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The interactive multisensor snow and ice mapping system

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Abstract:

The interactive multisensor snow and ice mapping system (IMS) was developed to give snow and ice analysts the tools, on one platform, to inspect visually the imagery and mapped data from various sensor sources to determine the presence of snow and ice and to depict snow- and ice-covered areas on a map on a daily basis, in one hour or less. Snow and ice analysts in the National Environmental Satellite, Data, and Information Service have been creating weekly maps showing the extent of snow cover for the Northern Hemisphere since 1966 using visible imagery from polar-orbiting and geostationary satellites and surface observations as data sources. The current process is mostly manual and time-consuming, taking up to 10 hours to produce a map during the snow season. Where cloud cover precludes an unobstructed view of an area during the entire week, the analysis from the previous week is carried forward. Each week the analyst draws a new map by hand, then digitizes the extent of snow and ice cover using an 89 × 89 line grid overlaid on a stereographic map of the Northern Hemisphere. The hand-drawn map is photocopied and distributed and the digitized map is saved to a file for use in National Weather Service numerical models and for archival storage. IMS was designed and built to replace and improve this process by producing a more accurate and timely product. © 1998 John Wiley & Sons, Ltd.

KEY WORDS satellite remote sensing; environmental data; snow and ice cover; geographic information system; climate

INTRODUCTION

The National Oceanic and Atmospheric Administration's (NOAA) weekly snow map is the longest satellite-derived environmental data set available. An experimental system, designed to improve snow charting accuracy and usefulness, has been built. In addition, passive microwave (mw) data will be a new data source in the creation of a daily map. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) began producing an experimental daily snow map from this new system, the interactive multisensor snow and ice mapping system (IMS), in February 1997, and an operational product in November 1997 (Ramsay, 1998). The IMS product will provide a daily Northern Hemisphere (NH) snow map for use in specifying the surface boundary conditions in numerical weather forecast models run by the National Weather Service's (NWS) National Centers for Environmental Prediction (NCEP) (Foster and Chang, 1993). The daily IMS snow maps will replace a weekly snow map that NESDIS has produced since 1966 (Matson and Wiesnet, 1981; Matson *et al.*, 1986).

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THE NEED FOR A DAILY SNOW PRODUCT

The NESDIS weekly snow maps were used by NCEP as numerical model initialization data. However, large errors in the near surface temperature forecasts occurred owing to the infrequency of the weekly product. It was not possible to increase the frequency of the current product because of cloud obscuration of the snow/no snow boundary. NCEP replaced the weekly snow maps with US Air Force (USAF) daily snow maps in 1993, which improved the model results to some extent (Bocchieri, 1996). A daily snow cover product then became a high priority at NOAA when it was discovered that errors in the USAF daily snow maps were also causing cool season, low level temperature forecast errors (Petersen and Hoke, 1989; Mitchell *et al.*, 1993). These errors were created because the USAF snow map, which does not use the US Geostationary Operational Environmental Satellite (GOES) data for analysis, did not consistently reflect the retreat of snow cover under certain environmental conditions. NCEP prefers the use of GOES data in daily snow map production as this time sequenced imagery is used to discriminate snow from clouds (SAB, 1997).

The next attempt to improve model input was to use the special sensor microwave/imager (SSM/I) to produce a fully automated daily snow map with the all-weather capability of mw observations (Mitchell *et al.*, 1992). The resultant snow maps were fairly accurate, but it was found that under certain conditions, such as snow in forests, wet snow and melting snow, the SSM/I algorithms gave false results (Grody, 1991; Grody and Basist, 1996). NCEP is unwilling at this time to accept an automated mw-only snow product.

This experience and the current state of remote sensing science suggests that an analyst's editing is required to derive a reliable daily snow map.[1] So, in 1995 NOAA began development of the IMS as the most likely means to an accurate daily snow map. The IMS will make use of the SSM/I automated snow maps, visible imagery, station data and the previous day's snow maps and allows analysts to edit the results using their judgement. The IMS snow product will replace the weekly NESDIS snow analysis.

