This collection of results from various fields of study demonstrates the many applications derived from the European Space Agency's remote sensing satellite, ERS-1. Fostered by ERS-1 Pilot Projects campaigns, investigators from many European countries developed diverse projects. Three years of experience with many investigations have shown the innovative and promising uses of radar satellite technology for Earth observation.

The assured availability of ERS-1 data through ESRIN, from ESA ground facilities and infrastructure, combined with the scientific expertise in image processing, analysis and applications, was fundamental in utilising satellite information for these environmental monitoring projects. As new concepts and applications are developed, such information, initially of scientific interest, will be used increasingly for practical resource planning and monitoring of man's activities.

The European Space Agency extends its gratitude and appreciation to the contributors to this publication.

Scientific Applications Information:
ERS Data Utilisation Section
ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)
Tel: (+39) 6 941 80 419 or 371
Fax: (+39) 6 941 80 520

ERS Images and Programme Information:
ERS Help Desk
ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)
Tel: (+39) 6 941 80 600 or 711
Fax: (+39) 6 941 80 510

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Layout and Pre-Press: C. Liger-Marie

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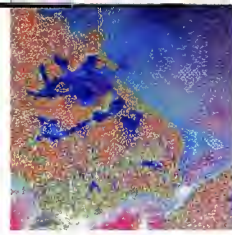
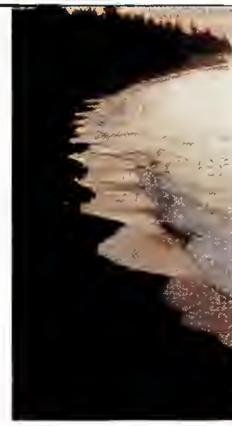
LAND and SEA

ERS-1 APPLICATIONS

ERS-1 Multi-Temporal Image of Copenhagen, Denmark 1992





APPLICATIONS OF ERS-1 DATA

Today's Technology

The use of satellites and their related technologies has profoundly changed our way of life these past three decades. From communications to unparalleled views of the Earth, satellites have provided services and information which were previously unavailable. More recently, the first in the new generation of European Remote-sensing Satellites (ERS-1) has been demonstrating the practical uses of its radar technology in remote Earth observations.

The information sheets in this brochure describe just some of the many projects utilising data products and images from ERS-1. Initially of scientific interest, these projects have demonstrated that practical and even commercially viable applications are possible today. From the monitoring of crops, tropical deforestation and flooding on land, to the tracking of oil spills, sea-ice and weather conditions on the oceans, ERS-1 has provided a wealth of information which is being used for practical, every-day applications.

ERS-1 multi-temporal image of Rome and surroundings.

Looking Forward

Continuity of satellite observations of the Earth will be ensured with ERS-2, the latest member of the ERS family, and later in the decade by Envisat. ERS-2 builds upon the successes of ERS-1, with an improved scanning radiometer (ATSR) and an additional sensor for global ozone measurements (GOME). The addition of this satellite will increase the amount and availability of Earth observation information considerably.

To provide for efficient delivery of ERS data products, a consortium of commercial distributors was organised. A variety of data products is available, from data delivered electronically in "quasi-real time" to precision images (PRI) available off-line.

For information on ERS data products and availability, contact the ERS Order Desk for your area.

ERS Consortium Contact Addresses

Europe, North Africa and the Middle East

Eurimage
ERS Customer Services
ESRIN
via Galileo Galilei
I-00044 Frascati (Italy)
Tel: (+39) 6 941 80 478
Fax: (+39) 6 941 80 510

Canada and the United States

Radarsat International
ERS Order Desk
3851 Shell Road
Suite 200
Richmond,
British Columbia V6X 2W2
(Canada)
Tel: (+1) 604 244-0400
Fax: (+1) 604 244-0404

All Other Regions/Countries

Spot Image
ERS Order Desk
5, Rue des Satellites
B.P. 4359
F-31030 Toulouse Cedex (France)
Tel: (+33) 62 19 4146
Fax: (+33) 62 19 4055

Comparison of SPOT versus ERS-1 Images. Various crop types in the agricultural region south of Seville are visible in each image. The composite (right) of 3 ERS-1 images acquired during three different months (July, August and September) is compared with an image from a SPOT satellite. Information obtained from each image is complementary. (Courtesy of Joint Research Centre of the European Communities.)

