A Cost-Effective Imaging Satellite Constellation

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Abstract

Imaging satellites utilize optical, infrared, or radar sensors to conduct the Earth observations, which are now extensively applied to our daily life. In the beginning we considered one-satellite mission, which is required to implement with high-resolution sensors, short revisit cycle, and global coverage. Now we considered mission conducted with multiple satellites, which may be operated by same or different countries, to increase the spatial coverage and to reduce the revisit cycle. Equatorial coverage can be achieved with multiple satellites, but the polar coverage can be done with a large field of regard. Daily revisit and global coverage can be both satisfied by selection of affordable number of satellites with certain field of regard. When taking into account operation complexity and polar coverage, it is recommended to use a constellation with shorter repeat cycle and large field of regard. One can also combine it with an equatorial orbit of 0-deg inclination or a polar orbit of 90-deg inclination.

Introduction

Solutions for daily revisit may have three categories: a GEO to continuously monitor for large events, a daily-repeat LEO to focally monitor for specific regions, and a constellation to intensively monitor for international cooperation. For international cooperation to develop satellites, there are various scenarios for the roles and responsibilities, including breakdown in systems, components, manpower, cost, schedule, and data distribution.

Imaging satellites utilize optical, infrared, or radar sensors to conduct the Earth observations, which are now extensively applied to our daily life. In the beginning we considered one-satellite mission, which is required to implement with high-resolution sensors, short revisit cycle, and global coverage. Now we considered mission conducted with multiple satellites, which may be operated by same or different countries, to increase the spatial coverage and to reduce the revisit cycle. An example is the RapidEye mission using five satellites to achieve daily revisit [1], and another example is GEOSS to integrate the existing and planning satellites and related systems worldwide for the seamless Earth observations [2].

FORMOSAT-2 is currently the only one satellite with daily revisit and global coverage, since it possesses features of daily repeat, high altitude, and large field of regard [3]. During its four year mission after launched in 2004, the satellite could take the first-time images and continuously monitoring for most events.

The capability of one satellite is nevertheless limited. In most cases of disasters, the area of interest is larger than the swath of a satellite, and the demand time is urgent and frequent more than that of one satellite can provide. Most existing satellites are designed with revisit cycles of 2 to 3 days. That means a constellation of 2 or 3 satellites can meet the requirement of daily revisit. But to cover the Poles, multiple satellites do not supercede single one, since all satellites are not passing over the Poles if one consider the Sun-synchronous orbits only.

Revisit and repeat

Revisit cycle can be realized in maximum or mean. The mean revisit cycle represents the expectation from users, while the maximum revisit cycle reflects the risk that a satellite fails to meet the expectation. It occurred one disaster per one month averagely. The lessons learned are mainly three: satellite capabilities always limited, satellite response always later, and satellite operations always complicated. The occurrence is stochastic, but the relief of disaster is mandatory. Therefore, It may be useful to consider the “regular and quick satellite

constellation" to have the mission schedule of satellites independent for each day and for each orbit.

Repeat orbit can simply the mission operations, imaging scheduling, and image processing, especially for those with shorter repeat cycles of 1, 2, or 3 days.

Table 1 lists the altitudes and the inclinations of Sun-synchronous orbits varying with the mean motion with increment of the mean motion of 1/12 rev/day. Those with shorter repeat cycles of 1, 2, or 3 days are marked with bold face. The mean revisit cycle varying with the altitude for Sun-synchronous orbits is shown in Figure 1, from which we can see minimum mean revisit cycles fall on some of the orbits with shorter repeat cycles.

Table 1 Repeat Sun-Synchronous Orbits

Mean Motion (rev/day)	Altitude (km)	Inclination (deg)
14.000	**888.**	**99.001**
14.083	860.	98.876
14.167	831.	98.754
14.250	803.	98.634
14.333	**775.**	**98.516**
14.417	747.	98.401
14.500	**720.**	**98.288**
14.583	693.	98.177
14.667	**666.**	**98.068**
14.750	639.	97.961
14.833	613.	97.856
14.917	587.	97.753
15.000	**561.**	**97.653**
15.083	535.	97.554
15.167	510.	97.456
15.250	485.	97.361
15.333	**460.**	**97.267**
15.417	435.	97.175
15.500	**411.**	**97.085**
15.583	386.	96.997
15.667	**362.**	**96.909**
15.750	338.	96.824
15.833	315.	96.740
15.917	291.	96.657
16.000	**268.**	**96.576**

