by Andy Rost

SNOW BOARD

A look at the importance of snow information

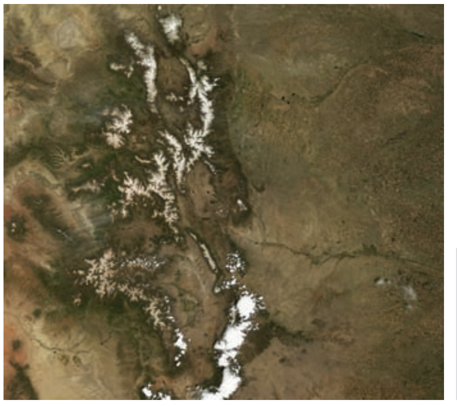
Under the umbrella of the NWS, the National Snow Analysis (NSA) provides valuable snow accumulation information

Water from melting seasonal snowpacks is a critical water resource in many mid-latitude regions of the world. In western USA, snowmelt from mountain basins has historically provided 70-90% of the annual run-off, and the winter snowpack acts as a reservoir to store water for spring and summer delivery to soils and streams. Studies have estimated the economic impact of snow in the USA at several hundred billion dollars per year. The value of water from spring snowmelt can exceed US$348 billion per year. The value of snow-related tourism in the USA exceeds US$7.9 billion per year, and snow removal from streets and highways in the USA exceeds US$2 billion annually.

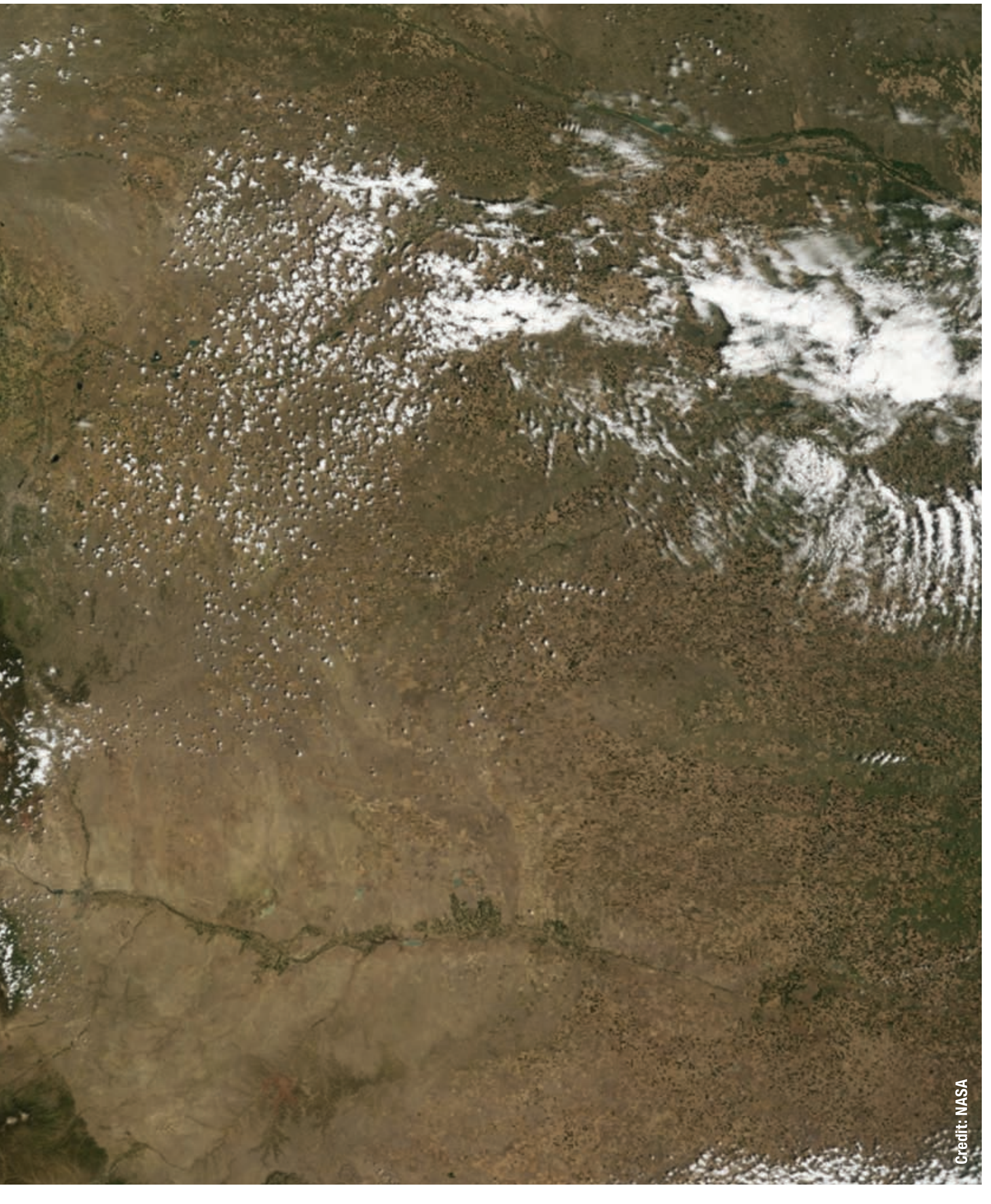
Given the significant impact that snow can have on our lives and communities, there is an obvious need to monitor the snowpack accurately and consistently to meet a broad range of user interests and requirements. The National Weather Service (NWS), which issues river and flood forecasts, and provides hydrometeorological data and products to support the nation's water resource managers, established the National Operational Hydrologic Remote Sensing Center (NOHRSC) in Chanhassen, Minnesota, as its center of expertise in satellite and airborne remote sensing and geospatial data analysis.

