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Merging AVHRR and SMMR data for remote sensing of ice and cloud in polar regions

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Abstract. Multispectral data from the Advanced Very High Resolution Radiometer (AVHRR) were digitally processed and merged with Scanning Multichannel Microwave Radiometer (SMMR) imagery. Five channels of AVHRR data, four channels of SMMR brightness temperatures and SMMR-derived ice concentration and ice type were co-registered to a polar stereographic grid. The merged data sets are currently being used in combination with meteorological information for integrated studies of clouds and sea ice.

1. Introduction

The important role that polar processes play in the dynamics of global climate is widely recognized (Polar Research Board 1984). Remote-sensing of the distribution and characteristics of clouds and sea ice is required to monitor climate variability in the Arctic and Antarctic, as well as to provide input to global climatic models.

Optical-wavelength sensors can provide data with a high spatial resolution but are limited by the long periods of winter darkness poor lighting conditions and persistent cloud cover common in polar regions. Passive microwave sensors operate independently of solar illumination, can view the surface through cloud cover and provide surface information not contained in visible or thermal infrared imagery. However, existing passive microwave sensors yield data with a relatively poor spatial resolution. A combination of digital multispectral data appears to be a logical way of capitalizing on the unique capabilities of each group of sensors, while overcoming some of the problems inherent in remote sensing at high latitudes. Comparison of data from these two sensor groups has been undertaken previously by Choudhury *et al.* (1987) for vegetation studies and d'Entremont and Thomason (1987) for cloud analysis. This work describes a set of merged digital data consisting of visible, near-infrared and thermal infrared imagery from the Advanced Very High Resolution Radiometer (AVHRR) and passive microwave imagery from the Scanning Multichannel Microwave Radiometer (SMMR) combined into a form suitable for the analysis of cloud and sea ice cover.

2. AVHRR and SMMR data

The AVHRR sensors carried on board the NOAA-7 satellite sample the Earth in five spectral channels (0·58–0·68 μm, 0·725–1·0 μm, 3·55–3·93 μm, 10·3–11·3 μm, 11·5–12·5 μm), with a nadir resolution of 1·1 km. Partial orbits of Global Area Coverage (GAC) data (which is a reduced-resolution product created through on-board satellite processing to yield a nadir resolution of 3 km × 4 km) for 6–13 January and 1–7 July, 1984 are used in this study. The imagery covers areas in the Arctic with a permanent ice cap, snow-covered and snow-free land, sea ice and ocean, and a variety of cloud types over each of these surfaces.

First-order calibration of the AVHRR GAC data was performed using the calibration coefficients contained in the image files and the methods described in the NOAA Polar Orbiter Users Guide (NOAA 1984) and in Lauritsen *et al.* (1979). The data values recorded in channels 1 and 2 were converted to spectral albedo in per cent, and channels 3–5 were converted to radiance in milliwatts/(m^2-steradians-cm), then to brightness temperature in Kelvin using an approximation of the inverse of the Planck function. The percentage reflectance values produced for channels 1 and 2 by this method are only approximations of albedo and so care is required when comparing these values to broad-band albedos sensed over a wider spectral range (Shine *et al.* 1984).

To mitigate the effects of solar zenith angle differences along the wide swath of AVHRR, channels 1 and 2 were normalized by dividing the pixel value by the cosine of the solar zenith angle for that pixel as provided in the GAC data records. Since only one zenith angle is given per eight data pixels, the intermediate zenith angles were interpolated linearly. Under the assumption that atmospheric effects can be neglected due to the typically low water vapour content and low temperatures in polar atmospheres, no other adjustments for these effects were made.

A final step in the AVHRR data correction involved extracting the reflected-energy component from the emitted component in channel 3. Brightness temperatures estimated from channel 4 were converted to expected radiances for channel 3 using an inverse calculation of the Planck approximation with channel 3 parameters (the assumption is that emissivity of the surface is constant in these two channels). Subtraction of these radiances from the actual radiances measured in channel 3 yields the component of energy in channel 3 attributable to reflection.