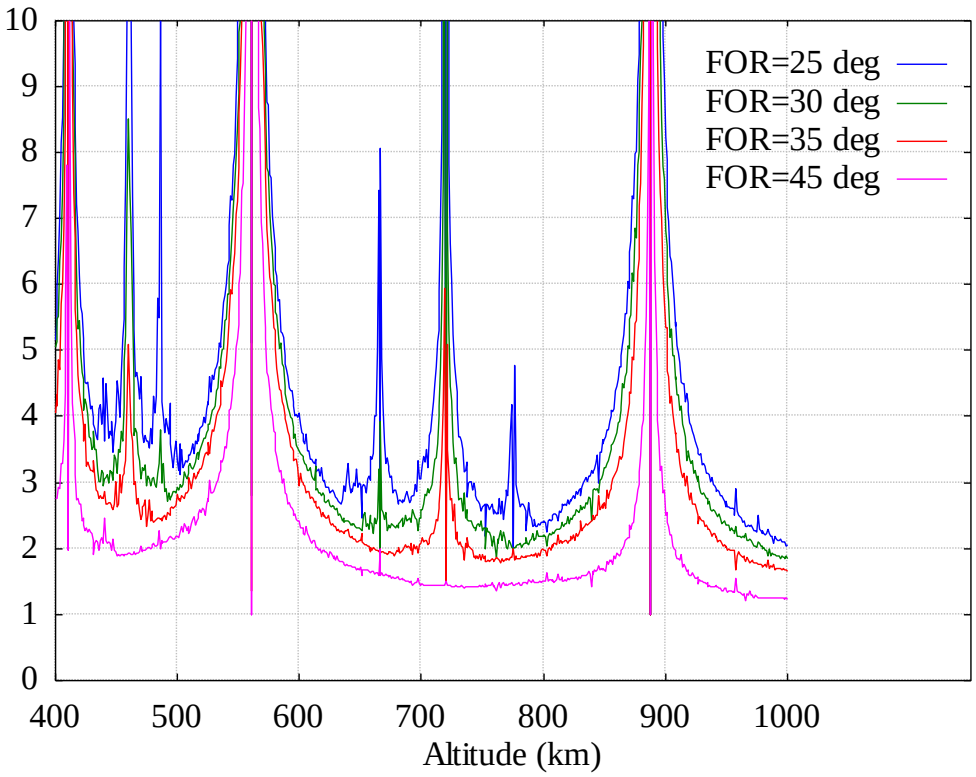

Figure 1 Mean Revisit Cycles for Various Field of Regard

Coverage

Imaging satellites are most operated in Sun-synchronous orbits to keep the sunlight condition and simplify the satellite design. Poles attract increasingly concerns for the global warming effects. Originally the imaging satellites are not required to cover the Poles, but now the situation is different. Equatorial coverage can be achieved with multiple satellites, but the polar coverage can be done with a large field of regard.

Figure 2 shows the required field of regard to cover the Equator and the Poles for the constellation of 1, 2, or 3 satellites phasing in the true anomaly or the right ascension of ascending node. One satellite at 888 km altitude, the field of regard to cover the Poles is 53.6 deg, which is at the limit for side looking with distortion ratio as high as 4.9. This is still useful in urgent needs for imaging of large disaster area. Two satellites at 720 km altitude (corresponding to 14.5 rev/day mean motion) can reduce the field of regard to 42.4 deg to cover the Equator. Three satellites at 666 km altitude (corresponding to 14.5 rev/day mean motion)

can reduce the field of regard to 33.8 deg to cover the Equator. But to cover the Poles they still need large field of regard.

