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Statement of
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before the

Subcommittee on Commerce, Justice, Science and Related Agencies
Committee on Appropriations
U.S. House of Representatives

Mr. Chairman and Members of the Subcommittee, thank you for the opportunity to appear today. I am a glaciologist, an ice scientist. My 35 years of research have focused on the dynamics of glaciers, ice caps and ice sheets. I've led 15 field expeditions to Antarctica, participated in many other field expeditions to other glaciers and ice sheets, and developed numerous techniques to use satellite data to more effectively understand the roles of ice in our climate.

Satellites, especially those developed and launched by NASA, have revolutionized our understanding of ice sheets' role in climate change and remain an indispensable tool in the pursuit of accurate sea level rise projections for this century to support decision makers. Despite their remoteness, the great ice sheets of Greenland and Antarctica affect most of the world's population through their direct and immediate impact on sea level. They contain over 70 percent of all the freshwater on the planet, enough ice to raise sea level 65 meters (213 feet). Yet, even a 1-meter rise in sea level will flood 2.2 million square kilometers of coastline, displace 145 million people worldwide and result in the loss of $944 billion of combined global Gross Domestic Product (Anthoff, 2006).

Historical data tell us two very important facts about ice sheets, climate change and sea level. First, sea level has increased at rates 15 times faster than the present rate for centuries at a time, albeit not since the beginning of human civilization. Accelerating sea level rise is real: it rose 2 Centimeters (cm) in the 1700's; 6 cm in the 1800's; and 19 cm in the 1900's (UNEP, 2009). Thanks to NASA's TOPEX/Poseidon and the joint US-European Jason missions, we know that sea level at the beginning of this century is rising at a rate of 31 cm per century (Leuliette et al., 2004). However, these rates pale in comparison to a rate of 500 to 600 cm per century during a centuries-long interval centered at about 14,200 years ago (Fairbanks, 1989). Such high rates are not possible by melting ice alone, but require rapid discharge of flowing ice directly into the ocean. Second, ice sheets shrink (raising sea level) whenever the world warms. This historical relationship was used in a recent study to predict that the atmospheric warming reported in the

Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (FAR) would raise sea level as much as 1.4 meters by 2100 (Rahmstorf, 2007). Another study, also published after the IPCC FAR, concluded that future sea level rise contributions from ice sheets alone would be in the range of 0.8 to 2 meters by 2100 (Pfeffer et al., 2008). These rates would put land ice's contribution to sea level well beyond that due to thermal expansion: today they are roughly equal.

Satellite sensors are the indispensable tools that tell us what ice sheets and global sea level are doing right now. We know about these astonishingly large and fast changes in ice sheets only because the necessary satellite data have been collected. Without imagery from NASA's Terra and Aqua satellites, in combination with synthetic aperture radar (SAR) imagery from the European Space Agency's (ESA) Earth Resources Satellites (ERS) 1 and 2, Canada's Radarsat and Japan's ALOS satellites, we would not have seen floating ice shelves in the Antarctic Peninsula, present for at least the last 10,000 years, disintegrate in weeks. Without satellite laser altimetry data from NASA's ICESat satellite, we would not be able to monitor the pattern of ice-sheet thickening and thinning that shows where ice is building up at rates of a few centimeters per year, while other ice is being drained back into the ocean at alarming rates of more than a meter per year (Zwally et al., 2006). Without SAR data from ESA's ERS-1 and 2 and Canada's Radarsat combined with optical image data from Landsat, we would not have observed the sudden and dramatic accelerations of deep outlet glaciers (Rignot and Kanagaratnam, 2006), frequently at rates of many tens of percent per year up to 500 percent in just two years (Scambos et al., 2004); and without gravity data from NASA's Gravity Recovery and Climate Experiment (GRACE) satellite we would not be able to remotely "weigh" entire ice sheets on a monthly basis and observe that the ice sheets have gone on a crash diet and are shedding mass at an increasing rate (Luthcke et al., 2006) (see Figure 1). All of these dramatic results are unusual. Either the changes are so large that they can only occur once in many millennia because recovery takes many thousands of years; or so rapid that they cannot have been sustained for many years without causing measurable signatures in the ice or the adjacent environment that are absent. Most observations and measurements fall well outside the range of natural variability experienced during human history. Neither the rate nor the eventual magnitude of continued ice loss is known. Satellite sensors are an essential means to monitor evolving ice loss.

Rapid ice loss is the result of increased ice flow. The very best climate models, those used by the IPCC to forecast future climate, are good for predicting changes in ice sheet accumulation (snowfall) and melting -- two major factors that contribute to ice sheet growth or shrinkage -- but they are dismal at predicting future ice flow -- the final factor in determining ice sheets' impact on sea level. This was acknowledged in the IPCC report with the statements: "Larger values (of sea level rise) cannot be excluded…" and "…understanding of these effects is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise." This weakness of the IPCC report would have gone unnoticed were it not for the satellite observations mentioned above.