BACKGROUND

There is concern in the climate community that the new, more frequent and more accurate multisensor product will cause a discontinuity in the long-term climate record. The current NESDIS snow product plays an important role in the monitoring of global climate variability and change (Matson and Parmenter-Holt, 1985; Robinson *et al.*, 1993). This 30-year data set is sufficiently important that the NOAA Climate and Global Change program funded a reworking of the 1966–1972 portion of the record by analysts at Rutgers University to bring it into better consistency with the later years of the product. This is being redone to correct mapping inconsistencies between the early years and those since 1972. With the completion of the 1966–1972 period, a 30-year consistent product will be available for study. The new daily snow maps must be compared with and calibrated against the weekly maps. It is critical that for an overlap period, NESDIS produce both the weekly and the daily snow maps and that a detailed validation of both products be done.

It is also important that a comparison between the two snow maps be undertaken to determine what differences occur between the products and why and under what circumstances the discrepancies exist. If these discrepancies can be documented, it may be possible to re-analyse a major portion of the 30-year satellite-based snow cover record in the future [e.g. passive microwave imagery from satellite sensors with the ability to detect snow cover first became available from Nimbus-5 in 1972 (Townshend *et al.*, 1991)]. NESDIS has agreed to generate both the weekly and daily snow maps for 15 months, covering a complete snow season. This effort will provide for the validation and intercomparison of the old and new snow map products and will allow the climate record to be extended without break into the future. It will make the

[1] The National Aeronautics and Space Administration (NASA) will launch the moderate resolution imaging spectroradiometer (MODIS) in 1998 (Hall *et al.*, 1995). Automated snow maps will be produced from MODIS visible, near-infrared and short-wave infrared imagery combined with the use of a cloud-screening algorithm. NOAA analysts, at NASA's invitation, have participated in the review of the MODIS snow mapping algorithm and have discussed the possibility of using MODIS snow maps in NOAA's operational snow mapping applications at NESDIS and NOHRSC.

transition between the two products as seamless as possible and provide the opportunity to maintain the integrity of the long-term record.

It is anticipated that the validation and intercomparison will produce suggestions for improvement of the new daily product. For example, SSM/I data will be used for the first time in NESDIS operational snow cover mapping. The use of mw data is intended to improve the detection of snow cover under cloudy conditions and at night (Lo, 1986; Ferraro *et al.*, 1996). More accurate data will improve short-term weather forecasts, and improve the global climate change snow cover data set.

THE WEEKLY SNOW MAP

Snow and ice charting currently performed by NESDIS is done to produce analyses depicting NH snow and ice cover. In contrast to low resolution hemispheric snow maps (190 km per pixel), daily high resolution river basin snow maps (1 km per pixel) used in local US forecasts are produced at the NWS National Operational Hydrologic Remote Sensing Center (NOHRSC). The primary data source for NH snow mapping is advanced very high resolution radiometer (AVHRR) visible imagery acquired from the NOAA polar operational environmental satellites (POES). Secondary data sources include geostationary imagery, USAF snow analyses, National Ice Center (NIC) sea ice edge charts and surface observations. Figure 1 illustrates the use NESDIS snow analysts have made of POES, starting in 1966, and the increasing use of GOES, introduced in 1975. The use of the European geostationary meteorological satellite (MET, but more recently referred to as METEOSAT) began in 1988 and Japan's geostationary meteorological satellites (GMS) in 1989. The use of imagery from geostationary satellite sensors has significantly reduced the use of AVHRR imagery, although it remains the primary data source in NESDIS snow mapping. The coverage provided by both polar and geostationary satellites is shown in Figure 2. The clear ovals depict geostationary coverage (from left to right: GMS, GOES, MET and GMS again). Snow and ice cover identification is made by manual inspection of imagery and graphics products, online time sequenced imagery video loops, and the previous week's analysis (SAB, 1997).