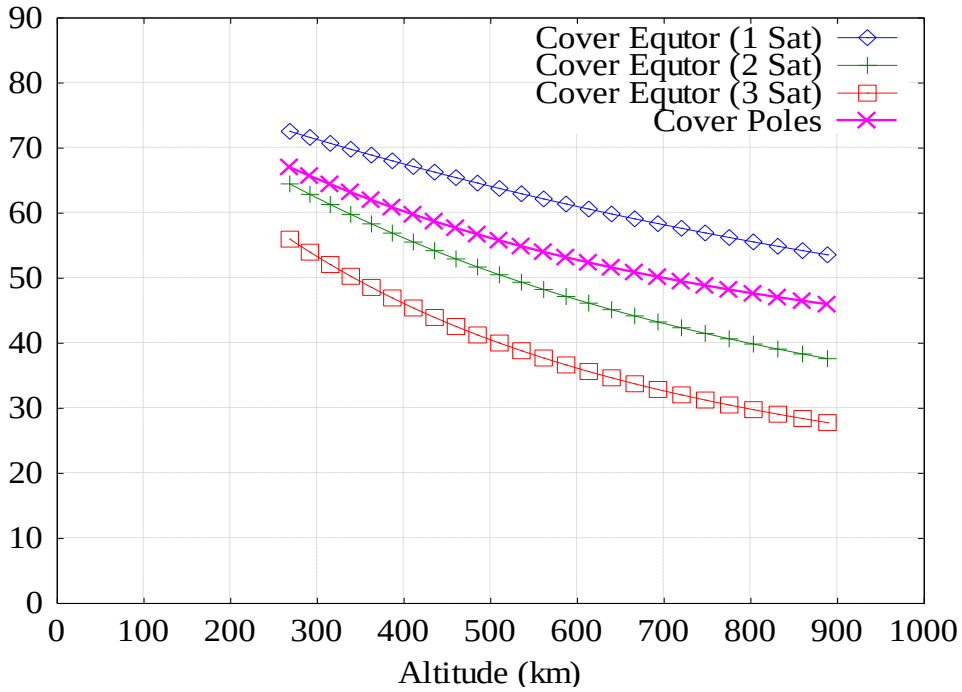

Figure 2 Field of Regard (FOR) to Cover Equator and Poles

FORMOSAT-2 is at 888 km altitude, and has taken the first high-resolution satellite image of the Amundsen-Scott South Pole Station with 46 deg field of regard, as shown in Figure 3 and 4 [3,4]..

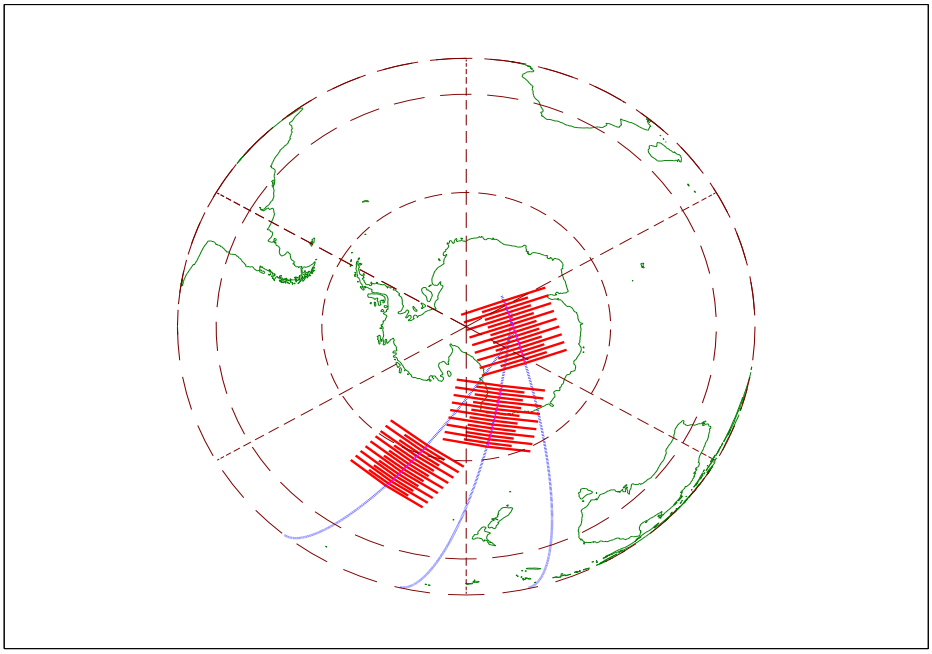

Figure 3

Figure 4 Limit Imaging of Amundsen-Scott South Pole Station (90 deg S), 2006.10.6

Daily revisit and global coverage

Constellation with same inclination and altitude can be phasing in the true anomaly or the right ascension of ascending node according to the requirement of same local solar time or same GMT time. Daily revisit and global coverage can be both satisfied by selection of affordable number of satellites with certain field of regard. When taking into account operation complexity and polar coverage, it is recommended to use a constellation with shorter repeat cycle and large field of regard.

The coverage of 14 rev/day orbit with 53.6 deg FOR is shown in Figure 5.

