Low-Frequency, Multi-channel Microwave Radiometry for Cryospheric Monitoring

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1. Introduction: Key questions for Earth System Science in the coming decade.

Earth's cold regions are changing rapidly and fundamentally altering our understanding of how future changes will impact human activity at all latitudes (Chapters 2c, 5 and 6 in [1]). Diminishing arctic sea ice cover is altering plans for commercial exploration for natural resources, commercial shipping, and a range of military operations. Fluxes of fresh melt-water from the Greenland and Antarctic ice sheets as well as glaciers and ice caps in the Arctic are primary contributors to rising global sea level. Shrinking permafrost cover changes arctic land-erosion patterns and contributes to release into the atmosphere of methane, an important greenhouse gas. Rapid changes in the planet's seasonal snow cover are raising the planet's overall albedo, and releasing snowmelt earlier in the season, before it is needed by local water management agencies.

Prior to the last Decadal Survey for Earth Science, the key cryospheric questions were cast in terms of the state of the cryosphere and how it was changing [Chapter 9 in [2]). But as suggested above, subsequent observations well document the dramatic change presently being witnessed. Consequently, at issue now is how fast will changes in ocean and land ice progress and what should be the human response to these changes. To answer these questions and to provide improved predictability, sustained observations of snow and ice mass, extent, surface topography, motion, and surface temperature are essential from several, proven, spaceborne instruments. Similarly, unique and complementary airborne observations of snow and ice thickness are a crucial part of the observational mix. Finally, a new generation of observing tools is also necessary to acquire geophysical information on parameters important to cryospheric models but are so far only sparsely measured in situ – in particular subsurface temperature [3]. This white-paper introduces a new concept of low-frequency, multi-channel microwave radiometry that should be one of the tools considered to address a variety of geophysical products, including sub-surface temperature and other physical properties of ice sheets, sea ice, permafrost, and seasonal snow cover. It is also noted that such a system can provide advantages in the measurement of other land quantities as well, such as sub-surface soil moisture and vegetation biomass.

2. Timeliness and Readiness to Address Key Questions

To address the issue of a changing cryosphere and to provide improved predictability, sustained observations are absolutely essential from several proven instruments (synthetic aperture radar, lidar altimetry, imaging radiometers, gravimeters). The climate records obtained from these spaceborne sensors are crucial benchmarks demonstrating the far reaching impacts of climate change.

Given the successes of the Aquarius, SMOS and SMAP L-band radiometers, a new set of measurement capabilities is now maturing. Observations from those single band instruments have been applied to studies of sea ice and ice sheets, and may be useful for studying seasonal snow. These missions have also motivated design and development of a new generation of low-frequency, multi-channel radiometers operating at frequencies less than 2 GHz that promise to fill basic knowledge gaps about the subsurface regime of icy regions [4]. The prospect of transitioning from single frequency (1.4 GHz) radiometers to multiple frequency channels (< 2 GHz) comes from recent progress in radio frequency interference mitigation techniques for operating in these bands. The success of the RFI processor in the SMAP mission, as well as continued technology developments, indicate that observations in frequencies below the protected 1.4 GHz band should be possible in the future, particularly in the cryosphere.

3. Fundamental Attributes of Space-based observations to address these Questions

The global span of cryospheric processes and the strong daily to seasonal swing in the extent of snow and ice makes studying the cryosphere an especially challenging scientific objective. Seasonal snow varies tremendously as a function of wind, vegetation, and topography, limiting ability to directly transfer knowledge among study areas, and underlining the need for global measurements. Moreover the variety of forms in which ice and snow can be manifest in earth systems means that no single observing system is capable of making adequate observations. Rather an ensemble of techniques is required to fully appreciate and eventually understand the complexities of the cryosphere and its interaction with other earth systems.

Spaceborne techniques satisfy requirements for spatial extent and, in most cases, the revisit periods commensurate with cryospheric processes. While the deep sub-surface temperature of ice sheets is a quantity that varies only on long time scales, sea ice, permafrost, and other cryospheric dynamic processes require more frequent observations. Airborne sensors, deployed for example by NASA’s Operation IceBridge, supplement with the their flexibility to obtain information about local to regional scale processes and to deploy aircraft-unique instruments that are more complicated to implement from a space-based platform. The low-frequency, multi-channel microwave radiometer system envisioned here will be soon be tested in situ and from aircraft. A spaceborne system will provide the global reach required for ice sheet, sea ice, seasonal snow cover, permafrost, and research.

3.1 Existing, planned and required programs necessary to provide the capabilities to answer key questions.

NASA's successful deployment of SMAP and the planned deployments of ICESat-2 and GRACE Follow-on are necessary capabilities for continuing several of the key cryospheric records discussed above. In addition, interferometric synthetic aperture radar measurements are in progress or are planned by the international community and these should be taken advantage of in the fashion of past successful collaborations [5]. As suggested above, a critical gap in this observing suite is the measurement of subsurface temperatures and other physical properties at depth. The new concept of low-frequency (few hundred MHz to several GHz) multi-channel microwave radiometry offers a way forward. Such systems can be configured also to achieve fine spectral resolution (100 MHz or better) as a 'hyperspectral' radiometer for specific applications. Surface deployment of such a prototype is now underway with an aircraft campaign slated for 2016. While there are major challenges for a space-based system, recent work on instrument design and on RFI mitigation suggest that a satellite instrument can be conceived and operated successfully. The configuration of frequency channels and operating modes for a space-based system can be optimized to tradeoff science requirements versus the number of channels and instrument size.

3.2 Linking space-based observations with other observations.

Understanding and reacting to the evolving behavior of glaciers and ice sheets, sea ice, permafrost and seasonal snow requires combinations of observations - some of which can be obtained from space and some which can only be obtained from aircraft or in situ campaigns. For example, globally extensive, spaceborne measurements of ice-surface elevation are complemented by airborne UHF radar measurements of snow and ice thickness. As suggested above, the concept described here will provide new information on subsurface temperature and structure. For example, fine-spectral resolution measurements in the UHF portion of the spectrum may be able to be used to infer information on the vertical stratigraphy of the seasonal snow pack. Preliminary studies have shown that temporal autocorrelation in such measurements should carry information on vertical stratigraphy of seasonal snowpacks, including its overall depth [6]. Such information would be vital to water managers, weather forecasters, and the science community as a whole, particularly when augmented and/or combined with other sources of information on snow properties. The passive microwave aspect of the proposed system also complements other mission proposals for snow sensing based on the use of dual-frequency SAR systems. Passive microwave measurements provide – albeit at coarser spatial resolution – sensitivity to temperature information and potentially to snow composition that is not available from SAR systems, and at much lower cost and complexity.

4.0 Anticipated scientific and societal benefits

NASA's continued commitment to cryospheric observations is essential for better predicting the future of Earth's ice and snow climes. Results from such scientific research is also critical for developing and evaluating contingencies against those consequences, such as sea level rise, that have a direct human impact.

5.0 Science community involvement.

Studies of Earth's cryosphere span from the oceans to the land and encompass most geophysical scientific communities. Consequences of changes to Earth's snow and ice cover have societal impacts of concern to the social sciences as well as engineering disciplines dealing with infrastructure.

6.0 Source Bibliography

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