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GENERATION OF LEVEL 3 SMMR AND SSM/I BRIGHTNESS TEMPERATURES FOR THE PERIOD 1978-1999

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Summary

The NOAA/NASA Pathfinder Program was initially designed to assure that certain key remote sensing data sets of particular significance to global change research were scientifically validated, consistently processed and made readily available to the research community at minimal cost. Through this Program the National Snow and Ice Data Center (NSIDC), University of Colorado has successfully processed, archived and distributed the SMMR and SSM/I Level 3 (EASE-Grid format) Pathfinder data sets for the period 1978 to 1999. These data are routinely distributed to approximately 150 researchers through various media including CD-ROM, 8mm tape, ftp and the EOS Information Management System (IMS). At NSIDC these data are currently being applied in the development and validation of algorithms to derive snow water equivalent (NASA NAG5-6636), the mapping of frozen ground and the detection of the onset of melt over ice sheets, sea ice and snow cover. The EASE-Grid format, developed at NSIDC in conjunction with the SMMR-SSM/I Pathfinder project has also been applied to AVHRR and TOVS Pathfinder data, as well as ancillary data such as digital elevation, land cover classification and several in situ data sets. EASE-Grid will also be used for all land products derived from the NASA EOS AMSR-E instrument.

Background

The NOAA/NASA Pathfinder Program was initiated in 1993 to facilitate the application of currently archived satellite remote sensing data for global change research. The primary goals of the program were to assure that these data and associated products were 1) scientifically validated and of research quality, 2) placed in a readily accessible working data archive, and 3) were available long-term at a minimal cost. It was also noted that Pathfinder principal investigators should maintain close contact with users in order to provide products of the highest quality. Ultimately it would be the level of acceptance and use of these products by the research community that would determine the success of the work. With regard to the NSIDC SMMR and SSM/I Level 3 Pathfinder, we feel that these specific goals have been successfully achieved. For example, the development of the satellite swath to earth grid interpolation scheme used for the Level 3 SSM/I brightness temperature products was developed in close collaboration with key members of the remote sensing science community and the current data set is being routinely distributed to more than 150 researchers at no cost through various media including CD-ROM, 8mm tape, ftp and the EOS Information Management System (IMS), (see Appendix 1, A through D for details).

The availability of a standard gridding scheme is a fundamental requirement for systematic time series studies and the direct digital comparison of different remote sensing algorithms, as well as the validation of algorithms, through comparison with surface measurements and other ancillary data sets which have been processed into a common grid. To this end, the NSIDC has developed the Equal Area Scalable Earth Grid (EASE-Grid). The NOAA/NASA Pathfinder Program Level 3

EASE-Grid passive microwave brightness temperatures were the first remote sensing products to benefit from EASE-Grid. The complete time series includes both the SMMR(Scanning Multichannel Microwave Radiometer) data (1978-1987) and the SSM/I (Special Sensor Microwave Imager, 1987 to 1999), thus providing a 22 year time series of satellite passive microwave data in a common format (Armstrong and Brodzik, 1997). The initial development of the EASE-Grid resulted from the recommendations of the NASA SSM/I Products Working Team (SPWT). The EASE-Grid is available in two equal area projections, full global cylindrical and azimuthal for full Northern or Southern Hemispheres (Armstrong and Brodzik, 1995).

The EASE-Grid provides a flexible earth grid format that is between swath data (e.g. one file per orbit) and an averaged (time and space) daily or multi-day product, with its associated reduction in precision. For the SSM/I Pathfinder brightness temperatures, the interpolation scheme used to translate from swath data to the earth grid is considered optimal. It is based on weighting coefficients derived from the actual instrument antenna pattern. In general, the particular method used to interpolate from swath data to the fixed earth grid is unique to each sensor and application, while the common format (the equal-area projections combined with an infinite number of possible grid definitions) provides a versatile framework in which to work. EASE-Grid data users are finding that visualization, intercomparison and analysis operations are greatly simplified. Finally, it should be noted that while the NSIDC EASE-Grid SMMR and SSM/I Pathfinder project has been included in the category of "Polar Pathfinders", it is, in fact, global in coverage and the primary product, earth gridded brightness temperatures, is designed to support not only the study of snow and ice but all aspects of earth system science.

