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Monitoring the dynamics of ice shelf margins in Polar Regions with high-spatial- and high-temporal-resolution space-borne optical imagery

Cheng-Chien Liu [a,b,*], Yueh-Cheng Chang [a], Stefani Huang [c], Sheng-Yun Yan [c], Frank Wu [c], An-Ming Wu [c], Soushi Kato [b], Yasushi Yamaguchi [d]

[a] *Institute of Satellite Informatics and Earth Environment, National Cheng Kung University, 701 Tainan, Taiwan ROC*
[b] *Department of Earth Sciences, Earth Dynamic System Research Center, National Cheng Kung University, 701 Tainan, Taiwan, ROC*
[c] *National Space Organization, 8F, 9 Prosperity 1st Road, Science Based Industrial Park, Hsinchu, Taiwan, ROC*
[d] *Department of Earth and Environmental Sciences, Graduate School of Environmental Studies, Nagoya University, Japan*

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ABSTRACT

We report the new satellite data of Polar Regions collected by Formosat-2 during the recent Polar Imaging Campaign (March 2006–September 2007). Formosat-2 is the first satellite with a high-spatial-resolution (2 m) sensor placed in a daily revisit orbit. Together with its agility of pointing ±45° both across and along track, we are able to acquire the optical imagery with 2 m resolution at any place in Polar Regions everyday. We demonstrate its applications with regard to observing the sea ice condition, monitoring the daily changes in ice shelves, and tracking floating ice with sizes of tens of meters for ten consecutive days from 3/24/2006 to 4/2/2006 in the vicinity of Alert, Canada. We successfully track the dramatic movement of ice floes during the breaking-up and refreezing event near the main flaw lead, with the velocity as high as 5 km/day. The results indicate that high-spatial- and high-temporal-resolution optical imagery taken from Formosat-2 could be a very useful data source with immediate impact on the research of Polar Regions.

1. Introduction

One of the prime activities occurring during International Polar Year (IPY) 2007–2008 is to coordinate and collect satellite data of changing polar environments (Rapley et al., 2004). Due to the lack of sunlight and ubiquitous cloud cover in Polar Regions, satellite synthetic aperture radar (SAR) data acquisitions have been the most widely used approach to monitor and map the vase Polar Regions. For example, the earlier efforts in maneuvering Radarsat-1 in a special mode provided radar images with a spatial resolution of 30 m over the entirety of Antarctica during September to October 1997 (Jezek et al., 1998). The Global Inter-agency IPY Polar Snapshot Year (GIIPSY) project also coordinates various observations from C-band RADARSAT-1 and Envisat ASAR, the L-band PALSAR instrument on ALOS, and the X-band of the TerraSAR-X, with an intention to achieve complete bi-polar mapping of the dynamic margins of the large Antarctic and Greenland ice sheets (Drinkwater et al., 2008). From the complementary point of view, there is an ever-increasing need in acquiring the space-borne optical imagery with both high-spatial- and high-temporal-resolutions.

Applications of space-borne optical imagery on the Polar Regions are currently restricted by its spatial and temporal resolutions. Kargel et al. (2005) explained how the latitude limit of high-spatial-resolution optical satellite observation was pushed to ~81° North and South by Landsat (30 m) in 1980s, and extended to ~86° by ASTER (15 m) in 2000s. However, there is still no space-borne high-spatial-resolution optical image of the Polar Regions with latitudes higher than 86°. Another issue is the temporal-resolution of the satellite operated in the general near-polar orbit, which is usually low from a few days to a few tens of days. To detect the subtle and dynamic changes that occur in the Polar Regions with higher latitudes, we need a new system with not only high-spatial- but also high-temporal-resolution.

2. Formosat-2

Operated by the National SPace Organization (NSPO) of Taiwan, Formosat-2 is the first satellite with a high-spatial-resolution sensor placed in a daily revisit orbit (Liu, 2006). Its imagery is available for 2 m in panchromatic (0.45–0.90 μm) and 8 m in multispectral from visible to near-infrared (0.45–0.52, 0.52–0.60, 0.63–0.69, 0.76–0.90 μm) with scene coverage of 24 km×24 km. Equipped with two-axes high torque reaction wheels, Formosat-2 is able to point not only to ±45° across track, but also to ±45° along track (Liu et al., 2007). Fig. 1

* Corresponding author. Department of Earth Sciences, Earth Dynamic System Research Center, National Cheng Kung University, 701 Tainan, Taiwan, ROC. Tel.: +886 6 275 7575x65422.
E-mail address: ccliu88@mail.ncku.edu.tw (C.-C. Liu).

