# SEA ICE MAPPING WITH ERS-1 IMAGES

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## Abstract

Mapping of arctic sea ice is being accomplished in a near-automated fashion using European ERS-1 satellite radar images. We report about a software system developed under NASA-funding and denoted as Geophysical Processing System, and about results from more than 1 year of operations. Of a total of 9,000 processing requests from the user commmunity, the system produced 8,000 successful responses. Major reason for "failure" to map sea ice was the absence of such ice in certain areas.

## 1. Introduction

We can study the problem of sea ice mapping as an example of a high data volume remote sensing application. Numerous satellite imaging systems are currently active or nearing operation (Table 1). Data rates are high, as is easily documented in Table 2. Therefore it is important that concepts be developed that permit one to cope with large satellite imaga data quantities. We propose that centralized systems for automated analysis of images should be operated near the ground data systems, and that they be developed as discipline-specific processors for a specialized user community (Table 3). We will illustrate this concept with a sea-ice mapping system denoted as the Geophysical Processing System (GPS). It is the result of an initiative of the academic sea ice community which convinced NASA to sponsor the development of such a discipline-oriented solution, place it at the University of Alaska, and make its analysis results available to the interested user community, for example through the Internet computer networker or by one of many other ways to sign onto the Archiving and Operations System.

Sea ice, its motion and age have long been an item of geophysical interest. Sea ice is a major factor in defining global weather and an impediment to arctic exploration.

In the past, detailed observations of sea ice had to be made by human explorers in the field, and/or by limited numbers of weather stations placed on the ice and monitored by radio. With the advent of satellite imagery, sea ice was observed in Landsat images (Hibler et al., 1975), and most prominently through low resolution microwave radiometry (Gloersen, Salomonsen, 1975).

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**Table 1**: Earth observing satellites generating images at high image data rates

| |
|---|
| European ERS-1<br>Japanese ERS-1<br>Russian Alma 3<br>French SPOT<br>Landsat MSS and TM<br>AVHRR (USA) |
| Future Radarsat (Canada), EOS (US/International) etc. |

**Table 2:** Typical data rates from Satellite Imaging Sensor

| | |
|---|---|
| Typical pixel size | 10 m to 30 m |
| Swath width | 60 km to 180 km |
| Number of pixels per scan line | 6,000 |
| Speed of satellite | 7.000 meters per second |
| Pixels per second | 1.4 million |
| Time to collect 1 Gigapixel | 12 minutes |

**Table 3**: Centralized discipline-processing systems as a solution to the high data rate problem

- Design Elements
  - Automated analysis
  - Part of the ground data system
  - Users receive images and analysis results
- Feasibility
  - Technology exists
  - Technology is affordable
    - Work-stations, accelerator boards, software, image analysis hardware, algorithms

It is rather obvious that visible light imaging will not support continuous observation due to long arctic nights and frequent cloud coverage. All-weather imaging would be feasible with passive microwave radiometry which would permit one to measure surface temperature on a global scale. However , this would produce only at a coarse resolution images with pixels in the range of several kilometers. Temperature can be an indicator for sea ice. Therefore such images were used as a source for coarse notions about sea ice motion and type.

However, all-weather imaging is possible with imaging radar, and therefore it was with great interest that the sea ice community awaited the launches of satellite radar systems as listed in Table 1. Previously it had been amply demonstrated that sea ice motion can be measured from radar images (Hall and Rothrock, 1981; Leberl et al., 1979, 1983, Vesecki et al., 1988), but it was unclear in how far this task could be fully automated.

## 2. The Geophysical Processing System

### 2.1 Building Blocks

The GPS is the result of systems integration and innovative algorithms for sea ice motion, classification and wave spectra analysis in open water images. Table 4 contains the major building blocks, Table 5 the main functions. The GPS does not itself contain large data quantities. Instead it taps into the vast repository of images in the ground data system to which the GPS is attached. As the results are computed, a motion or classification map goes back into the ground data systems repository.

