The Harmony mission: applications and preliminary performance

Lopez Dekker, J.F.; Biggs, Juliet; Chapron, Bertrand; Hooper, Andy; Kääb, Andreas; Massina, Simona; Mouginot, Jeremie; Buongiorno Nardelli, Bruno; Pasquero, Claudia; More Authors

Publication date
2019

Citation (APA)
Lopez Dekker, J. F., Biggs, J., Chapron, B., Hooper, A., Kääb, A., Massina, S., Mouginot, J., Buongiorno Nardelli, B., Pasquero, C., & More Authors (2019). *The Harmony mission: applications and preliminary performance*. Paper presented at 6th Workshop on Advanced RF Sensors and Remote Sensing Instruments, ARSI'19, Noordwijk, Netherlands.

The Harmony mission: applications and preliminary performance

Paco Lôpez-Dekker[1], Juliet Biggs[2], Bertrand Chapron[3], Andy Hooper,[4] Andreas Kääb[5], Simona Massina[6], Jeremie Mouginot[7], Bruno Buongiorno Nardelli[8], Claudia Pasquero[9], Pau Prats-Iraola[10], Pierre Rampal[11], Julienne Stroeve[12] and Klaus Scipal[13]

[1] Delft University of Technology, The Netherlands
[2] University of Bristol
[3] Ifremer
[4] University of Leeds
[5] University of Oslo
[6] Centro Euro-Mediterraneo per i Cambiamenti Climatici
[7] Universite Grenoble Alpes
[8] Italian National Research Council
[9] University of Milan
[10] German Aerospace Center
[11] Nansen Environmental Research Center
[12] University College London
[13] European Space Agency

Abstract

This paper provides a compact overview of Harmony, an Earth Explorer 10 mission candidate dedicated to the observation of dynamic deformations of ice, solid earth and ocean surfaces. Harmony consists of two receive-only small Synthetic Aperture Radar (SAR) satellites using Sentinel-1 as illuminator, which will alternate close formation phases, dedicated to single-pass cross-track interferometry, with StereoSAR phases dedicated to the study of ocean surface motion and 3-D land surface deformations. In addition the payload includes a compact Thermal Infrared (TIR) camera.

1 Introduction

The Harmony mission (previously known under the acronym STEREOID, for Stereo Thermo-optically Enhanced Radar for solid Earth, Oceans and Ice Dynamics) is one of the 3 European Space Agency (ESA) Earth Explorer 10 mission candidates. At time of writing, the mission is in the initial state of a competitive Phase-0 study. This paper aims at providing a general overview of the mission, together with a discussion of the science objectives.

Somewhat atypically for an Earth Explorer mission, Harmony has multiple science objectives supporting mutually different scientific domains. In the current phase the mission is anticipated to provide unique simultaneous observations of ice flow and elevation changes over mountain and outflow glaciers. On solid-earth it will provide global seismic strain maps, exploiting Harmony's sensitivity to 3-D deformation signals. Over oceans it will support the study of air-sea interactions, focusing on small-scale ephemeral processes that are crucial for vertical transport of heat, greenhouse gases, and nutrients. In addition it will allow the study of processes within extreme weather events, such as Tropical Cyclones and Polar Lows. Furthermore, it will allow the study of instantaneous sea-ice drift velocities and sea-ice topography, both linked to sea-ice-air interaction processes.

Harmony's mission concept is to fly two C-band receive-only radar satellites in a configurable formation with Sentinel-1 C or D, which will be used as illuminator. Formation flying allows an in-orbit reconfiguration of the observation geometry. This in-orbit configurability is the key enabling the multi-purpose nature of the mission. In addition the payload will include a compact TIR camera.

