THE INTERACTIVE MULTISENSOR SNOW AND ICE MAPPING SYSTEM

Bruce H. Ramsay[1]

ABSTRACT

The Interactive Multisensor Snow and Ice Mapping System (IMS) was developed to give snow and ice analysts the tools, on one platform, to visually inspect 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 89x89 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, timely product.

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 (mv) 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 (Ramsay, 1995). 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).

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 (Robinson, et al., 1993; Matson and Parmenter-Holt, 1985). This 30 year data set is sufficiently important that the NOAA Climate and Global Change program funded a reworking of the 1966-72 portion of the record by analysts at Rutgers University to bring it into better consistency with the later years of the product. They are being redone to correct mapping inconsistencies between the early years and those since 1972. With the completion of the 1966-72 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's 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's also important that a comparison between the two snow maps be undertaken

[1]Senior Land Scientist, NOAA/NESDIS (E/SP22), Room 510, NOAA Science Center, 5200 Auth Rd., Camp Springs, MD 20746, e-mail:bramsay@nesdis.noaa.gov

Paper presented Western Snow Conference 1997, Banff, Alberta, Canada

to determine what differences occur between the products and why and under what circumstances the discrepancies exist. 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 transition between the two products as seamless as possible and ensure the integrity of the long-term record.

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

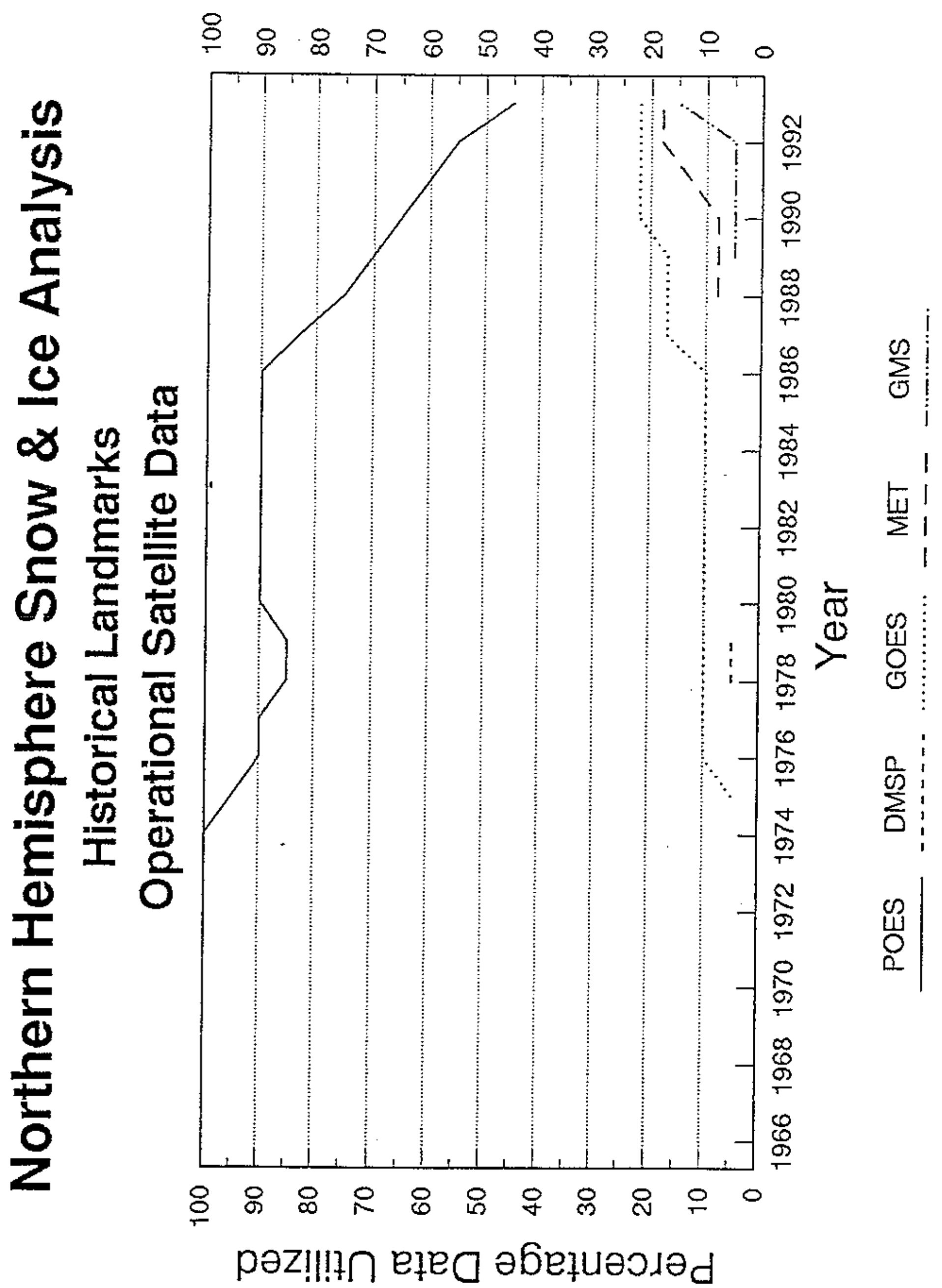
THE WEEKLY SNOW MAP

Snow and ice charting currently performed by NESDIS is done to produce timely, high quality analyses depicting NH snow and ice cover. In contrast to low resolution hemispheric snow maps (190 kilometers (km) per pixel), daily high resolution river basin snow maps (1 km per pixel) used in local U.S. forecasts are produced at the NWS National Operational Hydrologic Remote Sensing Center (NOHRSC, 1996). The primary data source for NH snow mapping is