

# Future needs of remote sensing science in Antarctica and the Southern Ocean: A report to support the Horizon Scan activity of COMNAP and SCAR

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## Summary

Remote sensing science of Antarctica and the Southern Ocean requires corresponding in situ measurements and research to maximize the scientific return from the satellite observations. The specific activities required are:

- Calibration and validation of satellite remote sensing data
- Logistical support for remote sensing by wheeled aircraft and unmanned aircraft systems (UAS)
- In situ observations and research to be combined with remote sensing work to answer key science questions

Future work will require infrastructure that can support in situ and airborne activities over the complete range of environments on the Antarctic continent and in the Southern Ocean during all seasons. If this operational need is not met, it will not only degrade the utility of the remote sensing observations themselves, but also impinge on the most important science for connecting change in the Earth's southern polar regions with the global system.

This white paper offers a brief, integrated overview of these needs within the context of the specific questions developed for the Horizon Scan (Kennicutt et al. 2015).

## Introduction

Antarctica and the Southern Ocean are critical components of the global system. Both influence, and are influenced by, global ocean and atmospheric circulation. Antarctica's ice sheet is undergoing rapid change, making it a major factor in current and future sea level rise (Shepherd et al. 2012), with direct impacts to society and the global system. Remote sensing from space offers a robust way to characterize changes occurring in this region, and to link them to ongoing changes in climate.

## Science Drivers and Specific Needs

The general science questions and specific roles of remote sensing for the study of Antarctica and the Southern Ocean are covered in the Horizon Scan (Kennicutt 2015), as well as various remote sensing-specific reports and white papers, especially:

- The CEOS Earth Observation Handbook ([http://eohandbook.com/eohb2014/case\\_studies\\_the\\_changing\\_cryosphere.html](http://eohandbook.com/eohb2014/case_studies_the_changing_cryosphere.html))
- The US National Research Council summary report, Linkages Between Arctic Warming and Mid-Latitude Weather Patterns
- The WMO Polar Space Task Group's strategic plan and various other reports and white papers.

Satellite observations have revealed significant changes occurring in the Antarctic cryosphere, including increases in sea-ice growth, outlet-glacier retreat and ice-shelf fracture. The causes of these changes, and the processes that drive them, however, are only partly understood. Answering the fundamental science questions requires synthesizing remote sensing and in situ observations, especially to understand couplings among the cryosphere, the oceans and the atmosphere. These couplings are the keys to improved predictions of future sea level rise and better knowledge of the connection between sea ice and global climate.

Particular needs of in situ measurements that require local infrastructure considerations include:

- Evaluating feedbacks to the ocean and atmosphere due to changes in sea-ice cover;
- Determining the distribution, thickness and mass balance of sea ice, and addressing the impact of surface melt, albedo change and snow cover;
- Isolating the various contributions to ice-sheet mass balance, such as accumulation rates, surface mass balance and ice–ocean interactions, and evaluating their sensitivities to forcing;
- Mapping bedrock topography beneath ice sheets and ice shelves, and improving knowledge of the physical processes controlling fast glaciers and ice streams;
- Opportunities for calibration and validation of remote sensing products in the land, sea and air throughout the year.

## Calibration and validation of satellite remote sensing data

Satellite remote sensing is key to (1) identifying the processes and properties that control the form and flow of the Antarctic ice sheet ([Horizon Scan Table III: Question 25](#)), (2) determining the thresholds that lead to irreversible loss of all or part of the Antarctic ice sheet ([Horizon Scan Table III: Question 28](#)), and (3) observing how large-scale processes in the Southern Ocean and atmosphere affect the Antarctic ice sheet, particularly the rapid disintegration of ice shelves and ice margins ([Horizon Scan Table III: Question 31](#)).

Proper calibration and validation of data collected by orbiting platforms are essential to quantifying these processes, properties and thresholds accurately. Typically, satellite missions are concerned with two kinds of calibration/validation: (1) cross-calibration of instruments designed to continue a time series of remote-sensing measurements to remove relative biases, and (2) calibration and/or validation of new instruments through comparisons with ground-based data. For example, GPS-based measurements of surface elevations may be used to validate satellite-based altimetry-derived elevations.