**Table 4:** The Geophysical Processing System

| | |
|---|---|
| Hardware | |
| | Sun-4 |
| | SkyBOLT array processor |
| Software | |
| | Ingres data base |
| | PV-Wave visualization software |
| Large system of applications | |

Users can query the data base and obtain not only the radar images, but also the mapping products.

### 2.2 Image Matching for Ice Motion Detection

At the center of a successful sea ice motion system needs to exist a robust algorithm to detect motion, and to decide whether the images show the same ice or not. An approximation of ice motion is computed from climate data which are an element of the system and derive from weather stations and long term predictions of sea ice dynamics. At a user's request, two or more images are being selected from the AOS and checked for the likelihood that ice motion exists in the image pairs. Numerous reports have been published in the past describing the strategy used in the GPS (for example McConnell et al., 1990, 1991; Kwok et al., 1990, 1992). Image matching is implemented in a manner that applies to "dissimilar images". Several algorithms exist and get assembled into a process depending on the results of intermediate processing steps. One may refer to this approach as "plumbing" a system from individual algorithmic components.

2.3 Ice Classification and Wave Spectra

The radar images of sea ice can also be used to classify the pixels into 2 to 4 classes of different objects, most typically into open water, new ice, multi-year ice.

In open water, one may use the water wave pattern to infer wind speed and direction. Wave data result from a spectral analysis of the coherent patterns in the images.

**Table 5:** Main functions of the Geophysical Processing System

| | |
|---|---|
| Connected to Archival and Operations System (AOS) | |
| | Receives user requests to analyze images (Internet, Decnet, Modem) |
| | Receives images from AOS |
| | Computes products (motion vectors, ice classes, ocean wave spectra) |
| | Delivers products to AOS |
| User interaction | |
| | Connect to AOS for images and products |
| Ancillary data | |
| | Wind, climate, temperature etc. |
| | Stored, used, retrieved |

## 3. ERS-1 Data and Mapping Results

Figure 1 presents a location map, and Figure 2 one of two sea ice images taken at 72 degrees North with the European ERS-1 satellite and its synthetic aperture radar sensor.

These images are being routinely produced since Fall 1991 and at resolutions of 12.5 m per pixel. Each image covers 100 x 100 sqkm. At the current time the Alaska AOS contains an excess of 30,000 such images collected from the area covered by the receiving station; 25,000 images contain ocean data.

Images are available at full-resolution and at down-sampled pixel sizes of 100 m. GPS employs the 100 m pixels for ice motion and ice classification, and full-resolution to compute more spectra.The images can typically be considered to be of excellent quality. Figure 3 presents the ice motion vectors. Figure 4 is another ERS-1 image, Figure 5 the classification result into first year ice (light grey), open water/new ice (dark grey), land (black). This result is obtained completely automatically. In the event of ambiguity, or errors, an error message is put into an "operator alert manager" so that human intervention is easily integrated into the system to remove errors or resolve ambiguities.

Table 6 presents the accomplishments to date. Of a total of 9,000 matching requests made to the GPS since 1/1992, a total of 8,000 could be successfully completed. The major reasons for failure in the remaining 1,000 was due to the absence of ice.

