Operational Processing of Multi-Source Snow Data

by

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ABSTRACT

Near real-time quantitative assessments of areal extent of snow cover and snow water equivalent (SWE) provide valuable insight and information for water management, hydrologic forecasting, and emergency preparedness entities throughout the United States and Canada. Since 1986, the National Operational Hydrologic Remote Sensing Center (NOHRSC) of the National Weather Service (NWS) has provided these data in rasters and alphanumeric tabulations generated using satellite image processing, spatial interpolation, and GIS analysis.

Composite use of multi-source satellite (i.e., Advanced Very High Resolution Radiometer (AVHRR) and Geostationary Operational Environmental Satellite (GOES)), point (i.e., manual and telemetered observations), and line (i.e., airborne gamma radiation surveys) data is now accomplished through the newly developed NOHRSC Operational Product Processing System (OPPS). OPPS ingests and databases classified (i.e., snow, ground, cloud, and unknown) satellite areal extent of snow cover rasters and all identified point and line samples of SWE and snow depth. OPPS generative capabilities include user prioritized composite raster generation and multi-source gridded estimates of SWE and snow depth. OPPS spatial estimation processes for SWE and snow depth combine point and line data with composited satellite areal extent of snow cover rasters. OPPS can 1) output rasters in any of several common GIS formats, 2) create displayable images with user-defined vector overlays, and 3) integrate raster data within basin boundaries to produce alphanumeric data products. OPPS products can be stored and distributed using the NOHRSC electronic bulletin board system, FTP'd over Internet to interested cooperators, and sent to NWS offices over AFOS.

INTRODUCTION

Near real-time quantitative assessments of areal extent of snow cover and gridded snow water equivalent (SWE) provide valuable insight and information for water management, hydrologic forecasting, and emergency preparedness agencies throughout the United States and Canada. Since 1986, the National Operational Hydrologic Remote Sensing Center (NOHRSC) of the National Weather Service (NWS) Office of Hydrology (OH) has provided these data in rasters and alphanumeric tabulations generated using satellite image processing, spatial interpolation and GIS analysis. Until recently, each of these processes were performed independently. They are now largely integrated in the newly developed NOHRSC Operational Product Processing System (OPPS).

Estimates of the extent, depth, and water equivalent of snow are developed at the NOHRSC from a variety of dynamic data sources including:

1) Satellite imagery acquired daily at a variety of resolutions from a variety of sensors (i.e., Advanced Very High Resolution Radiometer (AVHRR) and Geostationary Operational Environmental Satellite (GOES));
2) Airborne gamma radiation snow water equivalent data sets; and
3) Station observations reporting point data on snow water equivalent, snow depth, air temperature, etc. (i.e., SNOTEL, snow course, aerial markers etc.).

Analyses of these data are supported by static data sets including hydrologic basin boundaries at various scales, thematic land use and land cover grids, and digital elevation models.

Prior to OPPS, each data type was analyzed by a separate data processing system. A given snow estimation product may have employed a variety of input data sources and therefore more than one process was required. For instance, to produce a tabulation of SWE by elevation band, the following processes were executed:

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1) Acquire and analyze satellite imagery to produce an areal extent of snow cover map;
2) Spatially interpolate snow water equivalent station observations;
3) Mask the SWE spatial interpolation with the snow cover map to ensure that SWE is estimated only where snow is observed;
4) Stratify interpolated SWE by elevation bands; and
5) Sum SWE within each elevation band for individual hydrologic basins.

While each individual process was highly automated, the integration of intermediate outputs into the final products was both labor intensive and procedurally redundant.

OPPS DESIGN

OPPS was developed to meet the following design objectives:

1) To streamline, to the greatest extent possible, the production of snow estimation products in an operational environment;
2) To integrate, in an automated and objective manner, a wide variety of input data sources used to produce snow estimation products;
3) To develop and employ state-of-the-art spatial data processing algorithms tailored to the task of producing snow estimation products from integrated input data sources; and
4) To automate the dissemination of generated products.

A major objective in the design of OPPS was to automate data integration. Primarily through the use of spatial interpolation techniques and polygon membership modeling, OPPS is capable of integrating raster data with point, line and areal vector data. The integration of variable resolution raster data is supported by run time data sub- and super-sampling functions allowing OPPS to define a range of output product resolutions without regard to the resolution of the input data.

The spatial integration of raster and vector data is supported by automated procedures which exploit the temporal distribution of the input data. Many OPPS processes are designed to evaluate data within windows of opportunity centered on a target date. Because OPPS is designed to address snow estimation on a continental scale, there is a strong possibility that suitable input data are not available for a given instant in time. For example, processes which require satellite image derived maps of areal extent of snow cover are often hampered by cloud cover. By integrating the cloud-free portions of multiple snow cover maps acquired during a window of opportunity, OPPS can minimize the impact that cloud cover has on the snow estimation process. Similar mechanisms were designed into OPPS for the treatment of each input data source.