The National Snow Analysis (NSA) is the product of a complex automated operational infrastructure, designed, developed, operated, and maintained by the NOHRSC. The NSA provides hourly comprehensive snow accumulation information in the form of Geographic Information System (GIS) ready data sets, interactive web-based maps, hydrometeorological time series plots, and text products. These products are generated in near-real time and incorporate all appropriate directly and indirectly observed data and modeled information related to snow. The products consist of: snow modeling and data assimilation; national Snow Observation Database; airborne snow

"The small sample size is aggravated by the fact that the observations are not randomly distributed"



Each winter and spring, airborne dust settles on the snow cover in the San Juan Mountains, Colorado



surveys; satellite snow cover mapping; snow analyses, maps, and interactive visualization tools; and integrated snow datasets for geospatial applications.

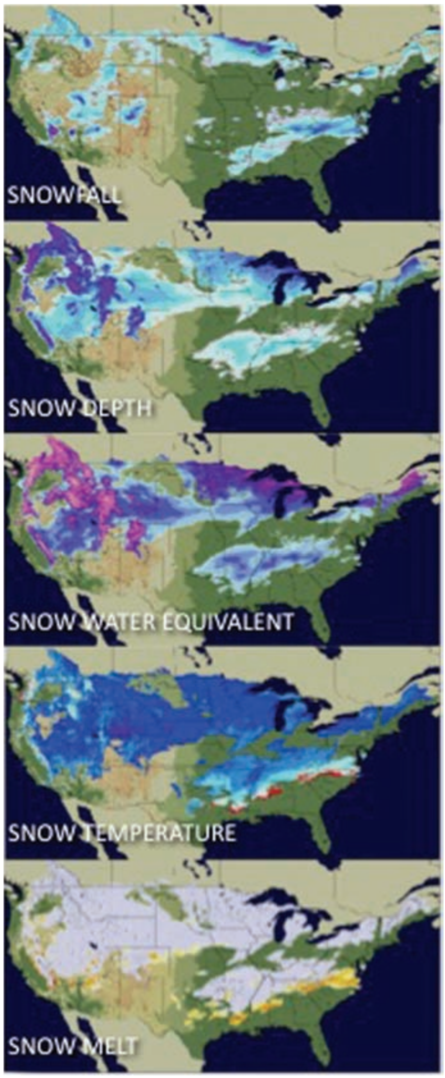
Snow modeling and assimilation

The centerpiece of the National Snow Analyses is the Snow Data Assimilation System, or SNODAS. SNODAS includes an energy and mass-balanced, spatially-uncoupled, vertically-distributed, multilayer snow model which runs operationally at 1km spatial resolution and one-hour temporal resolution for the entire CONUS and those parts of southern Canada that flow into the USA. The model's primary state variables are snow water equivalent and snowpack energy content (mass and energy fluxes). The model also generates dozens of additional model states describing all aspects of the snowpack, including snow depth, blowing snow, snow sublimation, and snowmelt.