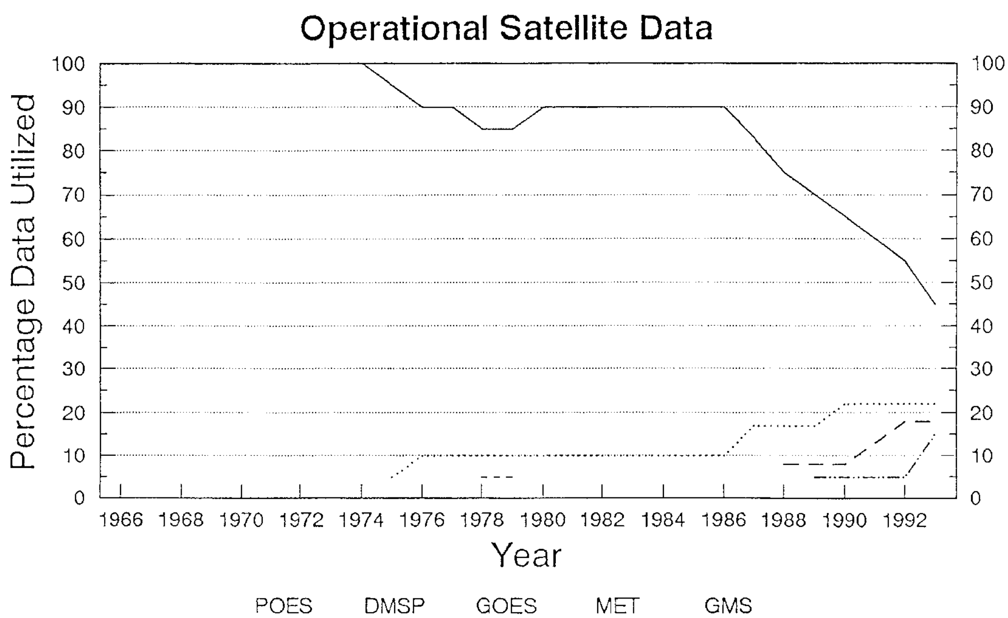

Figure 1. Use of operational satellite data by NESDIS anaysts in NH snow and ice analysis

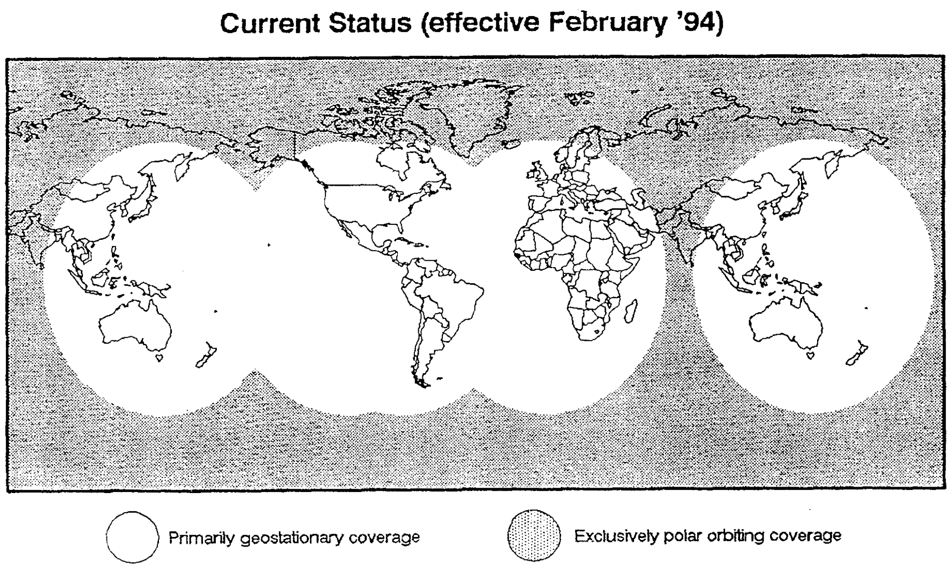

Figure 2. Global satellite coverage used in snow/ice analysis

Chart quality is predicated on the availability of clear sky visible imagery and the meteorologist's experience. As the meteorologist identifies snow and ice boundaries in the imagery, he or she prepares a finalized polar stereographic snow map by transferring the boundary lines to a paper chart, an example of which is shown in Figure 3. An electronic version of the snow map is then created by the digitization of the paper chart to an 89 × 89 grid [cell resolutions are dependent upon latitude and range from 16 000 to 42 000 km^2 (Hughes *et al.*, 1996)] overlaid on a NH polar stereographic map. Monthly snow and ice cover climatologies are then derived from the electronic version for use by the NWS Climate Prediction Center (CPC) and for archival storage. Quality control is self-imposed by the meteorologist doing the analysis or by the focal point meteorologist. The snow map, which takes up to 10 hours to complete during the snow season, is faxed to users in the NCEP, CPC, Department of Agriculture, universities, foreign governments and other customers (SAB, 1997).