Predictive ice sheet models will improve only when all of the important processes responsible for these dramatic changes are adequately understood. Satellite observations lead the way in identifying areas undergoing change; an effort that also requires careful and often laborious fieldwork. Here too, satellite observations serve an indispensable role; that of guiding field studies to where they can be most effective and giving valuable context for the regional spatial and temporal pattern of change around the field studies. This field work, frequently augmented by airborne-based measurements that add important spatial detail in particularly dynamic areas, is underway by a number of Federal agencies (often with important international partnerships) in a number of locations distributed across both Greenland and Antarctica. These sites were identified by satellite data as the key "hot spots" that promise to reveal the key physical processes as quickly as possible.

The sudden and dramatic changes of ice sheets being witnessed by scientists through recent satellite observations make the continuation of satellite observations imperative. There are at least four critical specific functions necessary for a understanding ice sheets' continuing role in climate change that can only be supplied through a sustained satellite observational program: (1) monitoring the ongoing change to quantify their impact on sea level; (2) monitoring the entirety of ice sheets to discover early signs of other areas as they begin to change rapidly; (3) providing critical regional information necessary to augment ongoing field studies aimed at understanding and quantifying the processes responsible for dramatic ice sheet changes; and (4) providing comprehensive data sets of ice sheet change to improve numerical models which initialize and validate predictive estimates of future ice sheet behavior and sea level contribution.

The critical nature of continued and improved satellite observations of ice sheets was recognized by the National Research Council (NRC Decadal Survey (NRC, 2007) which recommended improvements in key ice-sheet measurement capabilities in their highest priority (Tier 1) satellite missions. NASA is presently working to launch both a laser altimeter mission (ICESat-II) to measure the changing elevations of ice sheets and an interferometric SAR mission (DESDynI) that will measure changes in their motion. The Decadal Survey also recommended missions of importance to precisely measuring sea level rise, including Surface Weather and Ocean Topography (SWOT) and Gravity Recovery and Climate Experiment II (GRACE II).

No other place on earth is as poorly instrumented as the ice sheets. Human scientific exploration of these harsh and remote parts of the planet is expensive and dangerous. Yet no other place on earth is covered so densely by satellites that orbit the earth to high latitudes. Satellite observations have given us unprecedented knowledge of these unfamiliar regions and have enabled us to witness recent dramatic events as they unfold. The direct connection between ice sheet mass loss, global sea level rise, and the resulting impact on coastal communities worldwide, makes ice sheet change an important and inescapable part of our lives. Sustained, high-accuracy, high-temporal, and high-spatial-resolution satellite observations such as those recommended by the NRC Decadal Survey hold the key to overcoming the challenge of credible predictions of multi-decadal ice-sheet conditions to enable informed policy decisions.

