MONITORING GLOBAL SNOW COVER

by

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ABSTRACT

A methodology to monitor global snow cover has been developed by the National Snow and Ice Data Center (NSIDC), University of Colorado, for use by the U.S. Air Force Global Weather Central (AFGWC). The snow model supports the daily, operational, analysis of global snow depth and age and represents a state-of-the-art system with respect to data available at AFGWC. The model provides improved spatial interpolation of surface reports by incorporating digital elevation data, the application of regionalized variables (kriging), and through the use of a global snow depth climatology. Where surface observations are inadequate, the model applies satellite remote sensing (SSM/I). Techniques for extrapolation into data-void mountain areas and a procedure to compute snow melt are also contained in the model.

INTRODUCTION

The National Snow and Ice Data Center (NSIDC) of the University of Colorado has developed an enhanced version of the global snow cover model which is operated by the U.S. Air Force Global Weather Central (AFGWC). The snow model supports the daily, operational, analysis of global snow cover (Hall, 1986). The new NSIDC model provides improved spatial interpolation of surface reports and incorporates satellite remote sensing (Armstrong and Hardman, 1991). Snow cover information is provided for each grid point within a selected portion of the AFGWC RTNEPH 1/8 mesh (40 km) grid system (land mass north of 20 deg. north latitude and south of 20 degrees south latitude where permanent or seasonal snow cover can be expected). The projection is polar stereographic, true at 60 degrees latitude. The basic data generated for each grid point are calculated average and maximum snow depth (cm), age in days of the total snow cover, number of days since the last surface accumulation of 2.0 cm or more, and appropriate data source flags and summary diagnostics.

SURFACE STATION REPORTS

The model relies on measured snow depths available from the World Meteorological Organization (WMO) synoptic data collection network. While there are more than 5000 reporting stations for the Northern Hemisphere, station density is highly variable and station reporting is not consistent throughout the entire sample. Therefore, model operation varies according to the density of surface station data.

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In geographic locations where measurements from surface reporting stations are available with a sufficiently high density, at least one data point within 100 km of a given grid point, these data represent the primary model input. A fixed data base consists of latitude, longitude, and elevation for each grid point as well as a list of the 10 closest reporting stations. For each model run, the reports from the 5 closest surface stations are obtained. Each grid point value is meant to reflect the best estimate of the average snow depth within the area immediately surrounding that grid point. In order to achieve this, an inverse-distance weighting interpolation scheme is used in regions where surface observations are the most dense, i.e. more than one observation within 50 km of the grid point. This interpolation scheme is supported by a digital elevation data base (5-arc minute resolution). This allows the influence of a measurement site on given grid point to decay with changes in elevation as well as horizontal distance.

In regions where surface observations are less dense, but there is at least one observation within 100 km of a grid point, an interpolation technique based on the theory of regionalized variables (kriging or optimal interpolation) is applied (Oliver et al., 1989). The technique of kriging was chosen as it provides the most accurate and realistic spatial interpolation from randomly distributed reporting stations to fixed gridpoints. This interpolation method is based on the average spatial variation of snow depths within the area of interest and therefore requires a snow depth climatology in order to calculate the initial variances. The USAFETAC Global Snow Depth Climatology (Foster and Davy, 1988) provides the source for average monthly snow depths at the required 40 km resolution.

Mountainous areas are often locations of the fewest station reports. While linear interpolation between points in areas of non-mountainous terrain may sometimes lead to errors due to storm track variability, linear interpolation in zones where orographic precipitation dominates is not an acceptable approach (Chang and Chiu, 1989; Alford, 1985). Therefore, an extrapolation method based on elevation difference has been developed for the NSIDC model to provide an approximate correction for the orographic precipitation effect in data-void mountainous areas. Due to the orographic effect, mean snowfall amounts at mid-latitude locations are often directly proportional to elevation. The gradients of precipitation with elevation are inversely proportional to mean elevation of the interval (Alford, 1985; Meiman, 1970). Therefore, the precipitation gradient coefficient used in the extrapolation depends on the mean elevation of the region.

The only exception to the procedure described above involves the geographic areas of Greenland and Antarctica which are permanently covered with snow and ice. Due to inadequate surface observations in these areas and the fact that SSM/I snow depth algorithms cannot provide useful information for semi-infinite snow depths, these areas are simply flagged as "permanent snow and ice". However, where surface station data are available in Greenland and Antarctica, depth and age are calculated for those grid points within 50 km of a reporting station.

SATELLITE REMOTE SENSING

In regions where there is an average of less than one reporting station within 100 km of a grid point, remote sensing techniques are applied. Although no single sensor can provide all of the information required by the model, the global, all-weather, day/night capability of passive microwave (DMSP-SSM/I) provides essential input to the calculation of snow extent and depth (Robinson et al., 1984; Schweiger et al., 1987; Rango et al., 1989). Efforts to produce a reliable snow depth algorithm on regional to global scales have been made by several investigators (Kunzi et al., 1982; Hallikainen and Jolma, 1986; Chang et al., 1987; Goodison, 1989; Aschbacher, J. 1990. The Chang et al. algorithm is being used in the prototype AFGWC snow model but NSIDC is currently comparing and testing the various algorithms referenced above (Armstrong, 1990b). However, it is assumed that no single algorithm will be entirely appropriate on the global scale and thus regional algorithms will evolve.

