NEW VIEWS OF THE EARTH

Application Achievements of *ERS-1*

(Preliminary version)

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December 1995

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Printed at ESRIN for the Second ERS Applications Workshop, London, UK - 6-8 December 1995

Layout: ESA Publications Division

 - ISBN 92-9092-141-2

This document was produced under ESA contract by ESYS Limited and ESA ESRIN Data Utilization Section and follows the volume SP-1176/I: "Scientific Achievements of ERS-1". It is part of a series of three documents presenting highlights from the full range achievements of the ERS-1 mission.

The final version will be published by ESA Publications Division, in early 1996 under the reference "SP-1176/II".

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Preface

On July 17, 1991, the European Space Agency (ESA) launched ERS-1, the first European Remote-sensing Satellite. Continued operation of ERS-1 beyond its scheduled lifetime and the parallel operation of its successor ERS-2 launched on April 20, 1995, are providing unprecedented opportunities for development of scientific, operational and commercial applications of Earth observation data.

The full range of achievements of the ERS-1 mission are being reviewed by ESA and the highlights presented in a series of three publications:

I. Scientific achievements of ERS-1;
II. Application achievements of ERS-1;
III. Engineering achievements of ERS-1.

In the context of the original mission objectives, Volume I which was issued in April 1995, demonstrates how ERS-1 data are being used within the international science community to improve our knowledge and understanding of the Earth's environment. Beyond the anticipated fields of oceanography, polar science and climate research, the data have stimulated applications in much broader areas including solid Earth and terrestrial sciences. ERS-2, which incorporates new and enhanced instruments, guarantees continuity of this vital source of information which is providing the basis for forecasting and managing the effects of natural and man made changes on our environment. This publication, Volume II, demonstrates how the mission is achieving objectives to develop and promote economic and commercial applications. Original targets for development were identified as planning of coastal, marine and sea ice activities and exploration of the potential of SAR data for land applications. Technologies and techniques developed by the science community are being taken up by value adding organisations to address the needs of users in government and commercial sectors. Examples presented here illustrate how the use of ERS-1 data in meteorological, marine, sea ice, land and mapping applications by the Earth observation industry and user communities has surpassed expectation.

Novel techniques and the tandem operation of the two ERS satellites are opening up new application possibilities. Interferometry, never considered in the original objectives, can be used on the one hand to detect movements in the Earth's surface down to a scale of centimetres and on the other to produce or improve large scale digital elevation models at a fraction of the cost of conventional methods.

The results presented here can only provide a snapshot. The process of market development is dynamic and new opportunities are being created as market awareness improves and technology advances. By the time this document goes to press more projects will have been initiated and will be progressing to operational status. Volume III will be published in 1996.

The successful launch of ERS-2, preparation for Envisat and planning for future ESA missions will contribute to data and service continuity establishing Earth observation as a key management tool for the twenty first century.

Guy Duchossois
Head of Earth Observation Mission Management Office

1. ERS DATA APPLICATIONS

1.1. A tool for decision making

Effective management relies on accurate and timely information. This applies at every level, from politicians deciding on international policies for combating global warming to individual farmers deciding when to harvest crops. Management decisions are driven and influenced by a wide range of motives - environmental, humanitarian, political and commercial. The need to manage our activities and their influence on our environment drives an ever increasing demand for information.

Earth observation from satellites is unique in the range of information which it can supply to the decision maker. It has the advantages of providing homogenous, repetitive and continuous coverage of the Earth's surface, in a cost effective way. It provides access to remote and inaccessible areas of the world, where information may otherwise be sparse or non-existent.

The ERS programme is a major element of the European Earth Observation Programme. The ERS-1 satellite, launched on July 17, 1991, measures a range of parameters from three instruments. Use of advanced microwave techniques means that data can be acquired day or night and over areas where cloud cover precludes the use of optical instruments. This complements information provided by other missions operating in the visible and infra-red ranges.

The examples presented in this document demonstrate how ERS-1 is achieving its application objectives and, as a consequence, how use of ERS-1 data is playing an increasingly important role in decision making which is affecting all of our lives.

1.2. Observing capabilities

This document concentrates on applications rather than satellite technology. However, it is appropriate briefly to review how data from each of the sensors on ERS-1 were originally expected to contribute to applications development and to assess the extent to which they have been successful.

Table 1-1 was originally produced at the time when specific application objectives were defined for the mission. Ticks indicate the application areas anticipated for each sensor and the shaded squares identify applications which are presented in the collection of examples contained in this summary document.

	Instruments				
	Altimeter	ATSR	Active microwave instrument		
Application objective			SAR image mode	SAR wave mode	Wind scatterometer
Weather forecasting		√			√
Sea state forecasting	√			√	√
Offshore activity	√	√		√	√
Ship routing	√	√		√	√
Fisheries	√	√			√
Sea ice and iceberg	√	√	√		
Oil pollution		√	√		
Coastal processes		√	√		
Land applications	√		√		

Table 1-1: Sensor applications

1.3. The original application objectives

The original objectives, defined more than ten years before the launch, clearly specified the major application areas for which ERS-1 could play a role. The key areas targeted were:

❑ **Forecasting weather, ocean and ice conditions**

It was anticipated that the accuracy of weather and ocean forecasting could be improved by incorporating ERS-1 data into existing models. In addition to established meteorological applications, these forecasts would be of value for:

- Offshore operations;
- Ship routing;
- Fishing;
- Navigation and other economic activities in ice infested waters.

Improved knowledge of sea-state conditions was recognised as an essential component in the planning of offshore engineering activities especially in the area of oil exploration and exploitation. Optimisation of ship routing to determine the quickest and safest passage saves time and hence fuel and money. For all marine applications, efficiency and safety are of utmost importance while operating in ice infested waters and this depends critically on accurate information. The value of SAR imagery in particular, for monitoring sea ice and icebergs, had already been established using airborne data. It was anticipated that ERS-1 would provide additional benefits associated with wide area and repeat coverage.

❑ Experimental applications

At the time of the ERS-1 mission specification, the following applications were identified as experimental:

- Oil and chemical pollution monitoring;
- Coastal management;
- Land applications.

This document demonstrates the great advances which have been made in the development of these applications - taking them beyond experimental status.

Oil and chemical pollution can cause extensive damage at immeasurable ecological and economic cost. The design and construction of coastal structures relies on a wide range of information on shoreline processes, sea state, bottom topography and bathymetry. ERS-1 data are playing a significant role in both oil slick detection and coastal management.

It was recognised that the SAR could contribute greatly to the achievement of land application objectives. The major potential economic land applications of SAR data, either in isolation or as an all weather complement to optical data, were identified as:

- Monitoring the rate of seasonal land cover change;
- Monitoring crop development;
- Monitoring water resources, hydrology and soil moisture;
- Monitoring forestry change;
- Cartography;
- Land cover determination;
- Geological mapping;
- Seasonal and perennial snow mapping;
- Permafrost (frost-line changes).

- ❑ **Development aid**

There is a requirement for cost effective management of natural resources and the environment in developing countries. The advantages and benefits of Earth observation applications in these areas are well recognised and are supported by bi-lateral and multi-lateral aid programmes and the activities of specialist inter-governmental agencies.

It was recognised that many of the applications of ERS-1 data would be of particular value in developing countries, especially for the monitoring and control of marine resources and development of offshore activities.

1.4. Applications development today

In its original concept, ERS-1 was considered both as an experimental and pre-operational system. It was to demonstrate that the concept and technology, for both the space and ground segments, could achieve specified performances and that for appropriate applications, it could demonstrate operational capability.

ERS-1 observations are providing the international science community with information which is vital to the understanding of processes controlling the atmospheric, ocean, terrestrial, cryospheric and solid Earth systems. Improved knowledge and understanding is essential to the management of our environment. The significant results in this area have been highlighted in Volume I of this series, "Scientific Achievements of ERS-1"[1].

In addition to scientific achievements, it was anticipated that a gradual transfer of applications from experimental towards operational users would take place, preparing the future users for subsequent satellite systems. ERS-1 was considered a "market opener" for Europe, demonstrating our ability to compete in the world wide market and contribute to the global monitoring of coastal zones and oceans.

In each of these respects, ERS-1 has achieved and surpassed expectation:

- ❑ The concept and technology have been successfully qualified;
- ❑ An operational capability has been demonstrated;
- ❑ Assimilation of ERS-1 data into weather and ocean forecasting is operational;
- ❑ Marine applications especially in ice monitoring, oil slick detection and bathymetric survey are becoming well established in user organisations;
- ❑ Users are anticipating long term continuity of data as inputs to planned operational applications;

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[1]ESA Publication SP-1176/I

- ❑ Europe is recognised as a world player in the provision of Earth observation satellite systems and information.

Although originally oriented towards ice and ocean monitoring, land applications have developed as a result of both the unique and complementary nature of SAR data. Most notably, ERS-1 SAR imagery is being used by exploration and service companies for geological survey and by the European Union as a tool for monitoring within the Common Agricultural Policy.

Projects in agriculture, forestry, land cover mapping, flooding and hydrology feature strongly in the applications development programmes presented in Chapters 4 and 5 of this document, and they are maturing more quickly than anticipated. Applications in general have benefited from the mature use of optical satellite and airborne data. In many cases ERS-1 data are being integrated directly into operational services as a complementary source offering the benefits of wide area and all weather coverage.

In addition to the strong foundation provided by ESA's research and technology development and ESA's Announcement of Opportunity and Pilot Projects, development of ERS-1 applications has been accelerated through:

- National applications development programmes of ESA Member States in Europe and Canada;
- The programmes of the European Union, at Directorate General level and within the Joint Research Centre at Ispra.

The net result of these programmes has been both the expansion of applications and, equally important for the future of Earth observation, the development of a market for ERS-1 data and value adding services.

1.5. Earth observation market development

Growing availability and confidence in Earth observation data is stimulating the market and encouraging increased involvement and investment by value adding organisations and end users. Industry and user investment is occurring now at a project level and small entrepreneurial companies are being established to address niche markets on the basis of real commercial opportunities. A growing value adding and service industry is providing the essential link between data providers and market users.

The range of ERS-1 data users is large, from individual scientists and small high-tech firms to multi-institutional research groups, international companies and critical public services. Public sector users in national, European and international government are currently the primary users of Earth observation data and derived information. Demand from departments with responsibility for agriculture, the environment, pollution control, meteorological services, ice services, coastal protection, transport (especially coastal, marine and ice), fisheries, forestry and hazard management is providing a stimulus to the rest of the market.

Demand from the private sector is characteristically price and service sensitive. Requirements are diverse and the volume of data demanded is typically lower than for the public sector. However, as a result of national and European Union shared cost actions and the success of public sector applications, the private sector is gradually gaining the confidence necessary to commit to investment in Earth observation products and services. In particular, companies involved in oil, gas and mineral exploration, shipping, offshore engineering, agribusiness, timber production, insurance and civil engineering are all contributing to the demand for Earth observation data and services.

Although, in the medium term, public sector funds for research and technology will continue to play a critical role in promoting the development of the Earth observation market, demonstration of applications is fast providing an improved basis to consider larger scale industrial investment.

Demand for ERS-1 data has exceeded expectation. The value of commercial sales of ERS-1 data in 1994 was close to one million ECU. Forecast growth in the order of 15 to 20% per year, provides a good indication of the success of product and service development, increased awareness and understanding of benefits by users.

1.6. Data services

The satellite and its sensors are only part of the picture. Achievement of the application objectives relies also on the timely collection, processing and dissemination of data. To meet these objectives, operation of the ERS satellites is supported by a world wide ground segment.

ESA directly operates five ground stations in Europe and Canada for the reception of ERS-1 SAR and low bit rate data (ATSR, radar altimeter, scatterometer and SAR wave mode data). In addition, around twenty national and foreign ground stations world wide are equipped for the reception of SAR imagery complementing the global network for ERS-1 data acquisition.

Delivery of ERS-1 data to users, depending on coverage and product type, can be provided within a few hours. Fast delivery global wind and wave data are processed and dispatched within less than three hours of observation to meteorological and other operational services. Scheduled fast delivery SAR images can be made available to national centres within one day from ESA ground stations in Sweden and Italy.

ESA's SAR fast delivery services are complemented by processing systems operated at the ground stations in Tromsø in Norway, Gatineau in Canada, Fairbanks in Alaska and West Freugh in the United Kingdom. A number of other national ground stations also provide direct services to national users.

Archive data are particularly important for many users and a large variety of off-line products are being provided on request by the four processing and archiving facilities (PAFs) in France, Germany, Italy and the UK. ERS-1 has provided more than half a million distinct SAR images, each with an area of 100 by 100 kilometres, covering much of the Earth's land surface and a continuous global data set of low bit rate data.

The ERS consortium (ERSC) of Eurimage, SPOT Image and Radarsat International, supported by a network of national distributors, has been providing ERS-1 services and support to commercial users all over the world since 1992.

1.7. Looking forward

❑ Continuity of data

Operational applications rely on the reliable and continuous supply of data which must include continuity from one mission to the next. The operational instruments on ERS-2 are the same as those on ERS-1, with the addition of three channels in the visible part of the spectrum on the Along-Track Scanning Radiometer (ATSR-2) which will improve the vegetation monitoring capability, the Global Ozone Monitoring Experiment (GOME) and the Precise Range and Range-rate Equipment (PRARE). Launch of ERS-2, on April 21, 1995 provides continuity of data for users and applications development until the launch of Envisat.

Following ERS-2, the next generation of satellite, Envisat-1, with even more advanced sensors, will be launched and will take over the service to users until 2005. Beyond this the continued development of the market must face the challenge of commercially supported systems - dedicated to specific markets and applications.

❑ Tandem operation

Towards the end of 1993, it became clear that ERS-1 would remain technically operational well beyond its 30-month design lifetime. It was recognised that advantages and benefits in both research and applications could be achieved by flying two identical sets of instruments and in particular a unique SAR data set could be collected for interferometry applications. In response, the ESA Council adopted a resolution on tandem operations which will keep ERS-1 operational until May 1997 and allow tandem operations for a nominal duration of nine months from the end of the ERS-2 commissioning phase. The driving force behind this was the requirement for SAR interferometric data.

The tandem operation enhances the utility of the data for operational and commercial applications, also offering increasing data availability, frequency of coverage and unique opportunities for dual sensor applications.

❑ Product development

In response to user requirements, new products, services and applications are continually being developed and introduced. These include multi-temporal products, merged SAR and optical products for enhanced imaging, filtered SAR products for accurate mapping and classification and interferometric SAR products for generation of digital elevation models and change detection.

The potential of satellite interferometry was not fully recognised at the time of ERS-1 launch. The technique is still being developed but has already found a wide range of applications. In particular, digital terrain models from interferometry provide a potentially important data set for many applications, for example in improving flood forecasting models, determining water availability for irrigation, power production, industry and agriculture. They can be used to simulate viewing perspectives for land-use management and telecommunications network planning as well as for terrain correction of remotely sensed data from ERS-1 and other Earth observation missions. The use of SAR interferometry techniques will allow the generation of medium resolution digital elevation models over large portions of the Earth's land and ice masses. Used in a differential interferometry mode, the SAR tandem data sets will also offer the unique opportunity to detect and measure topographic changes of the order of a few centimetres for example caused by earthquakes, landslides, volcanic action and glacier motions. The plans for full exploitation of the global tandem data sets are currently being discussed by ESA, the member states and industry.

Development of new tools for extracting and presenting information are important in helping to reduce product generation times and costs. This is critical to making Earth observation products and services cost effective and accessible to more users.

2. MARINE OPERATIONS

One of the major benefits originally anticipated from using ERS-1 data was the improvement of weather and sea state forecasts for marine operations world wide. This is proving to be justified as many demonstrations of operational benefits within the marine market place and commercial services are emerging.

Marine conditions change very rapidly and can vary considerably between locations only a few kilometres apart. Consequently, weather and sea state forecasts are critical to activities such as ship routing, fishing, locating offshore installations, planning offshore operations and co-ordinating rescue services. Ship detection, feasible under certain conditions using ERS-1 data, has the potential to assist management in the busiest shipping areas of the world. Information on bathymetry, ocean currents and fronts is of commercial value to large scale engineering works such as dredging, laying pipelines and cables, assembling offshore structures, rescue and salvage. Ocean surface features are needed for underwater navigation and communications.

Errors in planning or operations related to any of these activities can be costly in terms of human lives as well as economically. Accurate and reliable information has to be delivered to the customer promptly (within hours of observation) regardless of whether the customer is in an office, on a ship or offshore installation or manning a remote coast guard station. To serve this marine market, the ERS-1 fast delivery service, development of an operational mobile communications infrastructure and the parallel development of ocean and weather forecasting models are all essential components.

❑ ERS-1 contribution

Already, use of fast delivery products from the ERS-1 radar altimeter, scatterometer, SAR and ATSR instruments is improving the accuracy and coverage of weather and sea state forecast services. As a global observing system, ERS-1 offers consistent and geographically homogenous data, filling the gaps existing with conventional observation systems. It offers monitoring and forecasting for areas of the world where such services did not previously exist. Cost benefits are being demonstrated within operational environments, by members of the marine community working together with value adding companies and research organisations supplying Earth observation services.

Use of off-line products from ERS-1 is also providing benefits in this market. Time series of sea state information are being developed as a basis for predicting conditions. This assists in a whole range of activities - planning the timing and logistics of offshore activities to minimise risks to personnel, assessing marine risks, coastal defence planning, wave energy resource evaluations and setting engineering design parameters. With the continuity of data offered by ERS-2, longer time series will increase the potential value of these datasets. Historic wave and wind information is also being used for hindcasting, to confirm ocean and weather conditions at particular locations and at specific times. This is helping insurance companies in risk analysis, settling claims and supporting other management and legal procedures.

❑ Market potential

The size, diversity and risks facing the marine industry offer potential for developing markets for Earth observation data and services. This economic potential is indicated in the example applications given later in this chapter. However, in general, it is considered that optimum ship routing can typically save up to 10% in transit time on long voyages, with corresponding savings in fuel costs. There is a growth in the number and size of ships navigating key routes across the North and South Atlantic, around the Pacific rim and Persian Gulf. The world tanker fleet has increased from 37 million dead weight tons in 1954 to 250 million dead weight tons in 1992. Several ships are now over 500,000 dead weight tons.

The pressure to reduce costs applies equally to the purchase of fuel and labour as it does to information services and the necessary infrastructure to receive this information. The cost of providing improved weather and sea state forecasting services to the shipping industry must therefore be kept to a minimum. Key factors in achieving this will include the development of a broad and global customer base to reduce unit prices, developing low cost automated procedures which generate standardised products and integration with maturing mobile global telecommunications services.

❑ Example applications

The following sections provide examples of how ERS-1 data are being used by the offshore industry, container shipping operators, fishing fleets, national coast guards, scientific cruise ships, world yacht race organisers and race participants as well as military organisations. All of these customers are active in evaluating the benefits to their organisations of improvements in:

- Sea state forecasting;
- Sea state hindcasting;
- Weather forecasting for marine areas.

Value adding organisations from the private and public sectors are active in supplying Earth observation based services to this market in Europe and North America. Those which have provided input to the examples presented below include:

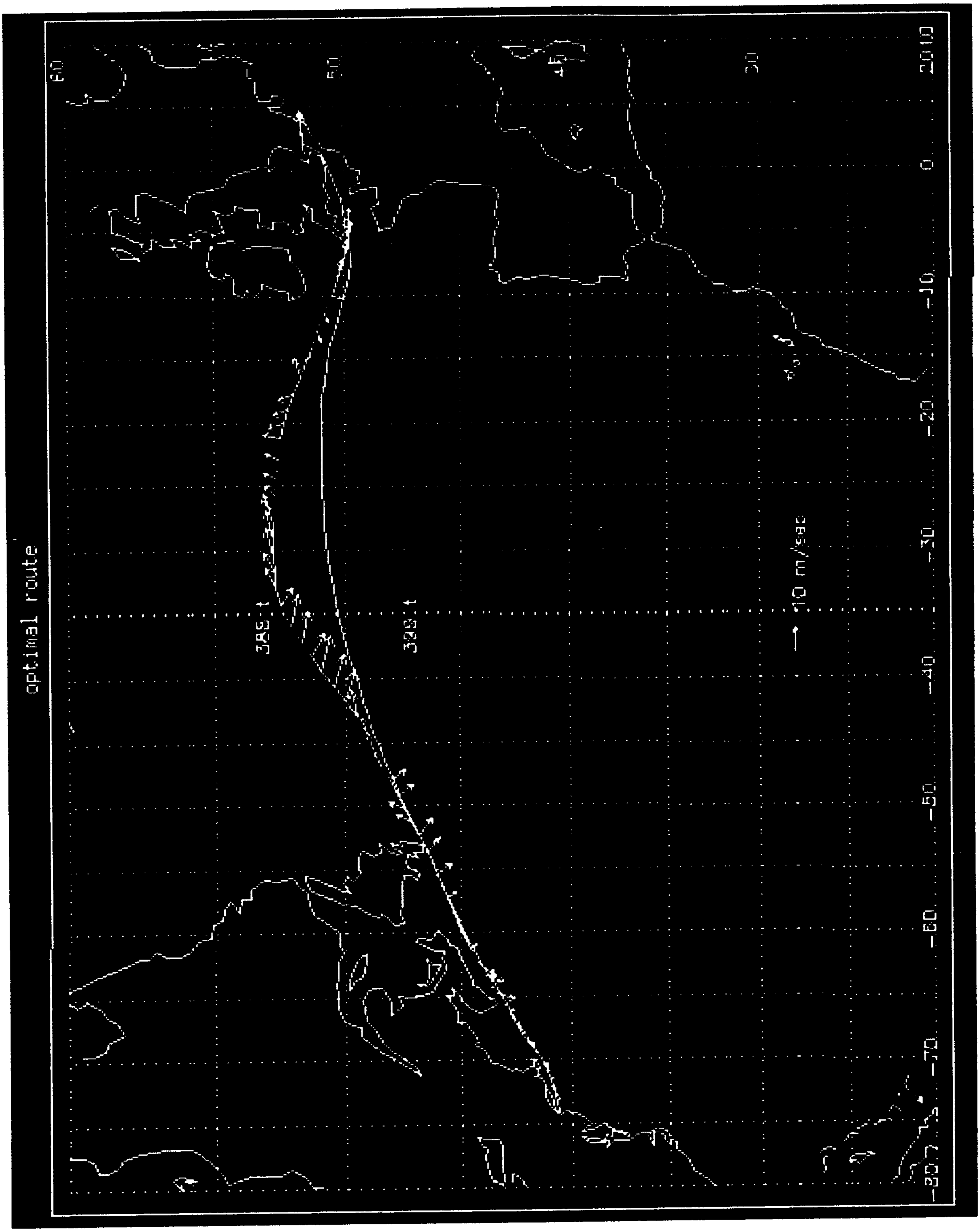
- ARGOSS, The Netherlands;
- Atlantic Centre for Remote Sensing, Canada;
- Atmospheric Environment Service, Canada;
- CLS Argos, France;
- Daimler Benz Aerospace, Germany;
- Defence Research Agency, Farnborough, UK;
- European Centre for Medium range Weather Forecasts, UK;
- James Rennell Division of the Southampton Oceanography Centre, UK;
- METEO-FRANCE, France;
- MétéoMer, France;
- Meteorological Office, UK;

- Norwegian Space Centre, Norway;
- Satellite Observing Systems, UK;
- Service Hydrographique et Oceanographique de la Marine, France.

USER COMMENT

"The normal method with weather faxes, it's a very good way of course, but it gives us only a very rough structure of the weather. We need a precise one in areas such as the Doldrums or in small passages such as Cape Horn and the Bass Strait, so satellite information is very important".

Isabelle Autissier, New York to San Francisco record holding yachtswoman.



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330 t
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50
40
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-40
-50
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-70
-80

2.1. Sea state forecasting

Figure 2.1 Forecasts for ship routing

Long distance transport by sea can be expensive in fuel and time. Furthermore, there are penalties for late deliveries or unforeseen stoppages. Considerable savings can therefore be made if shipping is routed more efficiently and through less dangerous areas. To achieve this, rapid real time knowledge of meteorological and sea state conditions is required.

A demonstration project commenced in May 1995 to highlight the savings possible by using sea state forecasts derived from a combination of ERS-1 data and a numerical wave modelling package operated at the European Centre for Medium range Weather Forecasts. The system, provided by Dornier GmbH and Daimler Benz Aerospace, has been installed on a container ship belonging to the Hapag Lloyd shipping company. The objective is to assess performance in both the North Atlantic and North Pacific regions. This demonstration will run for one year over a number of Atlantic and Pacific transits. Based on forecasts issued by the European Centre for Medium range Weather Forecasts, the computer system installed on the ship's bridge provides the captain with information on wind and sea state conditions. This information is then used to determine appropriate navigation actions to ensure an optimal route at all times. Estimates of the financial savings made as a result of route optimisations so far, are in the region of five percent of the total costs for each transit.

Radar altimeter data from ERS-1 are received by the European Centre for Medium range Weather Forecasts and assimilated into the wave forecasting model. Sea state forecasts over ten days are then produced and partitioned into their dominant wind-sea and swell components. These parameters are updated routinely every 24 hours, and additionally on the request of the ship's master. Transmission of data to the container ship is via the Inmarsat marine telecommunications satellite. In addition, wind field forecasts are also transmitted. Based on data relating drag to ship speed and sea state, a fuel cost function is evaluated. Additional penalty functions for untimely arrival, hazards and potential engine damage are determined and an optimal route minimising the overall cost function is then calculated by the on board system. The Figure illustrates a comparison for an Atlantic crossing between the 'great circle route', which minimises the distance travelled, and the optimal route based on the wind and wave forecast data. The crossing of the container ship 'Bonn Express' from Thamesport to New York took 182 hours between March 24, 1994 and April 1, 1994. The arrows along the optimal route indicate the wind conditions met during the crossing. With respect to a typical travel time of seven days and the price of oil at present, financial benefits of between 1,500 ECU and 3,000 ECU can be expected. A complete evaluation of the savings will be conducted at the end of the one year demonstration phase.

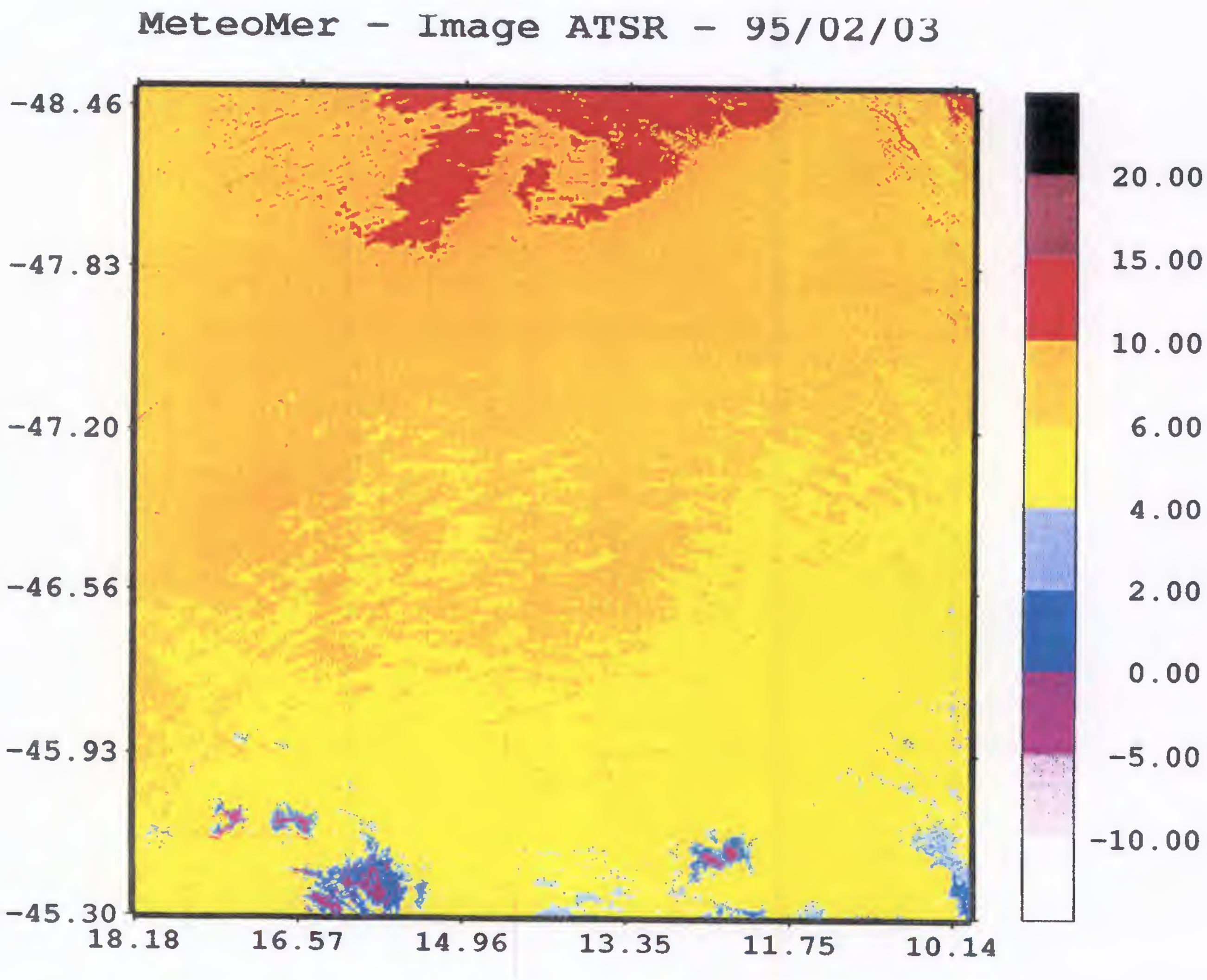
Courtesy of U Frembgen, F Jaskolla, Daimler Benz Aerospace, Friedrichshafen, Germany; A Woods, European Centre for Medium range Weather Forecasts, UK

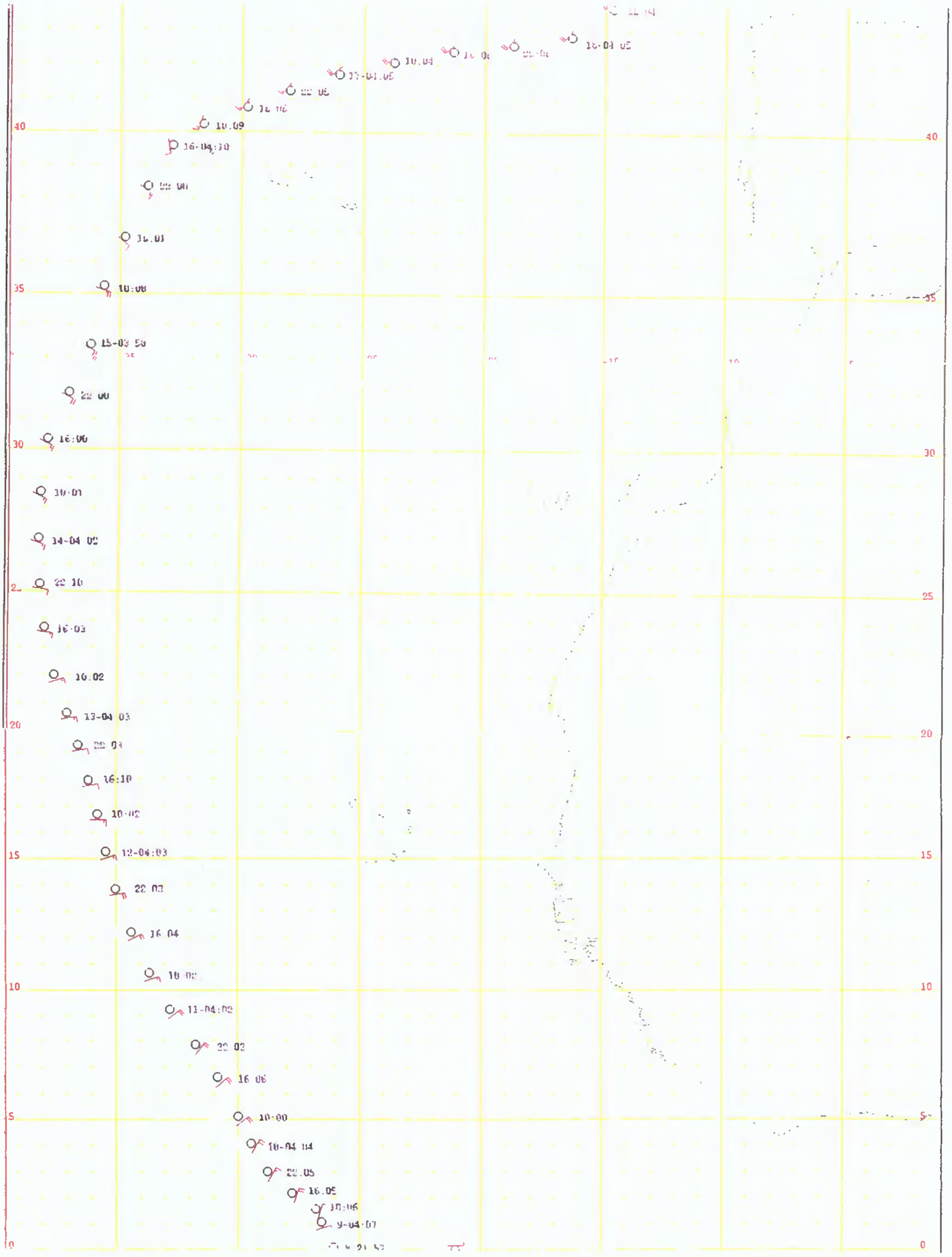
Figure 2.2 Forecasts for the Whitbread Round-the-World yacht race

MétéoMer currently provide operational sea state forecasts alongside the more traditional marine meteorological forecasts. These forecasts are based entirely on satellite data with no reliance whatsoever on in-situ measurements (for example buoy data, voluntary observing ship reports etc.). Their system is known as the Integrated Swell Forecasting System and was developed jointly by MétéoMer and IFREMER, the French oceanographic research institute. The forecasts utilise ERS-1 fast delivery SAR, radar altimeter, scatterometer and SAR wave mode data. In addition, ATSR fast delivery data are also incorporated.

One of the more spectacular applications was the provision of real time forecasts to some challengers in the notoriously competitive Whitbread Round the World yacht race. Figure a is an ATSR image of part of the Southern Ocean. Regions of strong winds were identified from the image by experienced interpreters in MétéoMer, and the information transmitted to crews. Figure b shows a wind forecast along the route taken by the yacht.

Courtesy of P Lasnier, MétéoMer, Puget-sur-Argens, France

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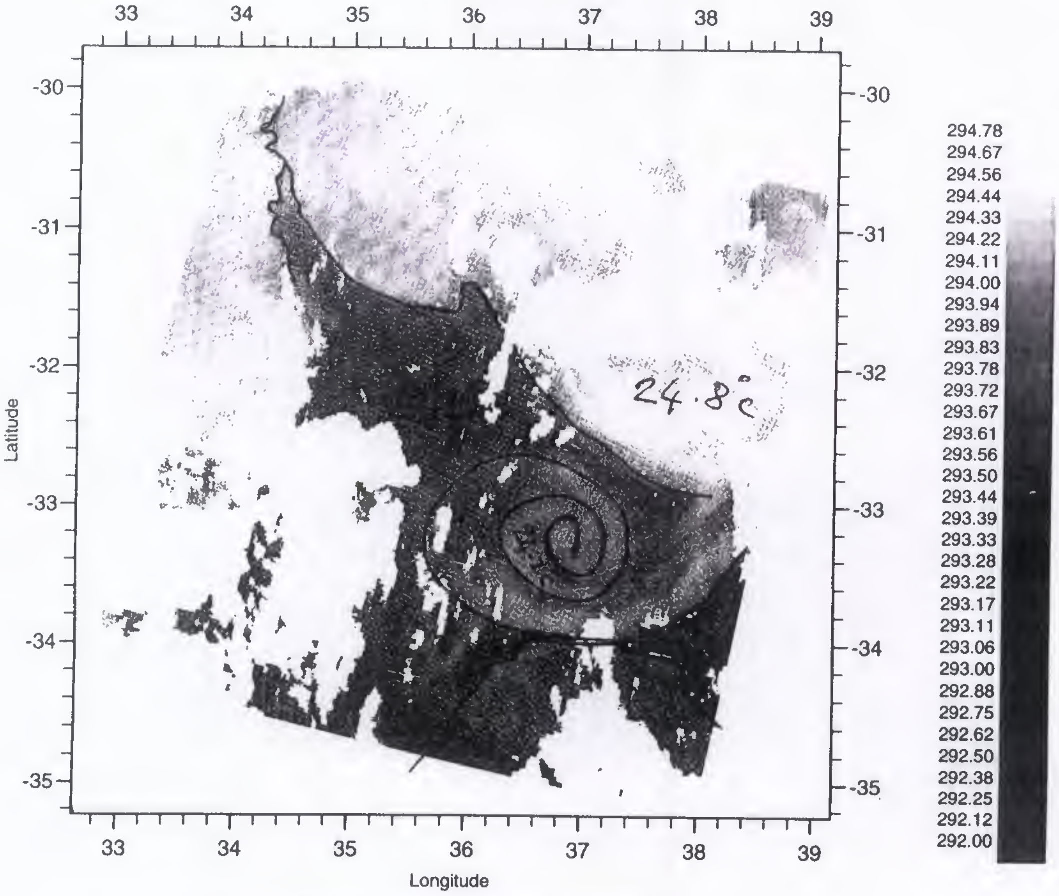

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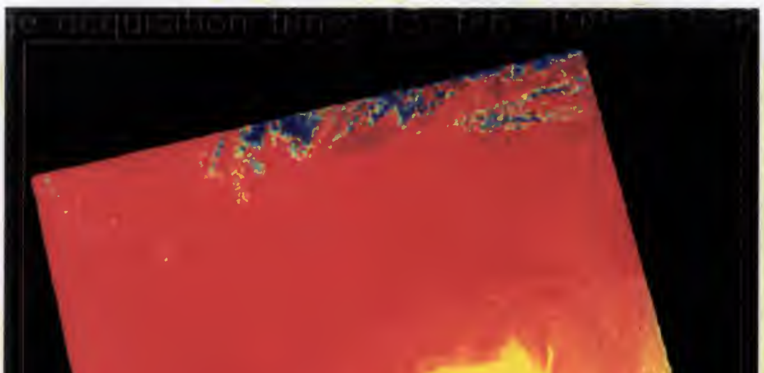


Figure 2.3 Forecasts for scientific cruises

The James Rennell Division of the Southampton Oceanography Centre ran two research cruises between January 7 and March 10, 1995. The cruises took place onboard RSS Discovery (cruises D213 and D214). They were held in the south west Indian Ocean, which is a region of high surface variability. The main concern was to provide the scientists with information about the prevailing sea surface conditions so that they could be taken into account when changing the ship's survey plans for operational or scientific reasons.

ERS-1 ATSR data were acquired in near real time from the Tromsø Satellite Station. Sea surface temperature data, derived using the SADIST processing system, were sent to the James Rennell Division in Southampton where they were quality controlled, annotated with key sea surface temperature features and then faxed to RSS Discovery for operational support. This was considered to be a cheaper method than sending compressed image data via Inmarsat. The information assisted the interpretation of features seen in the subsurface hydrographic data and was instrumental in planning the sampling strategy. It was used to help ensure that the survey track crossed the boundaries between currents. At the time of transmission of the fax shown in Figure a (Figure b shows the image from which the fax was derived) the RSS Discovery was just to the south of this image (34.8°S; 35.3°E). She was then able to proceed northwards along the western edge of the lower eddy and through the middle of the higher eddy taking conductivity and temperature measurements.

Courtesy of T Forrester and GD Quartly, James Rennell Division of the Southampton Oceanography Centre, Southampton, UK

Figure 2.4 Forecasts for offshore lifting operations

Offshore heavy lifting operations, such as the positioning of rig structures, can be carried out only if wave heights remain at a reasonably low amplitude for the duration of the operation and the period of the local swell is sufficiently different from the natural periods of the vessels involved. During such operations, decisions need to be made shortly before or during the task to ensure the safety of personnel and to minimise the likelihood of damage. These decisions must be based on accurate short and medium term sea state forecasts.

A demonstration project was carried out by Delft Hydraulics, supported by the Netherlands Remote Sensing Board, to provide sea state forecasts to Heeremac Engineering Services, an offshore engineering company, during a number of operations including heavy lifting and exploratory drilling. Figures a and b show examples of such operations. Figure a is the installation of an integrated deck onto a support platform while Figure b shows a jacket installation for Shell Nelson. Both of these operations require mild weather conditions.

ERS-1 radar altimeter and scatterometer products were used to correct first guess fields of a numerical sea state forecasting model (PHIDAS) and an improved forecast was generated. Figure c shows the wind field from the PHIDAS model, and the model corrected with ERS-1 data. SAR wave mode data, wind field forecasts from the UK Meteorological Office and wavebuoy measurements were also used. The forecast contained information on significant wave height, period, wave length and direction, as well as wind direction and strength. In addition, data on approaching swells were provided. These data were then used to compute parameters such as crane tip motions for lifting operations, to prevent high tension variations within the lifting equipment and dangerous impact forces between the lifted objects and other vessels.

In August 1995, a new private organisation, ARGOSS (Advisory and Research Group on Geo Observation Systems and Services), was launched linking data suppliers, the space industry, research organisations and end-users. Among others, the activity of ARGOSS covers the further development of the wave forecasting system to provide fully operational systems and services. Furthermore, ARGOSS is providing contract research services on the use of satellite observations to improve wave forecasts. Implementation plans are currently under development to provide pre-operational services to the offshore industry to support offshore activities in the North Sea and Norwegian Sea areas.

Courtesy of G J Wensink, ARGOSS, Am Emmeloord, The Netherlands

Original and corrected wind field

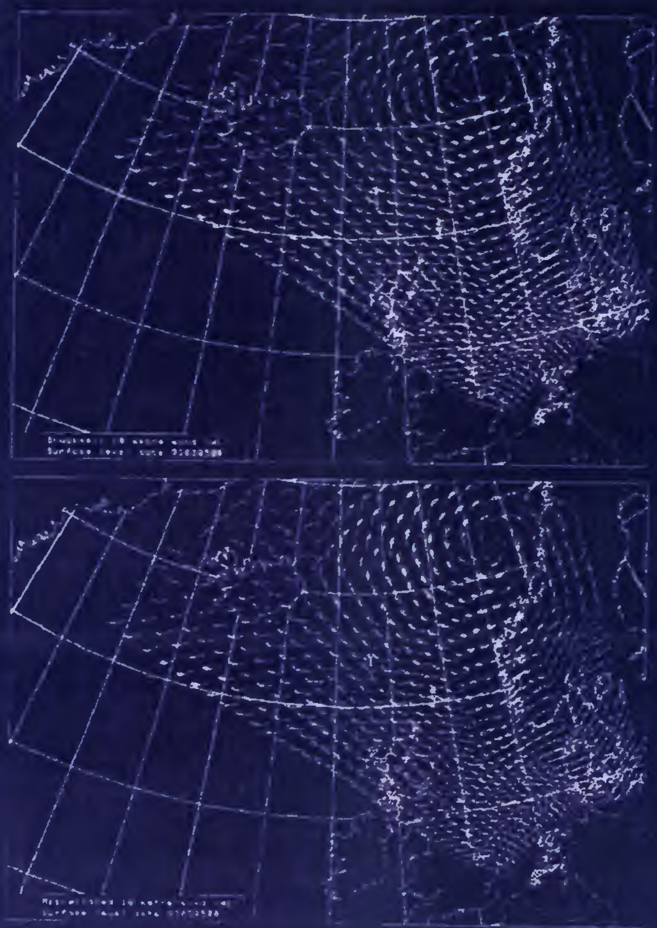


Figure 2.5 Forecasts for underwater communications

The ocean exhibits variations in temperature, density and salinity over scales that can vary from a few centimetres to hundreds or even thousands of kilometres. Mesoscale features such as currents and fronts give rise to sudden changes in ocean properties. These features strongly influence local ocean circulation. Their analysis is therefore important to optimise local navigation and, when translated into sound speed intensity, the local tuning of acoustic instrumentation. Conventional data gathering methods rely on the deployment of a number of instruments such as conductivity-temperature-depth (CTD) probes and expendable bathythermographs (XBTs). This is both expensive and time consuming. Satellite altimetry allows new and better methods, and combined with numerical modelling, opens the way to an operational forecast system.

The Service Hydrographique et Oceanographique de la Marine has developed a preliminary version of an operational system for analysing and forecasting the ocean circulation. This service, known as SOAP (SOAP is a French acronym for Nowcast and Forecast Operational System), is based on the assimilation of radar altimeter data into a numerical model of ocean dynamics. Since the summer of 1993, SOAP has been operating routinely to describe the Azores front dynamics and ocean forecast reports have been provided to Navy users every fortnight. ERS-1 fast delivery radar altimeter data and orbit data are retrieved and processed daily. The ocean current variability is derived from the local sea surface slopes calculated from the radar altimeter signal. To validate the system, outputs of the model are analysed by oceanographic experts and compared with ship measurements.

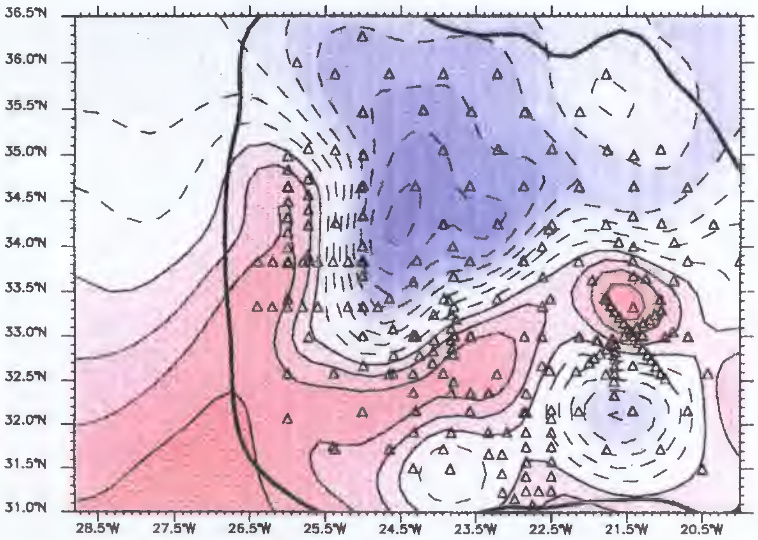
Four different measurements of the Azores front circulation at 125 metres depth on October 26, 1993 are shown in the Figures. The dynamic topography field represented on these maps can be understood as the ocean equivalent of the pressure field used in meteorology to describe atmospheric circulation. Thus, the same vocabulary (anticyclone, depression) and the practical experience in reading meteorological maps can be used. The first two Figures are based on conventional measurements: CTD probes and XBTs (Figure a), and drifting buoys (Figure b). The dark line is the validity limit of the data. The last two Figures were derived from ERS-1 radar altimeter data: radar altimeter data assimilated into an ocean circulation model (SOAP method: Figure c) and radar altimeter data only, simply interpolated to 125m depth (Figure d). Though the estimations a, b and c were based on three independent sets of data, the main features appeared clearly in the three estimations. For example, the strong depression (in blue) in the centre forcing the Azores current to meander southward (26° W) before continuing eastward (33° N) can be seen in each of the maps. Comparing Figures c and d shows how the numerical model fed with radar altimeter data improves the estimation which was calculated from radar altimeter data only.

These comparisons highlight the accuracy of ocean circulation made by a system like SOAP, based on the assimilation of radar altimeter data into a numerical ocean model. This allows oceanographic experts to analyse in quasi-real time, measured properties based on the plotted courses drifting buoys (Figure b) together with model predictions based on the assimilation of ERS-1 radar altimeter data (Figure c) and model predictions based on radar altimeter and climatology data. The position of a front can be located with an accuracy comparable to that obtained by conventional weather forecasters dealing with atmospheric phenomena. It is these fields which allow oceanographic and acoustics experts to predict the transmission properties of a given region of ocean.

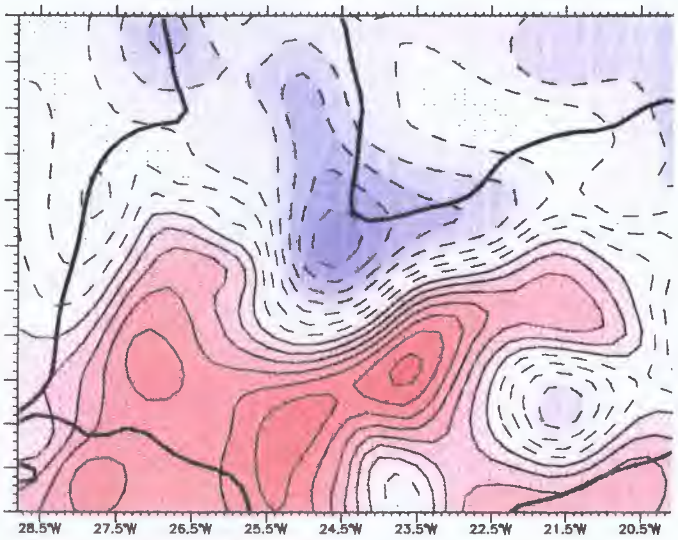
Courtesy of P Bahurel, Service Hydrographique et Oceanographique de la Marine, Toulouse, France; E Dombrowsky, CLS Argos, Toulouse, France

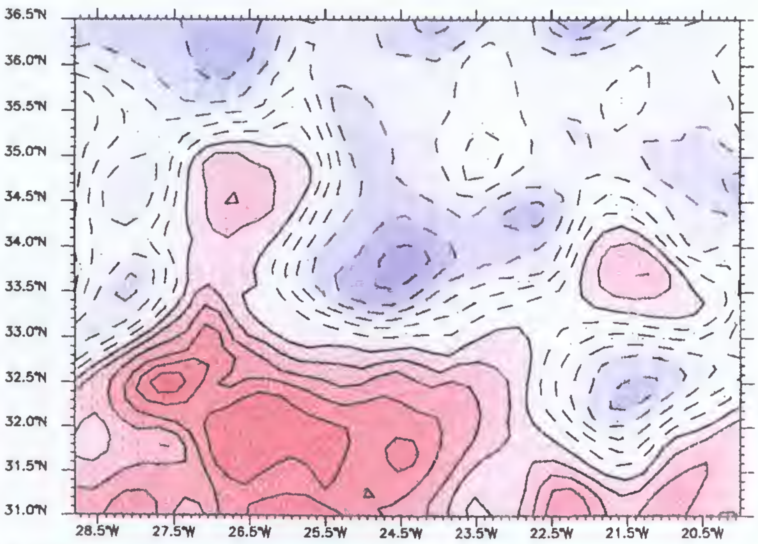
ASSIMILATION OF ERS-1 FDP ALTIMETER DATA INTO AN OCEAN CIRCULATION MODEL THE FRENCH NAVY'S « SOAP » FORECASTING SYSTEM.

125 m dynamic topography synoptic estimates - 26 october 1993 - Azores front

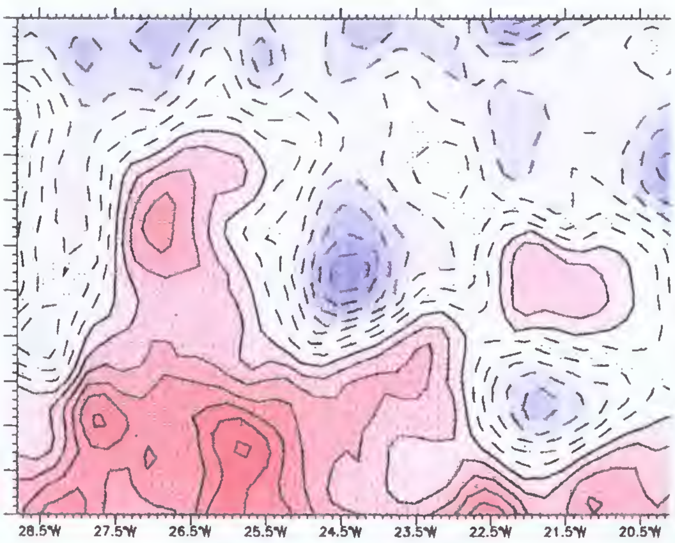


In situ measurements : CTD + XBT





Assimilation of ERS-1 altimeter data into an ocean model : **SOAP forecast**



ERS-1 data only, interpolated with the help of climatolog

ERS-1.SAR.STRIP

10km North Flight Illum.