PROJECT DESCRIPTION

The IMS is a UNIX workstation application that provides the analyst with the ability to draw, erase, label, save, edit and distribute maps showing the extent of snow and ice over a hemisphere of the Earth. Snow analysts use IMS to produce experimental daily NH snow maps from a variety of satellite imagery and derived imagery and station-mapped products in approximately one hour. IMS gives snow and ice analysts the tools, on one platform, to inspect visually the imagery and mapped data from various sensor sources to determine the presence of snow and ice, to depict snow- and ice-covered areas on a map, to save it and then to convert the map to a lower resolution for use by an archive process. The software also provides the ability to compare snow maps and other mapped data sets, such as elevation, vegetation type and land use (Star and Estes, 1990). Appropriate header data in the final snow map and an ancillary map containing information about data sources and quality flags will be implemented prior to the start of validation (Ramsay, 1995).

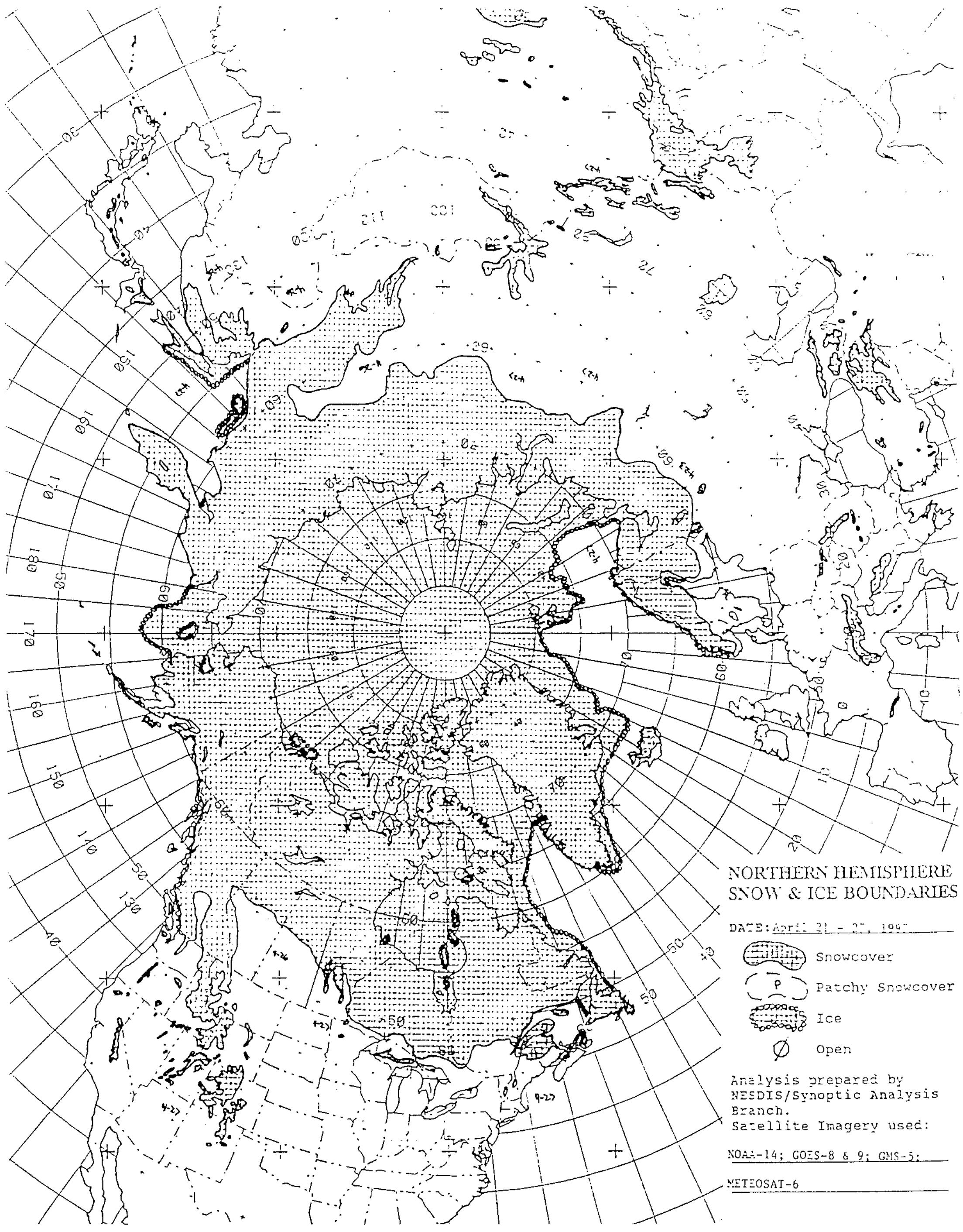