Passive microwave data used in this study were acquired on 6, 8 and 10 January and 2, 4 and 6 July 1984 by the SMMR on Nimbus 7 (Gloersen and Barath 1977). The SMMR collects data in five microwave channels (6·6 GHz, 10·7 GHz, 18·0 GHz, 21·0 GHz and 37·0 GHz), with horizontal and vertical polarizations for each channel. The instantaneous field of view of the sensor varies with channel, ranging from 148 km × 95 km for the 6·6 GHz channel to 55 km × 41 km and 27 km × 18 km for the 18 GHz and 37 GHz channels, respectively. The data stored in these grids are recorded as brightness temperature in Kelvin. No distinction is made between day, night and twilight orbits and data from overlapping orbits are averaged to yield a daily value. SMMR data mapped to polar stereographic grids are archived in the Cryospheric Data Management System (CDMS) of the National Snow and Ice Data Center.

3. Combining AVHRR and SMMR data

Merging of the AVHRR GAC and SMMR data required selection of a common grid size that offered a compromise between spatial resolution and data volume. A polar stereographic projection yielding equal-area pixels true at 70° latitude was selected as the desired map base, with a 5 km grid cell (pixel) size. This pixel size represents a slight degradation of the AVHRR GAC spatial resolution but has the advantage, in terms of data processing, of being an even multiple of SMMR 25 km × 25 km cells used in the CDMS archive. The SMMR data were converted to 5 km cell sizes by simple duplication of pixels, thereby avoiding any artificial increase in spatial resolution. Sea ice concentration and old ice fraction were calculated from the SMMR data using the NASA Team Algorithm (Cavalieri *et al.* 1984). This algorithm is based on the normalized difference between vertically- and horizontally-polarized emissivity at 18 GHz and the normalized difference between vertically-polarized data at 18 GHz and 37 GHz.

Nearest-neighbour remapping of the AVHRR data to the polar projection was performed using the ground locations, in latitude and longitude, provided in the GAC records. Since locations are provided only at every eighth pixel, coordinates for the intermediate pixels were interpolated linearly and transformed from latitude/longitude to polar grid coordinates using standard map projection routines. Unfilled grid cells were interpolated by an average of non-zero neighbours. The reduction in ground resolution at the edges of the orbit swath due to the Earth's curvature is handled by pixel duplication so that the grid cell size remains constant across the rectified polar-stereographic image. No adjustments were made to compensate for viewing angle dependencies, as one of the goals of creating this data set is to investigate these effects. Accuracy of the AVHRR navigation using this method is expected to be within 25 km, roughly corresponding to an individual SMMR pixel.

4. An application

Examples of a calibrated and registered AVHRR channel 1 image, centred approximately on Novaya Zemlaya (75°N, 60°E), and covering the Kara and Barents Seas (figure 1), and SMMR 37 GHz data for the same area (figure 2) illustrate the differences in resolution and information content between the two sensors. The colour-composite of AVHRR channels 1 and 4 plus SMMR-derived ice concentration shown in figure 3 demonstrates the ability to map ice concentration and ice edge position beneath cloud cover.

The merged AVHRR—SMMR data sets are proving useful for a variety of applications that benefit from near-simultaneous observations of clouds andd surfaces. These data are being used to determine the spectral and textural properties of