Advanced Very High Resolution Radiometer (AVHRR) visible imagery acquired from NOAA Polar Operational Environmental Satellites (POES). Secondary data sources include geostationary imagery, U.S. Air Force snow analyses, National Ice Center (NIC) sea ice edge charts, and surface observations (NIC, 1996). Figure 1 illustrates the use NESDIS snow analysts have made of POES, starting in 1966, and the increasing use of U.S. Geostationary Operational Environmental Satellites (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 the manual inspection of imagery and graphics products, online time sequenced imagery video loops, and the previous week's analysis (SAB, 1997).

Chart quality is predicated on the availability of clear sky visible imagery and the meteorologist's experience. After all snow and ice boundaries have been identified, the analyst prepares a finalized polar stereographic snow map by transferring the boundary lines to a paper chart as shown in Figure 3. An electronic version of the snow map is digitized for 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, Climate Prediction Center (CPC), Department of Agriculture, Universities, Foreign Governments, and other customers (SAB, 1997).

THE NEED FOR A DAILY SNOW PRODUCT

A daily snowcover product has been a high priority at NOAA since 1993 when it became clear that errors in the snowcover initialization of the NCEP numerical models were causing forecast errors (Petersen and Hoke, 1989; Mitchell, et al., 1993). NCEP has long used the NESDIS weekly snow maps as initialization data. However, large errors in the near surface temperature forecasts continue due to the infrequency of the weekly product. It is not possible to increase the frequency of the current product because of cloud obscuration of the snow/no snow boundary. The weekly snow maps were replaced with U.S. Air Force daily snow maps which improved the results to some extent. However, NCEP would prefer the use of GOES data in daily snow map



Northern Hemisphere Snow & Ice Analysis
Historical Landmarks
Operational Satellite Data
Percentage Data Utilized
100
90
80
70
60
50
40
30
20
10
0
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
Year
POES
DMSP
GOES
MET
GMS

Figure 1

Global Satellite Coverage Used In Snow/Ice Analysis

Current Status (effective February '94)