Synthetic Aperture Radar (SAR) companion mission concepts have been object of in-depth studies for at least the last two decades [1, 2, 3]. Companion SAR configurations are a sub-set of the broader set of multi-static SAR configurations, whose scientific value and technological feasibility have been fully established and demonstreted in orbit by the TanDEM-X mission [4]. In fact, TanDEM-X has demonstrated many of the ideas initially studied in interferometric cartwheel studies [1]. Triggered by the clear scientific benefits of multi-static SAR systems, in the last few years different companion mission concepts have been studied in depth. Especially, receive-only companions have been studied extensively, in particular in the context of SAOCOM-CS [2] (later re-proposed as PARSIFAL [5]), and SESAME [3]. Multistatic SAR concepts using receive-only companion satellite offer an elegant and cost-effective solution, in particular when combined with high performing host systems, such as Sentinel-1 [6].

2 Science Objectives

Harmony has scientific objectives relating to the cryosphere, oceans, and solid Earth. Despite this diversity of domains, all objectives relate to the improved observation of dynamic processes causing a vertical or horizontal deformation of the surface. Table 1 provides a summary of some of the main product-level requirements in terms of sensitivity and spatial resolution.

For solid Earth, the main goal of the mission is to provide a global strain map. Surface strain is a good proxy for fault-stress accumulation, and is strongly linked to earthquake occurrence rates. The strain rate is typically estimated using networks of geodetic GPS receivers, being fundamentally limited by spatial sampling. In contrast, repeat-pass interferometry has been demonstrated to provide high resolution wide-area surface deformation measurements, vastly improving the quantification and localization of strain hotspots. However, even combining ascending and descending orbit views, retrieval of 3-D surface deformation using satellite based InSAR observations remains an ill-conditioned problem. In particular, current InSAR systems are generally insensitive to North-South deformation. Harmony will fill this gap, allowing unambiguous estimation of the 3-D deformation signals.

In addition, during the cross-track interferometric phases, Harmony will allow quantifying topographic changes associated to extreme events, for example, volcanic eruptions and landslides.

In the Cryosphere, Harmony will allow to study dynamic events characterised by a massive increase in glacier ice-flow velocities and accelerated loss of ice volumes. During this events, glaciers respond to strong atmospheric warming, reaching an irreversible tipping point after which the glacier rapidly collapses. In this context, Harmony will provide the unique capability to measure simultaneously surface height variations and flow-velocities with a consistent spatial and temporal sampling.

Harmony will also fill major gaps in observations of glacier mass balance. Harmony will fill these gaps by delivering comprehensive, spatially detailed measurements of surface elevation change (SEC) of glaciers, ice caps and outlet glaciers of ice sheets over well-defined epochs. These data will be the basis for deriving the mass balance of the ice bodies over annual to multi-annual time spans and for improving regional and global scale estimates on glacier melt contributions to sea level rise. Over the ice sheets the mission will focus on outlet glaciers and areas of complex topography, an important complement to altimeter measurements, as demonstrated with high resolution SP-InSAR repeat DEMs of TanDEM-X over outlet glaciers in Greenland and Antarctica [7, 8]). Precise, comprehensive mass balance observations will also help to quantify the impact of climate change on the water supplied by glaciers, a topic of particular concern for runoff from high-mountains in Asia and South America [9].

Over oceans, Harmony will retrieve high resolution surface conditions (SST, winds, waves and surface current) in order to improve our understanding of air-sea interactions (i.e. momentum and heat fluxes). The high resolution relative velocity measurements, combined with the multi-angle backscatter measurements will provide access to the surface deformation field, quantified in terms terms of surface divergence and strain, vorticity, and shear.

Parameter	Accuracy	Spatial resolution
Relative Ocean Surface motion	15 cm/s	4 km^2 to 25 km^2
Surface wind	1.5 m s^{-1}	25 km^2
Relative SST	0.25 K	2 km^2
Sea-ice drift	0.2 m s^{-1}	1 km^2 to 16 km^2
Surface Elevation Change (Ice)	1 m	100 m × 100 m
Surface Elevation Change (Land)	1.5 m	30 m × 30 m
3D surface deformation rate	1 mm yr^{-1}	100 m × 100 m

Table 1: Main Harmony sensitivity requirements.

