Solutions Network Formulation Report

NASA's Potential Contributions to Avalanche Forecasting Using Active and Passive Microwave Measurements

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1. Candidate Solution Constituents

a. Title: NASA's Potential Contributions to Avalanche Forecasting Using Active and Passive Microwave Measurements

b. Author: Slawomir Blonski, Science Systems & Applications, Inc., Stennis Space Center, MS

c. Identified Partners: U.S. Department of Agriculture Forest Service, National Avalanche Center

d. Specific DST/DSS: Regional Avalanche Centers

e. Alignment with National Application: Disaster Management

f. NASA Research Results – Table 1:

Missions	Sensors/Models	Data Product
Aqua (since 2002)	AMSR-E[1]	Snow water equivalent (AE_DySno)
CloudSat (since 2006)	CPR[2]	Snowfall rate (experimental)
GPM[3] Constellation (~2013+)	GMI[4], DPR[5], and others	Snow depth, snowfall rate
SCLP[6] (~2016-2020, proposed)	SAR[7], microwave radiometer	Snow depth, snow water equivalent
NASA Grant NAG5-7459	Snow model	Snow water equivalent, snow depth

[1]AMSR-E: Advanced Microwave Scanning Radiometer – Earth Observing System; [2]CPR: Cloud Profiling Radar; [3]GPM: Global Precipitation Measurement; [4]GMI: GPM Microwave Imager; [5]DPR: Dual-frequency Precipitation Radar; [6]SCLP: Snow and Cold Land Processes; [7]SAR: Synthetic Aperture Radar

g. Benefit to Society: Improved predictions of snow avalanche hazards

2. Abstract

This Candidate Solution is based on using active and passive microwave measurements acquired from NASA satellites to improve USDA (U.S. Department of Agriculture) Forest Service forecasting of avalanche danger. Regional Avalanche Centers prepare avalanche forecasts using ground measurements of snowpack and mountain weather conditions. In this Solution, range of the *in situ* observations is extended by adding remote sensing measurements of snow depth, snow water equivalent, and snowfall rate acquired by satellite missions that include Aqua, CloudSat, future GPM (Global Precipitation Measurement), and the proposed SCLP (Snow and Cold Land Processes). Measurements of snowpack conditions and time evolution are improved by combining the *in situ* and satellite observations with a snow model. Recurring snow observations from NASA satellites increase accuracy of avalanche forecasting, which helps the public and the managers of public facilities make better avalanche safety decisions.

3. Detailed Description of Candidate Solution

a. Purpose/Scope

"DENVER Jan 7, 2007 (AP) — Crews fired artillery shells on Sunday to safely trigger avalanches before they could pose a threat to traffic on a mountain highway, a day after a huge snow slide knocked two cars off the road in a high pass and buried them. Eight people had to be rescued from the cars that were swept off the main highway to one of the state's largest ski areas Saturday." (Weller, 2007)

This recent press report illustrates the dangers still posed by snow avalanches and the need for accurate avalanche forecasting in support of making decisions on preventive actions. In the United States, avalanches kill about 30 people each year. Avalanches also disrupt transportation routes and communication networks. While predicting occurrence of every avalanche is not possible, experts are able to forecast avalanche danger for a particular location. These forecasts are valuable tools in reducing danger to people and property. Awareness of avalanche danger helps individual people avoid becoming an avalanche victim. Transportation departments of state governments use the avalanche forecasts to make decisions on winter road closures in mountain pass areas. In the most severe cases, avalanches are safely triggered in a controlled manner before they can occur unexpectedly.

Avalanche forecasts are prepared by professional mountain meteorologists and avalanche specialists based on mountain weather and snowpack information from a network of remote, automated weather stations that measure precipitation, snow depth, temperature, wind, and humidity. To prepare such products, forecasters need to determine

- the current snowpack structure and stability,
- how the current and recent past weather is affecting this snow stability, and
- how specific future weather will modify this stability and affect avalanche danger.

Forecasters gain this knowledge by watching and monitoring the snowpack as it develops from the first snowflake in the fall until the snowpack slowly stabilizes and melts in the spring. Only then are forecasters able to know and understand snowpack structure during its early season development and to determine if weak layers that form when a shallow snowpack exists might affect snow stability and influence forecast decisions through a portion or perhaps the entire forecast season (Moore, 2006).