**Figure 1**: Location map for example images for ERS-1 Sea ice motion measurement

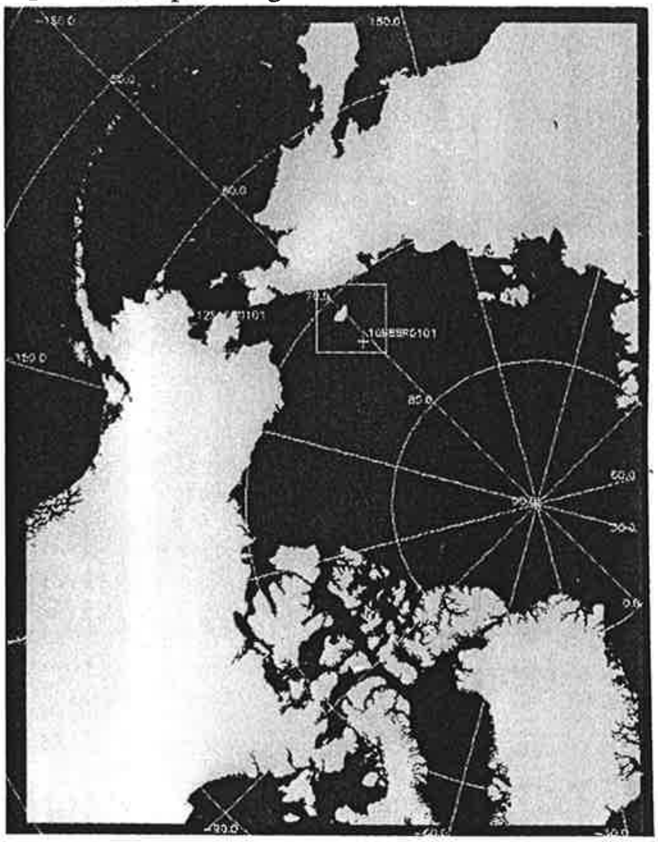


**Table 6:** Performance of the geophysical processing system

| | | |
|---|---|---|
| Operational since | | 1/1992 |
| Number of ocean images in AOS | | 25,000 |
| Memory used for images in AOS | | about 1,250 GB |
| Size of each image | | 100 x 100 sqkm |
| Pixel sizes | low resolution | 100 m |
| | high resolution | 12.5 m |
| Time to process an image pair | | 20 minutes |
| Time to process for classification | | 5 minutes |
| Processing requests handled for motion | | 4,900 |
| Processing requests handled for classification | | 3,800 |
| Satisfactory results delivered for motion | | 3,500 |
| Satisfactory results delivered for classification | | 3,500 |
| 2 major reasons for failure to deliver<br>(time of separation too great, e.g. 12 days) | | No ice |

**Figure 2**: Arctic sea ice on an ERS-1 radar image by ESA. Area is at 74 degrees north, 178 degrees west, covering 100 x 100 sqkm, taken on day 79 in 1992 (© ESA)