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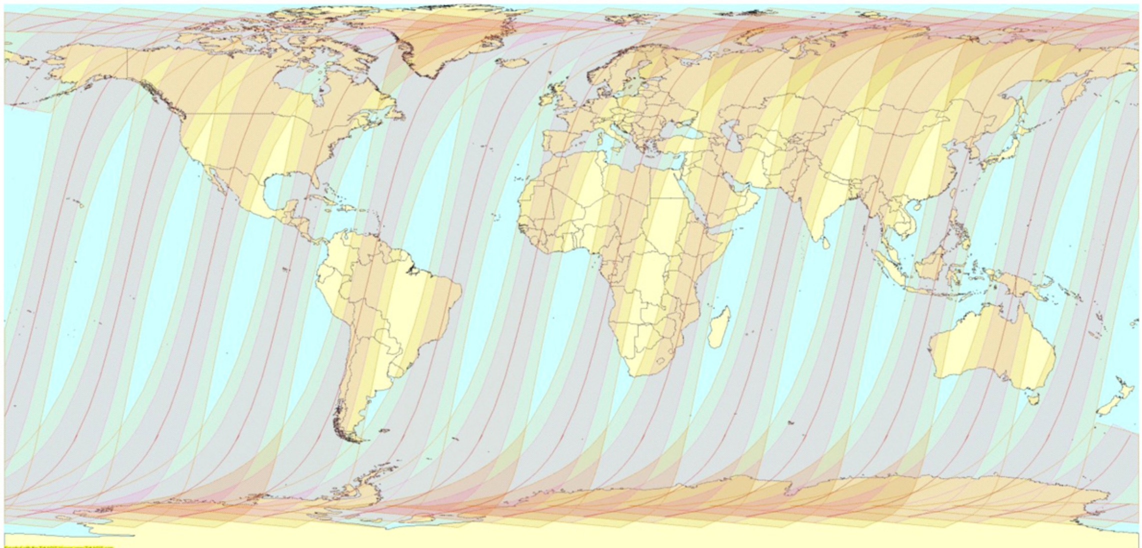

Fig. 1. Map of the accessible areas and the ground track of FORMOSAT-2 orbits with ±45° viewing angle across track (side looking).

gives the map of the accessible areas and the corresponding ground tracks of Formosat-2. To achieve the daily revisit orbit, the global coverage is limited in low latitude but there is no gap at all in Polar Regions. This characteristic enables us to acquire the optical imagery with 2 m resolution at any place in Polar Regions everyday. For example, we successfully took the first space-borne optical image of the Amundsen-Scott South Pole Station using Formosat-2 on 18 December 2006 (Liu et al., 2008), which has never been imaged by other high-spatial-resolution space-borne optical sensors before.

To support IPY 2007–2008, NSPO launched a Polar Imaging Campaign (PIC) starting in March 2006. Fig. 2 shows the areas that have been imaged, up to February 2008. Note that Formosat-2 is a commercially-operated satellite that only has 8 min of orbit time before the content of onboard memory is completely broadcasted to three ground stations located in Taiwan, Sweden and Norway. It is not solely dedicated to taking images in Polar Regions. Although Formosat-2 is able to acquire imagery at latitudes higher than 86°, only those regions with clear scientific objects identified by IPY are continuously observed by Formosat-2, as listed in Table 1. Table 1 also shows the cloud free image frequency recommended by IPY. Some regions, such as the high Arctic, are notoriously cloudy places that lack sunlight. But when high pressure systems remain over some regions for extended time periods, Formosat-2 would become very useful to provide high-temporal-resolution imagery in those regions. In this paper, we demonstrate the potential of Formosat-2 imagery in observing the sea ice condition, monitoring the daily changes in ice shelves, and tracking floating ice with sizes of tens of meters for ten consecutive days. Note that the sequence presented here is not just a best case scenario that we picked from the database. If the weather is permitted, Formosat-2 is indeed able to conduct the site surveillance for consecutive days. These unprecedented images could be a very useful data source with immediate impact on the research of Polar Regions.

3. Image processing

We acquire the level-1A and level-2 images of Polar Regions from NSPO almost everyday. These products are processed by applying basic radiometric calibration and by projecting the raw image onto a spheroid using the ephemeris data onboard to correct the satellite orbit and altitude. These products, however, both suffer from the problem of band-to-band misregistration described in Liu et al. (2007). We employ the automatic Formosat-2 image processing system (F2-AIPS) to produce the higher level products as described in Liu (2006), including band-to-band coregistration, spectral preserved pan-sharpening and multi-temporal imagery matching. Since the geometrics of ground features on the ice shelves are retained well in the consecutive Formosat-2 images, we may apply the technique of fast normalized cross-correlation to coregister the multi-temporal imagery. Note that we visually screen all consecutive images and define the changing and unchanging regions. For example, the broken up and floating ice shelves would be masked as changing regions. Only the points in the unchanging regions are used to coregister the images. The rest of the process is fully automatic, and it takes only 2 h to process one standard scene of Formosat-2 imagery (12×12 km^2).

4. Observing sea ice conditions

Sea ice conditions are usually observed from aerial, shipboard, shoreline platforms, or satellite microwave remote sensing, and reported voluntarily to authorities because of concerns with the safe passage of ships. Smith (2000) provided a detailed guide for observers to objectively determine three basic parameters of sea ice conditions: concentration, stage of development, and form. From the 2 m optical imagery taken by Formosat-2, the concentration and the form of ice floes can be accurately determined, and most of the development stages can be discriminated. Therefore, Formosat-2 provides an avenue to monitor the sea ice conditions of Polar Regions from space. Fig. 3 gives an example of sea ice observation near a newly-forming flaw lead with an approximate size of 8 km in length and 600 m in width in the vicinity of Alert, Canada. Fig. 3(a) is basically a snapshot of an active area interleaved with first-year ice, flaw leads, and thicker, multiyear floes. The multiyear ice can be distinguished by the long shadows cast by the increased height above the water and the generally more ridged features on the surface. Taking a closer look around the main flaw lead (Fig. 3b), however, reveals at least five types of sea ice (labeled from A to E) in this active region. The ice floe with dark tone and smooth surface in the midst of the flaw lead (region C) represents a newly-frozen ice floe with thinner thickness. A few brash or very small floes with the order of 5–50 m in diameter are trapped and frozen in region D. If the environmental conditions remain the same without other interferences, the thicknesses of both the C and D regions would be increasing and eventually developing into regions