rockets, lies in their sporadic data gathering intervals, potentially missing critical variations in the space environment. To rectify this, our research recommends the deployment of sensors on the initial tether during its construction phase, facilitating the continuous collection of data crucial for understanding the intricacies of the space environment. This early data collection will be instrumental in informing the final design of tether climbers, payloads, motors, and other components, thereby ensuring the space elevator's robustness and adaptability to the dynamic conditions encountered throughout its operational trajectory.

4. In summary, our hypothesis advocates for a paradigm shift in data collection methods for space elevator development, emphasizing the necessity of continuous and real-time information acquisition through a strategically deployed deployment tether. This approach lays the foundation for informed decision-making in the subsequent phases of space elevator construction and operation.

4. Understanding the levels in depth

Section 2 provides a concise overview of the anticipated characteristics of Earth's atmospheric and spatial layers within specified altitudinal ranges. The subsequent subsections within this section aim to elucidate the intricacies and challenges inherent in each layer. Furthermore, these subsections will meticulously examine the current state of available data, affording a comprehensive understanding of the complexities associated with these distinct layers. By delving into the specifics, this paper endeavors to contribute valuable insights into the challenges posed by each layer and critically assess the extant corpus of data, thereby advancing our comprehension of the atmospheric and spatial domains under consideration.

4.1.1. Layer 1 The Troposphere

We are now going to study in depth about these layers, the challenges they offer and how much do we already know about them:

Troposphere (0-12-50km):

1. Turbulence: Tropospheric turbulence, caused by changes in air pressure and temperature, can affect the stability of the climber. It can lead to discomfort for passengers and crew and potentially cause damage to electronic equipment and cargo.
2. Thunderstorms: Thunderstorms in the troposphere can generate lightning, strong winds, and hail, all of which can pose risks to electronic equipment and climber. Lightning strikes can damage sensitive electronic systems on aircraft and interfere with communication systems.
3. Icing: When flying through clouds in the troposphere, climber can encounter supercooled water droplets that freeze upon contact, leading to ice accumulation on its surfaces. This can affect the aerodynamics of the climber and potentially impact its performance.
4. Tornadoes and Waterspouts: In regions where tornadoes and waterspouts form, these high-energy vortexes can pose severe risks to climber and electronic equipment (Equator experiences least tornados and storms)

4.1.2 Layer 2 The Stratosphere

The stratosphere is generally characterized by more stable and less turbulent conditions compared to the troposphere, which makes it a less challenging environment for electronic equipment, flight, and space missions. However, there are still some factors that can impact operations in the stratosphere:

1. Temperature Extremes: While the stratosphere experiences relatively stable temperature conditions with increasing altitude, the temperature can still be extremely cold, especially at higher altitudes. Extremely low temperatures can affect the performance of materials and electronic components.
2. Ozone Layer: While the ozone layer in the stratosphere is beneficial for absorbing harmful UV radiation, it can also pose challenges to spacecraft and satellites. Ozone can cause degradation of materials used in the climber and can influence how certain materials interact with the space environment. (Graphene?)
3. Radiation Exposure: The stratosphere is above a significant portion of the Earth's atmosphere, which means there is less protection from cosmic and solar radiation. This can affect the performance of electronic components and increase the risk of radiation-induced damage.
4. Pressure Variations: While the pressure changes in the stratosphere are much less pronounced than in the troposphere, there are still pressure variations that can affect equipment and materials. Spacecraft and satellites designed for stratospheric operations need to account for these pressure variations.
5. Spacecraft de-Orbits: The lower part of the stratosphere is sometimes used for specific types of space missions, such as launching weather balloons or conducting scientific research using high-altitude balloons. These missions need to account for wind patterns and atmospheric conditions at these altitudes.