Figure 3. A stereographic snow map showing snow and ice boundaries

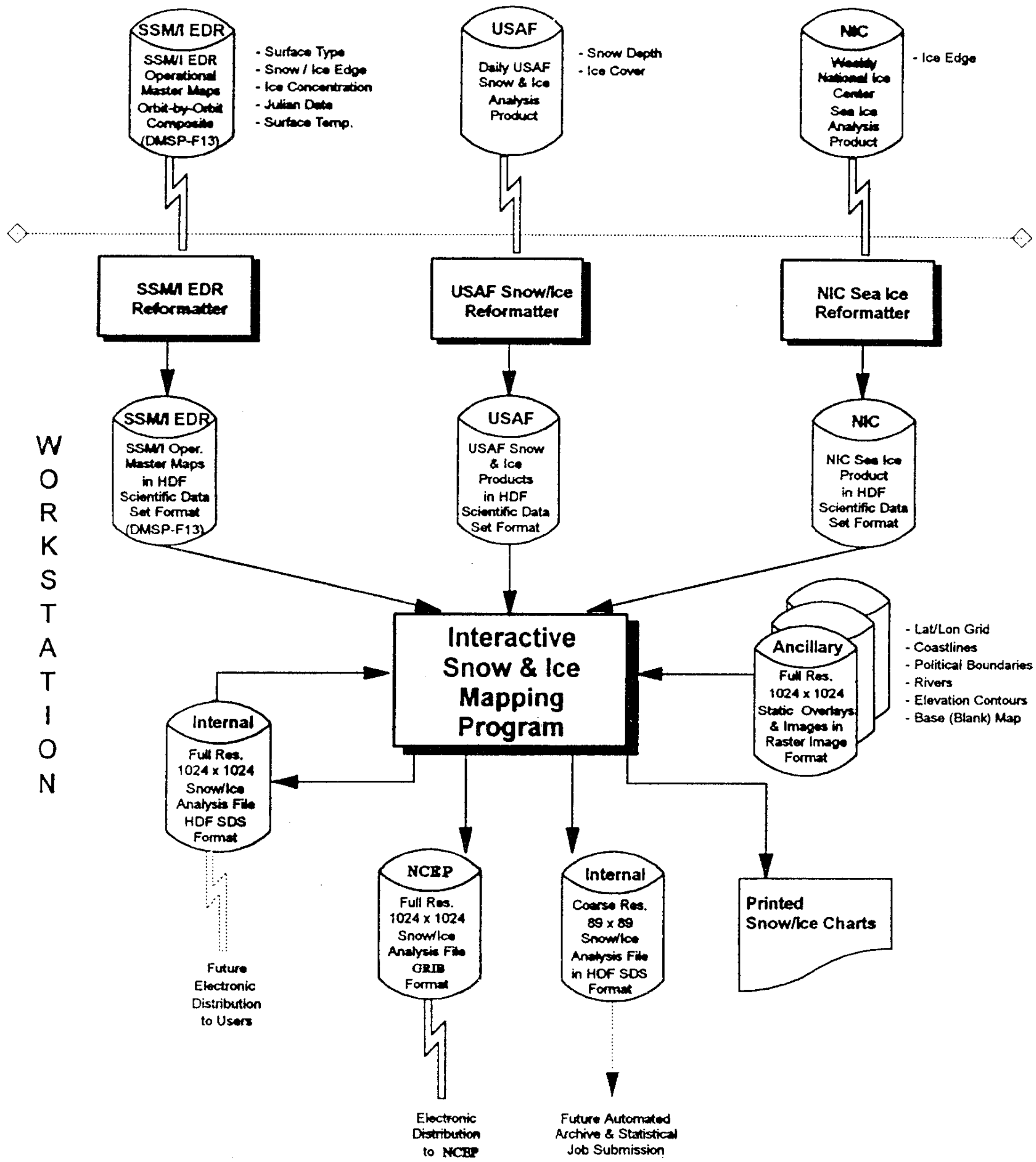

Figure 4. Flow chart showing data processing of IMS

The flow of IMS data processing is shown schematically in Figure 4. Files are automatically transferred electronically from their host computer systems to the IMS workstation. SSM/I environmental data records (EDRs), USAF daily snow maps and sea ice edge charts are shown to represent the variety of data sources previously identified. The input data sources are resampled to a standard 1024 × 1024 pixel matrix at 23 km per pixel resolution, and reformatted into the hierarchial data format scientific data set (HDF SDS).

The imagery or data files are then available to the analyst for display and use through the interactive snow and ice mapping programme. Also available are ancillary data sets to assist in mapping such as a latitude/longitude grid, coastlines, political boundaries, rivers and elevation contours, among others. When the analyst completes the snow map it is automatically saved and reformatted from HDF SDS to American standard code for information interchange (ASCII), and to graphical interchange format (GIF), and electronically transferred to an operational file-server for access by NCEP and other authorized users, as well as for transfer to archival storage at the NOAA National Climatic Data Center (NCDC) and the University of Colorado's National Snow and Ice Data Center. Prior to product validation, the IMS snow ma[illegible] be reformatted to gridded binary (GRIB) for use by NCEP.

Figure 5 is a screen print of the IMS graphical user interface and an IMS NH snow map. The online system uses a colour display with ice coloured yellow (intermediately shaded grey in this reproduct[illegible] in white, land in brown (darker grey), and water in blue (black). Pull down menus are available in [illegible] left corner of the screen, tool palette buttons are located on the upper right portion of the interface, with static overlays positioned immediately below in the lower right corner. Along the bottom are buttons for the display of current imagery and data. A complete NH snow map for 15 May 1997 (from a GIF image) is shown in Figure 6.

