Satellites as Indicators of Space Weather

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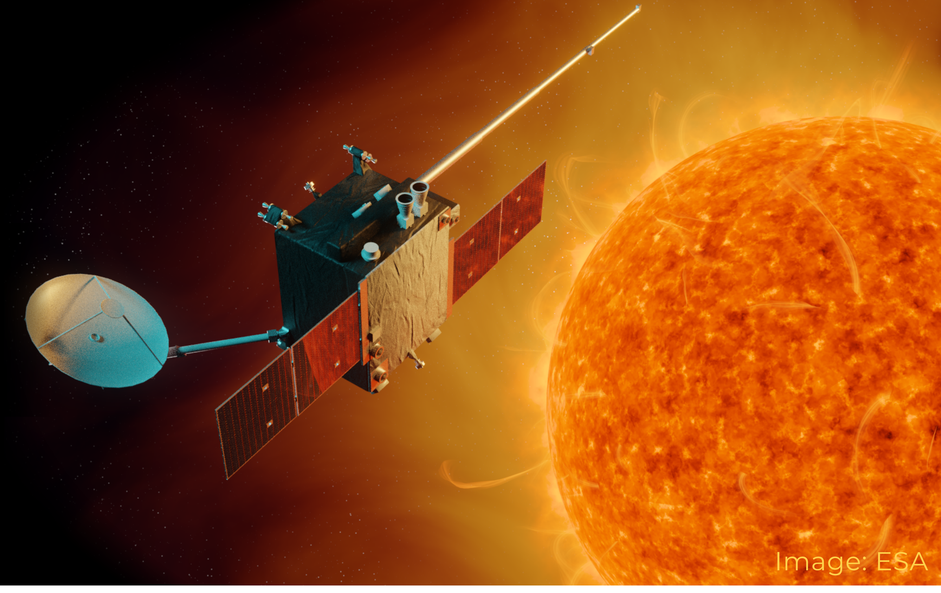
Image: ESA

Abstract

It is known that changes in solar behaviour throughout the solar cycle has an **impact on satellite behaviour**. Solar flux affects dramatic changes in thermospheric temperatures, which then impacts composition and density, imparting levels of drag that may vary significantly throughout an ~11-year cycle. Because of this, **satellite operators have fought hard for improved methods of predicting and understanding space weather**.

The impact of **unmonitored solar storms** on the deployment and decay of satellites in LEO has become more well-known, since recent incidents—such as the failed February 2022 Starlink deployment by SpaceX—have reached mainstream media. And predictions that the current (25th) solar cycle will be **significantly more active** than the previous cycle are increasing (see **Figure 1**). So as solar activity peaks once more, we ask: **can the *results* of solar fluctuations be used to tell us more about them?**

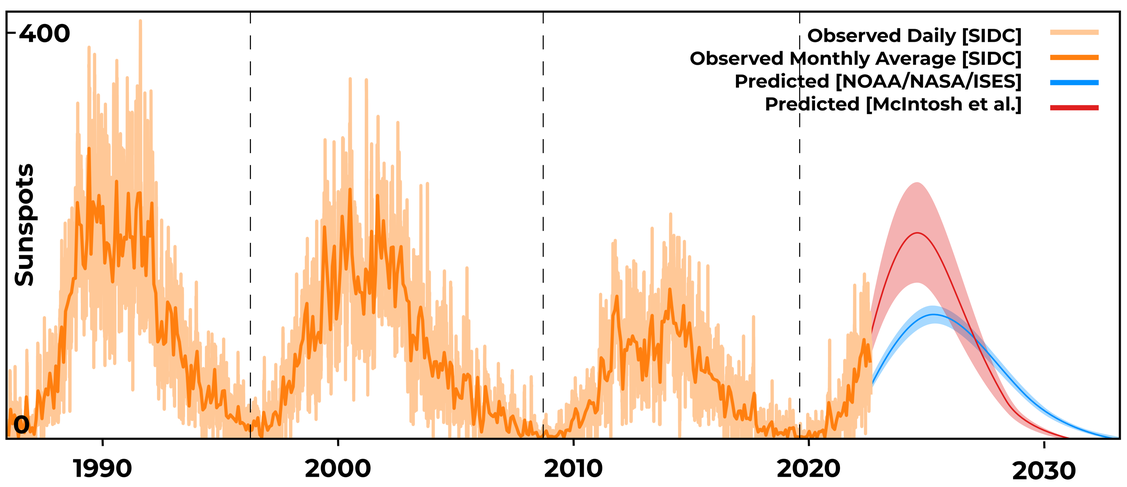

Figure 1. *The observed sunspots for solar cycles 22-24 (1986-2020), shown in comparison to conflicting predictions for solar cycle 25. Source: NASA, citing [1].*

