INTERNATIONAL ICE CHARTING WORKING GROUP (IICWG)

December 9, 2015

Attn: Ola Gråbak
European Space Agency
Via Galileo Galilei – Casella Postale 64
00044 Frascati (Rm) - ITALY
(Via e-mail: Ola.Grabak@esa.int)

Dear Ola;

Re: EOEP-5 Polar Mission Concept

We are writing as co-chairs of the International Ice Charting Working Group (IICWG) in regard to the Polar Mission Concept under the Earth Observations Envelope Programme 5.

The IICWG members comprise the major national ice services in the world and have the mandates from their respective governments to monitor and chart sea ice and iceberg conditions in their respective areas of interest. The group has long been a supporter of ESA's satellite programs for global ice monitoring and congratulates ESA for the successes of its Envisat and Sentinel programs for ice observing.

At our most recent meeting last October, you invited the IICWG to consider the needs of the operational and supporting science communities for the next generation of earth observation satellites. We know that observing floating ice from space has been, and continues to be, the subject of considerable scientific investigation, much of it sponsored by ESA. We are also aware of the Polaris project to define the user needs and high-level requirements for the next generation of observing systems for the Polar Regions. Nevertheless, we think it is beneficial for the IICWG to confirm the high level requirements for operational sea ice and iceberg monitoring and charting.

We are pleased to submit the attached succinct statement of requirements for your consideration. This document has been vetted through the members of the IICWG and represents a general consensus of the community.

Thank you for the opportunity to provide this input. If there are questions, or if you would like further information, please do not hesitate to contact us through the IICWG Secretariat noted below.

Sincerely,

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Cc: David Arthurs, Ed Kennedy - Polar View
John Falkingham – IICWG Secretariat
Wolfgang Dierking – AWI
IICWG Ice Service Heads

Earth Observations Polar Satellite Mission Concept for Sea Ice and Icebergs:

Requirements of operational services and science applications

Sensors

Synthetic Aperture Radar (SAR) is, by far, the preferred sensor for monitoring sea ice and icebergs operationally and for supporting related science applications because of its all-weather, day/night, and high-spatial resolution capability. SAR images are used to discriminate ice types in terms of age and ice surface structure. These parameters can be used to provide a reasonable proxy for ice thickness over an area and not just a transect (the latter being the case with radar altimeters). However, *visible and infrared optical sensors* are also of critical importance to complement sea ice characterization.

Passive microwave radiometers have a long history of use. They are valuable for sea ice climatology applications and as input to synoptic scale numerical weather prediction because of their global daily coverage potential. Because of their low spatial resolution and underestimation in areas with ice melt and low concentration (common along the ice edge and in summer months), passive microwave radiometers are the sensor of last resort for operational sea ice monitoring.

The ice charting community feels that the future for *optical and passive microwave sensors* is assured by requirements arising from other applications and, thus, this document focuses on SAR.

Frequency

The prevailing opinion is that continuity of *C-band* data is needed for the foreseeable future, with mission concepts similar to those developed for Sentinel-1 and the Radarsat Constellation Mission. However, extending such missions with companion satellites to facilitate quasi-simultaneous *C- and L-band* data acquisitions is strongly desired to improve the retrieval of sea ice parameters and ice type classification. In such case, the satellite formation has to be close enough to alleviate the effect of sea ice drift when combining the data. The pros and cons of *C- and L-band* (as well as *X-band*) have been investigated in a number of studies to be found in the scientific literature. It was noted that the additional use of *L-band* improved the accuracy of ice classification and ice thickness retrievals considerably, and highlighted potential hazards within the sea ice such as deformation features (ridging and rubble) and icebergs. Remarkably, even a preference for *L-band* SAR instead of *C-band* has been indicated in single cases.

Resolution and Swath Width

Wide swath image coverage of *400-500 km* should be maintained for repeatedly mapping changes of regional ice conditions. On the other hand, a *spatial resolution of 8-15 m* is required for the detection of small icebergs. A satellite constellation flying in close formation would offer the possibility to combine wide-coverage, coarse-resolution imaging with acquisitions of high-resolution imagery at smaller swath widths, provided that different swath widths could be selected at each frequency band. X- and C-band reveal equivalent information (whereas the L-band provides data that are complementary to C- or X-band), but higher spatial resolution can be achieved with X-band for a given number of looks. It is important to note that the spatial resolution of operational ocean–sea ice models is being improved to resolve local processes on scales of a few kilometers down to several hundred meters. Hence, high-resolution SAR imaging is an essential tool for improving and validating such models.

