SESAME

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DOI
10.1109/IGARSS.2017.8126905

Publication date
2017

Document Version
Final published version

Published in
2017 IEEE International Geoscience and Remote Sensing Symposium: International Cooperation for Global Awareness, IGARSS 2017 - Proceedings

Citation (APA)
Rott, H., Lopez-Dekker, P., Solberg, S., Ulander, L., Nagler, T., Krieger, G., Prats-Iraola, P., Rodriguez-Cassola, M., Zonno, M., & Moreira, A. (2017). SESAME: A single-pass interferometric SEntinel-1 companion SAR mission for monitoring GEO- and biosphere dynamics. In *2017 IEEE International Geoscience and Remote Sensing Symposium: International Cooperation for Global Awareness, IGARSS 2017 - Proceedings* (Vol. 2017-July, pp. 107-110). Article 8126905 IEEE. https://doi.org/10.1109/IGARSS.2017.8126905

SESAME: A SINGLE-PASS INTERFEROMETRIC SENTINEL-1 COMPANION SAR MISSION FOR MONITORING GEO- AND BIOSPHERE DYNAMICS

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ABSTRACT

SESAME (SEntinel-1 SAR companion Multistatic Explorer) is a passive SAR satellite mission proposed for the ESA Earth Explorer Program. SESAME comprises two receive-only C-band SAR satellites flying in close formation to build a single-pass SAR interferometer (SP-InSAR) using the active signal of the European Sentinel-1 satellite. The SESAME mission addresses applications in geoscience and climate research that require repeat measurements of high precision elevation data over land surfaces including ice covered areas and forests, exploiting the SP-InSAR and multistatic observation geometry of the satellite formation. The objectives, the measurement approach and geo-bio-physical products of the mission are described.

Index Terms— SAR interferometry, Sentinel-1, surface topography, glacier mass balance, landslides, forest biomass

1. INTRODUCTION

Single-pass Interferometric SAR (SP-InSAR) satellite missions offer unique opportunities for observing dynamic features on the earth surface that are associated with distinct temporal changes of shape and elevation of land surfaces, ice bodies, and forested areas. SP-InSAR topographic products from the Shuttle Radar Topography (SRTM) and TanDEM-X missions have demonstrated the great value of this technique for solid earth, cryosphere and biosphere applications [1]. However, available topographic databases with global coverage are lacking the capability to regularly and extensively capture and quantify key features as required for studying dynamic processes that are shaping and transforming the land surfaces, ice bodies and vegetation cover.

In order to tackle this critical gap in Earth observation, the satellite mission SESAME (SEntinel-1 SAR companion Multistatic Explorer) was proposed to ESA in response to the Call for Proposals for Earth Explorer Mission EE-9. SESAME comprises two receive-only C-band radar (passive SAR) satellites flying in close formation to build a single-pass SAR interferometer which uses the active signal of Sentinel-1 SAR. The Sentinel-1 (S1) satellites are a main space component of the operational European Copernicus program, providing regular repeat observations of land surfaces and ice bodies in interferometric mode [2].

2. MISSION OBJECTIVES

The main SESAME mission objectives are addressing applications in geoscience and climate research that require repeat measurements of high precision elevation data over land surfaces including ice covered areas and forests, and exploit the multistatic observation geometry of the satellite formation. Primary scientific objectives are

For cryosphere:

- Quantifying the temporal change of volume and mass of glaciers, ice caps and outlet glaciers of ice sheets.
- Mapping the extent and volume of subsidence and erosion caused by permafrost degradation.

For solid earth:

- Quantifying the displaced volume of landslides, debris flow, mudflows, and volcanic events.
- Demonstrating the capability of the SP-InSAR constellation for supporting emergency response after geo-disasters.
- Monitoring 3D surface motion of unstable ground and volcanic zones.

For biosphere:

- Monitoring boreal forest height and biomass.