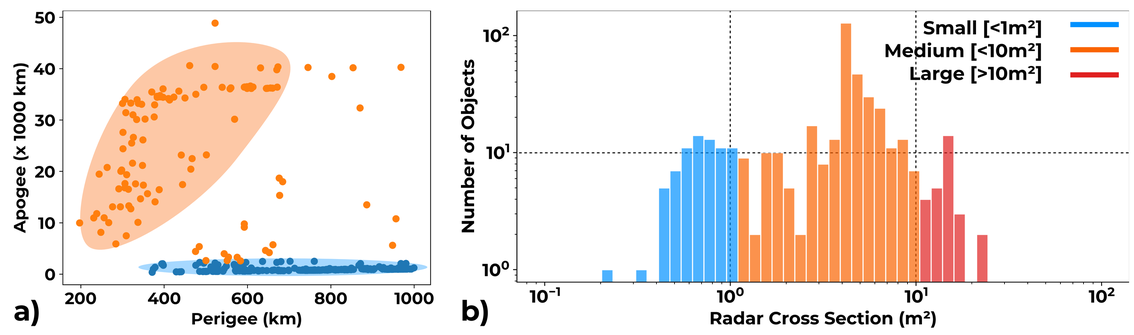

Figure 2. *Properties of the selected target objects: a) current orbit (near-circular or highly eccentric), b) size category (based on Radar Cross Section).*

Methods

To assess the **correlation between solar activity and the movement of objects in orbit**, historical datasets of each were compared. To better account for variation between solar cycles, data was selected to include all of solar cycle 22 (beginning September 1986) onwards.

First, the historical detections of **all objects currently in orbit** were obtained from the Space-Track archive. To isolate objects which solar flux would likely impact the most, objects were filtered to include only **objects that touch LEO** (perigee < 1000km). So that analysis could consider the size of objects, only **objects with a known RCS** were included. And to ensure that any change in object altitude could not have been a powered maneouvre, objects were filtered to a category of debris where the date they became debris could be reliably known: **discarded rocket body debris**. Once filtered for objects **launched pre-September 1986**, this left **438 objects** to be included in analysis—around 2% of on-orbit and catalogued objects (see **Figure 2**).

Next, measurements of **daily solar flux** was obtained from NOAA's Total Solar Irradiance archive. This data comprises of collated readings from NASA's **space weather monitoring satellites**—including ERBS, NIMBUS, SMM, UARS and ACRIM I/II/III—as well as NOAA's own.

What did we learn?

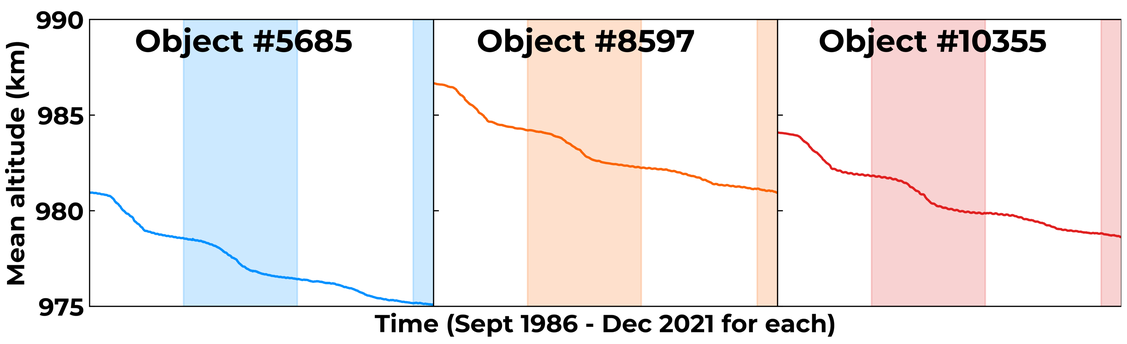

Figure 3. *Change in mean altitude of three random objects from the target group. Shaded/unshaded regions indicate distinct solar cycles (cycles 22-25).*

Objects immediately showed a **significant increase in rate of altitude decay surrounding the peaks of solar cycles**, and a decreased rate near solar minimums. This was highly consistent throughout the target group, as is shown for randomly-selected objects in **Figure 3**.