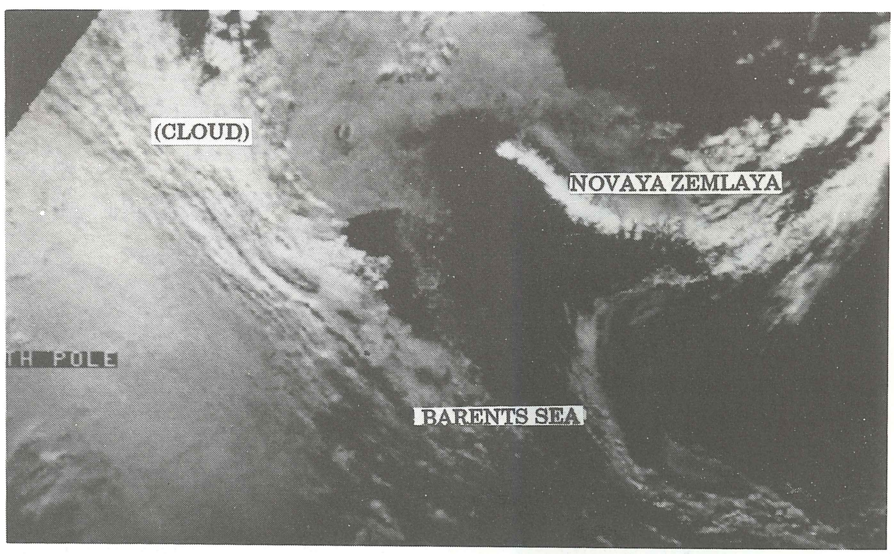

Figure 1. Calibrated and registered AVHRR channel 1 image centred approximately on Novaya Zemlaya and covering the Kara and Barents Seas.

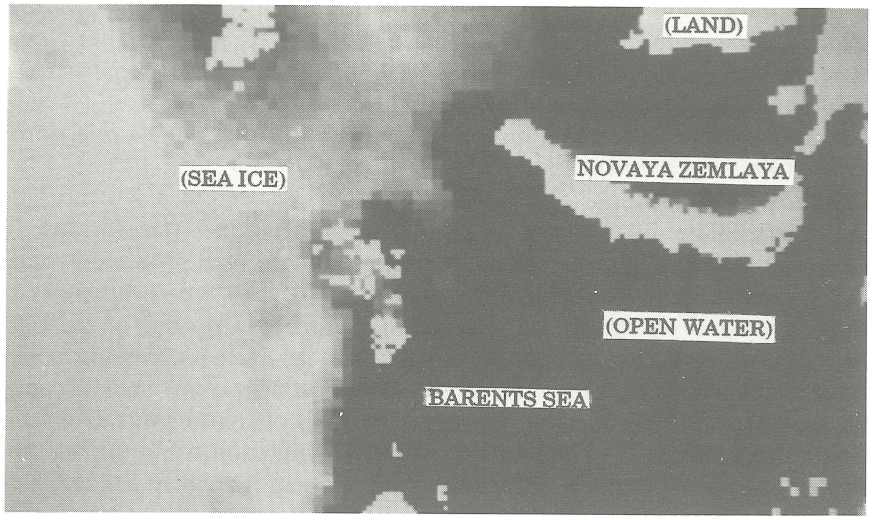

Figure 2. SMMR 37 GHz horizontal polarization data for the same area shown in figure 1.

clouds over snow-covered and snow-free land, permanent ice cap, open water and different concentrations and conditions of sea ice as part of a continuing effort to adapt the International Satellite Cloud Climatology Project (ISCCP) algorithm (Rossow *et al.* 1985) for use in polar regions. The combined data sets allow spatial and temporal thresholds to be chosen based on surface conditions and have shown that the surface often changes within the time periods over which the ISCCP algorithm operates. This situation is illustrated in figure 4, which consists of cloud