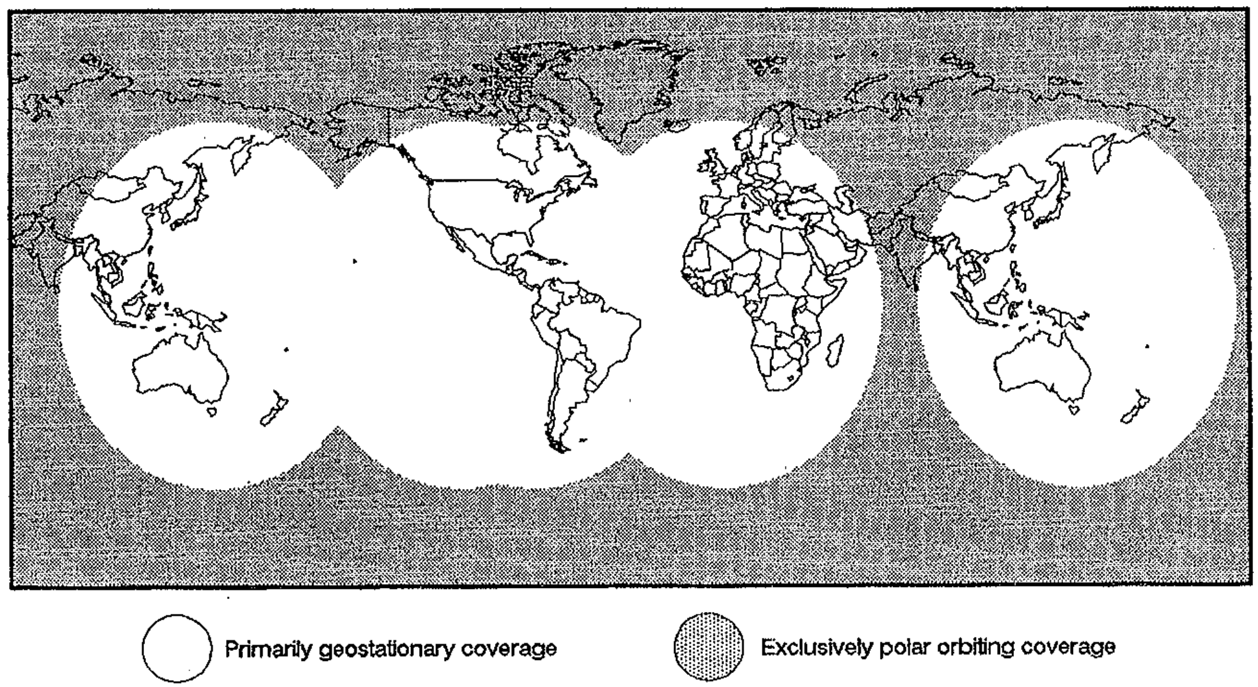
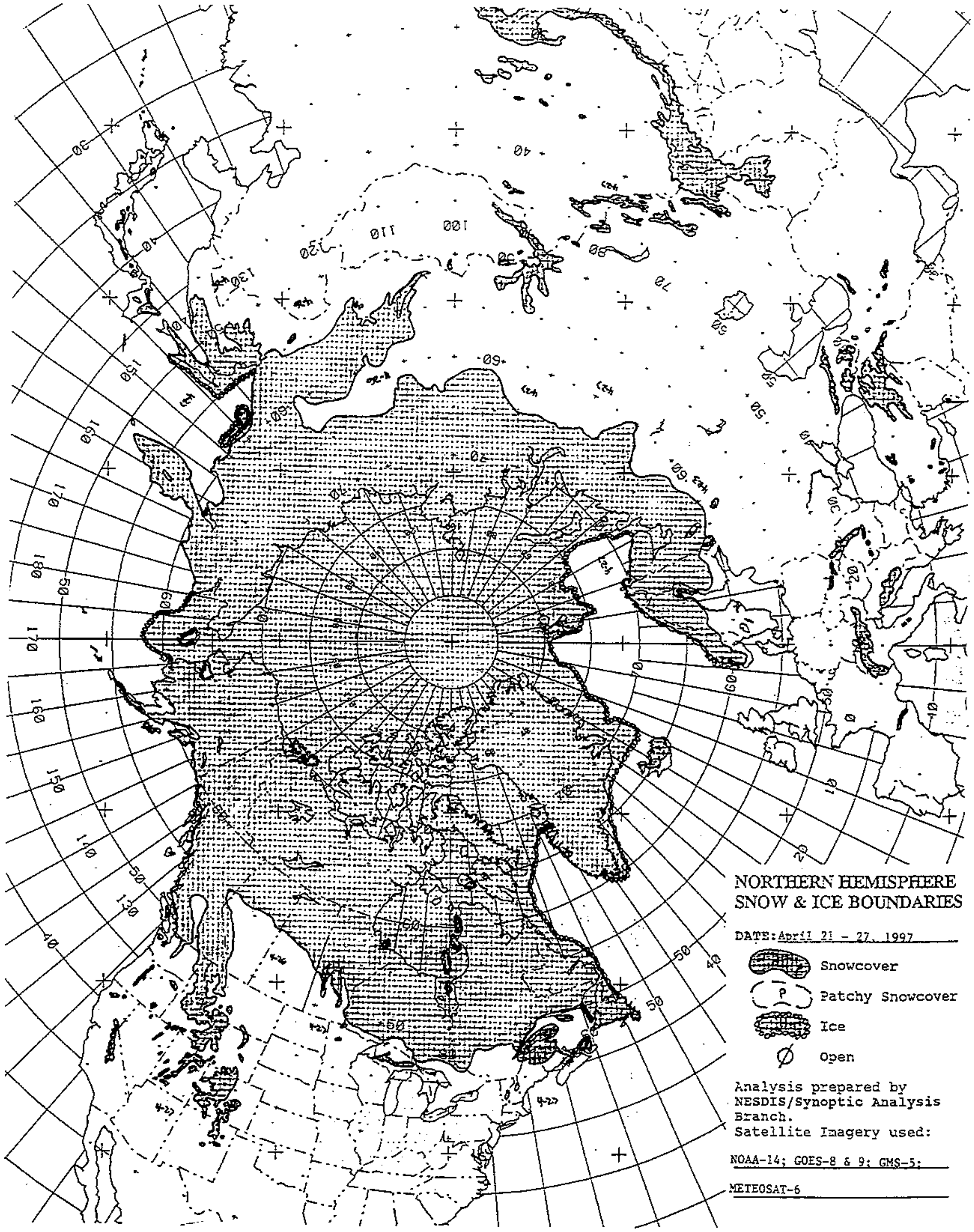