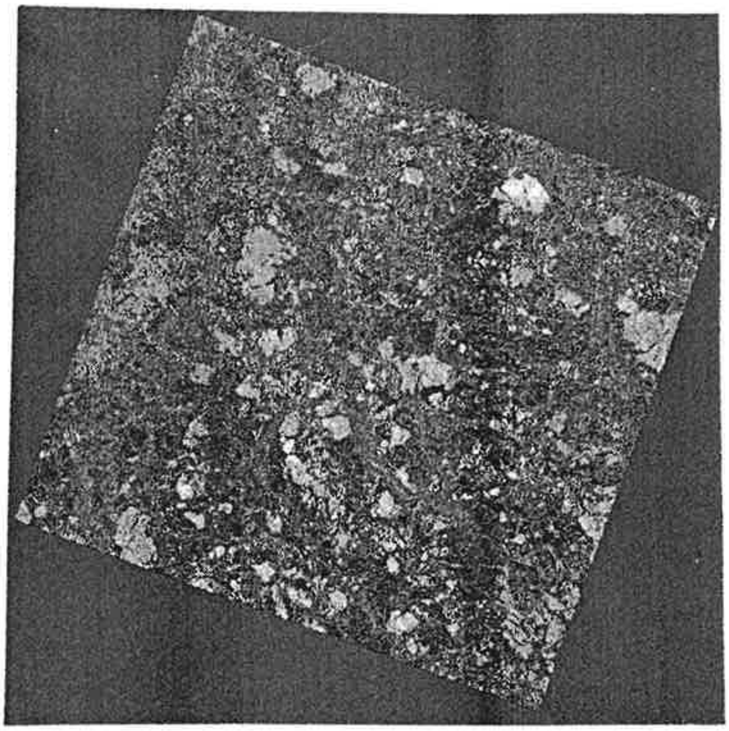
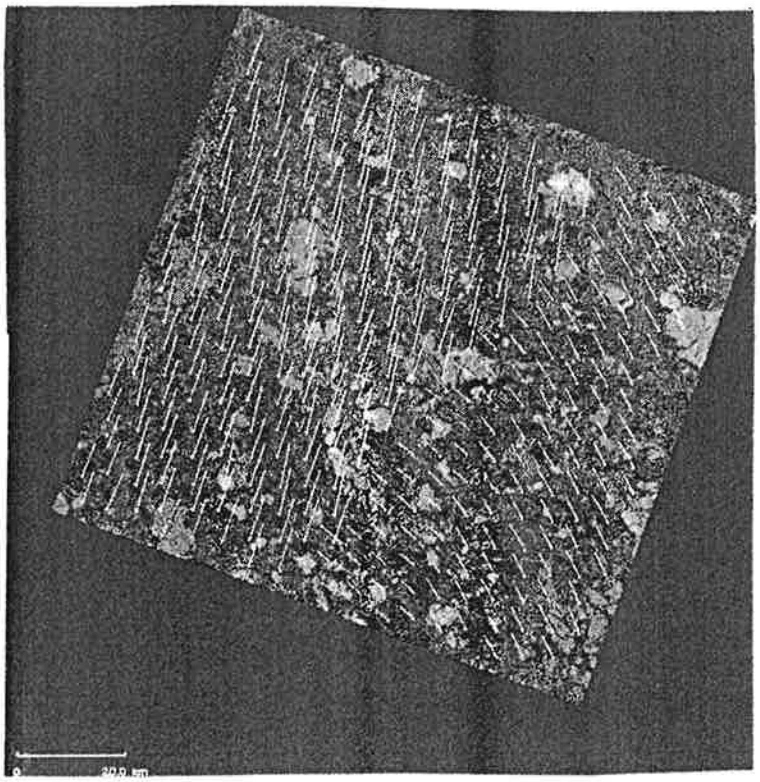


**Figure 3**: Sea ice motion using images on the 79th and 82nd day of 1992 (3 days apart). 74 degrees north, 178 degrees west.



The most urgent uncertainity in the entire system is the inability to <u>verify</u> the results. Confidence in the motion vectors and ice classification is only based on previous experiments with aircraft SAR or Seasat satellite radar images.

## 4. Outlook

We propose in this paper the Geophysical Processing System as a sample implementation of a high volume remote sensing application that has been able to cope with large data quantities. We agree that high data rates can be accommodated if the analysis is near the ground data system, in the current case the Archival and Operations System (AOS).

In this manner we have access to a large data base which, in the current example, already exceeds 50,000 images after only 1 year of operation.

The Geophysical Processing System was developed in an effort in excess of 15 person years, but operates a hardware that can be replicated for perhaps US$ 100,000. It is a "discipline-oriented" solution which focusses on serving only one purpose (a specialized application), however for a large group of globally distributed users. This differs from personal, departmental or regional remote sensing systems (see Table 7).

We believe that we have demonstrated with unequivocal success that the chosen approach to a large data volume, complex remote sensing problem is valid and recommend that similar thinking be applied to other applications as well.

**Figure 4**: Arctic sea ice on an ERS-1 radar image by ESA. Area is at 64 degrees north, 163 degrees west, covering 100 km x 100 km, taken on day 85 of 1992 (© ESA)

