The Coverage Analysis for Moon-based Platform at Three-Polar Regions on Earth

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Abstract. More and more attention has been paid to taking the Earth as a whole for researching. Though space-borne and airborne platform have acquired various data from the Earth, the existing Earth observation system lack the ability of long-term continuous observation at a global scale. We propose a new platform, Moon-based platform, which is used for observing Earth from the Moon and discuss the coverage performance for observing Three-polar regions. Three-polar regions is characterized by its large scale and need long-term observation. Moon-based platform is the ideal platform. The coverage performance of the Moon-based platform depends on Moon orbit parameters, the attitude of the Moon and the attitude of the Earth. The position of the Moon are calculated from Jet Propulsion Laboratory ephemerides. The attitude of the Moon calculated from the libration Euler angles and the attitude of the Earth derived from the Earth orientation parameters. After introducing the coordinate system transformation, a preliminary coverage geometry are conducted. With the help of coverage geometry model, the simulation about Three-polar regions is presented. The result shows that the Moon-based platform has the advantages of large observing areas, long observation time windows and rich observing angles combination.

1. Introduction
In order to get the comprehensive data of the Earth, scientists have been studying and developing Earth observation science and technology. Though space-borne and airborne platform have the ability of acquiring observing data of the Earth, when taking the Earth as a whole for researching, we will have to face the problems of temporal coherence and spatial continuity in the global scale. With the tide of lunar exploration and exploitation, Moon is the only natural satellite of Earth, with the advantages of large observing areas, long period time of observation and rich observing angles combination, turning out to be an ideal platform for observing large regions on Earth. However, the spatial coverage performance, temporal coverage performance and angular coverage performance from Moon-based platform on these large regions remains largely unknown.

The analysis of coverage performance for Moon-based platform including spatial, temporal and angular coverage performance serve to realize the important characteristics of observing from the Moon. The spatial coverage for Moon-based platform is defined as a region on Earth where the Moon-based platform is seen at a minimum predefined elevation angle. The temporal coverage refers to the start time, the end time and the duration of observing a region on Earth. The angular coverage offers great significant parameters to the multi-angle remote sensing and the observation system to detect the Earth’s energy balance.

Observing the Earth from the Moon is not a new conceptual observation method. In 1972, Apollo 16 astronauts used a far-ultraviolet camera to obtain the Earth’s atmosphere and corona images and
spectra[1]. At the early 21st century, Johnson[2] and Hamill[3] proposed that deploying visible or near infrared instruments on the Moon to observe the Earth. They discussed some advantages and limiting factors, such as spatial and temporal resolution. Guo discussed that deploying different kinds of sensors on the Moon have the capacity to acquire data for researching global change[4]. At present, some scholars are researching the coverage performance of the Moon-based platform. In 2012, Zhang proposed the Moon-based Earth observation simulation technology based on the Jet Propulsion Laboratory(JPL) ephemerides, preliminarily analysing the regularity of observed regions[5]. The Moon-based observation simplified geometry model is shown and simulation of cloud, cyclones and water vapor dynamic is presented from his research. But errors in Earth orientation tend to be larger than those based on Earth orientation parameters(EOP) that describe irregularities in the rotation of the Earth. In 2014, Ding studied the coverage performance analysis of Earth observation from Moon-based for global change detection[6]. The point-by-point method is used to calculate the coverage indicators on the basis of orbit simulation and spherical ground triangulation. The approach can evaluate more precise results but he neglected the libration of the Moon. This could cause a great error of evaluate the angular coverage performance.

This paper discusses the coverage performance for Moon-based platform at Three-polar regions on Earth. We used one-year position of Sun, Earth and Moon in the Earth centered inertial coordinates and one-year libration Euler angles of the Moon based on JPL ephemerides. We correct the Earth attitude by using the EOP and the Moon attitude is corrected by libration Euler angles. Then, we establish the coverage simplified geometric model and analysis the coverage performance of Three-polar regions. Finally, we attempt to better understand the coverage performance from Moon-based platform on Three-polar regions.

2. Three-polar Observation and Coverage
The Arctic, Antarctic and Tibet Plateau are known as the Three-polar regions with the characteristic of large area. They are all the world’s largest storage of cold and carbon which are the sensitive regions of global environment change. The Three-polar regions is a dynamic system including many interacting components that are constantly changing. The interaction and feedbacks of Three-polar regions among these components are complex and register high variability in time and space. To understand the global sensitive factors of Three-polar regions on temporal and spatial variation, it has been recognized the need to obtain detailed data at a large scale. For this purpose, many agencies launched the Earth observing system satellites that are currently monitoring many of the characteristics of Three-polar regions like temperature or snow cover[7]. It is well known that the structure and the functioning of Three-polar regions are largely determined by the regularities of global sensitive factors. But this sensitive factors regularity suffers frequent nonlinear changes that gives more complexity to the system and introduces uncertainty. For this reason, the assessment of how global sensitive factors respond to global environment change depend strongly on the time scale[8]. The analysis of these observing data set allows for modelling and predictions that provide valuable information for researching. Though many studies on polar regions or Tibet Plateau exists, there is still no researches on taking the Three-polar regions as a whole. It is feasible to deploy sensors on the Moon to observe Three-polar regions on Earth. The coverage performance from Moon-based observation at Three-polar regions on Earth is important. For the large regions, the special geographical position and the necessity of the study purposes, Three-polar regions are suitable for our study.