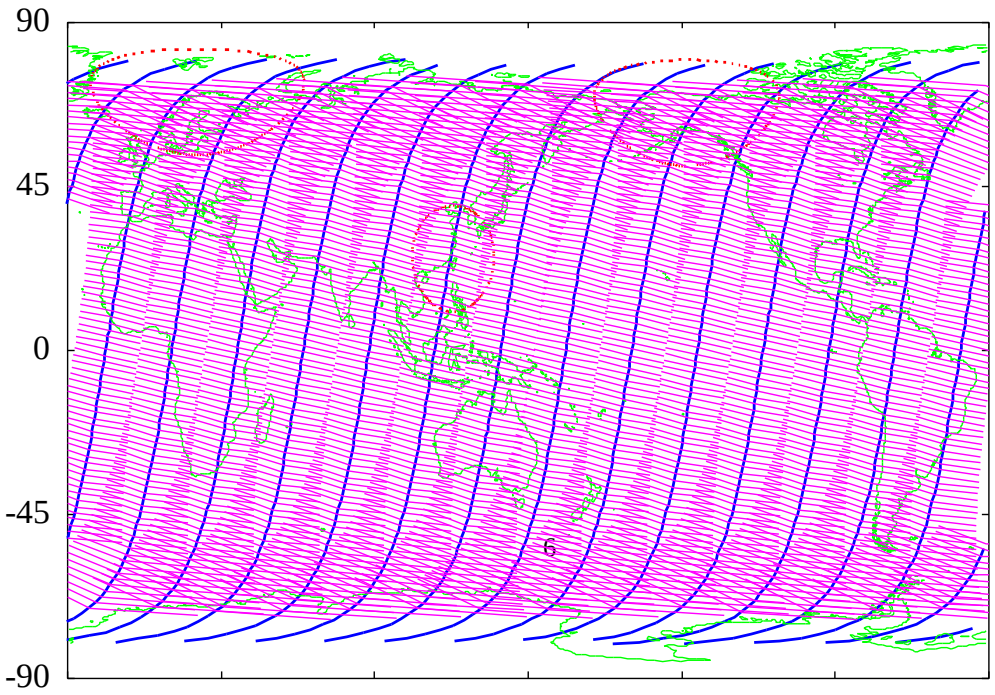

Figure 5 Coverage of 14 rev/day Orbit with 53.6 deg FOR

The coverage of 14.5 rev/day orbit with 45 deg FOR is shown in Figure 6, from which we can also see the overlapping area even possessing one-day revisit. As a minimum, one satellite visits on one day, and another satellite for the other day. When considering international coperation, each partner owns one satellite, and operates two satellites with mutual benefit, which is the lowest cost subject to daily revisit and global coverage.

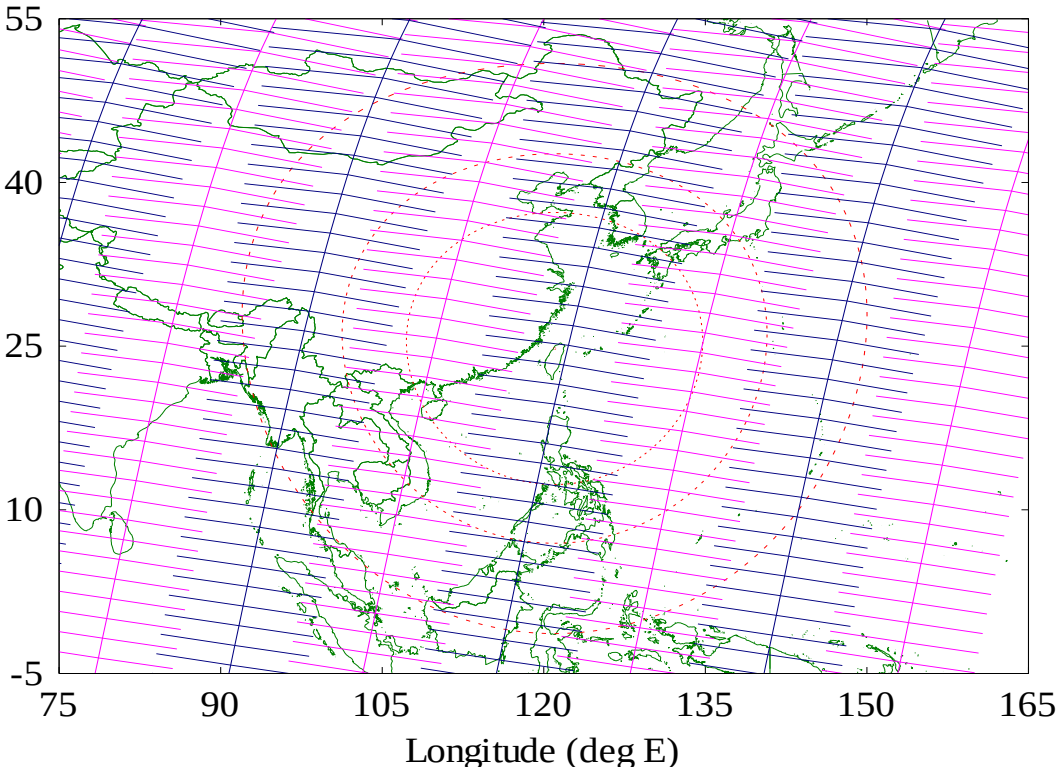

Figure 6 Coverage of 14.5 rev/day Orbit with 45 deg FOR

If the equatorial or polar coverage is required, a combination of Sun-synchronous orbits with an equatorial orbit of 0-deg inclination or a polar orbit of 90-deg inclination may be a straightforward solution, respectively.

Conclusion

Equatorial coverage can be achieved with multiple satellites, but the polar coverage can be done with a large field of regard. Daily revisit and global coverage can be both satisfied by selection of affordable number of satellites with certain field of regard. When taking into account operation complexity and polar coverage, it is recommended to use a constellation with shorter repeat cycle and large field of regard. One can also combine it with an equatorial orbit of 0-deg inclination or a polar orbit of 90-deg inclination.

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