This Candidate Solution, when implemented, will provide forecasters with additional information about state and evolution of snow cover based on measurements from present and future NASA remote sensing satellites. Snowpack data will be extended beyond locations of existing weather stations with daily temporal coverage and availability of long-term time series.

b. Identified Partner(s)

Under the auspices of the National Avalanche Center (http://www.avalanche.org/~nac/), the USDA Forest Service administers a number of regional avalanche forecasting centers, such as the NWAC (Northwest Weather and Avalanche Center), the Colorado Avalanche Information Center, and the Utah Avalanche Center (Figure 1). The Avalanche Centers are cooperatively funded by a variety of federal, state, and private agencies, and they are often co-located with regional NOAA (National Oceanic and Atmospheric Administration) NWS (National Weather Service) Forecast Offices. For example, NWAC is co-located with the Forecast Office in Seattle, WA, and its cooperators include the Washington State Department of Transportation, Washington State Parks and Recreation Commission (including Snowmobile and Snowpark Programs), NOAA NWS, National Park Service, Pacific Northwest Ski Areas Association, Friends of the Avalanche Center, and others.

Avalanche Centers promote safety by helping reduce the effects of avalanches and adverse mountain weather on recreation, industry, and transportation through data collection and through mountain weather and avalanche forecasting and education. The Centers produce and distribute a variety of mountain weather and avalanche forecast products that include current information on snowpack structure and avalanche danger as well as forecasts of expected changes in snow and avalanche conditions.

Figure 1. Locations of the regional Avalanche Centers. (map courtesy of USFS National Avalanche Center, http://www.avalanche.org/~nac/forecastcenters/forecast_index.html)

The public can access the avalanche advisories in multiple ways:

- by calling and listening to recorded telephone messages (hotline),
- by listening to live interviews given by forecasters on local radio stations,
- by accessing Avalanche Centers' Web sites on the Internet (also from mobile phones),
- by subscribing to e-mail alerts and/or audio advisory podcasts, and
- by listening to an avalanche warning broadcasted by the NOAA weather radio (only in times of extreme or unusual avalanche conditions).

At present, avalanche forecasts are mainly based on *in situ* observations of weather and snow conditions that include measurements of air temperature, wind speed and direction, precipitation amount, snow depth, and SWE (snow water equivalent. Because SWE measurements are much more complex than the snow depth measurements, SWE measurements are made less frequently than snow depth measurements (AAA/USDA FS NAC, 2004).

c. NASA Earth-science Research Results

Passive microwave sensors deployed on Earth-observing satellites provide information on global distribution of snow depth and SWE (Kelly et al., 2003). Microwave brightness temperature measured by spaceborne radiometers originates from (1) radiation from the underlying surface, (2) the snowpack, and (3) the atmosphere. The atmospheric contribution usually is small and can be neglected over snow-covered areas. Under this condition, microwave measurements can be used to extract snowpack parameters. Snow crystals are effective scatterers of microwave radiation. The deeper the snowpack, the more snow crystals are available to scatter microwave energy away from the sensor. Hence, microwave brightness temperatures are generally lower for deep snowpacks (more scatterers) than for shallow snowpacks (fewer scatterers). Based on this fact, SWE retrieval algorithms have been developed and applied by scientists at NASA, NOAA, and academia (NSIDC, 2005). To estimate snow depth using passive microwave observations, additional assumptions about snow density need to be made because microwave radiation is sensitive to both depth and density and not just a single variable.

The AMSR-E (Advanced Microwave Scanning Radiometer — EOS (Earth Observing System)) instrument on the NASA EOS Aqua satellite has provided global passive microwave measurements of terrestrial, oceanic, and atmospheric variables for the investigation of water and energy cycles since 2002. Although the primary mission of the Aqua satellite ends in 2007, it is expected that, with NASA Senior Review approvals, the mission can be extended until 2015 because of sufficient propellant reserves (Guit, 2006). AMSR-E level 3 data products contain SWE data mapped to Northern and Southern Hemisphere 25-km EASE-Grids (Equal-Area Scalable Earth Grids). However, estimating snow storage in mountainous terrain is a challenging task. Complex topography together with the protruding exposed rocks within a sensor footprint makes it difficult to extract the snow signature. The AMSR-E footprint is not able to resolve the complicated terrain effects in a mountainous region. Different viewing directions of the mountain from the ascending and descending orbits of the satellite further complicate the problem. Therefore, measured brightness temperatures may not give accurate SWE estimates (Kelly et al., 2004).

The CPR (Cloud Profiling Radar) is the sole instrument launched into Earth orbit onboard the CloudSat spacecraft in April 2006. This 94-GHz nadir-looking radar uses millimeter-wavelength radiation to observe cloud particles and to determine the mass of water and ice within clouds. Thus, CloudSat CPR provides observations necessary to advance understanding of cloud abundance, distribution, structure, and radiative properties. CloudSat observations are well suited for assessing the frequency of occurrence of snowfall events and for categorizing them into coarse intensity bins. Quantifying snowfall intensity is more challenging since retrieval calculations are very sensitive to the choice of a particle size distribution function and to shape of snow crystals. Multi-sensor approaches that merge high-frequency, passive microwave and radar observations offer the potential to reduce these uncertainties by constraining the range of possible solutions. While CloudSat and Aqua maintain a close formation in space that provides near-simultaneous and collocated observations with the instruments on these two satellites, the combination of CPR 94-GHz radar reflectivity measurements and AMSR-E 89-GHz brightness temperature data enables the creation of a prototypical data product with satellite-based snowfall measurements (L’Ecuyer et al., 2005). This approach is still experimental, and its accuracy needs to be established.

