RINGS: Collaborative international effort to map all Antarctic ice-sheet margins

International initiative "RINGS" aims to bridge the gap in disparate satellite observations and will help constrain societally-relevant Antarctic contributions to future sea-level rise.

The IPCC's recent Special Report on Ocean and Cryosphere in a Changing Climate (SROCC) addresses a rapidly increasing sea-level contribution from the Antarctic Ice Sheet. The lack of ice thickness data at the margin of the ice sheet (grounding zone) is highlighted as one of the main sources of uncertainty for accurate estimation of Antarctic ice discharge, and adds to discrepancies with other satellite-based mass change estimates. It is also the location where the bed topography matters the most as it controls the stability of the grounding zone. There is therefore an urgent need to carry out airborne surveys around the entire Antarctic Ice Sheet margin.

The ice discharge of the Antarctic Ice Sheet to the ocean can be calculated by a combination of ice thickness data and satellite-measured ice flow speed near the grounding zone. While satellites such as Sentinel-1 and Landsat-8 can routinely measure ice-flow speed, **limited knowledge of ice thickness leads to large uncertainties in ice discharge and eventually in overall assessments of Antarctic mass balance**, estimated as the difference between ice discharge at the grounding zone and mass input (snowfall) to the entire ice sheet. Mass balance estimated in this way currently differs significantly from other estimates based on mass changes from gravity anomalies detected by GRACE/GRACE-FO satellites or ice-elevation changes from altimetry using the CryoSat-2 and ICESat-2 satellites.

Ice thickness changes with time. However, once bed topography is measured using ice-penetrating radar with high precision and positioning control, ice thickness changes in the future can be monitored using ice sheet surface elevation changes measured with satellite altimetry missions such as CryoSat-2 and ICESat-2. The existing BEDMAP and BedMachine compilations provide pan-Antarctic baselines for bed topography. While BEDMAP3 is being developed by a new SCAR Action Group, BedMachine version 2, released in 2020, is the most recent bed topography map, and includes nearly 67 million radar data points collected since 2007. According to the locations of post-2007 radar data used for BedMachine, 12% of the Antarctic margin has at least one radar data point within 1 km from the margin, and 30% has a data point within 1-5 km (Fig. 1, Matsuoka et al., 2022, doi: 10.1029/2022EO220276). Therefore, the bed topography is relatively well known for about one third of the Antarctic margin. However, 58% of the margin has no data within 5 km, and 28% has no data within 20 km. Thus, **ice thickness for more than half of the Antarctic margin is insufficiently sampled for the purposes of estimating ice discharge with a high degree of confidence.**

Availability of bed topography data is not uniform around Antarctica (Fig. 2, Matsuoka et al., 2022). For example, the Amundsen Sea sector has the best data coverage, though still one quarter of the margin has no data within 5 km. In contrast, nearly three quarters of the margin has no data within 5 km in Enderby Land and eastern Dronning Maud Land. Looking more locally, fast-flowing glaciers have better data coverage than slowly moving ice in many regions, but even for glaciers that are comparatively well-studied, data are not always available continuously along the margin. This is because radar data are often collected along ice flowlines, rather than across the glacier. Compiling individual datasets collected for different purposes with different standards is a pragmatic, but not ideal, solution. **Systematic collection of new radar data in the vicinity of the margin specifically**

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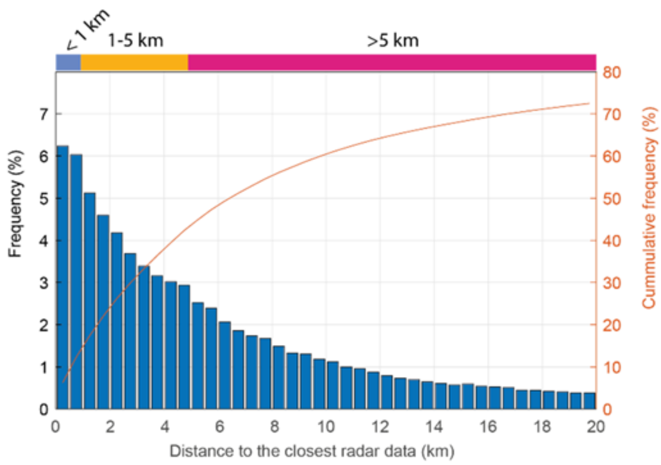

Fig. 1: Histogram showing the radar data availability in the vicinity of the ice-sheet margin. Bins are each 0.5 km, and about 28% of the margin has no radar data within 20 km.