Technical Note

The radar instrument is sensitive to the geometric characteristics of vegetation and soil surface, and to humidity of soil and plants. Different crops require different field preparation, which depends on environmental conditions (temperature, rainfall, soil composition) and common management practices, such as crop rotation schemes. With a resolution of 25 meters, ERS-1 winter imagery can provide early information on crop distribution. During the growing season, each crop has its own unique characteristics (geometry, specific development, etc.) which can be detected with the ERS-1 radar.

Contact Addresses:

M. Milnes
Logica UK Ltd.
Sugar Beet Project, Space Division
Byron House, Business Park
No. 4 Randalls Way, Leatherhead,
Surrey KT22 7TW, (United Kingdom)
Tel: (+44) 171 637 9111
Fax: (+44) 137 222 7018

H.G. Kohl
Joint Research Centre of the European Communities (JRC) - Institute for Remote Sensing Applications (IRSA)
AIS - TP441
I-21020 Ispra (Varese) (Italy)
Tel: (+39) 332 785449
Fax: (+39) 332 789074

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)

- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
- ERS Help Desk
  Tel: (+39) 6 941 80 600 or 711
  Fax: (+39) 6 941 80 510

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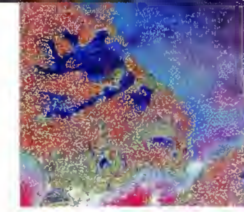
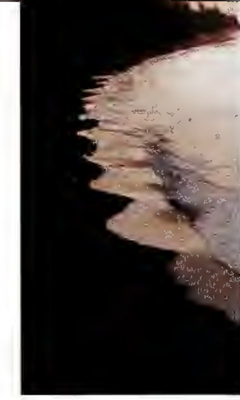




CROP MONITORING

Crop Yield Prediction

Accurate assessments of crop acreages, their geographical distribution and yield forecasts are needed for planning harvests and managing food the stocks and their distribution. In fact, the agricultural policies of many nations are based on yearly trend estimates. The availability of land-use maps and statistical databases is of great help in deciding the quantities to exchange, and in establishing quotas and prices.

Conventional yield prediction systems are based on ground surveys, with limited verification using aerial photography.

Modern technology is assisting in improving age's old agricultural practices

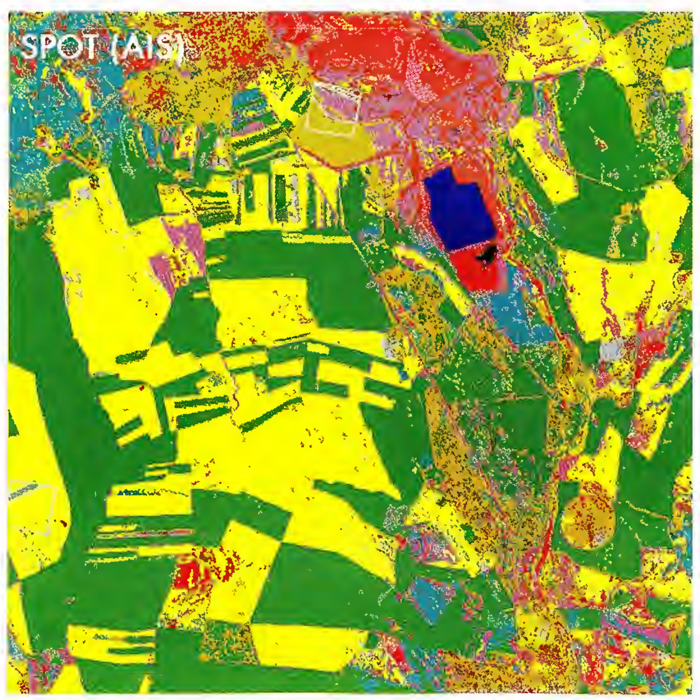
Although the information provided by field surveys may be accurate, the overall quality is not always homogeneous due to subjective human judgment and the use of different survey methods.