In the field of cryosphere research the main objectives are dealing with measurements of volume change and mass balance of glaciers, ice caps and outlet glaciers of ice sheets and with mapping the extent and volume of subsidence and erosion caused by permafrost degradation. For solid earth the main objectives aim at the quantification and temporal evolution of volume and mass displaced by landslides, debris flow, mudflows and volcanic events, as well as the monitoring of 3D surface motion of unstable ground and volcanic zones. The SP-InSAR capability shall also be utilized for emergency support activities after geo-disasters, providing rapid information on displaced mass volumes complementary to SAR amplitude images and to repeat-pass SAR interferometry. For the biosphere, the main objective is to monitor boreal forest height and biomass changes.

In addition to these primary objectives, there are several secondary objectives aimed at exploiting the capabilities of bi-static SAR and SP-InSAR for specific scientific and technical questions. The proposed tasks include the filling of gaps in current topographic data sets over land and ice surfaces, mapping the surface topography of icebergs in order to estimate the volume, measuring the velocity of drifting sea ice with high spatial resolution, and observing forest height and biomass outside the boreal zone.

3. MEASUREMENT APPROACH

The SESAME system concept employs a single-pass cross-track SAR interferometer using two receive-only C-band radar satellites flying in close formation relative to each other at an along-track distance of roughly 200 km with respect to the Sentinel-1 C or D satellite which will be used as a transmitter of opportunity.

The main driver for the mission design is the repeated generation of digital elevation models (DEMs), or in case of forest canopies digital surface models (DSMs) by means of single pass SAR interferometry. The expected height accuracies range from a few decimeters up to 1 to 2 meter at horizontal resolutions ranging from 50 m to 200 m. SESAME's emphasis is on dynamic processes, producing regular SP-InSAR repeat acquisitions. The applications are mainly those where, for different reasons, repeat-pass InSAR techniques are not applicable, such as processes where changes are sudden and involve height changes large compared to the operating wavelength, or targets for which SAR signals decorrelate quickly.

In addition to comprehensive time series of DEMs and DSMs, SESAME will provide stacks of bistatic SAR images, providing a additional line-of-sight components for the estimation of 3D deformation. The current monostatic SAR missions provide basically just two InSAR observation geometries corresponding to the ascending and descending tracks. As a result, there is a gap in the observation of the north-south component of solid earth deformations, which will be filled by SESAME.

4. GEO- AND BIO-PHYSICAL PRODUCTS

The observational requirements for bio- and geo-physical parameters to be delivered by the mission are based on spatial and temporal observation needs and accuracies specified in international planning documents of the Integrated Global Observing Strategy (IGOS) for Climate, Geohazards and Biosphere monitoring. The main geo- and bio-physical products to be delivered by SESAME are:

- Precise, high-resolution digital elevation models (DEMs) over land surfaces and ice.
- Maps of topographic change over different time intervals obtained by DEM differencing for cryosphere and solid earth applications.
- Maps of 3D surface velocity.
- Digital surface models of the upper forest canopy.
- Geocoded, terrain corrected bi-static backscatter images

In addition to these main Level-2 products several experimental products will be generated for specific research studies.

5. CRYOSPHERE AND SOLID EARTH APPLICATIONS

For cryosphere monitoring, spatially detailed measurements of surface elevation change of glaciers, ice caps and outlet glaciers of ice sheets will be used for monitoring volume change and mass balance over annual to multi-annual time spans and for improving regional and global scale estimates on glacier melt contributions to sea level rise.

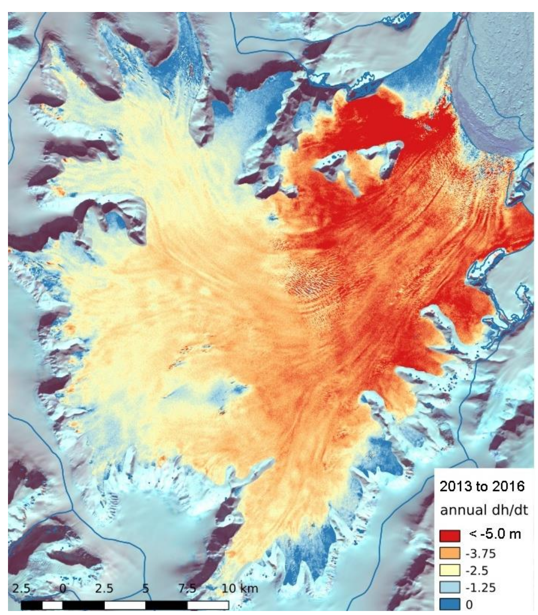

Fig. 1. Map of annual glacier surface elevation change dh/dt (m/year) 2013 to 2016 on Drygalski Glacier, Antarctic Peninsula, derived from TanDEM-X SP-InSAR data.