4.1.3 Layer 3 The Mesosphere

1. Temperature Extremes: The mesosphere experiences extremely low temperatures, with temperatures dropping as low as -100°C (-148°F). These frigid temperatures can affect the performance of electronic equipment, especially if it is not adequately insulated or designed for cold environments. Extreme cold can cause materials to become brittle and can affect the functioning of batteries and other electronic components.
2. Radiation: The mesosphere is exposed to higher levels of solar and cosmic radiation compared to the

lower atmosphere. This radiation can pose a threat to sensitive electronic equipment and can potentially disrupt communication systems and sensors on satellites and spacecraft.

3. <u>Meteoroids and Space Debris</u>: The mesosphere is also a region where meteoroids and space debris can be encountered. These small particles and debris can pose a risk to spacecraft and satellites as they pass through this layer.

4.1.4 Layer 4 The Thermosphere

The Thermosphere is a unique and challenging region of Earth's atmosphere for space missions due to its extreme temperature variations, low density, ionization, and potential impacts on satellite communication and dynamics. Challenges and Threats to our missions:

1. <u>Orbital Decay:</u> Despite its low density, the thermosphere contains enough gas particles to cause drag on low Earth orbit (LEO) satellites and spacecraft. This can lead to a gradual decrease in altitude and can require periodic adjustments to maintain an orbit.
2. <u>Communication Disruption:</u> The ionization in the thermosphere can affect radio and satellite communication signals as they pass through this layer. The ionosphere's variability, including day-night fluctuations, can impact signal propagation.
3. <u>Material Compatibility</u>: The extreme conditions in the thermosphere require specialized materials that can withstand rapid temperature changes, high levels of radiation, and ionization. Graphene, known for its exceptional mechanical and electrical properties, may offer advantages in terms of strength and conductivity but would need to be carefully engineered and tested for compatibility with the thermosphere environment.
4. <u>Space Debris and Micrometeorites Collision Risk:</u> Space debris, which can be found in the thermosphere, poses a collision risk to active satellites and spacecraft. The high velocities in LEO make even small debris particles a potential threat.
5. <u>Thermal Extremes:</u> Space missions that traverse the thermosphere may experience significant temperature extremes, with the climber's surfaces exposed to intense solar radiation on one side and rapid cooling on the other.

4.1.5 Conclusions from Level -1

Based on the information extrapolated from above we can now determine what are the factors about which we need to collect data for, based on them we can come up with concept test ideas. Let us now list down factors regarding which we need more information.

1) Temperature at different zones/Temperature Invariance effect.
2) Pressure & Wind Speed at various zones.
3) Ozone Concentration and reaction with Graphene.
4) Varying concentration levels of ionization for communications test

Radiation levels test for long exposure of radiation on elevator materials.

4.2.1 LEO [Low – Earth Orbit]

Characteristics and Special Features:

1. Altitude Range: LEO typically extends from approximately 160 kilometers (100 miles) to 2,000 kilometers (1,243 miles) above the Earth's surface.
2. Orbital Period: Satellites in LEO have relatively short orbital periods, typically ranging from about 90 minutes to 2 hours. They circle the Earth rapidly.
3. Proximity to Earth: LEO is close to Earth, which makes it suitable for a wide range of missions, including Earth observation, communication, scientific research, and space station operations (e.g., the International Space Station or ISS).
4. Lower Latency: LEO offers lower latency communication compared to higher orbits, making it suitable for applications that require real-time data transmission.
5. Space Debris: LEO is crowded with space debris and defunct satellites, posing a significant collision risk to active spacecraft. Tracking and collision avoidance are critical.

Challenges and Threats to Space Missions:

1. Orbital Debris: Space debris in LEO poses a significant collision risk. Even small fragments can cause significant damage to spacecraft. Monitoring and mitigating this debris is essential for mission safety.
2. Atmospheric Drag: The presence of residual atmosphere at LEO altitudes causes drag on satellites and spacecraft. This leads to gradual orbital decay, necessitating periodic adjustments to maintain the desired orbit.

