EFFECTS OF ORBIT DEGRADATION TO DIWATA-2 DATA PRODUCTS AND OPERATIONS

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ABSTRACT: The STAMINA4Space program of the Philippines is the country's current space program focusing on spaceborne remote sensing systems. As it is a new field for the Filipinos, studies about their microsatellites, Diwata-1 and Diwata-2, are still in development. This paper studies the effects of orbit degradation of Diwata-2 to its operation and products. Future pass times of the microsatellite over the Philippines were simulated using SGP4 and J4 propagators over different altitude levels predicted by its orbit decay model. In addition, the local times of the ascending node were also noted for changes due to altitude. It has been shown that there is a decrease in the number of passes within suitable operating times and the local times of the ascending node were earlier but with a larger time difference between succeeding pass times. These changes affect the quality of the satellite's products with the main cause being the fluctuating sun zenith angles, among others.

1. INTRODUCTION

The PHL-Microsat program is the precursor of the Philippine's current space program, the Sustained Support for Local Space Technology and Applications Mastery, Innovation and Achievement (STAMINA4Space) Program. One of the achievements of the said program is the launch of two microsatellites, Diwata-1 and Diwata-2, with the former being launched on March 23, 2016 and the latter on October 29, 2018. The Diwata-1, launched three years ago, is nearing the end of its life expectancy and its altitude rapidly dropping. Thus, its data products have more pronounced blurring due to the velocity of the microsatellite nearing the 300km mark altitude limit. As seen in Figure 1, the edges on image taken by Diwata-1 during its later stages are more blurred, thus, affecting the data quality.

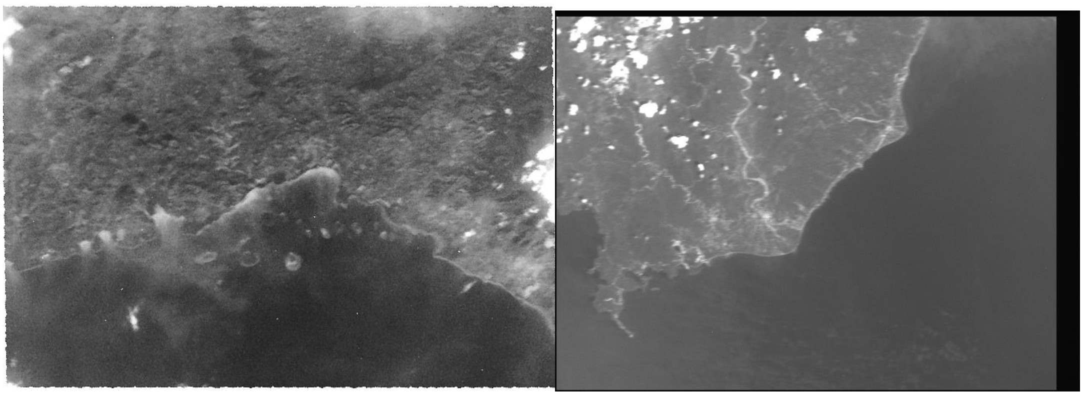

Figure 1. Diwata-1 images captured in 2016 (left) and 2019 (right).

The Diwata-2, at an altitude of 600km, is still in its early stages. Thus, to achieve its objectives, which is to provide data for vegetation and disaster assessment and management, it is necessary to determine its life expectancy for it to provide quality and accurate data. As the satellite approaches different altitude levels due to time and other perturbations, the effects of orbital drift become more prominent. Currently, the satellite passes through the Philippines twice daily. However, with the other pass happening at night, the satellite's operational hours are when it passes during the day, between 11am and 2pm. During this, commands are uploaded, and data products are downloaded for use. This is also the only time interval when the satellite captures images of the Philippines.