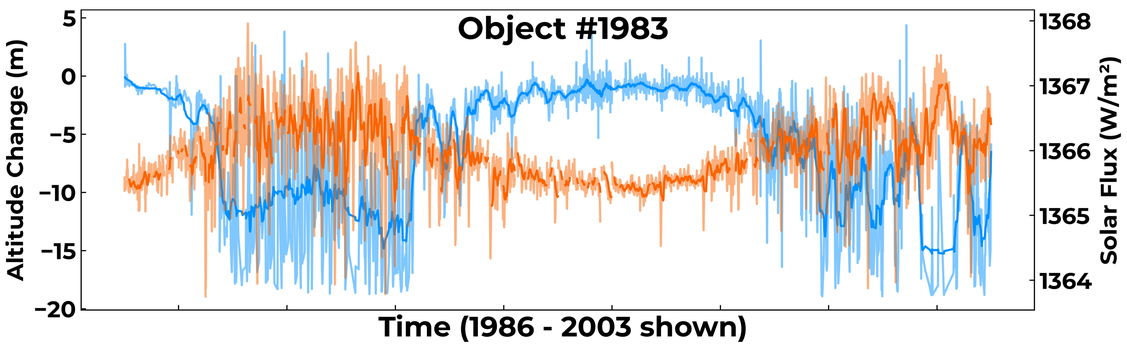

Figure 4. *Daily change in altitude versus daily solar flux for a random object from the target LEO group. True value and rolling average ($\sigma = 20$) shown.*

Objects whose entire orbits fell inside LEO (apogee < 1000km) showed **more significant correlation**. This supports that fluctuation is due to solar flux effects on the upper atmosphere and resulting drag. Correlation is shown for randomly-selected LEO objects in **Figure 4**.

Correlation between solar flux and object decay showed some variation, with the highest correlation being at a delay of **~2 days between solar flux and change in decay rate**. This likewise supports what is known about solar wind transit time to Earth (see **Figure 5**).

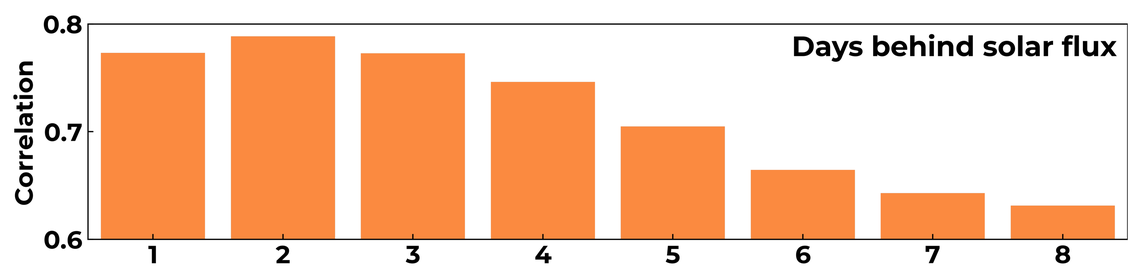

Figure 5. *Correlation between solar flux and altitude decay per 24-hour period.*

Summary

In this study, **large debris objects that have been present in LEO for the last three solar cycles** (launched pre-1986) were identified—a few hundred objects. Then, ephemerides were summarised and analysed to identify **changes in altitude or decay rate** that would **correspond to changes in solar activity** during the last three cycles. Results indicate that measurement of large and well-tracked debris objects **may be used as an indicator of solar flux**, even well into the past.

References
1. McIntosh, S.W., Chapman, S., Leamon, R.J. et al. Overlapping Magnetic Activity Cycles and the Sunspot Number: Forecasting Sunspot Cycle 25 Amplitude. *Sol Phys* **295**, 163 (2020). **doi:**10.1007/s11207-020-01723-y

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