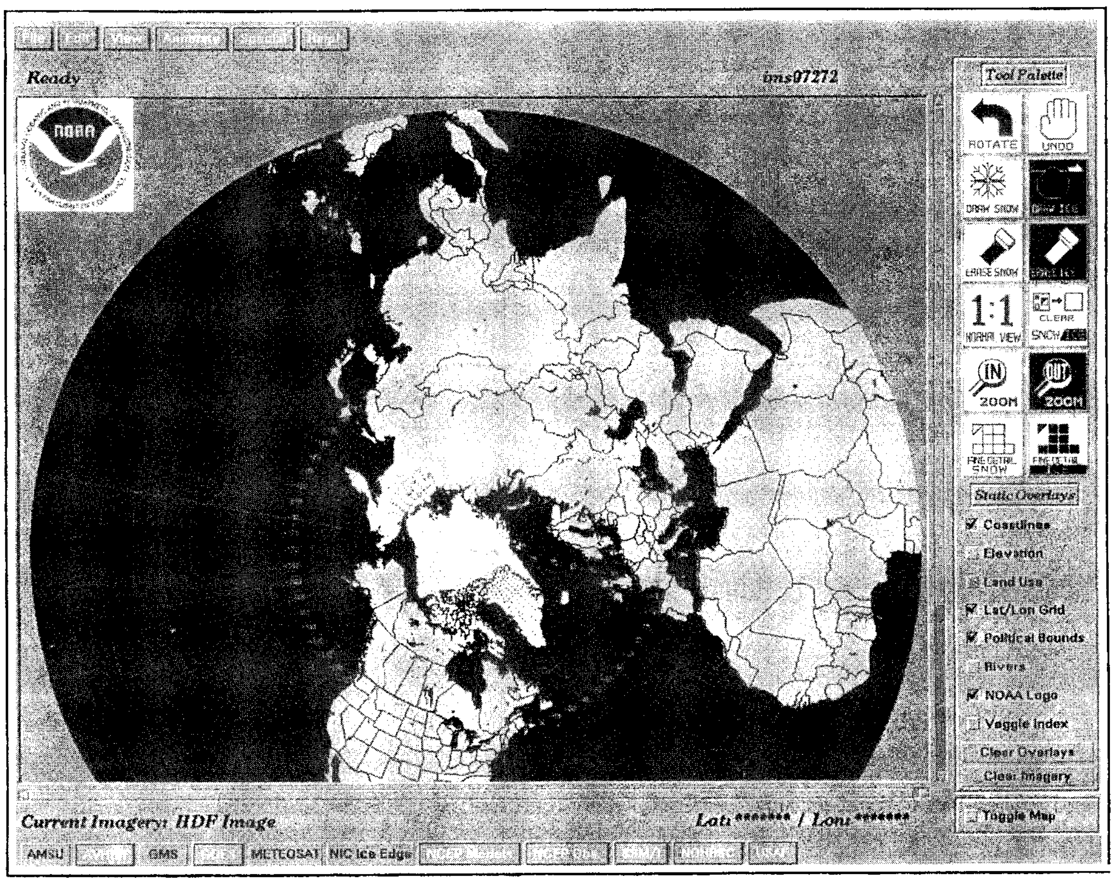

Figure 5. IMS graphical user inerface with an IMS NH snow map

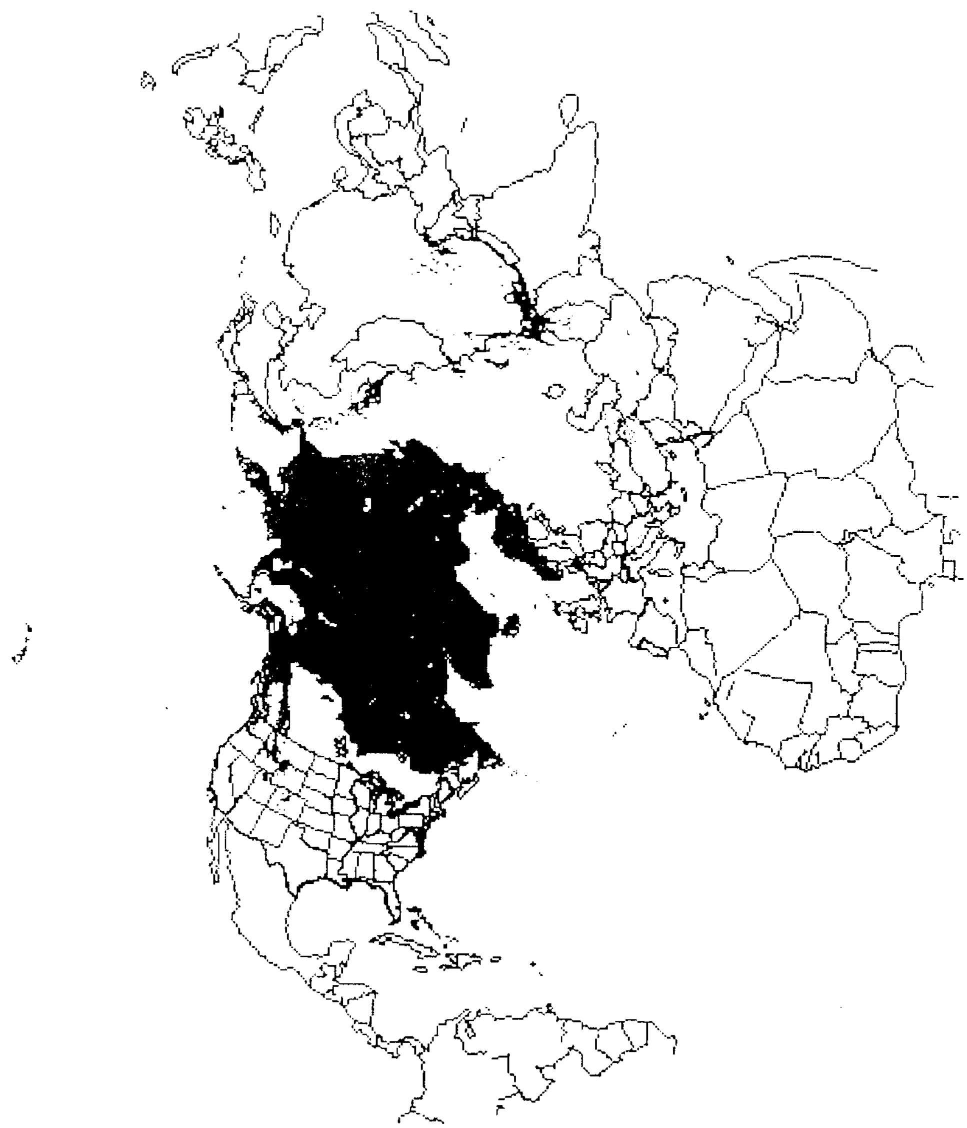

Figure 6. NH snow map for 15 May 1997

VALIDATION PLAN

NESDIS, NWS and Rutgers University will work together in the development of a detailed validation plan, the selection of validation data including the new and old operational products, the construction of a temporally and spatially coincident database of these data and products and the application of quality control procedures to all data sets collected. Other data will be collected as they become available from various data centres, such as US cooperative station data from the NCDC. Although point measurements from station data will provide groundtruth, the map quality assessment will be made from the inter-comparison of multiple sources of data. All validation data and the snow maps will be digitized to facilitate analysis using geographical information system (GIS) methodologies. The GIS will permit the manipulation, analysis and output of the data sets in any desired spatial or temporal framework (Mather, 1987; Star and Estes, 1990; Wilkie and Finn, 1996).

The IMS validation database now being designed will include, at a minimum, the following data sets for a given day: IMS snow maps, USAF snow product for the same day, automated SSM/I snow maps, selected SSM/I brightness temperature maps, imagery from AVHRR, GOES, GMS and METEOSAT used in the IMS, station data (snow cover, snow depth, maximum/minimum temperature, etc.) for the same day, ancillary data (vegetation, land cover, elevation, etc.) and the NESDIS weekly product produced for that day. GIS methodologies will be used to convert each data product to a 1° latitude by 1° longitude resolution on a daily time frame for initial analysis (with the exception of the weekly NESDIS snow Validation rules and a protocol for the intercomparison will be established by NESDIS, NCEP, Rutgers. The GIS will permit the application of a rigorous statistical analysis. Results may then be any preferred map projection.