ARCHIVE ID:	PH-FSS-00493	FREQUENCY:	5.3 GHz		COPYRIGHT ESA 1994
ACQ. DATE:	4 May 1994	POLARISATION:	VV	PIXEL SIZE:	50.0 x 50.0 m
ACQ. TIME:	10:50:36	INCIDENCE ANGLE:	23.0 DEG	GROUND AREA:	562.4 x 100.6 km
CENTRE:	50.77 N 1.11 E	ORBIT:	14642	RECIPE:	KJM100
PROCESS DATE:	23 Mar 1995	LOCATION:	English Channel		

Processed by CSC26 DRA (F) from data transcribed by DRA West Freugh.

Figure 2.6 Ship detection in the Dover Straits

A demonstration project was conducted, prior to the installation of a fully operational system, to assess the capability of ERS-1 SAR for detecting shipping in UK waters. The test area chosen was the Dover Straits, one of the busiest shipping areas in the world. The land based coastal surveillance radar data from the UK Coast Guard was used to validate the information obtained from ERS-1 SAR. As well as demonstrating the feasibility of detecting ships using SAR, the test was also designed to demonstrate the capability of the system to process the large amounts of data in near real time. The operational system is expected to be installed at West Freugh before the end of 1995.

The system relies on a new fast SAR processor, developed by the UK Defence Research Agency, which produces a strip image along 700 kilometres of ground track (Figure a). A ship detection algorithm is then applied to the image and a table of possible detections is produced. The detection algorithm incorporates a variable threshold level which is set by local statistics. In addition, there are various algorithms to identify collections of bright targets associated with single vessels and to fit an ellipse to the targets in order to determine the direction of motion. The demonstration highlighted the ability of the processor to distinguish large oil tankers and commercial bulk carriers in a variety of wind and sea conditions.

The strip image is available within an hour of the satellite overpass. Once the full system has been installed at West Freugh, ship detection tables are expected to be available within two to four hours. The product is aimed at the UK Coast Guard as well as government departments such as the Ministry of Agriculture, Food and Fisheries for fisheries protection and monitoring, and environmental protection agencies to support pollution control.

Courtesy of C Brownsword, Defence Research Agency, Farnborough, UK

2.2. Sea state hindcasting

Figure 2.7 Wave climatology service for marine engineering - Cliosat

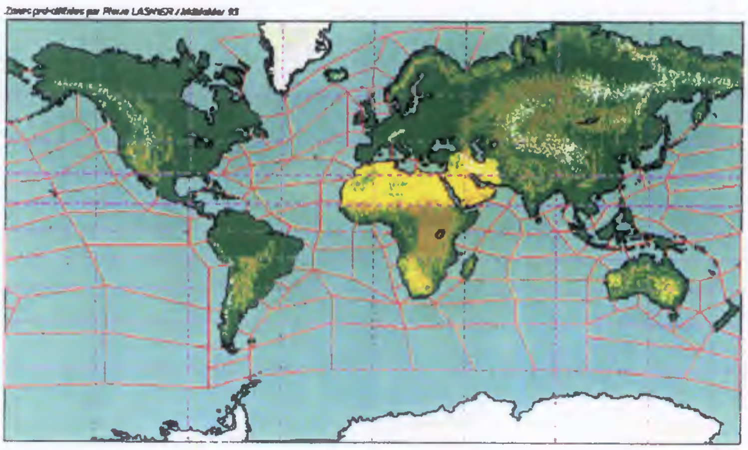
The Cliosat system is a new, commercial, wave climatology service developed and provided by MétéoMer. The system provides reliable long term statistics on climate coherent global areas (as defined within the meteorological community) and local specific areas. These are available for any part of the world, including remote and poorly documented areas, and are required primarily by marine engineers.

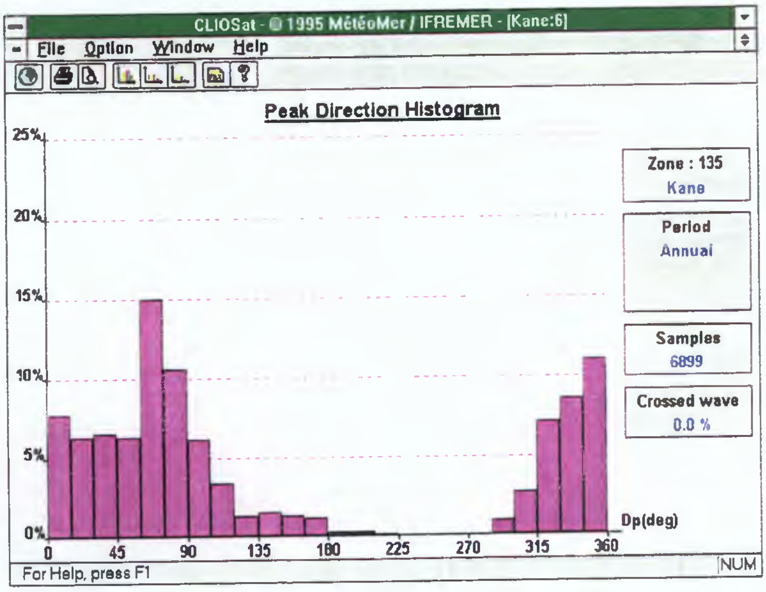
The system is based solely on satellite data including ERS-1 radar altimeter, scatterometer and SAR wave mode data. It provides standard products including:

- Statistics and histograms of significant wave height, peak period and peak direction;
- Scatter diagrams of significant wave height, peak period and peak direction combinations;
- Estimates of extreme values of wave height and ranges within specified areas;
- Information on observations.

Figure a illustrates the ocean sectors within which information is currently available. Figures b to d are examples of this information for the Kane zone. Information is available on standard CD-ROM or diskette for use with a PC. The system is expected to expand the range of services already offered by MétéoMer to the offshore engineering community.

Courtesy of P Lasnier, MétéoMer, Puget-sur-Argens, France




CLIOSat - © 1995 MétéoMer / IFREMER - [Kane:6]
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Peak Direction Histogram
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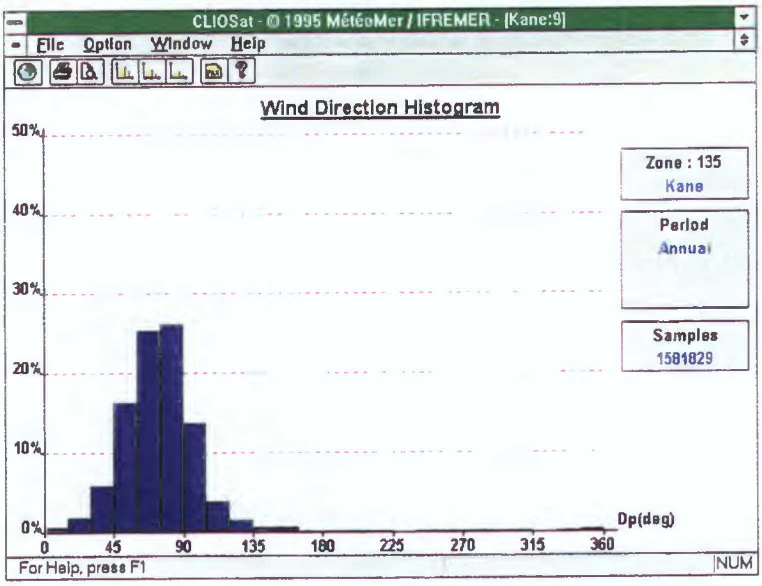
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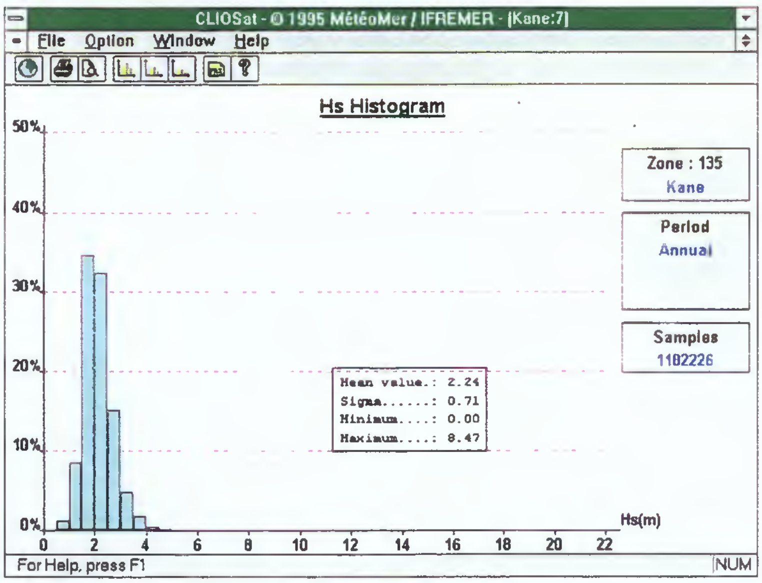
CLIOSat - © 1995 MétéoMer / IFREMER - [Kane:7]
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Hs(m)
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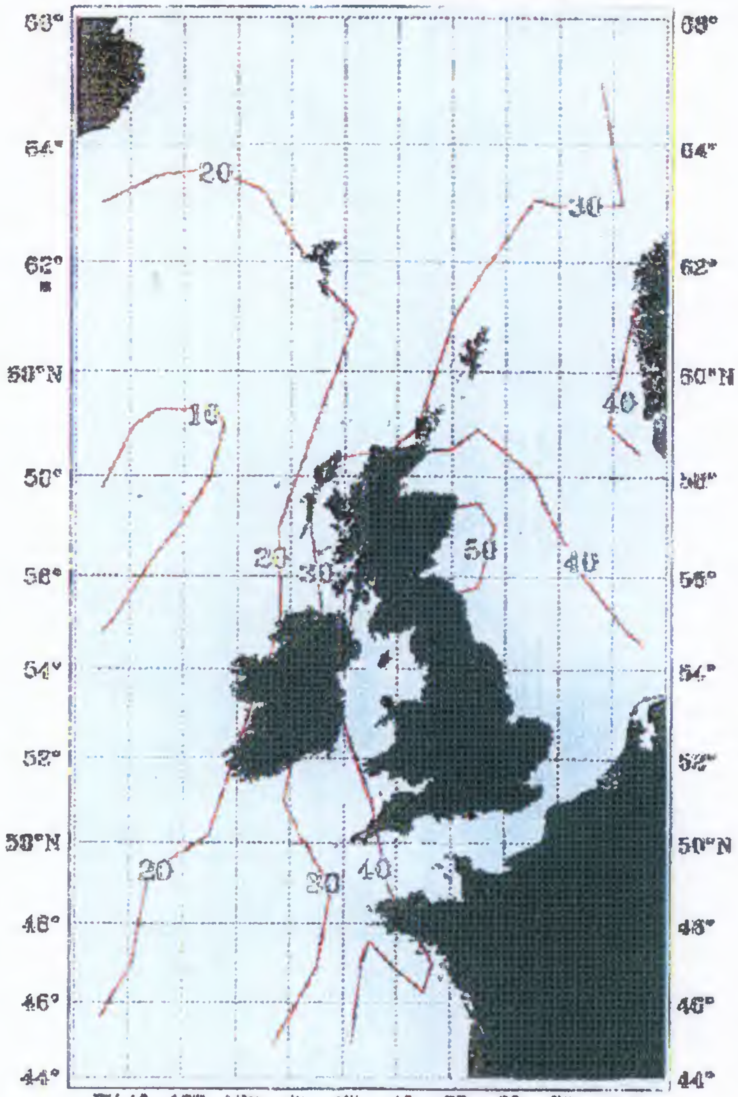
Mean value.: 2.24
Sigma......: 0.71
Minimum....: 0.00
Maximum....: 8.47
For Help, press F1
NUM

Summer: Prob. of Sea State 3 (%)
(Sign. wave height: 0.5–1.25 m)



Map 17

Figure 2.8 Wave climatology service for marine engineering - WAVSAT

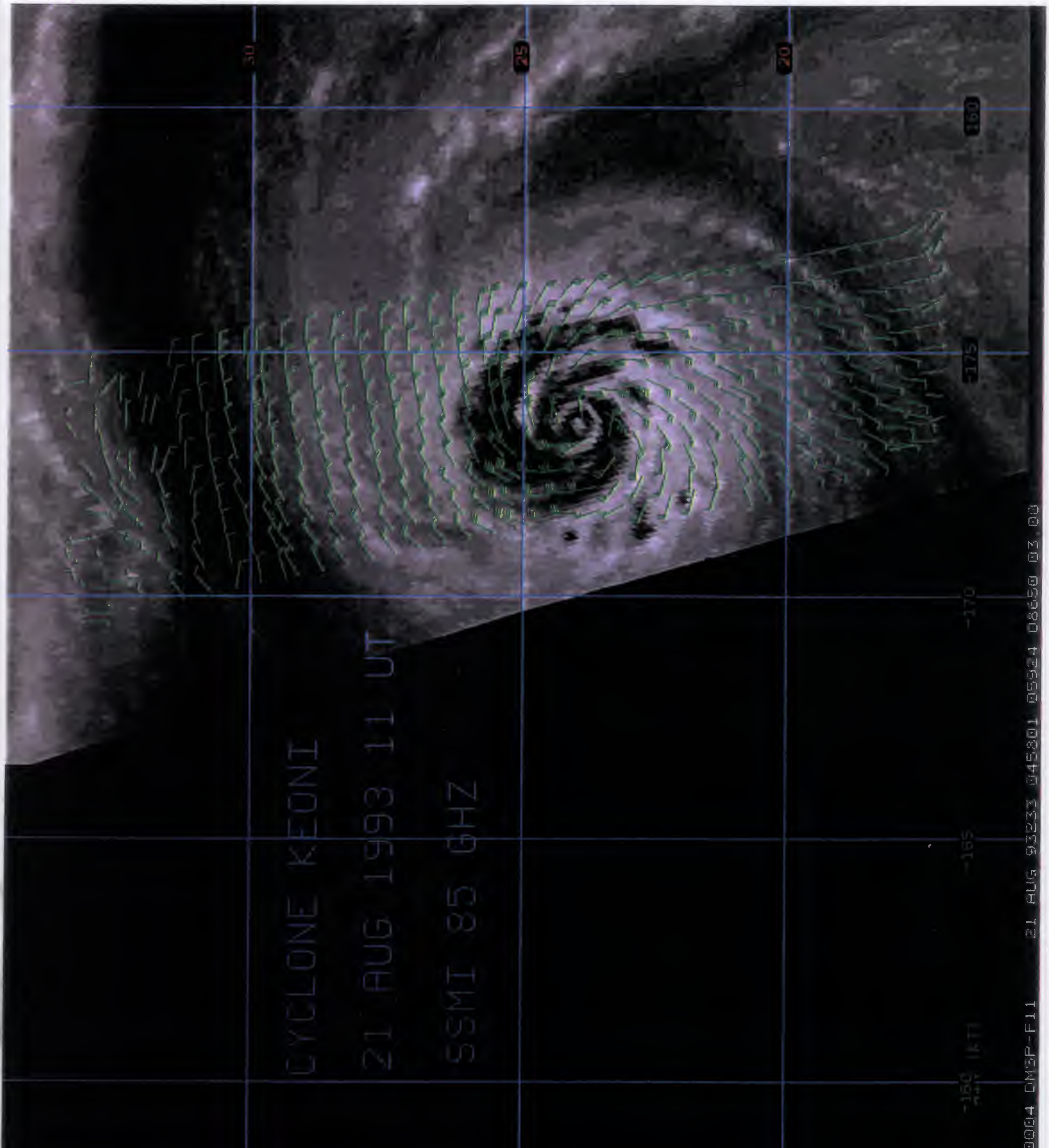
Satellite Observing Systems supply a wave climatology service, WAVSAT, to a wide variety of users for locations world wide. Typical applications have included:

- Supply of a wave climatology to an oil company planning a marine seismic survey in the Falklands area, a region where few data previously existed;
- Completion of a study for the UK Royal Navy to determine the wave climate around the UK for each season to estimate the probability of encountering various sea conditions against which sea trials of new vessels can be conducted. The Figure shows a portion of the wave climatology data provided to the Royal Navy. It shows the percentage probability of sea state 3 (significant wave height of 0.5 to 1.25 metres) occurring during the summer.

Additional users include oil and gas companies operating mobile rigs and carrying out seismic surveys, marine warranty and insurance companies required to certify the safety of marine vessels and structures for operation in particular environments, and oil production operators requiring mooring strategies for transferring oil from the well to the tanker via a riser pipe.

Off-line ERS-1 radar altimeter data comprise one source of data. Additional sources are the TOPEX/Poseidon and Geosat radar altimeter data as well as wavebuoy and visual observations for areas close inshore where radar altimeter readings become too inaccurate to provide useful results. The measurements are stored in a data base and combined using routines developed in-house for the calibration and merging of the data from the various instruments. Additional measurements are available from the James Rennell Division of the Southampton Oceanography Centre in the UK. The final product is a set of extreme and average significant wave heights for the period and location specified by the user. The analysis of a specific site can be made available within seven days and for larger studies within a matter of weeks.

Courtesy of P Stevens, Satellite Observing Systems, Godalming, UK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2.3. Weather forecasting for marine areas

Figure 2.9 Forecasting at the European Centre for Medium range Weather Forecasts

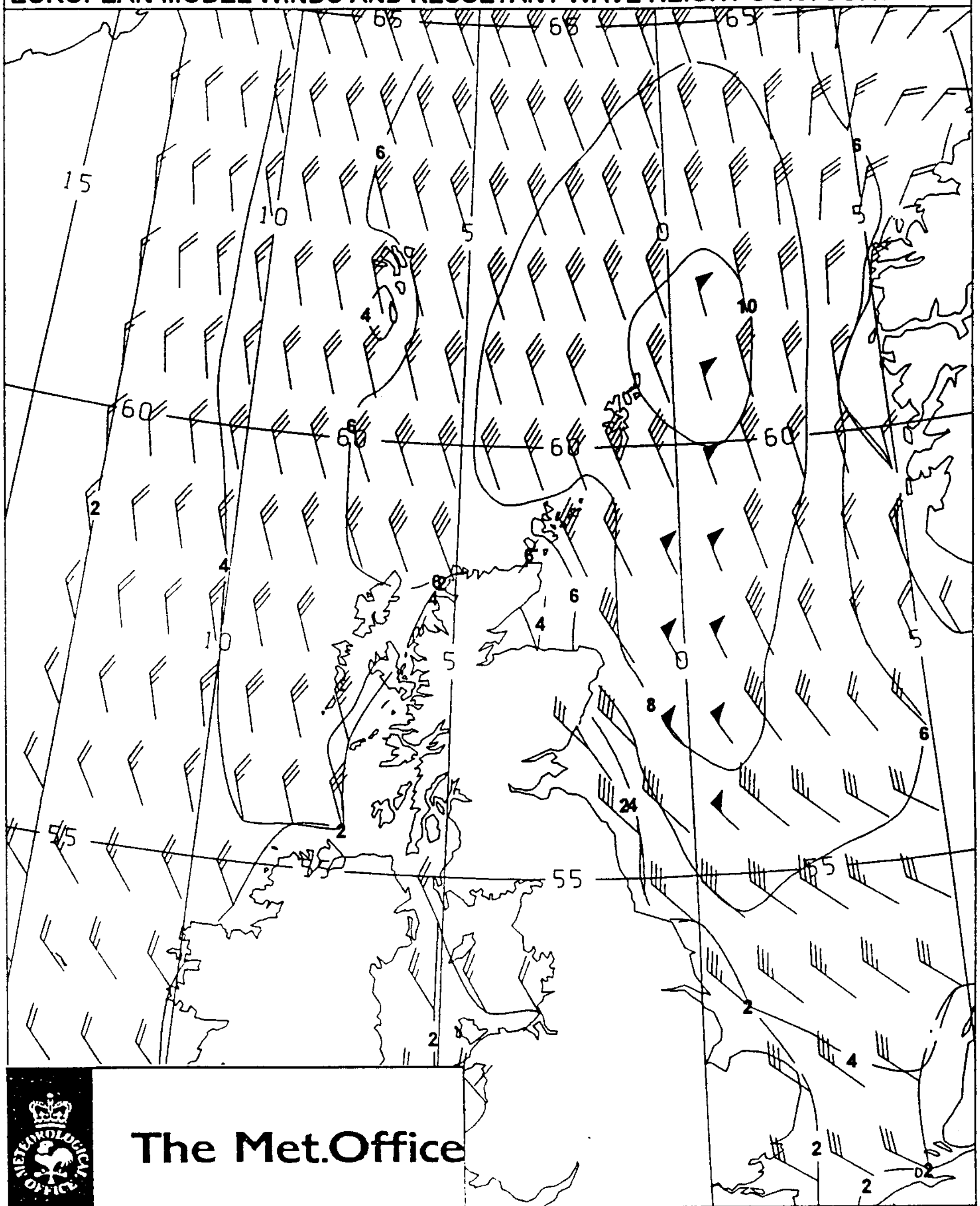
The European Centre for Medium range Weather Forecasts provides operational meteorological forecast services to the national meteorological services of its seventeen participating states as well as sea state forecasting services. This European Centre has been using ERS-1 data in the provision of meteorological services since 1992. As with the national meteorological services, a wide variety of data sources is required in the production of the initial data products on which the forecast services are based. These include ERS-1 scatterometer data, SSM/I passive microwave data and NOAA TOVS data, balloon and airborne measurements, buoy and shipborne observations and weather station reports. These data form the basis of an initial analysis field produced at 1200 UTC daily.

The numerical forecasting model, operated on a dedicated Cray C90-16 computer, then propagates the initial data forward in time steps of twenty minutes to provide forecasts in six hour steps for up to five days ahead and twelve hour steps for five to ten days ahead. Both global and regional forecasts are provided. These forecasts are transmitted to national weather services every six hours via the Global Telecommunications System. In addition to the weather services of participating states, various products are made available via the World Meteorological Organisation to other meteorological agencies.

Scatterometer data are incorporated in such a way as to correct forecast surface wind fields continually over oceans. These corrections are then propagated through the numerical model to provide corrections to other parameters such as atmospheric pressure, temperature, humidity. Trials demonstrated that the incorporation of scatterometer data could improve the accuracy of the short range forecasts by approximately five percent over forecasts where scatterometer data were not included. The Figure illustrates the use of scatterometer data to improve the accuracy of the wind data for a tropical cyclone, Keoni (August 21, 1993), so that initial values of atmospheric parameters at the model grid points better match the actual values. The superposition of the scatterometer measurements clearly improves the identification of various parts of the cyclone.

Courtesy of H Roquet and A Woods, European Centre for Medium range Weather Forecasts, Reading, UK

EUROPEAN MODEL WINDS AND RESULTANT WAVE HEIGHT CONTOURS



ANALYSIS VALID 1200 UTC SUN 01 JAN 1995

Figure 2.10 Forecasting for shipping operators and offshore oil companies

The UK Meteorological Office has been providing tailored products incorporating ERS-1 data to a number of customers, predominantly shipping operators and offshore oil production companies, since 1992. Scatterometer, radar altimeter and SAR wave mode data are incorporated into the general forecast products such as the five day ocean weather forecast. These are combined into numerical models which provide initial analysis fields of wind and wave data. Wind and wave forecasts based on these are then provided to the customer.

In addition to the general marine forecast products, specific support is available from the UK Meteorological Office to marine operators during particular campaigns. On average, around 1000 ship routing contracts are carried out annually with support provided to between 30 and 40 customers at any one time. The model predictions are analysed by experienced maritime engineers and optimal routes are recommended to the ship masters. For the oil industry, the model outputs are extrapolated to the shallow waters around the UK to provide operational advice and assistance in the planning and execution of tasks such as drilling and lifting operations. A third customer area is the coastal protection and engineering industry where users are supplied with forecast data extrapolated from the nearest grid point to the location of interest via a transform incorporating the local coastal bathymetry. Companies such as Delft Hydraulics and HR Wallingford buy such products from the UK Meteorological Office in order to provide support services, such as sea defence work, to local authorities.

As well as the forecast and real time services, the UK Meteorological Office has also established a databank of sea state conditions based on measurements collected since 1986. Commercial products, again specifically tailored to the customer requirements, are available from this databank. Typical customers are marine engineering firms analysing particular areas for construction purposes and oil companies planning and analysing potential surveying campaigns when bidding for exploration licences.

In many instances the UK Meteorological Office is competing directly with private industry for the contracts to supply meteorological services. In other cases however, the UK Meteorological Office forms a component in a consortium. For example, Oceanor, the Norwegian marine engineering company, and OceanRoutes, the ship routing company, have both collaborated on a number of projects. The commercial services supplied by the UK Meteorological Office are meeting the basic customer requirements and the level of satisfaction with the product is high. Short term market evolution is driven by the ever increasing customer expectations in areas such as graphical interface capabilities and presentation formats which is led both by the competition and by the customers capabilities themselves. The Figure illustrates a sample forecast product provided by the UK Meteorological Office.

Courtesy of J Foot, S Bell and J Hopkins, UK Meteorological Office, Bracknell, UK

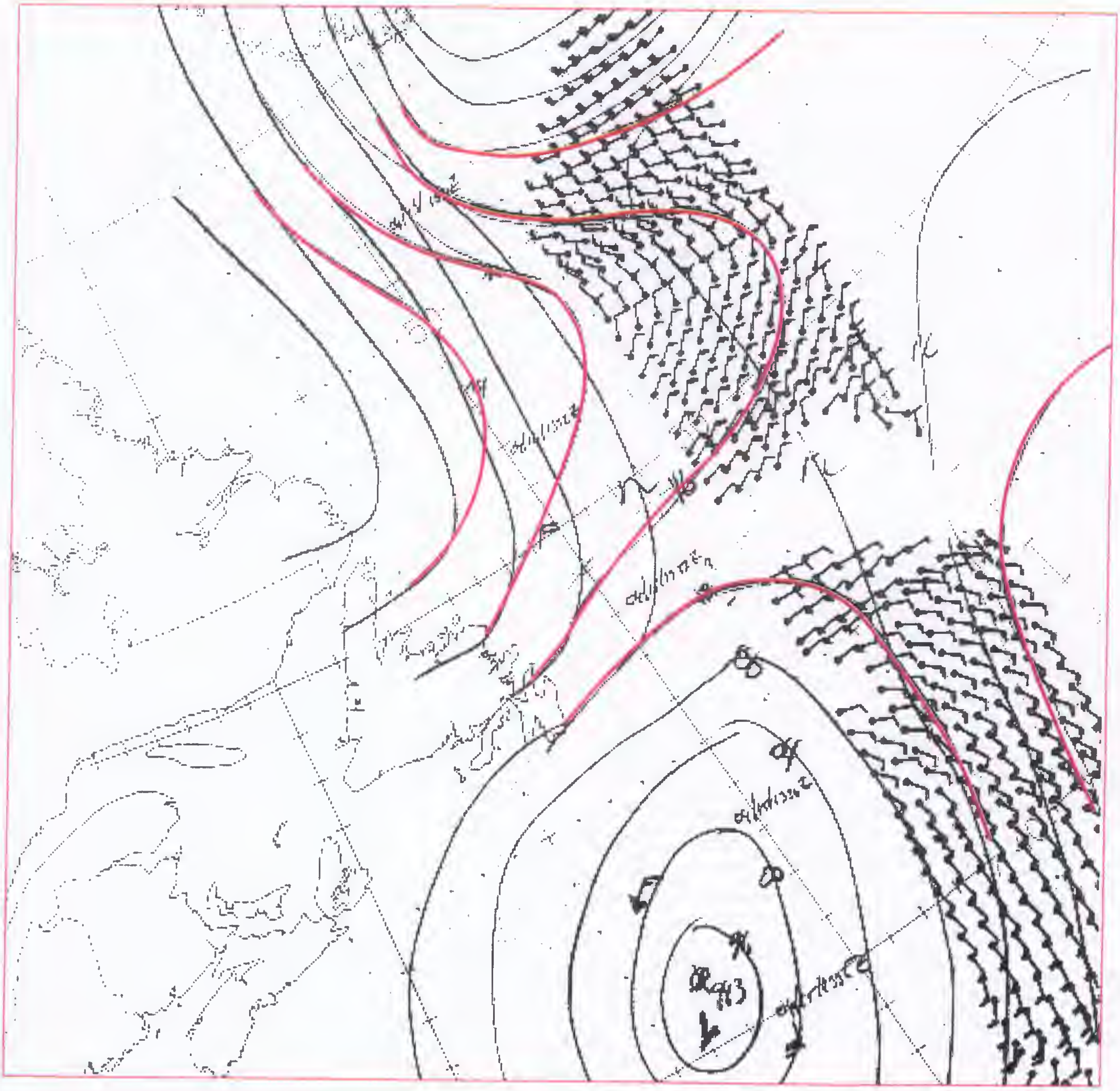
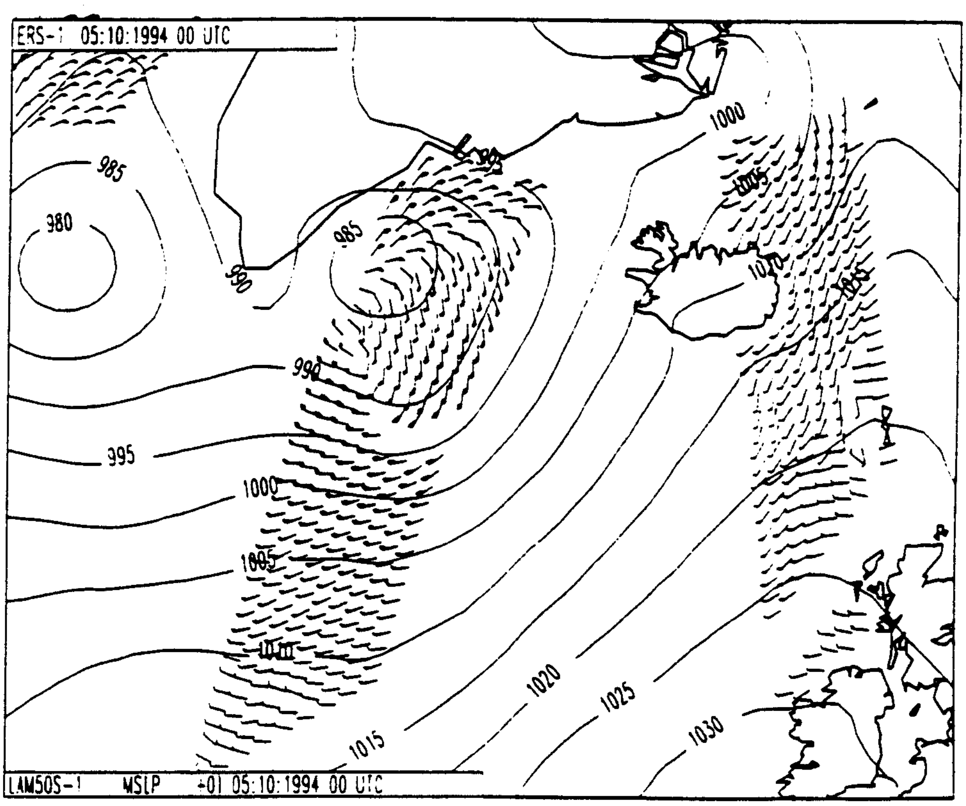


Figure 2.11 Forecasting at the Atmosphere Environment Service Canada

There are eight regional offices in Canada under the Atmospheric Environment Service with a responsibility for short range weather forecasting. Four of these offices have marine forecasting programmes. The offices located at Gander in Newfoundland and Halifax in Nova Scotia together with the Arctic Weather Centre at Edmonton in Alberta are the principal users of ERS-1 scatterometer data in the provision of operational forecast services.

Scatterometer measurements are received by the Canadian Meteorological Centre (CMC) in Montreal over the Global Telecommunications System from ESA-ESRIN. The data are then decoded and processed into "pseudo-ship" observations (so that they can easily be assimilated into the numerical prediction model) and transmitted to the regional offices. These measurements are then used to correct the numerical predictions. During the demonstration phase, significant improvements in the wind field forecasts were observed when scatterometer measurements were included. The Figure illustrates the alterations made to a pressure distribution field through the incorporation of the scatterometer data. The black lines are the isobars (contours of equal atmospheric pressure) produced by the numerical model and the red lines are the isobars generated as a result of assimilating scatterometer data. Wind field forecasts are provided to a variety of marine operators including oil and gas companies, shipping operators and the Canadian Coast Guard.

Courtesy of P King, Atmospheric Environment Service, Ottawa, Canada; B Whitehouse, Atlantic Centre for Remote Sensing, Toronto, Canada



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1025
1030

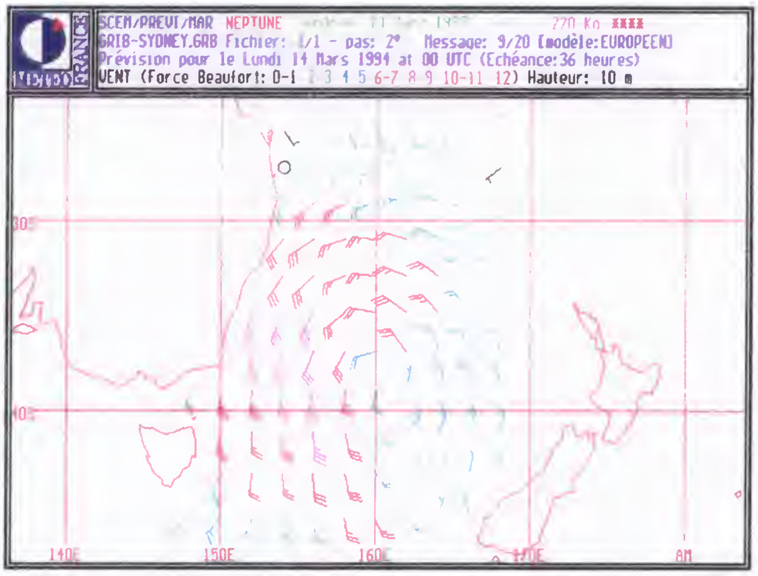
Figure 2.12 Forecasting at the Norwegian Meteorological Institute (DNMI)

ERS-1 scatterometer wind observations have been received operationally at the Norwegian Meteorological Institute (DNMI) since the launch of the ERS-1 satellite in 1991. These data have been available to meteorologists in near real time for the last two years, and their operational use in weather monitoring has increased. The scatterometer wind observations are capable of resolving mesoscale wind structures on the sea surface with great accuracy. This, combined with the high number of observations, makes the data very useful for weather monitoring and the identification of fronts and severe storms.

The fast delivery wind scatterometer observations are received at DNMI via the Global Telecommunications System and are used in two ways: subjective weather analysis and monitoring by on-duty meteorologists and objective (numerical) analysis to produce initial fields for the forecast models. The Figure shows the wind fields derived from scatterometer data and the mean sea level pressure predicted by the forecast models on October 5, 1994.

Scatterometer wind observations continue to be used operationally in subjective analyses at DNMI, and from January 1995 the data have been included in the objective analysis for numerical weather prediction models. As a general conclusion, use of scatterometer wind observations in the weather forecast models significantly improves the quality of the forecasts.

Courtesy of G D Strøm, Norwegian Space Centre, Oslo, Norway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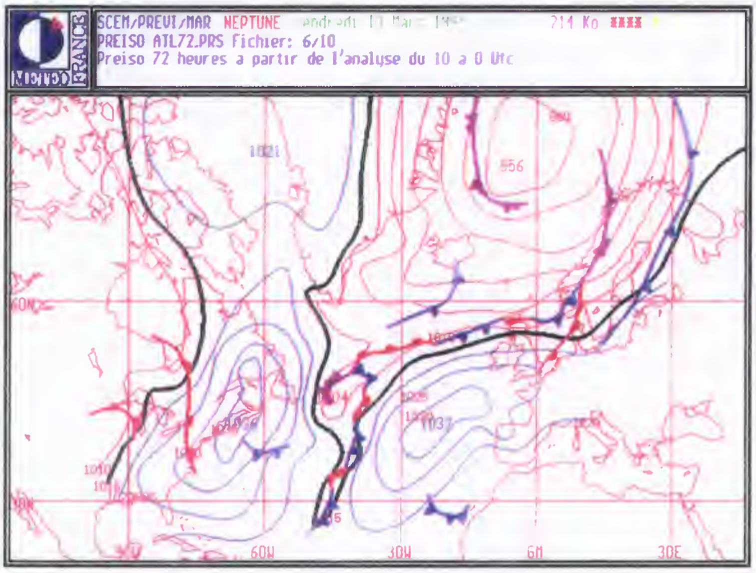
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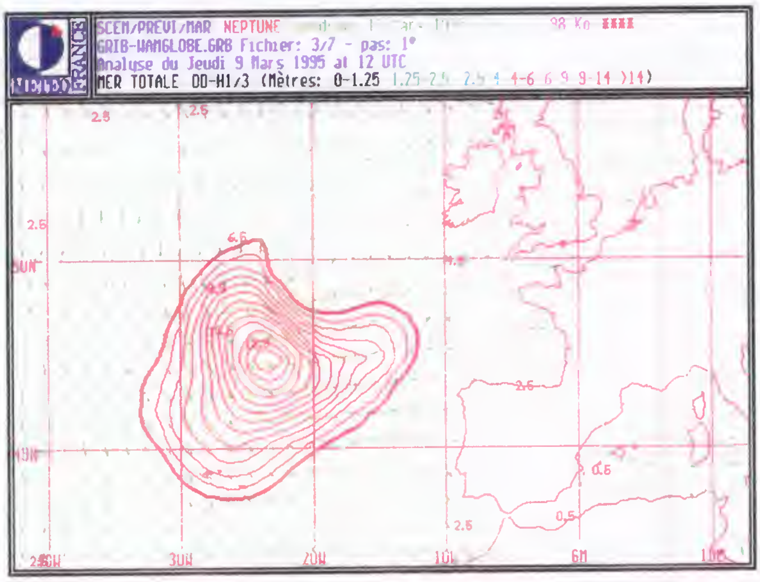
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30W
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Figure 2.13 The Neptune service at METEO-FRANCE

METEO-FRANCE has introduced the Neptune service which allows marine customers to receive meteorological data (such as numerical prediction data or charts) on a specific maritime zone or over the course of a voyage in real time. The data are transmitted via the Inmarsat C satellite to an onboard PC or Macintosh equipped with the appropriate decoding and image processing software. Received data can be viewed either in the form of a chart or alternatively in a particular user specified format for applications such as ship routing or storm warnings. Thus optimal use of both meteorological nowcast and forecast data is now possible, increasing both efficiency and safety.

Depending on the particular requirements of the customer, Neptune provides the following data:

- Pressure, wind (speed and direction) and swell (height, direction and period). Forecasts are provided with a spatial resolution of 0.5° longitude for a five day period;
- A chart of fronts and isobars containing both an analysis of the current situation and a forecast for the following three day period;
- Sea surface temperature analysis.

These products are generated from the numerical forecast data from both METEO-FRANCE and also the European Centre for Medium range Weather Forecasts. Altimeter data are already being incorporated into wave forecasts and scatterometer data will soon be assimilated both at METEO-FRANCE and the European Centre for Medium range Weather Forecasts.

Two main categories of customers have been identified and targeted with specific services:

- Fishing fleets and offshore operations (for example test drilling) where meteorological data products are available from any of seven zones;
- Shipping operators and yacht races where 'point to point' data are available along the course of the voyage. This service is costed according to the number of forecasts required. The Figure illustrates a variety of products available with the Neptune system.

Figure a: Wind speed and direction in the Tasman Sea on March 14, 1994.
Figure b: A 72 hour pressure forecast for the North Atlantic on March 10, 1995.
Figure c: Wave height and direction in the North east Atlantic on March 9, 1995.

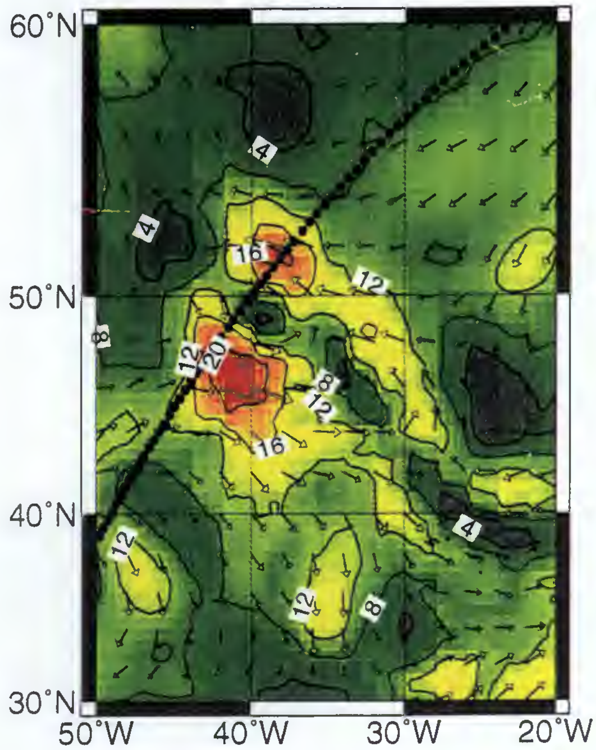
Courtesy of J Poitevin, METEO-FRANCE, Toulouse, France

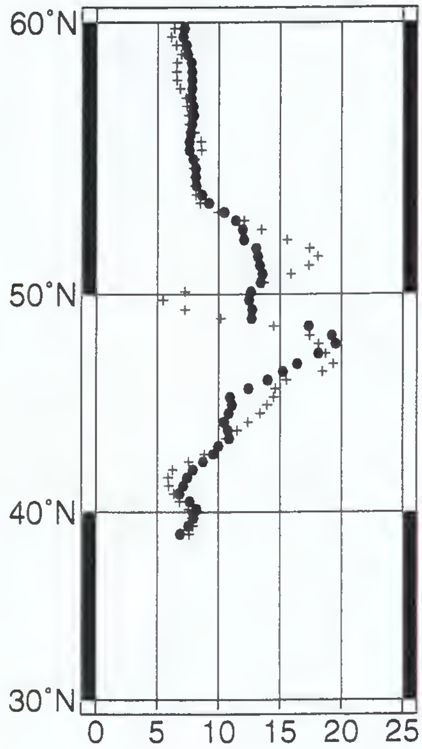
Figure 2.14 Forecasting at METEO-FRANCE

METEO-FRANCE incorporate ERS-1 data products into their standard marine forecasting service provided to shipping and offshore operators. A numerical model of the atmosphere, ARPEGE, provides basic analysis fields from which a marine wind and wave forecast is produced. The model ingests data from a number of sources including ship and buoy data, visible and infra-red satellite data and weather stations report. ERS-1 scatterometer data are also used to provide corrections to the wind fields derived from the numerical models. The Figure illustrates the differences that the incorporation of the scatterometer data make in the wind (Figure a) and wave (Figure b) field predictions. The upper diagrams show the prediction using scatterometer data while the lower diagrams show the prediction without scatterometer data for October 8, 1993. The plots on the right compare the predictions with the observed speed derived from TOPEX data. The wind fields incorporating the scatterometer data agree more closely with the observed fields in features such as the sharp wind speed peak observed ahead of the cold front (depicted as a black line). These improvements occur systematically, yielding substantial increases in the accuracy of the forecast products.

Courtesy of J Poitevin, METEO-FRANCE, Toulouse, France scatt wind 93.10.08, 12 UT

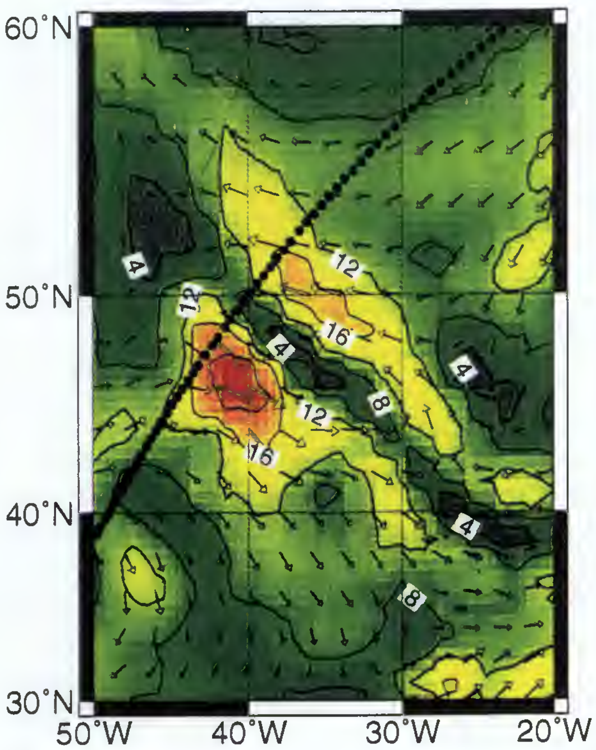
TOPEX speed

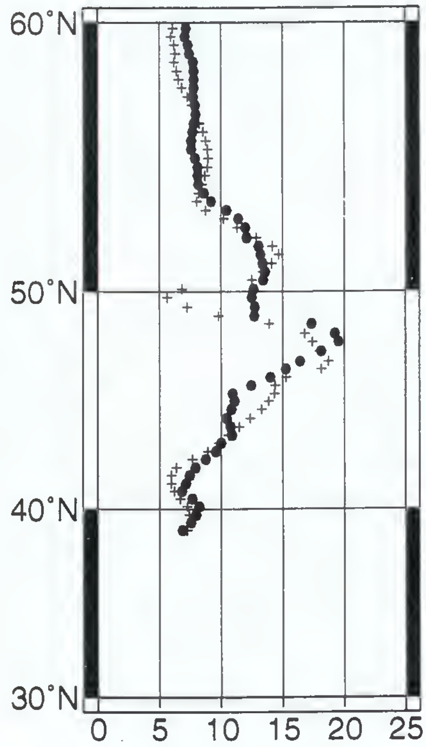




noscatt wind 93.10.08, 12 UT

TOPEX speed





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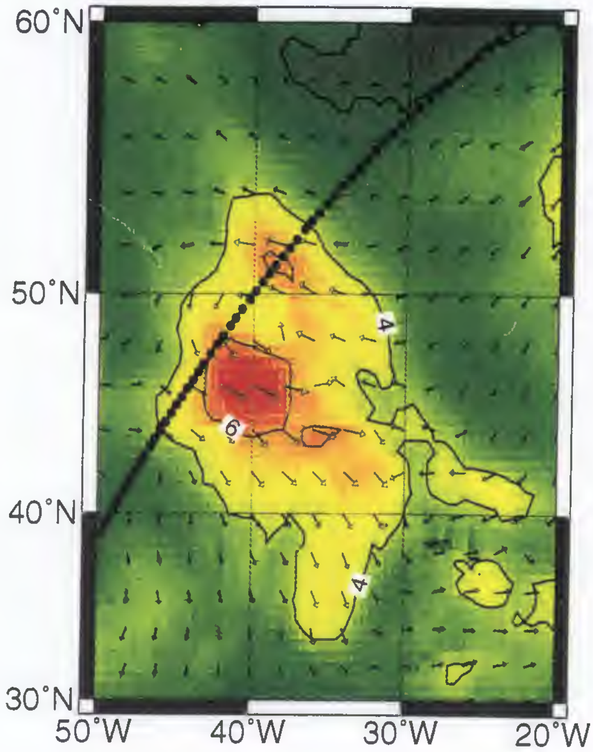
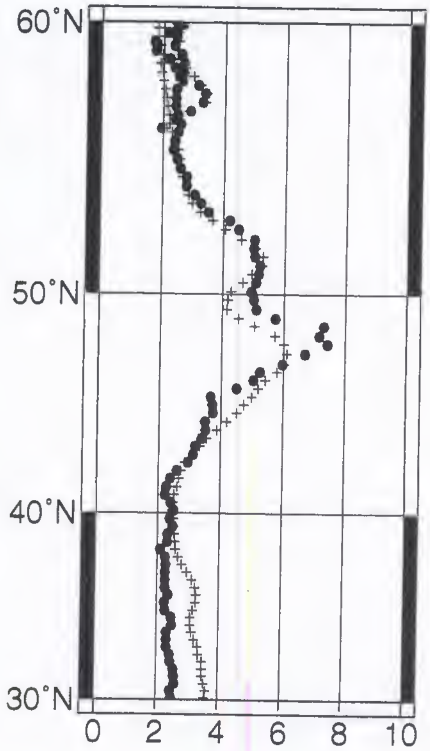


TOPEX SWH



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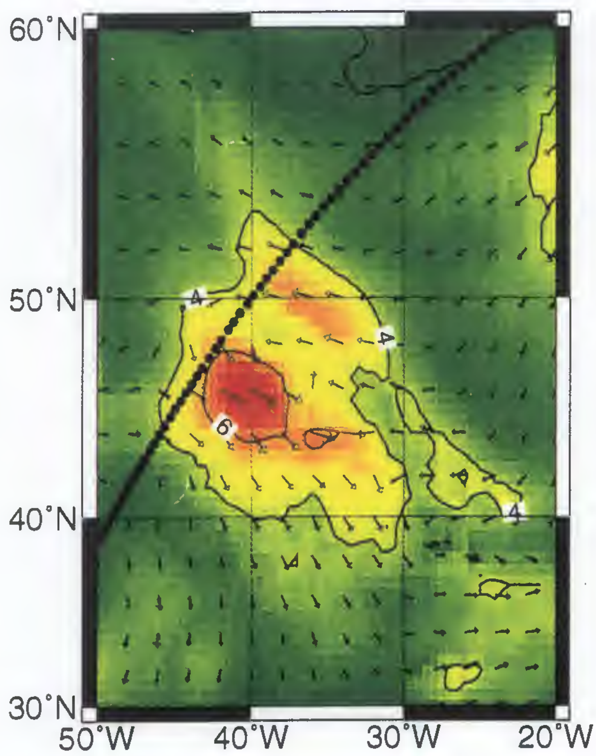
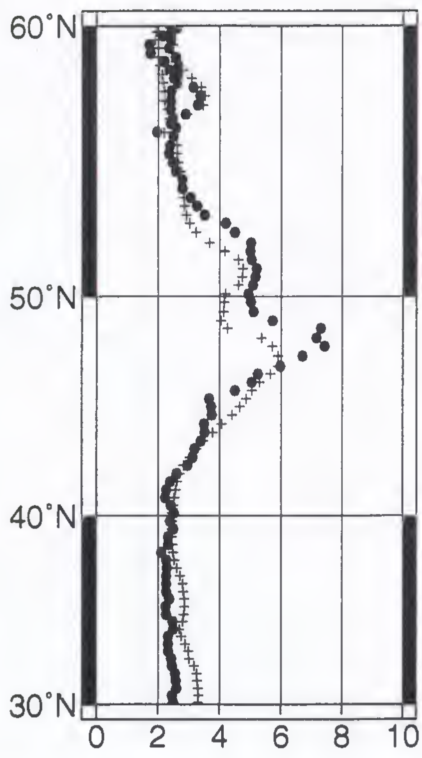


TOPEX SWH



3. SEA ICE NAVIGATION

A key objective defined for the ERS-1 mission was to stimulate improved sea ice and iceberg monitoring for offshore activities and ship routing in polar regions. As the examples in this chapter will show, ERS-1 data are being integrated into operational sea ice forecasting services in Scandinavia, Canada and the USA and new services are being developed to capitalise on this unique data source.

Daily sea ice information is required for navigation during winter throughout the northern Baltic, along the Canadian and northern USA east coasts and around Alaska, and during summer in the Russian and Canadian Arctic. Three to seven day forecasts are also needed for strategic planning. The type of information required includes location of the ice edge, definition of ice types, estimates of total ice concentration and concentration per type, and measurement of ice drift direction and speed. The ESA publication "Scientific Achievements of ERS-1" (SP1176/I) shows very clearly that data from the ERS-1 SAR can meet this information need. There is a very strong international science community from which expertise is being drawn to help develop market oriented sea ice products and evolve commercial services.