SNODAS was developed by the NOHRSC as a flexible and robust geospatial data analysis framework for integrating all of the available snow-related data into the most accurate, consistent, and complete analysis of the snowpack available. SNODAS is a complete end-to-end system that begins by ingesting raw data and finishes by producing and distributing graphical and text products. The heart of SNODAS includes numerical modeling and data assimilation, which consists of three principle components: model-forcing data ingest and downscaling; a full physically-based, spatially distributed snow model; and data assimilation.

The NOHRSC snow model is forced by gridded mesoscale numerical weather prediction model data provided by the Earth System Research Laboratory Rapid Update Cycle two model and satellite-derived solar radiation data.

Small errors and biases are inherent in all modeling systems. SNODAS attempts to account for some errors and biases in forcing



The NOHRSC National Snow Analysis products are produced hourly at 1km² spatial resolution including, snowfall, snow depth, water equivalent, snowpack temperatures, and snow melt.

data by using ground-based temperature observations to remove biases from downscaled temperature forcing grids, and ground-based precipitation and RADAR data are used to remove biases from downscaled snow and non-snow precipitation forcing grids.

Ground, airborne, and satellite snow observations are regularly assimilated into the snow model. This multisensor fusion with the model helps to ensure the best possible estimate of snowpack conditions. These adjustments, however, are limited by the characteristics of, and uncertainty in, the observations themselves. Ground observations are typically made at a point. Airborne observations are made along flight lines.

National Snow Observation Database

To facilitate the unique snow observation assimilation process, the NOHRSC continuously ingests and quality controls all available snow related ground observations. These observations come from a wide variety of public and private data collectives, data streams, and observation networks across the country. The data are stored and managed in a relational database system and processed by SNODAS.

The NOHRSC gathers meteorological and snow related observations from approximately 85,000 unique ground observation stations. Approximately 16,000 stations report snow water equivalent and snow depth. During the 2008-2009 snow season the NOHRSC received 4.8 million snow water equivalent observations, 5.9 million snow depth observations, and an additional 2.2 million snowfall observations. The total number of observations processed during the 2008-2009 snow season was 3.9 billion.

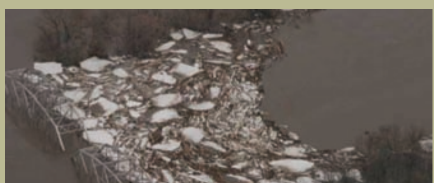
Airborne snow surveys

While the number of ground-based snow observations may seem large, it actually represents an extremely small sample size when one considers the size of the snow model's domain and the length of time that snow is a significant feature on the landscape. The small sample size is aggravated by the fact that the observations are not randomly distributed. Most observations are made near population centers or where snow is known to have a high socio-economic or commercial impact. Unfortunately, this often does not include areas where snowmelt flooding occurs.

To help mitigate this problem, the NOHRSC measures snow water equivalent using airborne remote sensing of gamma radiation. Natural terrestrial gamma radiation emitted by potassium, uranium, and thorium radioisotopes in the upper eight inches of the soil is used to infer snow water equivalent on the ground. Sensors in the aircraft detect and measure the gamma radiation. A one-time background radiation spectrum is first measured when there is no snow on the ground. Water in the snowpack attenuates the naturally emitted radiation – there is a linear relationship between the amount of water overlying the snowpack and the degree of attenuation. The difference between the background radiation spectrum and the radiation spectrum measured while there is snow on the ground provides an ability to measure snow water equivalent with an error

SNOWMELT FLOODING

Some degree of snowmelt related flooding occurs every year in the USA. Although most of these events are relatively minor, nine of the most devastating floods in the 20th Century in terms of property and lives lost were directly related to snowmelt. The 1997 snowmelt flood along the Red River of the North caused in excess of US$5 billion in damage. The severity of snow-related flooding is contingent upon many factors, such as antecedent soil moisture conditions, frost depth during the melt season, rain-on-snow events, temperature and humidity, and river ice jams. Therefore, continued and improved snowpack observation and analysis is essential to protecting life and property in the country. Improvement in snowpack observation and analysis is also essential to water resource management, numerical weather prediction, and climate research and modeling. The role of snowpack modeling in supporting adaptation to climate change and water ecology has been highlighted in the Intergovernmental Panel on Climate Change Report on Climate Change, in addition to several other reports.



of less than one centimeter of water. The NOHRSC uses two low-flying (500ft above ground) NOAA aircraft flown by NOAA Corps commissioned officers to make airborne snow water equivalent measurements across the lower USA and Alaska. Each winter airborne snow measurements are made from a network of over 2,200 strategically located flight lines covering portions of 31 states and seven Canadian provinces. The data are delivered to the NOHRSC and distributed to other NWS offices and the NOHRSC website within one hour after the survey aircraft land each evening.

