Assessing and Understanding Greenland and Antarctic Ice Sheet Mass Balance

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1. Introduction

Over the last decade, our understanding of ice sheet mass balance, and the processes that control it have advanced significantly, in large part due to the contributions of satellite and airborne remote sensing techniques. These observations have been revolutionizing our understanding of the Greenland and Antarctic ice sheets, revealing changes that are in some cases much more dramatic than were ever expected, from collapsing ice shelves to accelerating outlet glaciers, to increasingly negative ice sheet mass balance. When coupled with in situ observations and robust process models, these large-scale four-dimensional observational capabilities (Fig. 1) are helping us understand the nature of the changing ice cover, the processes that control it, and what the implications for the future may be.

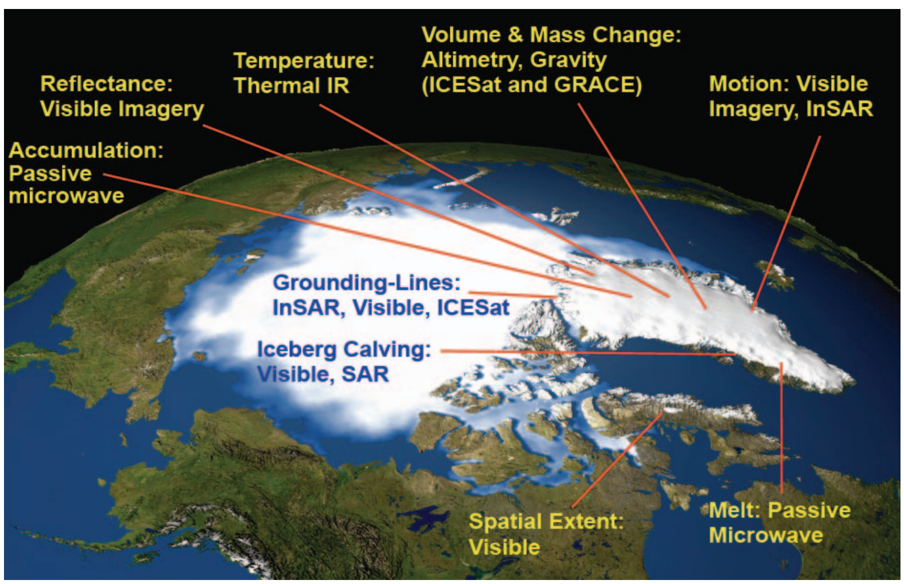

Figure 1: Various ice sheet parameters, and the satellite capabilities for observing their behavior. In addition to the satellite capabilities shown, airborne measurements of ice sheet elevation, ice thickness, ice bed state, detailed gravity, etc. provide fundamental information about the processes that govern ice sheet change

2. Recent Ice Sheet Changes

A major focus of ice sheet research has been to quantify ice sheet contributions to sea level rise. In particular, there are several capabilities that have enabled observationally based estimates of ice sheet mass balance within the last decade. These include: airborne laser altimetry from the

Airborne Topographic Mapper (ATM) e.g. [1], satellite laser altimetry from the Ice Cloud and Land Elevation Satellite (ICESat), e.g. [2] and [3], gravity change measurements made by the Gravity Recovery and Climate Experiment (GRACE), e.g. [2] and [3] among others, and flux-based assessments derived from inteferometric synthetic aperture radar (InSAR) observations, e.g. [4] and [5]. These approaches have revealed quite clearly that the two ice sheets are shrinking and that their rate of ice loss has been increasing since the mid 1990s. However, there are some significant differences in the magnitude of ice losses estimated by these various approaches.

While these differences raise uncertainty about the exact magnitude of ice sheet mass balance, they contain critical information about the influence of the processes that are driving the that imbalance. This is because each approach is sensitive to different aspects of the mass balance equation. By examining these observations, in conjunction with other remote-sensing measurements, in situ data, and model results, the dominant mechanisms of change can be deconstructed. Thus we can create a comprehensive picture of the current state and its possible implications for future mass balance.

Collectively, these observations indicate that there has been widespread acceleration of outlet glaciers throughout Greenland and in parts of Antarctica; calving fronts and grounding lines are in retreat; both ice sheets are losing mass at an accelerating rate; melt in Greenland is on the rise; there is significant draw-down of inland ice in response to outlet glacier acceleration; and there is widespread summertime acceleration in large areas of the Greenland ablation zone, the impacts of which are not yet fully understood.

The integration of these observations with models is taking ice sheet research well beyond its earlier goal of assessing current mass balance toward understanding the details of these phenomena that control ice sheet mass balance, with an ultimate goal of predicting of their future sea level contributions. As such, in addition to ongoing surface balance modeling, and ice sheet flow modeling, attention is increasingly being focused on processes at the ice ocean interfaces, where the potential for instability lies. Understanding in these areas has been significantly advanced by remote sensing observations, and modeling efforts have been ramped up substantially to describe the physics that underpin the phenomena observed.

3. The Future

Because the tools to observe and model ice sheet behavior at the appropriate scales have only been in place in the last two decades, we are just beginning to gain a clear understanding of the interactions between ice sheet and the climate system. Evolving that understanding into the ability to predict future ice sheet contributions requires sustained remote sensing observations, complemented by robust modeling and in situ activities. Toward that end, future key remote sensing observations include mass change, flow rates, elevation changes, melt characteristics, bottom topography, ice sheet bed state, etc. All of these capabilities have been demonstrated. Investments by NASA in comprehensive airborne measurement campaigns through Operation Ice Bridge, are expanding our knowledge of some detailed processes, and important contributions are expected from the European Space Agency's Cryosat-2 mission. Moreover the National Research Council's Decadal Survey [6] has helped put some of these critical ice sheet observing capabilities into development for launch in the next decade. The current challenge for understanding the future behavior of ice sheets to carry these observations forward in a sustained and integrated manner.

3. References

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