**Community Review of Southern Ocean Satellite Data Needs**

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Through widespread engagement of over 100 individuals, this white paper represents a brief summary of the Southern Ocean community’s satellite data needs for the coming decade. Including perspectives from a range of stakeholders (both research and operational), it is designed to provide the rationale and information required for future planning and investment. The full background and recommendations are available as a forthcoming publication, which should be consulted rather than this white paper, if possible.

The Southern Ocean is vast but globally connected, and the communities that require satellite-derived data in the region are diverse. It has a profound influence on the global ocean circulation and the Earth’s climate. It uniquely connects the Earth’s ocean basins and plays a key role in global overturning circulation, thereby regulating the capacity of the ocean to store and transport heat, carbon, and other properties that influence climate and global biogeochemical cycles. Global climate and sea level are influenced strongly by ocean-cryosphere interactions in the Southern Ocean. Changes in sea-ice extent or volume result in changes in the Earth's albedo, water mass formation rates, air-sea gas exchange rates, and effects on marine organisms from microbes to whales.

The Southern Ocean is vast and *in situ* observations will likely always be sparse and hard to obtain, thus space-based data are crucial for studying and understanding the Southern Ocean. While many existing missions collect data over the Southern Ocean (i.e., polar-orbiting satellites), this review identified significant areas for improvement in the coming decade.

The communities that require satellite-derived data in the Southern Ocean are diverse. Through extensive community engagement, this review has endeavoured to bring together both the current best practice and future needs of a wide range of stakeholders, including observational scientists, modellers, and Southern Ocean operators. As one survey respondent astutely noted: “[Researchers] work with what we have available. The more we have available, the better the research in general.” This is not to say that researchers are greedy – but instead that more and better satellite data will systematically contribute to improved science and deeper understanding of the Southern Ocean, a critical component of the global climate system yet one that has historically been under-observed and understood.

Important observable variable include sea ice properties (extent, concentration, thickness, edge, snow loading, motion, and charting), sea surface temperature, iceberg, sea surface height, atmospheric parameters, marine microbe observations, marine biology and related activities, terrestrial cryospheric connections, sea surface salinity, and air-sea gas exchange. Challenges are often quite specific to the parameter of interest. For example:

* For sea ice concentration, radiometric signatures for areas with thin ice tend to overlap with open water signatures, leading to underestimation.
* When thick snow cover on sea ice in the Southern Ocean causes flooding in the interface between the sea ice and snow, it introduces ambiguities when interpreting sea-ice concentration, extent, and thickness from satellite-derived data.
* For many data sources, limited bandwidth available to transmit data restricts data collection.
* Spatial and temporal resolution both limit the utility of sea surface temperature observations.
* Existing altimeters remain ambiguous in the Southern Ocean due to the sea state (*i.e.*, presence of sea ice or large waves) and lack of knowledge on how altimeter waveforms are tracked in these settings.
* Atmospheric profilers also have difficulty detecting and quantifying low level clouds and precipitation.
* Many relevant sensors collecting data (on atmospheric properties) are nearing or exceeding a decade old.
* The unique bio-optics, microbial community structure and photo-physiology, lack of regularly verified and operationalized products, the physical location, and the scarcity of *in situ* samples for verification are major limitations to the development and use of ocean color remote sensing in the Southern Ocean and Antarctica.
* One of the major limitations for iceberg monitoring is that iceberg movement can have varying speeds due to ocean and atmospheric forcings. It is difficult to detect an iceberg at the scale of approximately <5 m long unless the user has prior knowledge of its existence and specifically orders high resolution data to follow its trajectory.
* Polar ocean waters are cold and L-band radar observations are less sensitive to salinity in cold waters. In addition, salinity retrieval is less accurate for very rough sea surfaces. Finally, the presence of sea ice and icebergs in the sensors’ field of view adds complexity to the monitoring of SSS in the high latitudes.
* In the Southern Ocean, the presence of sea ice can affect scatterometer measurements to wind velocities and directions. In addition, the presence of liquid precipitation can also contaminate wind measurements.
* In terms of data availability, while RapidSCAT on board the International Space Station (launched in 2014) is seen as a replacement for the Ku-band SeaWinds, it only includes coverage up to ~58°S. Therefore, a largest limitation to remote sensing of Southern Ocean wind velocities and directions is a lack of Ku-band scatterometry data. The planned CFOSat will be able to remedy this data gap, with its planned launch in 2018.