Snow depth algorithms have proven to work well over non-complex terrain such as high plains and steppes. However, in complex mountain terrain, and within dense coniferous forest these methods have yet to be proven and present certain operational limitations. In order to flag SSM/I algorithm output which might be unreliable, the geographic areas where these factors play a significant role are identified. Areas of complex terrain are flagged in the SSM/I snow depth output by computing the root-mean-square differences in elevation between each grid point and the surrounding eight grid points to provide an average terrain variability at each grid point. The average variance represents the terrain variability at the individual grid point. Within complex terrain, the computed depth from SSM/I may be less than actual depth. This results from the fact that the SSM/I value for an individual pixel represents a spatial integration over an area of approximately 625 km^2. Within such a large area of complex terrain the SSM/I brightness temperature value will represent a mixture of surfaces which are basically emitters (snow-free rock or soil surfaces) or scatterers (snow). Increased microwave emission (brightness temperature) originating from the snow-free surfaces typically found in complex mountain terrain will tend to reduce or "offset" the increased scattering which is associated with increased snow depths (Danes, 1989). Areas of dense coniferous forest are flagged using the AFGWC AGROMET global vegetation data set (Vegetation Type 7, coniferous forest). Again, in many cases, an increased brightness temperature caused by dense vegetation extending above the snow surface may cause the computed depth to be less than the actual depth (Hall et al., 1985).

Passive microwave algorithms are also sensitive to snow structure and particularly to grain size. Geographic regions where large average diameter (> 2.0-3.0 mm) snow grains (depth hoar) might be commonly observed in dry snow could be flagged, although this component is not present in the current version of the prototype model. The primary factor controlling grain growth in a sub-freezing snow cover is the magnitude of the vertical temperature gradient across the snow layer between the warm ground and the colder air above. As a general rule, a vertical temperature gradient equal to or exceeding 10°C/m, and present in the snow cover over at least a few weeks in time, is considered sufficient to cause increases in grain size and the development of depth hoar (Armstrong, 1985). Using the AFGWC Snow Depth Climatology combined with AGROMET mean monthly air temperature data, and assuming a ground-snow interface temperature of 0°C, it would be possible to indicate general areas where temperature gradients of 10°C/m or greater could be expected. The user would note that in these areas the computed depth from SSM/I would typically be greater than the actual depth (Hall, 1987). This is due to the fact that increased grain size causes increased scattering of the microwave energy and thus a lower brightness temperature or emissivity. An initial effort to characterize snow grain size on a regional scale is currently underway (Armstrong, 1990a; Armstrong and Rango, in preparation).

While SSM/I algorithms are capable of clearly identifying the boundary between dry snow and bare ground (wet or dry) the signature of wet snow is very similar to that of bare ground. Because the dielectric properties of ice and water are so different, even small amounts of liquid water present on the surface of snow grains will transform the material from being primarily a scatterer to being an emitter (Schanda and Hofer, 1977; Maetzler and Hueppi, 1989). As a result, the passive microwave signal generated by wet snow cannot be distinguished from snow-free terrain (Foster et al., 1984; Rott, 1987; Kunzi et al., 1982) In order to distinguish the snow/soil boundary during melt conditions the model monitors the 37

Ghz brightness values and notes those occurrences when values increase by more than 5-10 °K between successive satellite passes over the same location on the ground. Such a short-term increase in brightness temperature would be indicative of a melting snow surface.

If the operational SSM/I output indicates that the snow covered area in a given data sparse region is rapidly retreating, but it is suspected that this may be a response to wet snow rather than the absence of snow, (based on significant depths being present just prior to the observation) two procedures are followed. Snow covered area is monitored using visible wavelength satellite data (DMSP-OLS) when and where atmospheric conditions permit. In addition, decrease in snow thickness is approximated by applying a melt algorithm which is driven by gridded AFGWC shelter-height air temperature data. The algorithm contains a melt coefficient which is sensitive to coniferous forest cover and time of year. It is based on the National Weather Service River Forecast System - Snow Accumulation and Ablation Model (NWS Model) (Anderson, 1973). The snow melt algorithm is applied to grid points and is not intended to provide data for individual surface stations when reports are missing. However, if a sufficient number of surface stations fail to report, the algorithm will check for possible snow melt. All snow depth values resulting from snow melt calculations will be adjusted to surface station depths when such data again become available.

In the future, when multi-channel AVHRR data become available at AFGWC, snow/cloud discrimination algorithms may also be developed which take advantage of the fact that while snow is relatively "black" in the near infra-red wavelengths, liquid-water clouds continue to exhibit high reflectivity at these wavelengths. Such algorithms have been developed previously as research tools (Scharfen and Anderson, 1982) and are now used operationally by the National Weather Service, Office of Hydrology (Carroll et al., 1989).

CLIMATOLOGY

If no surface or satellite data are available, the last calculated depth at the grid point will persist for a period of three days, after which the calculated snow depth value moves towards climatology (USAFETAC Global Snow Depth Climatology (Foster and Davy, 1988). Grid point depth is set to "yesterday's" depth plus the factor 0.1 times the signed difference between "yesterday's" depth and climatology. The analysis grows towards climatology until such time as adequate surface station reports and/or satellite data become available. Data source flags are contained in the output so the user is aware of the presence of climatology-derived values in the grid. Snow climatology data are also used to characterize individual geographic areas to support the optimal interpolation (kriging) described above.

CONCLUSION

The global snow model described above is currently undergoing testing and validation at NSIDC. Remote sensing data sets, including AVHRR and DMSP-OLS, are being compared to the computed snow extent, while regional-scale, high-density surface observation networks are being used as validation data for snow depth. The full model is expected to become operational at AFGWC in 1992. The comparison, testing, and validation of regional passive microwave algorithms will continue at NSIDC. These results will support the capability at NSIDC to produce, archive, and distribute global-scale, gridded, snow cover products based on data from the DMSP SSM/I. This work is being supported by the NASA Interdisciplinary Research Program in Earth Sciences (NAGW-1839). The prototype snow model developed for AFGWC has been funded through a Military Interdepartmental Purchase Request (MIPR No. 88-041).

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