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Observation duration analysis for Earth surface features from a Moon-based platform

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Abstract

Earth System Science is a discipline that performs holistic and comprehensive research on various components of the Earth. One of a key issue for the Earth monitoring and observation is to enhance the observation duration, the time intervals during which the Earth surface features can be observed by sensors. In this work, we propose to utilise the Moon as an Earth observation platform. Thanks to the long distance between the Earth and the Moon, and the vast space on the lunar surface which is suitable for sensor installation, this Earth observation platform could have large spatial coverage, long temporal duration, and could perform multi-layer detection of the Earth. The line of sight between a proposed Moon-based platform and the Earth will change with different lunar surface positions; therefore, in this work, the position of the lunar surface was divided into four regions, including one full observation region and three incomplete observation regions. As existing methods are not able to perform global-scale observations, a Boolean matrix method was established to calculate the necessary observation durations from a Moon-based platform. Based on Jet Propulsion Laboratory (JPL) ephemerides and Earth Orientation Parameters (EOP), a formula was developed to describe the geometrical relationship between the Moon-based platform and Earth surface features in the unified spatial coordinate system and the unified time system. In addition, we compared the observation geometries at different positions on the lunar surface and two parameters that are vital to observation duration calculations were considered. Finally, an analysis method was developed. We found that the observation duration of a given Earth surface feature shows little difference regardless of sensor position within the full observation region. However, the observation duration for sensors in the incomplete observation regions is reduced by at least half. In summary, our results demonstrate the suitability of a Moon-based platform located in the full observation region.

Keywords: Moon-based platform; Observation duration analysis; Remote sensing; Analysis

1. Introduction

Our understanding of Earth system science has continually improved in recent decades owing to the development and use of different Earth observation platforms. In particular, air-borne and space-borne platforms have been widely used for regional scale observations (Guo, 2016). The National Aeronautics and Space Administration (NASA) and other agencies launched the Earth Observing System (EOS) in 1991, a program that comprises a series of Earth observation satellites in Earth orbit (King and Greenstone, 1999a, 1999b; Asrar et al., 1992). The EOS satellites monitor various kinds of features of the Earth's land biosphere, geosphere, atmosphere, and oceans (Schlesinger 2006, Parkinson 2003). The Copernicus Programme of the European Space Agency (ESA) and European Commission aims to achieve high-quality and

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wide-range Earth observation capacity (Denis et al., 2016) by collecting data from different Earth observation platforms, including satellites and air-borne platforms (Butler, 2014). China launched the civilian High-Definition Earth Observation Satellite (HDEOS) program in 2013, which will substantially improve the capability for disaster relief, resource exploration and monitoring, and environment survey (Tong et al., 2016; Wang et al., 2016). Moreover, some of those missions observe the Earth by using multiple space-borne platforms (Tobias, 2000). In addition, a space-borne platform can be equipped with different kinds of sensors. The low-orbit International Space Station (ISS) which involves the international collaboration of 16 countries from five space agencies: NASA, the ESA, Russia's Federal Space Agency (Roscosmos), the Canadian Space Agency (CSA), and the Japan Aerospace Exploration Agency (JAXA), and provides a platform for scientific experiments (Guo et al., 2016). It can also serve as an Earth observation platform (Jules, 2008).

With the development of space technology, increasing attention has been paid to observation of the Earth from observation platform that has longer distance to the Earth, since it has the advantages of large spatial coverage, long temporal duration, and could perform multi-layer detection of the Earth. Compared with space-borne and air-borne Earth observation platforms, the Moon has specific features that would complement existing Earth observation systems. First, one side of the Moon is always facing the Earth since its rotation and revolution periods are the same. Second, because of the great distance between the Earth and Moon, a Moon-based sensor could observe almost the entire Moon-facing hemisphere of the Earth, allowing for global-scale observations with continuously changing angles, which could improve the quality of the global energy budget data (Pallé and Goode, 2009). Furthermore, the Moon-based platform could observe a given region of the Earth over a long period of time or acquire the observation data from the subsurface to the plasmasphere synchronously (Ye et al., 2016), making it possible to collect continuous and multi-layer observation data of the Earth. Finally, the Moon has stable geological conditions and abundant space to install sensors (Ouyang, 2005); therefore, multiple sensors could be installed to measure different parameters of the Earth under the same imaging condition.

Previously, Guo suggested that Moon-based Synthetic Aperture Radar (SAR) would have the ability to monitor global change (Guo et al., 2014, 2012; Liu et al., 2016) proposed a Moon-based Earth observation system and discussed its application to large-scale geoscience phenomena. Further, Ye et al. (2016) have discussed a three-polar-region observation scheme using Moon-based Earth observation. Similarly, Song et al. (2017) have shown that the polar regions of the Moon may be the best areas for establishing a Moon-based observatory. Fornaro et al. (2010) have analysed the potentials and limitations of Moon-borne SAR imaging. Those previous research all have a basic need to determine the observation geometry of the Moon-based platform. Owing to the great distance from the Earth, the Moon-based platform would experience a narrower field of view than current platforms; therefore, more precise calculations of position and orientation would be needed. In addition, images acquired by a Moon-based sensor on the Earth hemisphere scale would include both sunlit and night sectors; therefore, the observation geometry of a Moon-based platform would be much more complicated than those of space-borne and air-borne platforms.

To determine the observation geometry of a Moon-based platform, some scholars have presented ideas for the observation geometric model of this platform. Moccia and Renga (2010) have considered the geometry of the Moon-based SAR system and calculated some of the key observation parameters. Zhang (2012) has proposed a Moon-based Earth observation simulation based on the Jet Propulsion Laboratory (JPL) ephemerides, and preliminarily analysed the regularity of the observed regions. Those geometric models incorporate certain hypotheses to account for the attitudes of the Moon and the Earth. The peculiarity of these approaches is the use of analytic models instead of a more precise numerical one. Further, different positions on the lunar surface have different observing angles and, therefore, equating the position of the Moon-based platform with the barycentre of the Moon would generate unacceptable errors in the observation geometry (Ye et al., 2017c). Thus, the positions of the Earth surface features must be considered when developing the observation geometry. In recent years, although Ren et al. (2017) have improved the relevant simulation methods and observation geometry, studies concerning the coverage performance of the Moon-based platform have not yet provided information on the variation of temporal coverage at different Earth surface features when sensors are placed at different positions on the lunar surface. One of the major expected problems is associated with relation of the sensor positions to the positions of the surface features on Earth. That is important for calculation of the observation duration for the Earth surface features (i.e., the time intervals in which Earth surface features can be observed by a sensor). For observation duration calculations, an optical sensor can observe almost half the Moon-facing hemisphere, including the night and sunlit parts; thus, it is necessary to evaluate the calculation of the time intervals during which the Earth surface features are illuminated by the Sun and can be observed by an optical sensor. In addition, certain variables such as the elevation angles of the Earth surface features must be considered in the observation geometry.

To fully utilise the Moon-based platform, the observation performance must be analysed, especially by simulating different positions on the lunar surface, and thus giving support to site selection from the simulation result of observation duration performance. In this study, we considered the observation duration of Earth surface