❑ ERS-1 contribution

The benefits of using Earth observation data for sea ice navigation were well established before ERS-1 was launched. Operational sea ice services have incorporated a range of satellite and airborne data into forecasts since the 1960s. The ERS-1 SAR is providing important additional sources of information, available in all weathers and during the hours of darkness. These complement traditional satellite sources.

Fast delivery data services from ERS-1 and high bandwidth communications for mobile users operating near or within the ice edge or in thick pack ice that typically exists in the polar regions, are critical. In many cases, ice breaker, ship or rig personnel wish to receive full resolution satellite images to perform their own interpretation (see user comment).

Historical information is also being used to develop specialised sea ice data bases for establishing design parameters for ships and offshore platforms and to select optimum shipping routes. Such statistics of ice conditions also help in real time operations to estimate the degree of anomaly in the present ice situation as an input to long term forecasting.

❑ Market potential

Sea ice services have been established in many countries with ports that are frequently affected by sea ice. Some ports can remain ice bound for nine or ten months in the year. This causes expensive delays and generates additional hazards for shipping. In many cases, ice breaker support is essential for trading and importing vital raw materials.

Ice forecasts are normally provided by a national agency, as maintaining access to sea routes is vital to national economies. Countries which provide such forecasts include

China, Russia, the USA, Norway, Canada and the states surrounding the Baltic Sea (Finland, Sweden, Denmark, Germany, Poland, Estonia, Latvia, Lithuania and Russia). The agency responsible for the service varies from country to country and includes national meteorological agencies, environmental and transport ministries.

The market for sea ice information services is dominated primarily by ice breaker operations and also by the needs of oil and gas exploration companies operating in polar regions. Exploratory drilling and operational production can be safely carried out only with accurate and reliable ice information. Supplying the operation sites as well as transporting the oil places additional demands for shipping and support from ice breaker services.

Due to the high biological activity in the marginal sea ice zone fishery fleets are also very interested in knowing the position of the ice edge. It is economically vital that environmental conditions are well understood to develop optimal production and distribution strategies. Scientific and tourist cruises operating in polar regions, as well as insurance companies also have an interest in improved information.

As an indicator of market potential, between 1890 and 1977, 250 merchant vessels over 100 tonnes were lost due to ice. In the period 1970 to 1983, 231 ships were identified that had been damaged by ice in Arctic waters. It has been found that strengthening the ships is not the best solution, but improved navigation through and around ice is of much greater importance.

❑ Example applications

The following sections present examples of how ERS-1 data are assisting ice breakers in the Baltic, the Barents Sea and Greenland shipping areas, the coast guard, shipping and oil companies operating in Canada and Alaska, shipping in the Northern Sea Route and the Great Lakes and ocean drilling in the Greenland Sea. Two types of services can be distinguished:

- Operational sea ice services in Canada, Denmark, Finland, Sweden and USA;
- Activities aimed at providing direct support to customers who need more extensive ice monitoring information than can be offered by the operational services. Many of these are still at the demonstration level.

As the examples below demonstrate, ERS-1 SAR data are being used operationally within well established national sea ice services. This use is based mainly on visual and therefore manual interpretation. In parallel, value adding companies in Europe are developing the next generation of dedicated workstations which incorporate new results from the science community to automate feature interpretation and tracking. Demonstration projects being conducted by the Nansen Environmental and Remote Sensing Centre in Norway, GEC Marconi Research Centre and Earth Observation Sciences Limited in the UK, have been undertaken as part of these developments and some examples are given below.

In addition, limited demonstrations are also being performed using ERS-1 data in areas where ice services are not currently using ERS-1 data. These demonstrate the use of sea ice information in areas where there is potential for increased shipping and offshore exploration, but where there is limited commercial activity at present. The Northern Sea route between Europe and Japan is an example of such an area. This route is only navigable with ice breaker support, so efficient deployment of the ice breaker fleet is essential. In addition to financial savings from shorter transportation routes along the northern coast of Russia, additional economic opportunities arise from the fact that the East Siberian and Kara Seas are rich in hydrocarbon deposits.

To be understood by all users, ice charts are constructed by the operational ice forecasting agencies, in a standard format. This format is specified by the World Meteorological Organisation (WMO) and known as the "WMO egg code". It takes the form of an oval icon corresponding to a designated region of a sea ice chart. The icon usually includes four lines. The first contains a single number that represents the total ice concentration, reported in tenths. The second comprises partial concentrations (also in tenths) of existing ice types. The third includes numerical codes to designate ice types. The ice type is an indicator of the development stage, or equivalently, the average thickness (measured in centimetres and calculated for the local region of the map) of the four ice classes present within the map area. The fourth line has codes which correspond to the predominant ice forms. Examples of such icons can be seen in the ice charts illustrated within this chapter although regional variations to the code do exist.

The examples below have been provided by the following value adding organisations:

- Atmospheric Environment Service, Canada;
- Danish Meteorological Service, Denmark;
- DOC/NOAA/NESDIS Office of Research and Applications, USA;
- Earth Observations Sciences Limited, UK;
- Finnish Institute of Marine Research, Finland;
- GEC Marconi Research Centre, UK;
- Nansen Environmental and Remote Sensing Centre, Norway;
- NOAA Great Lakes Research Laboratory, USA;
- Swedish Meteorological and Hydrological Institute, Sweden.

A user survey to determine the impact of including ERS-1 SAR data within the Swedish Meteorological and Hydrological Institute (SMHI) sea ice services, was conducted from January 18 to March 31, 1995. Log forms were completed by ice breaker officers on each occasion where SAR data were utilised. SAR data were distributed to five different ice breakers.

Evaluation of SAR aboard ice breakers

The limitation of the transmission system (this was intended as a demonstration system only and primarily for text transmission) was cited as the primary constraint with the result that in most cases, only two ice breakers had regular access to the SAR data. However, these ice breakers did find the SAR data useful and the following user comments were made:

- Interpretation of the imagery is not a problem as ice breaker officers are used to sophisticated ship radars and seem to have no problem adapting to SAR. The interpretation was evaluated on a scale from one (interpretation easy) to five (interpretation difficult). The overall ranking turned out to be 1.9 on average;

- Information about ridges, an important feature in winter navigation, was quite well furnished by the SAR images. According to the questionnaire:

➔ Known ridges were almost always recognised;

➔ New, previously unknown, ridge features were detected in the SAR data in approximately 20% of the images;

➔ In only 8% of the SAR data could ice information of relevance to navigation not be identified.

- There were many occasions where operational use of the SAR information had a direct influence on the service provided by the ice service. During the period January 19 to March 11, 53% of the images were used for vessel assistance and 33% for ship routing. Although based on a limited data set, these results broadly indicate the usefulness of this information and how the imagery were utilised on board the ice breakers. Comments added to the questionnaires indeed strengthen this conclusion. The comments on the SAR data were broadly as follows:

➔ Very sharp and distinct image;

➔ Images show that correct routes were chosen;

➔ Leads and cracks are easily recognised;

➔ Ridge areas stand out well.

There were only two difficulties reported concerning the use of the SAR imagery. These were that the ice type could be difficult to identify and that the distinction between ice and open water could not be definitely identified in a number of cases.

- One particular case where SAR data could have provided invaluable assistance provides an example of what would occur in general if the SAR data were not available. On January 19, the ice breaker Ymer was required to assist a merchant vessel which was caught in an area of thick ice ridges outside the port she had just left, assisted by the local ice breaking tug. No information of the prevailing ice situation was available so the merchant ship was left in the drift ice by the tug awaiting ice breaker assistance. As noted by the master on board Ymer, had the SAR data been available, local harbour authorities could have been informed about the ice situation and the tug told to assist the merchant ship to a location some nautical miles ahead where only a thin ice cover was present and where the merchant vessel could have managed independently of ice breaker assistance.

Summary

The SAR imagery were most frequently used in producing and controlling the daily ice map of the northern most part of the Baltic Sea. The SAR coverage of the Bothnian Sea covered the area where shipping and ice breaking operations are frequent. The imagery were used for ice mapping, ice breaker operations and ship routing. The images were highly appreciated and easily interpreted by the crew. It was concluded by several ice breaker masters that an image resolution of 100 metres was sufficient to distinguish ridged areas and at the same time obtain a sufficiently large geographic coverage per image.

Swedish Meteorological and Hydrological Institute

3.1. Operational sea ice services

Figure 3.1 Sea ice monitoring in the Baltic Sea

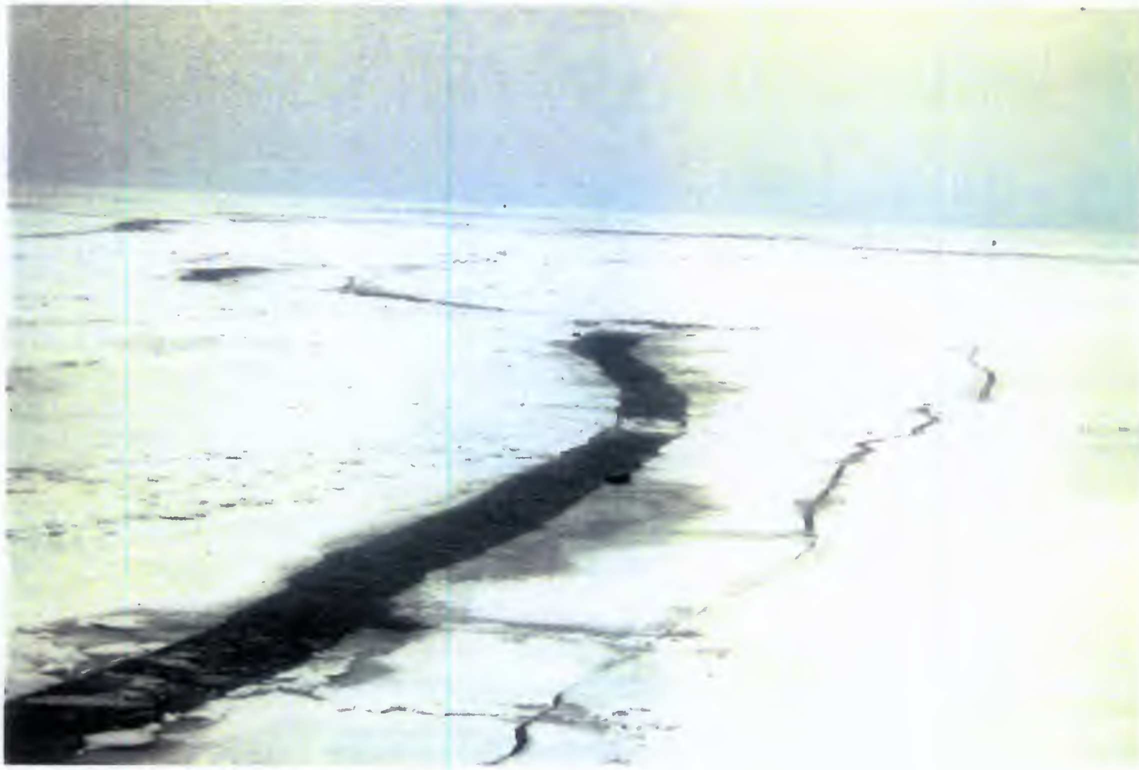
The Swedish and Finnish ice breaker fleets have been co-operating since 1958 in the provision of ice breaker support to shipping operating in the ice infested waters of the Gulf of Bothnia (Figure a). The Finnish and Swedish Ice Services, operating under the Finnish Institute of Marine Research and the Swedish Meteorological and Hydrological Institute (SMHI) respectively, provide an operational ice monitoring and mapping service to shipping authorities and also to the ice breakers operated by the Finnish and Swedish Boards of Navigation. These operations aim to keep major Finnish and Swedish ports open all year round.

Ice information is compiled from NOAA AVHRR imagery, ice breakers, fixed observing stations and aerial reconnaissance. In addition, the Ice Services have been incorporating ERS-1 SAR imagery since 1993. The ice information is issued on a daily basis. Low spatial resolution SAR images are produced by Tromsø Satellite Station and transmitted via Internet both to the Technical Research Centre of Finland (VTT) and to the SMHI. At the Technical Research Centre of Finland, the data are geometrically rectified before being retransmitted both to the Finnish Ice Service and to the individual ice breakers over the Nordic Mobile Telephone (NMT) network. Currently SAR images are used directly by ice breaker captains to optimise their route. At SMHI, the images are visually interpreted by experienced ice analysts to identify ice types. The SAR data are also combined with the pre-existing data sources such as in-situ reports and NOAA AVHRR images by both the Finnish Ice Service and the SMHI to produce charts of ice conditions and sea surface temperature for the Baltic Sea. Examples of such charts are shown in Figure b (Finland) and Figure c (Sweden).

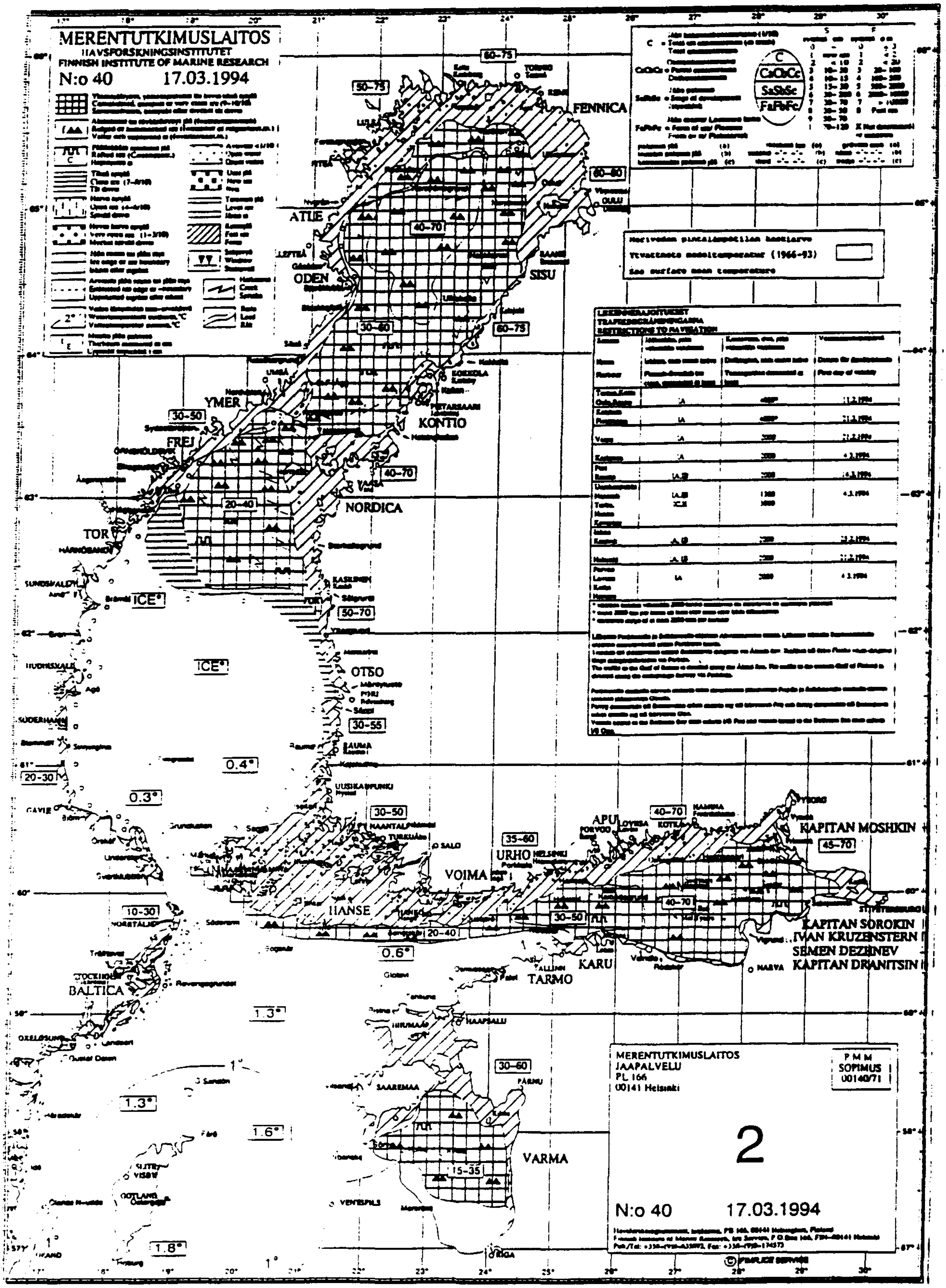
In addition, particular ships can be advised by radio on the location of useful leads in the ice, thus removing the need for ice breaker assistance. Operating an ice breaker service is extremely expensive. The annual operating costs for the Finnish Board of Navigation ice breaker fleet are estimated to be in the region of 20 to 30 million ECU. So there is a major incentive to optimise fleet deployment. There is considerable ship traffic during the ice season. During a normal winter season, some 1,500 to 2,500 cases of direct ship assistance are provided by Swedish ice breakers and Finnish harbours are visited on average 4,000 times during the period of ice cover. Cumulative operating costs for merchant shipping in ice infested waters are large when fuel costs and ice related delays are accounted for. The improved level of service provided by the Baltic Ice Services as a result of the incorporation of ERS-1 SAR imagery together with the optimal deployment and routing of the ice breaker fleets can therefore generate substantial cost savings. Studies have shown that the level of information contained within a SAR image is superior to that contained within a NOAA AVHRR image for this application.

Courtesy of H Gronvall, Finnish Institute of Marine Research, Helsinki, Finland; B Håkkensson, Swedish Meteorological and Hydrological Institute, Gothenburg, Sweden

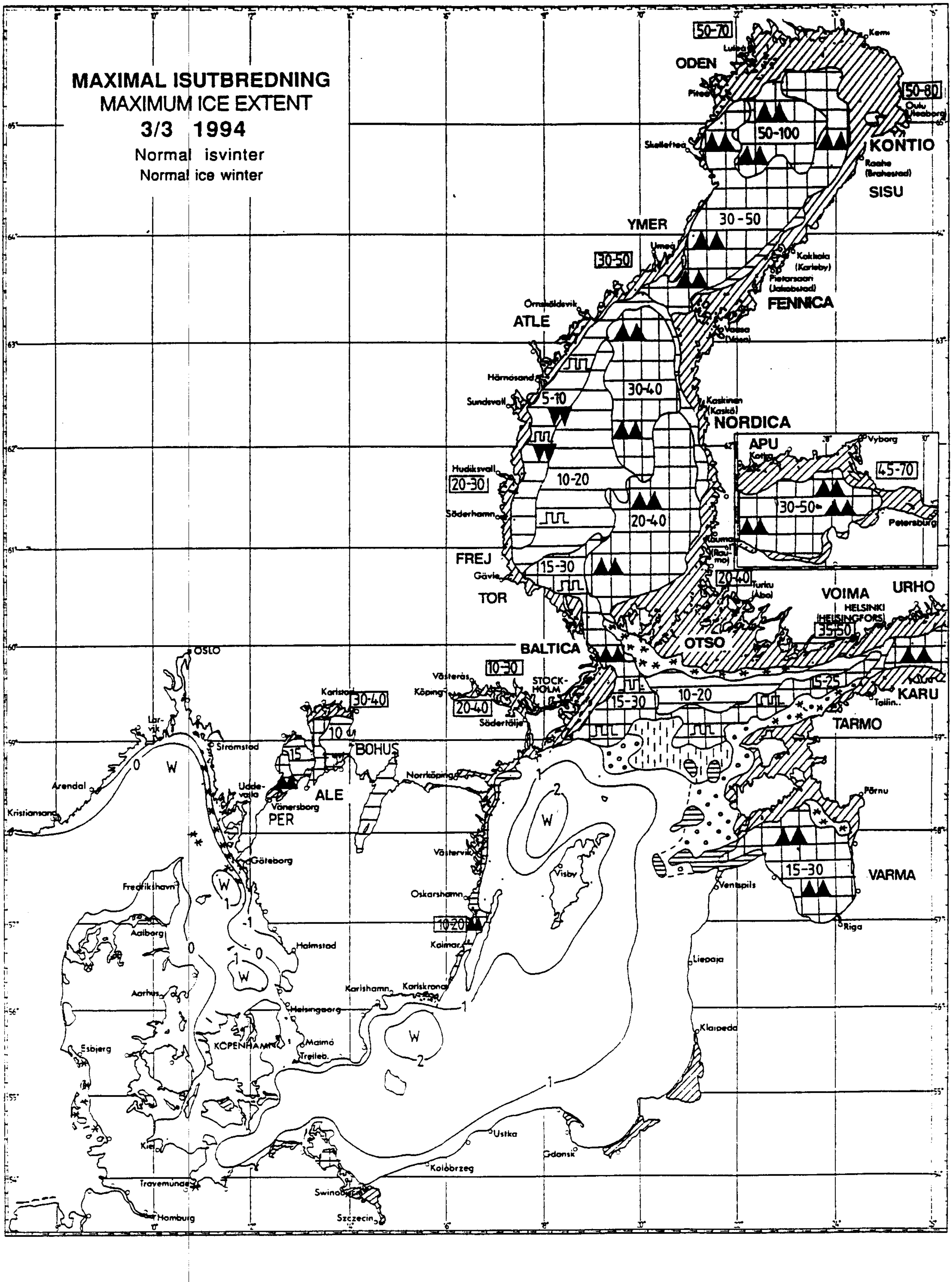
Ice station 3 in Sea of Bothnia in March 21, 1994.



Ice station 4 in Bay of Bothnia in March 23, 1994.



Ice Chart of 17 March, 1994.


MAXIMAL ISUTBREDNING
MAXIMUM ICE EXTENT
3/3 1994
Normal isvinter
Normal ice winter
ODEN
KONTIO
SISU
YMER
FENNICA
ATLE
NORDICA
APU
FREJ
TOR
VOIMA
URHO
BALTICA
OTSO
KARU
TARMO
BOHUS
ALE
PER
VARMA
50-70
50-80
50-100
30-50
30-40
5-10
10-20
20-30
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15-30
45-70
30-50
35-50
10-30
30-40
15-25
10-20
Luleå
Kemi
Piteå
Oulu (Uleaborg)
Skellefteå
Raahe (Brahestad)
Umeå
Kokkola (Karleby)
Pietarsaari (Jakobstad)
Örnsköldsvik
Vaasa (Vasa)
Härnösand
Sundsvall
Kaskinen (Kaskö)
Hudiksvall
Söderhamn
Vyborg
Kotka
Petersburg
Rauma (Raumo)
Gävle
Turku (Åbo)
HELSINKI (HELSINGFORS)
OSLO
Västerås
Köping
STOCKHOLM
Södertälje
Karlstad
Tallinn
Larvik
Strömstad
Arendal
Kristiansand
Uddevalla
Vänersborg
Norrköping
Pärnu
Göteborg
Västervik
Visby
Ventspils
Frederikshavn
Oskarshamn
Aalborg
Kalmar
Riga
Halmstad
Liepaja
Aarhus
Karlshamn
Karlskrona
Helsingborg
Klaipeda
Esbjerg
KÖPENHAMN
Malmö
Trelleb.
Ustka
Kiel
Gdansk
Kolobrzeg
Travemünde
Swinoujscie
Hamburg
Szczecin
W

Figure 3.2 Sea ice monitoring in the Canadian Arctic

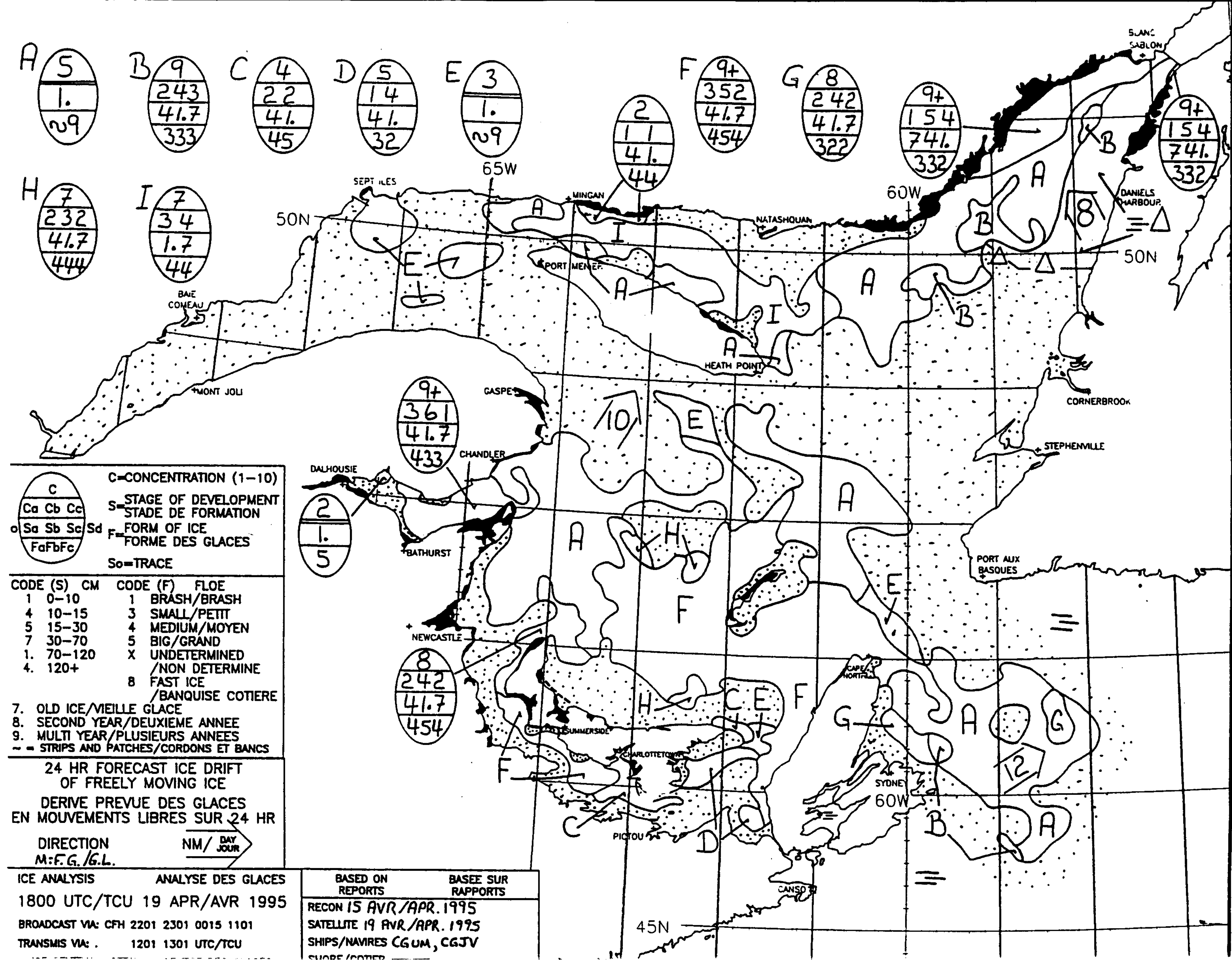
The Ice Service Environment Canada (ISEC) is responsible for providing ice forecasts for Canadian territorial waters. Forecasts are provided year round to a variety of customers including shipping operators, fishing vessels and the offshore oil and gas industry for the design and maintenance of production rigs. The principal user however is the Canadian Coast Guard which maintains an ice breaker fleet for escorting shipping within Canadian waters and requires ice forecasts to plan the escort operations. The focus for operations varies throughout the year. Summer activities concentrate on the North West Passage, Arctic waterways and the Southern Beaufort Sea. The focus moves towards the Canadian east coast as the Arctic ice consolidates in November and December. From January through to April, attention concentrates on the ice in the Great Lakes, Labrador Sea and the Gulf of St Lawrence.

ERS-1 SAR imagery have been incorporated into the production of the forecasts since 1992. Images are acquired at the Gatineau ground stations and processed to a spatial resolution of 100 metres before being transmitted to Ice Service Environment Canada over a digital link. Images are usually available for analysis four to six hours after the satellite pass. The analysis combines data from ERS-1 and airborne SAR images with meteorological data using the capabilities of the Ice Data Integration and Analysis System (IDIAS) to produce daily ice charts. The charts contain information on total ice concentration, ice types, concentration per type as well as identification and delineation of features such as leads, polynyas and pressure ridges. Charts are faxed via HF marine radio or transmitted on a PC to PC communication link to shore stations, ice breakers and ship masters. Charts are available within six to twelve hours of the data acquisition. Figures a and b illustrate the operation of the IDIAS and Figure c is an example of an ice forecast chart for the Gulf of St Lawrence on April 15, 1995.

Savings in fuel and transit times through ice infested waters under Canadian control are quoted as several million ECU per annum. In addition, the savings from the optimal deployment of the ice breaker fleet are estimated to be in the region of 11.5 million ECU per annum.

Courtesy of M Shokr, Atmospheric Environment Service, Ottawa, Canada


ERS1 13 JAN 1993 1500Z LM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D 5 14 41. 32
E 3 1. ~9
F 9+ 352 41.7 454
G 8 242 41.7 322
H 7 232 41.7 444
I 7 34 1.7 44
9+ 154 741. 332
2 11 41. 44
9+ 361 41.7 433
2 1. 5
8 242 41.7 454
BLANC SABLON
DANIELS HARBOUR
CORNERBROOK
STEPHENVILLE
PORT AUX BASQUES
SEPT ILES
MINGAN
NATASHQUAN
PORT MENIER
HEATH POINT
BAIE COMEAU
MONT JOLI
GASPE
CHANDLER
DALHOUSIE
BATHURST
NEWCASTLE
SUMMERSIDE
CHARLOTTETOWN
PICTOU
CANSO
CAPE NORTH
SYDNEY
50N
45N
65W
60W
C=CONCENTRATION (1–10)
S=STAGE OF DEVELOPMENT
STADE DE FORMATION
F=FORM OF ICE
FORME DES GLACES
So=TRACE
CODE (S) CM
1 0–10
4 10–15
5 15–30
7 30–70
1. 70–120
4. 120+
CODE (F) FLOE
1 BRASH/BRASH
3 SMALL/PETIT
4 MEDIUM/MOYEN
5 BIG/GRAND
X UNDETERMINED /NON DETERMINE
8 FAST ICE /BANQUISE COTIERE
7. OLD ICE/VIEILLE GLACE
8. SECOND YEAR/DEUXIEME ANNEE
9. MULTI YEAR/PLUSIEURS ANNEES
~ = STRIPS AND PATCHES/CORDONS ET BANCS
24 HR FORECAST ICE DRIFT OF FREELY MOVING ICE
DERIVE PREVUE DES GLACES EN MOUVEMENTS LIBRES SUR 24 HR
DIRECTION
NM/ DAY JOUR
M:F.G./G.L.
ICE ANALYSIS
ANALYSE DES GLACES
1800 UTC/TCU 19 APR/AVR 1995
BROADCAST VIA: CFH 2201 2301 0015 1101
TRANSMIS VIA: . 1201 1301 UTC/TCU
BASED ON REPORTS
BASEE SUR RAPPORTS
RECON 15 AVR/APR. 1995
SATELLITE 19 AVR/APR. 1995
SHIPS/NAVIRES CGUM, CGJV


(C) ESA 1992

Figure 3.3 Sea ice monitoring of United States coastal waters

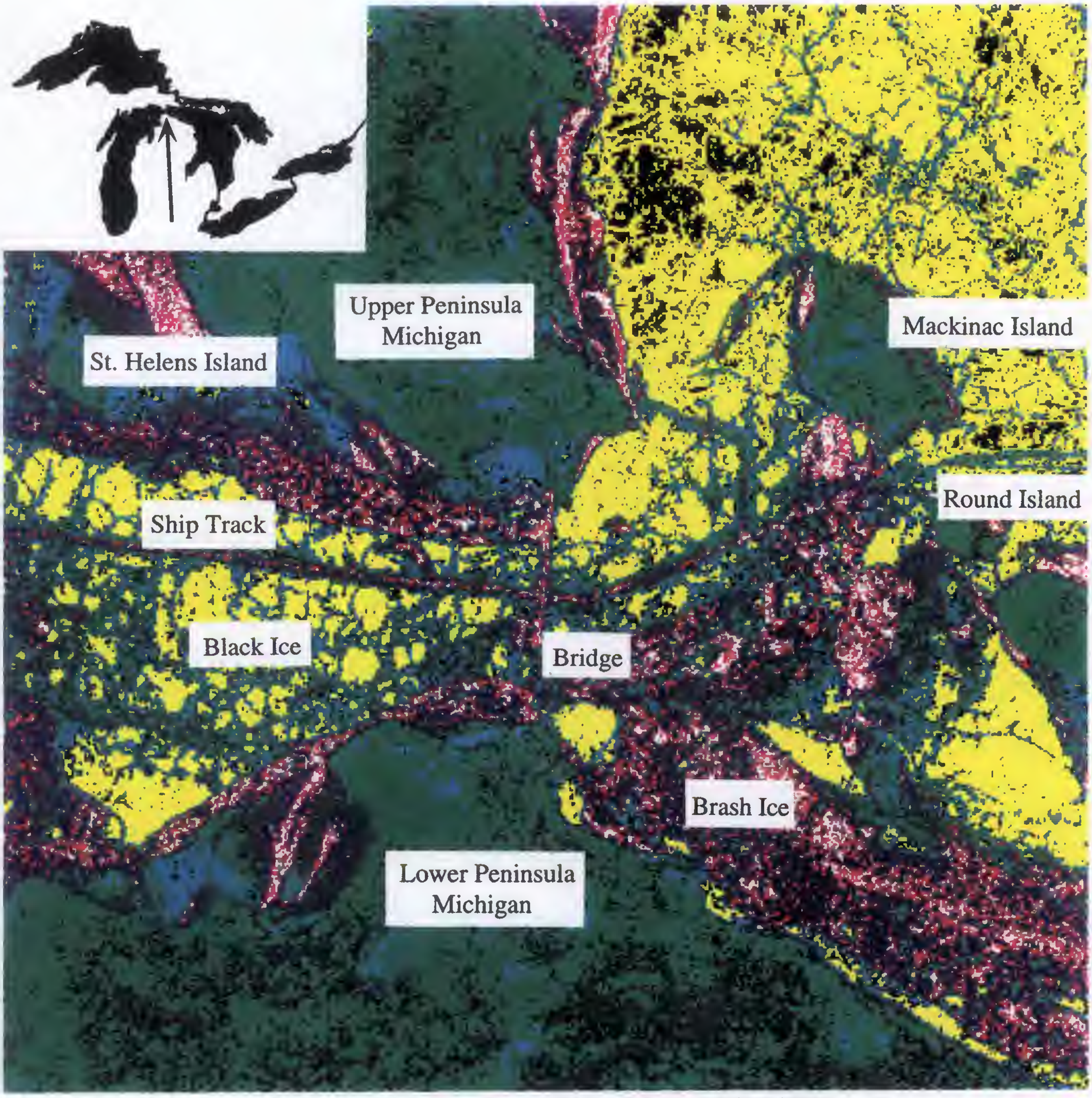
The CoastWatch programme operated by National Environmental Satellite Data and Information Service (NESDIS) of the US National Oceanic and Atmospheric Administration (NOAA) has the goal of providing satellite data and products for near real time monitoring of USA coastal waters in support of operational environmental management. Currently, visible, infra-red and sea surface temperature images derived from NOAA satellites are the main products distributed via eight regional nodes around the country to over 200 users in the USA Government, state governments, universities and secondary schools. Efforts are underway to add ocean colour, ocean winds and waves together with SAR imagery and derived products to the operational product suite.

To develop the capability to utilise SAR for operational coastal and river applications, a successful SAR applications development and demonstration programme has been conducted with ERS-1 data in Alaska and the Great Lakes. SAR applications of operational utility to CoastWatch include the monitoring of (1) ice cover and type, iceberg distribution and wave conditions for coastal transportation and oil activities, (2) flooding due to river ice jams for protection of life and property, (3) ocean fronts, eddies and current boundaries for fishery studies and (4) fishing vessel location and distribution for fishing enforcement. As a result of this successful demonstration, operational systems for processing, communication and analysis of SAR data are currently under development.

SAR data acquired at the Alaska SAR Facility located in Fairbanks, Alaska and processed in near real time are routinely sent to the National Ice Centre in Suitland, Maryland. Here they are analysed together with other satellite imagery to produce maps of ice cover in Alaskan waters. These analyses, along with selected SAR images, are used by the CoastWatch Regional Site in Anchorage, Alaska (located at the NOAA National Weather Service Forecast Office) to provide guidance for shipping, oil activities and activities taking place on the ice. This service is particularly important in Alaskan waters where coastal and river routes are the principal means of transport. In Alaska, 78% of the population live on or near the coast and only one percent of the area is served by roads. Ice forming in coastal waters and estuaries not only provides a hindrance to transport and other activities such as oil production support, but also causes a risk of river flooding due to the occurrence of river ice jams in the spring.

The Figure shows the Yukon River Delta (lower right corner) with a band of shore fast ice, followed by a narrow band of open water or thin ice and then a consolidated pack of ice floes of different sizes. Mariners are advised to avoid the shore fast ice and the larger floes.

Courtesy of W Pichel, DOC/NOAA/NESDIS Office of Research and Applications, Washington, USA.



Ice Types-Straits of Mackinac-2/24/93

Figure 3.4 Sea ice monitoring in the Great Lakes, United States

The Great Lakes is an area of considerable shipping traffic. Accurate ice maps are essential for ship routing and ice breaker deployment during the winter season. The National Ice Centre in Washington DC produces an analysis of ice conditions in the Great Lakes three times a week. In previous years, the best routinely available data source was to a resolution of one kilometre from the NOAA AVHRR instrument. ERS-1 SAR images, at a spatial resolution of 100 metres, and which are available in all weather conditions, have greatly improved the quality of the Great Lakes ice analyses.

During the National Oceanic and Atmosphere Administration (NOAA) CoastWatch SAR Ice Applications Demonstration, a programme to assess the utility of satellite SAR and develop experience for its use for Great Lakes ice analysis, ground data for several study areas were collected coincident with the ERS-1 overflight. The ground data were used to interpret and classify ice types and distribution in the SAR data using computer based digital image processing techniques.

The Figure illustrates an annotated ERS-1 SAR image of the Straits of Mackinac on February 24, 1993. Different ice types in the ice cover can be distinguished. A ship track can be seen in the ice covered straits as well as the Mackinac Bridge connecting the lower and upper peninsulas of Michigan. Computer algorithms developed from this work will aid ice analysts in their interpretation and mapping of Great Lakes ice cover.

Courtesy of G Leshkevich, NOAA Great Lakes Research Laboratory, Ann Arbor, USA

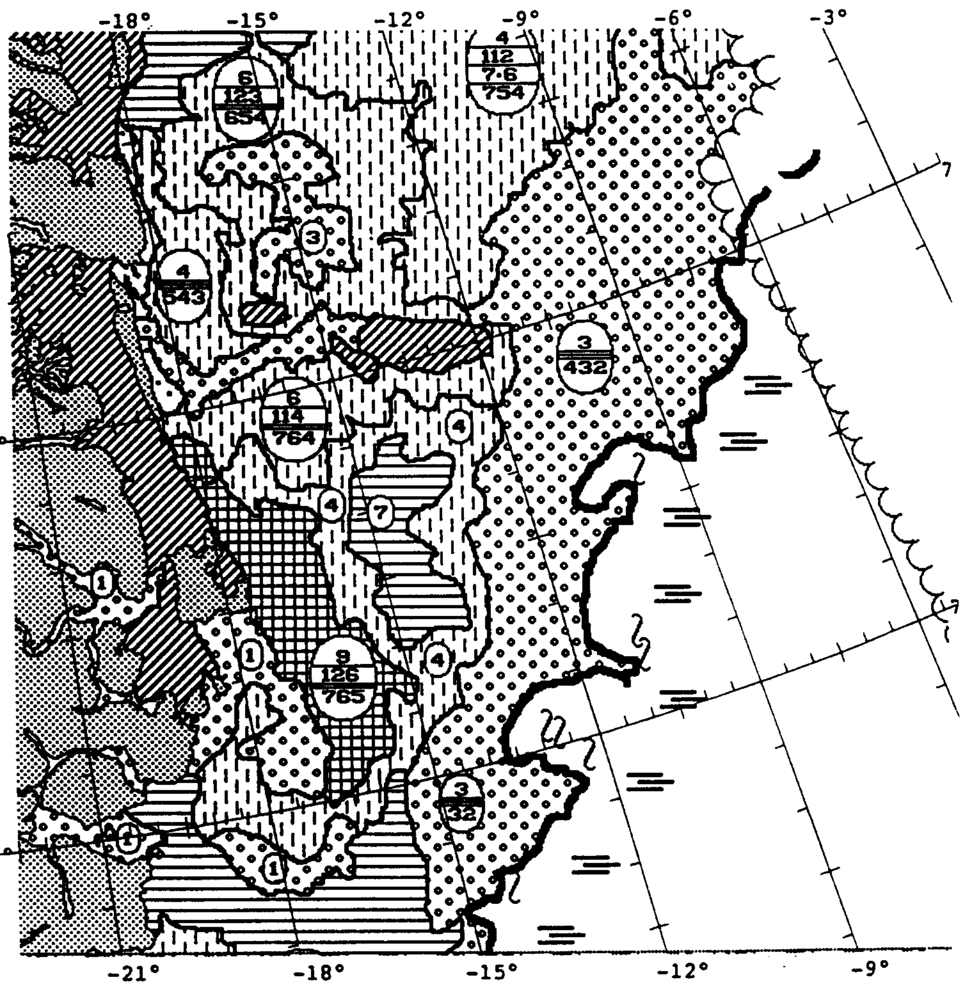
Figure 3.5 Sea ice monitoring in the waters off Greenland

The provision of sea ice forecasts in sea areas to the west and south of Greenland has been the responsibility of the Royal Danish Meteorological Institute since 1959. Previously the acquisition of ice information on which the forecasts were based was obtained using airborne observations and, with the availability of NOAA AVHRR data, satellite based infra-red images. Unfortunately, clouds often obscure part or all of the infra-red images. A project incorporating ERS-1 SAR data into the operational service has been running since 1992. SAR images are obtained from Tromsø and Kiruna ground stations and processed at the ElectroMagnetics Institute, Technical University of Denmark. These are then forwarded to the Meteorological Institute where ice interpreters visually analyse the data, together with airborne and NOAA AVHRR data, using a PC based system. Ice maps are then produced (Figures a and b) and transmitted to users and ice breakers in the Greenland shipping areas.

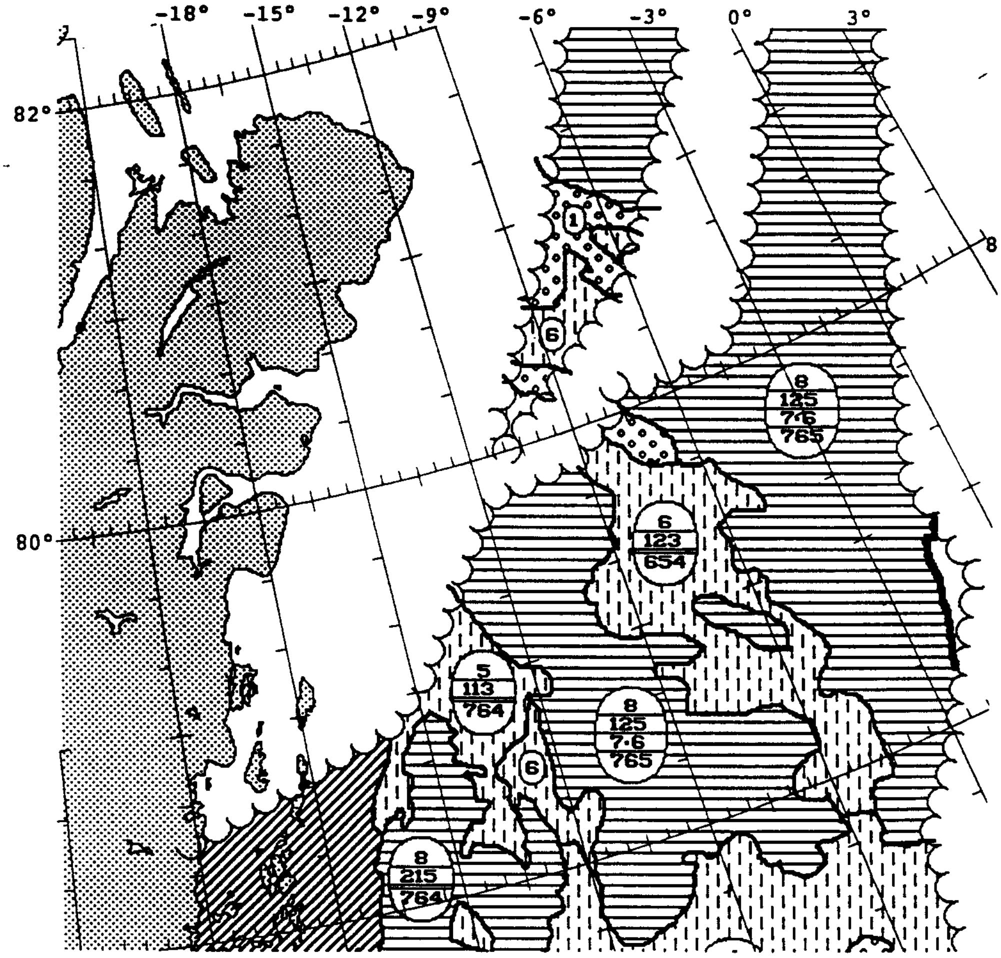
Financial benefits arising from the incorporation of SAR data are expected to be in the region of 1 million ECU due to a lowering in the demand for airborne surveys. Incorporation of ERS-1 SAR is hoped eventually to render the airborne data redundant.

Courtesy of H Valeur, Danish Meteorological Service, Copenhagen, Denmark

8 AUGUST 1992
SATELLITE BASED ICE-CHART
GREENLAND EAST COAST
Section C
DANISH METEOROLOGICAL INSTITUTE



8 AUGUST 1992
SATELLITE BASED ICE-CHART
GREENLAND EAST COAST
Section A
DANISH METEOROLOGICAL INSTITUTE



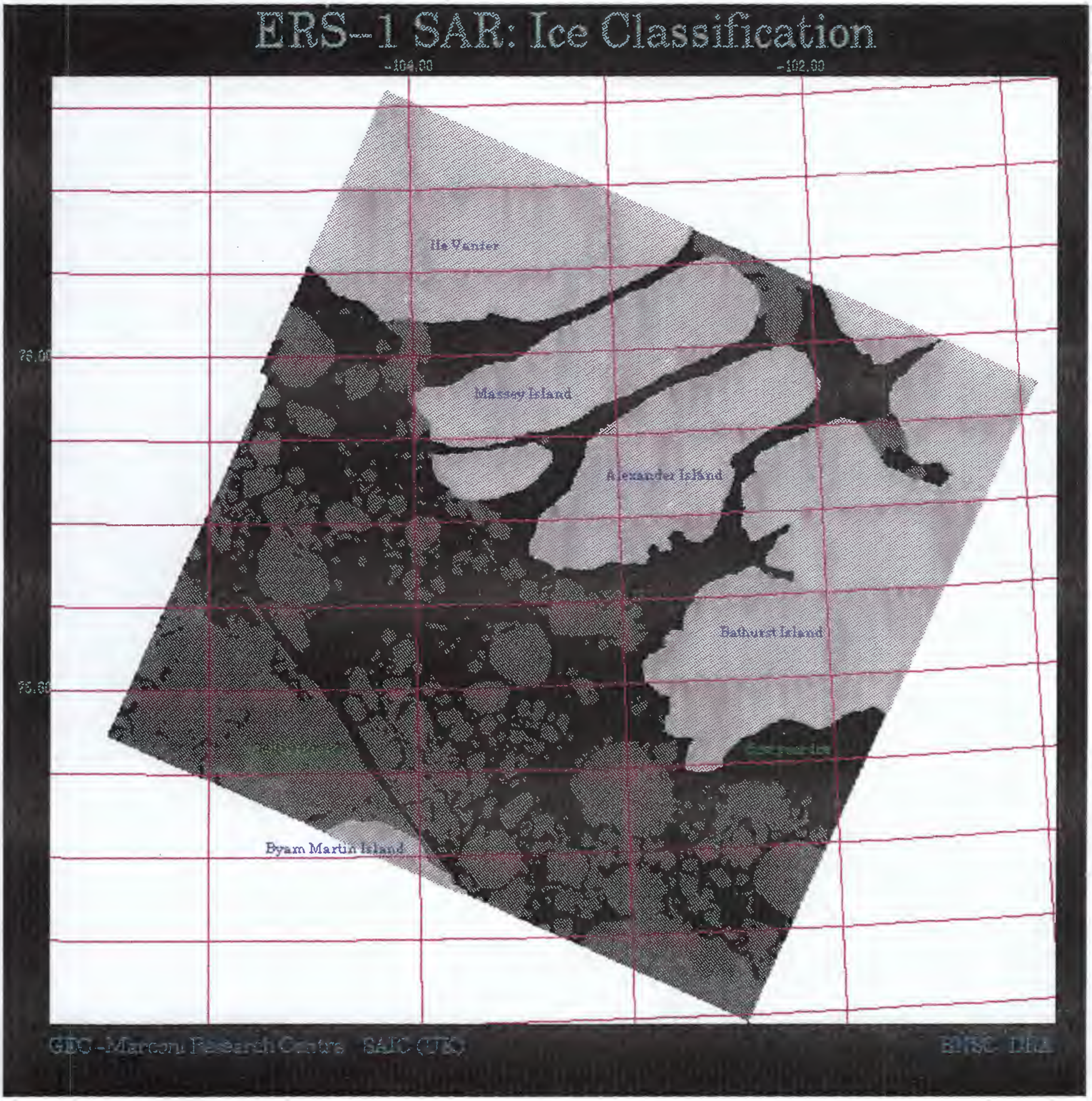
3.2. Sea ice demonstration activities

Figure 3.6 Sea ice mapping in support of offshore exploration

Value adding companies operating dedicated workstations can provide customers with sea ice information products required for safe and efficient operation in ice infested waters. A demonstration was conducted in August 1994 by the GEC Marconi Research Centre, Chelmsford, UK to provide support to NunaOil who were conducting a seismic survey in the ice infested Greenland Sea. Maps of local ice concentration and ice movement derived from ERS-1 SAR images were delivered in near real time, by fax to the MV Thetis, the vessel carrying out the survey. In addition to NunaOil, the Canarctic Shipping Company are also evaluating the products with a view towards full operational use.

ERS-1 SAR images were received at the West Freugh ground station and transmitted via conventional land lines to the GEC Marconi Research Centre. The images were processed automatically on a dedicated system, the Ice Prediction and Analysis Platform (IPAP) to produce three ice concentration and ice movement maps. These were then faxed, together with additional information on the orbit and acquisition details, to the MV Thetis via the Inmarsat marine communications satellite. Ice concentration and motion maps were received by the master of the ship within three hours of the satellite overpass, which in a number of cases, allowed sufficient time to make operational decisions regarding the survey route and the deployment of the hydrophone arrays. The Figures illustrate example ice information products that are based on ERS-1 SAR data and are similar to those supplied to NunaOil. Figure a shows an interpretation of ice types based on an automatic classification algorithm. Figure b is an example ice edge movement product and Figure c is an example pack-ice motion product.