In addition to the passive microwave data, the EASE-Grid is also being used for other products developed for the NASA Polar Pathfinder Program such as AVHRR and TOVS (Schweiger et al 1999), as well as the following environmental data sets being distributed by NSIDC: Northern Hemisphere Weekly Combined Snow Cover and Sea Ice Extent ; Arctic and Antarctic Research Institute (AARI) 10-Day Arctic Ocean Sea Ice Observations; Arctic Water Vapor Characteristics from Rawinsondes; IGBP Global Land Cover Classification; GLOBE land elevation data set; Circumpolar Active-layer Permafrost System (CAPS) map; CRREL Global Seasonal Snow Classification; and the NSIDC Near Real-TIme Ice and Snow Extent (NISE) product. The EASE-Grid will also be used for snow and ice products derived from EOS MODIS and for the land products from AMSR-E which include snow extent and water equivalent, surface soil moisture and temperature.

An example of the application of the EASE-Grid passive microwave time series is shown in Figures 1 and 2. Figure 1 shows a comparison during the full 22 year time series of Northern Hemisphere snow covered area derived from SMMR and SSM/I data with the NOAA snow covered area derived from visible-band satellite data. Figure 2 shows the comparison of the temporal trends in snow extent as provided by these two data sets (Armstrong and Brodzik, 1999).

Status of Level 3 SMMR and SSM/I Pathfinder Data Processing and Distribution

SMMR

The basic approach which was undertaken with the Level 3 SMMR Pathfinder data was that it should be as compatible with the SSM/I Level 3 data as possible. To this end the grids are identical, the selection of overlapping orbits is identical, and the resampling (interpolation) function

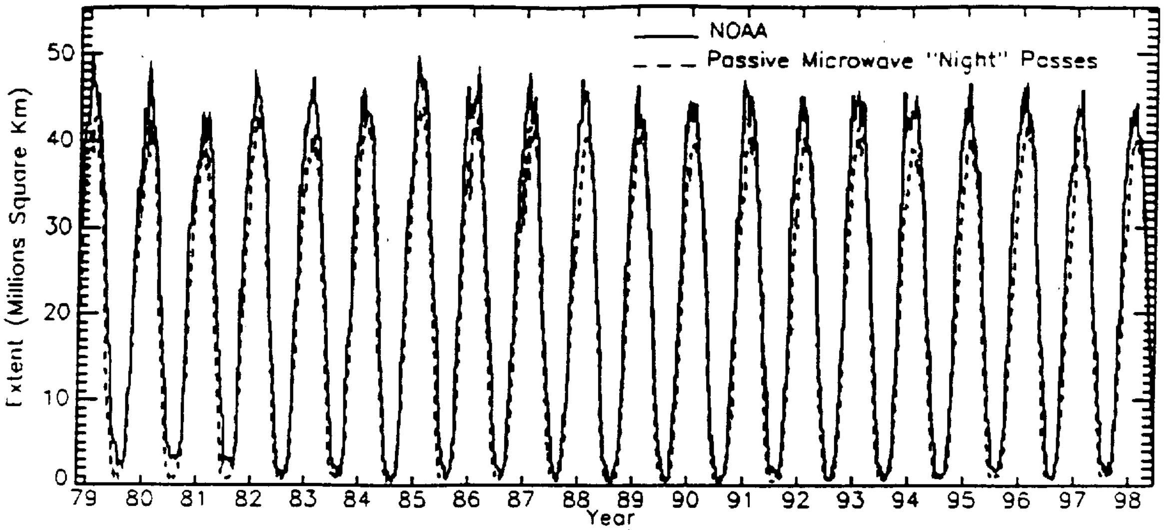

Figure 1 Northern Hemisphere snow-covered area (excludes Greenland) derived from visible (NOAA) and passive microwave (SMMR and SSM/I) satellite data (1979-1998).