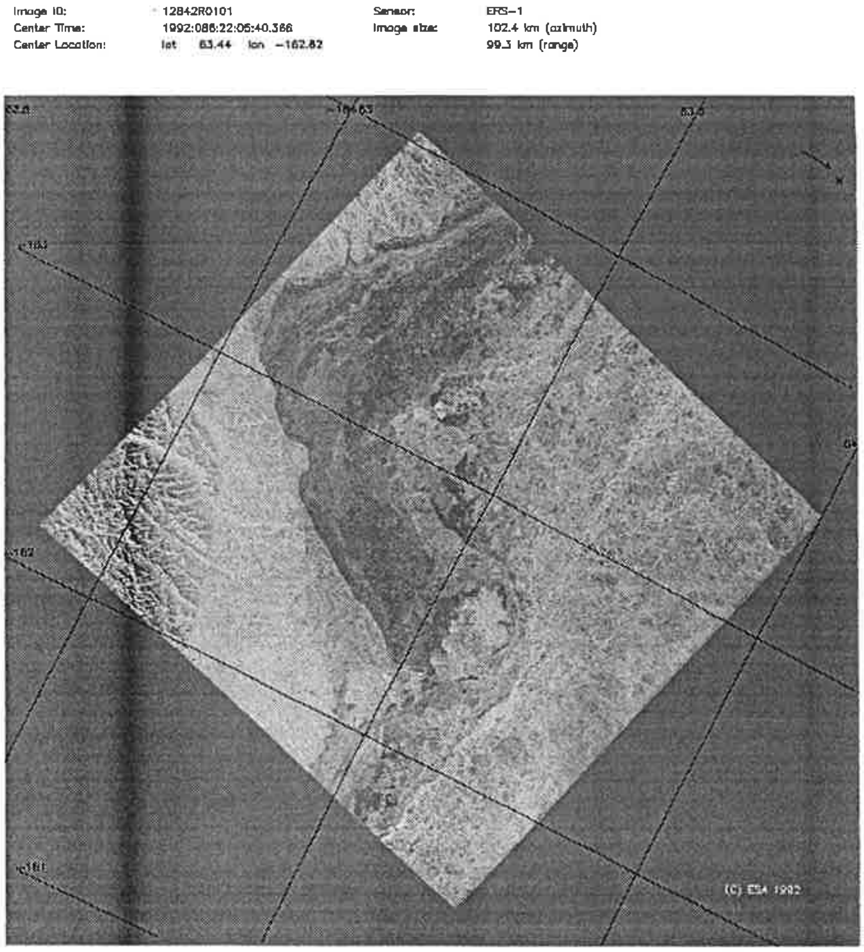
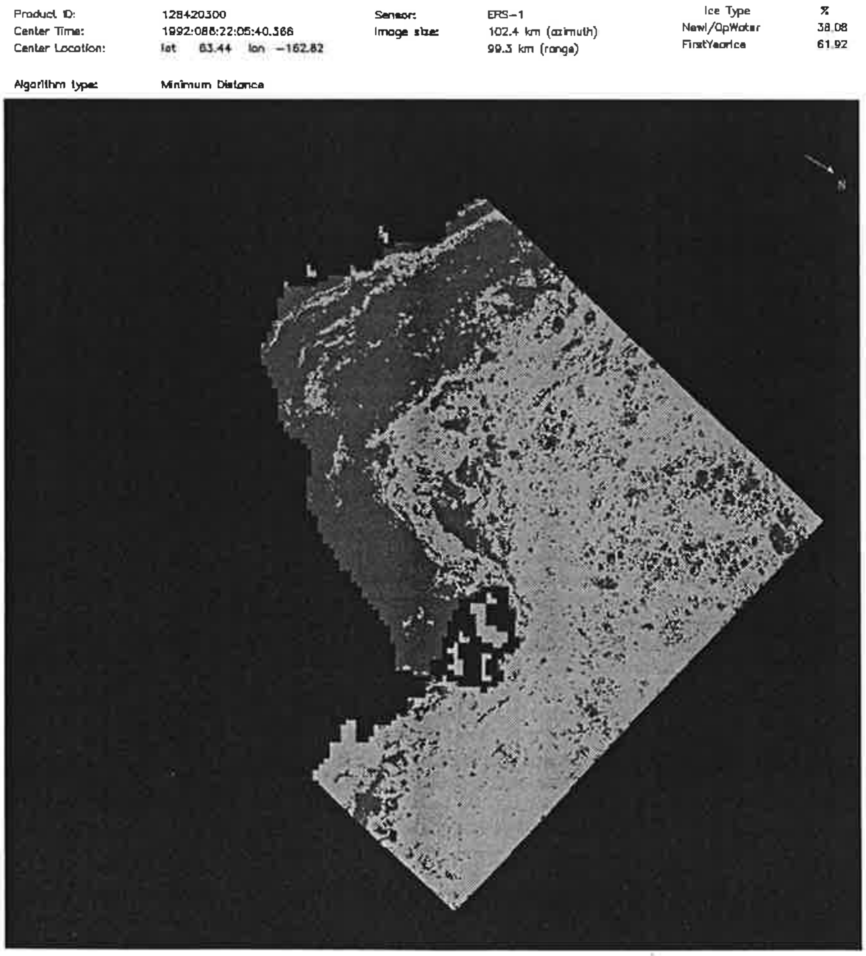