2. DETERMINING THE ORBITAL DRIFT EFFECTS TO THE DIWATA-2 OPERATION

Swinnen, et al (2014) defined the impacts of the orbital drift to the reflectance values of SPOT-VGT images. Differences in overpass times mean different cloud formations in the area, different sun zenith angle values (SZA), and different sun azimuth angles, leading to anisotropy effects. Higher values of SZA (or when the sun is near the horizon) lead to uncertainties in radiance measurement due to a longer path in the atmosphere. Hagolle (2007) studied the effects of the sun zenith angle changes to the reflectance values. A change of 3^0 at 20^0 SZA would introduce a ~2% RMSE change to the reflectance values. The Philippines generally have lower SZA values in a year due to its location near the equator. Hagolle (2007) also states that the reflectance RMSE values increase moderately until 50^0, where it increases exponentially after that.

The solar elevation angle (SEA) within a year were calculated and simulated for Manila (14.5995^0 N, 120.9842^0 E) at the operational extreme times (11am and 2pm). SEA values during 11am ranges from 50^0 to 77^0 and 2pm values range from 43^0 to 62^0. A lower value of SEA would mean a higher value of the SZA, and generally, SEA values are lower during the winter solstice when the sun reaches its minimum declination. However, these are still acceptable values, as the SZA values do not exceed 50^0. As such, current operational times for the Diwata-2 are still suitable for a high quality of data.

Orbital drift affects the pass times of satellites over an area, introducing changes to reflectance values due to a change in the SZA. Hagole (2007) states that the effects of sun zenith angle changes at low latitude areas such as the Philippines are more pronounced than places at higher latitudes, where the initial SZA values are already high. Thus, solar elevation angles for other times were also simulated. Among the results, only the 10am SEA values are still acceptable, while for other times the SEA values exceed the acceptable 50^0 value.

The sun zenith angle does not only affect the reflectance values of Diwata-2's output images. Magallon, et al (2018) related the sun elevation angle to be a cause of disturbance to Diwata-1's pointing capabilities together with the sun azimuth angle. This also applies to the Diwata-2 as its Attitude Control and Determination System (ACDS) also considers the relative sun illumination to determine the position of the sun. Higher elevation angles result in higher Earth surface albedo to be picked up by the ACDS. Thus, changes in the SZA due to changes in pass times of a different altitude satellite would affect the attitude data of Diwata-2, which could result of it missing its targets more frequently.

Another effect of orbital drift is the change in the spatial resolution of the satellite's images due to a change in velocity which differs from the payloads' shutter speeds. Such effect was shown earlier in the Diwata-1 images.

3. SIMULATING THE ALTITUDE OF DIWATA-2

The IPS Radio and Space Services, Sydney, Australia created an algorithm to simulate and predict the altitude of a satellite as a function of days passed in orbit. Its algorithm consists of applying the space environment effects, mainly the solar radio flux (F10.7) and the geomagnetic index (Ap), to model the atmospheric density, which in turn affects the drag force applied to the satellite which causes its orbital decay. It is stated that although most coefficients needed are known, there are still uncertainties since the satellite's attitude changes the effective cross-sectional area affected by the drag force, therefore, causing variations in the model. It is also stated that there is a 10 percent uncertainty to the attitude prediction models when nearing its life end.

Applying the algorithm to the Diwata-2 properties and with a 69.8 F10.7 and a 0 Ap, figure 2 is obtained. According to the results, Diwata-2 will approach re-entry levels after 40 years, way longer after the life expectancy of its payload and electronics at 5 years.

