A VISION FOR AN INTERNATIONAL MULTI-SENSOR SNOW OBSERVING MISSION

Edward Kim

NASA Goddard Space Flight Center

1. INTRODUCTION

Discussions within the international snow remote sensing community over the past two years [1,2] have led to encouraging consensus regarding the broad outlines of a dedicated snow observing mission. The primary consensus—that since no single sensor type is satisfactory across all snow types and across all confounding factors, a multi-sensor approach is required—naturally leads to questions about the exact mix of sensors, required accuracies, and so on. In short, the natural next step is to collect such multi-sensor snow observations (with detailed ground truth) to enable trade studies of various possible mission concepts. Such trade studies must assess the strengths and limitations of heritage as well as newer measurement techniques with an eye toward natural sensitivity to desired parameters such as snow depth and/or snow water equivalent (SWE) in spite of confounding factors like clouds, lack of solar illumination, forest cover, and topography, measurement accuracy, temporal and spatial coverage, technological maturity, and cost.

2. CANDIDATE MEASUREMENT TECHNIQUES AND CONFOUNDING FACTORS

The list of candidate measurement techniques (sensor types) includes passive and active optical sensing, passive and active microwave sensing, and gamma radiation sensing. Of these we exclude gamma sensing as not being practical from space. Below is a brief summary of each measurement technique, including major advantages and limitations.

5.1. Passive optical sensing

This category includes multispectral [3] & hyperspectral imaging spectroscopy as well as photogrammetric methods. All sense reflected solar energy at visible and infra-red wavelengths and relate absorption or reflectance to snow properties such as snow covered area, albedo, and grain size. Examples of existing/past multispectral sensors include AHVRR, SPOT, MODIS [4], MERIS, and VIIRS. Lack of solar illumination prohibits observing, and clouds and dense forests obscure observations. Complex topography can be a limitation in certain cases.

5.2 Active optical sensing

Lidar can measure snow depth by differencing altimetry observations taken weeks to months apart. The technique has satisfactory accuracy especially for deeper snow depths (meters) where other techniques suffer. SWE can be generated by scaling with estimated snow densities. As an active technique, solar illumination is not required. But as with other optical techniques, clouds and dense forest obscure the observation. Accuracy is a function of both single-shot altimetry accuracy and knowledge of relative platform position at widely separate times. Examples of airborne lidar include decades of ice sheet observations by LVIS [5] and ATM instruments plus more recent snow-in-basin observations by the ASO [6]. Examples of spaceborne lidar include ICESat 1 & 2, and the upcoming GEDI missions, but spaceborne lidar snow retrieval is still a developing field and some key questions remain.

5.3 Passive microwave sensing

Natural blackbody emission from soil is attenuated in proportion to the overlying snow burden. This has been exploited for nearly 4 decades by passive microwave sensors from space to produce daily global snow depth, SWE, and snow extent products [7,8]. As a microwave technique, solar illumination is not required, and clouds are mostly transparent. However, there is saturation at ~150mm SWE, relatively large footprints (so complex topography is an issue), and forest cover to contend with. Wet snow blocks observing, but conversely melt onset is strongly detected. Numerous heritage instruments exist, but the availability of future instruments is in question.

5.4 Active microwave sensing

There are several radar techniques that retrieve SWE or depth. As a microwave technique, solar illumination is not required, and clouds are mostly transparent, but wet snow blocks observations while making melt highly visible. SAR-based techniques are of key interest due to their high spatial resolution that is an asset in complex topography. At least 2 frequencies are required for SWE retrievals relying on volume scattering [9, 10], but algorithms could use more maturing, particularly with respect to dealing with forest cover. An interferometric technique is potentially applicable, too. Cost is a big consideration for any spaceborne radar.

5.5 Confounding factors

As mentioned above, the recurring confounding factors include clouds and lack of solar illumination for all the optical techniques. For the microwave techniques, forest cover and wet snow are the primary factors. Technological maturity and cost are factors for radar and radar/lidar, respectively.

3. EXAMPLE TRADE STUDIES

Clearly, a mission concept that includes all of the above sensor types would be highly complex, risky, and unaffordable. Trade studies are needed to quantify which sensing techniques work well (and which do not) for which types of snow and which confounding factors, so that intelligent minimization and leveraging can be applied to yield a more practical, less risky, and more affordable overall concept or concepts. Such a concept will not be able to measure snow everywhere all the time for all snow types and for all confounding factors. However, this is the normal situation with all Earth observing missions. The key will be to understand the compromises that will need to be made, and for that the snow remote sensing community needs quantitative trade studies. Even before obtaining the multi-sensor field data to actually perform the detailed trade studies, a few such key trade studies can still be outlined, and these will be presented.

4. NEXT STEPS NEEDED

The most pressing need is for accurate multi-sensor observation dataset together with accurate ground truth. This needs to cover some number of snow types and with the key confounding factors, but the exact mix is perhaps a trade study itself. The observations are best done via airborne sensors. A strawman concept for such an observation campaign will be outlined.

5. REFERENCES

[1] NASA Snow Remote Sensing Workshop, Boulder, Colorado, August 2013.

[2] Workshop on Novel Mission Concepts for Snow and Cryosphere Research, ESA/ESTEC, The Netherlands. September 2014.

[3] Dozier, J. “Spectral signature of alpine snow cover from the Landsat Thematic Mapper,” Remote sensing of Environment, 28:9-22. 1989.

[4] Hall D.K., G. A. Riggs, V. V. Salomonson, N. E. DiGirolamo and K. J. Bayr. “MODIS snow cover products,” Remote Sensing of Environment, 83, 181–194. 2002.

[5] Blair, J. B., D. L. Rabine., and M. A. Hofton. “The Laser Vegetation Imaging Sensor: A Medium-Altitude, Digitisation-Only, Airborne Laser Altimeter for Mapping Vegetation and Topography,” ISPRS Journal of Photogrammetry and Remote Sensing, 54: 115-122. 1999.

[6] Deems, J. S., T. H. Painter and D.C. Finnegan. “Lidar measurement of snow depth: a review,” Journal of Glaciology, 59 (215), 467. 2013.

[7] Chang, A., J. Foster, and D. Hall. “Nimbus-7 SMMR derived global snow cover parameters,” Annals of Glaciology. 9: 39-44. 1987.

[8] Kelly, R.E.J. “The AMSR-E Snow Depth Algorithm: Description and Initial Results,” Journal of The Remote Sensing Society of Japan. 29(1): 307-317. 2009.

[9] Rott, H.; M. Heidinger, T. Nagler, D. Cline and S. Yueh. “Retrieval of snow parameters from Kuband and X-band radar backscatter measurements,”.Proc. IGARSS 2009, Vol. 2, 144--147. 2009.

[10] Rott, H., et al., “CoReH2O-A Candidate Earth Explorer Mission for Snow and Ice Observations,” in ESA-CliC-EGU Workshop 2012, edited, Italy. 2012.