3. Moon-based Platform Coverage Geometry
The Moon-based platform devoted to Earth observation coverage geometry presents peculiar features which are different from airborne platforms or spaceborne platforms. First of all, the line-of-sight vector representation and the coverage observation geometry are quite different; moreover the platform, on which the sensors will be built up, is not only a spaceborne platform, but a whole, quite stable celestial body. So we need to develop a new coverage geometric model combining existing methods of spaceborne observation geometry.
3.1. Dynamic Models for Moon-based Platform

In case of a Moon-based platform, the coverage analysis must begin with the definition of Earth-Moon relative motion model. For the sake of simplicity both Earth and Moon were assumed spherical. On this basis very high precision lunar ephemeris DE series and EPM series exploitable for Lunar exploration[9], and the lunar and planetary theory JPL DE421 were more elaborated. Therefore, DE421 was selected by us because DE421 is a general purpose ephemeris, including the Moon libration and Earth nutation[10].

It is worth emphasizing that the Earth and Moon cannot be considered as point-like bodies and their orbital motion must be disentangled from their intrinsic rotations. The DE421 ephemeris provides the Moon three positions coordinate components of the geocentric coordinate system as a function of the barycentric dynamical time (TDB) expressed in Julian centuries starting from J2000. To determine the attitude of the Moon, DE421 were applied to calculate the three libration Euler angle. International Astronautical Union (IAU) include the rotation matrix of Earth orientation and to derive the observed target position in an inertial reference frame, the Earth rotation was account for.

From the point of view of the orbital motion of Moon theory should include construction of five local coordinate systems attached to: (1) the inertial geocentric coordinate system; (2) the Earth-Centered Earth-Fixed coordinate system; (3) the selenographic coordinate system; (4) the inertial selenocentric coordinate system; (5) the Moon-Centered Moon-Fixed coordinate system. To derive this position in an inertial geocentric coordinate system, it is necessary to introduce the relevant transformations of these coordinate systems.

![Image](image_url)

**Figure 1.** Simplified geometry model of Moon-based observation

3.2. Coverage Geometry

It is worth noting that, it is more difficult to calculate the coverage of Moon-based platform. Because optical sensors on the Moon-based platform can’t be observed at night. The sunlit area on Earth is a hemisphere and the Moon-based observation coverage is the overlapping area. Therefore, we define a spatial coverage as the observed proportion of the observed region.

The basic geometry between the Moon-based platform sensor and observed target is depicted in Fig 2. The points indicate the Moon-based platform sensor (S), observed target (T) and then the third is the Earth’s center (O). The nadir point is indicated by S’. These two lines SP₁ and SP₂ passing at point P₁ and P₂ represent horizon planes. R represents the radius of Earth and h represents the distance from Moon-based platform to nadir point. There are another four variables in Fig. 2: ε is elevation angle of observed target, α is nadir angle, λ is geocentric angle of observed target T and η is the angle between the line ST and the line SO. As soon as R, h and 𝜀\text{min} are known, the λ\text{max} can be calculate by these following equations:
\[
\sin \alpha = \frac{R}{R + h} \\
\sin \eta_{\text{max}} = \sin \alpha \cos \epsilon_{\text{min}} \\
\lambda_{\text{max}} = 90^\circ - \epsilon_{\text{min}} - \eta_{\text{max}}
\]

The most needed parameter is the \( \lambda \). This parameter will be used to judge whether can be observed by Moon-based observation.

\[
\arccos \left( \frac{R_t \cdot R_s}{|R_t||R_s|} \right) < \frac{\pi}{2} \\
\lambda = \arccos \left( \frac{R_t \cdot R_m}{|R_t||R_m|} \right) < \lambda_{\text{max}}
\]

**Figure 2.** This is the spatial coverage geometry for Moon-based observation (not in scale for sake of clarity).

**Figure 3.** This is the angular distribution of Moon-based platform on Earth.

We construct a technique diagram of Moon-based observation for optical sensors spatial and temporal coverage analysis. The technology diagram of Moon-based coverage simulation includes three parts: the calculation of real-time locations of Earth and Moon; rendering of basic scene; the calculation of coverage time matrix. In the next step, we import the coordinates of test area and find out whether the regional boundary points are observed. We define the observed point with number ‘1’ and unobserved point with ‘0’, forming a Boolean Matrix. After all matrixes of boundary points are obtained, we calculate the intersection of them.