The best and most reliable groundtruth data for validation are station reports. Under normal operating conditions the analysts will have limited time to use the detailed station data, such as that from US and Canadian cooperative sites, when drawing the maps. The station data, both snow cover and snow depth, will be saved with the coincident satellite snow cover product in the map cell that contains the ground station. Other coincident data will be saved as well. The data will be made available to the scientific community for study. This coincident data set will be used for statistical analysis, for diagnostics of product accuracy, for improving the automated satellite snow cover algorithms and for developing improved or new mw snow depth algorithms.

After the validation data is collected by NOAA/NESDIS, the validation and intercomparisons will be conducted mostly at Rutgers University. A rigorous statistical analysis comparing the weekly and IMS products will be performed. The Rutgers analysts will provide objective third party validation and suggestions for improvements to the IMS. Biases between the old and new maps will be described and documented. The data will be studied to determine if the differences were characteristic of season, of snow condition (melting, refrozen, etc.), time of observation, data source, land cover type, elevation and other land characteristics that may influence the products. Similar statistics will be generated comparing the weekly and IMS products to the coincident station report data set described above. Such a data set will be smaller because of the spatially limited station observations. It will have snow depth, however, so that differences between the old and the IMS products can be compared as a function of snow depth. This comparison may help in improving the SSM/I snow cover and snow-depth retrieval algorithms. Analyses will also be done to determine the effects of land use, terrain and vegetation type and density on the retrieved snow cover and snow depth.

SUMMARY

NOAA/NESDIS satellite-derived snow cover maps are important in monitoring the Earth's climate. Weekly maps are deficient because of poor temporal coverage and the use of visible imagery limited by cloud cover and night fall. IMS will provide meteorologists with the use of multisensor imagery and data in the production of daily NH snow maps. Planned research will validate the change from weekly to daily snow maps including the use of mw imagery.

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