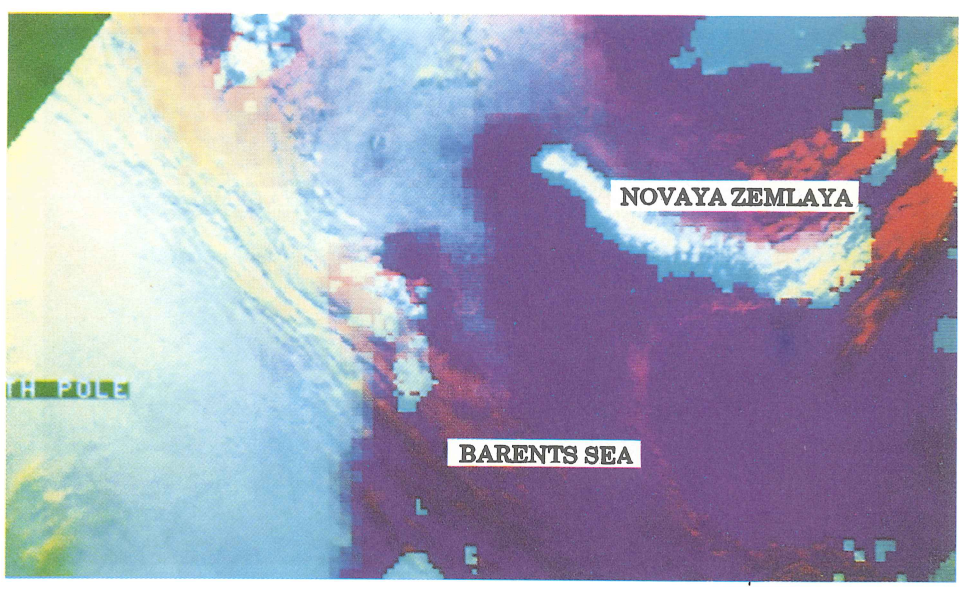

Figure 3. A composite of AVHRR channels 1 and 4, and SMMR-derived ice concentration for the areas shown in figure 1.

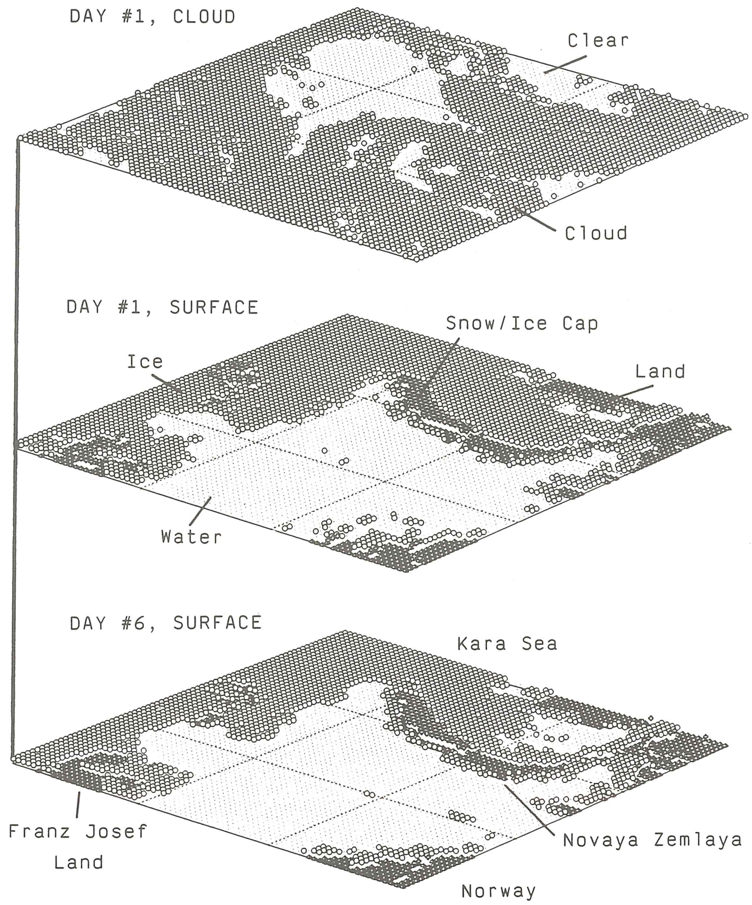

Figure 4. Cloud cover and surface types for a single day and surface types for the same area five days later. Area covered is 1500 km^2. The combined AVHRR/SMMR data set provides for the mapping of cloud over varying surfaces, as shown here for changing ice extent north-east and south of Novaya Zemlaya.

mapped with the AVHRR data and surface types identified using SMMR (18 GHz and 37 GHz) and SMMR-derived sea ice concentrations. Cloud cover and surface types are shown for the first day of the seven-day analysis period. Surface types are again shown for the sixth day. The change in ice extent to the north-east and south of Novaya Zemlaya, and the associated change in surface albedo and temperature that will in turn affect the spectral responses of overlying cloud, illustrate problems that will limit the applicability of the ISCCP algorithm in areas with snow and ice cover.