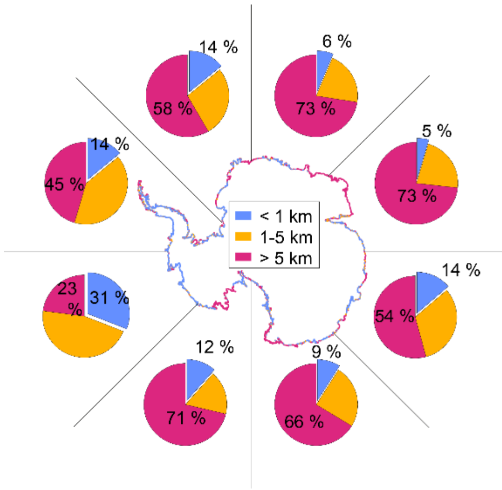

Fig. 2: Availability of radar data within < 1 km, 1-5 km and > 5 km from the ice-sheet margin. The pie charts show the fraction of these availabilities in each region around Antarctica.

aiming for ice-discharge estimates is a crucial step to monitor the current status, and predict the future, of the Antarctic Ice Sheet.

To fill this major knowledge gap across all the margins of Antarctica for the first time, we propose **Antarctic RINGS** as an ambitious and challenging initiative in a truly international cooperation. **The primary objective** of RINGS is to provide more accurate and complete reference data for robust assessments of ice discharge around the entire Antarctic margin. This dataset will also tremendously improve the accuracy of ice-sheet models by providing a better mapping of the grounding zone. When this dataset is combined with satellite altimetry data over the entire ice sheet, it can also be used to constrain mass input from snowfall to Antarctica, which is currently estimated using regional climate models but hardly validated over a large region. **The secondary objectives** of RINGS are to (1) better constrain the likelihood and rates of predicted future retreat of the ice-sheet margin by determining basal boundary conditions in adjacent inland areas, (2) better quantify ice-ocean interactions by providing novel knowledge of the bathymetry of the cavity beneath adjacent ice shelves, and (3) perceive subglacial hydrology for constraining basal mass balance of the ice sheet and subglacial geology particularly relevant to sediments and heat flow. To reach these objectives, it is necessary to complete not only the primary ring at the ice-sheet margin, but also a seaward ice-shelf ring and a landward ring, using airborne geophysical instruments such as radar, gravity, magnetics and lidar altogether.

RINGS builds upon and will compliment highly successful international efforts such as **BEDMAP, BedMachine, IBCSO** to characterize bed topography of the Antarctic continent; the **IMBIE team** and **ISMASS** to quantify recent ice sheet change; and **ISMIP** to model Antarctic ice sheet evolution in the future and predict its effects on future global sea-level rise. It is essential to coordinate RINGS with **SCAR's** new scientific research program **INSTANT** (Instabilities and Thresholds in Antarctica). Marginal zones of the ice sheet have multiple tipping elements, which can potentially lead to abrupt and dramatic changes to the Antarctic Ice Sheet and Southern Ocean. Deepened understanding of these tipping elements requires interdisciplinary efforts between the glaciological, oceanographic and geophysical communities. RINGS will generate novel synergies between disciplines, and directly contribute to future **IPCC** assessments of Antarctic contributions to global sea-level rise.

The RINGS initiative will require substantial **international pooling of logistic and scientific resources** and capabilities in different geographic sectors of Antarctica, to achieve systematic coverage of ~62,000-km long Antarctic margin, which is a quarter longer than Earth's circumference. This is a

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challenging task, especially given the poorer weather along the coastal regions. The RINGS missions could be split into various national campaigns, provided common protocols are strictly followed by these surveys. Considering the limited range of current ski-equipped aircraft, such as a Twin-Otter (~1000 km) and Basler (~1800 km), **long-range aircrafts** with extended ranges up to ~4000 km would be an important asset. A long-range aircraft would also have the important environmental advantage of reducing the need for fuel caches at remote locations. Such a long-range aircraft could also give more opportunities for additional reconnaissance geophysical data. Unmanned Aerial Vehicles (**UAV**) are an emerging platform particularly suited for follow-on high-resolution surveys, targeted on sectors that are either under ongoing rapid change or exhibit significant potential for future change.

The first step of RINGS is to clarify the current knowledge gap to a greater extent and assess impacts of new data that fill these knowledge gaps at different levels. This work can be done using location data of BedMachine's input radar data and soon-to-be-available BEDMAP3 open-data depository. **The second step of RINGS** is to develop a set of protocols to systematically collect, analyze, and share comprehensive airborne geophysical datasets collected by individual regional efforts. The second step can be efficiently done at a workshop including major aircraft operators and radar survey groups. **The new SCAR's action group RINGS** can be an ideal platform to complete these tasks and generate large momentum in the international Antarctic community to carry out this ambitious project that is crucial to precisely estimate the future sea-level contribution from Antarctica.

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In total, we have 56 members at 37 institutions in 15 nations as of 15 June, 2022. * denotes Steering Committee members and ^ denotes the APECS representative.

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