In the future, passive and active microwave measurements of snowpack and snowfall will be provided by a constellation of satellites from the GPM (Global Precipitation Measurement) mission (Bennartz and Ferraro, 2005). The GPM Core satellite carrying the GMI (GPM Microwave Imager) and the DPR (Dual-frequency Precipitation Radar) is scheduled for launch in 2013. A GPM Constellation satellite is to follow a year later with the microwave radiometer onboard. Inclusion of higher frequencies (100–200 GHz) in the GMI measurements will allow observations of falling snow in addition to the snowpack measurements (Skofronick-Jackson, 2006).

Further in the future, snowpack and snowfall measurements may also be provided with better accuracy and temporal coverage by the proposed SCLP (Snow and Cold Land Processes) satellite mission envisioned to carry a dual-frequency SAR (Synthetic Aperture Radar) and a high frequency passive microwave radiometer (NRC, 2007). Launch of the SCLP satellite is suggested around 2016 to 2020; however, given the proposed mission’s heritage, need, and international momentum, an earlier launch is feasible. A combination of active and passive microwave instruments will provide the needed spatial resolution and heritage for key climate data records, respectively. The two high-frequency SAR channels are sensitive to volumetric scattering in snow, but they sample a range of depths and so are capable of characterizing both deep and shallow snowpacks. The dual polarization mode SAR enables discrimination of the radar backscatter into volume and surface components. The dual-frequency passive microwave radiometer would provide additional information to aid the radar retrievals and would also provide a link to snow measurements from previous, recent, and planned passive microwave sensors. A multi-resolution configuration would even provide spatial resolution on the order of 50–100 m for spatial variability at the hill-slope scale.

d. NASA Earth-Science Models

An algorithm combining a snow accumulation and melt model (referred to as *snow model*) and satellite passive microwave brightness temperature measurements was created to improve the estimation of snow water equivalent and snow depth derived separately from each source (Chen et al., 2001). The snow model has been developed at the University of Washington with NASA funding (Guo et al., 2003). The algorithm uses a neural network to combine the inversion of passive microwave remote sensing measurements via dense media radiative transfer modeling results with the snow accumulation and melt model to yield improved estimates of the spatial distribution and temporal evolution of SWE and snow depth. In the inversion, snow grain size evolution is constrained based on pattern matching by using the local snow temperature history. If such ground station data are not available, grain size patterns from other regions of the world that have similar climate and temperature patterns can be chosen. This fusion approach may also increase spatial resolution of the snowpack data (Derksen et al., 2005).

e. Proposed Configuration's Measurements and Models

Snowpack and snowfall measurements from current ground weather stations that are used by the Avalanche Centers forecasters will be augmented with NASA satellite measurements of SWE, snow depth, and snowfall rate covering mountain areas beyond the range of the stations. Estimates of spatial distribution and temporal evolution of snowpack will be further improved by the use of a snow model to combine satellite and *in situ* measurements based on model physics. Enhanced spatial and temporal information about snow cover in the mountains will be used by Avalanche Centers' meteorologists to prepare more accurate forecasts of snow conditions and to provide advance warnings of avalanche hazards.

4. Programmatic and Societal Benefits

By improving predictions of natural hazards, this Candidate Solution aligns with the Disaster Management National Application.

The main benefit of improved avalanche forecasting will be a reduction in the number of avalanche accidents. People make decisions for themselves or for others about avalanche safety based on information from avalanche forecasting groups. Each of these groups might be focused on a well-defined area, such as a transportation corridor or skiing area, but usually it provides information for a large geographic area. Recurring snow observations from NASA satellites have a potential to improve accuracy of avalanche forecasting for these extended areas. Throughout winters, avalanche forecasters will issue more accurate bulletins to help the public and the managers of public facilities make better avalanche safety decisions.

More reliable and accurate avalanche and mountain weather forecasts will allow transportation departments of state governments issue less frequent closures of mountain pass roads, saving direct maintenance costs and reduce public impact. Mountain area businesses will attain considerable annual savings through the lower road closure times. Moreover, safety margins for highway travelers will increase through a more effective and responsive avalanche control and highway maintenance program.

Ski resorts and schools will benefit from improved avalanche forecasts through savings in daily area operations, school and work planning, lift operations, and snow safety programs. Forest Service personnel will be able to conduct more efficient maintenance and grooming of popular cross-country and snowmobile trails as a direct result of the enhanced forecasts.

5. References

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