

NOAA's National Snow Analyses

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Introduction

The National Operational Hydrologic Remote Sensing Center (NOHRSC) produces the NOAA National Snow Analyses (NSA) for the coterminous U.S. (CONUS) using airborne and satellite remote sensing observations, all electronically available in situ observations, and snow modeling and data assimilation methods. The NOHRSC maintains two snow survey aircraft to make airborne snow water equivalent measurements across a network of over 2200 flight lines covering portions of 31 states (including Alaska) and 8 Canadian provinces. The NOHRSC maps the sub-pixel fractional extent of snow cover for the coterminous U.S. and Alaska using polar-orbiting satellite data. The NOHRSC ingests approximately 10,000 *in situ* snow depth and water equivalent observations from over 40,000 stations across the U.S. These remote sensing and *in situ* data are merged with modeled snow information to produce comprehensive analyses of snowpack conditions across the nation. The NOHRSC snow model is an energy-and-mass-balance, spatially-uncoupled, vertically-distributed, multi-layer snow model run operationally at 1-km² spatial resolution and hourly temporal resolution for the nation. *In situ* and remotely-sensed snow observations are assimilated daily into the simulated snow-model state variables. The NOHRSC's NSA output products are distributed in a variety of interactive map, text discussion, alphanumeric, time-series, and gridded formats. NSA product formats include: (1) daily national and regional maps for nine snowpack characteristics, (2) seasonal, two-week, and 24 hour movie-loop animations for nine snowpack characteristics, (3) text summaries, (4) a suite of interactive maps, text, and time series products, and (5) selected gridded snow products for the CONUS. The NSA provide information about snow water equivalent, snow depth, surface and profile snowpack temperatures, snowmelt, surface and blowing snow sublimation, snow-surface energy exchanges, precipitation, and weather forcings in multiple formats.

Graphical and interactive NOHRSC products are available online from the NOHRSC web site (www.nohrsc.noaa.gov). Gridded NSA data products are archived and provided by the National Snow and Ice Data Center (NSIDC) web site (nsidc.org). The following provides a brief description of the remote sensing, *in situ*, and data assimilation products, with guidance to further information available on the NOHRSC web site. Then, information is provided about the gridded NSA data sets that are available through NSIDC.

Airborne Snow Survey Program

Salient information about the Airborne Snow Survey Program is given on the NOHRSC web site including information on: current snow survey schedule, airborne photography, flight line index, flight line maps, and airborne snow data. For technical information about the gamma radiation spectrometry methods used to make the snow measurements, see the *Airborne Snow Survey Program User's Guide: 2001 March 1* on the NOHRSC's Technology web page.

Satellite Remote Sensing Program

The NOHRSC applies spectral unmixing methods to AVHRR data to estimate the sub-pixel fraction of snow cover for the CONUS and Alaska. Maps are produced for each satellite swath within these regions when there is sufficient solar illumination. The maps indicate the fraction (percentage) of snow cover occurring within each pixel. The nominal resolution of the satellite data is about 1 km.

In Situ Snow Observations

The NOHRSC ingests surface hydrometeorological observations from over 40,000 U.S. stations through a wide array of networks and data streams. On a typical day during the snow season, about 10,000 snowpack observations are received. Typically, about 10% of these are snow water equivalent observations, and the remainder is snow depth observations. These data are assimilated together with the remote sensing observations, but most are also redistributed via the NOHRSC web site as text products and data archives; see the National Snow Analyses link on the NOHRSC web site, under

Station Snow Reports. Further information about accessing these data is available on the NOHRSC's help page. In addition, all electronically available snowfall observations are ingested and provided on the same web page, and are available graphically on the Interactive Mapping site of the web site.