Based upon survey responses and subsequent community consultation, this review includes many recommendations for the future of Southern Ocean remote sensing including, in no particular order, to:

* Commit to continuity of **all** satellite data workhorses (using quantitative standards to determine the quality and quantity of data needed to observe trends), including visible imagers, ocean color sensors, scatterometers, passive microwave sensors, and active radar sensors (note: continuity may possibly be interrupted if a timeseries is long and precise enough that a statistical level of certainty in observations is reached),
* Coordinate a combined campaign by (European) states, many of whom are signatories to the Antarctic Treaty, to ask for satellite data coverage of the Southern Ocean and Antarctica,
* Clarify acquisition and data sharing plans for Southern Ocean satellite data across agencies,
* Increase the spatial and temporal resolution (potentially with the inclusion of non-sun-synchronous orbits) of key parameters identified above (within physical, engineering, and budgetary constraints),
* Create a systematic, synoptic ice charting system for the entire Southern Ocean,
* Increase availability of Ku-band scatterometer data,
* Support the development of Southern Ocean-specific algorithms for essential climate variables and derived parameters,
* Implement widespread, multi-sensor, consistent calibration and validation for campaigns for important products in the Southern Ocean,
* Encourage innovation in development of (automated) ancillary data collection (e.g. through the use of ships of opportunity and autonomous platforms),
* Facilitate and support operationalization of researcher-led product and algorithm development with agency support, and implement pipelines for continuously updated datasets wherever they are held, as possible,
* Provide useable uncertainty estimates / documentation along with all products,
* Improve atmospheric correction models for high-latitude use,
* Consider investing in hyperspectral satellite data for polar regions,
* Consider a joint laser and radar altimetry mission for sea ice and ice sheets,
* Reduce the cost and increase the availability of (high-resolution) SAR data for the Southern Ocean community (using free and commercial optical imagery as an example),
* Collect more multifrequency (Wide Swath) SAR imagery (especially L-band),
* Focus on both widespread, long-term monitoring, process-based studies (*e.g.*, polynyas or marginal ice zone), and areas of environmental and human activity (*e.g.*, Amundsen-Bellingshausen region, Weddell Sea, Antarctic Peninsula), and to
* Commit to best practice in fast, easy, centralized, and comprehensive data access (both scientific and operational) and use (*i.e.*, multiple levels of products and tools) for all Southern Ocean stakeholders.

A theme across all Southern Ocean satellite applications is the need for coincident data collection, including the need for coincident data for calibration and validation of satellite-derived products, as well as coincidently collected satellite data required to fully observe the interdependent variables of complex systems. Survey respondents identified the desire for *in situ* measurements of almost every remotely sensed parameter for product calibration and validation; a time window of +/-3 hours between *in situ* and satellite observations was identified in one survey response. In addition to *in situ* measurements, survey respondents identified significant added value by combining multiple remote sensing datasets. In order to bridge the gap to low-resolution synoptic observations, there need to be efforts made to collect both high resolution and low resolution data coincidentally (within the limits of the type of data being collected). Examples of implementing this suggestion include planning near-synchronous orbits for satellite constellations or timing airborne data collections to overlap with satellite overpasses. Further innovating in planning on this front is necessary.

There are many similarities between Arctic and Antarctic/Southern Ocean remote sensing, but different geographical settings do introduce unique challenges to each. Although differences exist in the validity and accuracy of specific algorithms and corrections between the northern and southern hemisphere polar oceans, data requirements are largely the same. However, some missions focus acquisitions and data analysis predominantly on Arctic objectives, following political/national priorities of the key data providers. We hope that this white paper provides a starting point for understand remote sensing of the Southern Ocean and its global role. More information is available from SOOS, CliC and the full report.