**Figure 4.** This is the technique diagram of Moon-based Earth observation for optical sensors coverage analysis.

The observation angle of Moon-based platform refers to the relative azimuth angle and observer viewing zenith angle. The observer viewing zenith \( \theta \) is the angle of axis Z and vector OM and \( \emptyset \) is the relative azimuth angle defining the azimuth angle position of the observer relative to the solar plane (Fig. 3).
4. Moon-based Platform Coverage Simulation

We use the actual Moon orbit data to simulate the time windows, observation ranges and observation angles when observing Three-polar regions from Moon-based platform and calculate coverage through a mask. In one calendar year (366 d), 8 observations are completed on the Arctic region and 9 observations are completed on the Antarctic region (Table 1, 2). Mean duration of Antarctic region are 13 Days and mean duration of Arctic region are 10 Days. These shows that Moon-based platform serves the sustained observing needs of the polar regions. It can be seen from Table 1 that all observation are completed from March to September in 2016. From Table 1 and Table 2, there are one more observation time when observing Arctic regions. Because nadir point in the northern hemisphere is longer than the duration it in the southern hemisphere. Explained by the Kepler's second law, the asymmetric shape of the orbit lead to the observing characteristic.

Figure 5. This is the simulated image of Tibetan Plateau.

Figure 6. This is the simulated image of Tibetan Plateau.

Figure 5 shows the coverage simulation of Moon-based observation on Tibetan Plateau in 2016. Tibetan Plateau is located in the mid-latitude regions of the northern hemisphere, so it can be completely covered by one observation of Moon-based platform. Tibetan Plateau is observed 310 times in 2016. About 1471 hours will be observed in 2016 and the time coverage reached 16.7%. The longest observation time window will be on June 5. It can be seen from Figure 6 that we can observe the whole Tibetan Plateau every month. Because the direction of the Moon revolves in the same direction with the Earth's rotation. In August, there will be the more time observed. Besides, it also can be observed continuously. This is an excellent opportunity to observe Tibetan Plateau in order to obtain more information.

|   | Start Time(UTCG) | Stop Time(UTCG) | Duration(Sec) |
|---|------------------|-----------------|---------------|
| 1 | 20 Mar 2016 20:54:38 | 23 Mar 2016 04:01:25 | 198406 |
| 2 | 6 Apr 2016 15:31:12  | 19 Apr 2016 10:10:28  | 1103956 |
| 3 | 4 May 2016 02:20:30  | 16 May 2016 17:07:32  | 1090021 |
| 4 | 31 May 2016 11:34:31 | 13 Jun 2016 01:28:50 | 1086858 |
| 5 | 27 Jun 2016 18:55:02 | 10 Jul 2016 10:48:06 | 1093983 |
| 6 | 25 Jul 2016 01:16:12 | 6 Aug 2016 20:01:21 | 1104309 |
| 7 | 21 Aug 2016 08:13:06 | 3 Sep 2016 04:11:33 | 1108707 |
| 8 | 17 Sep 2016 17:01:24 | 21 Sep 2016 21:49:38 | 362894 |
Table 2. The time windows when observes the Antarctic regions.

|   | Start Time(UTC(G) | Stop Time(UTC(G) | Duration(Sec) |
|---|------------------|------------------|---------------|
| 1 | 1 Jan 2016 15:09:56 | 15 Jan 2016 00:21:46 | 1156309 |
| 2 | 29 Jan 2016 00:47:09 | 11 Feb 2016 08:10:34 | 1149804 |
| 3 | 25 Feb 2016 09:00:08 | 9 Mar 2016 18:03:02 | 1155774 |
| 4 | 30 Sep 2016 22:27:31 | 14 Oct 2016 17:30:28 | 1191777 |
| 5 | 28 Oct 2016 04:43:38 | 11 Nov 2016 04:51:08 | 1210049 |
| 6 | 24 Nov 2016 11:33:04 | 8 Dec 2016 14:46:17 | 1221192 |
| 7 | 21 Dec 2016 19:48:15 | 1 Jan 2017 00:00:00 | 879104 |

Figure 7. The angular coverage of Antarctic regions.

Figure 8. The angular coverage of Arctic regions.

Figure 7 and Figure 8 shows the angular coverage of polar regions. It is obvious that observing by Moon-based platform offers a much angular coverage, which is of great significance to the multi-angle remote sensing and observation system to detect the Earth’s energy balance.

5. Conclusion

This paper presents a new concept of Moon-based observation. In monitoring Three-polar regions, Moon-based platform has a good performance in coverage, including temporal, spatial and angular. The result shows that Moon-based observation has large spatial coverage advantages in the research of Three-polar regions. The time windows changes with respect to the latitude of regions so the Tibet Plateau region has more observing time than Arctic and Antarctic region. Much angular coverage of Three-polar regions is shown. The multi-angles observation have contribution to the observation system to detect the Earth’s energy balance. Besides, the Moon-based platform also provides long time-series data, which is greatly exceeds other platforms. In general, the Moon-based platform have a good
performance in coverage of Three-polar regions on Earth. The simulation method will be essential part of foreseen future work.

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