An example for an SP-InSAR product on glacier surface elevation change by DEM differencing is shown on Fig. 1. The analysis of elevation change for Drygalski Glacier (Antarctic Peninsula) is based on DEMs derived from TanDEM-X interferometric image pairs (CoSSc) acquired on 20 June 2013 and 27 July 2016. Since more than two decades the glacier is largely out of balance due to dynamic instability triggered by collapse of the buttressing Larsen-A ice shelf in 1995. The current mass deficit is on the order of 2 Gt/year [3]. The DEM differencing method provides accuracies for surface elevation change better than one meter [4] which is an excellent basis for obtaining accurate estimates of changes in glacier volume and mass.

SESAME will apply a similar concept as TanDEM-X. It will have a higher duty cycle, providing regular repeat observations of the surface topography of glaciers, ice caps and outlet glacier of ice sheets at high spatial resolution. This will offer a unique basis for monitoring the annual mass balance of glaciers world-wide.

In the solid earth domain SESAME will deliver dynamic models of surface elevation that are urgently needed to capture changes caused by geo-hazards such as landslides, debris flows, volcanic eruptions, and lava flows. In spite of the importance for observation and quantification of these processes, the availability of dynamic models on surface elevation is still very limited. The SESAME mission will be able to fill this critical gap by providing repeat acquisitions of precise, spatially-detailed surface elevation data that are matching the particular observation requirements of the processes to be studied. The temporally and spatially dense topographic data, together with repeat observations of 3D surface motion on basis of the bi-static observation geometry, will provide significant advancements for studying the kinematics of active landslides, as well as for modelling subsurface processes and for hazard assessment related to volcanism.

The great potential of SP-InSAR for mapping and monitoring changes in surface topography and volume displacement related to landslides, volcano outbreaks and lava flows has been demonstrated with DEM sequences derived from TanDEM-X data (e.g. [5] [6] [7]). SESAME will further enhance the SP-InSAR potential for societal needs by supporting emergency response activities after natural disasters. The SESAME observations will deliver rapid updates on change of surface topography after landslides, debris flows, mud flows and volcanic events, complementing the repeat-pass InSAR monitoring capability of the Sentinel-1 mission. Spatially detailed data on surface elevation change will provide quantitative information on displaced volumes immediately following the event.

6. FORESTRY APPLICATIONS

A main objective in the biosphere domain is monitoring of boreal forest height and biomass. Time series of SP-InSAR based digital surface models of the upper forest canopy will be used to derive temporal changes in forest biomass. This information is largely derived from changes in InSAR phase height above ground, together with coherence and backscatter [8]. For regions where high quality digital terrain models are available, biomass stock will be derived from the InSAR phase height above ground. SESAME will also provide important data for assessing changes in tropical biomass and deforestation.

7. CONCLUSION

Dynamic models of surface elevation are needed to capture changes caused by geo-hazards such as landslides, debris flows, volcano eruptions, lava flows, and permafrost thaw subsidence and erosion, to quantify changes in the mass and dynamic response of glaciers and ice sheets, and to estimate changes in forest height, density and biomass. In spite of the importance for observation and quantification of these processes, the availability of dynamic models on surface elevation is still very limited. The SESAME mission will be able to fill this critical gap by providing regular repeat acquisitions on surface elevation that are matching the repeat observation requirements of a wide range of geo- and biospheric processes. The proposed technical concept is a very cost-effective and scalable approach to a powerful single-pass InSAR capability offering major advancements for observation of dynamic features in geo- und biosphere systems.

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