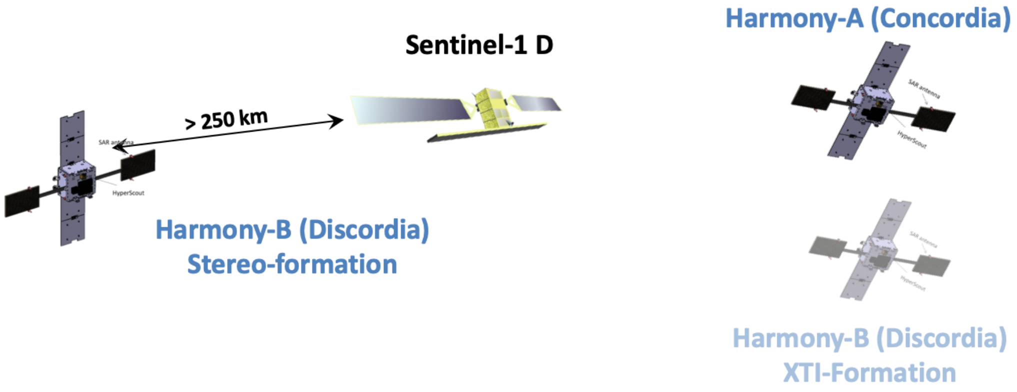

Figure 1: Illustration of Harmony's mission concept showing the two formation flying configurations.

Moreover, the mission aims at fully characterizing extreme weather events, such as tropical cyclones or polar lows, in order to improve our understanding of their physics. This will be done by providing high-resolution estimates of winds vectors and possible total surface current (TSC) fields within these systems. In this regard, Harmony can be understood as a unique blend between a SAR system and a multi-beam scatterometer. This application will also be enabled by the availability of x-pol data, which shows no saturation under high wind conditions.

For sea ice and the Marginal Ice Zone, Harmony will provide measurements of instantaneous drift velocity vectors and deformation. Sea ice drift strongly influences sea ice thickness distribution and, as a consequence, indirectly controls air-sea ice-ocean interactions. Harmony's potential to study sea-ice-ridges is currently under evaluation. Both types of measurements have been demonstrated with the TanDEM-X mission [10, 11]

Finally, from a pure radio-scientific perspective, Harmony will also allow the exploration, for the first time, of the information content present in true multistatic data.

“

3 Mission Architecture

Fig.1 provides a cartoon illustrating Harmony's system concept. It consists of two receive-only C-band radar satellites flying in a configurable formation with Sentinel-1D, which is used as illuminator.

Harmony will alternate between two flying configurations:

1. A close-formation configuration focused on single-pass cross-track interferometric measurements.
2. A so-called stereo configuration [12], during which one of two spacecraft, Harmony-A (Concordia), will fly in the order of 300 km ahead of Sentinel-1, while the other, Harmony-B (Discordia), will fly roughly at about the same distance behind Sentinel-1. This maximizes the line-of-sight (LoS) diversity, hereby providing the best sensitivity to motion-vectors.

The current conceptual mission plan assumes two full-year close formation phases at the beginning and the end of a five year mission. Aside from allowing the estimation of surface elevation changes (primarily over