Courtesy of K Partington, GEC Marconi Research Centre, Chelmsford, UK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Bathurst Island
Byam Martin Island

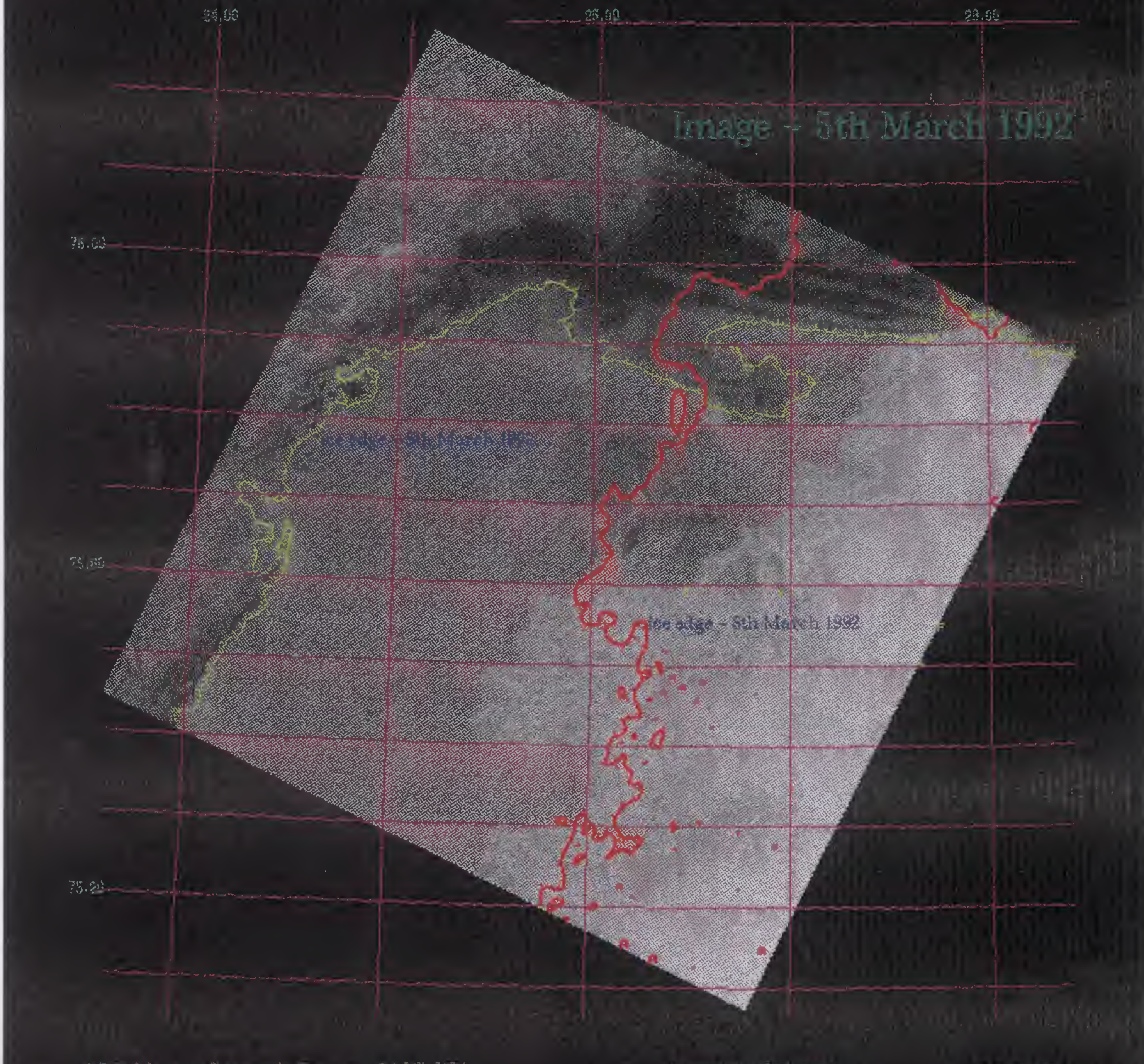
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Image - 5th March 1992
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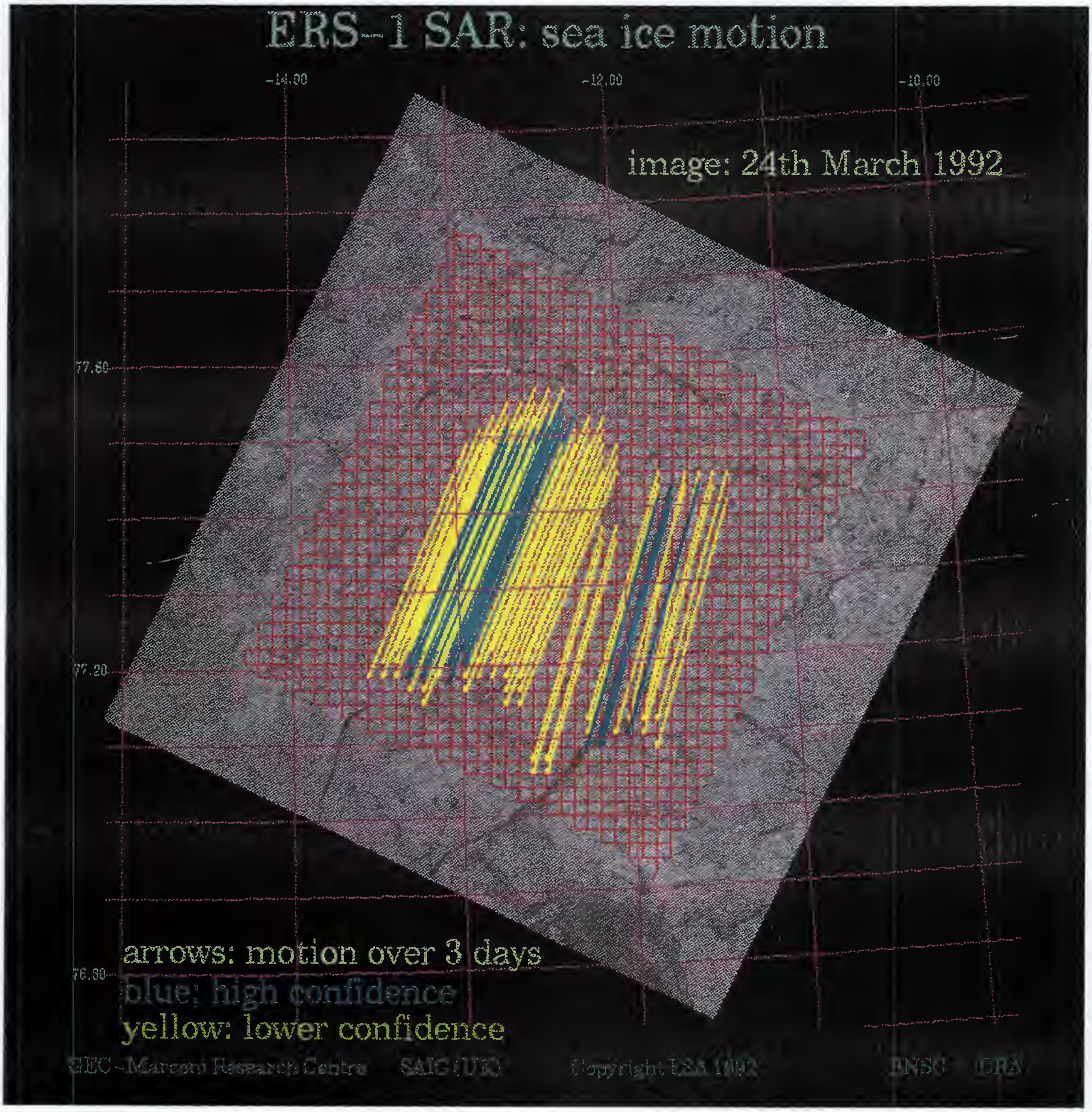
Ice edge - 8th March 1992
Copyright ESA 1992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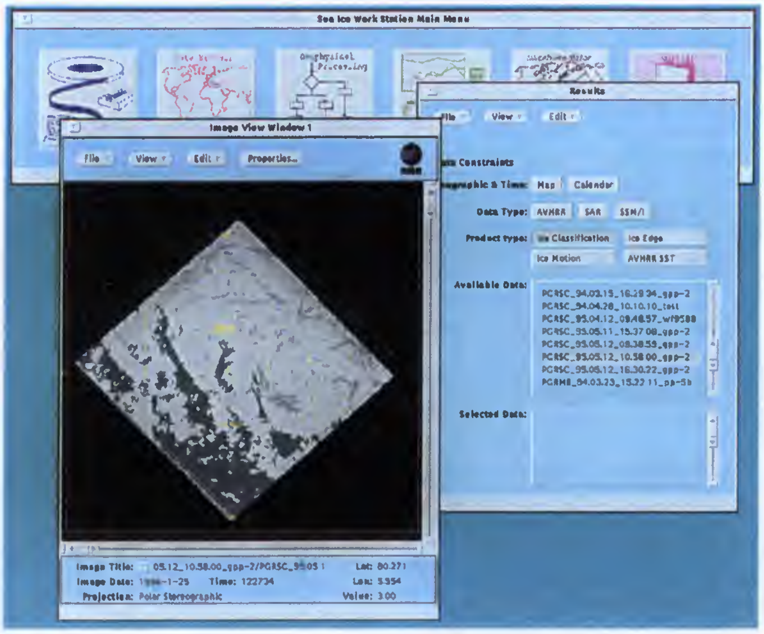
77.20
76.80
arrows: motion over 3 days
blue: high confidence
yellow: lower confidence
GEC-Marconi Research Centre
SAIC (UK)
Copyright ESA 1992
DRA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View
Edit
Properties...
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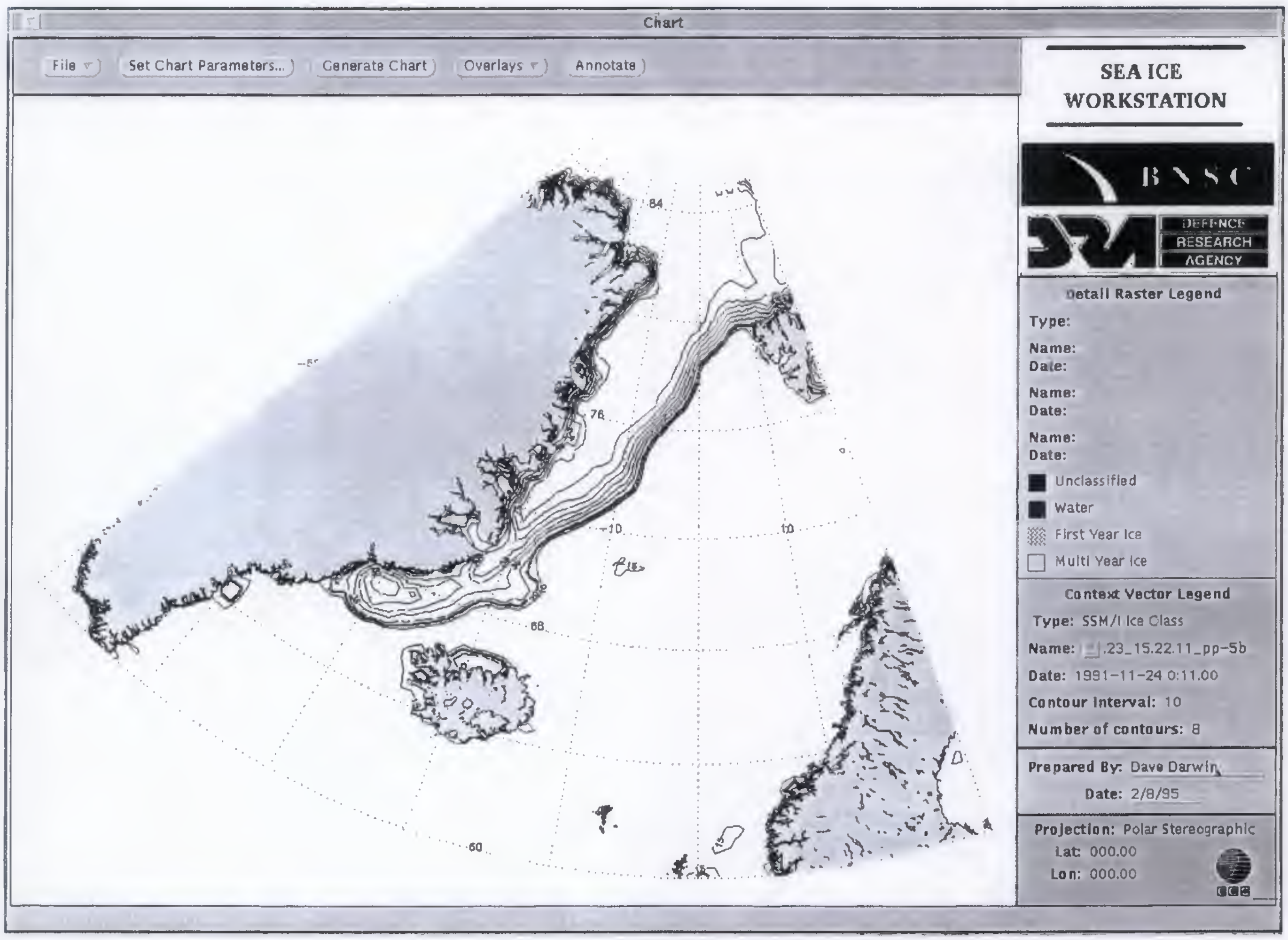
AVHRR
SAR
SSM/I
Product type:
Ice Classification
Ice Edge
Ice Motion
AVHRR SST
Available Data:
Selected Data:
Image Title:
Image Date:
Projection:
Polar Stereographic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Multi Year Ice
Context Vector Legend
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Contour Interval: 10
Number of contours: 8
Prepared By: Dave Darwin
Date: 2/8/95
Projection: Polar Stereographic
Lat: 000.00
Lon: 000.00
84
76
68
60
-10
10

Figure 3.7 The Sea Ice Workstation

A four month trial operation was carried out by Earth Observation Sciences Limited during 1994 using a dedicated Sea Ice Workstation to supply support products to operators engaged in activities in ice infested waters.

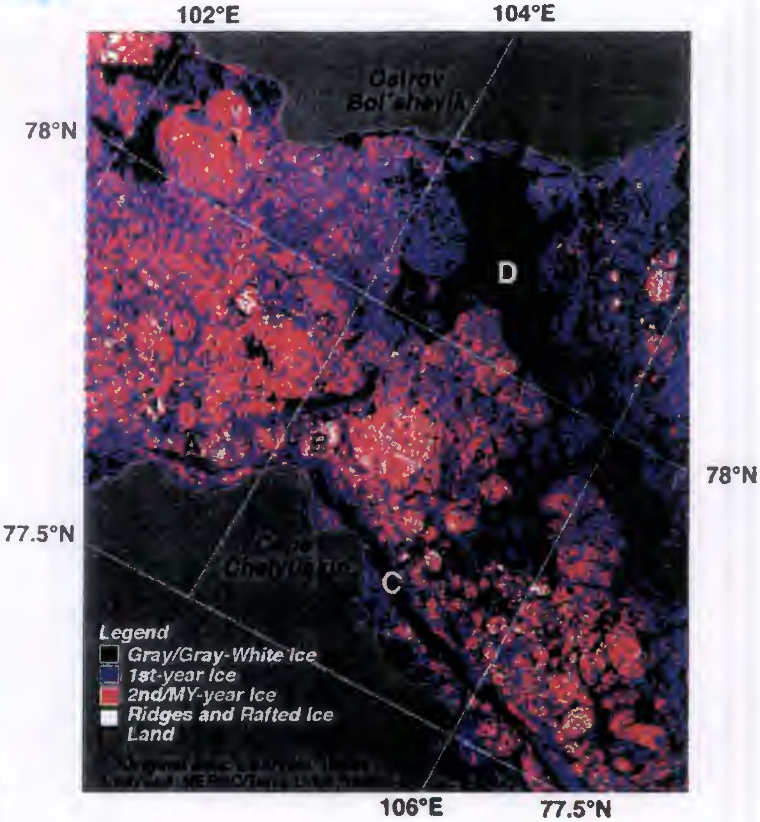
ERS-1 SAR images were processed to identify areas of open water, first year ice and multi year ice. These classified image products were then combined with NOAA AVHRR and SSM/I data to generate ice charts displaying ice motion vectors, ice types, ice concentrations and ice edge location, depending on the user requirements. These charts were supplied to a number of users including:

- An oil production platform operating in the Barents Sea;
- Meteorological organisations for input to forecasting models;
- Shipping operators for route planning (for example a strengthened vessel will be capable of negotiating first year ice but not multi year ice).

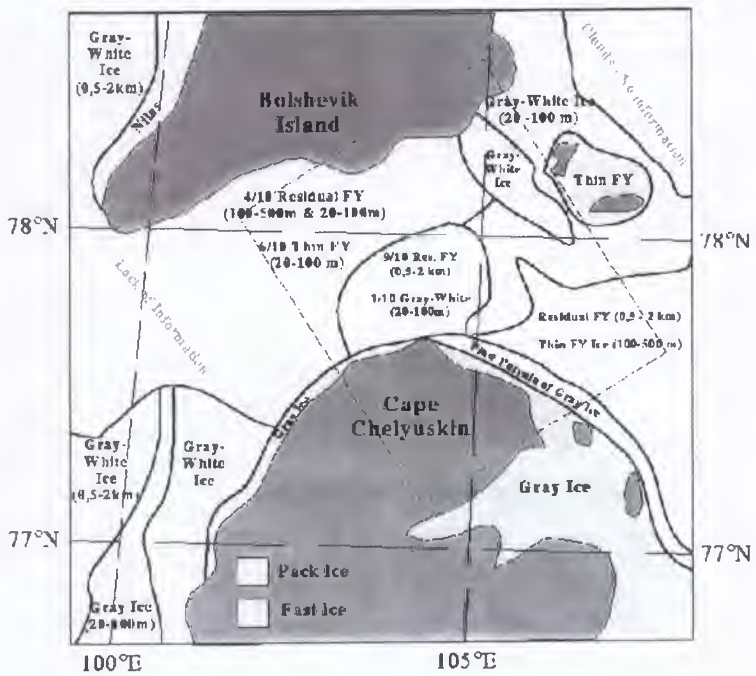
As a result of the demonstration project, a number of users are engaged in discussions regarding the possibility of a fully operational service.

The main selling point of such charts is that they can be customised to meet the specific need of individual customers. Alternative ice information products can suffer from limited coverage, low update periods and low spatial resolution. The Figure illustrates the work station showing a classified SAR image and an ice map.

Courtesy of D Boardman and D Darwin, Earth Observation Sciences Limited, Farnham, UK



102°E
104°E
78°N
D
A
B
78°N
77.5°N
C
Legend
Gray/Gray-White Ice
1st-year Ice
2nd/MY-year Ice
Ridges and Rafted Ice
Land
106°E
77.5°N



Gray-White Ice (0,5-2km)
Bolshevik Island
Gray-White Ice (20-100 m)
Gray-White Ice
Thin FY
4/10 Residual FY (100-500m & 20-100m)
78°N
6/10 Thin FY (20-100 m)
9/10 Res. FY (0,5-2 km)
1/10 Gray-White (20-100m)
Residual FY (0,5-2 km)
Thin FY Ice (100-500 m)
Cape Chelyuskin
Gray-White Ice
Gray-White Ice (0,5-2km)
Gray Ice
77°N
Pack Ice
Fast Ice
Gray Ice (20-100m)
100°E
105°E

Figure 3.8 The Northern Sea route

The extreme sea ice conditions along the northern coast of Russia limit human activities and shipping traffic is severely hampered by the ice conditions during most of the year, with only two or three months of ice free conditions along the coast. Russia has a major need for extensive year round sea transportation to support settlements along the Siberian Coast and rivers as well as for transport between Northern Europe and the Pacific through the Bering Strait. This 'Northern Sea Route' generates considerable savings as the route is approximately 6,000 nautical miles shorter than using the Suez Canal, reducing the transit time by approximately 10 days. It was opened to western shipping in 1991 and shipping activities in the region are supported by an extensive operational sea ice monitoring and forecasting service assisting the ice breaker fleet based at Murmansk.

The production and distribution of sea ice maps and forecasts is the responsibility of the Marine Operational Headquarters based at Pevek and Dikson. Information from ice breakers, other vessels, polar weather stations and airborne surveys together with NOAA AVHRR images and ERS-1 SAR imagery delivered in near real time are combined within the Marine Operational Headquarters to produce ice forecasts. These forecasts are then distributed to the ice breaker fleet and shipping in the region (Figure a).

A demonstration project to illustrate the applicability of near real time ERS-1 SAR data in operational sea ice monitoring and ice breaker deployment was conducted in 1993. SAR images and detailed ice maps were distributed to the Russian ice breaker fleets and the Russian Ice Monitoring Services in order to identify leads and other ice features of interest for navigation within ice infested waters.

Low spatial resolution (100 metres) SAR image products from Tromsø Satellite Station were produced using the fast SAR processing facility. These were then transmitted to the Nansen Environmental and Remote Sensing Centre via common data network lines in Norway. Annotated SAR images (Figure b) and data products (Figure c) were then transmitted by fax in near real time to the appropriate ice breaker captains via the Inmarsat satellite communication system. In addition, products were faxed to the Russian Ice Centre at Dikson.

Courtesy of OM Johannessen, Nansen Environmental and Remote Sensing Centre, Bergen, Norway

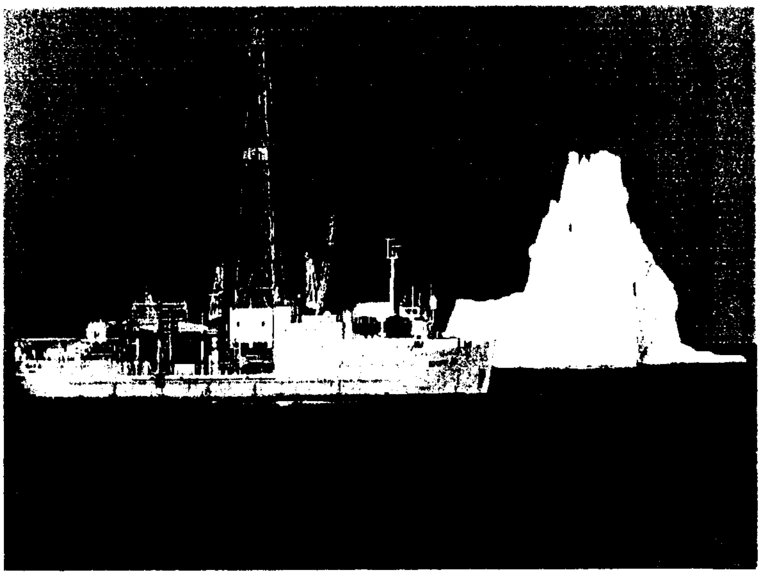
Figure 3.9 Special ice service for the Ocean Drilling Programme(ODP)

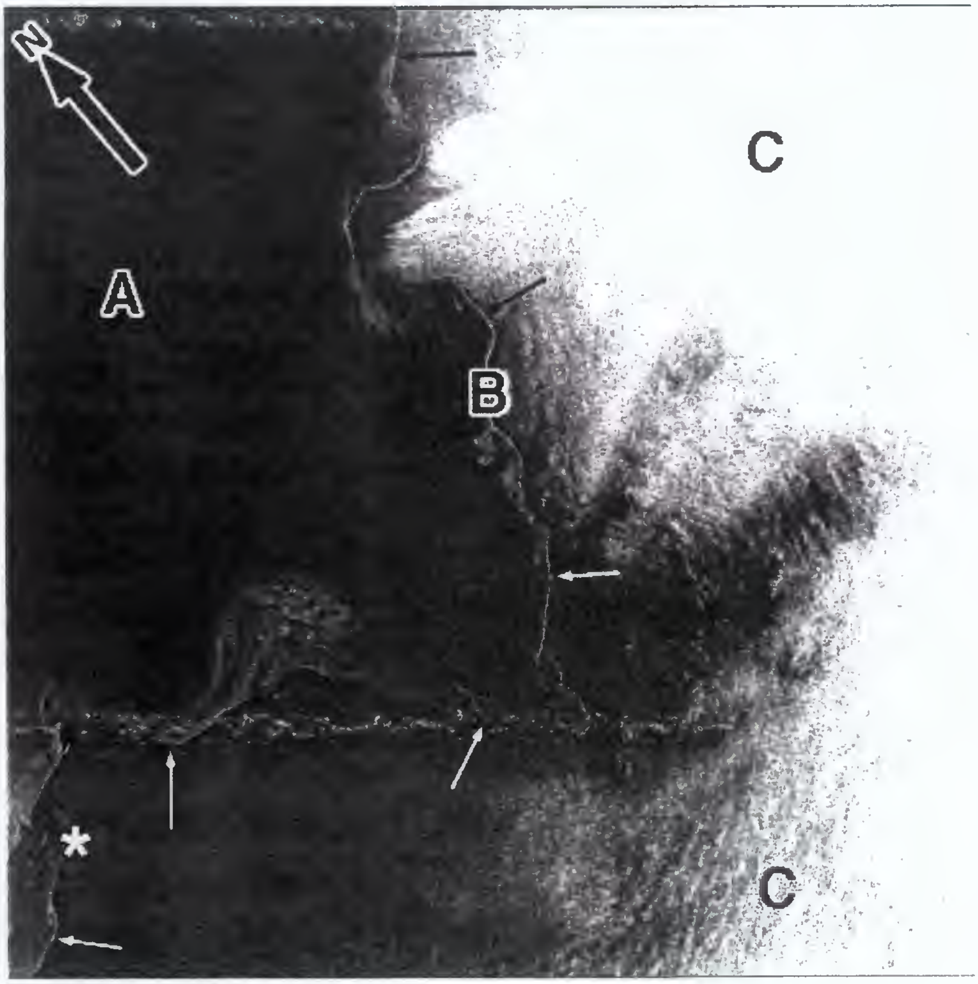
The Ocean Drilling Programme (ODP) is a global research programme to study the structure of the sea floor under the world's oceans. Drilling surveys are carried out by the JOIDES Resolution (Figure a), a specially refitted drill ship with computer controlled thrusters that can maintain the ship over a specific location. During August and September 1993, a drilling leg was carried out in the Greenland Sea and Fram Strait, an area where severe restrictions were imposed on the operations by the presence of sea ice. Accurate ice maps are required to plan and implement the drilling operations.

The ice breaker MSV Fennica (Figure b) was provided as support to the ODP by the Finnish Board of Navigation, patrolling and monitoring the ice edge region in the vicinity of the drill sites. Low spatial resolution (100m) SAR images were produced by the Tromsø Satellite Station every day and visually interpreted. Annotated SAR images were then transmitted to the ice breaker to provide information on ice edge location and ice motion. Figure c is an example of one of these images which was acquired on August 22, 1993. It shows:

A The compact Arctic pack ice;
B The ice edge (also indicated by arrows);
C Open water.

Courtesy of S Sandven, Nansen Environmental and Remote Sensing Centre, Bergen, Norway




N
A
B
C
C
*

4. AGRICULTURE AND FORESTRY

In the original mission objectives, observing the land surface was viewed as an experimental application for ERS-1 data. However, the ability to monitor seasonal land cover changes, crop development and forestry changes - independently of weather conditions - now offers one of the major potential economic returns for ERS-1.

There are still hurdles to be overcome in achieving this potential. Technically, interpretation of data from land surfaces is more complex than for the oceans, although there is potential to derive much greater information content, once methods have been researched. The range and diversity of potential applications is also much greater and this means that the market overall is more costly to capture.

Agriculture and forestry markets for Earth observation data already existed when ERS-1 was launched. These have been developed by the users of optical satellites over the previous ten to fifteen years. Some early market successes for ERS-1 data have therefore been based on the introduction of the new SAR data into these existing markets, where they provide a complementary source of information. Although the objective in the long term is to create new and larger markets, successes in existing markets have been possible in the short term and provide a marketing platform for attracting new customers.

❑ ERS-1 contribution

An important technique which has been developed for terrestrial applications is multi-temporal SAR analysis. SAR data, collected on different dates, are overlain to form an image composite. Each composite image is presented in different colours and analysed as a single data set. The advantage of multi-temporal analysis is that crops planted at varying times and developing at varying rates can potentially be identified, increasing the accuracy with which crop areas can be mapped and acreage estimated. Multi temporal analysis is also being applied to monitor changes in forested areas.

The ability to choose the time of observation is also important in agricultural applications and particularly for deriving suitable information to support yield prediction. The microwave capability offered by ERS-1 means that observation need not be constrained by weather or light conditions as are optical missions. However, as the ERS-1 mission was not designed for these applications, scheduling priorities and the long period between observations at any one point on the Earth's surface constrain the development of applications. Nevertheless, the example applications presented below demonstrate the potential value of SAR data for a range of users involved in agriculture and forestry.

❑ Market potential

Security of food supply is a concern throughout the world. Public and private sector organisations from local to global scales have been established to monitor food supply, with a responsibility to forecast local harvests and assess import or export requirements to control prices and meet population needs.

The twelve member states of the European Union prior to January 1995 had nine million farmers farming 129 million hectares of agricultural land with a value for agricultural production of 200 billion ECU (1990 figures). In 1992, the Common Agricultural Policy of the European Union had a budget of 36.5 billion ECU. This was 58% of the community's budget. Monitoring of the Common Agricultural Policy is now undertaken partly with Earth observation data which provides a common data source and standardised methodology for the collection of agricultural statistics. ERS-1 SAR data are gradually being introduced as part of this.

Global crop production and trade is summarised in Table 4-1 below. These are figures for 1993 and can vary on a global scale even by up to ten percent depending on the size of harvests. Monitoring this scale of production is a large undertaking and the value that ERS-1 data can provide to this is currently being evaluated in a large number of countries world wide.

Crop	**World production 1993 (million tonnes)**	**World trade 1993/4 (million tonnes, estimates)**
Cereals	1,875	188
Wheat	709	91
Coarse grains	800	82
Rice (paddy)	520	15
Roots and tubers	150 (grain equivalent)	not available

Table 4-1: Global crop production and trade (Source-FAO Annual Review (1993))

The requirements for information on the world's forests are varied. Some established mapping and monitoring systems are introducing ERS-1 SAR data and other organisations are beginning new projects as a result of having access to this new data source. ERS-1 data provide information for maps of forest extent and type in tropical areas which have not previously been mapped due to cloud cover. Information on forest damage can also be derived which is used for forest management.

Across the continent of Europe (this includes 47 countries) the main threats to forests are illegal logging, land clearance, disease, atmospheric pollution and fires. The introduction of non indigenous species since 1965 has altered the composition of European forests and wood production has increased by 18%. Forests cover 33% of Europe's land area, a ten percent increase over the last 30 years. The increase has occurred mostly in the south and west, while cover has remained stable or declined in eastern countries. In addition to the problems of disease, an average of 700,000 hectares of wooded land are burnt each year by in excess of 60,000 fires.

Globally, forest resources now attract unprecedented attention. This concern extends both to their value and to the environmental effects of their use. There are approximately 3,400 million hectares of forest globally, representing nearly 25% of the world's land area or 14% of the Earth's surface. Close to 58% are found in temperate and boreal areas and 42% in tropical areas. Pressures on forests to provide economic resources are increasing rapidly. The rate of tropical forest destruction is not known with any accuracy, but according to the Food and Agricultural Organisation of the United Nations the annual rate of tropical deforestation is around 15.4 million hectares. Tropical forests are by far the richest habitats on land. At least two thirds of the world's plant species occur in the tropics and sub tropics. Destroying them alters the hydrological cycle causing drought, soil erosion and flooding in areas where such events were previously rare. This is an area of great environmental concern with important impacts for climate change and biodiversity.

❑ Example applications

The following sections provide examples of how ERS-1 data are being used by the European Union and national government bodies throughout Europe, India, Southeast Asia, Africa and South America for:

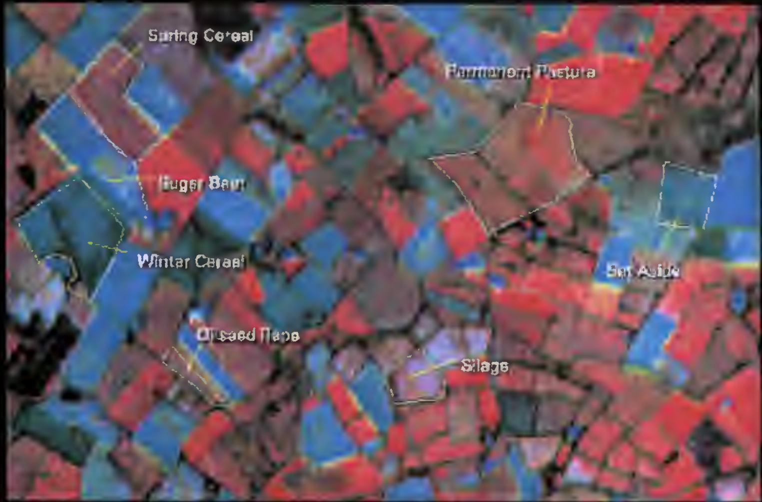
- Agricultural monitoring;
- Forest monitoring.

Agricultural monitoring systems which use Earth observation data have been established in several countries world wide. SAR data, which provide advantages in northern Europe and in areas of the world where crops grow during the rainy season, are being used within these existing services. Two examples are given below which show how ERS-1 SAR are being incorporated into monitoring systems developed by the European Union. Two further examples of development systems being demonstrated for the Indian and Indonesian governments are also included to illustrate the potential for future growth in this market.

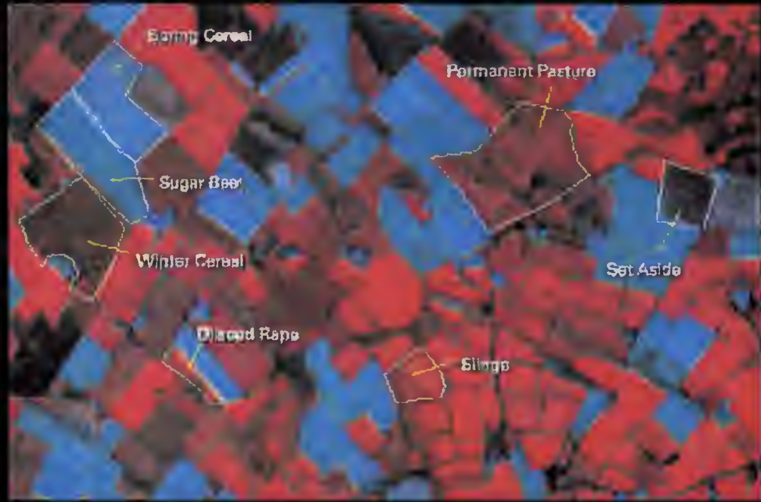
SAR data are being used alone, and in conjunction with other remotely sensed data, to map forest damage and to provide inventories of timber areas. These include long term monitoring projects of forest condition and mapping of forest type and extent by government and environmental organisations.

The examples below have been provided by the following value adding organisations:

- ERA Maptec, Ireland;
- Finnish Forest Research Institute, Finland;
- Geosys, France;
- Indian Space Research Organisation, India;
- Institute of Geodesy and Cartography, Poland;
- Joint Research Centre, Italy;
- Kayser-Threde, Germany;
- SCOT Conseil, France;
- Technical University of Finland.

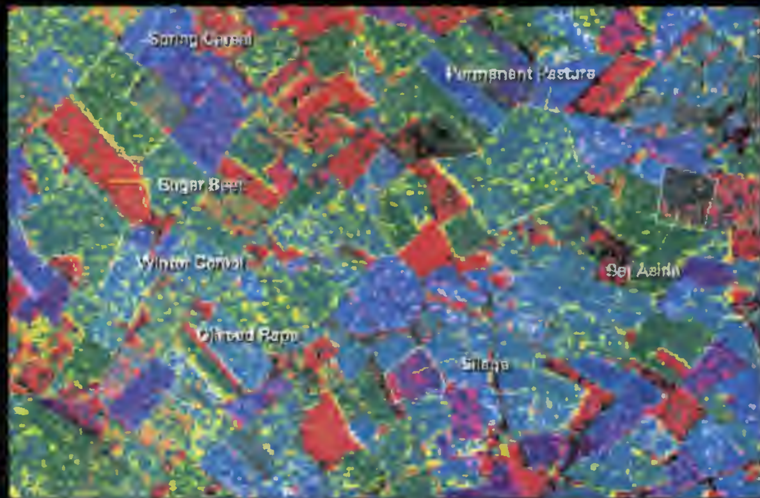


Spot XS Autumn Image



Spot XS Spring Image

Spot XS Early Summer Image



Composite Image Summer ERS-1(r)
Summer Spot IR (g)
Spring Spot IR (b)

Monitoring Arable Crop Area Aid Claims using Remote Sensing

Produced by

ERA-Maptec Ltd
5 South Leinster Street
Dublin 2
IRELAND

4.1. Agriculture

Figure 4.1 Monitoring agricultural subsidies in Europe

Under the European Union agricultural programme, subsidies are paid to farmers for keeping an agreed portion of land as set-aside, thus alleviating pressure on crop prices and surplus produce management. This makes the economic management of agricultural produce slightly less complex. To ensure that subsidies are paid only to farmers complying with the terms of their agreements, satellite data are used to monitor crops throughout the year. Responsibility for ensuring compliance with the terms of the agreement lies with the national government agricultural agencies.

A number of countries experience frequent heavy cloud cover at certain times of the year so that optical and infra-red satellite instruments may not be capable of providing the data required for continual monitoring. The ERS-1 SAR can provide data for cloud covered areas at any time of day or night. In addition, due to the high degree of complementarity between SPOT and SAR, combining the two data sets enables more accurate classification schemes to be implemented in the analysis of various crops.

In Ireland, responsibility for monitoring compliance with the agricultural agreements rests with the Department of Agriculture. On behalf of the Department, ERA Maptec acquire and analyse the satellite data together with any available ground data, to provide a crop surface coverage estimate and an identification of particular crops being grown in specific areas. Operational monitoring utilises SPOT or Landsat scenes acquired at four points over the course of the year. Due to prolonged cloud cover in the summer season of 1994 however, no suitable Landsat or SPOT data could be obtained and ERS-1 SAR data were used.

The Figure illustrates three SPOT scenes for a region of Ireland acquired at different times during the growing season. Different crop types are visible in each classification. By late summer, the addition of the SAR data allows the construction of an improved classification map, increasing the accuracy of the separation between cereal crops and potato/sugar beet crops. One specific culprit was identified as growing sugar beet and potatoes on an area of land for which a cereal crop subsidy was being claimed.

Courtesy of M Critchley, ERA Maptec, Dublin, Ireland


SPOT (AIS)
SPOT (S)
ERS (AIS)
SEVILLE
Classification Results: 1992
SPOT (AIS) : SPOT classification by AIS
SPOT (S) : SPOT classification by contractor
ERS (AIS) : ERS-1 classification by AIS
SPOT 23.03, 08.06, 01.07, 26.08 1992
ERS-1 27.05, 01.07, 05.08, 09.09 1992
Area: 10 x 10 km
Rice
Cotton
Water
Other
AIS
esa

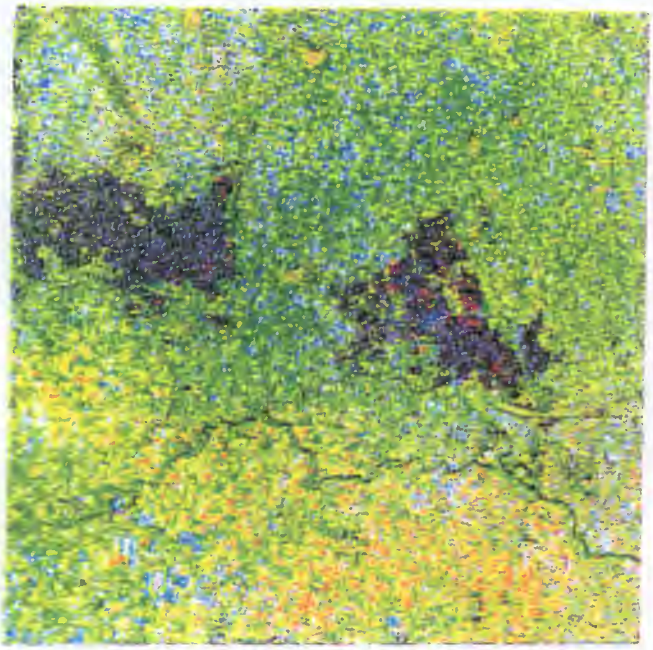
Figure 4.2 Estimating crop coverage in Europe

Under the framework of the European Union programme for Monitoring Agriculture by Remote Sensing (MARS), there is a major action devoted to the rapid estimation of crop surface coverage (and hence potential yield levels) over the entire European Union. This is based on the analysis of SPOT and Landsat optical data together with ERS-1 SAR imagery over 60 test sites and is implemented using computer aided visual interpretation of the images. The programme is conducted by the European Union Joint Research Centre in Ispra with the support of a limited number of European value adding companies.

At present, optical imagery is acquired at least four times during the growing season and the results are used to generate forecasts which are then sent to DG VI (Agriculture) at the European Commission headquarters in Brussels. Due to the nature of European Union agricultural policies and the nature of agricultural subsidies in particular, early crop acreage estimates are an important tool in the effective management and administration of the European Union. For example, such information allows the planning of distribution resources, subsidy levels and storage facilities.

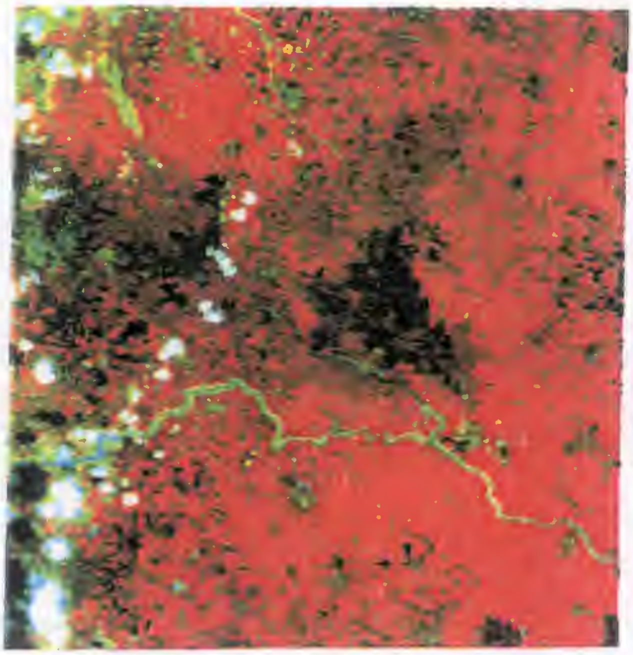
Due to unfavourable weather conditions in northern Europe, image acquisition by optical sensors can be extremely difficult. The all weather capability of the ERS-1 SAR allows year round data acquisition. SAR data are combined to form three and seven date multi-temporal data sets and are used with SPOT data to identify crop species. The Figure shows various classifications of rice and cotton for the Seville test site.

Courtesy of J Harms, SCOT Conseil, Ramonville, France



LEGEND

DARK BLUE : RICE
MAGENTA : IRRIGATED FALLOW
BLUISH-GREEN : PLOUGHED FIELDS
DARK : VILLAGE/TANKS/CANALS
YELLOW-GREEN : COTTON CROP



LEGEND

BROWN : RICE CROP
BRIGHT RED : COTTON
WHITE : CLOUD

Figure 4.3 The Indian Crop Acreage and Production Estimation Programme

The Crop Acreage and Production Estimation Programme is one of the major projects under the Remote Sensing Applications Mission within the Indian Ministry of Agriculture. Originally, the aim was to supply accurate timely and reliable information to the Ministry of Agriculture on the acreage and production of the major food grain crops (rice, wheat and sorghum) as well as oilseeds (groundnut and mustard) based on multi-spectral images from Landsat and the Indian IRS satellite. Due to excess levels of cloud cover, it was necessary to include ERS-1 SAR data as an alternative source for the production of crop inventory statistics.

A demonstration project was conducted over the Prakasham and Guntur districts in Andhra Pradesh, an area covered predominantly with alluvial black cotton soils. The principal crops in the area are cotton, rice, chillies, pulses and tobacco. SAR images were visually analysed at a 1:25,000 scale for a first analysis of the various land use and land cover classes. Multi-temporal SAR images were then constructed using three images acquired between July and November 1992 (Figure a). An IRS-1 image false colour composite was also used to aid interpretation of the land use and land cover classes (Figure b). The demonstration indicated the suitability of ERS-1 SAR for crop identification in the region, particularly for rice and cotton.

Analysis of the multi-temporal data then permitted a calculation of the area for rice and cotton crops and subsequent calculation of the yield levels. Figure c shows rice crops coloured in blue and cotton in yellow. Although the ERS-1 data were more expensive than the IRS data, the all-weather capability of the SAR is a distinct advantage over optical data.

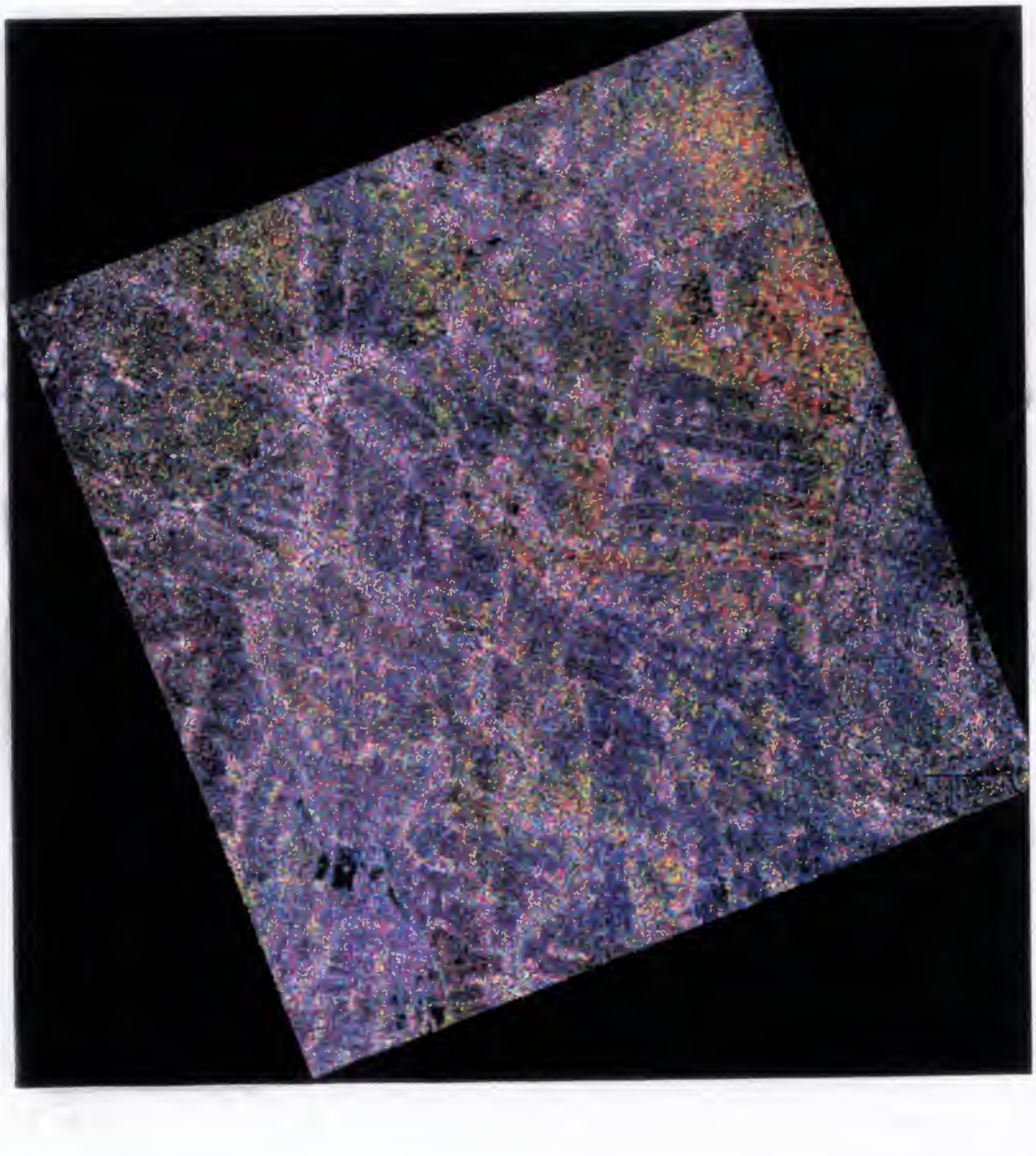
Courtesy of P Nageswara Rao, Indian Space Research Organisation, Bangalore, India

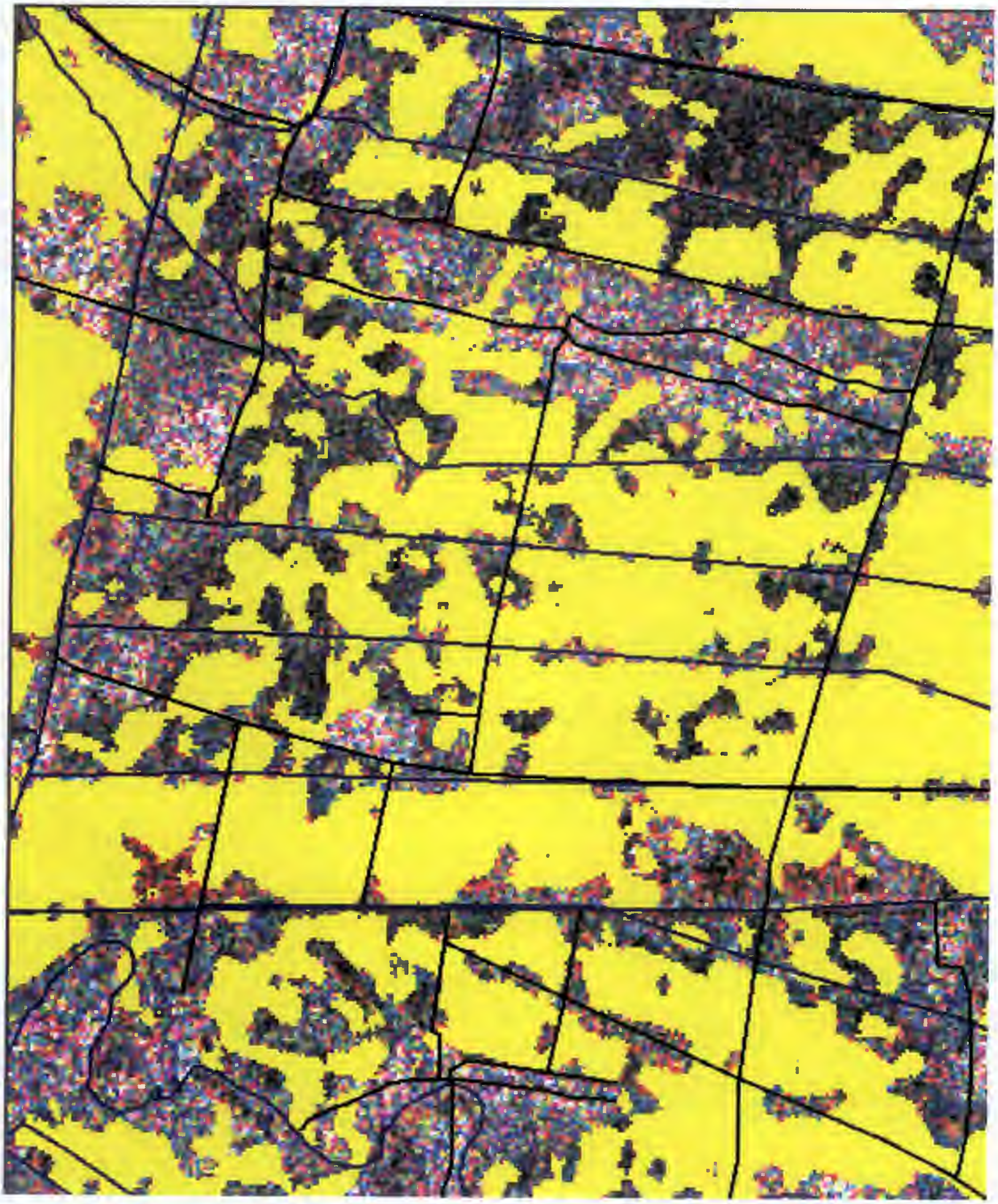
Figure 4.4 Rice monitoring in Indonesia

A technology demonstration and transfer project is currently underway in Indonesia using ERS-1 SAR data to map and monitor the rice crop area. This is being undertaken by SCOT Conseil and CESR of France. Approximately two million people live in the demonstration area. There are two rice crops a year, one during the wet (November to April) and one during the dry season. Annual precipitation levels are approximately 1800 millimetres per year (compared with less than 1000 millimetres per year in north west Europe), 75% of which occurs between November and April. The project began in April 1993 and is now close to operational status with the technology being implemented within the Indonesian national mapping agency (BPPT) and the Ministry of Agriculture.