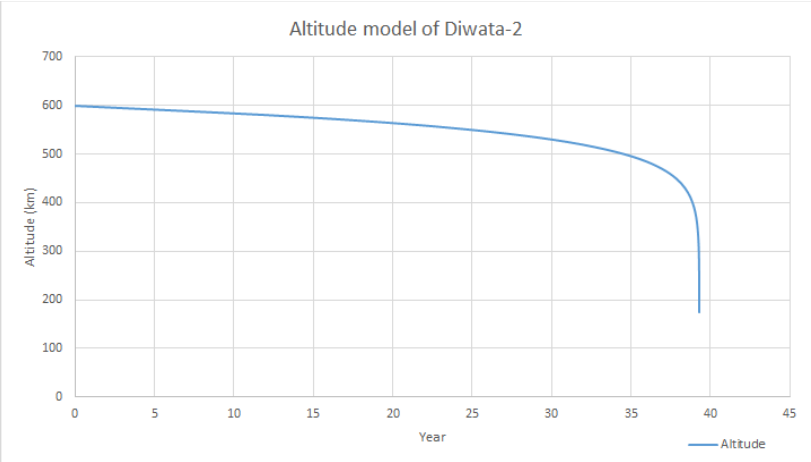

Figure 2. Diwata-2 altitude prediction model

It is worth noting that the specifications used to create the prediction model is the current configuration where its solar panels are not yet deployed. Diwata-2 has the capability to deploy its solar panels when a need for higher energy rises, thus increasing its area. By applying the same algorithm, the satellite would have an earlier re-entry age. However, for the purposes of the study, the model created by the current configuration will be used.

4. SIMULATING THE PASS TIMES OVER THE PHILIPPINES

The Systems Tool Kit (STK) software developed by Analytical Graphics, Inc. provides useful tools to model and predict the orbit of satellites using its TLE. It has a repertoire of satellite orbit data with the Diwata-2 included. One of its tools used in the study is the determination of pass times over an area, and for this study, the Philippines. It is also capable of changing the orbital information of satellites, thus convenient in changing the altitude of the Diwata-2. The software propagates a satellite's orbit through SGP4 propagation, which considers variations due to gravitational effects and orbital drag. Another propagator is the J4 perturbation propagator, which predicts a satellite's orbit based on the variations on the Keplerian elements but does not model other effects such as drag and third-body gravitational effects.

For this part, different altitude values according to the data gathered at the previous simulation are used to simulate the orbit of the Diwata-2 in a year. Five altitude values, its current at 600km, 590km (when it reaches its 5th year in orbit), 460km, 370km and 300km, are used for the simulation. The start pass times during the day over the Philippines (local time, left axis, dots) are plotted together with the satellite's altitude (km, right axis, crosses) as a function of the pass number in figures 3 to 7. The sensor attached to the satellite is a simple conic with a field of view of 15 degrees.