Figure 2



NORTHERN HEMISPHERE SNOW & ICE BOUNDARIES
DATE: April 21 - 27, 1997
Snowcover
Patchy Snowcover
Ice
Open
Analysis prepared by NESDIS/Synoptic Analysis Branch.
Satellite Imagery used:
NOAA-14; GOES-8 & 9; GMS-5;
METEOSAT-6

Figure 3

production. This time sequenced imagery is used to discriminate snow from clouds (SAB, 1997; GSBS, 1996).

The first attempt to improve model input was to use the SSM/I to produce a fully automated daily snow map with the all weather capability of mv 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 mv-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.[2] So in 1995 NOAA began the 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, 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.

PROJECT DESCRIPTION

The IMS is a UNIX workstation application that provides the analyst 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 visually inspect 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, save it, and then 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).

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), U.S. Air Force (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 1024x1024 matrix, 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 program. 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's 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 (NCDC, 1996; NSIDC, 1996). Prior to product validation, the IMS snow map will also be reformatted to gridded binary (GRIB) for use by NCEP.

Figure 5 is a screen print, in black and white, of the IMS graphical user interface and an IMS NH snow map zoomed to four times the normal display over North America. The online system uses a color display with ice colored

---

[2]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 and 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.

National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Interactive Multisensor Snow and Ice Mapping System Phase-I Processing Flow Diagram