5. Conclusions

The ability to retrieve information on albedo, physical temperature and brightness temperature from spatially and temporally co-located imagery is proving to be a useful aid in comparing the spectral and textural properties of ice and clouds in a broad range of the energy spectrum. The merged data sets capitalize on the unique capabilities of AVHRR and passive microwave data by reducing the inherent limitations of each sensor and provide a means to improve automated cloud mapping in polar regions. Other applications include analysis of directional reflectance and emittance differences, the investigation of the relationship between SMMR-derived ice concentration and AVHRR-measured albedo, comparison of ice concentration and ice-edge position as estimated by AVHRR and SMMR and comparison of AVHRR-derived temperatures with temperatures estimated from SMMR. Future work will investigate the utility of passive microwave data merged with the Level B3 AVHRR product to be archived as part of ISCCP (Schiffer and Rossow 1985) and will assess the potential contribution of such merged data sets to extend the time period of multisensor data available from the Special Sensor Microwave/Imager and the Optical Line Scan system on Defense Meteorological Satellite Program platforms and sensor combinations proposed for the Earth Observing System.

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References

CAVALIERI, D. J., GLOERSEN, P., and CAMPBELL, W. J., 1984, Determination of sea ice parameters with Nimbus-7 SMMR. *Journal of Geophysical Research,* **88,** 5355–5369.

CHOUDHURY, B. J., TUCKER, C. J., GOLUS, R. E., and NEWCOMB, W. W., 1987, Monitoring vegetation using Nimbus-7 scanning multichannel microwave radiometer's data. *International Journal of Remote Sensing,* **8,** 533–538.

D'ENTREMONT, R. P., and THOMASON, L. W., 1987, Interpreting meteorological satellite images using a color-composite technique. *Bulletin of the American Meterological Society,* **68,** 762–768.

GLOERSEN, P., and BARATH, F. T., 1977, A scanning multichannel microwave radiometer for Nimbus-G and Seasat-A. *I.E.E.E. Journal of Oceanic Engineering,* **2,** 172–178.

LAURITSON, L., NELSON, G. J., and PORTO, F. W., 1979, Data extraction and calibration of TIROS-N/NOAA radiometers. NOAA Technical Memorandum TM NESS 107, Washington, D.C., U.S.A.

NOAA, 1984, *NOAA Polar Orbiter Data Users Guide* (Washington, D.C.: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NESDIS).

POLAR RESEARCH BOARD, 1984, *The Polar Regions and Climatic Change* (Washington, D.C.: National Research Council, National Academy Press).

ROSSOW, W. G., MOSHER, F., KINSELLA, E., ARKING, A., DESBOIS, M., HARRISON, E., MINNIS, P., RUPRECHT, E., SEZE, G., SIMMER, C., and SMITH, E., 1985, ISCCP cloud algorithm intercomparison. *Journal of Climate and Applied Meterology,* **24,** 877–903.

SCHIFFER, R. A., and ROSSOW, W. B., 1985, ISCCP global radiance data set: A new resource for climate research. *Bulletin of the American Meteorological Society,* **66,** 1498–1505.

SHINE, K. P., HENDERSON-SELLERS, A., and SLINGO, A., 1984, The influence of the spectral response of satellite sensors on estimates of broadband albedo. *Quarterly Journal of the Royal Meteorological Society,* **110,** 1170–1179.