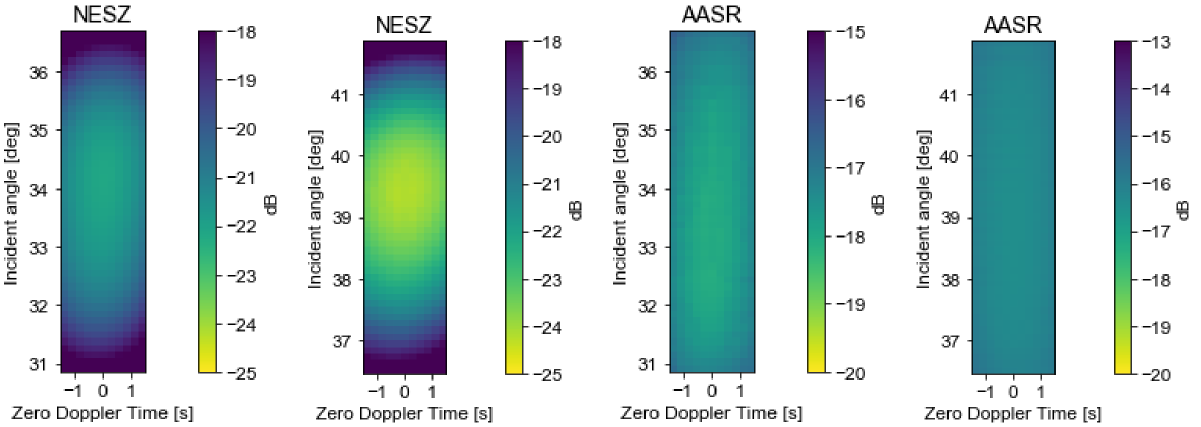

Figure 2: Preliminary NESZ and AASR calculated for the first sub-swath of the Interferometric Wide Swath mode.

glaciers) in the time spanned by the mission, this allows the observation of seasonal signals and the observation of extreme glacier events. It also provides a prolonged observation period adequate to observe volcanic events. A likely shorter close-formation is currently planned mid-way the mission.

Between the close-formation phases Harmony will fly in Stereo formation, mainly servicing the scientific goals relating to sea-air interaction, sea-ice-air interaction, and extreme weather events.

In this Stereo-SAR phase, instantaneous velocity vectors of the ocean surface and sea ice will be retrieved using a combination of Doppler Centroid anomaly techniques and short-baseline Along-Track Interferometry. The expected sensitivity is in the order of 15 cm/s at spatial resolutions ranging from 2 km × 2 km to 5 km × 5 km, depending on wind conditions. 3-D deformation of land and ice surfaces will be obtained using geometry-diverse repeat-pass differential interferometry.

4 Space Segment

One of the standard challenges of designing a companion SAR mission is to meet the requirement of a light-weight solution while providing adequate sensitivity and ambiguity suppression [13]. Harmony's preliminary system concept inherits the dual-phase-centre solution proposed for SESAME [3], with two small antennas with an in the order of 5 m along-track separation. Although these two phase centres are intended for azimuth ambiguity suppression, they can also be used to form a short-baseline along-track interferometer.

In both cases it is appealing (necessary in the ATI scenerio) to store the echoes received from both antennas to process them on-ground. This solution allows the implementation of Doppler-dependent azimuth digital beam-forming (DBF), keeping the maximum of the receive antenna pointed at the target for the duration of the synthetic aperture. Although the split-antenna concept results in extreme grating lobes on the receive pattern, in combination with the Sentinel-1 pattern it provides an adequately shaped two-way antenna pattern, which is necessary both for ambiguity suppression and for Doppler-Centroid estimation.

To illustrate some critical performance figures, Fig. 2 provides the Noise Equivalent Sigma Zero (NESZ) and the Azimuth Ambiguity to Signal Ratio (AASR) estimated for the system for the first two sub-swathes of Sentinel-1's Interferometric Wide Swath mode. In this case, the NESZ ranges from −17 dB to −23 dB, while the AASR ranges −17 dB to −18 dB. It is worth noting that this leads to a DTAR with is 6 dB to 7 dB better than what a solution with a single short antenna solution would provide.

In addition to the radar payload, Harmony will carry a compact Thermal Infrared (TIR) payload intended to provide relative Sea Surface Temperature (SST) measurements quasi-simultaneously with the radar observation, and to provide cloud-cover information to support the study of sea-air interactions.

5 Outlook

Harmony currently undergoes Phase-0 studies, with two industrial consortia studying possible space-segment architectures, which could potentially differ significantly from the presented one.

In parallel, the science objectives and requirements are scrutinised and product-level performance models are currently under development, which will be used to consolidate and fine-tune the final mission concept.

References

[1] D. Massonnet, “Capabilities and limitations of the interferometric cartwheel,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 39, no. 3, pp. 506–520, Mar. 2001.

[2] N. Gebert, B. Carnicero Dominguez, M. W. J. Davidson, M. Diaz Martin, and P. Silvestrin, “SAOCOM-CS - A passive companion to SAOCOM for single-pass L-band SAR interferometry,” in *EUSAR 2014; 10th European Conference on Synthetic Aperture Radar*, June 2014, pp. 1–4.