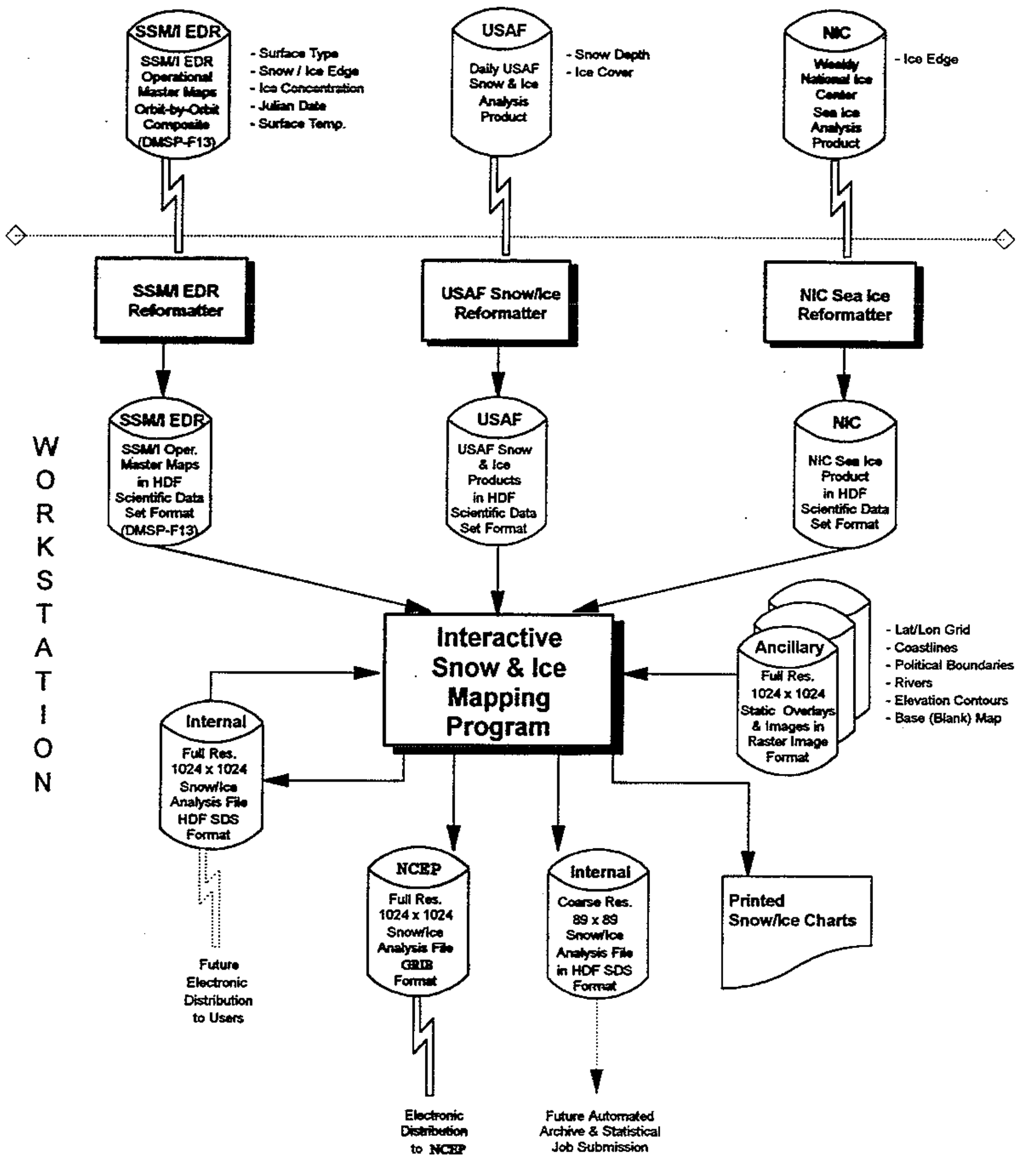


Figure 4

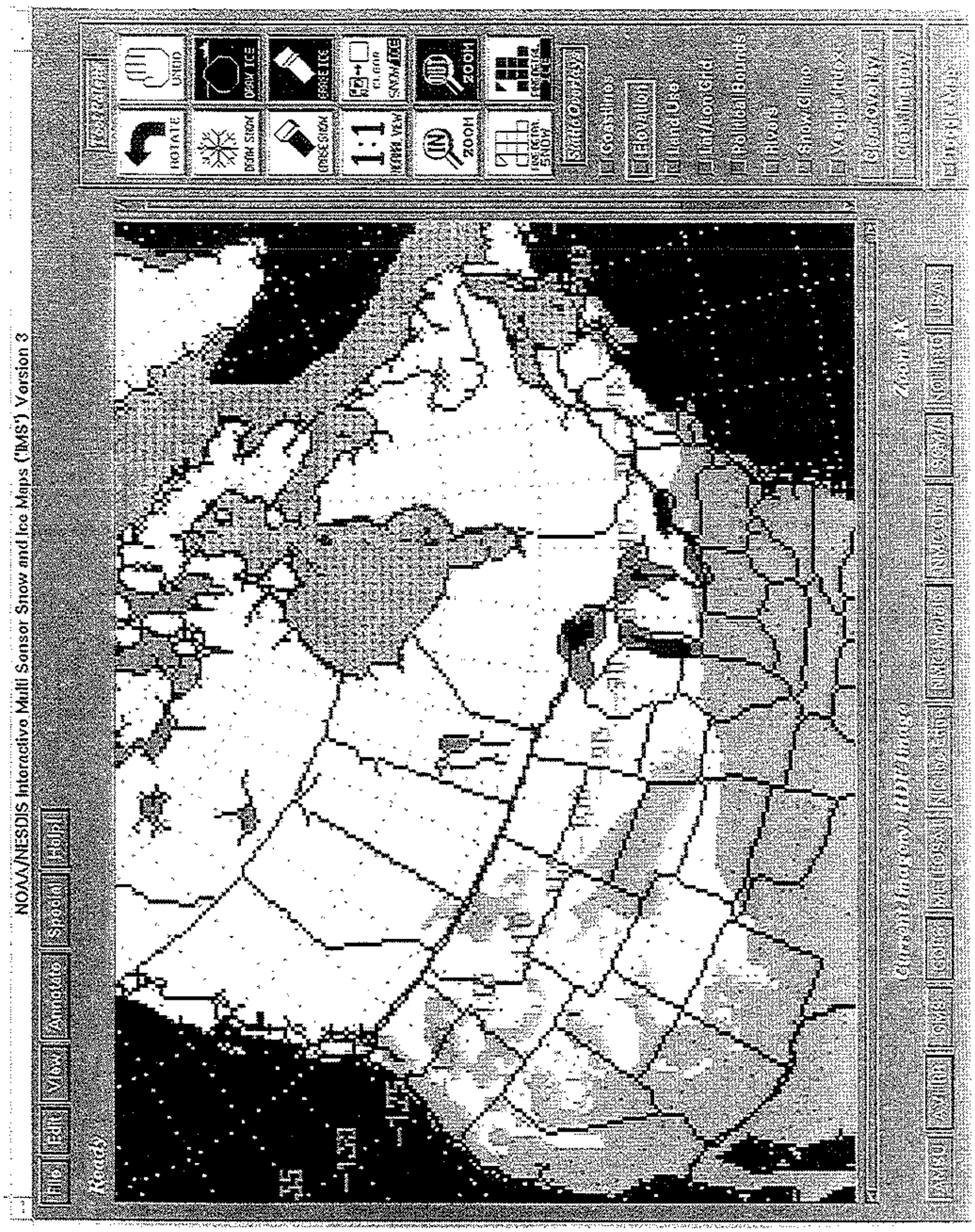

NOAA/NESDIS Interactive Multi Sensor Snow and Ice Maps ('IMS') Version 3
File
Edit
View
Annotate
Special
Help
Ready
ROTATE
UNDO
Coastline
Elevation
Land Use
Lat/Lon Grid
Political Bounds
Rivers

Figure 5

yellow (intermediately shaded/stippled in this reproduction), snow in white, land in brown, and water in blue. Pulldown menus are available in the upper 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 May 15, 1997 (from a GIF image) is shown in Figure 6.

VALIDATION PLAN

NESDIS, NWS, and Rutgers University will work together in the selection of validation data, construction of a time and spatially coincident data base of validation data, the new and old operational 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 centers (e.g., U.S. cooperative station data from the National Climate Data Center (NCDC, 1996)). All validation data and the snow maps will be digitized to facilitate analysis using geographic information system (GIS) methodologies. The GIS will permit the manipulation, analysis and output of the data sets in any desired spatial or temporal frame work (Wilkie and Finn, 1996; Star and Estes, 1990; Mather, 1987).

NOAA has scheduled the launch of NOAA-K for 1998, the first of a series of polar orbiters that will carry new instruments. NESDIS will collect a variety of ground-based data to calibrate and validate retrieval algorithms for the NOAA-KLM Advanced Microwave Sounding Unit (AMSU). One of the new AMSU products is automated snowcover so the data collection will include snow observations at surface stations. The IMS validation data set now being designed will make use of the ongoing validation effort by the NOAA-KLM project (Ferraro and Tarpley, 1997). The validation data set will include, at a minimum, the following data sets for a given day: IMS snow maps, U.S. Air Force snow product for the same day, automated AMSU and SSM/I snow maps, selected SSM/I and AMSU 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 or higher resolution on a daily time frame for initial analysis (with the exception of the weekly NESDIS snow product). Validation rules and a protocol for the intercomparison will be established by NESDIS, NCEP, CPC, and Rutgers. The GIS will permit the application of a rigorous statistical analysis. Results may then be output in any preferred map projection.

The best and most reliable ground truth 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 U.S. and Canadian cooperative sites, when drawing the maps (Rutgers, 1996). The station data, both snowcover and snowdepth, will be saved with the coincident satellite snowcover 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 snowcover algorithms and for developing improved or new mv snowdepth algorithms.

The post-data collection effort will concentrate on the validation and intercomparisons and 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