Geographical Coverage

Related to ice charting for sea ice navigation (including iceberg monitoring), the main *geographical focus* has been on transatlantic shipping lanes, on the margins of the Arctic Ocean, and on seasonally ice-covered sub-Arctic basins such as the Gulf of St. Lawrence, Baffin Bay, Bering, Baltic, Caspian, and Bohai Seas. However, keeping in mind the expected rapid changes of the Arctic ice cover over the coming decades, the entire Arctic up to the pole needs to be monitored to support future marine operations. The Arctic-wide coverage is also important for weather forecasting and climate change monitoring. There is also a huge need to increase the frequency and coverage of data acquisitions in the Southern Ocean to support tourist ships and re-supply operations for Antarctic research stations, especially during the Austral summer. For iceberg monitoring, it is necessary to extend the coverage over regions of high likelihood for iceberg encounters. There is also an additional need to provide coverage over inland lake bodies and river ways. Lake bodies that freeze play important roles in correctly forecasting weather conditions and have vital ports that require ice breaking to remain open. Ice covered rivers can prevent shipping traffic and can severely threaten life and property when ice jams cause flooding. For scientific applications, it is important to provide sustained seasonal coverage over selected sites such as the Global Cryosphere Watch Cryonet stations.

Temporal Resolution

The *temporal resolution* of data acquisitions with the Sentinel-1 *repeat cycle (12 days)* is sufficient for sea ice charting in the Arctic since, at higher latitudes, a given area can be imaged at least *once a day*. A higher temporal imaging of *less than a day* (e. g. twice a day) would be beneficial to improve sea ice drift and deformation retrieval. For iceberg detection and tracking, it is optimal to cover the same iceberg every 1-3 days. However, it is of minor relevance whether this is achieved by a shorter repeat cycle or by optimally selected orbits and swath widths from a constellation of satellites. To date, the temporal resolution of imaging in the Antarctic has been inadequate. Future missions should aim to bring Antarctic imaging up to the frequency that has been provided for the Arctic. The potential use of orbits that are not sun-synchronous, with the objective to capture diurnal or tidal effects, is of interest both for science applications and for operational services.

Polarization

With respect to *polarization,* the simultaneous use of *co- and cross-polarization (HH-HV or VV-VH)* is particularly beneficial for sea ice mapping. The ratio between the co-polarization channels *HH-VV* at L-band has shown high potential for automated sea ice classification and, along with the phase difference *HH-VV* (for the frequency range X to L), a potential for indirect retrieval of ice thickness. The robustness of such methods continues to be an active topic of research. Dual frequency and dual polarization capabilities will enhance the understanding of melt onset and melt pond formation, freeze-up, and new ice formation (e.g. in latent heat polynyas), important considerations for operational, as well as scientific applications. The use of cross-polarization can also aid in detecting icebergs within sea ice and discriminating them from small vessels. The operational sea ice community is interested in having fully polarimetric data available, although not at the cost of decreased swath widths. Hence, the possibilities of Compact Polarimetry need to be further investigated.

Noise Level

Regarding data quality, the *noise level* – or noise equivalent sigma zero (*NESZ*) – has to be as low as possible, in particular for the cross-polarized channels. As pre-launch investigations for Sentinel-1 demonstrated, a *NESZ* of -20 dB complicates the identification of new ice and even first-year ice in the cross-polarized channels. Intensity variations due to the antenna pattern dominate the observed radar signature. Hence, the *NESZ* should be -25dB or lower (which was achieved with the SAR systems of the ERS and Radarsat-1 satellites). Further, a lower *NESZ* has been shown to enhance iceberg detection. Proper post-launch calibration of the antenna and noise floor characteristics is essential to remove image banding artifacts in the range direction that hinder automated sea ice classifications.

Beyond SAR

First results with TanDEM-X demonstrate that sea ice topography can be imaged with cm-scale accuracy under favorable conditions (e.g. long baselines, bi-static configuration). Considering discussions on TANGOSat (a passive companion satellite for the SAOCOM mission), the sea ice community (especially science applications) is interested in investigating the possibilities that a *satellite tandem* (i.e. a passive companion C-band satellite attached to the Sentinel mission) would offer for measurements of sea ice topography and degree of deformation, indirect retrieval of ice thickness, and other interferometric applications. Moreover a C-band tandem would be beneficial for iceberg detection. A corresponding feasibility study should be carried out.

A further extension of a polar mission concept is to have a *complementary altimetry mission* consisting of both radar and laser altimeters for the retrieval of ice and, in particular, snow thickness. This is an important issue for inversion of ice thickness from freeboard measurements, which is not solved yet. An important topic for a feasibility study is to determine the optimal radar frequency needed for snow thickness retrieval. One of the emerging applications of radar altimetry is to complement operational ice charting as Near-Real-Time products are becoming available from current missions.

Wolfgang Dierking, AWI
John Falkingham, IICWG
with input from the IICWG members

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