Satellite Data for an Agricultural Policy

Information collected from satellites offers four main advantages, namely: repetition, objectivity, accuracy and restitution in a form that permits combination with other data, such as those regarding soil, as well as meteo or climate maps. Achieving accurate predictions several weeks ahead of the harvest can lead to better decisions. In addition, satellite information is homogeneous all over the observed areas.

Many crop monitoring systems make regular use of satellite images. The United States Department of Agriculture, for instance, utilises information from the Large Areas Crop Inventory Experiment (LACIE) Programme. Satellite data are also used in the European Union's MARS (Monitoring Agriculture with Remote Sensing) Programme and by agricultural companies such as British Sugar of the United Kingdom.

In collaboration with the British National Space Centre, British Sugar has used information from this programme to successfully predict sugar beet yields. These systems use data from U.S. Landsat and from French SPOT satellites. Analyses are performed on data acquired during the March-October growing period.



Detection of Wheat and Sunflower Fields Northwest of Seville Differences in vegetation cycles permit wheat fields (in green) to be distinguished from those areas cultivated in sunflowers (in yellow). The analysis and results from the composite SPOT image are very similar to those of the ERS-1 image (right) (Courtesy of Joint Research Centre of the European Communities.)

ERS-1 Data for Early Prediction

Data from ERS-1 have contributed significantly to early crop prediction programmes. Because the on-board imaging radar (Synthetic Aperture Radar, or SAR) makes it possible to observe the Earth's surface through clouds, quick estimates of planted crop acreage can be made early in the season.

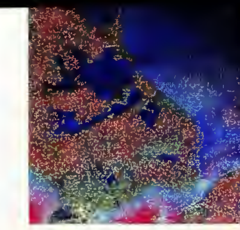
Integration of ERS-1 Data into the MARS Programme

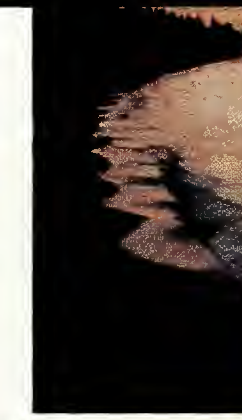
Researchers at the Joint Research Centre of the European Union have incorporated ERS data into the MARS Programme on an experimental basis. This ERS information is used successfully for Northern Europe test-sites when it proves difficult to obtain optical data due to bad weather conditions.

The analyses, carried out at three test sites (Seville in Spain, Great Driffield in the U.K. and Olsztyn in Poland), demonstrate that early detection and classification of crops are feasible by combining ERS-1 data acquired on different dates. Better discrimination of a target crop can be achieved during the period of crop growth when ERS-1 data are substituted for SPOT/Landsat data.

The combined use of both satellite data types, optical and radar, improves crop yield predictions significantly. Rapid and timely availability of this information is important in developing accurate crop forecasts.

A combination of 3 ERS-1 images (taken in April, May and July) was used to produce this composite image. Classification results show wheat fields in green, sunflower fields in yellow, and other land use areas in red. (Courtesy of Joint Research Centre of the European Communities.)





FLOODING SURVEILLANCE AND PREVENTION

The great floods which occurred in the United States and Europe in 1993 and 1995 have clearly shown how severe the consequences of such phenomena can be, even in countries where flood forecasting and prevention methods have long been developed, tested and implemented. Attempts have been made to improve these traditional methods. Only in recent times, however, has a significant step forward been made by setting up real-time warning systems, thanks to the availability of satellite technology.