National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

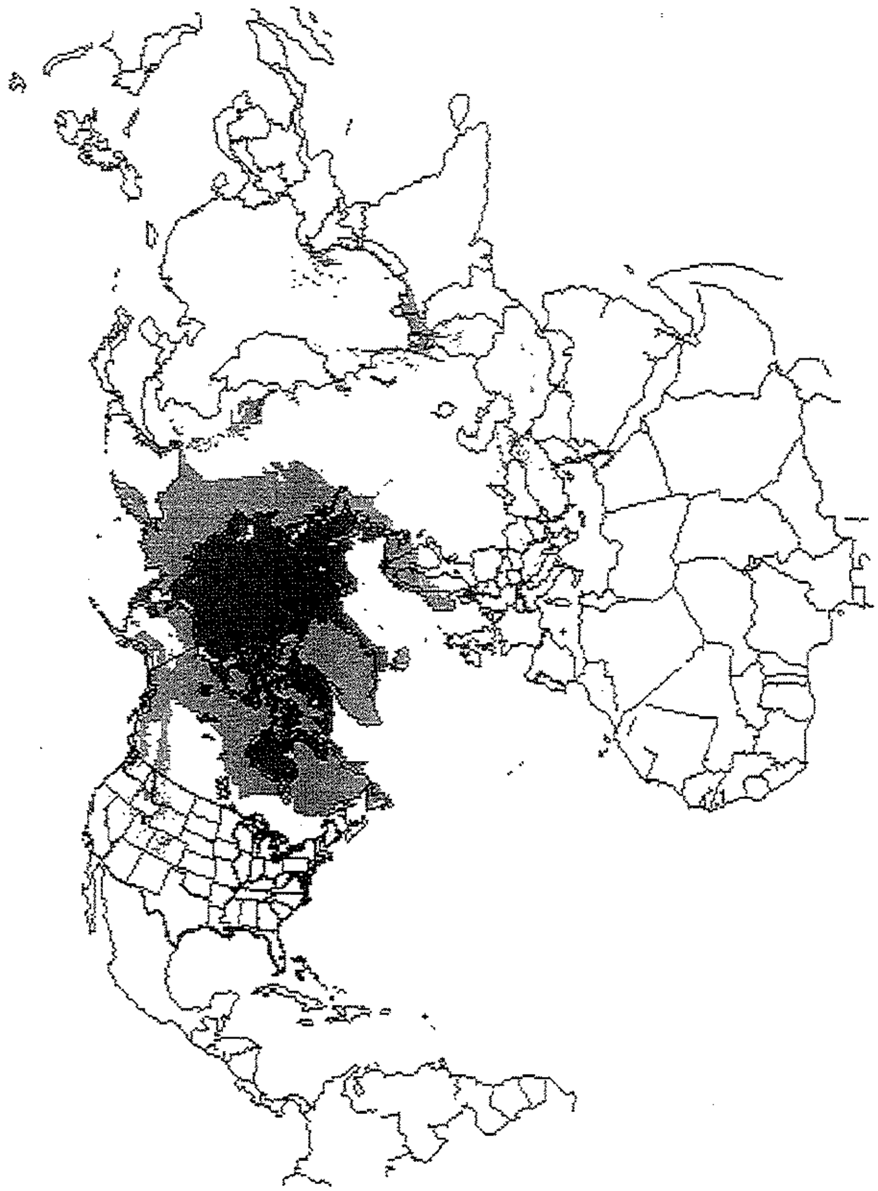


Figure 6

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 snowdepth, however, so that differences between the old and the IMS products can be compared as a function of snowdepth. This comparison will help in improving the SSM/I and AMSU snowcover and snowdepth retrieval algorithms. Analyses will also be done to determine the effects of land use, terrain, and vegetation type and density on the retrieved snowcover and snowdepth.

SUMMARY

NOAA/NESDIS satellite-derived snowcover maps are important in monitoring the Earth's climate. Weekly maps are deficient due to poor temporal coverage and the use of visible imagery limited by cloud cover and night fall. IMS will provide daily maps and the use of all weather mv data. Detection of snowcover in forested areas using mv data is sometimes difficult. This research will validate the change from weekly to daily snow maps including the use of mv imagery. It may also improve the accuracy of mv data in mapping snowcover in forested and other areas.

ACKNOWLEDGEMENTS

Funding for this project is provided by NOAA's Office of Global Programs, NESDIS, and the Office of System Development's Polar Program Office. The author thanks Dr. Dan Tarpley, Office of Research and Applications, NOAA/NESDIS, and Dr. Dave Robinson, Professor and Chairman, Department of Geography, Rutgers University, for their invaluable contributions to this project including the formulation of the validation plan. Thanks also to Dr. Ken Mitchell, NOAA/NWS, and Tom Baldwin, NOAA/NESDIS for their long term support.

REFERENCES

Ferraro, R.R. and Tarpley, J.D. Microwave Surface and Precipitation Products System (MSPPS) Validation Requirements: A "Practical" Approach. NOAA/NESDIS/Office of Research and Applications, 21 February 1997, V1.0.

Ferraro, R.R., Weng, F., Grody, N.C., and Basist, A., 1996. *An eight-year (1987-1994) time series of rainfall, clouds, water vapor, snow cover, and sea ice derived from SSM/I measurements*. Bulletin of the AMS, 77:5, May, 891-905.

Foster, J.L., and Chang, A.T.C., 1993. *Snow cover*. In R.J. Gurney, J.L. Foster, and C.L. Parkinson, eds., Atlas of Satellite Observations Related to Global Change, 361-370. London: Cambridge University Press.