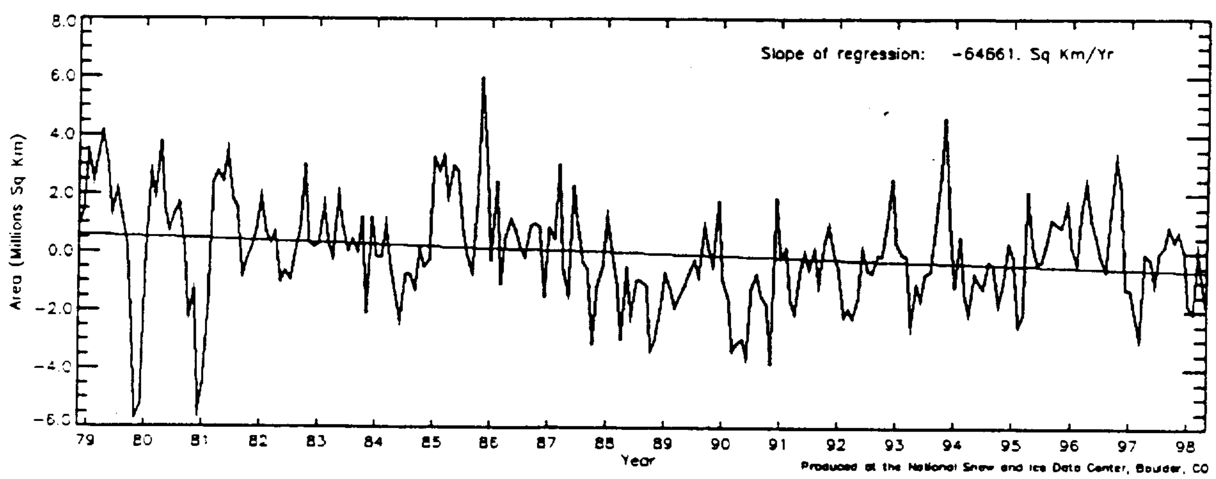

Figure 2a Visible-derived (NOAA) snow-covered area (x 10^6 km^2) departures from monthly means for the Northern Hemisphere, 1979-1998.

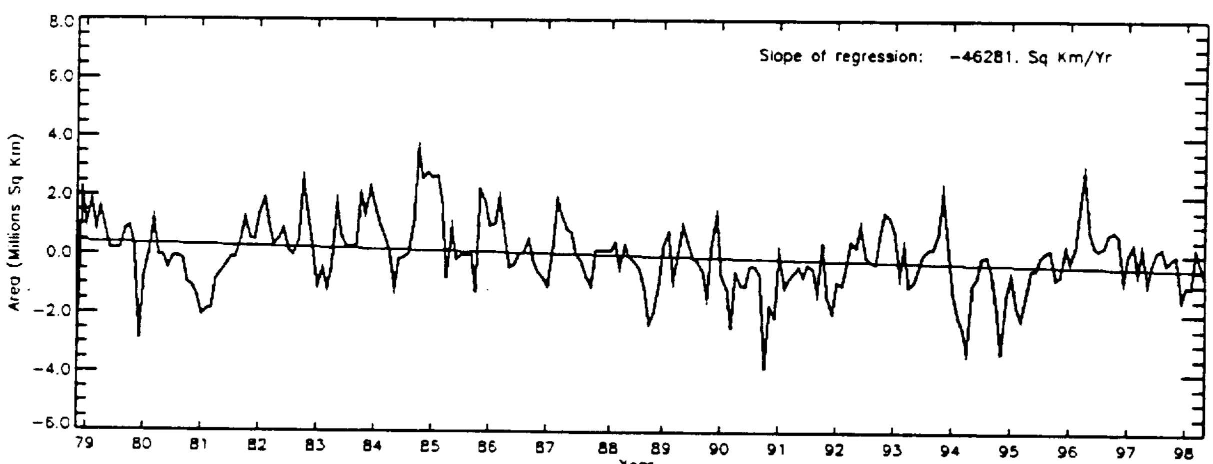

Figure 2b. Passive microwave-derived (SMMR and SSM/I) snow-covered area (x 10^6 km^2) departures from monthly means for the Northern Hemisphere, 1979-1998.

is similar, but cannot be identical. This is due to the fact that the antenna pattern information required for the Backus-Gilbert interpolation scheme applied to the SSM/I data is not available for the relocated samples in the SMMR Pathfinder data stream. Because of this fact, the processing time requirements have been minimal for SMMR as compared to SSM/I. One ascending and one descending SMMR file per day (when data are available) are produced by selecting those passes which are closest to noon and midnight in high latitude locations where there is more than one ascending or descending pass per day (as is done with the SSM/I). These data are gridded to the 25 km EASE-Grid.