Geocoded SAR images from Lapan, the Indonesian ground station, are combined into a three date data set (Figure a) which is classified to determine the variation in the rice surface over the growing season. Auxiliary data include aerial photographs, ground data and existing map data. Figure b shows an example of a rice surface area map where rice fields are shown in yellow, waterways and irrigation channels in blue and roads in black. Statistics on rice growth for the entire region are derived from these maps. The statistics are then supplied to the Ministry of Agriculture.

Courtesy of J Harms, SCOT Conseil, Ramonville, France





4.2. Forestry

Figure 4.5 Global tropical forest monitoring

The goal of this activity was to demonstrate the feasibility of extending the role of ERS-1 SAR coverage to global vegetation monitoring with particular reference to the tropical belt. This is part of the TREES study to map tropical forests using remotely sensed data, which was commissioned and implemented by the European Union through the Joint Research Centre. Nineteen study areas were selected in Southeast Asia, Africa and Central/South America. Three examples are discussed below:

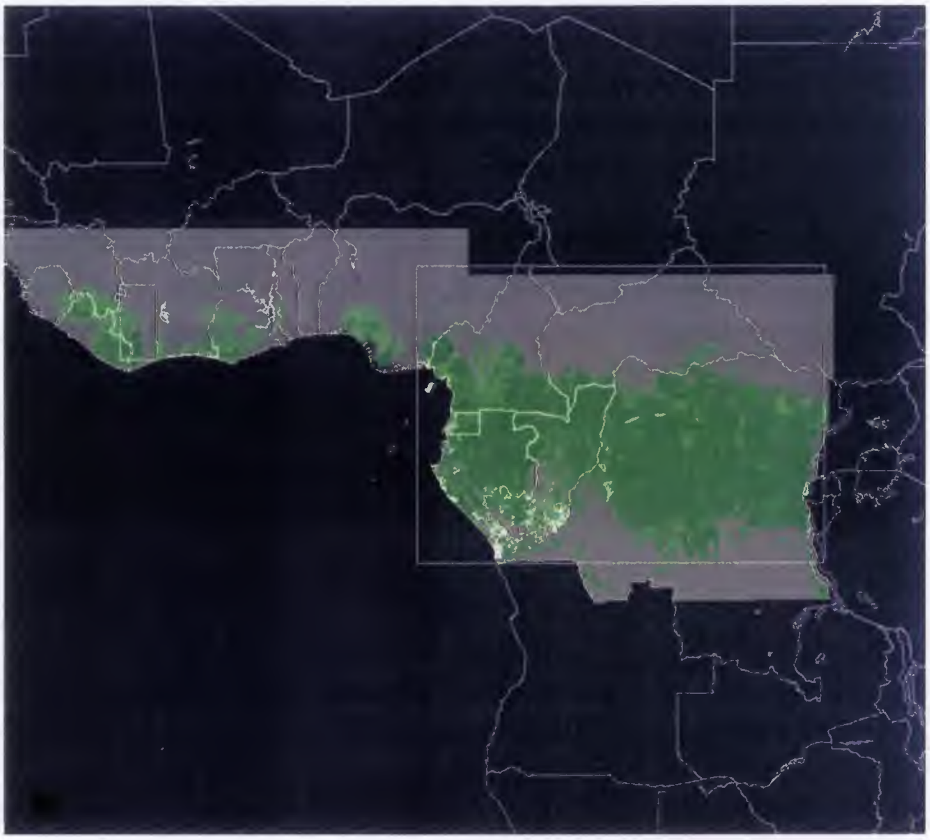
- The ERS-1 SAR mosaic of Central Africa contains 477 scenes (Figure a). These data have been acquired during the period from July 15 to August 28, 1994. The mosaic covers some of the lesser known forest areas of the world where existing assessments are relatively old and where little information has been collected on deforestation. The material provided by this ERS-1 Central Africa Mosaic constitutes a unique source of data on vegetation distribution at a continental scale. The most celebrated "all weather" characteristic of SAR has taken its full meaning in the present case with the provision of coverage for a whole equatorial region on demand and in a minimum amount of time. Since acquisition, a significant level of information on forest conditions has rapidly been extracted.

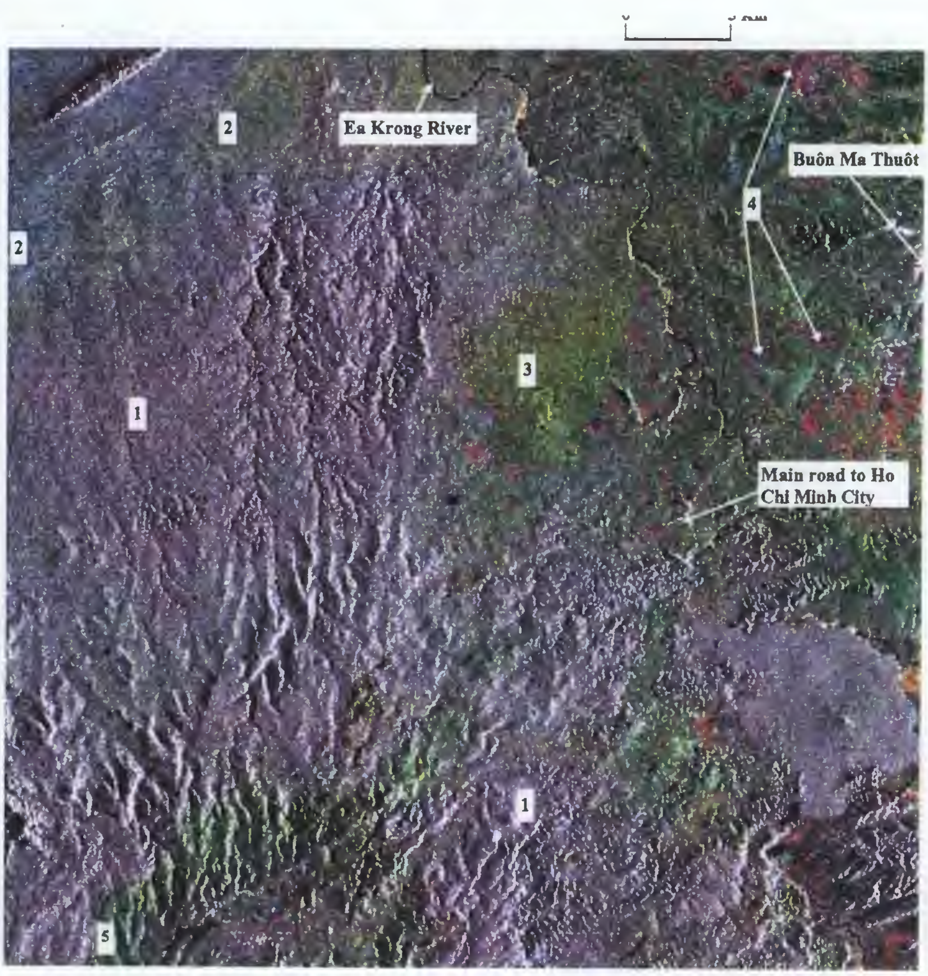
- The Tapajos National Forest in Brazil has large areas of cleared and regenerating forest. Quantitative measurements such as above ground woody biomass density, leaf dimensions and moisture content were made in areas of primary and regenerating forest. A multi-temporal SAR image of the area is shown in Figure b. A large square area of farmland can be seen in the lower half of the image. Maps showing the forested and non forested areas were produced.

- In Southeast Asia rapid tropical deforestation is occurring due to population and economic growth. Figure c is a three-date SAR composite image from De Lac Province, Vietnam where (1) denotes the evergreen forest, (2) seasonal forest, (3) upland crop, (4) paddy fields and (5) bush. The seasonal forest, evergreen forest and non forested areas were mapped (Figure d).

SAR data provide reliable information for updating existing forest cover data bases. The new perspective introduced by the large scale coverage of an entire bio-geographical domain is considered to be one of the newest and most promising contributions to the field of global vegetation monitoring.

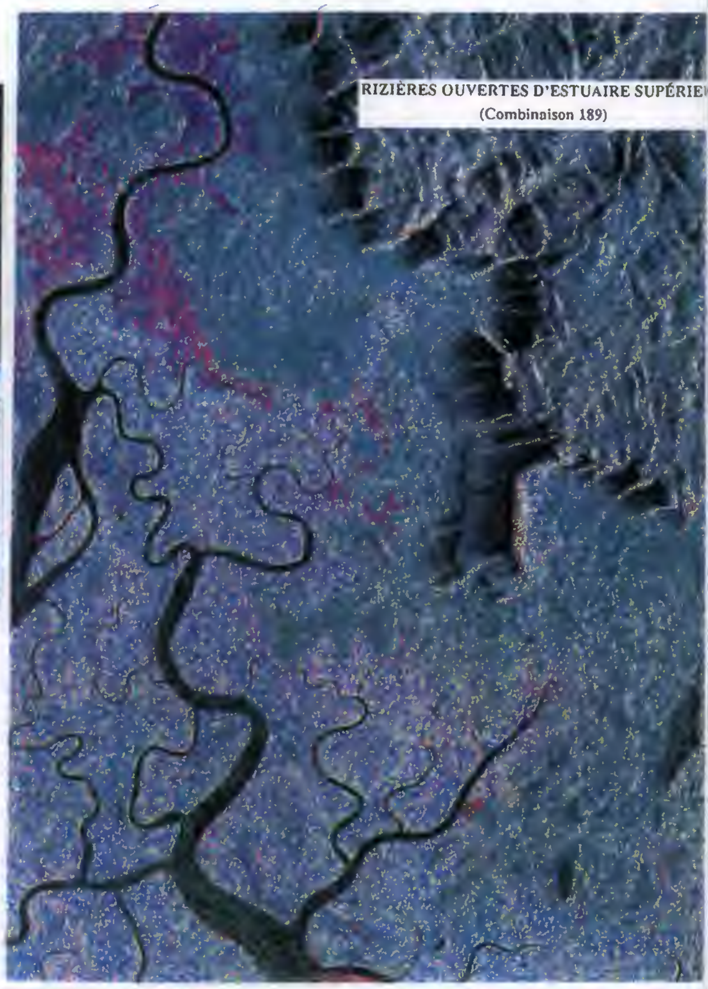
Courtesy of J-P Malingreau, Joint Research Centre, Ispra, Italy





Ea Krong River
2
2
Buôn Ma Thuôt
4
3
1
Main road to Ho Chi Minh City
1
5

evergreen forest
seasonal forest
non forest



RIZIÈRES OUVERTES D'ESTUAIRE SUPÉRIE
(Combinaison 189)

PHOTO-INTERPRÉTATION DES UNITÉS BOISÉES (UNITÉ 1 ET 2
(Frame 3411)

CLASSIFICATION FINALE

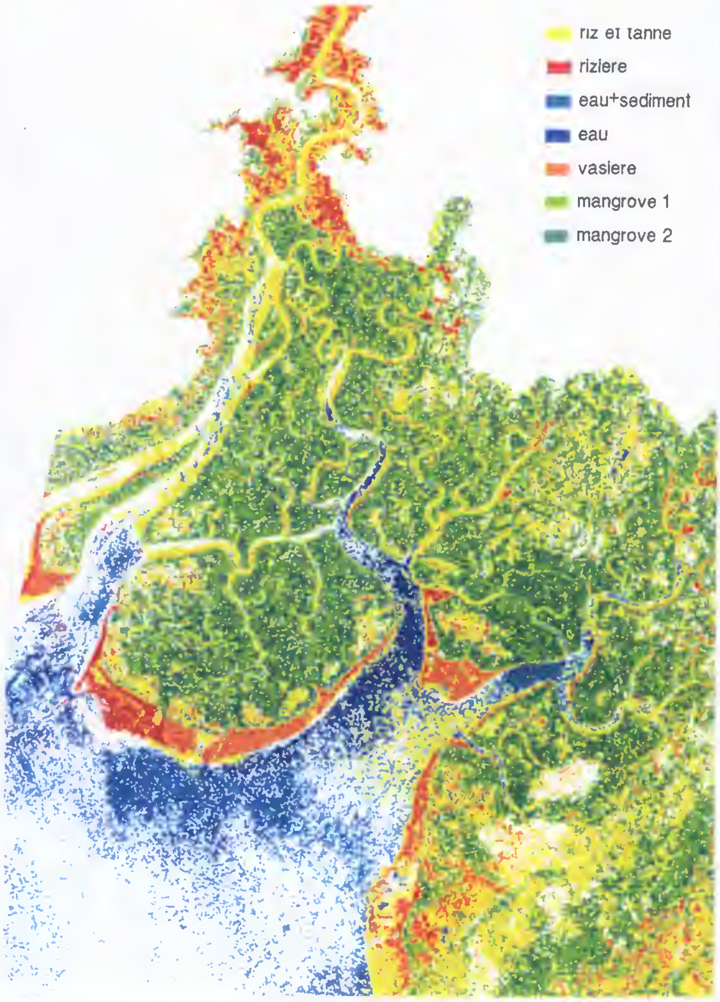


Figure 4.6 Mangrove monitoring in West Africa

Mangrove forests (Figure a) in western Africa offer a range of exploitable resources, including:

- Wood supplies for domestic needs in neighbouring cities and villages;
- Suitable ecosystems for rice cultivation;
- Salt;
- Fish.

The process of deforestation needs to be monitored. Therefore the mangrove forests are being mapped and their evolution analysed using ERS-1 SAR in conjunction with ground surveys and optical satellite images.

A demonstration project was carried out by the French company Geosys, to supply monitoring information based on ERS-1 SAR data to the Guinean National Forestry Protection Agency, DNFC. The project showed that by using a number of SAR images taken at regular intervals the degeneration and regeneration of the mangroves can be observed, and the extent of deforestation activities monitored and mapped. In addition to SAR data, SPOT XS and airborne photos were used. Due to the local weather conditions, it is not possible to use only optical satellite data for operational mangrove monitoring. Multi-temporal images based on six SAR datasets were constructed and classified into five categories of land cover. Land use maps of the study area can then be compared with the information derived from SAR data.

The mangrove forests are comprised of arhizophora-dominant mangrove, which is high and dense, and the avicennia-dominant mangrove, which is low and sparse, a degenerated form of the former mangrove type. Bare areas are visible where the mangroves have been clear-cut. Rice fields planted in earlier clear-cuts are also evident. Waterways and mud banks can be seen and, in an improvement over conventional techniques, it is also possible to distinguish water that contains sediment from clear water, and thus to map sediment transport.

Figures b and c show SAR composite images of mangrove forests. In particular wooded areas are visible in turquoise in Figure b, while in Figure c, rice fields can be detected (magenta colour). Figure d shows the final classification obtained from ERS-1 SAR data.

Courtesy of I Pons, Geosys, Ramonville, France

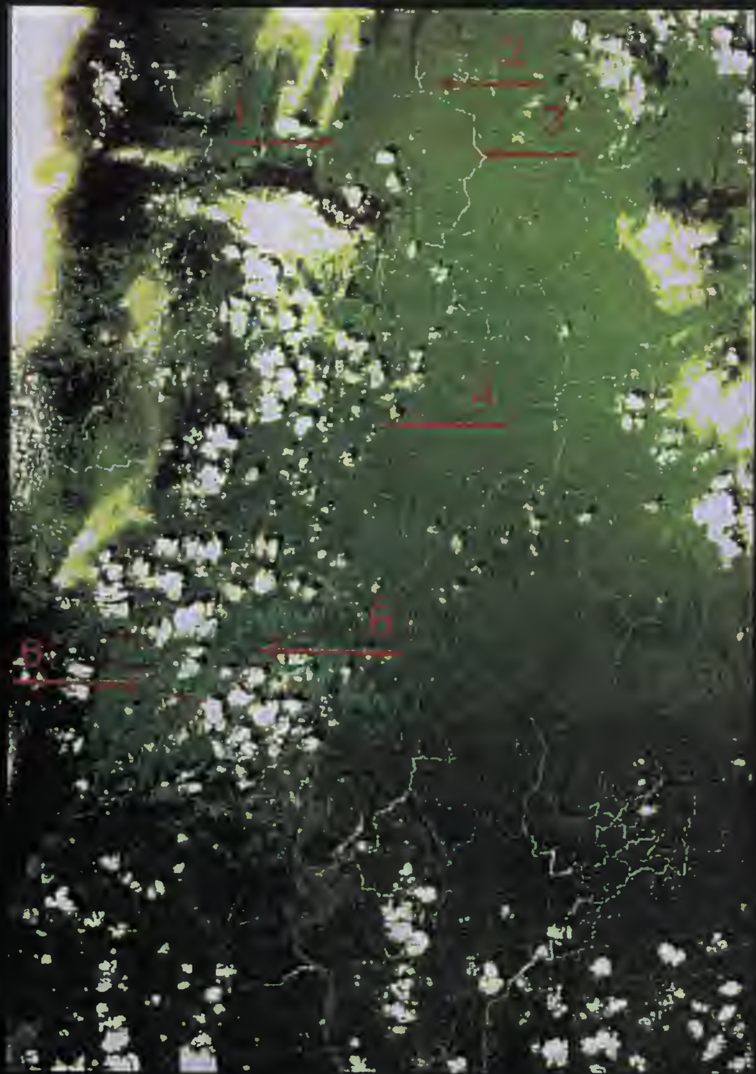
Figure 4.7 Tropical rainforest monitoring and land use planning in Borneo

The German company Kayser-Threde GmbH and the Zoologisches Institut der Ludwig-Maximilians, University of Munich are using ERS-1 SAR data for monitoring rainforest conversion and land use planning in the province of Kalimantan Timur in Borneo. The end user is the Indonesian Badam Petranahan Nacional (the national mapping and land planning agency) and the main focus is to develop a user friendly and easily portable evaluation system for ERS-1 SAR images which can operate under the conditions of tropical regions. The area includes examples of many different problems relevant to the protection and management of tropical forests (Figure a). As part of the development of an operational system, emphasis was placed on the visual interpretation of enhanced SAR images and the production of image maps to be used in the field. In addition to SAR images, Landsat TM, SPOT HRV and KFA-1000 high resolution optical images were acquired together with ground truth data (Figure b).

The results of the demonstration indicate that ERS-1 SAR images are valuable for land use planning and monitoring in tropical regions. The principal advantage of SAR, compared to optical Earth observation systems, is its all weather capability. This opens up the possibility of receiving a set of new images of the whole island of Kalimantan nearly every month. Even with the lower resolution and the reduced information content compared to high resolution optical images, SAR images can provide information about remote regions, where little data are available or cost prohibits the use of other methods on a regular basis. After more than 20 years of the Landsat mission there is no cloud free data set available covering Kalimantan. The aim of the programme is full operationalisation with the establishment of a Geographic Information System (Figure c) and complete technology transfer to the Indonesian end users.

Courtesy of S Kuntz, F Siegert and A Wanninger, Kayser-Threde, Munich, Germany

MIR KFA1000 Image



ERS-1 Image

1 Dipterocarp Forest, 2 Selectively Logged Areas, 3 Heath Forest and Logging Road, 4 Clear Cuttings, 5 Secondary Forest and Agriculture, 6 Settlements

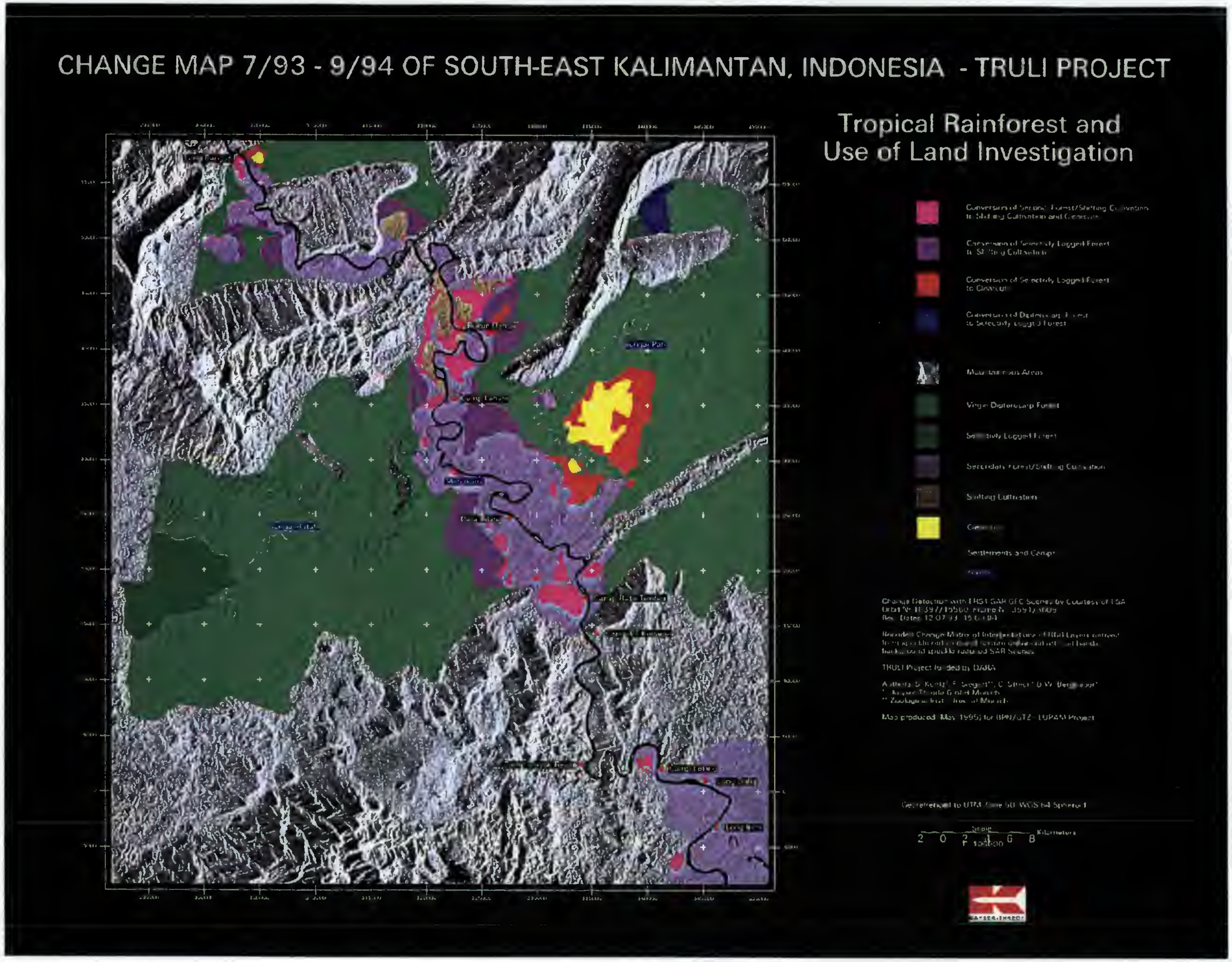

CHANGE MAP 7/93 - 9/94 OF SOUTH-EAST KALIMANTAN, INDONESIA - TRULI PROJECT
Tropical Rainforest and Use of Land Investigation
Conversion of Selectively Logged Forest to Clearcut
Mountainous Areas
Virgin Dipterocarp Forest
Selectively Logged Forest
Secondary Forest/Shifting Cultivation
Shifting Cultivation
Settlements and Camps
Scale
2 0 2 4 6 8 Kilometers

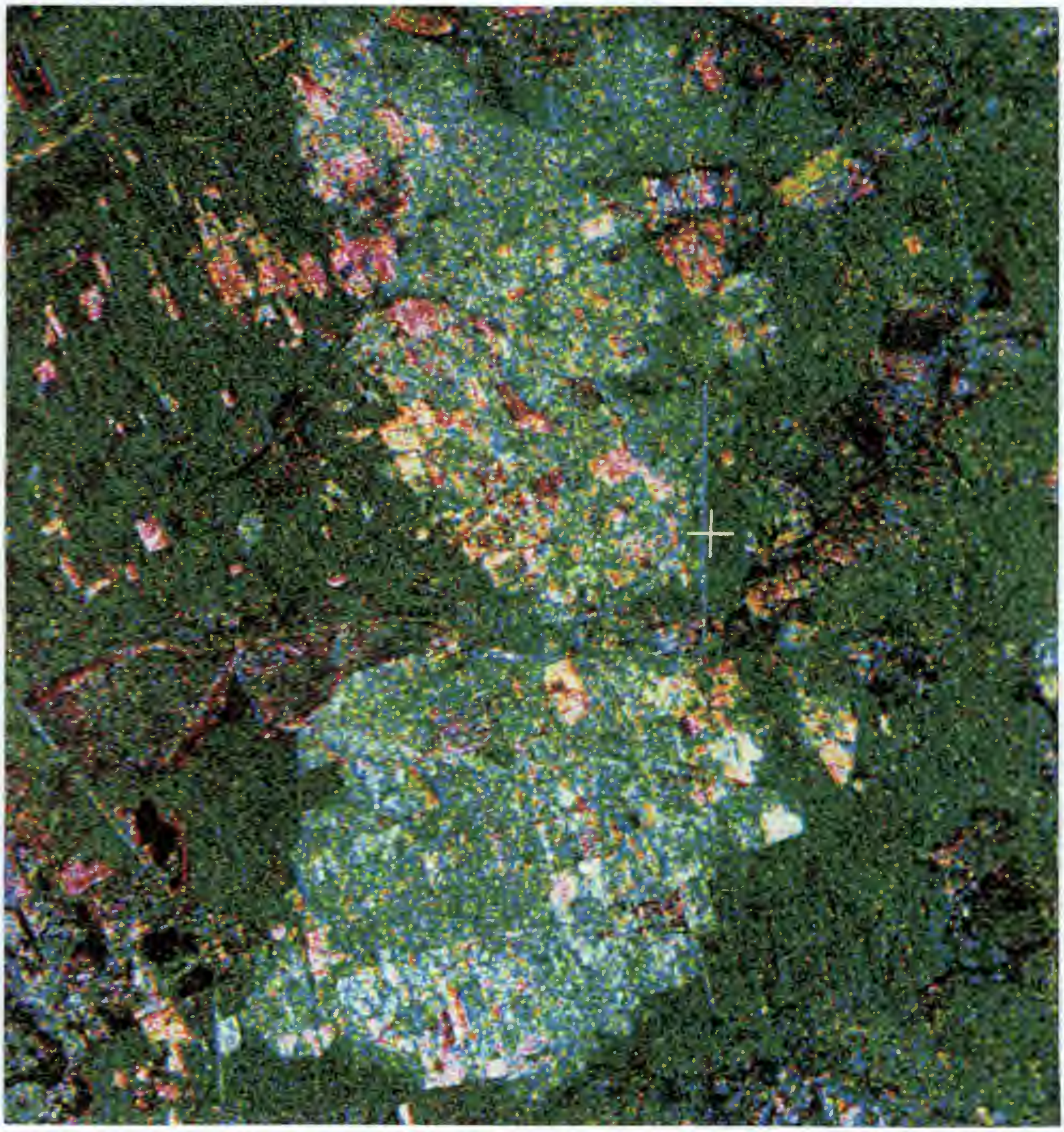
Figure 4.8 Forest disaster assessment in Poland

At the beginning of the seventies, the extent of environmental deterioration in Poland emerged. A large volume of information has been collected in recent years but due to the high incidence of cloud, little remotely sensed data were available prior the launch of ERS-1.

In 1992 an enormous forest fire broke out in the Upper Silesian industrial region of southern Poland (Figure a). It devastated more than 9,000 hectares of forest land. The boundaries of the burnt areas derived from the SAR image were superimposed on archived Landsat MSS data to evaluate the original forest type. The burnt site was imaged three times by ERS-1 SAR in July, August and September 1993. The composite formed from these images (Figure b) provides information for recultivation work.

A forest information database, held within the Institute for Cartography and Geodesy, was updated with information derived from the SAR images. The comparison between these two datasets allowed a full assessment to be made of the forest that had been destroyed. The results demonstrated the usefulness of SAR data in an operational application for forest disaster assessment, and the value of incorporating SAR data with other information within a forest information system.

Courtesy of A Ciolkosz, Institute of Geodesy and Cartography, Warsaw, Poland



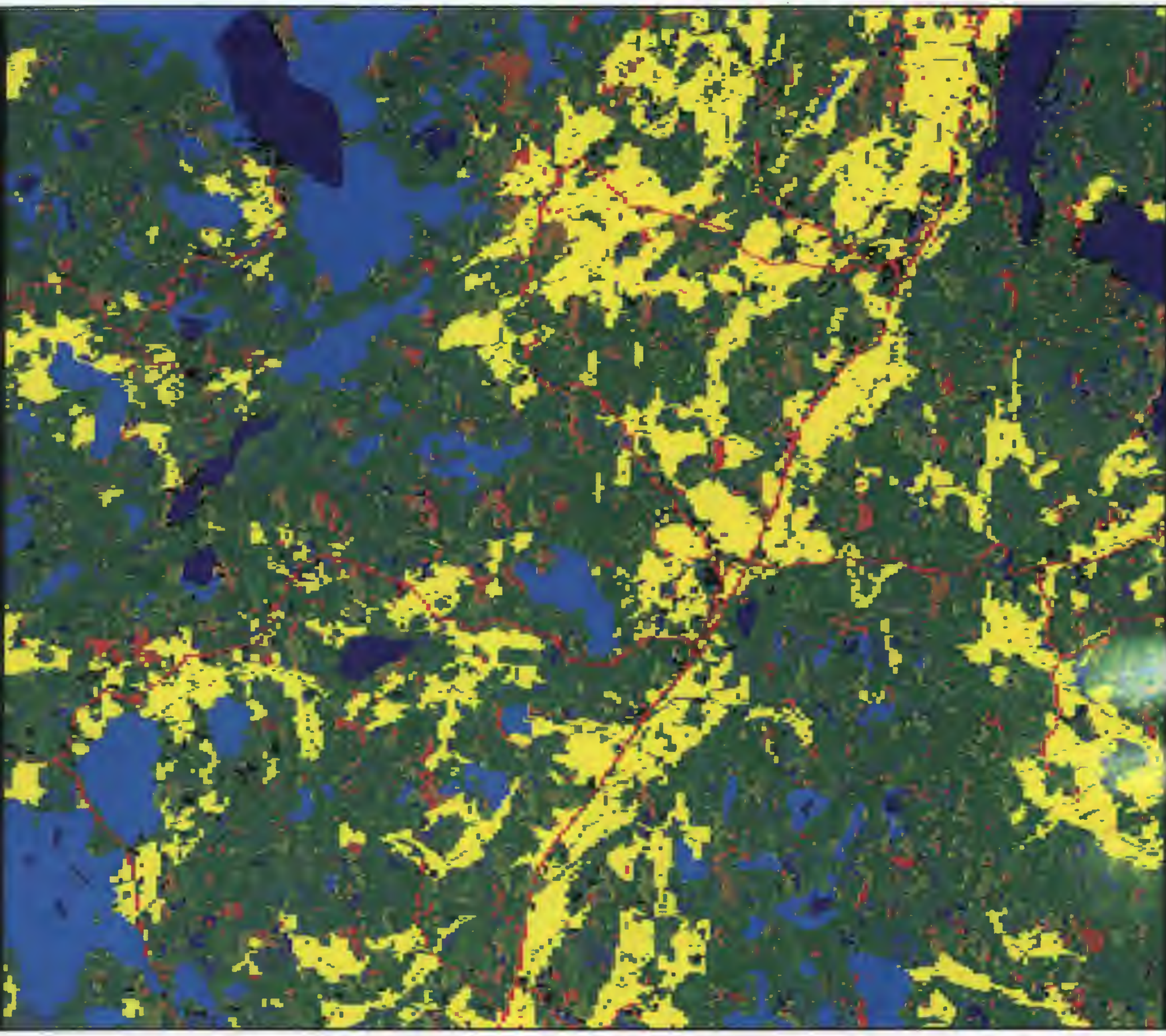


Figure 4.9 Large area forest inventory in Finland

In 1993, the Department of Forest Management in the Finnish Forest Research Institute began a demonstration project to estimate forest resources over large areas with ERS-1 SAR and auxiliary information sources. The aim was to integrate an operative forest inventory system utilising SAR data into current classification and timber volume mapping procedures.

The total land area of Finland is 30.5 million hectares. Forests cover 26.4 million hectares, of which 20.1 million hectares are classed as a productive forest land. 63% of the forest area is privately owned, the state owns 24%, companies 9% and the rest belongs to municipalities and parishes. The total annual net sales of Finnish forest industries was 9 billion ECU at the end of the 1980s and form by far the most important single industrial sector in Finland. Classification maps based on satellite data (Landsat TM) together with digital map data are already used operationally by local companies.

Six ERS-1 SAR images of the test site located in Porvoo, southern Finland, were used to estimate the timber volume. A mask has been applied to separate forest and non-forest areas. The Figure shows the result. The colours applied denote the following:

- Yellow:	Agricultural land
- Blue:	Water
- Light blue:	Bog land
- Red:	Roads
- Black:	Urban areas

Forest areas are coloured according to timber volume. Low levels of timber volume are coloured green, varying towards a red colour as the level of timber volume increases.

Courtesy of E Tomppo, Finnish Forest Research Institute, Helsinki, Finland

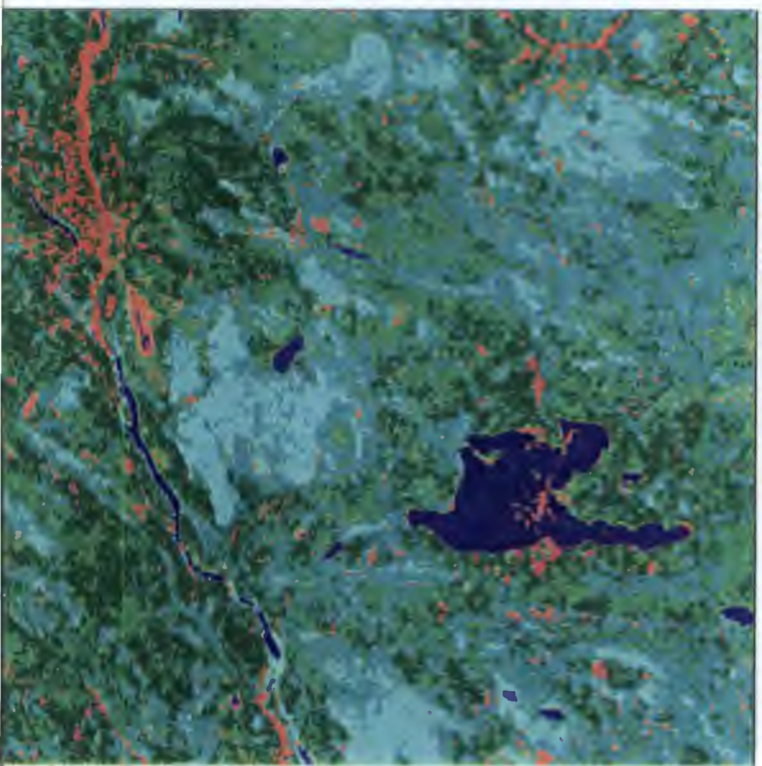
(a)

Figure 4.10 Sub Arctic land use mapping

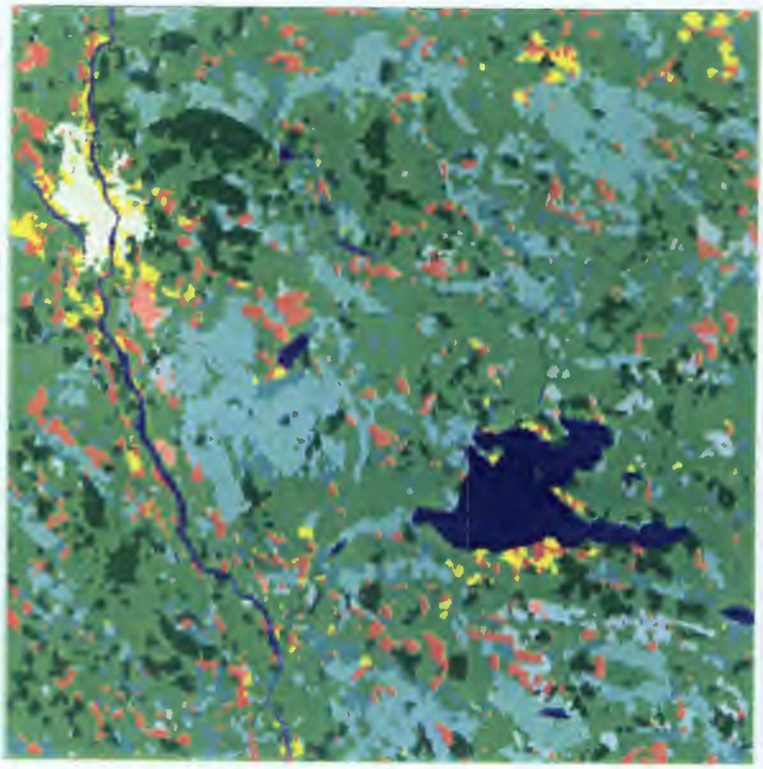
A sparsely forested region (pine, mixed and mire) with bogs, lakes and clear-cut areas in Sodankyld, Finland has been investigated to determine the capability of ERS-1 SAR for mapping vegetation in snow covered areas. SAR discriminates wet snow from other snow types, consequently it is also useful for mapping wet snow in drainage areas during the spring.

The classified map shown in Figure a is derived from SAR and is based on the different snow conditions over the area. Figure b shows a ground verified classification map based on a combination of LANDSAT and SPOT data. The suitability of SAR for land cover classification can be seen from the comparison. Classification maps such as that in Figure c are processed by the National Board of Survey, and are used by paper companies and by local authorities for natural resource management.

Courtesy of M Hallikainen, Technical University of Finland, Helsinki, Finland



(b)



(c)

5. ENVIRONMENT, RISK MONITORING AND MANAGEMENT

Although the management of environmental hazards was not envisaged as an original objective for the ERS-1 mission, a wide range of applications are being developed. No single warning or forecasting system is appropriate for all environments or for all types of hazard. However, each shares the following common characteristics: risk assessment and management, hazard monitoring and forecasting, warning formulation, transmission and dissemination of warnings and response mechanisms.

❑ ERS-1 contribution

Hazard management applications depend on data being available at critical times. Although the ERS-1 mission was not designed to offer an immediate rescheduling capability, the data have still been used for monitoring damage after disasters have occurred, or on an opportunistic basis, where data collection coincides with the actual event.

In particular, fast delivery SAR products are proving to be of great value in improving the accuracy of determining the nature and extent of disasters. The value of these products has been demonstrated particularly in oil spill detection, where surveys of large areas have been possible. Aircraft are then used to follow up any identified oil spills.

SAR products have also been used during several flood events, to permit immediate assessments of the areas at risk and decisions to be made on relief and clean up operations. Products derived from off-line ERS-1 SAR data provide accurate spatial information on the extent of previous flood events. This is being used for management planning for future events and has been shown to be of particular value in areas where flooding occurs regularly.

The capability of differential SAR interferometry to detect and quantify extremely small surface height variations or topographical surface movements, such as those occurring before a volcanic eruption or an earthquake, has been demonstrated in the last few years. This technique can also be used to monitor subsidence associated with mining.

❑ Market potential

The UN launched the International Decade for Natural Disaster Reduction in 1990 to:

'reduce through concerted international action, especially in developing countries, the loss of life, property damage, and social and economic disruption caused by natural disasters'.

Globally, damage inflicted by natural disasters kills an estimated one million people each decade and leaves millions more homeless.

Economic damages from natural disasters have tripled in the last 30 years. During the decade 1980 to 1989, the cost was 94 billion ECU. Before 1987 there was only one disaster the cost of which exceeded 0.8 billion ECU in insured losses. Since 1987 however, thirteen events of this magnitude have occurred. Prevention and preparedness measures can make a difference. Floods, tropical storms and drought account for most of the damage caused by natural disasters as shown in Table 5-1.

	Significant damage of more than 1% of GNP	**More than 1% of population affected**	**Deaths exceeded 100**
Floods	23	41	51
Tropical storms	19	22	30
Drought	16	48	not available

Table 5-1: Number of events which caused damage between 1988-1992
(Source: UN-IDNDR)

In Europe, after earthquakes, flooding events cause the greatest damage. In the period 1965-1992, there were 115 major flood events causing a total direct economic loss of nearly 13 billion ECU and affecting nearly 4 billion people. This represents over 20% of world wide financial losses due to flooding. As an example, the flooding that occurred in Italy during late 1994 resulted in 70 deaths and 5 billion ECU of property damage. The great floods which occurred throughout the USA and Europe in 1993 and 1995 have highlighted how severe the consequences can be for loss of life and property, even in countries where flood forecasting and prevention methods have long been implemented.

ERS-1 SAR data are being used in modelling work both to identify and assess areas at risk. Although this work is at an early stage of development, insurance and re-insurance companies have recently become interested in the potential to use Earth observation data to derive environmental risk assessments and property value statistics.

In addition to natural disasters, one of the major environmental concerns stems from oil pollution. During the last 30 years, pollution of the world's oceans has become a matter of increasing international concern. In spite of rigorous controls, deterioration of water quality, especially in waters subject to heavy shipping, continues at a high rate. Monitoring illegal discharges and early detection of accidental pollution events is an important component in ensuring compliance with marine protection legislation and the general protection of coastal environments. Traditionally, this service uses airborne patrols, but this is expensive and coverage is patchy, particularly for countries with jurisdiction over large maritime areas. Between 1978 and 1994 the International Oil Pollution Commission provided compensation for 73 oil spills ranging from 0.2 to 84,000 tonnes of oil spilt from tankers. Marine salvage companies recovered 1.25 million tons of oil from 14 stricken tankers in 1994. This is equivalent to 33 times the amount spilled from the Exxon Valdez in Alaska in 1989.

❑ Example applications

This chapter shows how ERS-1 data are being used to monitor natural and man made disaster events once they have occurred. Examples of activities in Norway, Holland, UK, Belgium, France, USA, Germany, Italy, Philippines and Ecuador are included. The principal customers for these services include local and national government agencies responsible for environmental protection, pollution control, infrastructure maintenance and disaster relief efforts. Examples are given below of how SAR data have been used specifically to:

- Identify and monitor oil slicks at sea, providing information for clean up operations and identifying the source of the spillage;
- Map flooded areas for disaster relief and for the management of the flood plain area;
- Measure and map Earth movements caused by natural and man made events.

The organisations which are active in developing this important application area and have provided information include:

- BRGM, France;
- CSI Piemonte, Italy;
- Dartmouth College, USA;
- Deutsche Projekt Union, Germany;
- Earth Observation Sciences Limited, UK;
- Federal Institute of Hydrology, Germany;
- GAF, Germany;
- Geosys, France;
- ITC, The Netherlands;
- Remote Sensing Application Consultants, UK;
- Rijkswaterstaat, The Netherlands;
- SERTIT, France;
- Norwegian Space Centre, Norway;
- University of Gembloux, Belgium;
- University of Liège, Belgium.

Tromsø Satellite Station
NORWEGIAN SPACE CENTRE

TELEFAX

Tromsø Satellite Station, N-[illegible] Tromsø, Norway. Tel: +47 77 [illegible] Fax: +47 77 [illegible]

To:	Norwegian Pollution Control Authority	From:	Tom Anderssen
Att:	Commanding Officer	Date:	9 August 1994
Telefax no.:	330 44257	Our ref.:	
Copy:		Pages:	1

Subject: **Possible oil spill detected in ERS-1 image**

Time of observation: 9 August 1994, 10:40 UTC

Slick position: N 65°58', E009°17'

Slick size: 47 km x 0.2 km

Oil spill probability: High

Possible discharge source: Ship (but no likely polluter is visible in image)

Comments:

Weather conditions seem low to moderate.
Slick is oriented in NE-SW direction.
Some ships are visible but none of these could be the discharge source.

Kind regards,

Tom Anderssen

5.1. Oil slick monitoring

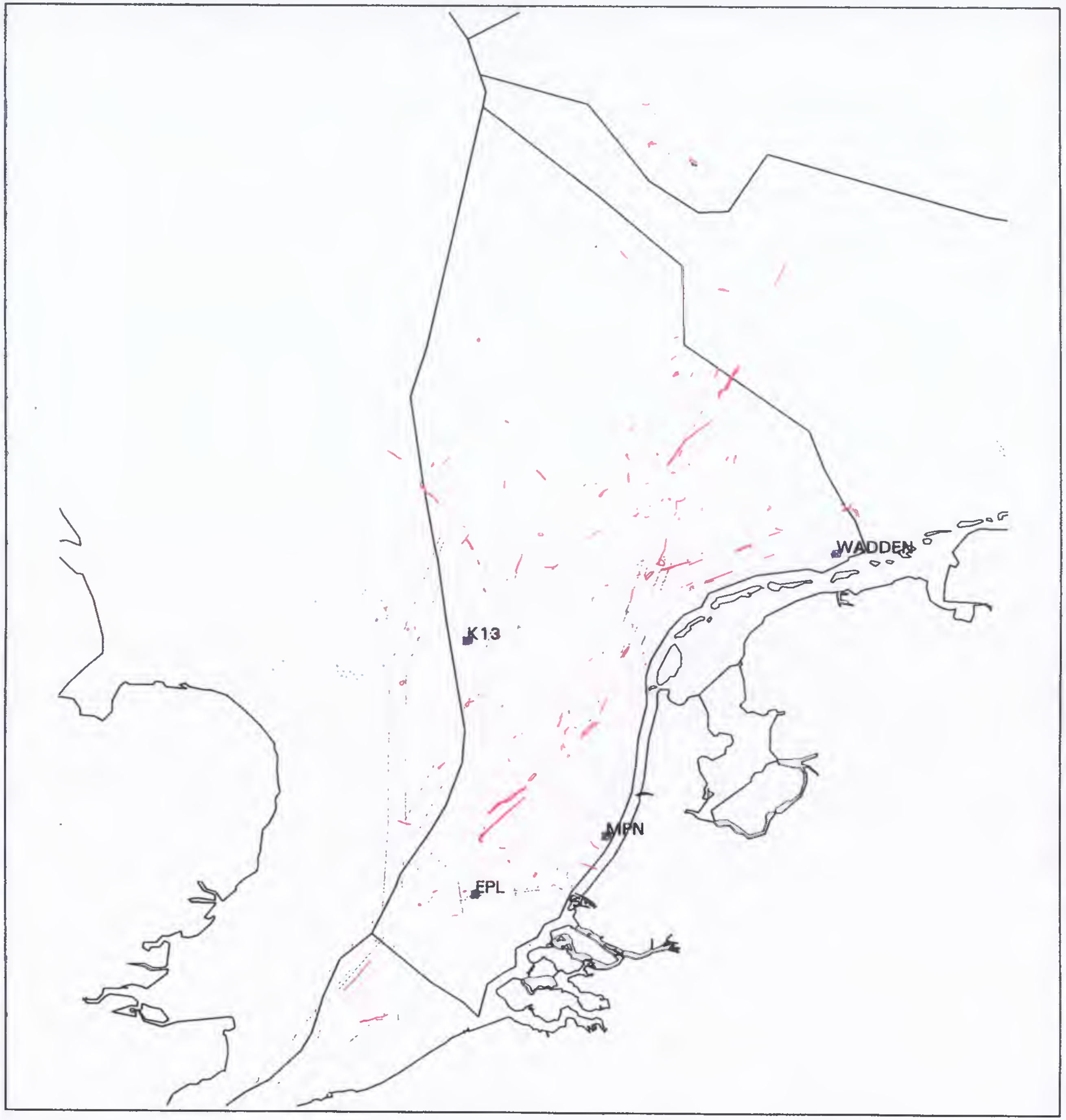
Figure 5.1 Oil spill detection off the Norwegian coast

A real time oil spill detection service, based on ERS-1 SAR imagery, is operated by Tromsø Satellite Station in Norway. This covers the North Sea, Baltic Sea and North Atlantic. Low spatial resolution (100 metres) SAR images (Figure a) are analysed by trained operators to confirm the presence of oil slicks. Once a slick has been positively identified, an alarm is sent to the relevant national authority. This alarm can be issued within two hours of data observation. It consists of a fax (Figure b) detailing the location of the slick and, where requested, the relevant sub-section of the SAR image is also sent over the Internet.

In the case of Norwegian territorial waters, the responsible national authority is the State Pollution Authority. On receipt of an alarm, an aircraft is dispatched to estimate the type and quantity of oil. In some case, even where no clean up operation was required, the organisation responsible for the oil slick has been notified and asked to supply further information about the cause of the spillage. Due to the high success rate in identifying slicks, the aircraft surveillance operations have now been coordinated with the ERS-1 schedule. Whenever possible, satellite and aircraft cover the same parallel and overlapping strips. Processing at the Tromsø Satellite Station is done in a way to allow aircraft verification with a minimum of time and flying distance.

For long term monitoring of the area, the use of ERS-1 SAR data with aircraft verification is proving to be a cost effective solution to meet the requirements of the authorities and environmental organisations charged with providing a maritime pollution monitoring and response service. On a promotional basis an oil pollution survey is being operated in all inner sea and coastal areas covered by the Tromsø Satellite Station. A fast delivery service is also available via the Internet for quick looks.

Courtesy of G D Strøm, Norwegian Space Centre, Oslo, Norway



Ministry of Transport
Public Works and
Water Management

ERS-1 SAR
Oil Spill Detection
detected oil slicks
from 930601
until 931219

oil slicks
oil platforms
monitoring station

Rijkswaterstaat
National Aerospace Lab NLR
ESA - BCRS

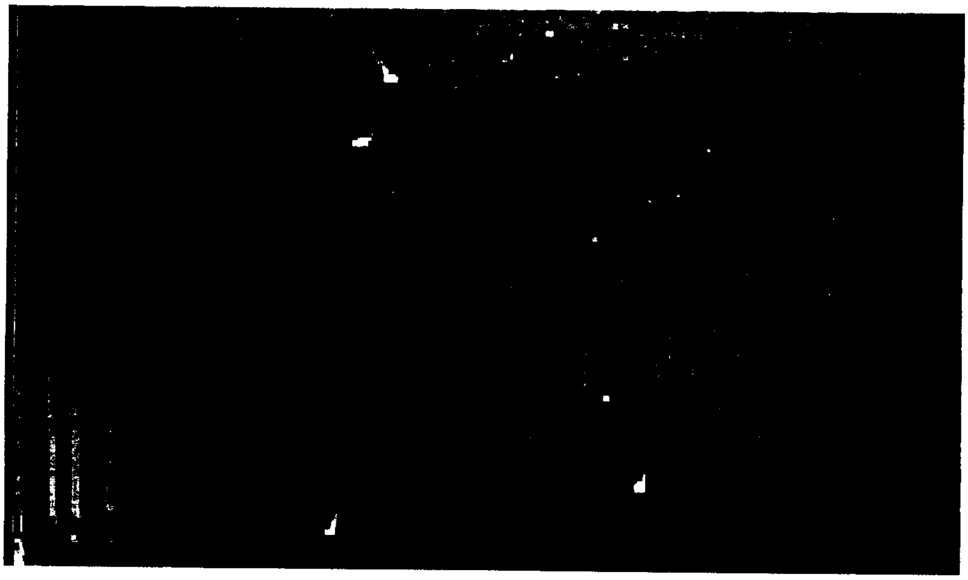
Figure 5.2 Oil spill detection off the Dutch coast

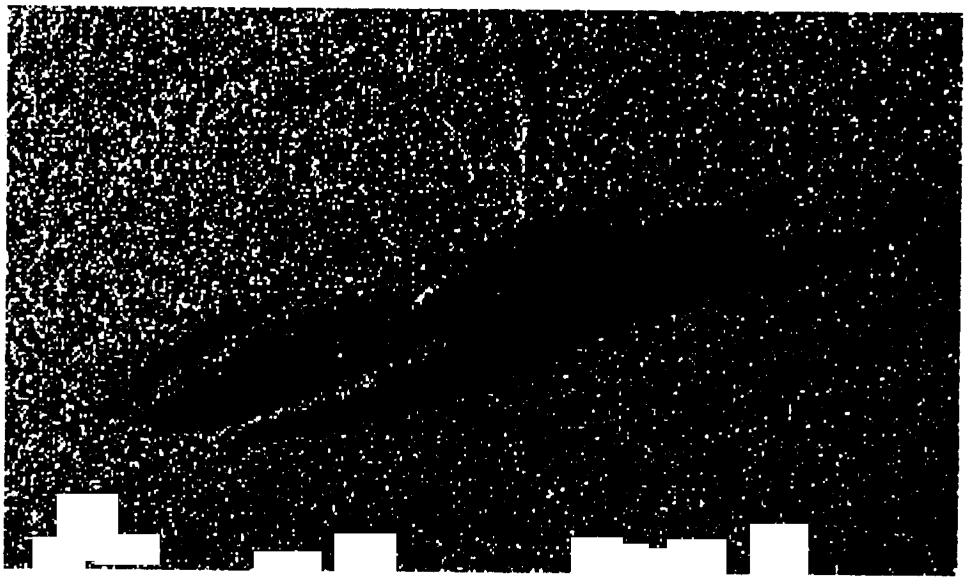
The North Sea is an important economic and ecological area. There are in the order of 420,000 ship movements along the Dutch coast annually and roughly 160 oil and gas platforms are in this area. Several ministries with different responsibilities are involved in monitoring and management of the area.