3. Radiation Exposure: While LEO is below the Van Allen radiation belts, it still exposes spacecraft and astronauts to elevated radiation levels, especially during solar storms.
4. Satellite Constellations: The growing number of LEO satellite constellations for global internet coverage raises concerns about orbital congestion and space traffic management.

Statistics (in Numbers) for LEO:

1. Altitude Range: Approximately 160 kilometers (100 miles) to 2,000 kilometers (1,243 miles).
2. Orbital Period: Orbits in LEO typically have orbital periods ranging from approximately 90 minutes to 2 hours.
3. Space Debris: As of my last knowledge update in September 2021, there were over 20,000 tracked objects in LEO, including active satellites and space debris.

4.2.2 MEO [Middle – Earth Orbit]

Characteristics and Special Features:

1. Altitude Range: MEO is located at higher altitudes, roughly between 2,000 kilometers (1,243 miles) and 35,786 kilometers (22,236 miles) above the Earth's surface.
2. Navigation and Communication: MEO is commonly used for navigation satellite systems like GPS (Global Positioning System) and for some communication satellites. These satellites have longer orbital periods than LEO.
3. Longer Satellite Lifetimes: MEO satellites benefit from lower atmospheric drag compared to LEO, resulting in longer operational lifetimes.
4. Wider Coverage: MEO satellites in navigation constellations offer broader geographic coverage compared to LEO systems.
5. Space Weather: Satellites in MEO are more exposed to space weather effects, including radiation from the Van Allen radiation belts.

Challenges and Threats to Space Missions:

1. Radiation: MEO satellites are exposed to higher levels of radiation, which can affect electronics and increase the risk of radiation-induced failures.
2. Space Traffic Management: As more navigation and communication satellites are deployed in MEO, managing orbital slots and preventing collisions become increasingly complex.
3. Positional Accuracy: Navigation satellites in MEO must provide precise positional data, and any anomalies can have significant real-world consequences.
4. Statistics (in Numbers) for MEO:
5. Altitude Range: Approximately 2,000 kilometers (1,243 miles) to 35,786 kilometers (22,236 miles).
6. Orbital Period: Orbits in MEO have longer orbital periods compared to LEO, depending on the specific altitude.
7. Navigation Constellations: Systems like GPS consist of multiple satellites in MEO, with the GPS constellation, for example, consisting of up to 32 satellites.

4.2.3 Magnetosphere

Radiation Exposure:

1. Challenge: The magnetosphere traps charged particles, creating radiation belts such as the Van Allen belts. These belts can expose spacecraft, satellites, and potential space elevator infrastructure to elevated levels of radiation.
2. Uncertainty: The exact intensity and fluctuations of radiation within these belts are not always well-predicted or understood. Prolonged exposure to high levels of radiation can pose risks to electronic components, materials, and, importantly, human occupants or cargo associated with a space elevator.

Electromagnetic Interference:

1. Challenge: The magnetosphere's dynamic interactions with the solar wind can induce electromagnetic disturbances in space. These disturbances may interfere with communication systems and the operation of sensitive electronic equipment.
2. Uncertainty: The precise nature and extent of these disturbances are complex and can vary, making it challenging to predict the impact on the reliability and functionality of space elevator systems.

Space Weather Events:

1. Challenge: The magnetosphere is intricately linked to space weather phenomena such as solar flares and coronal mass ejections (CMEs). These events can disrupt or damage spacecraft and infrastructure in space.
2. Uncertainty: The predictability of space weather events is an ongoing challenge. Sudden and intense solar activity can have unpredictable effects on the magnetosphere, and the ability to forecast such events accurately is limited.

Impact on Tether Systems:

1. Challenge: The space elevator concept involves the use of a tether extending from the Earth's surface

into space. The dynamic interactions of the tether with the magnetosphere, including potential currents induced by the Earth's magnetic field, could introduce mechanical stresses and challenges in tether stability.

2. **Uncertainty:** The detailed effects of the magnetosphere on a space elevator's tether system are not yet fully understood, requiring further investigation to ensure the structural integrity and safety of the infrastructure.