We completed the assessment of several interpolation techniques in direct collaboration with E. Njoku (JPL) and A. Chang (GSFC) and they agreed with our assessment that inverse distance squared was the best of the techniques tested. A full detailed report on the EASE-Grid SMMR processing technique can be found in "Intercomparison of Resampling Methods for SMMR Pathfinder in EASE-Grid Format" at http://www-nsidc.colorado.edu/PROJECTS/SMMRPF/report/index.html

Processing of the Pathfinder EASE-Grid SMMR TB time series (1978-1987) has been completed. Several minor problems were detected during the QC following the processing, most of which have been addressed via comments in the documentation. However, one problem, occasional mislocated orbits, required re-processing of about 1.5 years of data. This task was completed in September of 1999. Prior to the general distribution of the final data set, a prototype version is being distributed to several key remote sensing scientists. The final testing of this data set (beta version) will be accomplished through actual application of the brightness temperature data by these scientists in conjunction with their respective research activities.

SSM/I

The processing of SSM/I brightness temperatures into the EASE-Grid has been completed through June 1999. In our original 1995 Pathfinder proposal we stated that we would be processing 1998 data in 1998 which required that we catch up on the nearly ten year back-log of orbital data. Because of the numerically intensive processing requirements associated with the interpolation scheme, this was a rather ambitious goal. It was only achieved through the application of innovative computer coding techniques and processing methodologies. Thanks to an energetic, creative and ambitious team, and thanks to effective collaboration and temporary sharing of certain NSIDC DAAC hardware, we have accomplished this goal and are now processing 1999 data. For the first time since initial launch in 1987, gridded data with full global coverage are available to users in near real-time from NSIDC. It is anticipated that at least one current generation SSM/I sensor will continue to provide data through the year 2000 and, as detailed in a separate NASA proposal, we plan to continue to process SSM/I orbital data into the EASE-Grid at least until there is sufficient overlap with the EOS AMSR-E instrument to assure adequate cross-calibration.

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APPENDIX 1.

A. Polar Pathfinder Coordination

The Polar Pathfinder PIs agreed on the importance of a common gridding scheme and selected the EASE-Grid as the standard grid and projection. The EASE-Grid is composed of two fundamental parts: 1) a grid and projection scheme and, 2) a method to interpolate SSM/I data from swath to earth gridded coordinates. The grid and projection scheme are independent of the satellite sensor or data type such that the fundamental grid and projection format of the EASE-Grid provide the basis for a common gridding scheme. For the Polar Pathfinder passive microwave SMMR and SSM/I brightness temperatures the cell size for all channels is 25 x 25 km (with the additional 12.5 x 12.5 km cell size for the 85 GHz channel). For the AVHRR products, the cell size is 1.25 x 1.25, 5 x 5, and 25 x 25 and for TOVS, 100 x 100 km. A set of all Polar Pathfinder variables has been produced in the common 100 x 100 grid (Schweiger et al. 1999).

B. Enhancement of Processing Backus-Gilbert Interpolation

Although the Backus-Gilbert interpolation scheme (Poe, 1990) is considered to be the optimum method, it is highly machine-time intensive. Following the processing of data for the Pathfinder prototype test period, called the Pathfinder Benchmark Period (1 August 1987 to 30 November 1988) it was noted that at January 1996 processing rates the remaining period of SSM/I data from 1989 to 1998 could not have been processed within the time period of the current award using the Backus-Gilbert method. Therefore, certain reviewers from within and outside of NSIDC questioned the validity of this approach and the associated time requirements and suggested that less rigorous interpolation schemes be explored. On January 18 1996, the NSIDC/EASE-Grid development staff met with Barry Goodison (Atmospheric Environment Service, Canada) and Anthony England (University of Michigan) to discuss the continued use of the Backus-Gilbert interpolation scheme. Both Goodison and England took that position that there was no scientific justification for changing the interpolation scheme and strongly urged that we continue using the same scheme and that we seek another solution to the processing rate problem. The scientific programmers involved in this project reviewed the existing code and made modifications which increased the processing speed by 10 percent. In addition, a new procedure was put in place whereby all three earth projections for the same month were processed in sequence on the same work station. This approach increased I/O efficiency with respect to interaction with the NSIDC mass storage devices where the orbital data are stored. In addition we acquired a fourth processor to support this project. The net effect of the above enhancements was that the full SMMR and SSM/I time series could be processed during the period of this Pathfinder award.