Figures a and b show an example of an oil slick in the North Sea, detected by airborne and ERS-1 SAR instruments. Figure c shows the slicks detected over the second half of 1993 (June to December). This kind of spaceborne application is already used operationally by National Pollution Control Authorities, such as the Norwegian State Pollution Authority, while airborne applications are currently used for day to day inspection of the Continental Shelf under Dutch jurisdiction coordinated by the Dutch Coast Guard.

Low spatial resolution (100 metres) images are currently received in (near) real time. Slicks larger than 0.1-0.3 square kilometres are easily detected by visual inspection of the images. Smaller slicks may be detected depending on the sea state conditions and the image resolution.

Courtesy of LFF Janssen, Rijkswaterstaat, Delft, The Netherlands





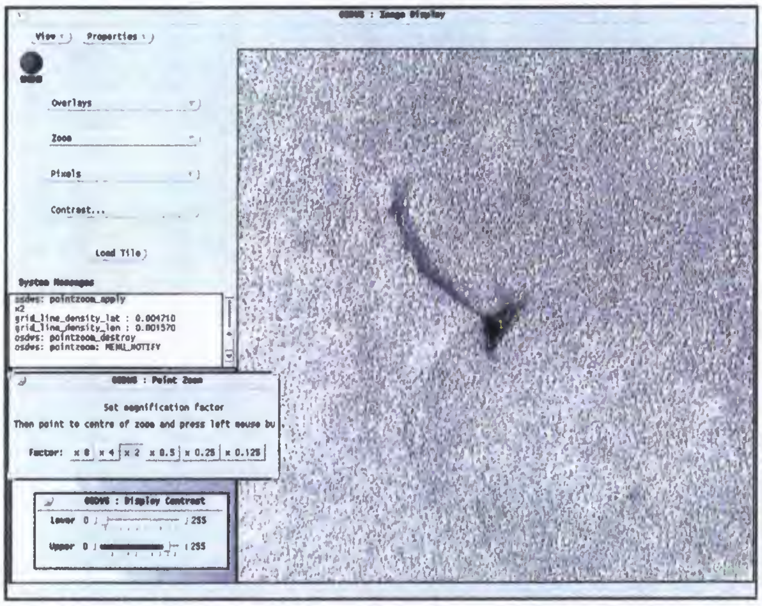

View
Properties
Overlays
Zoom
Pixels
Contrast...
Load Tile
osdvs: pointzoom_apply
x2
grid_line_density_lat : 0.004710
grid_line_density_lon : 0.001570
osdvs: pointzoom_destroy
osdvs: pointzoom: MENU_NOTIFY
Point Zoom
Set magnification factor
Then point to centre of zoom and press left mouse bu
Factor: x 8 x 4 x 2 x 0.5 x 0.25 x 0.125
Display Contrast
Lower 0 255
Upper 0 255

Figure 5.3 Oil slick detection workstation (OSDWS)

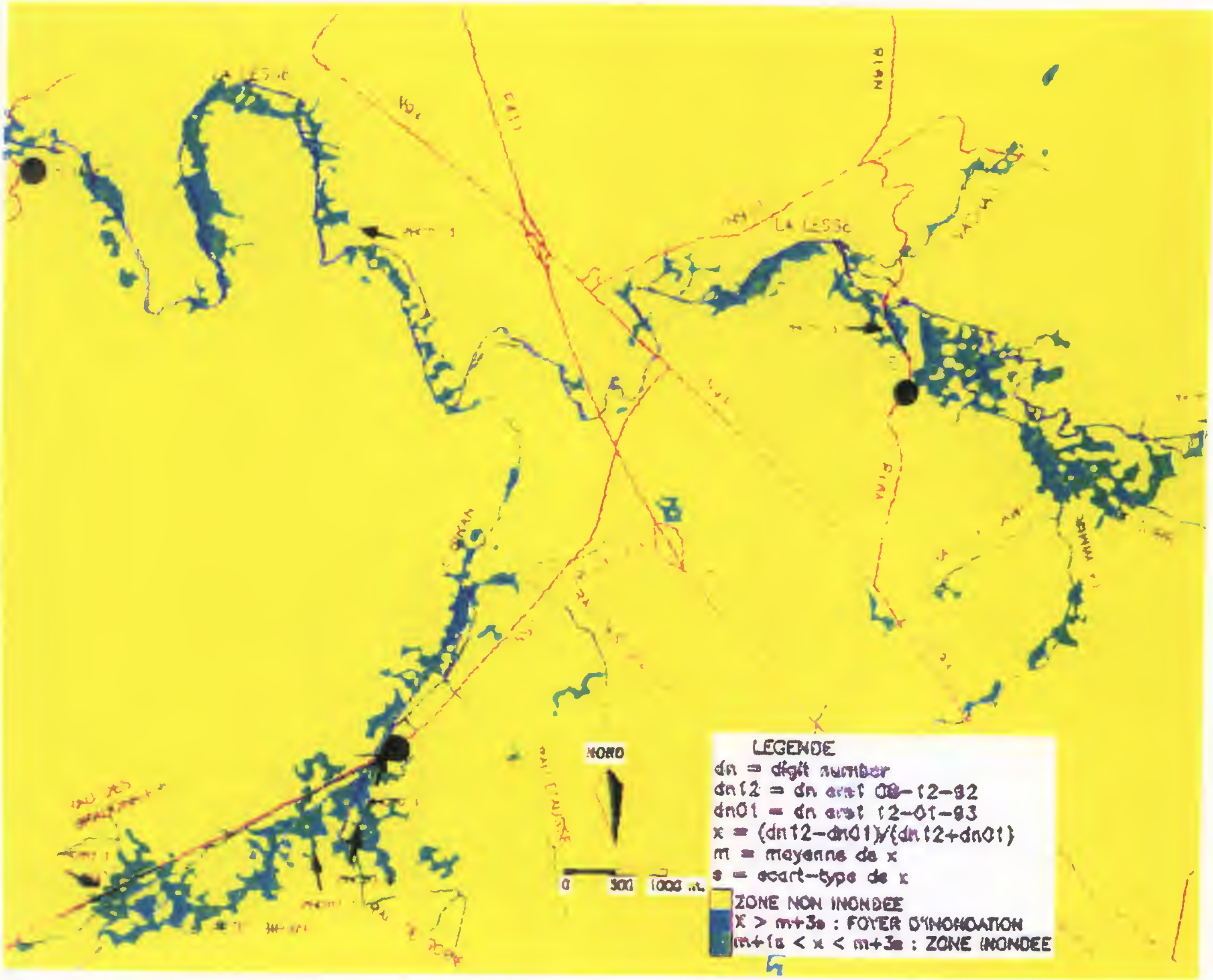
At present, the operational responsibility for monitoring UK territorial waters for pollution events rests with the Marine Pollution Control Unit. The Marine Pollution Control Unit routinely conducts airborne surveys using side looking airborne radar as well as infra-red and ultra-violet cameras. This monitoring is carried out subject to a fixed annual budget of flying time (around 600 hours) with which the UK coast must be observed for the entire year.

Earth Observation Sciences Limited, based in Farnham UK, have developed an Oil Slick Detection Workstation, under contract to the British National Space Centre through the Defence Research Agency Farnborough. ERS-1 SAR images produced at the West Freugh ground station are automatically analysed using this workstation to identify potential pollution events. The system is currently pre-operational and runs on a standard SUN configuration. A demonstration version has already been installed at the West Freugh ground station and a new operational version will be installed in the near future. The Figure illustrates the operation of the system.

The system first smoothes the SAR images and reduces the spatial resolution to 100 metres (although this can be altered by the operator) before applying an automatic segmentation algorithm to identify possible slick features within the image. The system then assesses each feature according to a set of oil slick discrimination attributes and assigns a probability that the feature is, in fact a man-made oil slick. A table is then produced containing information about the time and date of the image, the latitude, longitude and extent of the slick as well as the probability value assigned to it.

The operator can control the system to display all slicks with a probability above or below a certain value and output a chart showing a latitude and longitude grid and those slicks selected. In an operational environment, the chart could be faxed to pollution monitoring organisations such as the Marine Pollution Control Unit who then might investigate the likely pollution slicks with their aircraft to confirm the identification. For illegal spillages, the complementary information provided by satellite data may well assist the fast response necessary for identification and subsequent prosecution of the vessel owners responsible for the pollution event.

Courtesy of I Jory, Earth Observation Sciences Limited, Farnham, UK


NORD
0
500
1000
LEGENDE
dn = digit number
dn12 = dn ersl 08-12-92
dn01 = dn ersl 12-01-93
x = (dn12-dn01)/(dn12+dn01)
m = moyenne de x
s = ecart-type de x
ZONE NON INONDEE
X > m+3s : FOYER D'INONDATION
m+1s < x < m+3s : ZONE INONDEE
LA LESSE

5.2. Flooding

Figure 5.4 Flood plain management in Wallonia

Rainfall during the winter period combined with saturated soil conditions often leads to heavy flooding in the Wallonia region of southern Belgium. The Lesse, Sambre and Meuse rivers are particularly prone to flooding and this constitutes a serious threat to agriculture, city services, state utilities and tourism development. Local authorities, in particular the Ministre de l'Equipement et des Transports de la region Wallone, have implemented a geographic information system suitable for flood plain management. This places great emphasis on the monitoring of high risk areas. It combines soil maps, hydrographic network maps, topographic maps and in-situ soil moisture measurements to identify areas of potentially high water retention levels. These areas are then monitored using ERS-1 SAR data.

Areas prone to water retention can be easily recognised. River courses and flood areas are delineated from the images. In addition, these images can be combined with Landsat data to improve the classification of the flood features. This information is then combined with the soil and topographic data on a geographic information system to allow early identification of areas at risk from flooding. Thematic information derived from the geographic information system allows local authorities and state utilities to implement effective fast response relief measures during a flood event without having to wait for water levels to fall.

The Figure shows a flood map derived from this system during the winter of 1992/1993. Operational model based watershed monitoring is implicitly dependent on the availability of spatial and multi-temporal information provided by satellite based sensors. This is particularly true for the ERS-1 SAR which can operate independently of cloud cover and has a high repeat rate. Data can therefore be acquired during and immediately after a flood event. Perhaps more importantly, during periods of heavy rain, the levels of water retention can be regularly monitored by combining the ERS-1 SAR imagery with the geographic information system data and timely flood warnings can be issued.

Courtesy of M Badji, University of Gembloux, Gembloux, Belgium

Figure 5.5 Flood risk evaluation and monitoring in North East France

A demonstration project to highlight the use of ERS-1 SAR data together with SPOT images in flood monitoring was carried out in the Alsace region of France from 1992 until 1994. The region is prone to flood events from the Ill river, a principal tributary of the Rhine. The main focus was to use the level of soil moisture derived from the SAR images together with soil information from a geographic information system and a SPOT based DEM to identify and classify land areas at risk from flooding. The processing and analysis of the SAR data were carried out by SERTIT and the results delivered to the Service des Eaux et des Millieus Aquatiques d'Alsace.

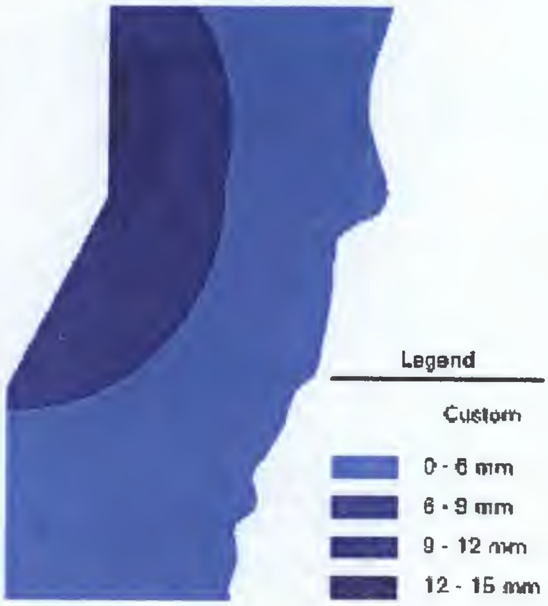
In addition to the DEM, SPOT data were used to generate multi-date images which formed the basis of a five class land cover map. SAR data used in the multi-temporal analysis were acquired during periods corresponding to different soil hydration levels. The processed SAR data were then used to determine a soil moisture index. Further data were derived from the geographic information system and SAR/SPOT data including the depth of underground water and the soil moisture capacity (an important factor in identifying areas at risk from flooding) in both normal and flood conditions. Figure a illustrates the derivation of a precipitation index from an ERS-1 SAR image and the related SPOT based land classification map.

As well as the identification of areas at risk from flooding and a quantification of the level of risk, the data can be used during a flood event to evaluate rapidly the level and extent of inundation. Based on the combination of multi-date SAR imagery and the work described above, a map of land cover affected during the 1990 once-in-a-century flood was generated. The Figures show output from the monitoring system. Figure b is a multi-temporal SAR image of the flooding in Alsace, Figure c shows a combination of the geographic information system output and multi-temporal data to provide a comparison between the flood extent and the official flood zone boundaries. A further combination of the geographic information system output with multi-temporal SAR and a multi-date SPOT classification to provide a thematic map of affected land cover is given in Figure d.

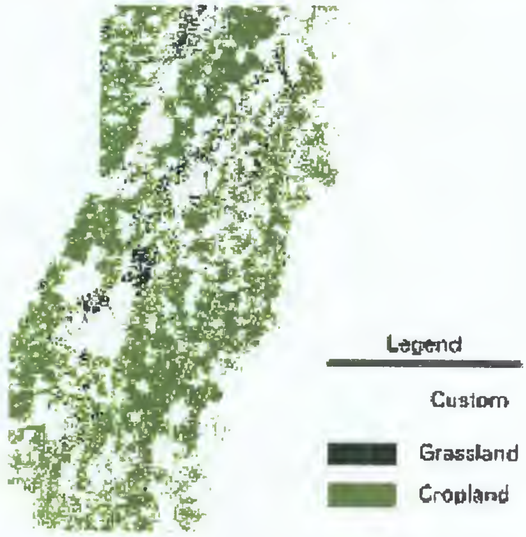
Courtesy of K Fellah and N Tholey, SERTIT, Illkirch, France

A GIS APPROACH FOR ERS SAR SIGNAL ANALYSIS

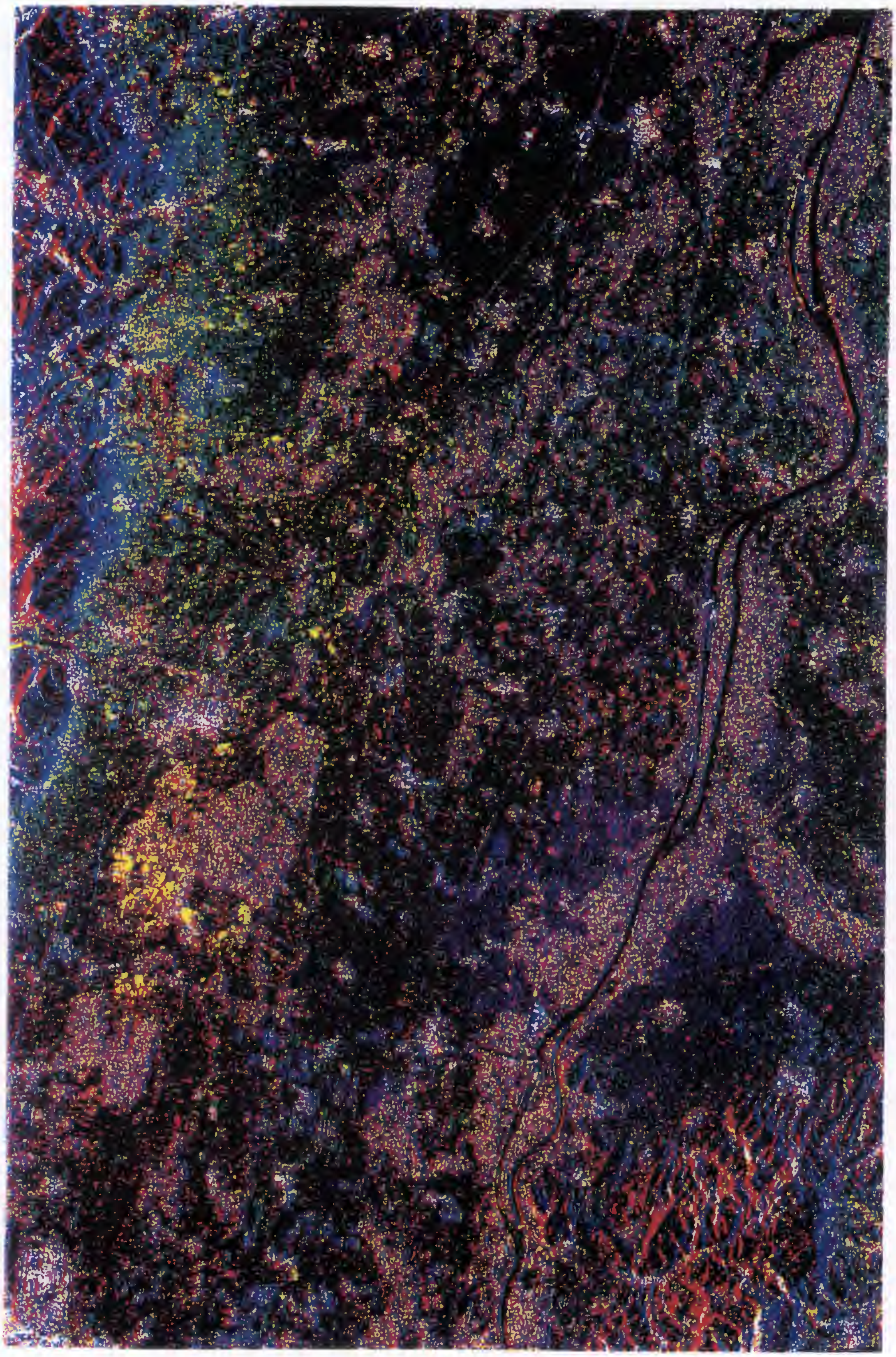
ERS-1 SAR data : 17 April 1992.
The signal intensity is shown over the cropland and grassland themes. Forestry theme is repesented in green and the other themes in light grey.



Antecedent Precipitation Index (ADI) Mapping

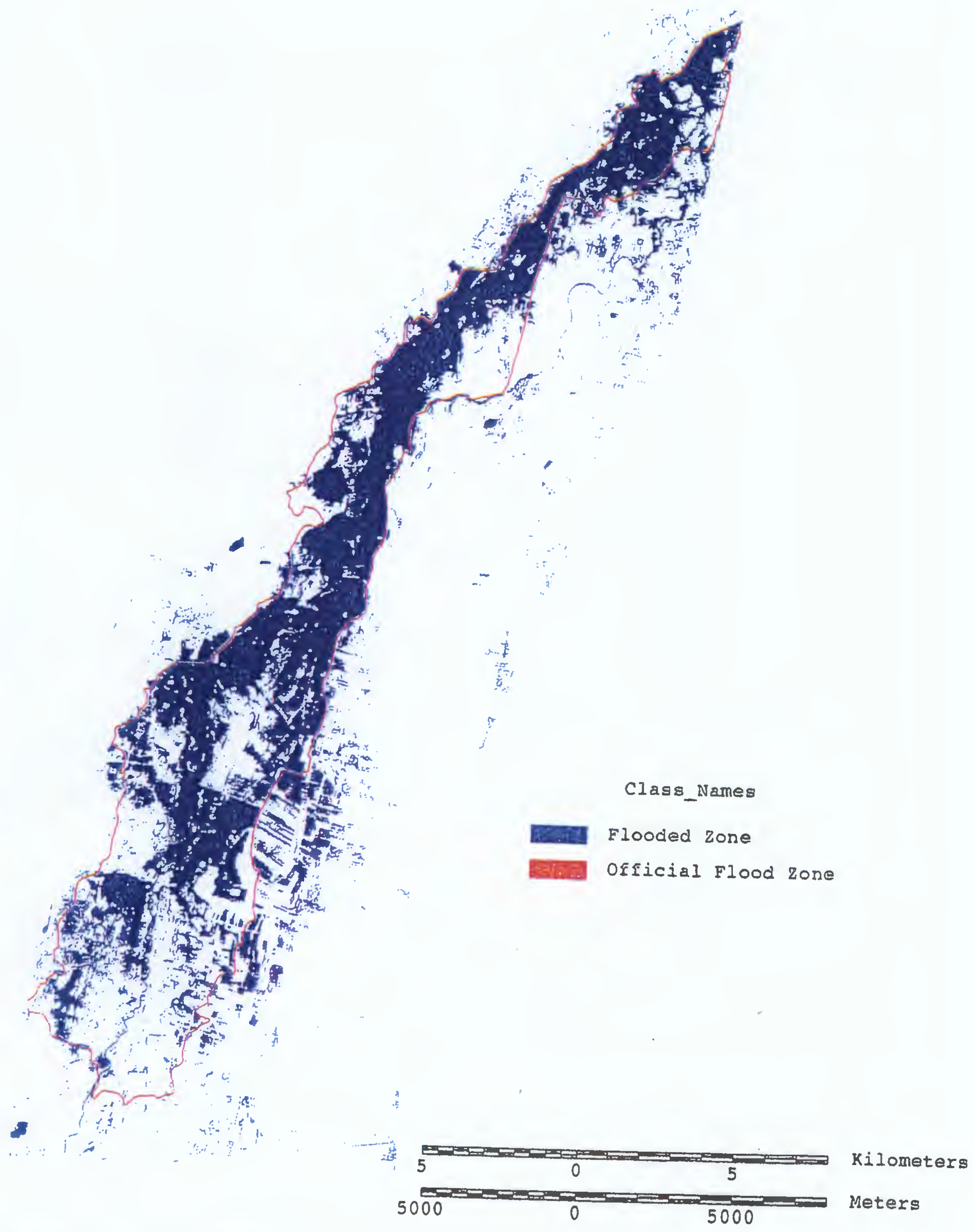


Landuse classification from SPOT synchronos data Cropland and Grassland themes.



© ESA - Traitement SERTIT

ERS-1 data : multitemporal color composite of the central Alsace flood zone
Northern France (Alsace)



Comparison between administrative flood zone boundaries
and the percieved flood extent
Northern France (Alsace)

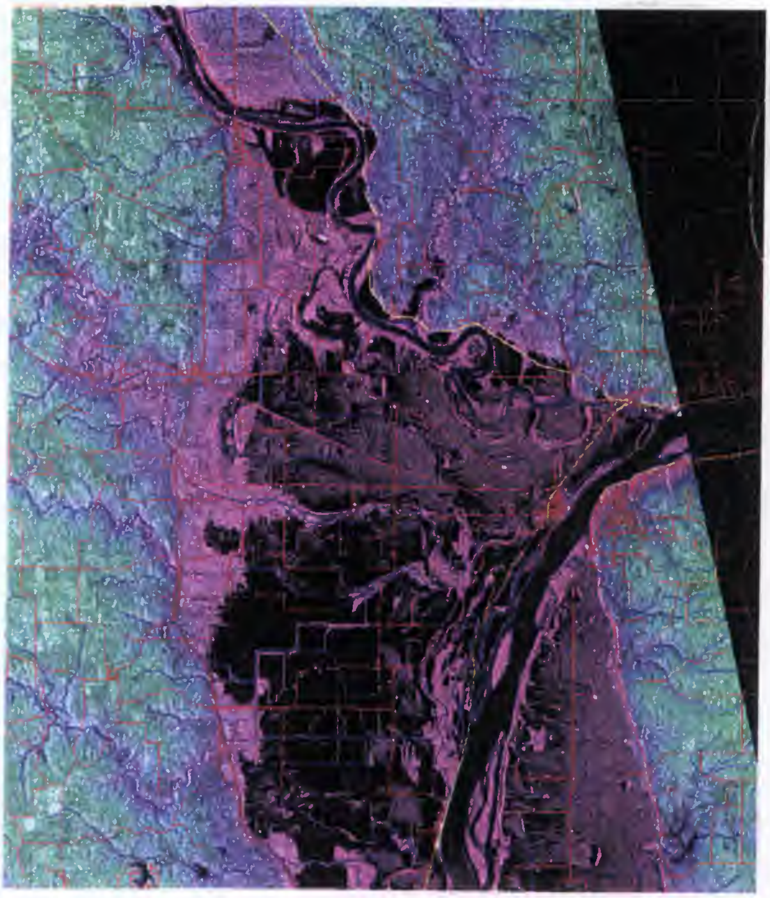


Figure 5.6 Flood mapping in the Mississippi

In 1992, the upper drainage basin of the Mississippi river experienced a wet autumn and an unusually heavy winter snowfall. In addition, in 1993, Wisconsin, Iowa and Illinois experienced the wettest June-July period since records began in 1885. Measurable rainfall fell within Iowa for 33 consecutive days and unusually heavy rains occurred in July, a month that is more commonly characterised by regional moisture deficits. As a result, major flooding events occurred along the Mississippi valley over a period of several months causing major loss of life and extensive damage to property and utilities. Parts of the region were declared a disaster area by the President of the USA and extensive relief operations were required.

Currently, the US. Army Corps of Engineers is using ERS-1 SAR imagery processed at the Department of Geography, Dartmouth College to map the course of flooding along the Illinois River Valley where numerous river control structures are maintained. Twelve SAR scenes of the Mississippi basin were acquired between July 7 and August 1, 1993. These were combined with US Geological Survey 1:24,000 scale topographic maps at Dartmouth College to determine the level of flooding over the basin. A map depicting the levels of flooding was then delivered to the US Army Corps of Engineers to facilitate strategic decisions on rescue priorities and response measures. The Figure illustrates a flood inundation map delivered to the US Army based on ERS-1 SAR data acquired close to the peak level of flooding. The black and grey areas indicate flooded land.

Courtesy of GR Brakenridge, Dartmouth College, Hannover, USA

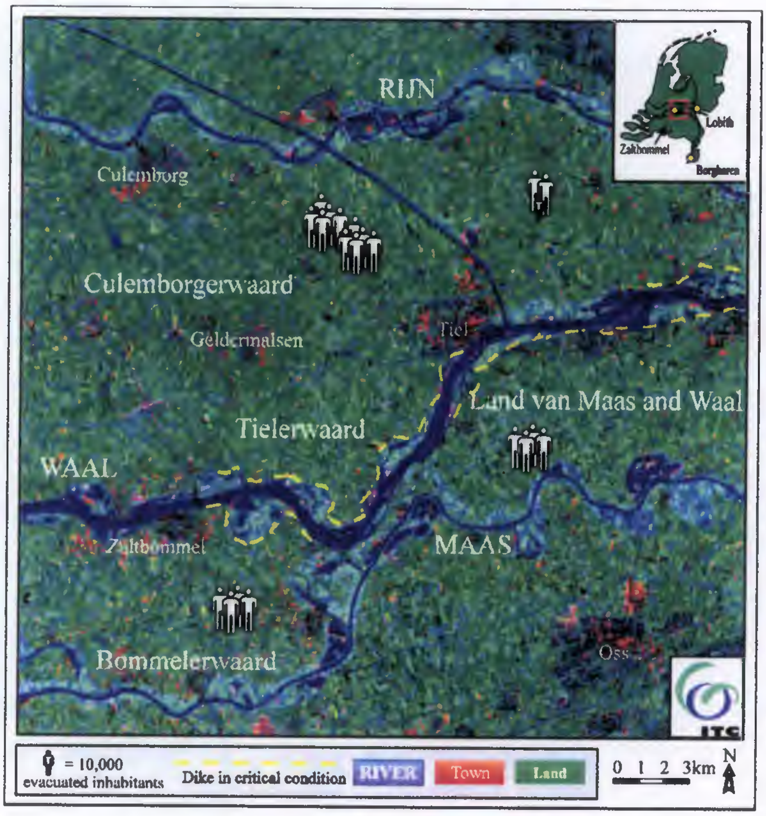

RIJN
Culemborg
Culemborgerwaard
Geldermalsen
Tiel
Land van Maas and Waal
Tielerwaard
WAAL
Zaltbommel
MAAS
Bommelerwaard
Oss
Lobith
Zaltbommel
Borgharen
ITC
= 10,000 evacuated inhabitants
Dike in critical condition
RIVER
Town
Land
0 1 2 3km
N

Figure 5.7 Provision of flood information in the Netherlands

The ITC, based in The Netherlands, is involved in knowledge transfer to developing countries and research in Earth Sciences. In the early part of 1995, a project was carried out in the framework of ITC's engagement in prevention of natural hazards which demonstrates the applicability of ERS-1 SAR images for real time flood monitoring.

At their highest peak levels, the discharge rates along the Lower Rhine and Waal rivers in central Netherlands reached between five and seven times the normal rates with the water level rising to nearly 7.5 metres above the summer levels.

On January 25, 1995 the water level of the Maas began to rise dangerously near the city of Maastricht in the southern Netherlands. Two days later, the level of the Rhine rose sharply so that on January 30, 75,000 inhabitants together with livestock had to be evacuated. In addition, water impregnation and seepage severely weakened winter dikes as a result of the prolonged period of the flooding and the extremely high water level. In response to the situation, the evacuation of nearly 250,000 residents from the area was ordered.

An ERS-1 SAR image was acquired on January 30, 1995 over the lower course of the Rhine and Maas rivers and compared with a pre-flood scene from September 21, 1994. In addition, a Landsat scene from July 1987 was used as a pre-flood reference in the multi-spectral and multi-temporal analysis. The Earth observation data were geometrically corrected and geocoded to the Dutch national projection using 1:50,000 scale topographic maps. All images were then resampled to 30 metres ground resolution. To enhance the flooded areas, the greyscale values on the January 1995 SAR image were inverted so that the flooded area would show up as bright patches. Further filtering and contrast stretching allowed the distinguishing of flooded areas from permanent water bodies in the multi-temporal, multi-spectral images

The Figure illustrates the areas under threat from flooding, determined using the multi-sensor image. It shows flooding in the southern Netherlands along the Lower Rhine (top), Waal (centre) and Mass (bottom) river system and graphically demonstrates the social and economic extent of this disaster.

Courtesy of C Pohl, ITC, Enschede, The Netherlands
(This work forms part of the PhD research of C Pohl, University of Hannover and ITC Research fellow)

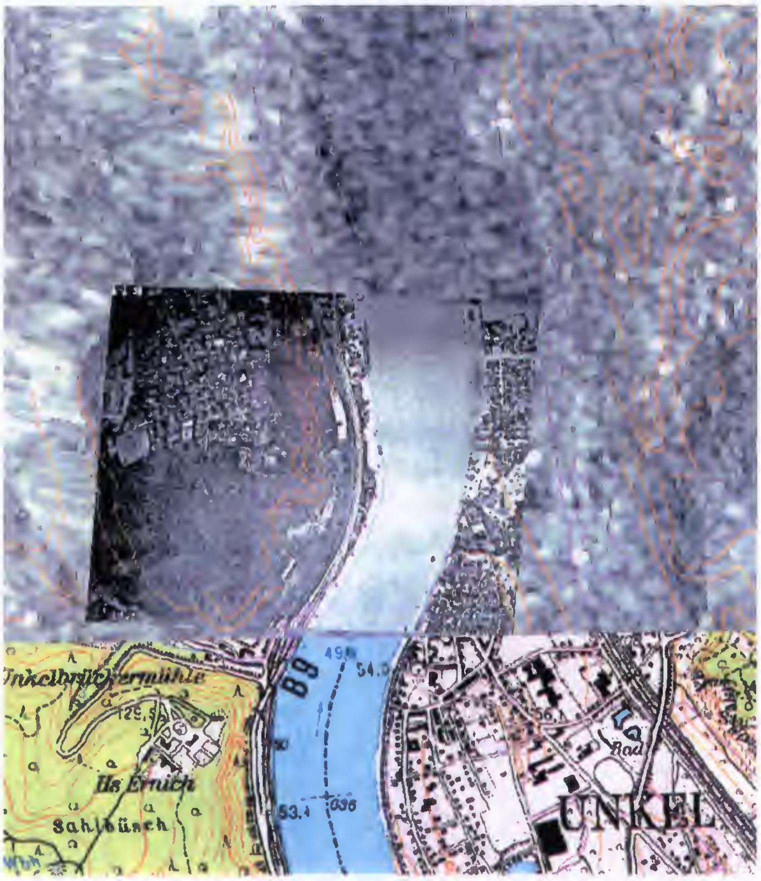

UNKEL

Figure 5.8 Flood mapping in Germany

In recent years, the many instances of severe flooding along the major rivers of the world have resulted in a heightened interest of governments and the public in water catchment management issues. In Germany, along the Rhine and its tributaries, many catchment areas experience extreme water levels and flooding.

A key tool to improve flood management and minimise damage is appropriate land use planning. This requires accurate knowledge of the flood extent as well as information about the dynamics of flood development. Current practice for acquiring flood data is to send out field workers who strike plugs every 500 metres at the highest water level. Afterwards the plugs are measured and the geographical reference is achieved by striking the plugs in the map profile. Despite the high accuracy achieved through this method, water authority boards are considering new possibilities of measuring the highest water level, due to the negative aspects of this method (price, time consuming, slow data processing, problems in getting data during the night, no geographical reference exists for the plugs).

SAR data cannot provide flood information with decimetre accuracy, but they are appropriate to overcome some of the difficulties faced by the field workers and administrative staff. They can provide a fast immediate overview of the actual flood situation, the geographical reference is available and the data are easily combined with digital information such as digital maps. Agencies currently trialling or evaluating the use of ERS-1 SAR imagery in flood monitoring and prevention include the Bundesansstalt fur Gewasserkunde (Federal Institute of Hydrology), GAF (a value adding company working in applications of Earth observation) and Deutsche Projekt Union.

The Figure shows a SAR image acquired during a flood event overlaid on a topographic map of the Unkel area. Contours have been superimposed on the SAR image to help delineate the extent of the flood.

Courtesy of A Kannen, Deutsche Projekt Union, Eberswalde, Germany; R Oberstadler, GAF, Munich, Germany; F Portman, Federal Institute of Hydrology, Koblenz, Germany

Figure 5.9 Flood monitoring and assessment in Piemonte, Italy

The flooding that occurred in Piemonte, Northern Italy in November 1994 was one of the worst disasters in this area this century. Approximately two thirds of the entire region was affected, mainly in the Tanaro, Belbo, Bormida and Po River basin areas.

One of the primary goals of the Piemonte authorities after the flood was to generate, in the shortest possible time, an accurate map of the flooded area from which a first assessment of the size of the flood and the extent of the damage could be made. Due to the scale of the flooding and the time constraints, Earth observation data were utilised. Bad weather conditions during and after the flood were a major constraint to using optical data and the first useful SPOT picture was only obtained on November 23, 1994. In contrast, the ERS-1 SAR data from November 9 provided the first estimate of inundated areas and was later used to support the SPOT estimates of vegetation damage, fluvial sedimentation and dynamic river processes.

The interpretation and classification of the SAR data were performed on a geographic information system which allowed the rapid comparison of data acquired at different times as well as combining data on rivers, areas at risk of flooding, land use and property. This enabled the generation of new thematic maps for input to the final map product; a 1:100,000 scale map of the main alluvial plains (Figure a). The alluvial plains are shown in yellow and the flooded areas in blue. This was integrated into the regional geographic information system for use in agricultural damage evaluation and land use planning by the Assessorato alla Pianificazione Territoriale, Regione Piemonte.

Courtesy of E Bonansea, CSI Piemonte, Italy

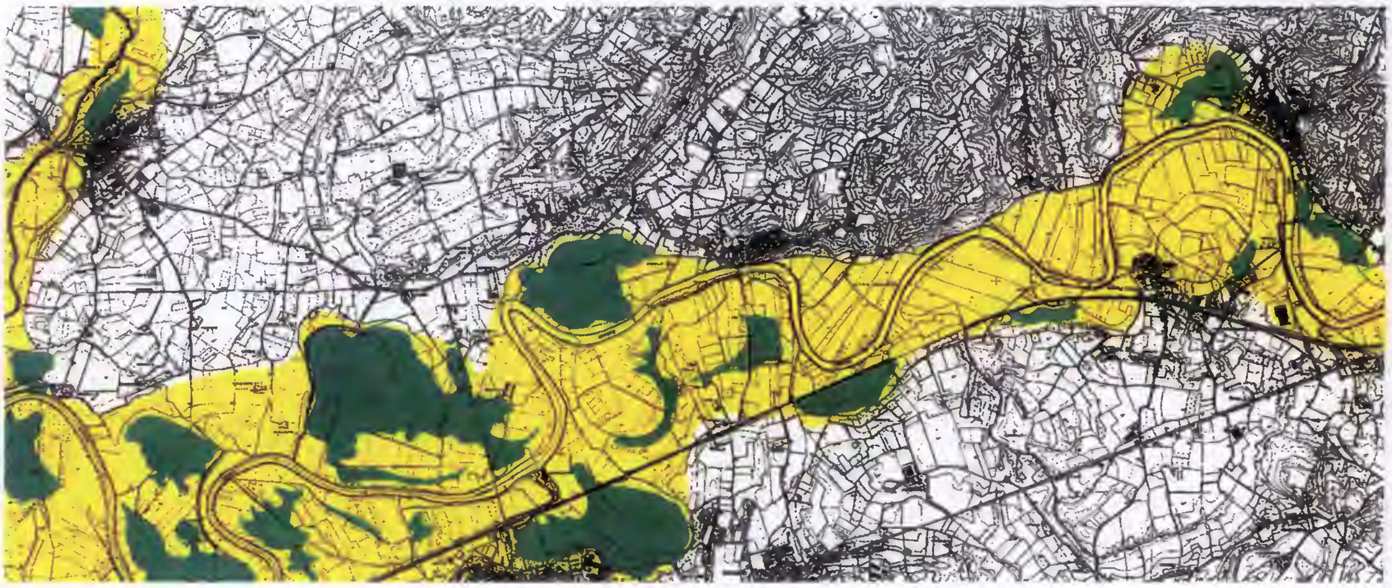


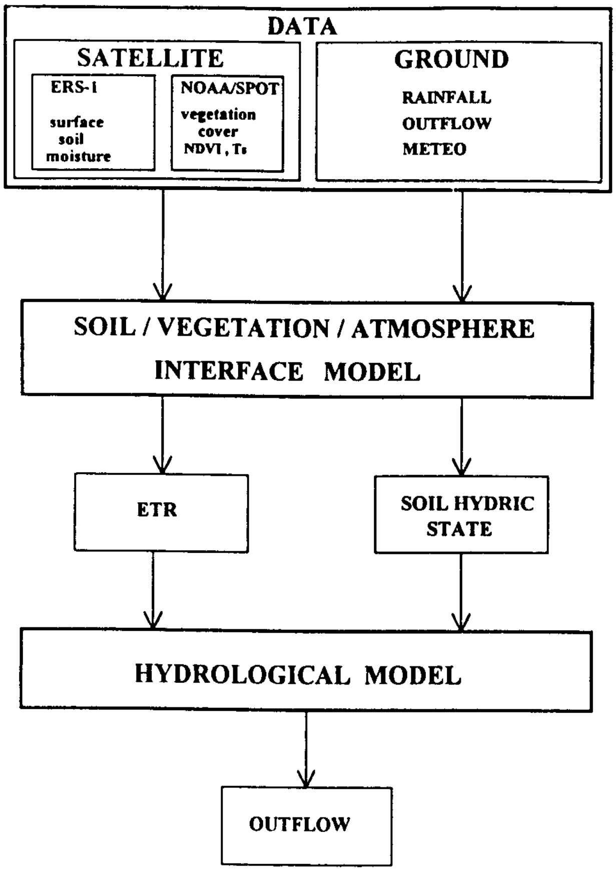
Figure 5.10 Operational hydrological monitoring

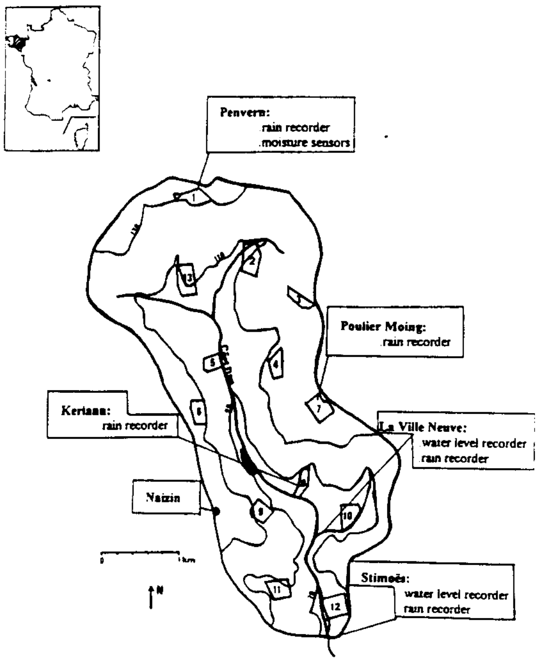
ERS-1 SAR images are combined with NOAA AVHRR and SPOT data for flood forecasting, irrigation management and other hydrological applications in a system that is currently close to full operational use within CEMAGREF, the French institute for forestry, hydrology and agriculture.

The demonstration phase of the project was carried out by Geosys in the Bretagne region of France. Backscatter levels in SAR images were used to determine soil moisture levels both at a catchment scale and on the scale of individual field parcels. NOAA AVHRR data were also used to measure surface temperature in order to estimate the amount of water loss due to evaporation. These results were combined with a land classification based on SPOT imagery and the results integrated into regional hydrological models. The operational service will focus on the incorporation of the SAR data into hydrological monitoring on a catchment scale.

Figure a illustrates the methodology used for the hydrological modelling and Figure b shows the Naizin experimental catchment area.

Courtesy of D Lepoutre, Geosys, Ramonville, France





5.3. Surface movement monitoring

Figure 5.11 Monitoring the impact of underground mining

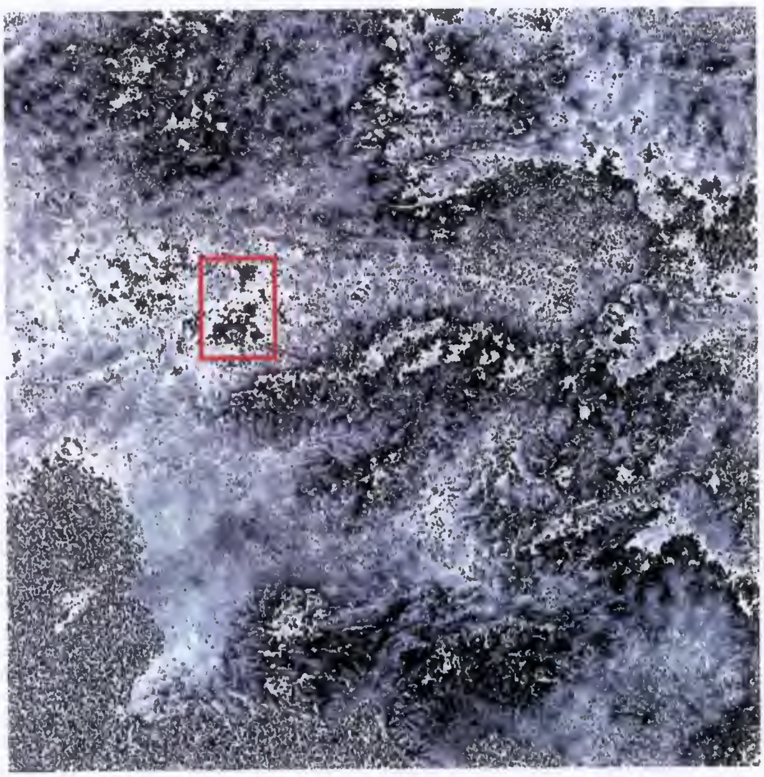
A demonstration project was conducted by BRGM, the French national geological institute, in which two ERS-1 SAR images, taken 35 days apart, were combined with a digital elevation model to monitor the impact of underground mining.

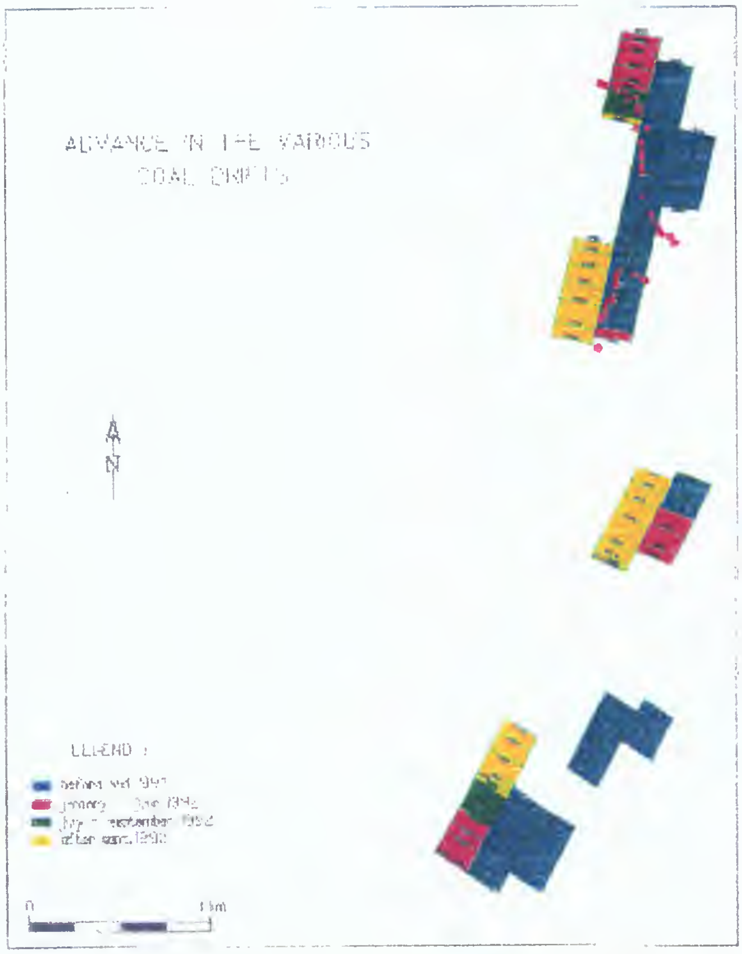
The test area is located in southern France (Figure a), an area with subsidence related to underground mining activity. Some of this subsidence, where it is associated with the collapse of regions from where the coal was extracted, occurs gradually, in step with the mining activity. This causes a topographical deformation without apparent rupture, but which can damage surface structures and installations.

Figure b shows part of the coal deposit that has been mined since 1990. Each block shows the monthly advance of the coal front. The base of available data is derived from two networks consisting of 160 benchmarks, which are measured twice a year (not in the Figure), and 36 benchmarks measured monthly and which are spaced at about 50 metres (red small squares).

By superimposing the mining schedule on the interferogram, an impact can be seen directly above each of the fronts. Figure c shows an enlarged view of the same area, the differential interferometry result effectively detects any changes in the surface above the area where underground mining takes place.

Courtesy of J Scanvic, BRGM, Orleans, France

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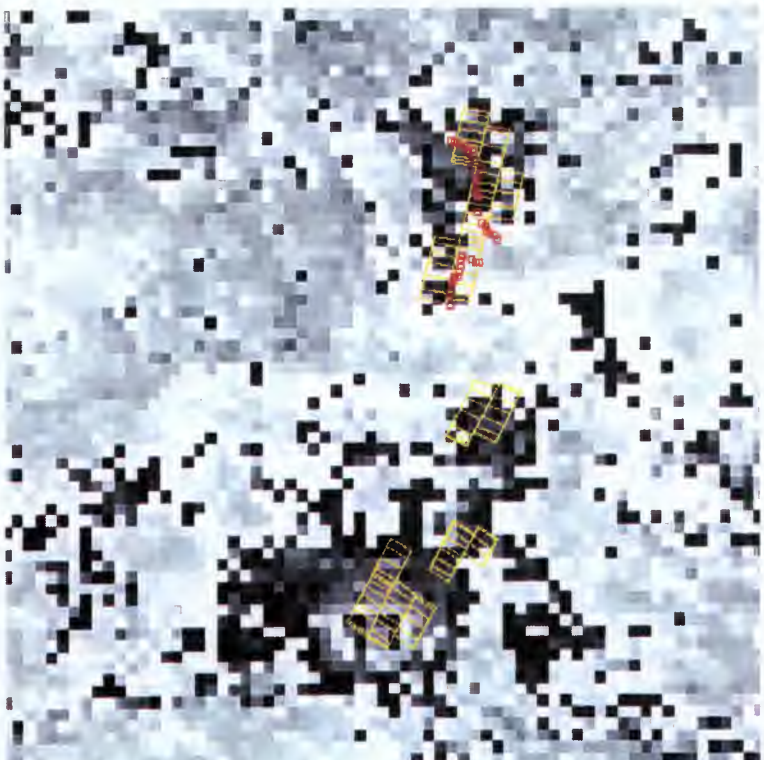

Figure 5.12 Identification of mudflows on Mount Pinatubo, Philippines

The development of an integrated plan to rehabilitate the mudflow affected areas surrounding Mount Pinatubo is hampered by the lack of comprehensive, accurate and timely information on landcover and mudflow boundaries. The ERS-1 SAR, with its all-weather sensing and cloud-penetrating capability, has the potential to provide accurate and timely information on the extent of damage in perennially cloud-covered tropical areas such as the Philippines.

The eruption of Pinatubo volcano, on June 15, 1991 (Figure a), located 90 kilometres north west of Manila city, resulted in between five to seven cubic kilometres of pyroclastic materials being expelled. This non-cohesive material distributed around the crater has covered the upper slopes of the volcano. The pyroclastic deposits range in thickness from some centimetres to more than 200 metres. In this tropical area, the movement of pyroclastic deposits commonly occurs during the heavy storms and typhoons. This process is known as a lahar and will normally occur within a few hours of a typhoon (Figure b).

A multi-temporal colour composition of two ERS-1 SAR images (July 25, 1993 and August 29, 1993) was generated (Figure c) in a joint project carried out at University Paris VI and the University of the Philippines. On the north east side of the Pinatubo volcano, successive typhoons have been reported. On July 25, the typhoon provoked flooding and lahar (L) deposits in the valleys of O'Donnel (O) and Sacobia-Bamban (SB). From August 17 to 18, the typhoons continued depositing lahars along streams, cutting Angeles city (A) and overlapping more ancient lahars to the north west of the town.

SAR data are particularly useful over volcanic areas during bad weather conditions when lahars are at their most destructive and when cloud cover adversely affects other spaceborne and airborne sensors. SAR imaging of the lahars-affected areas provides updated information to disaster managers, rehabilitation planners and decision-makers.