[3] P. López-Dekker, H. Rott, S. Solberg, M. Zonno, M. Rodriguez Cassola, P. Prats-Iraola, and A. Moreira, “Companion SAR Constellations for Single-Pass Interferometric Applications: The SESAME Mission,” in *Proceedings of IEEE Geoscience and Remote Sensing Symposium (IGARSS)*, Forth Worth, Texas, July 2017.

[4] G. Krieger, A. Moreira, H. Fiedler, I. Hajnsek, M. Werner, M. Younis, and M. Zink, “TanDEM-X: A Satellite Formation for High-Resolution SAR Interferometry,” *Geoscience and Remote Sensing, IEEE Transactions on*, vol. 45, no. 11, pp. 3317–3341, 2007.

[5] Mario Azcueta and Stefano Tebaldini, “Non-Cooperative Bistatic SAR Clock Drift Compensation for Tomographic Acquisitions,” *Remote Sensing*, vol. 9, no. 11, pp. 1087, Nov. 2017.

[6] R. Torres, P. Snoeij, D. Geudtner, D. Bibby, M. Davidson, E. Attema, P. Potin, B. Rommen, N. Floury, M. Brown, I. Navas Traver, P. Deghaye, B. Duesmann, B. Rosich, N. Miranda, C. Bruno, M. L’Abbate, R. Croci, A. Pietropaolo, M. Huchler, and F. Rostan, “GMES Sentinel-1 mission,” *Remote Sensing of Environment*, vol. 120, pp. 9–24, May 2012.

[7] Peter Friedl, Thorsten C. Seehaus, Anja Wendt, Matthias H. Braun, and Kathrin Höppner, “Recent dynamic changes on Fleming Glacier after the disintegration of Wordie Ice Shelf, Antarctic Peninsula,” *The Cryosphere*, vol. 12, no. 4, pp. 1347–1365, Apr. 2018.

[8] Helmut Rott, Wael Abdel Jaber, Jan Wuite, Stefan Scheiblauer, Dana Floricioiu, Jan Melchior van Wessem, Thomas Nagler, Nuno Miranda, and Michiel R. van den Broeke, “Changing pattern of ice flow and mass balance for glaciers discharging into the Larsen A and B embayments, Antarctic Peninsula, 2011 to 2016,” *The Cryosphere*, vol. 12, no. 4, pp. 1273–1291, Apr. 2018.

[9] Andreas Kääb, Etienne Berthier, Christopher Nuth, Julie Gardelle, and Yves Arnaud, “Contrasting patterns of early twenty-first-century glacier mass change in the Himalayas,” *Nature*, vol. 488, no. 7412, pp. 495–498, Aug. 2012.

[10] Dyre Oliver Dammann, Leif E. B. Eriksson, Joshua M. Jones, Andrew R. Mahoney, Roland Romeiser, Franz J. Meyer, Hajo Eicken, and Yasushi Fukamachi, “Instantaneous sea ice drift speed from TanDEM-X interferometry,” *The Cryosphere Discussions*, pp. 1–22, Dec. 2018.

[11] Wolfgang Dierking, Oliver Lang, and Thomas Busche, “Sea ice local surface topography from single-pass satellite InSAR measurements: A feasibility study,” *The Cryosphere*, vol. 11, no. 4, pp. 1967–1985, Aug. 2017.

[12] Valentina Boccia, Erik De Witte, Josep Roselló, Michel Tossaint, Craig J. Donlon, Klaus Scipal, Geoff Burbidge, Harald Johnsen, Franco Fois, Geir Engen, and David Bibby, “StereoSAR: A multi-static SAR mission concept to enhance Sentinel-1 capabilities for measuring ocean dynamics,” in *Sensors, Systems, and Next-Generation Satellites XXI*. Sept. 2017, vol. 10423, p. 104230A, International Society for Optics and Photonics.

[13] P. López-Dekker, P. Prats, M. Rodríguez-Cassola, and B. C. Domínguez, “Companion SAR missions: Scientific rationale and technical challenges,” in *2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, July 2017, pp. 141–144.