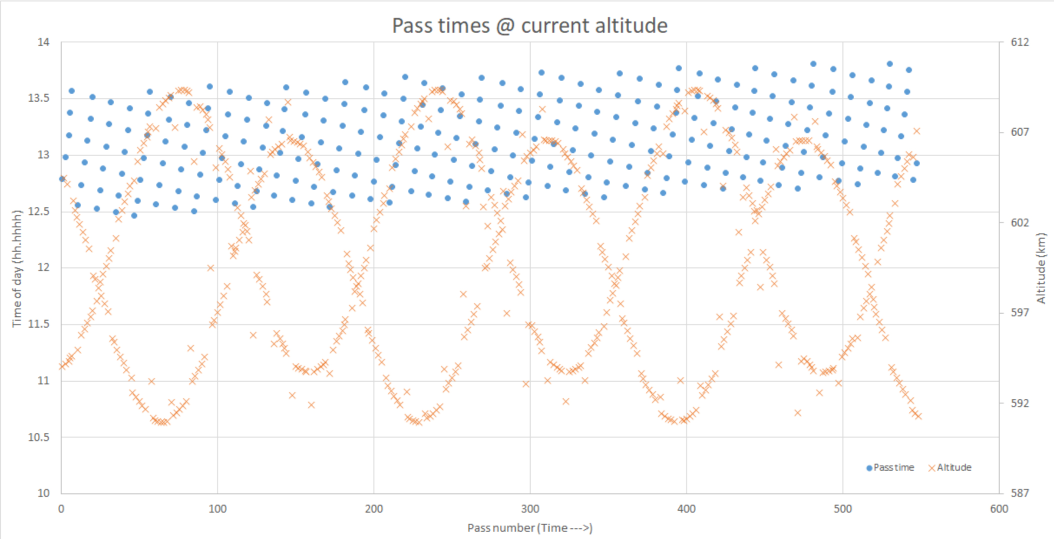

Figure 3. Pass times and altitude values at current altitude

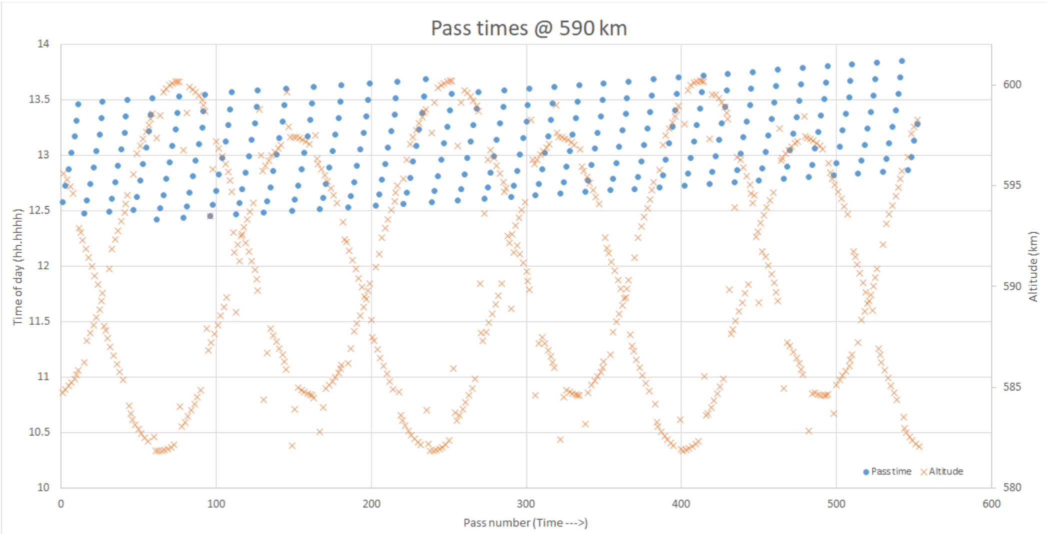

Figure 4. Pass times and altitude values at 590km altitude

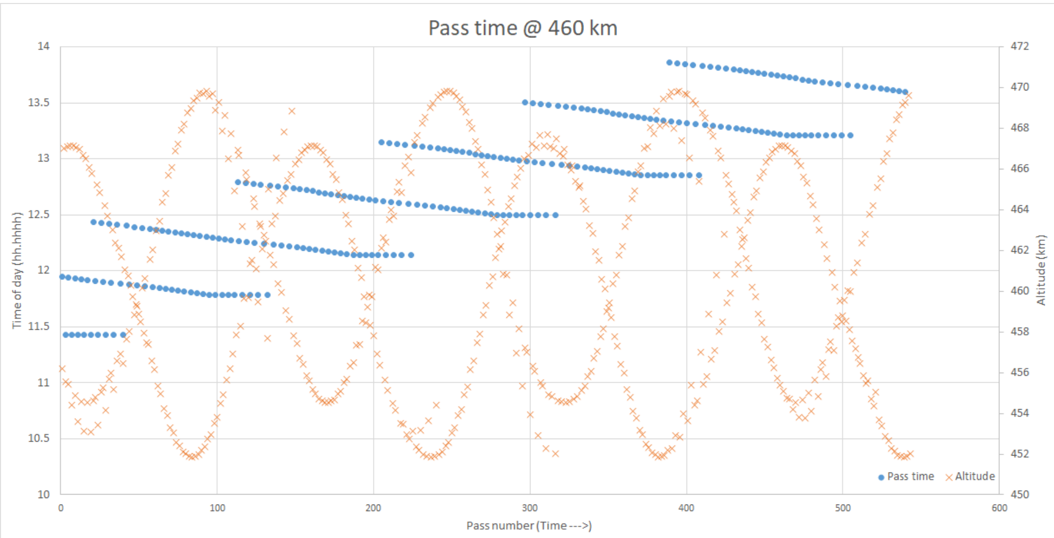

Figure 5. Pass times and altitude values at 460km altitude

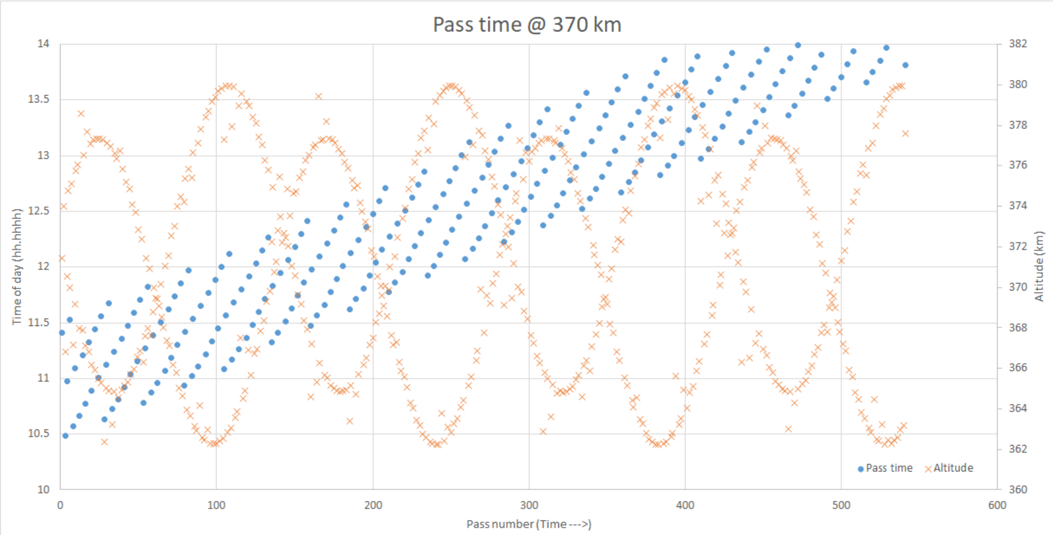

Figure 6. Pass times and altitude values at 370km altitude

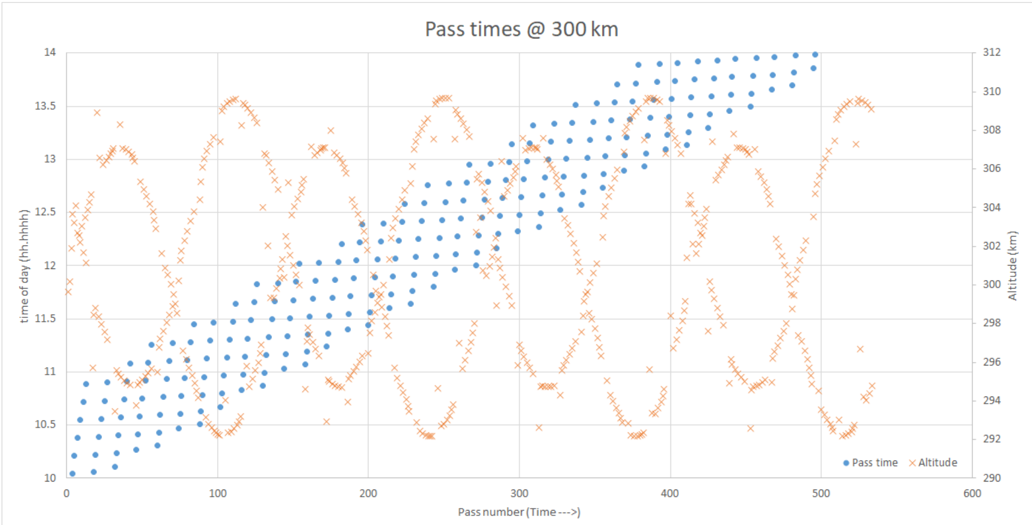

Figure 7. Pass times and altitude values at 300km altitude

The TLE used for the simulation is from September 4, 2019. Although the altitude change of the satellite within a year is similar for all altitude values, the pass times over the Philippines differ greatly through time, with the general trend of the pass time to be later as time goes by. In its current altitude, 600km, its pass times are within the allowable time frame (11am - 2pm). At the 590 km altitude, when the Diwata-2 reaches its fifth year, or on the end of life of its electrical components, all pass times during are still