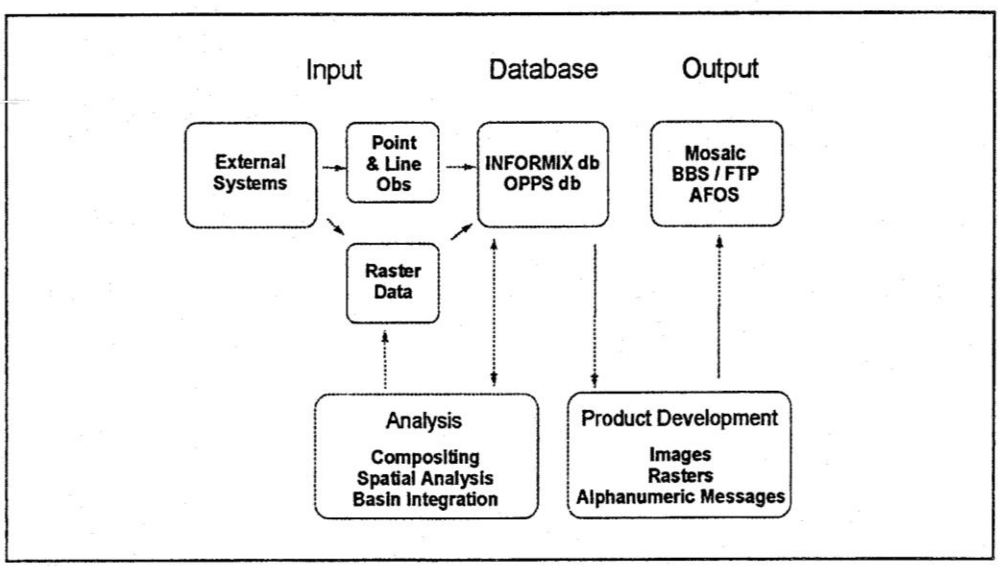

Figure 1: OPPS data/products/processing flow.

OPPS consists of a series synchronized programs communicating with one another through an INFORMIX database server and system calls (Figure 1). The OPPS programs fall into three classes: Database, Analysis, and Product Development. The OPPS programs are supported by the OPPS database consisting of static and dynamic tabular and graphic data. The dynamic portion of the OPPS database is constantly updated by a wide variety of inputs. The remainder of this paper describes, in some detail, the OPPS components and their relationships in the production of OPPS outputs.

OPPS INPUT

OPPS is designed to integrate data from a variety of sources, data- types, structures and formats. OPPS can handle both raster and vector data types. Raster data can be variable in resolution. Vector data may be either point, line or closed polygon structures.

To minimize distortions associated with map-projected coordinates, OPPS requires that all of its inputs be in geodetic (longitude and latitude or Earth) coordinate pairs. All calculations are performed in the geodetic coordinate system. The World Geodetic System 1984 (WGS 84) horizontal datum and the National Geodetic Vertical Datum of 1929 (NGVD 29) were selected for OPPS on the basis of the availability of digital elevation model (DEM) data. Many of the analysis programs in OPPS model orographic processes and, as such, are highly dependent upon DEM data. The highest quality of DEM data available in national coverage are in the WGS 84 and NGVD 29 datums.

Point observations of snow water, snow depth, precipitation, and surface air temperature are actively and passively acquired over Internet and are automatically ingested into the INFORMIX database. As airborne survey data become available, they also are ingested into the INFORMIX database.

Raster data inputs include areal extent of snow cover thematic rasters derived from the reclassification of satellite images acquired from the GOES and NOAA polar orbiter satellites. Snow cover rasters are produced on a daily basis and are registered with the OPPS database as they become available.

OPPS is capable of ingesting raster data in GRASS, ARC/INFO, and Global Imaging formats. OPPS will be capable of ingesting raster data conforming to the SDTS raster profile in the near future.

Point observation data are registered and stored as INFORMIX database records. OPPS is capable of ingesting flat files into the INFORMIX database. All line and areal vector structures are stored in OPPS as individual binary flat files whose headers are stored in the INFORMIX database. Since many spatial data analysis systems (i.e., GIS) are capable of exporting flat files, the OPPS approach for dealing with these types of data allows a great deal of flexibility.

OPPS DATABASE

OPPS maintains two databases:

1) The OPPS database, a UNIX file system which organizes OPPS raster and vector files into subdirectories; and
2) The INFORMIX database which:
    a) Stores the characteristics, identity, and location of each OPPS-generated product;
    b) Stores the characteristics, identity, and location of each OPPS static data set (i.e., DEMs, basin boundaries, etc.); and
    c) Stores non-raster OPPS input data (i.e., station observations) and attributes.

In addition to storing information on products, the INFORMIX database is also used to control the flow of integrated OPPS processes. Certain OPPS products are the consequence of multiple data processing operations where the output of one process is used as the input for a subsequent process.

These multiple processing operations are internally defined and, as such, are transparent to the user. When an OPPS product is requested, the request is registered into the INFORMIX database as a unique record. The individual processes required to produce that product are automatically queued by the OPPS subsystem. As subsequent processes are completed, their status is registered in the INFORMIX database and the next process in the queue is initialized. Queued processing continues until the final output product is generated.