Snow Data Assimilation System (SNODAS)

SNODAS is a modeling and data assimilation system developed by the NOHRSC to provide the best possible estimates of snow cover and associated variables to support hydrologic modeling and analysis. The aim of SNODAS is to provide a physically consistent framework to integrate snow data from satellite and airborne platforms, and from ground stations with model estimates of snow cover. SNODAS includes procedures to ingest and downscale output from Numerical Weather Prediction (NWP) models; a physically based, spatially-distributed energy- and mass-balance snow model; and procedures to assimilate satellite-derived, airborne and ground-based observations of snow covered area and snow water equivalent. SNODAS is run each day, with analysts deciding whether or not to use remote sensing and ground based observations to update the snow water equivalent state in the model. SNODAS products consist of gridded data sets for the continental United States at 1-km spatial resolution and 24-hour temporal resolution.

Principal SNODAS products include maps and gridded data sets of snow water equivalent, snow depth, snowpack surface and average temperatures, snowmelt, surface sublimation, and sublimation due to blowing snow. Remote sensing and *in situ* observations are used to update the snow water equivalent state variables in the models.

National Snow Analyses

The NOHRSC National and Regional Snow Analyses page provides a daily synoptic overview of snow conditions for the coterminous U.S. as well as for the 18 U.S. snow regions at a higher resolution. The Snow Analyses include maps and text descriptions of daily snow accumulation based on snow observations and modeled snowpack characteristics from SNODAS. They review both the meteorological observations of snowfall and snow on the ground as well as the snowfall and snow accumulation simulated by SNODAS. Regions of the greatest, or most interesting, snow precipitation are highlighted in the analyses. The Snow Analyses also provide an explanation of the variance between the NOHRSC snow model state variables and observed snow conditions. The analyses review the regions across the country where observed snow data have been assimilated into the snow model state variables. Unique snow data observations such as airborne snow water equivalent measurements are reviewed in the text product during the course of operational airborne snow survey missions. Image maps of snow characteristics and other graphics summaries are hyper-linked in the analyses to highlight specific points of interest. The Snow Analyses are prepared each weekday by NOHRSC personnel.

Interactive NSA Maps and Information

The NOHRSC Interactive Snow Information summary gives the end-user the flexibility to produce tailored graphic summaries suited to individual needs and requirements. The graphic maps from the Interactive Snow Information summary can be queried in either metric or English units. Clicking on the Interactive Products button on the side-bar menu gives the Interactive Snow Information page. The upper side-bar menu provides buttons to go to: NOHRSC home, the Snow Analyses pages, quick queries for time-series and text snow products (for users who know their station or basin IDs), and interactive help.

Interactive Help. The interactive help page provides information on: (1) navigation, display, and querying the interactive map server, (2) map products and text discussion products, (3) the Airborne Snow Survey Program, and (4) general help.

Default Settings. The interactive snow information page defaults to: (1) full U.S. map, (2) physical element equals snow water equivalent, (3) date equals most recent date and hour for which data are available, (4) zoom in selected (across top), (5) overlays equal states and stations (with labels), and (6) map preferences (lower side-bar menu) equals English units (can be changed to metric units), background image (DEM), high-contrast color palette for snow depth and water equivalent products (optional: if selected, recommend that background DEM is turned off), 512 pixels map width and height, JavaScript on, Smoothing off, session Cookies off. All of the above options are described on the interactive help

page. The scale for the selected physical element is given to the right of the map (or below if selected and refreshed). Unfortunately, we need to use a non-linear scale for the entire country. We do not have the ability to recalculate the scale on-the-fly for each zoom level. We have, however, added shallow snow depth and shallow snow water equivalent maps that can be selected from the physical elements list. The corner latitude and longitude coordinates are given on the map borders along with the east/west and north/south distances.

Interactive Options. It is possible to select any one of a variety of physical elements (e.g., snow water equivalent, snow depth, mean snowpack temperature, 24 hour change in water equivalent or depth, etc.). A variety of map overlays are also selectable from the side-bar menu. The map overlays selected from the side-bar menu have no impact on the query function described below. The date and hour of the map image can be selected.