C. EASE-Grid Software Ported to the University of Michigan

As a part of our collaborative effort with Dr. Anthony England we agreed to provide access to EASE-Grid processing software to graduate students at the University of Michigan. We arranged to port the EASE-Grid processing software to their DEC Alpha work station which involved moving and rebuilding all source code from our local standard SGI development and processing environment to the DEC environment and included typical changes required when software is ported between machines with difference architectures. Such a task is not trivial and required approximately 120 hours of senior scientific programmer time. The benefit of this effort is twofold. First the students at the University of Michigan are able to work with EASE-Grid in their particular environment and without need for additional detailed support from NSIDC. Second, such an exercise provides one of the best opportunities for overall code testing and quality control through the in depth use of the code by personnel not involved in the original program development. The final test was to produce brightness temperature images for the same day using code on the two different machines and then to compare the two by way of digital image subtraction. The result was successful as the files were essential identical.

D. History of the EASE-Grid Interpolation Scheme

In 1989 NASA Headquarters requested guidance from the scientific community on how to best construct geophysical products over land surfaces (specifically snow cover, rainfall, and vegetation) from SSM/I data. For this purpose a science working group was formed known as the SSM/I Products Working Team with a particular focus on surface types (snow cover, vegetation and soils) not already covered (in 1989) by other working groups. In addition, the SPWT was asked to recommend specific data formats for earth-gridded SSM/I data distributed by the National Snow and Ice Data Center (NSIDC). The SPWT noted that fundamental to advancing global change research is the availability of a standard reference system for direct digital comparison and interuse of remote sensing data sets on varying spatial and temporal scales. Therefore, one of the first tasks of the SPWT was to develop a standard format for the comparison and interuse of SSM/I data sets on varying spatial and temporal scales. The SPWT recommended that NSIDC, University of Colorado and The Radiation Laboratory, University of Michigan collaborate to develop a prototype earth grid, specific to the needs of SSM/I data, but with a potential for general application to any global scale data set. The result of this collaboration was the Version 0.0

Prototype of the Equal Area SSM/I Earth (EASE) Grid which was distributed in early 1993 to a broad user group, including the SSM/I Pathfinder Science Working Group (SWG), the Polar DAAC Advisory Group (PoDAG) and members of the MIMR Science Team. User response formed the basis for the development of the Version 1.0 format which was distributed for review in early 1994. The Version 1.0 format was approved by the NOAA/NASA Pathfinder SSM/I SWG for the generation of Level 3 products (Armstrong and Brodzik, 1995). The NOAA/NASA Pathfinder Program was designed to assure that certain key non-EOS data sets of particular significance to global change research are identified, scientifically validated and made readily available, at minimum cost, to the research community. Two of the key data sets so identified are the NASA Nimbus-7 SMMR and the Defense Meteorological Satellite Program (DMSP) SSM/I.

The availability of a standard gridding scheme is a fundamental requirement for systematic time-series studies. Such a scheme also supports the direct digital comparison of different remote sensing algorithms, as well as the validation of algorithms, through digital comparison with surface station and ancillary data sets which have been processed into the common grid. The basic concept of the EASE-Grid is to provide the remote sensing data user with an optimal earth grid format which is between swath data (e.g. one file per orbit) and an averaged (time and space) daily or multi-day product with its associated reduction in precision. The EASE-Grid maximizes the radiometric integrity of the original brightness temperature values, maintains high spatial and temporal precision, and involves no averaging of original swath data. The basis of the interpolation scheme to move from swath coordinates to earth-gridded coordinates is the methodology of Galantowicz and England (1991) which is based on earlier work by Stogryn (1978) and by Poe (1990). EASE-Grid brightness temperature data are available in two equal areal projections, cylindrical Full Global and azimuthal Northern and Southern Hemisphere. The cell size for all channels (19, 22, 37, and 85 GHZ) is 25 km with an additional 12.5 km cell size for the 85 GHZ channel.

The National Snow and Ice Data Center (NSIDC) is currently processing and distributing Level 3 SMMR and SSM/I Brightness Temperatures in EASE-Grid on CD-ROM. This NOAA/NASA Pathfinder project has resulted in a Level 3 passive microwave brightness temperature data set in a common format for the 22 year period 1978 to 1999. **This data set is described in detail, and example images are provided by accessing on-line data set information, URL http://www-nsidc.colorado.edu**