OPPS ANALYSIS PROGRAMS

In its present state OPPS consists of the following analysis programs:

Raster Compositing

This program generates composites from existing rasters in the OPPS database. It has two functions:

1) To produce a single mosaic raster of a larger area from multiple rasters of smaller geographically distributed areas; and

2) To produce a single composite raster from temporally distributed rasters occupying the same geographic area. As rasters are composited, unknown and cloudy pixels are replaced by pixels of known value.

Both functions can operate simultaneously and there is full control of how multiple rasters are integrated. Composite control is facilitated by prioritizing raster file attributes. Raster compositing may be constrained by vector feature outlines.

Areal Extent of Snow Cover by Elevation

This program produces a new raster in which the snow pixels in an areal extent of snow cover raster are represented by DEM elevation values. The resultant raster depicts the horizontal and elevational distribution of observed snow.

Inverse Distance Interpolation

This program accepts point and flight line observations as the x, y, and z sample data inputs into the inverse distance weighted mean spatial interpolation algorithm. The user controls where, geographically, sample points are to be gathered and how far the algorithm may search for sample observations.

No-snow pixels in an areal extent of snow cover raster can be used as sample observations of zero snow cover to constrain the interpolation. The snow cover raster may also be used to mask interpolated pixels for which no snow was observed by the satellite.

Temperature Interpolation

This program generates an inverse distance weighted mean interpolation of mean daily surface air temperature. Surface temperature observations are lapsed to a common elevation of 4500 meters. Temperatures interpolated at this elevation are lapsed back to the surface. The resultant product reflects the orographic effect on surface air temperature.

Degree Day Accumulation

This program sums the daily positive differences between interpolated surface air temperature and a specified base temperature for each pixel. The output is useful for calculating the number of snowmelt degree days beyond a given date. The area calculated may be constrained by vector feature outlines.

Orographic Interpolation

This program estimates SWE or snow depth in areas in which there are orographic dependencies. For each pixel:

1) Point observations within a user-defined search radius are identified and the average elevation and average snow value are calculated;
2) From an areal extent of snow cover raster, the elevation of the nearest snow line is identified. If the snow line is too distant or is non-existent, a user-defined default snow line elevation is used in its stead;
3) A linear relationship between elevation and snow value is established from the snow line and average elevation and average snow value observations;
4) Elevationally detrended residuals are computed for each snow value point observation using the relationship in (3);
5) An inverse distance weighted mean interpolated residual is computed;
6) An estimate of snow value is computed using the relationship in (3) and the elevation of the pixel being estimated; and

7) The estimate in (6) is modified by the interpolated residual in (5) yielding the final estimated snow value.

Again, the area developed can be constrained by a vector feature outline. Raster compositing can be used in conjunction with this program to produce an accurate estimate of SWE or snow depth over large areas.

Basin Analysis

This program will, on a basin-by-basin analysis, compute mean areal snow values (i.e., SWE, snow depth, etc.) by predefined elevation bands. The resulting tabulations are stored in the INFORMIX database as time-stamped records. As basins are examined throughout the snow season, additional basin analysis records are related to each basin, yielding a time series of basin snow data.

OPPS PRODUCT DEVELOPMENT

OPPS generates a variety of gridded products derived from raster and vector inputs using processes designed specifically for snow distribution estimation. Basin-integrated values can be summarized into coded Standard Hydrometeorological Exchange Format (SHEF) alphanumeric products specifically tailored to a specific user's needs.

All of the gridded products generated by OPPS reside in the OPPS database in a binary format designed to accommodate the needs of the NOHRSC. OPPS is capable of exporting these rasters into a variety of formats including GRASS, ARC/INFO ASCII grids, and Global Imaging (essentially a flat binary raster with an 80 byte header).

While these formats respond to the needs of those interested in performing further data analysis, some end users are interested primarily with images (pictures). To meet those needs, OPPS can also generate GIF, TIFF, McPaint, and PCX formatted image files. A variety of vector overlay features may be incorporated into these images, including states, basins, and observation points.

OPPS OUTPUT

The NOHRSC data are used operationally by the NWS, the Army Corps of Engineers and other Federal, state, and private agencies when issuing spring flood outlooks, water supply outlooks, river and flood forecasts, and reservoir inflow forecasts. In an effort to simplify the distribution of products to regular data users, OPPS has incorporated a sophisticated data distribution subsystem which automatically routes relevant and/or desired OPPS output products to agencies who have registered their Internet FTP addresses with the NOHRSC. Users can also access OPPS products via the NOHRSC Mosaic Home Page (http://www.nohrsc.nws.gov) or the NOHRSC BBS (612-361-6632).

CONCLUSION

The NOHRSC is an operational center within the National Weather Service Office of Hydrology which has, as one of its major responsibilities, the task of mapping snow cover characteristics for all of the United States and portions of Canada. While the NOHRSC has always employed state-of-the-art techniques in accomplishing this task, OPPS, for the first time, allows the snow hydrologist access to the full value of the available input data.

Through the integration of a broad variety of input data sources, the exploitation of temporal processes, and the design and implementation of data management and analysis programs tailored to snow distribution analysis OPPS, is capable of providing and distributing near-real time analysis of the highest quality currently available.