Deviation from Normal Snow Depth Maps. One of the selectable physical elements is the Monthly Depth Normal that gives the average snow depth (1961-1990) for a specific month (e.g., October, November, December, January, February, March, or April). The monthly normal snow depth products were provided by the National Climatic Data Center from the NCDC 1961-1990 Climate Atlas for the U.S. based on data from 5525 stations used in the NCDC U.S. Snow Climatology (TD-9641M). The NCDC monthly depth normal gridded maps are used with the daily NSA snow depth map to generate a Daily Depth Minus Normal map also available as a selectable physical element.

Plotted Snow Water Equivalent and Snow Depth Observation Values. The end-user can select from the physical element pull-down menu a national map that gives the observed value of the snow water equivalent or snow depth from the more than 10,000 stations that report snow observations to the NOHRSC. Daily, 2-day, or 3-day maps can be selected. The values are color coded by range; the user can pan and zoom the maps to the area of interest.

Snowfall Maps. The end-user can select from the physical element pull-down menu a national map that gives the observed values of daily, 2-day, or 3-day snowfall. The values are color coded by range; the user can pan and zoom the maps to the area of interest.

Cursor Mode. Above the map it is possible to select one of four cursor modes: (1) pan, (2) zoom in, (3) zoom out, and (4) query. It is possible to select the zoom factor from the pull-down menu on the upper right of the map. These functions are fully described on the interactive help (navigation) page. A number of map overlay elements are progressively disclosed as the user zooms in further (e.g., stations, cities, flight lines). For example, more than 18,000 stations are eventually revealed as the map is zoomed in further.

Query Mode. The NOHRSC station or basin time-series plots consist of a series of x-y graphic plots that use data from the selected reporting station or basin for the selected period-of-record. The plots include line graphs of NOHRSC snow model output and point indicators for a variety of observed hydrometeorological variables. The default is the station time-series. When the query button is selected from above the map, it is possible to generate time-series plots from the NOHRSC database for the point or area selected from the pull-down menu. With the query mode and station time-series selected, the user can move the cursor to a specific station on the map and left-click the mouse. A second browser is spawned that gives multiple time-series of modeled and observed information for that station. The station time series plots include graphs of modeled and/or observed snow water equivalent, snow depth, snow cover, snowmelt, snow surface temperature, mean snowpack temperature, air temperature, snow and non-snow precipitation, sublimation/condensation, various weather forcings, and snow surface energy exchanges. Upon first access, the default dates are the last two weeks and units are English; either can be changed and refreshed. If "cookies are on" the changed date and units will remain for future station queries. Details of the query function are given on the interactive help (querying) page.

Alphanumeric Data and Products. Alphanumeric summaries for selected NSA physical elements are available for National Weather Service (NWS) hydrologic forecast basins on a basin-by-basin basis. Summaries giving mean areal estimates of the selected physical element for NWS hydrologic forecast

basins can be grouped by NWS River Forecast Center (RFC), by NWS County Warning Area, by USGS Hydrologic Unit Code, by state, or by county. Alphanumeric summaries are available for snow water equivalent, snow depth, and areal extent of snow cover derived from the snow model. The summaries include the basin ID, date, minimum and maximum elevation in the basin, basin name (if available), and the mean, standard deviation, minimum, and maximum pixel values of the selected physical element for the basin. For basins where specific elevation zones have been identified, the same information is available for each elevation zone. The end-user can select the physical element, the date, and the units (English or metric) for the report.