4.3.1 Van Allen Belt

The Van Allen radiation belts and the space ranging from 12,000 km to 100,000 km present potential threats to space missions, including ambitious projects like the space elevator, while our understanding of these regions remains limited.

Radiation Exposure:

1. Threat: The Van Allen radiation belts, located between 1,000 km and 60,000 km, contain charged particles trapped by the Earth's magnetic field. Prolonged exposure to this radiation can pose a threat to electronic components, materials, and, importantly, human occupants or cargo associated with a space elevator.
2. Uncertainty: The precise effects of radiation exposure in this region, particularly within the context of a space elevator, are not fully understood. Variations in particle intensity and potential effects on materials and biological systems are areas of uncertainty.

Magnetic Field Interactions:

1. Threat: The interaction between the Earth's magnetosphere and the solar wind in the space beyond 12,000 km can introduce challenges related to magnetic field interactions. These interactions may impact the stability and functionality of a space elevator tether, composed of conductive materials.
2. Uncertainty: The exact nature of these interactions, including the potential induction of currents or other effects on the tether structure, is an area where our understanding is limited.

Data Gaps:

1. Challenge: Our current knowledge of the magnetosphere is derived from satellite measurements and observations, but there are limitations in coverage and resolution.
2. Uncertainty: Gaps in our understanding of the magnetosphere, especially in specific regions and under certain conditions, contribute to uncertainties in predicting its effects on space missions like the space elevator.

Space Debris:

1. Threat: Remnants of defunct satellites and space debris are found in higher altitudes, including the space ranging from 12,000 km to 100,000 km. Collisions with space debris pose a significant threat to the structural integrity of a space elevator tether.
2. Uncertainty: The extent and distribution of space debris in this region are not precisely known, and predicting collision risks for a space elevator is challenging due to uncertainties in tracking smaller debris particles.

Solar Wind Interactions:

1. Threat: The interaction between the solar wind and the Earth's magnetosphere, marked by the formation of a bow shock, may introduce challenges in terms of dynamic pressure and potential effects on a space elevator structure.
2. Uncertainty: Predicting the specific impacts of solar wind interactions on a space elevator tether and associated components is challenging due to uncertainties in the behavior of the solar wind and its effects on large structures in space.

Auroras and Atmospheric Dynamics:

1. Threat: The extension of auroras beyond the polar regions at higher altitudes introduces uncertainties in understanding the potential effects of charged particles on a space elevator structure.
2. Uncertainty: The precise conditions leading to extended aurora zones and their potential impacts on materials or systems associated with a space elevator are not fully known.

5. The Uncertain Factor

As we all must have understood by now from the paper that there are many uncertain factors in the development of Space elevator, but the one factor that has all our most curiosity is the effect of magnetosphere on our tether and climber. Let’s understand why it’s so interesting, as we know the space elevator is fixed, which simply means that it rotates with the Earth, but our magnetosphere is mostly at a constant fix, the bow shock facing the solar winds and the neutral point behind Earth. The Bow Shock roughly 90,000km above the surface is divided into 4 different zones, depending on the ionization rate, flow velocity, etc. the scale size varies from 102 to 106 km. the most concentrated area is about 17km. The climber travels at roughly 200-300km/hr. which means our climber would be spending a significant amount of time in there with our precious cargo and passengers. Hence we would be moving through different parts of it at different times.

