Processing NOAA-AVHRR Satellite Data for Sea Ice and Oceanographic Research in the Marginal Ice Zone of the Polar Seas

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ABSTRACT: This paper describes a method for NOAA-AVHRR satellite data processing in sea ice and oceanographic studies in the polar seas. This method includes geometrical processing to generate gridded and corrected images according to a polar stereographic map, ice and cloud discrimination during summer, and the production of combined sea ice and sea surface temperature imagery for watching marginal ice zone processes.

Introduction

Increasing research activity in the peripheral seas of the Arctic, specially in the Greenland, Norwegian and Barents seas, requires precise information about sea ice extent and concentration as well as about the marginal ice zone features which have been the subject of extensive scientific work in the last few years. During in-situ experiments using ships and aircrafts, this information has to be provided for scientists and crews as soon as possible to direct research work and also for safe sailing along or through the ice.

Satellite remote sensing is the only way to adequately sample surface conditions of a large-scale ice field. At the present day, four main types of spaceborne remote sensing systems may be used for sea ice surveillance and research:

- high resolution scanning radiometers operating in optical wavelengths as Landsat MSS adn TM, or Spot HRV, are limited by cloudiness and winter darkness. They offer very limited geographical coverage; the information obtained from these sensors is very precise due to their high resolution, but very scarce in both space and time for operational purposes.
- in contrast to visible and infrared data, passive microwave imagery allows nighttime as well as daytime coverage and is not obscured by clouds. However the spatial resolution is coarse, even for the present-day most advanced sensor, the SMM/I on board DMSP satellites (25 km for most of the 10 channels). With this resolution, mesoscale features in the Marginal Ice Zone are not resolved, and passive microwave imagery is therefore used for climatic surveillance rather than for in-situ operational research (NASA Science Working Group, 1984).
- in the future, radar imagery will be probably the most useful tool for sea ice studies and operational purpose. It has a fine resolution as well as the ability to sample all-season and all-weather data; it also makes possible to distinguish different ice types as multiyear, first year, new and thin ice. However, its use is at present limited due to the lack of active sensors aboard operational satellites and to the high cost of digital data processing.
- visible and infrared data from meteorological satellites, i.e. the data from the Advanced Very High Resolution Radiometers (AVHRR) aboard the NOAA satellites, are at present the only adequate ones for our applications: they provide precise ice edge location, ice concentration, ice motion as well as sea surface temperatures along the ice edge. These radiometers have a large geographical coverage, with a 2500 km wide swath, and quite a good spatial resolution of about 1.1 km at the subpoint, which allows to watch mesoscale features of the ice edge as eddies or ice tongues. These mesoscale features are an important subject of research work and also a bother to classical research vessels without icebreaking capabilities. Since they operate in the visible and infrared part of the electromagnetic spectrum, these radiometers are strongly affected by the cloud cover; cloudiness is very high in summer in the polar seas, with mean
values reaching 90% in the Greenland and Barents seas. This problem may be partially avoided by the dense temporal coverage at high latitudes of these satellites on near-polar orbits.

Operational use of AVHRR data for sea-ice or oceanographical research in the polar seas will thus require two main conditions:

- an adequate method for geometric processing allowing precise location of the ice edge and MIZ features; the accuracy of this method should be better than a few pixels, i.e. a few kilometers.
- an efficient way of sea-ice/cloud discrimination on partially cloudy imagery. Sea-ice/cloud discrimination on visible or near infrared imagery (channel 1 and channel 2 or the AVHRR) may be difficult and lead to errors even from experienced remote sensing scientists.

Both methods of geometric processing and enhancement for ice/cloud discrimination have to be simple and as less time-consuming as possible to provide the requested information to users in near real-time. The methods presented in this paper were elaborated when the author processed AVHRR data archived during MIZEX 83 and 84 (Gascard et al. 1988), and when he worked at the Tromsö Satellite Station during the ARCTEMIZ 88 summer campaign. The images hereafter were obtained on the SPHINX image processing system in the Laboratoire d’Optique Atmosphérique at the University of Lille (1).

Our methodology for AVHRR data processing will be illustrated by an AVHRR scene received at the Tromsö Satellite Station on September 4, 1988 during the ARCTEMIZ 88 summer campaign (2).

Geometric Processing of AVHRR Data

Satellite imagery from multispectral scanners like AVHRR is obtained according to the geometry imposed by the orbital parameters and the viewing capabilities of the scanner itself. In the case of AVHRR, geometric distorsion is severe due to the wide viewing angle (56° apart the nadir). Precise location of sea ice edge and particular features on AVHRR, requires preliminary resampling of the original data according to a mapping projection.

There are two main techniques that are commonly used to correct the geometric distortions present in digital image data:

- the first approach depends on establishing mathematical relationships between adresses of recognizable points in the original image and their corresponding coordinates on the ground or on the chosen map projection. From the pairs of original and map-located coordinates a warping algorithm may be established in the form of simple polynomials of first, second or third order. The more ground control points there are, the more likely it is the geometric correction will be satisfactory. This approach is not usable in our case, due to the drastic geometrical distorsion induced by the wide field of view of AVHRR and the large number of ground control points required for precise correction; ground control points are not available for marine areas, except on coastlines with a poor sampling over the images.
- the second approach is to model the nature and magnitude of the sources of distorsion and then establish correction algorithms based upon these models. The more common methods in satellite oceanography use spherical Earth and circular orbit models to perform the conversion of image (row and line) to geographical coordinates (latitude and longitude) according to the classical formulae in solid trigonometry (Robinson 1985).

Unfortunately, this second approach leads to poor results in the polar regions due to the flattening-out of the Earth at high latitudes and to the sensitivity of the results to slight inaccuracies in orbit inclination values near the top of the orbits. More sophisticated models are occasionnally used for better location of individual pixels on AVHRR imagery; they are based on elliptical orbits and ellipsoidal Earth (Ho and Asem 1986; Brush 1988). If used to produce fully corrected images, with pixels resampled according to a mapping projection, such models would lead to time-consuming computations; they are used to produce gridded images rather than connected images.

The method used to produce the images that are presented in this paper is a combination of a simple spherical Earth model and first order warping polynomials. The spherical Earth model provides a preliminary relation between the geographical coordinates φ (latitude) and λ (longitude) of every pixel and its original image coordinates x (row) and μ (line). The remaining error in pixel location (i.e. the difference between actual image coordinates and image coordinates computed according to the model) is assumed to vary linearly along the x and μ directions. Three ground control points only are then required to establish first order polynomials that allow to compute the correction to be applied to the x and μ values obtained from the model.

Using the relation between geographical coordinates φ and λ and the original images coordinates (row and line), including the correction provided by the control points, the original image data may be resampled according to any mapping projection. In our case, a polar stereographic projection was logically chosen. Latitudes and longitudes computed during the course of data resampling may also be used to get sun angle values required for visible or near infrared data calibration. The CPU time used on the HP-9000 computer available in Lille or on the VAX-11/730 at the Tromsö Satellite Station to produce a 512×512 pixels gridded polar stereographic image (Fig 1) is about 30 mm. Remaining pixel location error is about 3 pixels provided that the ground control points were adequately chosen. The