acceptable. The succeeding altitude graphs show more drastic changes and the lower the altitude goes, the number of acceptable passes become less and less. It is apparent that the time difference between passes increases through succeeding number of passes despite having earlier start times. Table 1 lists the numerical figures for the simulation.

Table 1. Summary of day pass times over PH

Altitude (km)	# of acceptable passes	% of acceptable passes	Average time between succeeding day pass times
Current	274/274	100%	17.8 s
590	277/277	100 %	18.6 s

460	258/271	95.2 %	37.1 s
370	246/271	90.8 %	56.9 s
300	228/267	85.4 %	69.4 s

It is worth noting that although the trend or the average time between succeeding day pass times increases as the altitude drops, the percentage of acceptable passes are still decent. Also, due to shorter periods of the satellite orbit, pass times at lower altitudes happen at earlier times. As such, passes before 10 am happened at the 300 km altitude. However, these passes do not have a discernible effect on satellite operations due to their few occurrences. Still, a larger time difference between succeeding day pass times would mean a larger deviation in reflectance values despite them being in the allowable time frame, as shown by Hagolle (2007).

5. ORBITAL DRIFT EFFECTS TO LOCAL TIME OF ASCENDING NODE

Swinnen, et al (2014) assessed the orbital drift of the SPOT-VGT1 and SPOT-VGT2 sensors through the local time of ascending node (LTAN), or the local time at the place when the satellite crosses the equator from the southern hemisphere to the north. Figures 8 to 12 shows the local times of the ascending node per period of the different altitude values of the orbit simulated over a year. Similar to the previous simulation, the TLE used was from September 4, 2019. The left axis shows the local time in decimal hours and is represented by the blue line. The right axis shows the difference in LTAN between succeeding periods and is represented by the orange line.

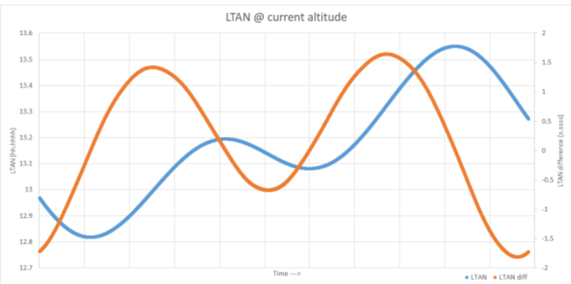

Figure 8. LTAN at current altitude.