**Table 7:** Levels of processing systems

| | |
|---|---|
| Personal systems on the scientists desk<br>1 user/system............ | Specialized application |
| Departmental system<br>10 users/system........... | Specialized application |
| Discipline system<br>100 users/system..... | Specialized application |
| Regional system (province, district)<br>500 users/system | Multiple applications |
| And beyond ?<br>5000 users/system | Multiple applications |

**Figure 5:** Sea ice classification using images at the 85th day of 1992 at 63 degrees north, 163 degrees west



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**Design of Mission Operations Systems for Scientific Remote Sensing**. Stephen D. Wall and Kenneth W. Ledbetter. Taylor and Francis, Basing Stoke, 1991, 223 pp., £ 39.00, ISBN 0-85066-860-3.

As with any satellite remote sensing mission that is ongoing, a participating remote sensing specialist is most likely to deal only with the Mission Operations System or MOS. This is a complex web of people, software, documents and responsibilities who run the day-to-day life of a satellite and its data. The book by two authors working on NASA remote sensing satellite missions is probably the only text to describe and discuss its subject. This alone already makes it a commendable effort of the authors to share their considerable experiences in Mission Operations Systems with the interested community.

The text is slim; it treats the topic in eight easily readable chapters. The first two chapters represent a very useful introduction into the world of managing large and complex development projects, as well as into the elements of a satellite system with platform, power, propulsion, data handling, etc. We learn about the elements of a satellite mission and about methods of designing Mission Operation Systems with "documentation trees" and N-square charts.

The next four chapters describe details of the four required functions of a MOS. This consists first of all its management with the typical organization chart for a MOS. Second it concerns the uplink to tell the satellite what to do next, and the downlink reporting what the satellite does and its sensors sense. Finally, there are contingency issues in case something unexpected occurs.

The last two chapters describe the MOS for NASA's Magellan mission to planet Venus, and present the authors' expectations for the continued development of future Mission Operations Systems. An attachment contains a glossary of about 150 items.

The perspective of the book is from NASA and the U.S. planetary space program, home of both authors who work at the Jet Propulsion Laboratory and at Martin-Marietta, a large U.S. aerospace contractor. This focus leaves potential differences between Earth-oriented and planetary missions, differences between manned and unmanned missions, and differences between space programs of the U.S. and of other nations somewhat in doubt.

The book is useful for students in aerospace engineering and all those participating or merely interested in any space programs. The references to "scientific" and "remote sensing" in the title of the book are probably not too relevant since non-scientific or non-remote sensing missions are presumably operated in a very similar manner.

As someone having been involved as a "consumer" of satellite remote sensing data and as a participant in satellite missions, I enjoyed the book as an eye-opener. Operating a satellite is certainly a much more complex undertaking than I thought, and I hope that the authors are correct in assuming that emerging technology will help reducing the complexity and costs of operating a satellite.

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Thank you.