The airborne snow observations are used by the NWS Weather Forecast Offices and River Forecast Centers when issuing river and flood forecasts, water supply outlooks, and spring flood outlooks. The observations are also crucial to the NOHRSC's data assimilation efforts. A strategically planned airborne survey can easily augment the number of ground observations by a factor of ten. In some cases, airborne data may be the only source for assimilation data.

"The NOHRSC uses ground-based, airborne, satellite, and modeled estimates of snowpack properties"

Satellite snow cover mapping

In addition to airborne remote sensing, the NOHRSC also engages in spaceborne remote sensing. Unlike airborne remote sensing, spaceborne remote sensing is able to provide a synoptic view of the entire continent. However, satellite images acquired by optical detection systems are unable to measure the water content of the snowpack. They are most useful, in cloud-free conditions, to detect the areal extent of the snowpack and, in some cases, the areal extent of flooding.

The NOHRSC uses satellite image data from the Advanced Very High Resolution Radiometer (AVHRR) on the NOAA polar orbiting environmental satellites and from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Earth Observation System's Aqua and Terra platforms. Spectral unmixing models are applied to the satellite image data to retrieve the fractional subpixel component of multiple spectral endmembers, including snow (by snow grain size). Or, to put it more simply, the NOHRSC maps fractional snow cover at the subpixel level.

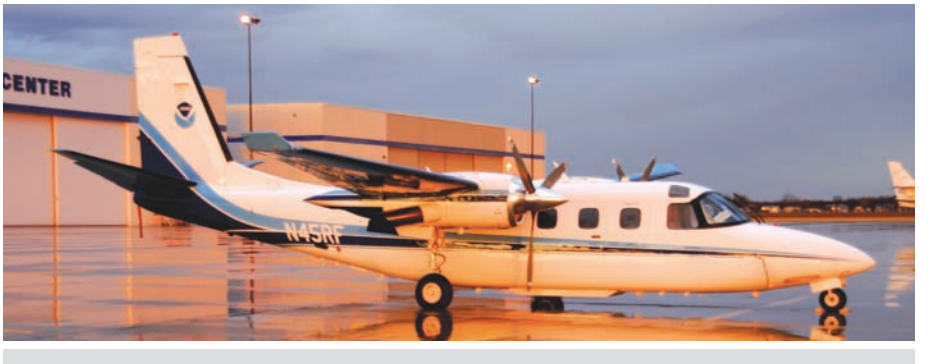
While snow maps derived from optical satellite imagery cannot tell us much about the water content of the snowpack, they are quite useful to the SNODAS data assimilation process. In addition to helping to constrain the NOHRSC's modeled extent of snow cover, a time series of snow fraction and snow grain information contained in these maps can tell us much about the accretion and depletion dynamics of the snowpack.

The NOHRSC uses ground-based, airborne, satellite, and modeled estimates of snowpack properties to create a variety of GIS-ready datasets, maps and alphanumeric products all in a variety of formats that describe snow cover conditions. Some of these products are shipped directly to the NWS River Forecast Centers to be incorporated into hydrologic forecasts. Others are shipped directly to various federal, state, research, and commercial stakeholders.

Modeled estimates can be compared to ground-based observations for snow water equivalent, snow depth, and snow density, as well as modeled and observed snow model forcing data. The user may also query the map for basin summaries of modeled snow properties.

Snow information is critical to the protection of human life, property, the environment, and the national economy. The Snow Data Assimilation System and National Snow Analysis incorporate all ground-based, airborne, spaceborne, and modeled snowpack information. This system provides the most comprehensive, accurate, and timely estimates of snowpack conditions available.

Andy Rost is director of the National Operational Hydrologic Remote Sensing Center based in the USA. Other contributors included Carrie Olheiser, meteorologist and operations manager at the National Operational Hydrologic Remote Sensing Center, and Anne Sawyer, hydrologist at the National Operational Hydrologic Remote Sensing Center



The NOHRSC airborne survey aircraft uses remote sensing of gamma radiation