Courtesy of M Wooding, Remote Sensing Application Consultants, Alton, UK

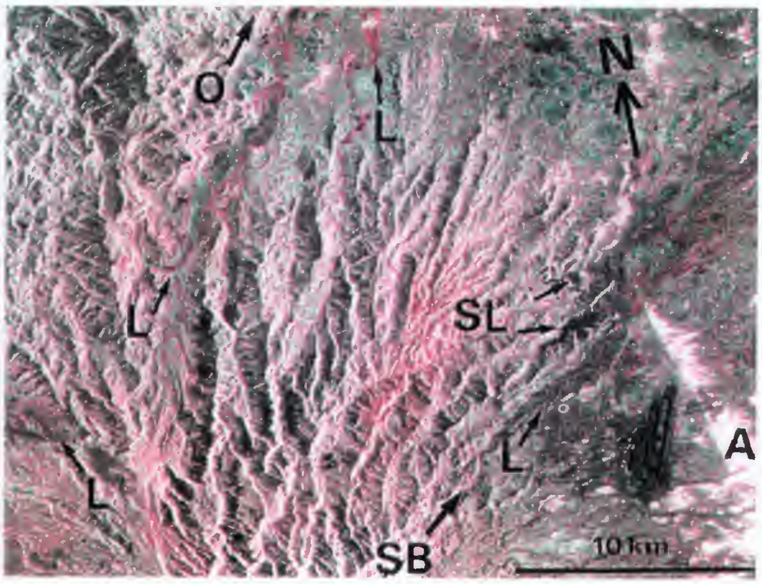
O
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Figure 5.13 Dam safety in Cordillera Real, Ecuadorian Andes

In 1993, a study of natural risk factors, particularly active faults, in the Pastaza basin (Central Andes, Ecuador) was requested by the Intsuto Ecuadoriano de Electrificacion for the production of a safety report on two hydroelectric dams already built together with a third that had been proposed.

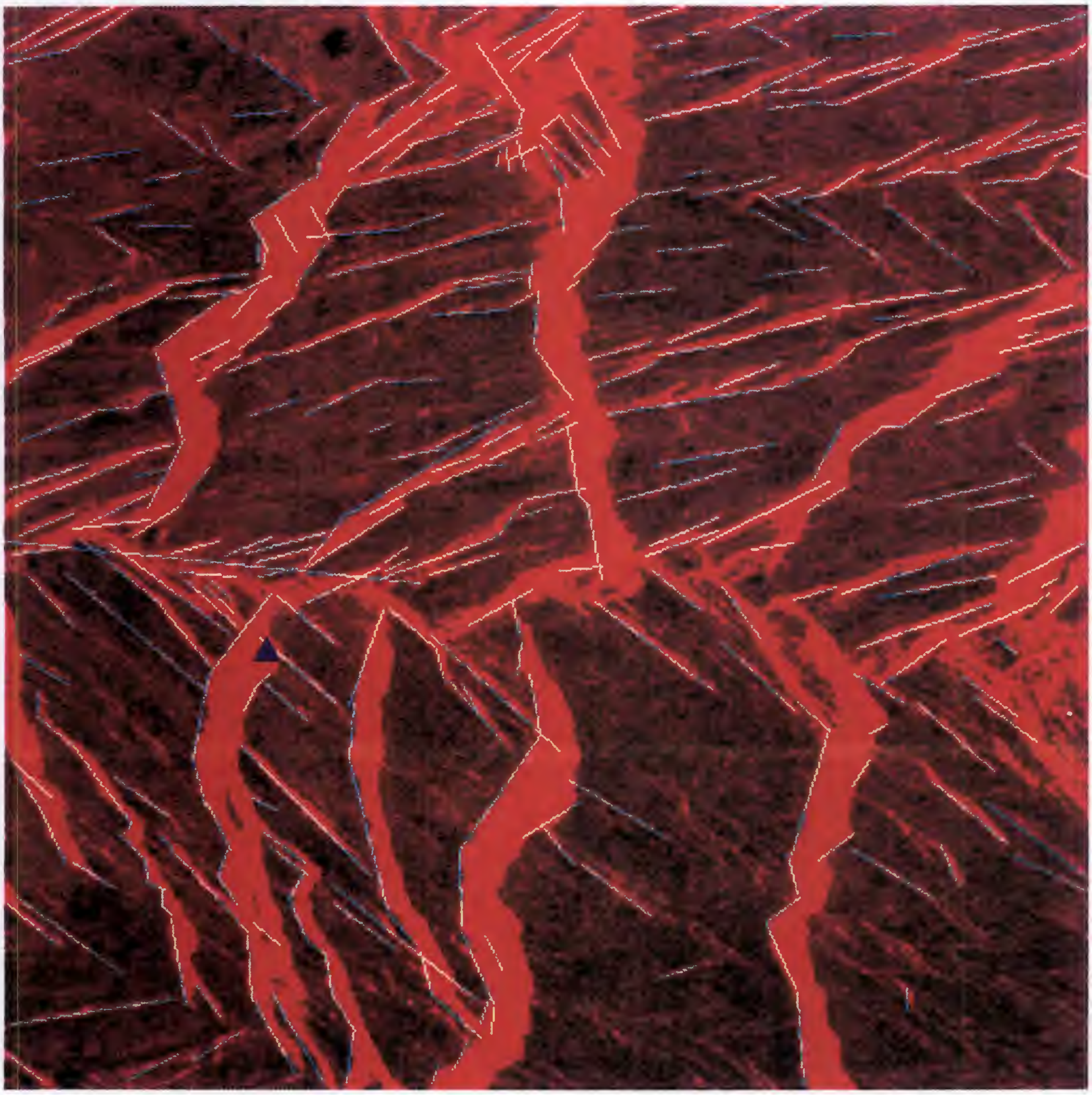
This study, carried out by the Laboratory of Geomorphology and Quaternary Geology of the University of Liège and financed by the Belgian Scientific Research Organisation as part of the TELSAT III Remote Sensing programme, used a combination of Landsat, SPOT and ERS-1 SAR data together with aerial reconnaissance and ground measurements. However, due to the permanent heavy cloud cover (greater than 60%) only the SAR data provided useful information.

Three levels of scale analysis were incorporated. These were:

- Synoptic view from two SAR images and a SPOT image;
- Regional view from aerial photos and the synthesis of a digital terrain model derived from topographic maps;
- Micro-tectonic study from local in-situ observations after locating potential active faults on the images (Figure a) and digital terrain model.

Field checks showed many recent tectonic movements including vertical displacement, erosion renewal deposits and fracture (Figure b). As a result of the whole study a number of restrictions concerning the sites chosen by the local authorities for the two hydro-electric dams already built, Agoyan and San Francisco, could be determined. Another aspect of this research is the production of a tectonic map at a 1:70,000 scale obtained by multi-scale Earth observation analysis of lineament features.

Courtesy of P Ozer and A Ozer, University of Liège, Liège, Belgium



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6. TOPOGRAPHIC AND GEOLOGICAL MAPPING

Topographic and geological maps are being compiled from ERS-1 data for areas of the world not previously mapped because of their remote location or high frequency of cloud coverage. The cartography market has always been important in the development of commercial Earth observation applications. For ERS-1, this is no exception. The improved ability which ERS-1 offers - its all weather capability and high geolocation accuracy - is proving extremely valuable for developing markets dependent upon large area mosaics and digital image maps.

The world's mapping industries are currently experiencing rapid technological and organisational change. Most of the world is now open to exploration and development and improved maps of land topography, land cover and geology and bathymetry are required. Increasingly, information is needed in digital formats enabling sophisticated analysis to be undertaken, producing products such as digital elevation and terrain models, where land cover information is draped over an elevation model. Digital data are also of great value in the rapidly expanding market for geographic information systems which are now being used extensively to integrate data from different sources for land management, monitoring and planning.

❑ ERS-1 contribution

ERS-1 data have been used to derive and map a range of physical features, for example surface elevation, land cover, bathymetry, geology and gravity fields.

The use of radar altimeter data for mapping gravity fields across the world's oceans has opened up a new source of information which is of great value to the hydrocarbon and mineral exploration industry. Gravity field maps provide information about the geology of the seabed and data from the ERS-1 radar altimeter are increasing the accuracy of these maps, particularly when combined with data from other radar altimeter missions and from ground surveys.

The use of ERS-1 SAR is providing a marked improvement in the accuracy of maps produced for many areas of the world. The SAR data are also being combined with data from optical sensors such as SPOT to help increase the geolocation accuracy of the latter. These maps are of value to a range of activities from managing and planning land use development to planning logistics of oil exploration activities.

ERS-1 SAR is also providing new information about geology and the structure of the land that is of value to hydrocarbon and mineral exploration companies. The side looking inclination of the SAR is useful for highlighting geological structures. This is particularly important as it enables a better identification of the lineament features associated with the presence of mineral and hydrocarbon deposits. Furthermore, lithological boundaries that would be masked by vegetation variations in optical images are considerably more straightforward to identify in the SAR images. Benefits have also been gained by the synergistic use of SAR with other data sets such as maps of lithology, mineralisation, geophysics and geochemistry. This helps to confirm or enhance geologic interpretation.

Using techniques developed for the oil pollution agencies, SAR products are being used to identify natural oil seeps at sea which indicate the location of oil bearing rocks beneath the ocean floor.

- **Market potential**

The cartography market for Earth observation products and services is becoming established while the geological mapping market is generally considered to be mature. Both are based mainly on non-time critical off-line products and are therefore not as demanding on the data supply chain as the more real time weather, ocean or sea ice forecasting applications. However, they are extremely competitive markets. A number of national agencies and major companies that previously provided the source of a large number of contracts for geological mapping, are now undertaking more work themselves. This is good for sales of satellite data, but difficult for the value adding companies which are developing commercial maps and services for exploration companies, government agencies and civil engineering projects.

The market for topographic maps is large. For example, the Ordnance Survey in Great Britain had an income of 70 million ECU in 1994/1995 which represented 75% of expenditure. The use of remotely sensed data and SAR in particular, is only just beginning to have an impact on this market. This is principally due to the improving spatial resolution of sensors. Such systems are now on the threshold of being able to support existing data coverage and meet the high spatial resolution specifications of developed countries.

As oil and gas companies face ever increasing demands for non-renewable resources, prospecting and production activities are pushing into ever more remote and inhospitable areas of the Earth, particularly in the Arctic. Harsh environmental conditions and the lack of any survey support infrastructure, combine to render conventional prospecting techniques such as marine seismic surveys prohibitively expensive. Radar altimeter based gravity maps offer a relatively low cost alternative, particularly since the ERS-1 orbit provides data to higher latitudes than were previously available from satellites. A number of separate geoid mapping activities based on radar altimeter measurements of ERS-1 together with TOPEX/Poseidon, and in some cases with Seasat and Geosat, are currently being implemented by a variety of value adding organisations.

The choice of techniques to locate a particular mineral depends on the nature of both the mineral and the surrounding environment. Traditional methods incorporated within the search for oil, gas and minerals encompass gravity, magnetic, seismic, well logging, electromagnetic and miscellaneous additional techniques for example geochemical or radioactivity surveys. In some cases, the method employed might give a direct indication of the presence of the resource sought (for example magnetometer surveys in the search for nickel or iron ores). In other cases, the method may only indicate whether or not conditions are favourable for the existence of the resource. A cost breakdown (at 1987 prices) for data acquisition associated with the various methods of surveying is given below:

- Land seismic - 1,700 ECU per square kilometre;
- Marine seismic - 223 ECU per square kilometre;
- Airborne gravity - 38 ECU per square kilometre;
- Land gravity - 48 ECU per station;
- Marine gravity - 36 ECU per station.

In comparison, the cost of acquiring ERS-1 SAR data is around 0.39 ECU per square kilometre. In 1987, for petroleum exploration purposes alone, 72.1% of the surveying was carried out using land based seismic surveys and 20.5% by marine survey. For gravity-magnetic surveys, 61.9% was carried out for petroleum exploration and 24.6% for mineral exploration.

In terms of total expenditure for data acquisition during the year 1987, 422 million ECU were spent on marine data acquisition in petroleum exploration world wide. 635 million ECU were spent on land based petroleum surveying and 10 million ECU on land based mineral exploration.

❑ Example applications

The following sections provide examples of:

- Topographic and bathymetric mapping;
- Geological mapping.

The examples show how government mapping and environmental agencies, telecommunications, exploration and civil engineering companies as well as marine port authorities, offshore engineering and shipping companies are all benefiting from mapping products from ERS-1.

Information from the following value adding organisations has been used:

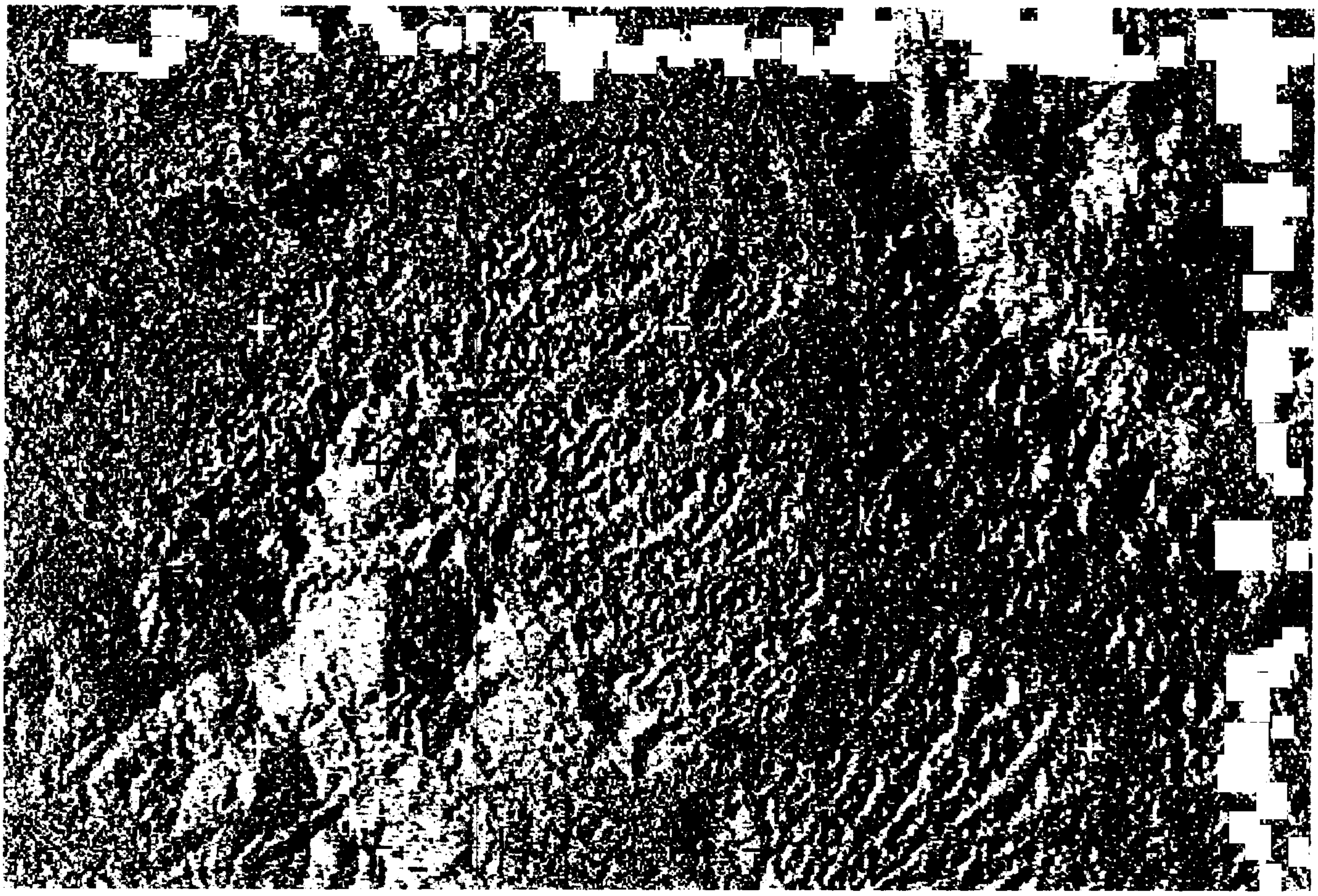
- ARGOSS, The Netherlands;
- BRGM, France;
- CLS Argos, France;
- ERA Maptec, Ireland;
- IFREMER, France;
- ISTAR, France;
- ITC, The Netherlands;
- Nigel Press Associates, UK;
- North East Exploration, Canada;
- Pecten International Company, USA;
- Satellite Observing Systems, UK;
- Systemes d'Information Reference Spatiale, France;
- TREICoL, UK;
- University Pierre et Marie Curie, France.

USER COMMENT

"Since the technology was declassified in the 1970's, oil and gas companies have utilised airborne SAR in the identification of natural oil slicks on the sea surface arising from seepage in undersea reservoirs. There were a number of problems inherent in this methodology, including the expense of airborne survey campaigns and the uncertainty associated with imprecise geolocation.

Since the launch of ERS-1, the coverage and spatial resolution of the available SAR imagery have enabled the detailed and repeated analysis of regions where natural slicks occur in order to better identify slicks corresponding to this seepage. The use of SAR data leads to major cost reductions in the acquisition of the necessary data. Both the market area and distribution infrastructure are currently in their early stages of development. This can give rise to difficulties such as the lack of suitable meteorological and ocean hindcast services needed to identify suitable SAR scenes and also the difficulty in obtaining suitable data on occasions. However, we fully expect that the near future should see the SAR products utilised on a regular basis within this application field. In short, the availability of the ERS-1 SAR data has made our jobs in exploration technology very much easier."

M McKeown, British Gas, UK



6.1. Topographic and bathymetric mapping

Figure 6.1 Digital terrain model and image map production

In many areas, maps can be either many years out of date or even non-existent. In addition, conventional map making techniques are time consuming and expensive. As a result of these and additional factors such as the availability of ready-made satellite image maps, the market for satellite based map products is growing rapidly. More and more users are integrating them into their management and decision making systems. There is currently a high level of user acceptance for optical based image map products although there is a major limitation in that these can be generated only for cloud free areas. SAR based image maps are not subject to these constraints. In addition, there is a high degree of complementarity between ERS-1 SAR and optical images which is used to improve, for example, classification for thematic map products. For tropical areas where demand for map products is also growing, ERS-1 SAR based products offer a unique tool for providing morphological information in forest covered regions where optical instruments are unable to penetrate the vegetation cover. Figure a illustrates a demonstration image map product for part of French Guyana and Figure b shows the only other map product available of this area.

ISTAR, based in France, provides a commercial image map and digital terrain model production service based on both SPOT and ERS-1 SAR imagery. Maps covering 50 by 50 kilometres are provided to a variety of customers including telecom companies for mobile communications related propagation studies, oil companies such as Total, Elf and Agip for geological surveys and civil engineering companies requiring digital terrain models of urban regions. Customers with high demands on precision such as the French Defence Mapping Agency utilise ISTAR products to avoid having to implement expensive Global Positioning Systems campaigns. These map products are available 'off the shelf' at a standard scale and projection, reflecting official national map-sheet systems. In the case of image maps, there are two methodologies for the use of SAR data. The first is the construction of an image map based solely on SAR data. The second is the mixing of SAR data with SPOT data to provide information on areas within the SPOT scene that were obscured by cloud.

The use of both digital terrain models and space maps derived from SPOT images is limited by the location accuracy of the SPOT data which is in the order of 500 metres. When SAR data are incorporated the location accuracy can be improved to better than 50 metres. ISTAR have carried out a demonstration project where SAR images were input to the SPOT image map production process to improve location accuracy using the superior positioning available with SAR products. Given the level of user demand for image map products based on optical data, there would appear to be a considerable market for such high precision optical image maps.

Courtesy of L Reonouard and F Perlant, ISTAR, Toulouse, France

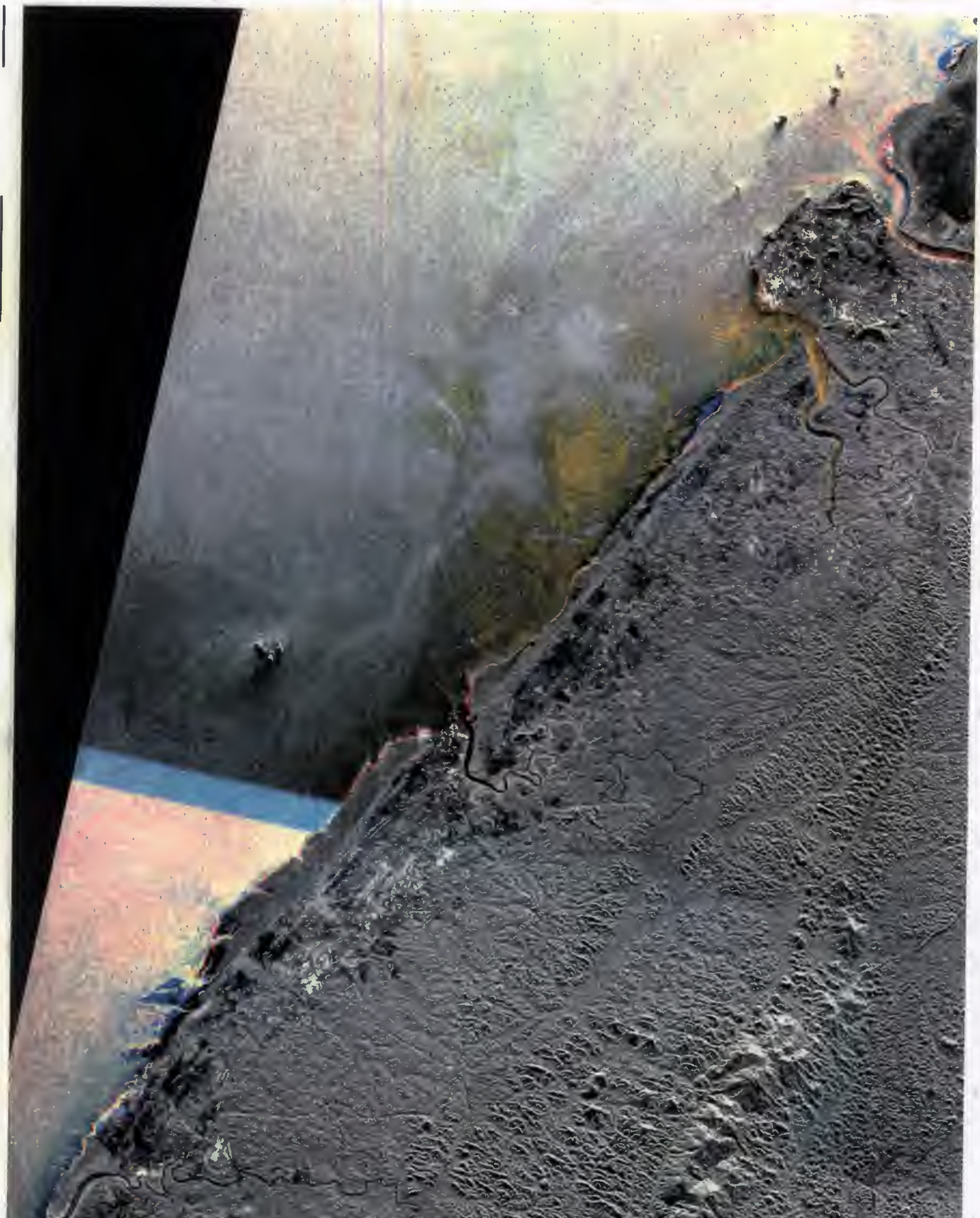
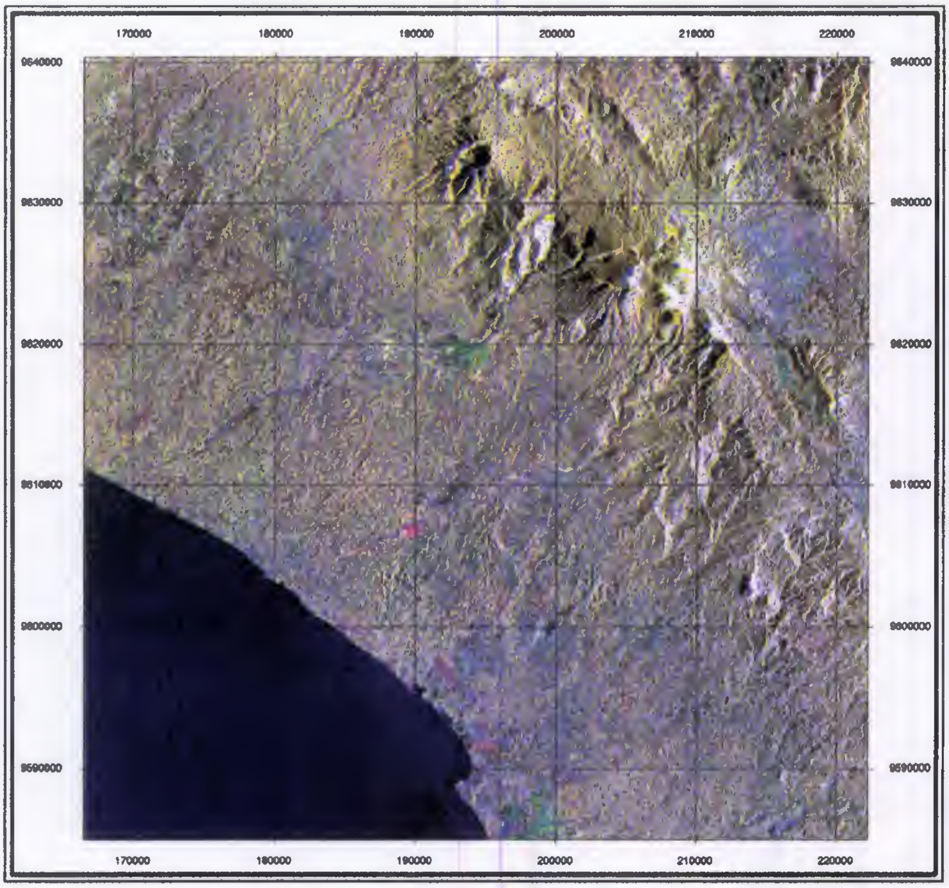


Figure 6.2 Image mapping of French Guyana

In tropical areas where conventional (optical) satellite information is unavailable, image maps generated from SAR data are precious tools. Such image maps are geocoded products, annotated in the same way as traditional maps. Image maps can also represent a solution when cartographic documents are outdated or are available in small-scale format only. Interesting features such as topographic relief and hydrological networks are visible in the ERS-1 SAR image maps. Information on land cover, i.e., forested areas, clear-cuts, agricultural fields and settlements, is also retrievable. Image maps have grids with geographic and cartographic coordinates for reference and are especially suited for medium to small-scale cartographic coverage (1:100,000 to 1:1,000,000).

A large area image map covering the whole of French Guyana has been developed. The Figure shows the coastal section of this image map. Both IGN Espace and the French Army have utilised the image map in the generation of a variety of map products. Further applications include its use as hill-shaded backgrounds for mid-to-small scale maps, for geological interpretation and planning, as well as for defining strategies for infrastructure development.

Courtesy of J-P Rudant, University Pierre et Marie Curie, Paris, France



ImageMap

INDONESIA

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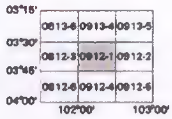
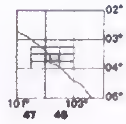




Grid Information

Grid Data	UTM Zone 48 South
Projection	Transverse Mercator
Spheroid	Indonesian Datum (ID 74)
Datum Shift related to NWL-9D	dx = - 2.891 m
	dy = + 14.757 m
	dz = - 0.224 m
Unit of Measurement	Meter
Central Meridian	105 degrees
Latitude of Origin	0 degrees
Scale Factor	0.9996
False Easting	500 000 m
False Northing	10 000 000 m

Scene Information

Satellite image map produced from merged ERS-1 SAR and JERS-1 SAR data resampled to 30 m.
Red = JERS-1 1993, Green = JERS-1 1994, Blue = ERS-1 1993

Satellite	Acquisition Date	Path/Row or Orbit/Frame
JERS-1 SAR	06-Mar-1993	117/306 & 117/307
JERS-1 SAR	20-May-1994	117/306 & 117/307
ERS-1 SAR	02-Nov-1993	12015/3681

In cooperation with
The International Institute for Aerospace Survey and Earth Sciences (I.T.C.)
350, Boulevard 1945, P.O. Box 6
7500 AA Enschede, The Netherlands
Geocoding by CCRS, Canada

Scale 1:100 000

10 0 10 Kilometers

Produced by
BAKOSURTANAL
National Mapping Agency, Indonesia
Jalan Raya Jakarta-Bogor Km 46
Cibinong, Indonesia

Figure 6.3 Updating topographic maps of Indonesia

In developing countries maps scaled 1:100,000 and larger are mostly out of date. In many areas, satellite maps at these scales do not exist at all due to permanent cloud cover. The aim of this project was to overcome the cloud cover problem using SAR. Together with existing optical data, SAR data are being used to produce image maps by applying digital image fusion techniques.

As a first example, three SAR scenes, one from ERS-1 and two from the Japanese mission JERS-1, acquired over a one year period, were combined in a multi-sensor, multi-temporal image map of south west Sumatra, Indonesia (illustrated in the Figure). The SAR images were geocoded and filtered to reduce the speckle. Two mosaics were then produced from the two JERS-1 SAR image pairs and these were combined with ERS-1 SAR to form a colour composite. Various features visible on the image map relate to differences of the wavelength and viewing angles between the two satellite sensors. The multi-sensor SAR data evaluated together provide a unique tool for topographic map updating in cloud covered regions and valuable information on the area under observation.

The final products of this project are digital image maps at a scale of 1:100,000 produced from multi-sensor satellite data and provided to the National Co-ordination Agency for Surveys and Mapping in Indonesia. The project started in January 1993 and will continue until December 1995. It is a co-operation between ITC in The Netherlands and the University of Bengkulu in Indonesia.

Courtesy of C Pohl, ITC, Enschede, The Netherlands
(This work forms part of the PhD research of C Pohl, University of Hannover and ITC Research fellow)

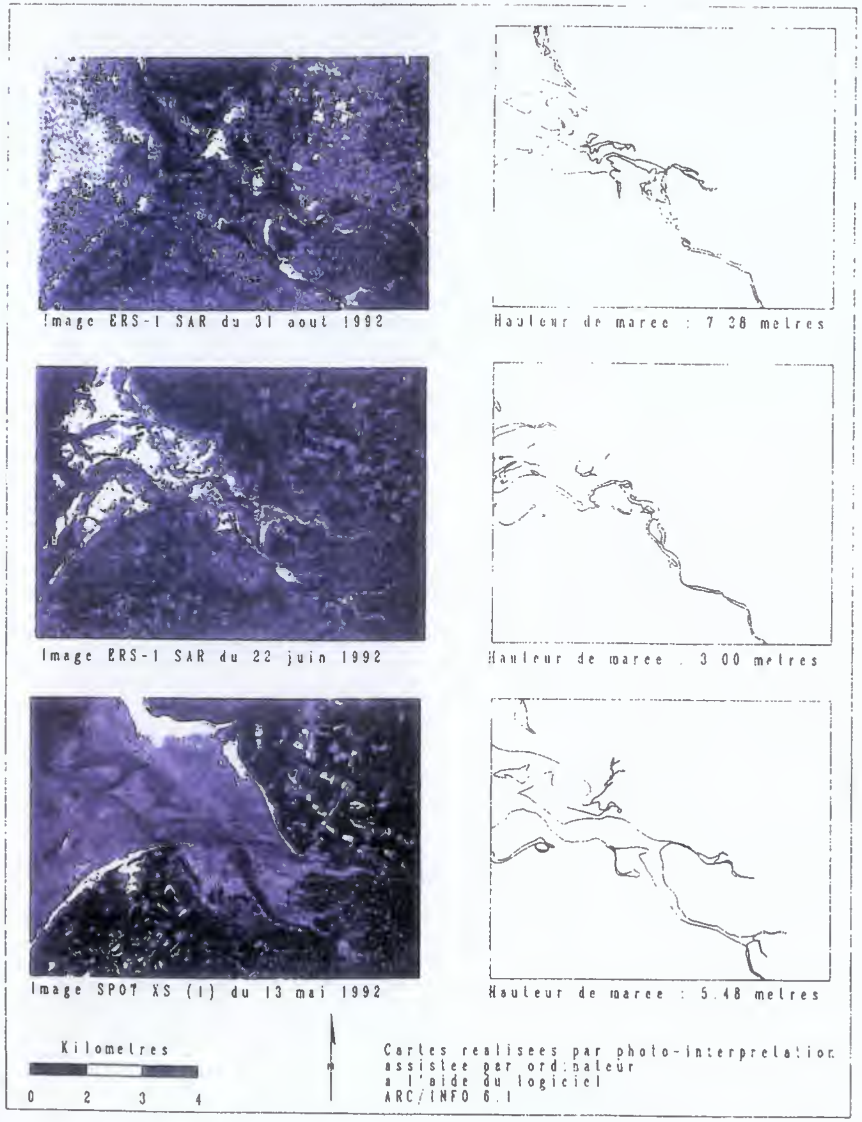
Figure 6.4 Land use mapping in an estuarine environment

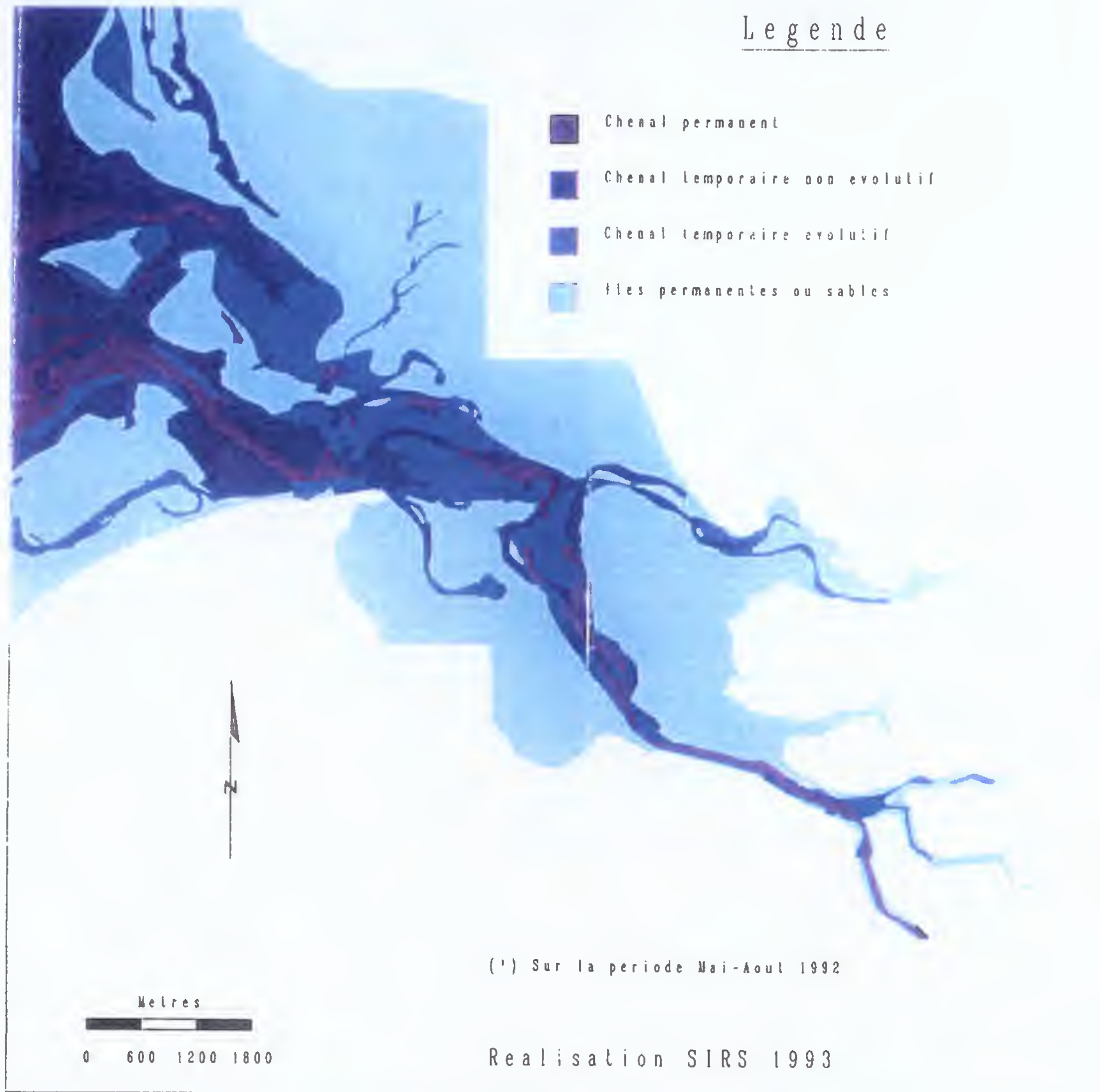
The French company SIRS has produced a digital GEOSPOT product from multi-date SPOT and ERS-1 SAR data for land use analysis in an estuarine environment. The demonstration was at a site in northern France at the Somme river estuary. This is an area with many coastal features and important marine and fluvial interactions.

A map of permanent and non-permanent river channels over the Somme estuary's tidal mudflats (Figure a) has been produced. A digital elevation model of the estuarine intertidal zone was obtained by correlating the water level extracted from three images recorded on different dates with the known tidal height at the time of imaging (Figure b). The digital elevation model is a useful tool for navigation or river pollution control in industrial areas. The coastal wetlands around the estuary have also been mapped using SPOT and SAR data. This has produced useful information for managing the ecology of the area (Figure c).

Courtesy of J Tignon, Systemes d'Information Reference Spatiale (SIRS), Wasquehal, France.

Chenaux permanents et chenaux temporaires : essai de classification. (*)

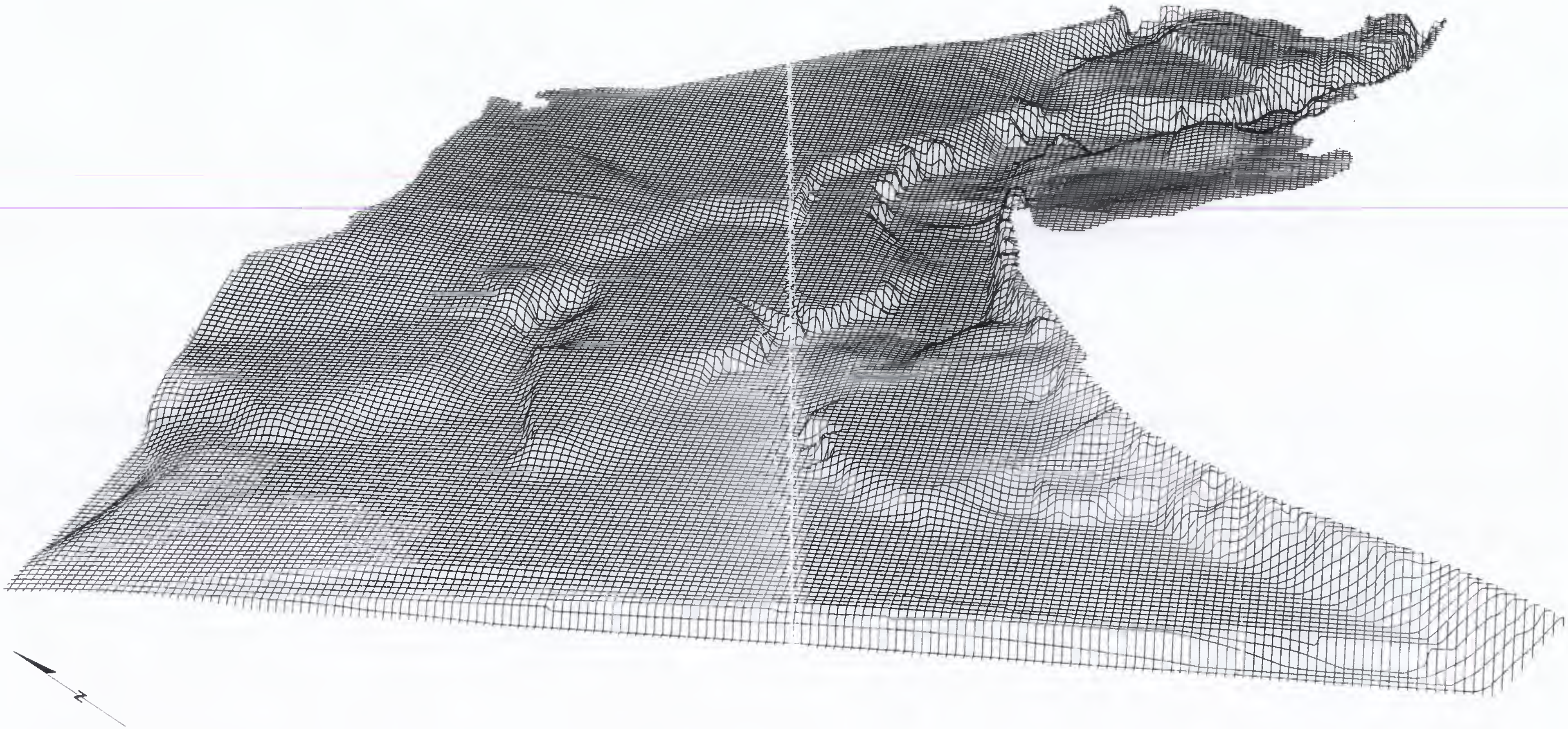




(*) Sur la periode Mai-Aout 1992

Realisation SIRS 1993

Modele Numerique de Terrain : estran de l'estuaire de la Somme

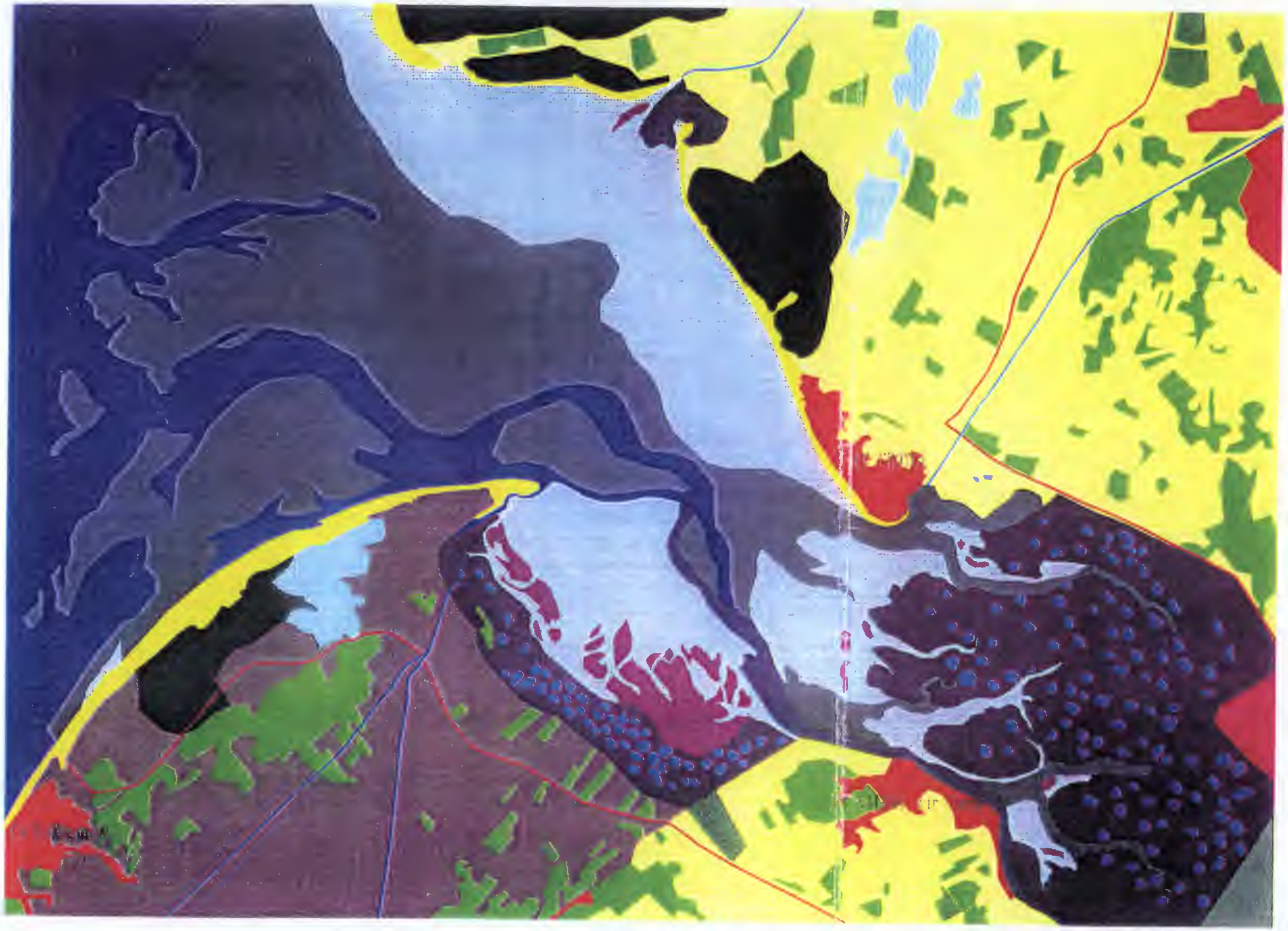


Zone etudiee : 10 Km x 9 Km

Facteur d'accentuation du relief : 50

Realisation SIRS 1993

Carte de Synthese : estuaire de la Somme



Legende

- Sedimentologie fine
- Sedimentologie grossiere
- Cordon dunaire
- Schorre
- Avancee du schorre sur la slikke
- Pres-sales
- Vegetation arbustive halophile
- Eau non turbide
- Eau turbide
- Etangs de chasse
- Forets
- Marais
- Terres arables
- Petit parcellaire en milieu humide
- Prairies
- Gravieres
- Lac de decantation
- Urbain
- Reseau routier
- Canaux de drainage/irrigation

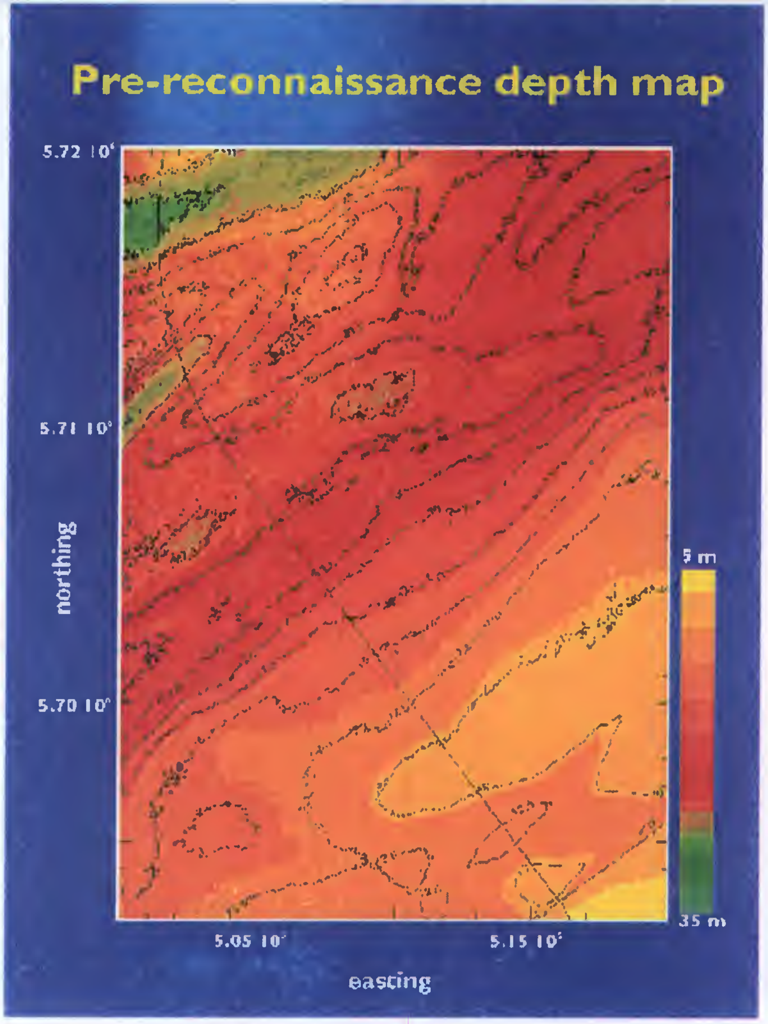
Metres

0 500 1000 1500

N

Carte realisee par photo interpretation assistee par ordinateur a l'aide du logiciel S.I.G. ARC-INFO 6.1.1 sur base des images SPOT XS du 13 mai 1992 et du 13 octobre 1992 ainsi que des images ERS 1 SAR du 22 juin 1992, du 31 aout 1992 et du 11 decembre 1992

Realisation SIRS 1993


Pre-reconnaissance depth map
5.72 10⁶
5.71 10⁶
5.70 10⁶
northing
5 m
35 m
5.05 10⁵
5.15 10⁵
easting

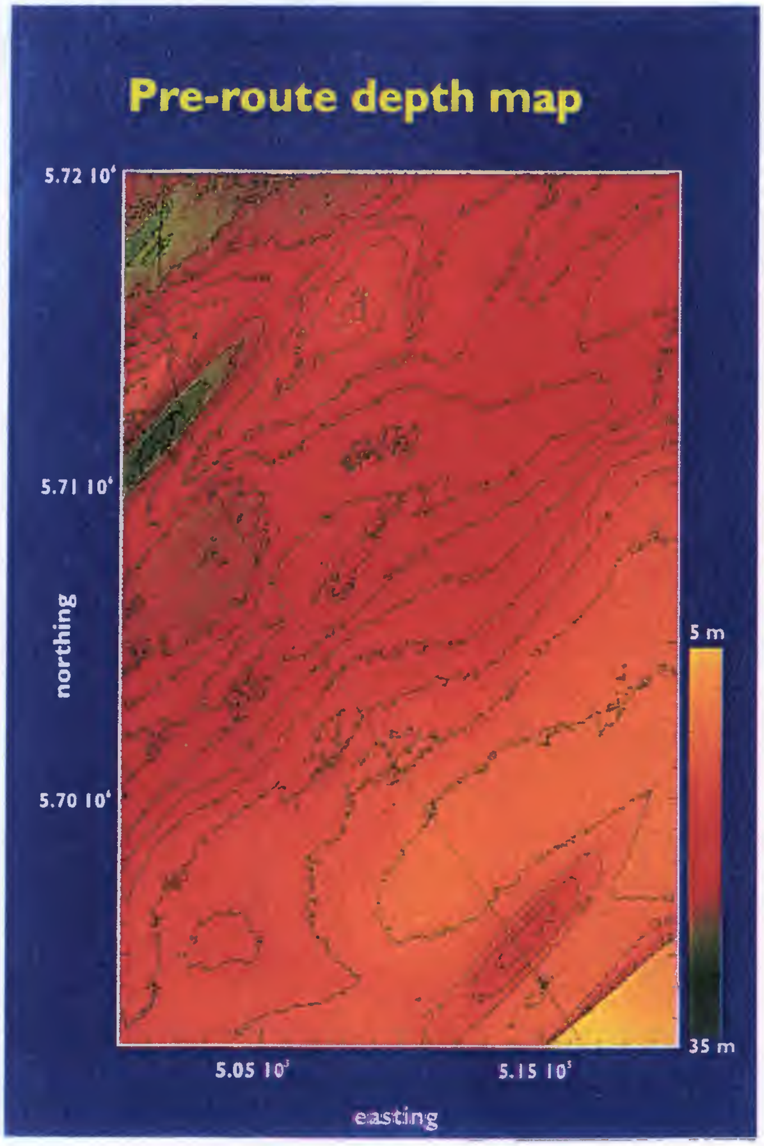

Pre-route depth map
5.72 10⁶
5.71 10⁶
5.70 10⁶
northing
5 m
35 m
5.05 10⁵
5.15 10⁵
easting

Figure 6.5 Bathymetric mapping in tidal waters

A detailed knowledge of the sea floor topography is vital in a range of applications including ship navigation, fishing and marine construction work. Traditional methods of sea bottom mapping, based on shipborne echo sounding, are expensive. Excluding costs generated by delays, conventional depth surveys are estimated to be in the region of 3,900 ECU per day.

Accurate maps of the sea bottom topography are required by offshore engineering companies engaging in activities such as pipeline laying. Generally a number of surveys of the bottom topography are carried out during a laying operation. The first survey, a reconnaissance survey, determines the topography of the area and forms the basis for the selection of the basic route for the pipeline. The second survey is carried out along the selected route as well as offsets of a few hundred metres in order to verify the corridor for the pipeline. A third survey, the pre-lay survey, is carried out just ahead of the laying barge and measures the proposed route to a higher degree of accuracy. Further surveys confirm the position of the pipeline once it has been laid.