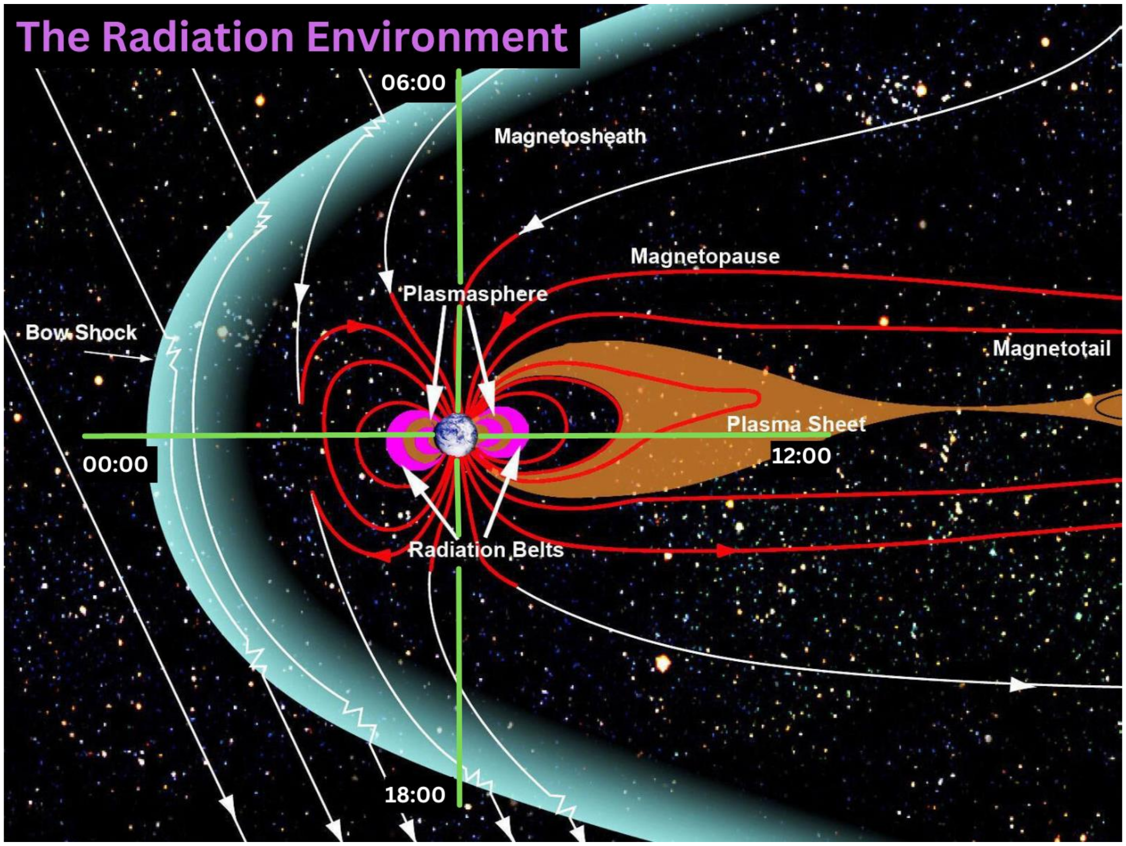

Figure 5.0 The position of the Space Elevator at different times.

Quite simply nothing has tested the effects of such long exposure of the Van Alen belt or Magnetosphere. We don't know what happens when we are there for a long time and what happens at the other end of it too. Hence that's why this paper proposes to build a test elevator line first for solving these mysteries and make the Space Elevator future safe.

Summary

The paper proposes a pivotal shift in data collection methodologies for space elevator construction, advocating continuous data acquisition through a dedicated mechanism with sensors deployed on the initial tether during construction. It underscores the need for enhanced understanding in critical factors for space elevator development, including the intricate interactions between the magnetosphere and solar wind, the influence of space weather events, and the magnetosphere's impact on the tether system. The complexity and unpredictability of electromagnetic disturbances arising from these interactions pose challenges to the reliability and functionality of space elevator systems. Ongoing challenges in predicting space weather events, particularly in the face of intense solar activity, necessitate comprehensive research. The paper emphasizes that detailed insights into the effects of the magnetosphere on the tether system remain incomplete, warranting further investigation to ensure structural integrity and safety. Furthermore, it underscores limitations in the existing knowledge of the magnetosphere, highlighting gaps in coverage and resolution derived from satellite measurements and observations. The development of a test Space Elevator system would prove crucial to the future of space elevator and ensure that mankind has a safe and reliable galactic highway always at it service.