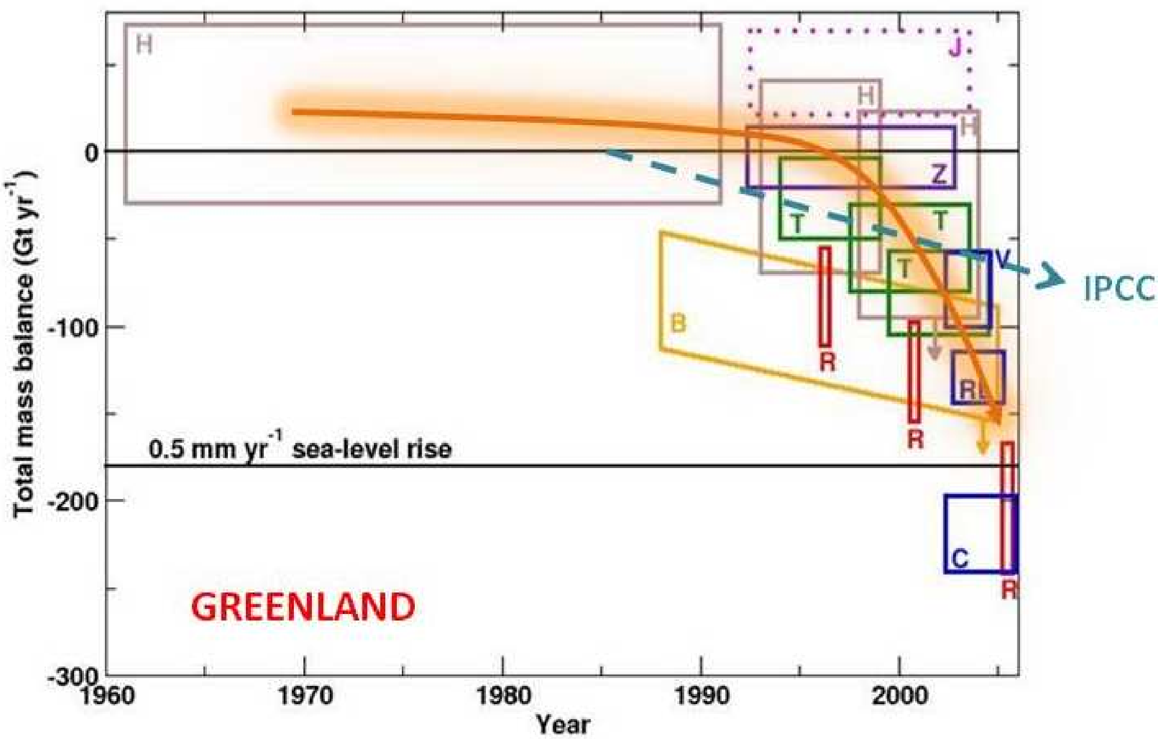

Figure 1. Estimates of Greenland ice sheet mass balance. Mass balance is the rate of mass change (usually measured in gigatons per year (Gt/yr.); -180 Gt/yr. is equivalent to a sea level rise of 0.5 mm/yr. Boxes indicate separate published estimates where box height represents the one-sigma uncertainty and width and position represent the time interval of the estimates. These estimates include separate data analyses from satellite radar and laser altimetry (gray and purple boxes, respectively), satellite synthetic aperture radar (red boxes), and satellite gravity data (green and blue boxes). The dashed line represents the mean IPCC estimate for Greenland's contribution to a total 0.59 m rise in sea level by 2100 projected through the century as a constant acceleration of sea level rise. The most recent observations of Greenland ice loss are already beyond the IPCC projection.

References cited:

Anthoff, D., R.J. Nicholls, R.S.J. Tol and A.T. Vafeidis, 2006. Global and regional exposure to large rises in sea level: a sensitivity analysis, Tyndall Centre for Climate Change Research, Working Paper 96, 31 p.

Church, J. A., and N. J. White (2006), A 20th century acceleration in global sea-level rise, Geophys. Res. Lett., 33, L01602, doi:10.1029/2005GL024826.

Fairbanks, R.G., 1989. A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation, Nature, Vol. 342, pp. 637-642.

Leuliette, E.W., R.S. Nerem, and G.T. Mitchum, 2004: Calibration of TOPEX/Poseidon and Jason Altimeter Data to Construct a Continuous Record of Mean Sea Level Change. Marine Geodesy, 27(1-2), 79- 11 94. 12

Luthcke, S.B., H.J. Zwally, W. Abdalati, D.D. Rowlands, R.D. Ray, R.S. Nerem, F.G. Lemoine, J.J. McCarthy, D.S. Chinn, 2006. Recent Greenland ice mass loss by drainage system from satellite gravity, *Science*, Vol. 314, No. 5803, pp. 1286-1289.

NRC, 2007. Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, The National Academies Press, Washington, D.C., http://www.nap.edu/catalog/11820.html

Pfeffer, W. T., J. T. Harper and S. O'Neel, 2008. Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise, *Science*, Vol. 321, pp. 1340-1343.

Rahmstorf, S., 2007. A semi-empirical approach to projecting future sea-level rise, *Science*, Vol. 315, No. 5810, pp. 368-370 (19 Jan 2007).

Rignot, E. and P. Kanagaratnam, 2006. Changes in the Velocity Structure of the Greenland Ice Sheet, *Science*, Vol. 311, p. 986-990.

Scambos T.A., J.A. Bohlander, C.A. Shuman and P. Skvarca, 2004. Glacier acceleration and thinning after ice shelf collapse in the Larsen B embayment, Antarctica, *Geophysical Research Letters* Vol. 31, no. 18, Art. No. L18402.

United Nations Environmental Programme, 2009. UNEP Year Book 2009; New Science and Developments in Our Changing Environment, C. McMullen and T. Hayden (ed.), SMI (Distribution Services) Ltd. UK, 63p., http://www.unep.org

Zwally, H.J, M.B. Giovenetto, J. Li, H.G. Cornejo, M.A. Beckley, A.C. Brenner, J.L. Saba and D. Yi, 2006. Mass Changes of the Greenland and Antarctic Ice Sheets and Shelves and Contributions to Sea Level Rise: 1992 – 2002, *Journal of Glaciology*, Vol 51 (175), p. 509-527.