Grody, N.C., 1991. *Classification of Snow Cover and Precipitation Using the Special Sensor Microwave Imager*. J. Geophys. Res., 96, 7423-7435.

Grody, N.C. and A. N. Basist, 1996. *Global Identification of Snowcover Using SSM/I Measurements*. IEEE Transactions on Geoscience and Remote Sensing, 34, 237-249.

Hall, D.K., Foster, J.L., Chang, A.T.C., Brown, K.S. and Riggs, G.A. *Mapping Snow Cover During the BOREAS Winter Experiment*. Proceedings of the Fifty-second Annual Eastern Snow Conference, 7-8 June 1995, Toronto, Ontario, Canada, 1-10.

Lo, C.P., 1986. Applied Remote Sensing. New York: Longman Inc.

Mather, P.M., 1987. Computer Processing of Remotely-Sensed Images: An Introduction. New York: John Wiley & Sons.

Matson, M. and Parmenter-Holt, F., 1985. Hydrologic and Land Sciences Applications of NOAA Polar-Orbiting Satellite Data. U.S. Department of

Commerce, NOAA.

Matson, M., C. F. Ropelewski, M. S. Varnadore, 1986. An Atlas of Satellite-Derived Northern Hemispheric Snow Cover Frequency. U.S. Department of Commerce, NOAA.

Matson, M. and D. R. Wiesnet, 1981. *New Database for Climate Studies*. Nature, 289, 451-456.

Mitchell, K.E., T.L. Black, F. Mesinger, and N.C. Grody, 1992. *Impact of SSM/I-based Snow/Ice Analyses in the NMC ETA Model*. 6th Conference on Satellite Meteorology and Oceanography. Atlanta, Georgia, 6-10 January 1992, American Meteorological Society, Paper 4.4.

Mitchell, K.E., G.J. DiMego, and T.L. Black, 1993. *Case Studies of the Impact of Improved Snow Cover and Sea Ice on Wintertime Forecasts of NMC's Regional NGM and ETA Models*. 13th Conference on Weather Analysis and Forecasting. Vienna, Virginia, 2-6 August 1993, American Meteorological Society, Paper 10.3.

Petersen, R.A., J.E. Hoke, 1989. *The Effect of Snow Cover on the Regional Analysis and Forecast System (RAFS) Low-Level Forecasts*. Weather and Forecasting, 4, June 1989, 253-257.

Ramsay, B.H. *Interactive Multisensor Snow and Ice Mapping System*, Proceedings of 1995 First Moderate Resolution Imaging Spectroradiometer MODIS Snow and Ice Workshop. Greenbelt, MD: National Aeronautics and Space Administration Conference Publication 3318, 1995.

Robinson, D.A., K.F. Dewey, R.R. Heim, Jr., 1993. *Global Snow Cover Monitoring: An Update*. Bull. Amer. Meteor. Soc., 74, 1689-1696.

SAB, 1996. Northern Hemisphere Snow and Ice Mapping Standard Operating Procedures. U.S. Department of Commerce, NOAA, Satellite Analysis Branch.

Star, J. and Estes, J., 1990. Geographic Information Systems: An Introduction. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Wilkie, D.S. and Finn, J.T., 1996. Remote Sensing for Natural Resources Monitoring: A Guide for First-Time Users. New York: Columbia University Press.

Internet and FTP Sites

GSBS, 1996. Geostationary Browse Server. Camp Springs, MD: NOAA/NESDIS, 29 November 1996: **http://goeshp.wwb.noaa.gov**

NCDC, 1996. National Climate Data Center. Asheville, NC: NOAA/NESDIS, 31 October 1996: **ftp://ftp.ncdc.noaa.gov/pub/data/inventories/COMPLETE-GUIDE.TXT**

NIC, 1996. National/Naval Ice Center. Suitland, MD: NAVY/NOAA/Coast Guard, 26 November 1996: **http://www.natice.noaa.gov/**

NOHRSC, 1996. National Operational Hydrologic Remote Sensing Center Operational Products. Chanhassen, MN: NOAA/NWS, 30 November 1996: **http://www.nohrsc.nws.gov/html/1996.html**

NSIDC, 1996. National Snow and Ice Data Center, Distributed Active Archive Center. Boulder, CO: University of Colorado, 30 November 1996: **http://www-nsidc.colorado.edu/NASA/GUIDE**

Rutgers, 1996. NJ State Climatologist. New Brunswick, NJ: Rutgers University, 30 November 1996: **http://climate.rutgers.edu/stateclim**