As the processes and properties that control the form and flow of the Antarctic ice sheet become clearer, existing data sets may be exploited in new ways, or new technologies may be developed to investigate them. Often, processes will be observed in the field, and questions will arise as to whether and how they can be observed and quantified on large scales, observable only from satellites. A good example of this concerns the production, transport and impact of water on ice sheets. In particular, how will changes in surface melt over the ice shelves and ice sheet evolve, and what will be the impact of these changes? ([Horizon Scan Table III: Question 29](#)) How does subglacial hydrology affect ice-sheet dynamics, and how important is it? ([Horizon Scan Table III: Question 26](#))

#### [Logistical support for remote sensing by wheeled aircraft and unmanned aircraft systems \(UAS\)](#)

Airborne remote sensing fills a critical gap in spatial resolution between the very broad coverage offered by satellite-based measurements and very localized in situ measurements. Airborne platforms also carry instruments that are not feasible, or have yet to be developed, for satellite applications, thus producing data sets that cover larger areas than ground-based measurements may, but with more detail than satellite measurements might offer. These instruments obtain critical data needed to constrain numerical models, such as bedrock elevations beneath the ice sheet and the bathymetry of the sea floor beneath ice shelves. Such data are key to determining how oceanic processes beneath ice shelves vary in space and time, how they are modified by sea ice, and how they affect ice loss and ice mass balance. ([Horizon Scan Table III: Question 30](#))

The principal logistical concern for these airborne platforms in Antarctica are the availability and maintenance of the runways needed, particularly for wheeled aircraft. Cross-wind runways and alternate landing areas need to be developed. Suitability of the runways for Unmanned Aerial Systems (UAS) also need to be considered, since they have stricter requirements.

#### [Collection of in situ ancillary data sets to be combined with remote sensing data sets to answer key science questions](#)

Obtaining in situ ancillary measurements provides critical data for modeling (spin-up or validation) and for interpretation of remote sensing data. For example, collecting GPS data from

bedrock informs estimates of glacial isostatic adjustment, which in turn influences the interpretation of satellite-based altimetry (e.g., ICESat-2) and gravity (e.g., GRACE) data.

There are also processes and properties that are not observable from current satellite platforms and alternative means of quantifying them are needed. For example, how do the geothermal heat flux, bedrock morphology and sediment distribution within the ice sheet bed affect ice flow and ice-sheet stability? ([Horizon Scan Table III: Questions 27, 36, 37, 38 and 41](#)) Similarly, how does small-scale morphology in subglacial and continental shelf bathymetry affect Antarctic ice sheet response to changing environmental conditions? ([Horizon Scan Table III: Question 24](#))

In other instances, the information desired may predate the satellite era, such as determining how marine-based Antarctic ice sheets changed during previous inter-glacial periods? ([Horizon Scan Table III: Questions 33, 34 and 40](#)), and more generally, how fast has the Antarctic ice sheet changed in the past and what does that tell us about the future? ([Horizon Scan Table III: Question 32](#)).

## Recommendations

As COMNAP leaders discuss future infrastructure needs in Antarctica and the Southern Ocean, it should be noted that improvements to remote sensing tools do not lessen the need to acquire in situ measurements; rather, they allow those measurements to be used to answer expanded, more compelling science questions. Given the improvements in remote sensing methods over the last decade, the time is ripe for process experiments based on in situ observations, for example, studying in situ cloud formation and properties. Field research is required to advance understanding of these processes, and to allow their integration into climate models, numerical weather prediction and climate data reanalyses.

Future work on ice sheet and sea ice science should consider that remote, long-term observations are needed away from established stations (e.g., serviced remote weather station type instruments, moorings and autonomous ocean vehicles). Future developments for atmospheric and ice-sheet surface mass balance require routine ground observations in the deep field and oceans to understand precipitation, blowing snow and general surface mass balance. This work should consider the need for calibration and validation of reanalysis codes in both measurements types and locations. Precipitation and blown snow measurements – not climatological averages, but for specific snowfall events – are desperately needed.

Future work in the Southern Ocean is required to measure bathymetry and subsurface water properties, especially to understand connections to the global ocean and the advection of heat to the polar ice sheets. Intense field campaigns are needed near the ice-sheet grounding line, and on and under ice shelves to address these questions.

Finally, the role of aircraft will grow for remote sensing observations of Antarctica, for both direct observations and satellite calibration and validation. Improving aircraft infrastructure to support a broader array of aircraft would be a cost-effective way to support this work since many sophisticated wheeled aircraft, unmanned systems, and their related instruments have been developed for use outside of Antarctica.

## References

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