SAR imagery give an indication of the bottom topography in shallow tidal seas such as those around the North Sea. Marine engineers can acquire a two dimensional synoptic overview of the bathymetry of the region. Combining conventional echo sounder data from a survey track with SAR images can shorten survey times considerably, thus saving thousands of ECU in costs. The advantage derives from the fact that less survey tracks are required to map the sea bottom to a given accuracy as the SAR data allow accurate interpolation between survey tracks.

A demonstration project was carried out by Delft Hydraulics, with Oceonics Intersite as the end user, to highlight the applicability of ERS-1 SAR images in bathymetric mapping applications. The project focused on the pipeline laying operations conducted by Statoil, the Norwegian State oil company in the North Sea off Zeebrugge in 1993. The mapping process is based on a dedicated workstation known as the Bathymetry Assessment System. SAR images, acquired under suitable marine and meteorological conditions (i.e. wind and current conditions that allow the bottom topography to be visualised within the SAR images), are used to infer the synoptic bathymetry using a numerical inversion procedure. The results are then combined with the conventional echo sounder data and bathymetry charts with accuracies in the order of 30 centimetres. The principal advantage of the system is that a bathymetry map of the required accuracy can be produced with greatly reduced costs (often by a factor of five to ten). The Figures illustrate bathymetry charts for the pre-reconnaissance and pre-route phases that were generated by the Bathymetry Assessment System and based on SAR data.

Courtesy of G J Wensink, ARGOSS, Am Emmeloord, The Netherlands

6.2. Geological mapping

Figure 6.6 Geological mapping for the mineral and hydrocarbon industry in Canada

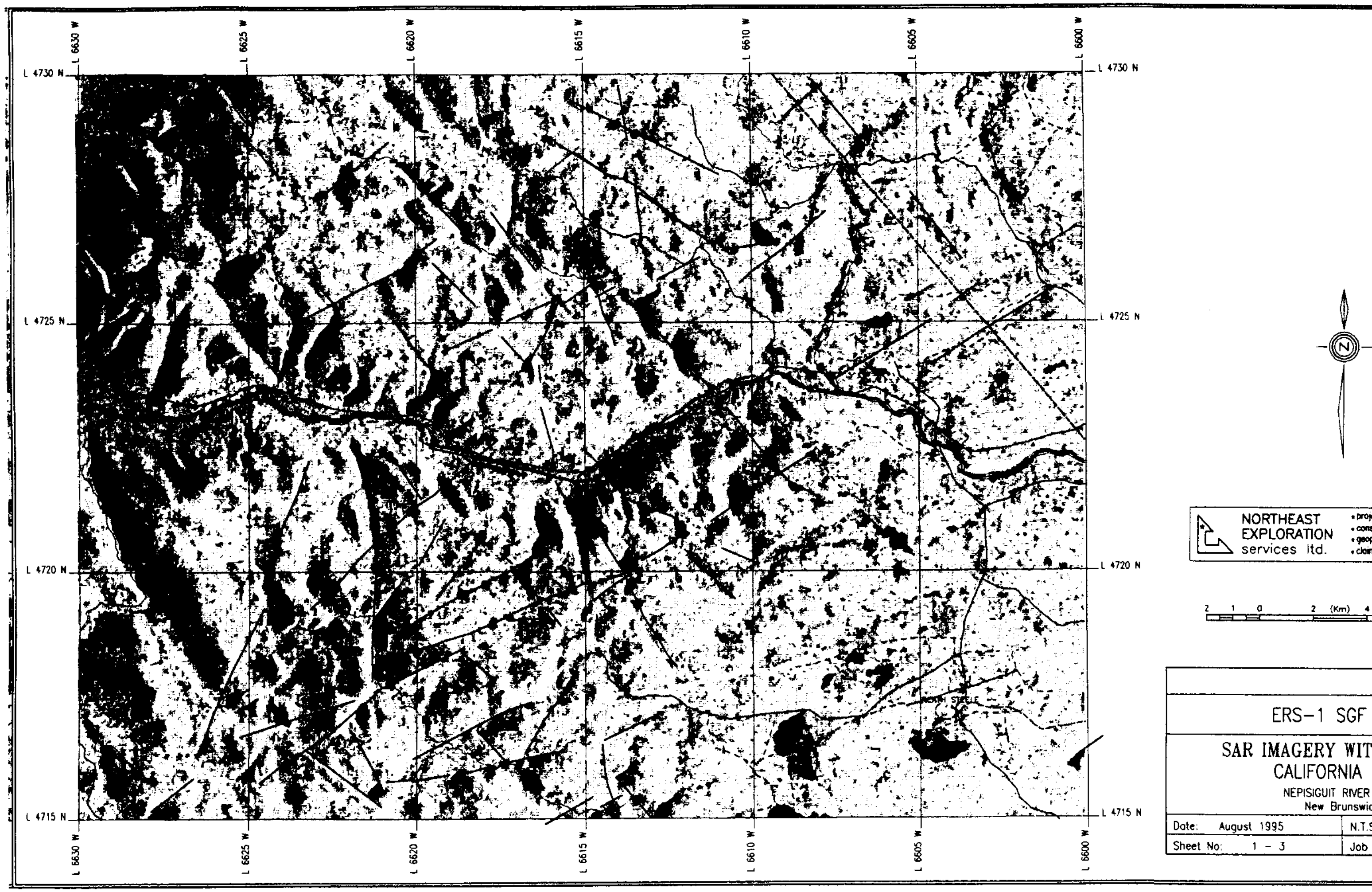
North East Exploration, part of Geomacadie Services Limited, undertakes contract exploration using a number of data sources (including Landsat, SPOT, ERS-1 SAR, geochemical survey data and magnetometer measurements) for a variety of customers in the mineral industries world wide. In addition, contracts are also performed in engineering geology applications such as investigations into the suitability of particular locations for potential land fill sites.

A number of mineral prospecting surveys have been undertaken based on ERS-1 SAR data. SAR images of the survey site are combined with airborne magnetometer measurements and in-situ data to map locations of likely metal reserves. A typical example was a base metal deposit survey carried out in New Brunswick. Customers include Norande and Metall Mining, a Canadian mineral company.

The end product is an interpreted geological map based on the visual interpretation of the SAR image by expert mineral geologists trained in the analysis of SAR images. In particular, lineament features are identified from the SAR image. Magnetometer and in-situ measurements such as geochemical analyses are then combined to determine areas associated with mineral deposits. The Figures illustrate a series of map products for the California Lake area of New Brunswick based on SAR data together with an airborne magnetometer survey and a geochemical survey. Figure a shows the lineaments identified on the SAR image. Figure b shows a combination of SAR and geochemical analyses with the different colours representing the occurrence of different base metal ores. Figure c is a combination of SAR with airborne magnetometer data.

Map products based on ERS-1 SAR data are attractive to the end users as the costs involved in obtaining the data are, in general, lower than for corresponding optical data. From the view of the service provider, the ERS-1 SAR is less affected by vegetation and other masking features such as roads and clear cuts which simplifies the interpretation required to generate a map product.

Courtesy of T Mersereau, North East Exploration, Bathurst, Canada

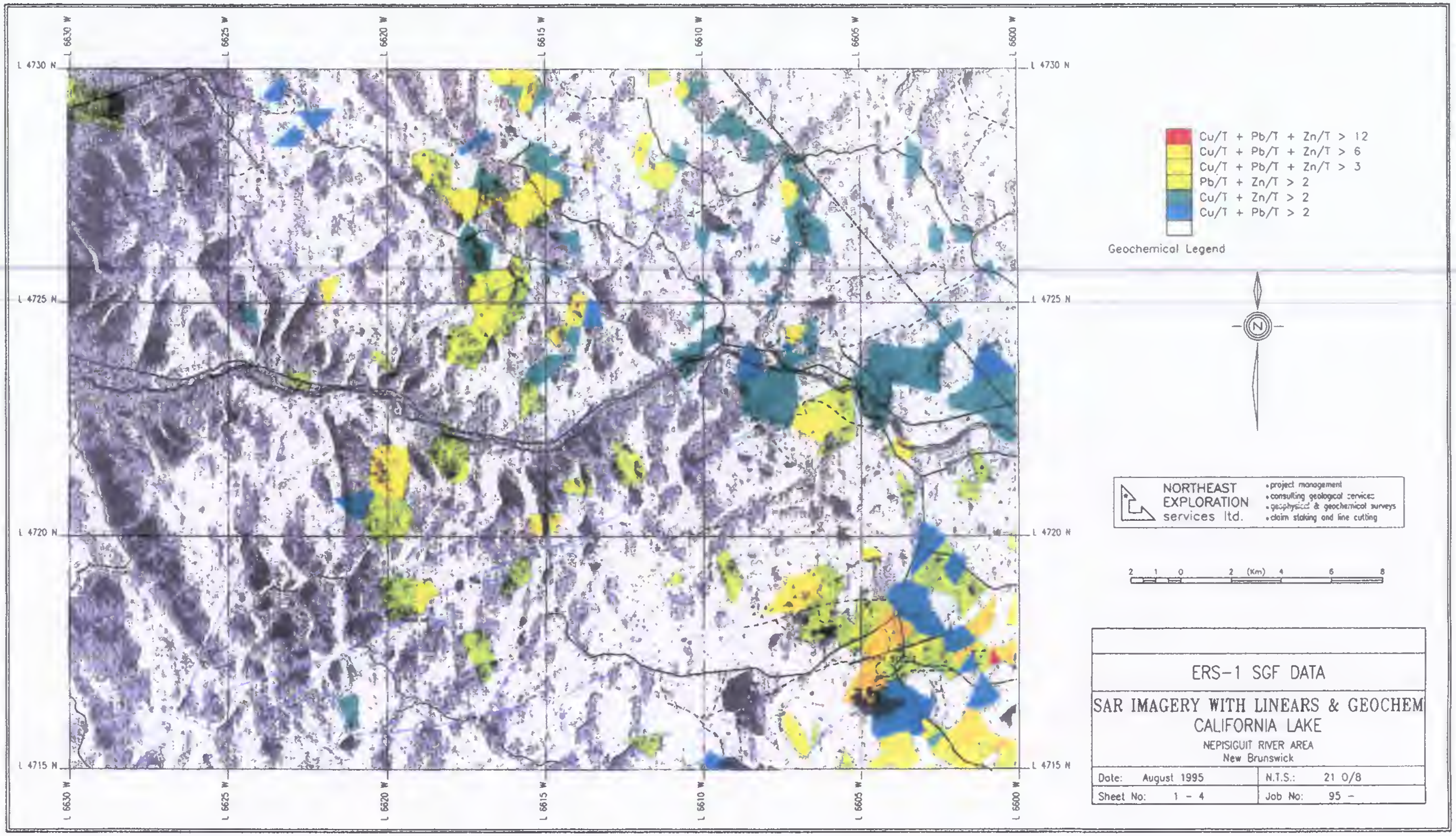


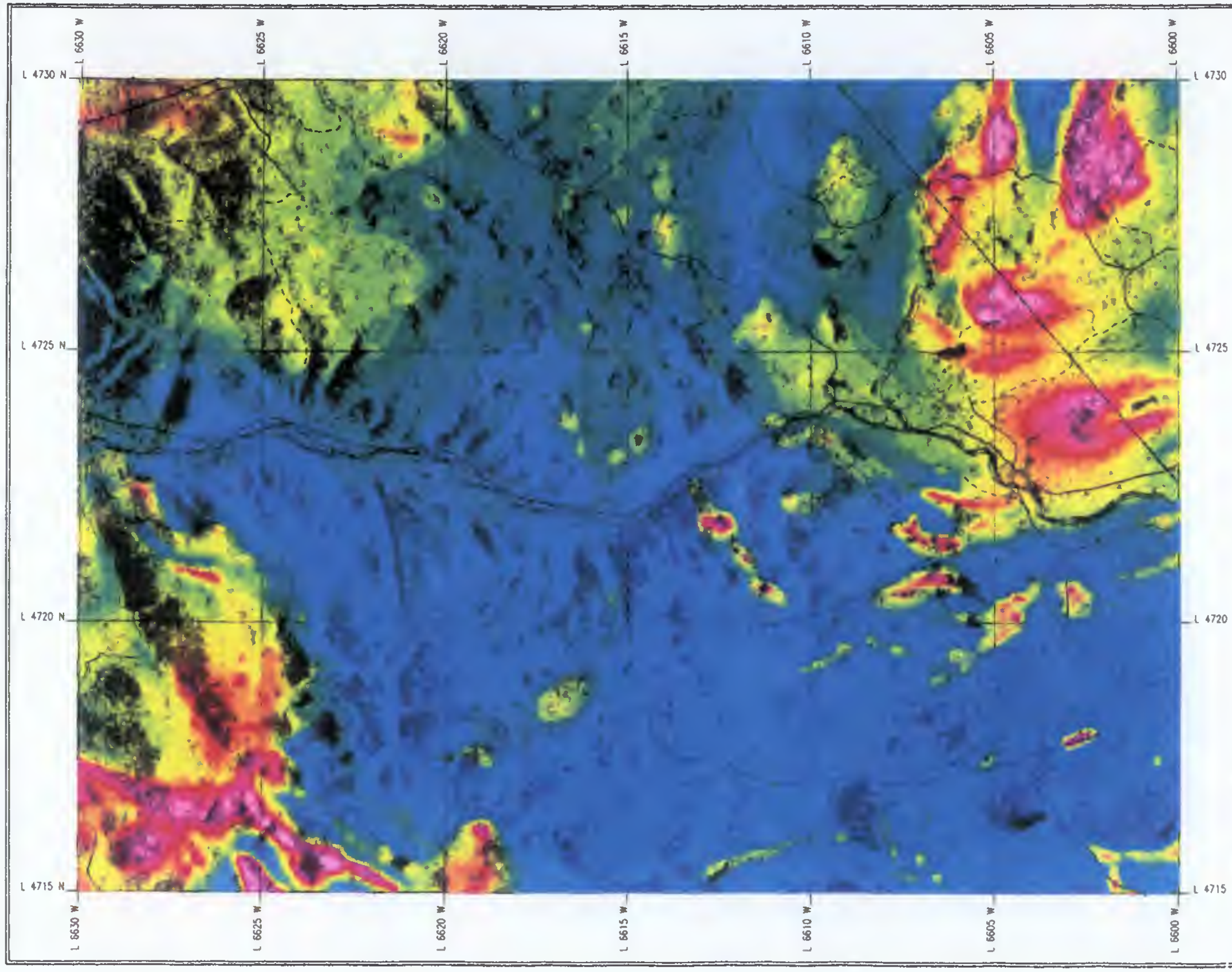
NORTHEAST EXPLORATION services ltd.
• project management
• consulting geological services
• geophysical & geochemical surveys
• claim staking and line cutting

ERS–1 SGF DATA

SAR IMAGERY WITH LINEARS
CALIFORNIA LAKE
NEPISIGUIT RIVER AREA
New Brunswick

Date:	August 1995	N.T.S.:	21 0/8
Sheet No:	1 – 3	Job No:	95 –


L 6630 W
L 6625 W
L 6620 W
L 6615 W
L 6610 W
L 6605 W
L 6600 W
L 4730 N
L 4725 N
L 4720 N
L 4715 N
Cu/T + Pb/T + Zn/T > 12
Cu/T + Pb/T + Zn/T > 6
Cu/T + Pb/T + Zn/T > 3
Pb/T + Zn/T > 2
Cu/T + Zn/T > 2
Cu/T + Pb/T > 2
Geochemical Legend
N
NORTHEAST EXPLORATION services ltd.
• project management
• consulting geological services
• geophysical & geochemical surveys
• claim staking and line cutting
2 1 0 2 (Km) 4 6 8
ERS-1 SGF DATA
SAR IMAGERY WITH LINEARS & GEOCHEM
CALIFORNIA LAKE
NEPISIGUIT RIVER AREA
New Brunswick
Date: August 1995
N.T.S.: 21 0/8
Sheet No: 1 - 4
Job No: 95 -



NORTHEAST EXPLORATION services ltd.

- project management
- consulting geological services
- geophysical & geochemical surveys
- claim staking and line cutting

2 1 0 2 (Km) 4 6 8

ERS-1 SGF DATA

SAR IMAGERY WITH MAGNETICS
CALIFORNIA LAKE

NEPISIGUIT RIVER AREA
New Brunswick

Date: August 1995	N.T.S.: 21 O/8
Sheet No: 1 - 1	Job No: 95 -

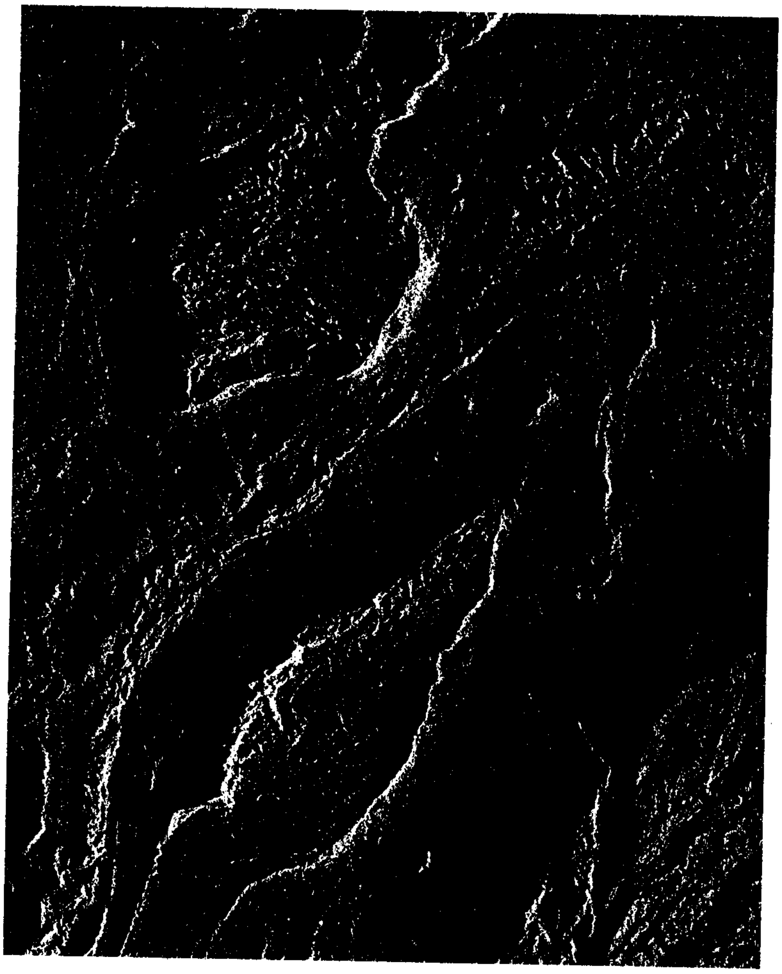


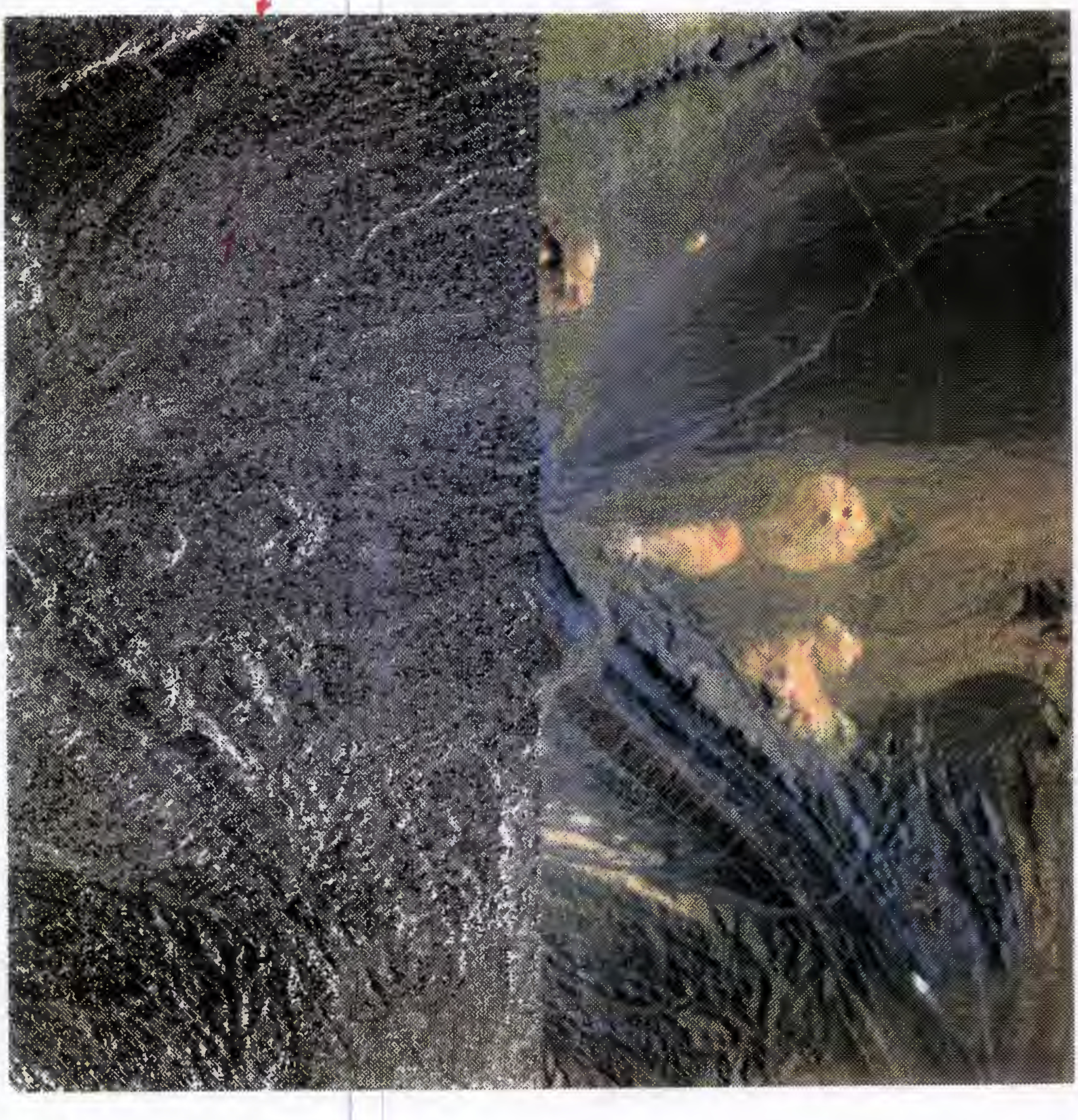
Figure 6.7 Geological mapping for the mineral and hydrocarbon industry in Ireland

Geological map products are provided to a variety of customers by ERA Maptec. Based in Ireland, the company provides both geological and thematic map products for locations world wide, particularly in areas which are inaccessible or where a suitable support infrastructure does not exist (for example remote areas of Asia, Indonesia, Central and South America).

Many data sources are utilised in the production of an interpreted geological map. Originally, optical data such as Landsat and SPOT were used but increasingly SAR images from ERS-1 and also from SIR-B, JERS-1 and Seasat archives are incorporated into the production process. In addition to satellite based data, airborne radar and airborne magnetometer measurements together with existing geological information are integrated into the final product.

In the case of ERS-1 SAR data, processing involves the interpretation of a terrain corrected enhanced image. This analysis is performed visually by specialists in the geological interpretation of satellite based SAR images. Structures of interest are identified and the auxiliary data are then used to provide an accurate geophysical interpretation. In particular, potential oil, gas and mineral (for example base metal) deposits are identified. Products are available within four to six weeks and are delivered as hard copy maps. Customers are predominantly mineral and hydrocarbon companies including BP, British Gas, Lasmo and the mineral company, Newmont. The Figure illustrates an example SAR based geological map provided by ERA Maptec.

Courtesy of M Critchley, ERA Maptec, Dublin, Ireland



CHUQUICAMATA AREA

LINEAMENT EXCLUSIVELY SEEN ON ERS1 IMAGE
(BRGM-FRANCE)

Figure 6.8 Geological mapping over desert terrain

The test images from the first Shuttle Imaging Radar (SIR-A) illustrated the ability of SAR to image geological features through sand cover. A project was undertaken by the BRGM, the French National Geological Research Institute, for the Chilean National Copper Mining Agency, with the aim of demonstrating the use of SAR to detect geological structures related to copper ore. The test area was the Atacama Desert region, in the north of Chile.

The demonstration showed that the ERS-1 SAR imagery, compared with Landsat TM imagery or aerial photographs, allows the identification of numerous linear features, associated with geological structures (faults) which affect the basement, through recent pediment fans of thick detrical unconsolidated deposits (0 to more than 50 metres in the studied area). These are caused by the subduction of the Nazca plate under the South American continent. The frequent seismic movements transmitted to the basement faults seem to cause movement or subsidence in the pediment deposit, which is demonstrated by normal conjugated faults. This phenomenon is easily identified by the SAR. Further work is to be undertaken to confirm this interesting first result. The image shows a comparison of the ERS-1 SAR and Landsat data. In particular, the lineament features that are visible only in the SAR image should be noted.

Courtesy of G Delport, BRGM, Orleans, France

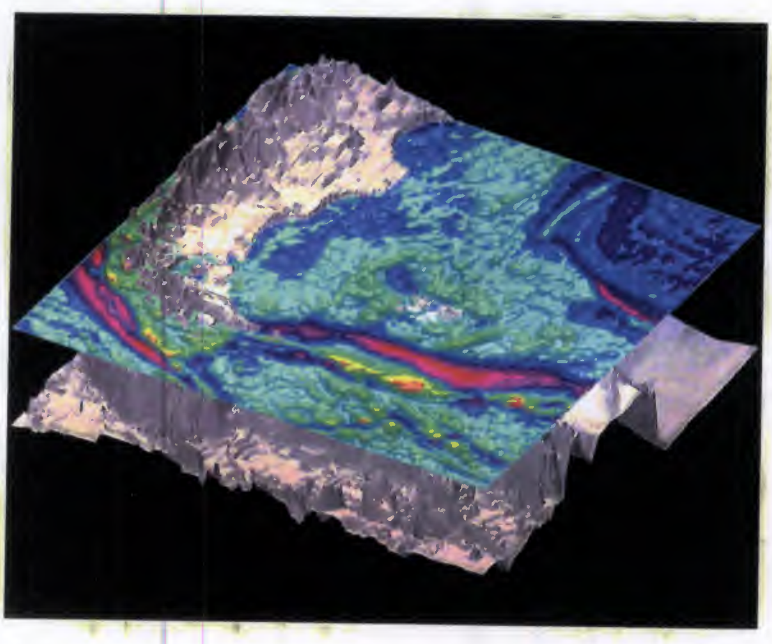


Figure 6.9 Gravity mapping for petroleum exploration

Satellite Observing Systems Limited, based in the UK, have recently begun providing an operational service in which radar altimeter data are used in the production of interpreted marine gravity maps of particular regions. Products have already been produced for regions world wide including the Gulf of Thailand, the Gulf of Mexico, the East China Sea, the Bay of Bengal, the Falkland Islands (see Figure) and the northern sea off the coast of Russia. Maps were also produced of the North Sea off the coast of the Shetland Islands and the North Atlantic around Rockall. These were made available to a number of oil and gas companies as well as to the British Geological Survey.

ERS-1 radar altimeter range data are processed to extract along-track surface slope at wavelengths of the order of 10 kilometres. The slope data are converted to grids of northing and easting slope deviations, and thence to gravity anomalies, using a procedure developed by US researchers. Coverage has been extended to ice-covered oceans in collaboration with Mullard Space Science Laboratory, who have developed techniques to process the more complex signals returned over sea ice. The process uses radar altimeter data to determine the along track slope of the sea surface. This means that it is no longer necessary to correct for errors in the estimated height of the spacecraft and this generates considerable improvement in the accuracy of the measurement.

The measurements incorporate radar altimeter data from ERS-1 together with Seasat, TOPEX/Poseidon and the recently declassified Geosat archives. Integration of the data from the different instruments is performed using in-house routines. Once the gravity anomalies have been determined, geophysical interpretations are performed by geophysicists from the British Geological Survey to highlight features and areas of interest to the end customer. Interpreted map products for a number of regions world wide have already been provided to a number of oil exploration companies.

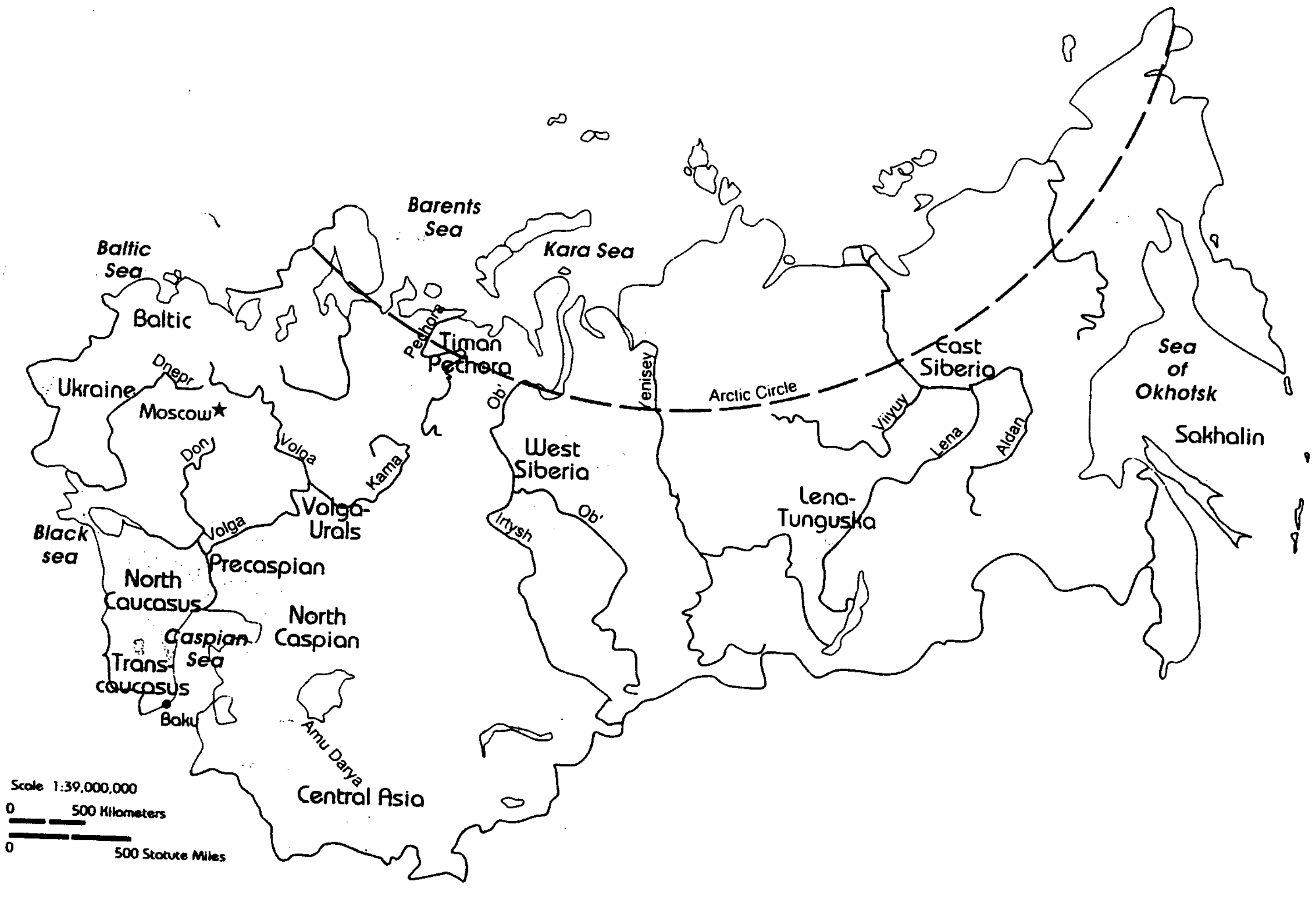
Courtesy of P Stevens, Satellite Observing Systems, Godalming, UK

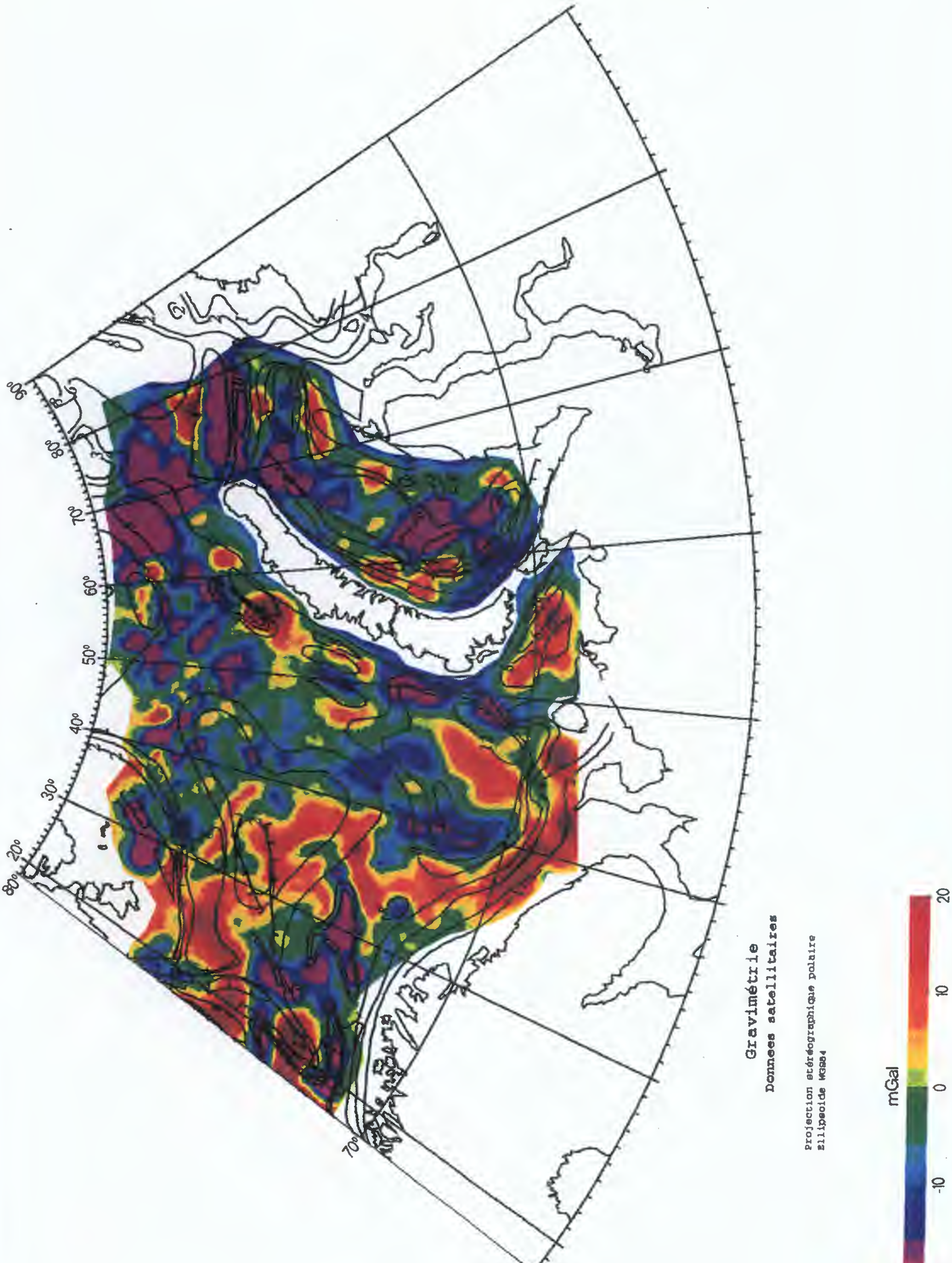
Figure 6.10 Gravity mapping for petroleum exploration in the Arctic (PEGASE project)

The continental shelf in the Arctic, north of Russia consists of a series of epicontinental seas, which are the offshore continuation of potentially oil and gas rich basins on land (Figure a). The geology of all these epicontinental seas is poorly known, due to the remoteness, the extreme climatic conditions and the extensive costs associated with seismic exploration. Earth observation satellites thus provide a unique opportunity to observe these inhospitable regions and radar altimeter sensors are an invaluable tool for studying the geological structures off the coast. The unique ERS-1 contribution comes from its high latitude coverage (81.5 degrees south and north), and the space and time density of measurements. The radar altimeter data have successfully been used for the precise determination of the geoid gravity field over the north polar area.

The work was performed as a collaboration between CLS Argos and IFREMER within the PEGASE project. Many features appear in the ERS-1 derived gravity field, that are not present in the original gravity maps derived from shipborne surveys. Analysis of the ERS-1 radar altimeter data provides a new perspective on the gravity structure of the sea basins off the north coast of Russia. The current phase of the project is to derive the boundaries and thickness of the sedimentary basins of the Russian Arctic continental margin from the ERS-1 inferred gravity field (Figure b). This work is being evaluated with the help of the oil companies Elf and Shell.

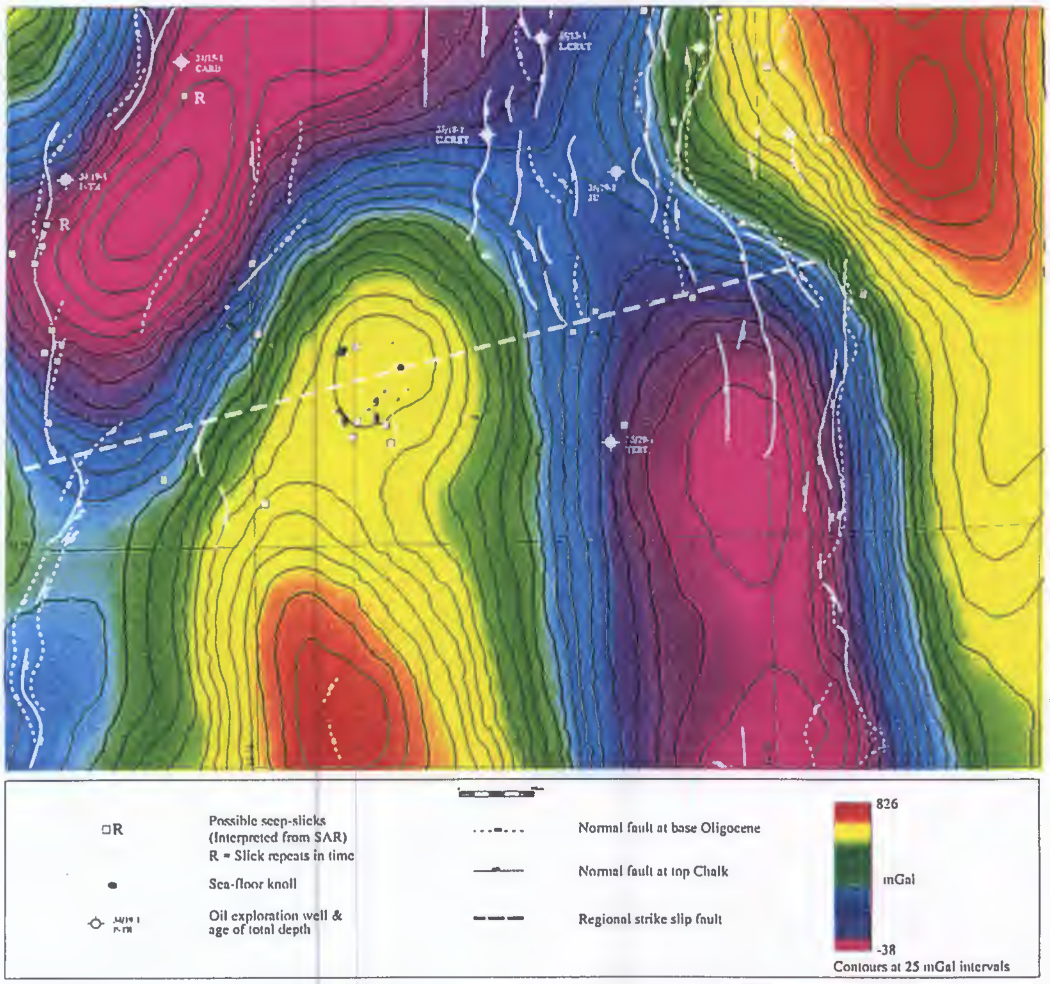
Courtesy of F Blanc, CLS Argos, Toulouse, France; L Geli, IFREMER, Brest, France





Sedimentary thickness contours (after Jackson and Oakey-1990) superimposed on the ERS-1 derived free-air gravity anomaly map.

BNSC
BRITISH NATIONAL SPACE CENTRE



DISTRIBUTION OF POSSIBLE SEEP-SLICKS
OF THE PORCUPINE TROUGH INTERPRETED
FROM SAR SUPERIMPOSED ON MAP OF FAULTS
& SEA FLOOR KNOLLS
WITH FREE AIR GRAVITY - 168 day altimetry
(From Hovland, Croker & Martin 1994)

NPA

OFFSHORE BASIN SCREENING™

TREICoL

Figure 6.11 Offshore basin screening™ for the hydrocarbon industry

Oil explorers use seismic surveying to map subsurface structures that might have oil. This is an expensive technique costing on average 5,500 ECU per square kilometre. Now, UK companies Nigel Press Associates and TREICoL offer a service to oil explorers offshore that saves time and money by prioritising seismic expenditure and focusing on the most prospective basins. This offshore basin screening service provides gravity maps, derived from satellite-based radar altimeter measurements, that represent the subsurface geological structure beneath the sea, combined with a map of sea-surface slicks, resulting from natural oil seepage, analysed on SAR images. The Figure shows an example of such a map for the Porcupine trough. The screening usually takes a few weeks and costs under 0.5 ECU per square kilometre. Altimeter data from ERS-1/2 are combined with data from four previous satellites resulting in track spacing as close as one kilometre. Other geophysical information are also used where available. The altimetry is converted to gravity that can outline the basins in which oil might occur. The major economic risk in exploration is whether a particular basin will be a source of hydrocarbons.

Onshore, oil explorers map surface seepage of oil or gas as clues to the presence of buried hydrocarbon sources. Offshore, there has been no generally available low-cost method to identify these seepage clues. The ERS-1 SAR can, at times of low to moderate wind speed, systematically detect slicks over vast swaths of ocean, whatever the cloud or light conditions. Nigel Press Associates and TREICoL, during a two year demonstration programme supported by UK government and the oil industry, established rules to categorise the diverse slicks observed on radar pictures, and are able to characterise slicks originating from sea-floor natural oil seepage. These seep-slicks are typically only a few percent of the total number of slicks. As seep-slicks often persist in time, SAR from repeat low-wind dates separated by months are used for the analysis.

Oil companies are using offshore basin screening to rank and select exploration blocks offered by governments, to prioritise where seismic data are bought or acquired and to locate wells. Currently the technique has been used by twenty separate oil industry consortia and a similar number are negotiating with Nigel Press Associates to screen areas around the world. The market for the service is estimated as 4 million ECU per year.

Courtesy of G Lawrence, TREICoL, Knebworth, UK; N Press, Nigel Press Associates, Edenbridge, UK

Figure 6.12 Natural oil slick detection

As a consequence of the growing demand for energy and raw materials, oil and mineral companies throughout the world are having to direct their exploration activities towards remote areas, rough seas, deep oceans and polar regions. Today, feasibility studies for oil exploration and exploitation are based on wide ranging information, concerning not only geological data but also increasingly on oceanography and statistics of sea state and wind conditions. Complementary information on potential drilling sites can be provided by satellite based instruments and ERS-1 SAR data in particular.

Natural oil seepages are a phenomenon that have been observed for many years. Promising oil fields may be located by finding such seeps and tracing the source. A consortium of petroleum companies and government agencies are using ERS-1 SAR data in the Gulf of Mexico where such seepages frequently occur. Data collected from regular satellite passes were processed in near real time and a team of specialists then analysed the images to locate and identify possible seeps. Detailed on-site inspection by submarine was then carried out for the most promising locations. The Figure shows an image of the Gulf of Mexico. The larger dark features are natural oil slicks from seepage.

Courtesy of EK Biegert, Pecten International Company, Houston, USA

7 SUMMARY

7.1 *Overview of applications*

❑ Marine Operations

The accuracy and coverage of weather and sea state forecasts are being significantly improved by the inclusion of ERS-1 scatterometer and radar altimeter data. Products and services are being made available by value adding organisations to a wide range of marine users. Shipping companies are using forecasts and climatologies derived from ERS-1 data to calculate optimal routing, using favourable meteorology and avoiding storms and heavy seas. Oil companies are using sea state information for planning the logistics of seismic surveys, in the development of mooring strategies for connection of oil tankers to riser pipes and the development of large scale engineering works for offshore operations. Sea state information is also being used by warranty and insurance companies

Marine applications typically require rapid interpretation and dissemination of information to users. Demonstration of the potential to extract information from satellite imagery is not enough. This requirement is recognised by service providers, and infrastructure and services for rapid processing and dissemination of information are being established.

❑ Sea Ice Navigation

Information from ERS-1 SAR data is being incorporated into operational sea ice monitoring and forecasting services and is routinely used by ice centres in the Baltic countries and in North America. As with many applications, the SAR data are being combined with data from a wide range of other sources to improve the accuracy of existing services. Data processing and delivery chains are being established to suit the particular information and delivery needs of each type of user. Progress is being made in demonstrating ship routing through the Northern Sea Route, the development of work stations for automatic production of sea ice maps and the use of these maps by exploration companies.

❑ Agricultural and Forestry

Applications of ERS-1 SAR data in agriculture and forestry are progressing on the basis of established optical based programmes which are already providing an operational service to commercial and government users. The use of SAR data is now established in the European Union's crop monitoring programme taking advantage of their all weather capability. Forestry projects in tropical and boreal forests are demonstrating the value of SAR data in areas which could not previously be mapped due to heavy cloud cover. Information is being obtained over both large and site specific areas for local development management projects and for global vegetation monitoring. For land applications in particular ERS-1 data are being used increasingly in combination with other data as an input to geographic information system based resource management systems.

❑ Hazard management

The all weather capability of the ERS-1 SAR makes it a valuable sources of information in the management of natural and man made hazards and disasters. Oil slick monitoring services are operational in Norway and are being developed and integrated with existing services in a number of other countries. The effective management of flood events relies on timely and accurate information. Collection of this information is often hampered by difficulties associated with severe weather conditions. SAR data are being used to map flooded areas, to predict areas at risk from flooding, for land use planning and management and to assist in flood relief. A range of other hazard related applications are being developed, most notably in mapping the effects of surface movements resulting from mining and volcanic activity.

❑ Topographic and geological mapping

Geological and topographic mapping applications using ERS-1 SAR data are well established. For exploration, SAR data are providing a unique source of information for geological mapping and for identifying and locating natural oil slicks. Value adding organisations are providing commercial services to the exploration industry using both SAR and radar altimeter data. The incorporation of SAR data into bathymetric mapping for pipeline laying has been successfully demonstrated and provides the basis for significant savings over conventional methods. In more general mapping applications, SAR data are being used in the production of image maps and topographic map updating. Development of interferometric techniques is providing unique opportunities for the production of digital elevation maps for areas not previously mapped to this accuracy. This new opportunity is now being taken up by commercial suppliers.

8 ANNEX 1: Further information on ERS-1 data

❑ Data availability

A wide range of ERS-1 products, from fast delivery to off-line products, are available to users. The SAR fast delivery products are generated and distributed to national centres by the Kiruna and Fucino ground stations within one day of instrument observation. The other fast delivery products are generated for a global coverage within three hours from sensing and are distributed to users via land telecommunication lines or satellite links.

Copies of all low bit rate fast delivery products are provided off-line by the processing and archiving facilities. The instrument raw data is sent from stations to the processing and archiving facilities for archiving and generation of precision products. Their delivery times depend mainly upon the time required for the data to get from the acquisition stations to the processing facilities. For data already archived, at processing and archiving facilities, SAR image products are generated and shipped, in average, within less than ten days. For further information, users can address enquiries to the Help and Order Desk as described below.

❑ The ERS consortium

The European Space Agency in January 1992 appointed the ERS Consortium (Eurimage, Radarsat International, SPOT Image) to market data from the ERS-1 satellite all over the world. The consortium members are:

- Eurimage based in Rome, Italy and covering data from Europe, North Africa and Middle East;
- RADARSAT in Vancouver, Canada and covering North America;
- SPOT Image based in Toulouse, France serving the rest of the world.

Each member of the ERS Consortium has a Customer Service department which can be reached at:

Eurimage	**RADARSAT International**	**SPOT Image**
ERS-1 Customer Service	ERS-1 Customer Service	Customer Service
Tel (39 6) 94180751	Tel (1 604) 2440400	Tel (33 62) 194146
Fax (39 6) 94180510	Fax (1 604) 2440404	Fax (33 62) 194051

❑ On line help services

ESA ESRIN	http://www.esrin.esa.it/
ESA ESRIN user services home page	http://services.esrin.esa.it/
ESA Guide and Directory Service (describes data, systems and applications)	http://gds.esrin.esa.it/
ESA ERS Help Desk	helpdesk@ersus.esrinvas.esrin.esa.it

❑ Publications

1. A range of publications from ESA provide more information on the utilisation of ERS-1. These can be ordered from the:

   ESA Publication Division
   ESTEC, Keplerlaan 1
   2200 AG Noordwijk
   The Netherlands
   Fax (31) 71 565 5433

   - ESA Bulletin - a quarterly journal with articles on all ESA programmes;
   - Earth Observation Quarterly - a quarterly journal with new science results and information about Earth observation activity;
   - Proceedings of the Second ERS-1 Symposium, October 11-14, 1993 Hamburg, Germany (SP-361);
   - Proceedings of the First ERS-1 Pilot Project Workshop, June 21-24, 1994, Toledo, Spain (SP-365);
   - Scientific Achievements of ERS-1 (SP-1176/I);
   - SAR Ocean Feature Catalogue (SP-1174).

2. The following publications can be ordered from the:

   ERS-1 Helpdesk, ESA ERIN
   Via Galileo Galilei
   I-00044 Frascati
   Italy
   Tel (39) 6 941 80 666
   Fax (39) 6 941 80 652

   - CD ROM Guide to ERS-1 - provides the user with a brief animated outline of the ERS-1 system, an overview of its most important features, and detailed information from user manuals. The guide is well illustrated with diagrams, photographs, satellite images and animated sequences (MS Windows);
   - CD ROM SAR Reference Coverage - a catalogue of ERS-1 SAR image data acquisition plus quick look images of Europe (MS Windows);
   - ERS User Handbook;
   - ERS Product Specifications;
   - Land and sea ERS-1 applications.

3. The following publications can be ordered from the:

ESA Public Relations Division
8-10 rue Mario Nikis
F-75738 Paris cedex 15
France
Fax (33) 1 4273 7690

- ERS-1 slide set;
- ERS-1 photo CD;
- What a wonderful world - a 24 min video presentation of the ERS-1 mission (VHS-PAL, SECAM or NTSC, in English, French, German of Italian);
- From ERS-1 to ERS-2: Destination Earth.

9. ACKNOWLEDGEMENTS

ESA would like to thank the following for providing the contributions used in this document.

Organisation		**Contact**
ARGOSS	Delft The Netherlands	GJ Wensink
Atlantic Centre for Remote Sensing	Toronto Canada	B Whitehouse
Atmospheric Environment Service	Ottawa Canada	P King M Shokr
BRGM	Orleans France	G Delport J Scanvic
CLS Argos	Toulouse France	E Dombrowsky F Blanc
CSI Piemonte	Piemonte Italy	E Bonansea
Daimler Benz Aerospace	Freidrichshafen Germany	U Frembgen F Jaskolla
Danish Meteorological Service	Copenhagen Denmark	HH Valeur
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University Pierre et Marie Curie	Paris France	J-P Rudant

ESA would also like to thank the following for their review comments.

ARGOSS	Delft The Netherlands	GJ Wensink
Atmospheric Environment Service	Ottawa Canada	M Shokr
CTS Consultants	London UK	S Culshaw
DG XII European Commission	Brussels Belgium	M Sharman
Institute of Hydrology	Wallingford UK	K Blyth
Nansen Environmental and Remote Sensing Centre	Bergen Norway	S Sandven
Ordnance Survey	Southampton UK	K Murray