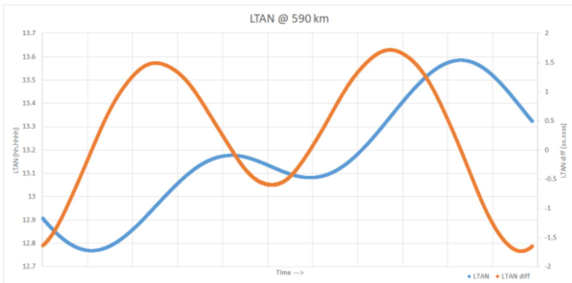

Figure 9. LTAN at 590 km

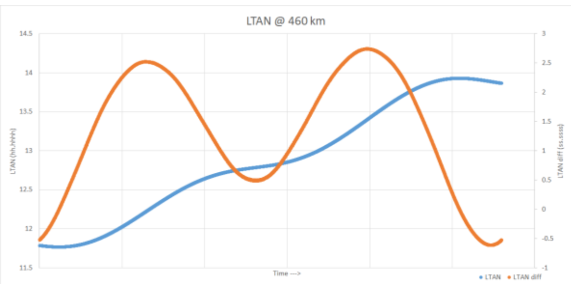

Figure 10. LTAN at 460 km

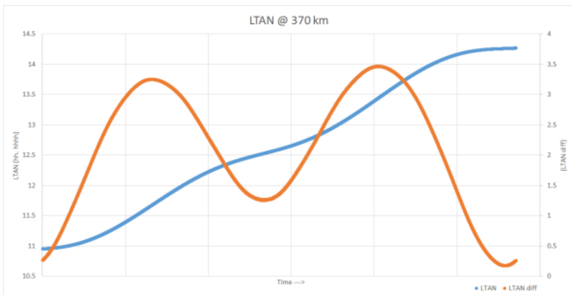

Figure 11. LTAN at 370km

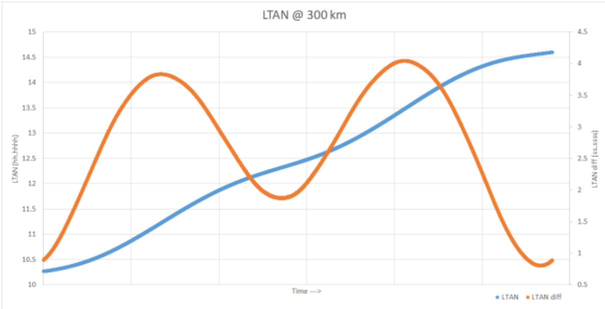

Figure 12. LTAN at 300 km

As shown in the figures above, the trend in the time difference between succeeding local times of ascending nodes is similar throughout different altitude levels. However, their magnitude increases at the lower altitude levels. As a result, although the LTAN of lower altitude levels happen earlier, its succeeding instances happen later. See table 2 for more details.

Table 2. LTAN at different levels

Altitude (km)	LTAN initial value	Average LTAN difference
Current	12:58:06.15	0.20 s
590	12:54:26.65	0.27 s
460	11:47:03.42	1.34 s
370	10:57:06.58	2.09 s
300	10:15:55.72	2.69 s

As seen in table 2, a higher value for the average LTAN difference would mean that the drift for the succeeding passes is larger. Thus, at lower altitudes, the effects of the drift on the satellite would be larger than its current state. It is also worth noting that although that the ascending node of the period happens at earlier times, it still happens in the allowable time frame (after 10am).

4. CONCLUSIONS

This study has simulated the effects of orbital drift to the operations of the Diwata-2 satellite. As mentioned by different studies, some of the effects include differences in reflectance values (Swinnen et al, 2014; Hagole, 2007), issues in the satellite's attitude values (Magallon, et al, 2018) and differences in the spatial resolution of the satellite due to the velocity. Thus, it is imperative for a space program such as the STAMINA4Space to determine the future orbits of its satellites.

Through the study, the pass times of the Diwata-2 over the Philippines were modeled over a year and although there is an effect on the drift, the number of pass times are still acceptable even within low altitude values. The local times of ascending node of the satellite were also simulated and a stronger drift was observed at lower altitude levels. However, although these values are still acceptable, the predicted lifespan of the Diwata-2 is only 5 years, meaning that the electronics and payload of the satellite will be defunct by the time it reaches such low altitude levels.

It is also worth noting that for most of the simulation, the orbit propagator used is the J4 propagator. As stated earlier, it does not account for the satellite drag and other gravity effects. Thus, the modeled orbits are less accurate than those using the SGP4 propagator. In addition, Magallon, et al (2018) studied the effects of TLE age on the actual determination of the satellite orbit and found out that the orbit shifts as the TLE ages depending on the propagator used. Thus, a better simulation would require using the SGP4 propagator to determine slightly more accurate orbital models.

5. REFERENCES

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