Time-series Plots of Modeled and Observed Data. The time-series plots give both modeled and observed data for the station. Station-specific information is provided in the upper left of the time-series plots and includes: station id and name, latitude/longitude, elevation, start and stop date for the time-series, forest density, and land use. The color-coded legend on the upper right describes the variables plotted. Assimilation (green line) indicates the point in time at which the NOHRSC staff assimilated snow depth or snow water equivalent observations for the region around the station into the snow model states. Snow cover (observed by satellite) is indicated by the colored tick-marks above the first time-series plot. Even if the modeled data and the observed data were perfect, the user should **not** expect the modeled and observed data to agree in all cases. The station data should be representative of a point; the modeled data should be representative of the 1-km² pixel in which the station falls. Both might be perfectly correct but not equal. Other time-series options from the pull-down menu are described on the interactive help (querying) page.

Time-series Quick Query. From the menu on the left it is possible to select a quick query for the NWS forecast basin time-series information. The user must select an RFC in which the basin resides; a listing of the SHEF IDs for all basins will be revealed; the user can then select the forecast basin by SHEF ID to obtain the time-series information. The user can also enter the station SHEF ID (if known) for a quick query of the time-series information for the selected station.

Text Product Quick Query. The user can select text products giving mean areal (and other statistics) snow water equivalent, snow depth, and snow cover for all NWS basins in either the selected: RFC, state, USGS Hydrologic Unit Code, NWS Country Warning Areas, or counties. After the geographic area is selected the data will be reported. It is possible to change the physical element, the date and hour to report the data, and the units (English or metric). These text products can also be retrieved directly from the main interactive snow information page by selecting query and basins by RFC, state, HUC, CWA, or counties.

Snow Depth Daily Climatology. The user can plot current year modeled and observed snow water equivalent and snow depth from over 5,000 climate stations along with the historic snow depth observations (1960 to last year) by the following process. On the Interactive Snow Information page, select from the left side-bar menu "climate points" and the associated filled square label. At the top center of the page select "query." From the pull-down menu to the right of the "query" button, select "station climatology". Move the cursor to the climate station (filled square) of choice and click to see the current and historic snow depth record. Select up to four years from the left to high-light historic snow observations (1960 to last year).

Data Access

The NOHRSC daily, 1-km², CONUS, gridded products (Table 1) are permanently archived and available from both the National Snow and Ice Data Center (NSIDC) in Boulder, Colorado. NSIDC has developed an on-line distribution system whereby any end users can access and select any of the available gridded products (Table 1) for their required spatial and temporal domain. Generally, files are available from NSIDC within one day of production at NOHRSC. Selected gridded NOHRSC products starting October 1, 2003, to the present are available now from NSIDC. Data for 2005 through the current year are available via FTP; select Access Data. For data from previous years and subsetting options, please select Subset Data. The SNODAS output fields are supplied to NSIDC as flat binary grids with a header/metadata file. These flat files can be read by user-written routines, off-the-shelf image processing packages, and by GIS and other mapping packages. Further information about the data, including format

details and access procedures, are available at <http://nsidc.org>. NSIDC strongly encourages you to register as a user of this data product. As a registered user, you will be notified of updates and corrections. Please contact NSIDC User Services to register.

Table 1. Daily NOHRSC Snow Products Archived and Available from NSIDC in Boulder, Colorado.	
Physical Element	Remarks
Snow Precipitation	24-hour total, 6Z-6Z
Non-snow Precipitation	24-hour total, 6Z=6Z
Snow Water Equivalent	Snapshot, 6Z
Snowpack Thickness	Snapshot, 6Z
Blowing Snow Sublimation	Total of 24 "per-hour" sublimation rates, 6Z-6Z
Snowpack Sublimation	Total of 24 "per-hour" sublimation rates, 6Z-6Z
Average Snowpack Temperature	Average of the 24 hourly vertically integrated averaged snowpack temperatures
Melt	Total of 24 "per-hour" melt rates out of bottom of the snowpack, 6Z-6Z

In addition, on an individual agreement basis the NOHRSC can generate and ship automatically, in near real-time only, 1-km², hourly or daily gridded products for all of the snow model and cumulative surface temperature variables summarized above for use in special projects. Contact Donald.Cline@noaa.gov for more information about direct-ship options.