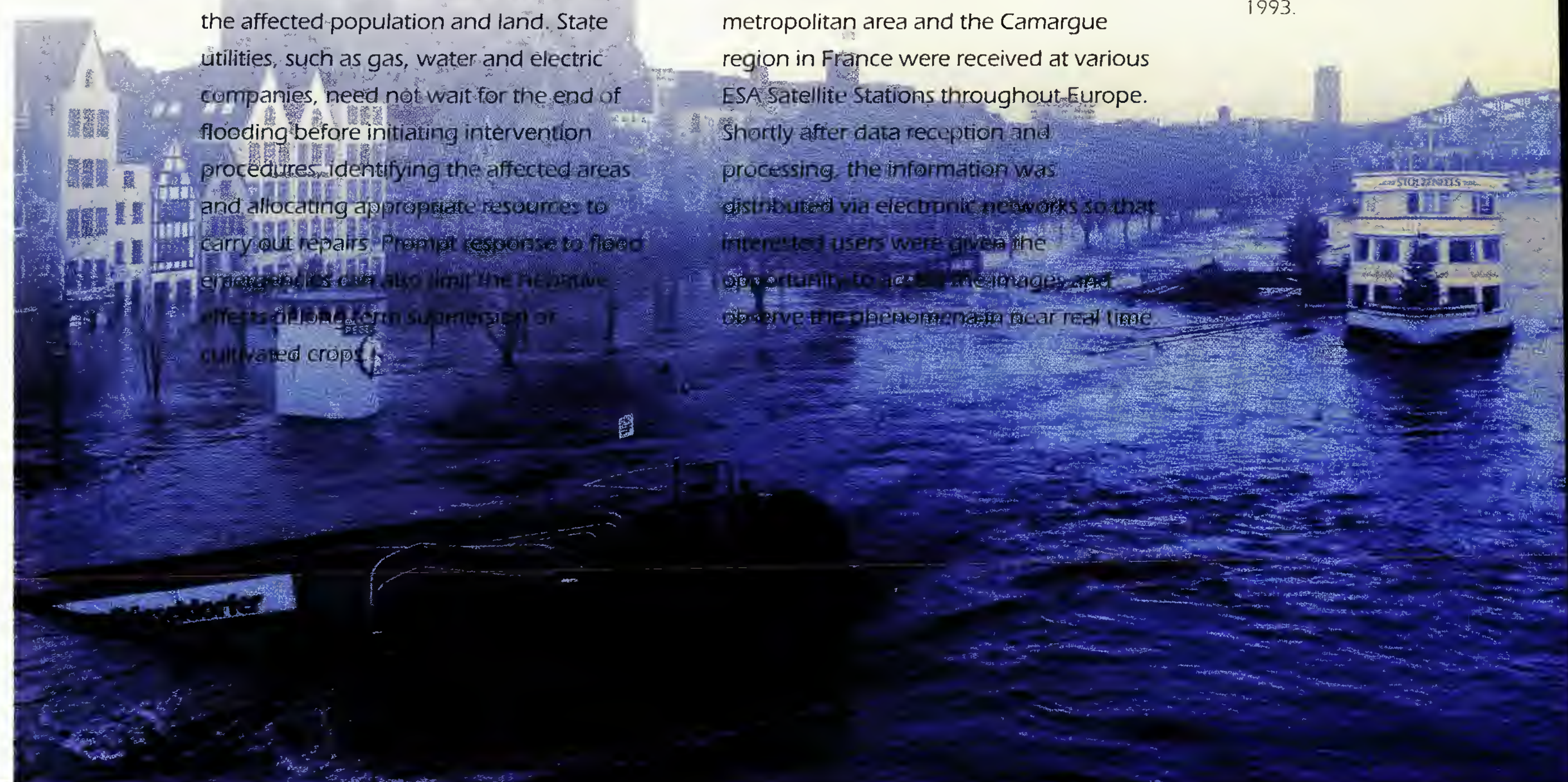
Based on these systems, flood emergencies can be managed well in advance by authorities responsible for environmental protection. This can limit the impact of natural phenomena on both the affected population and land. State utilities, such as gas, water and electric companies, need not wait for the end of flooding before initiating intervention procedures, identifying the affected areas and allocating appropriate resources to carry out repairs. Prompt response to flood emergencies can also limit the negative effects of long-term submersion of cultivated crops.

Real-Time Flood Monitoring in Northern Europe

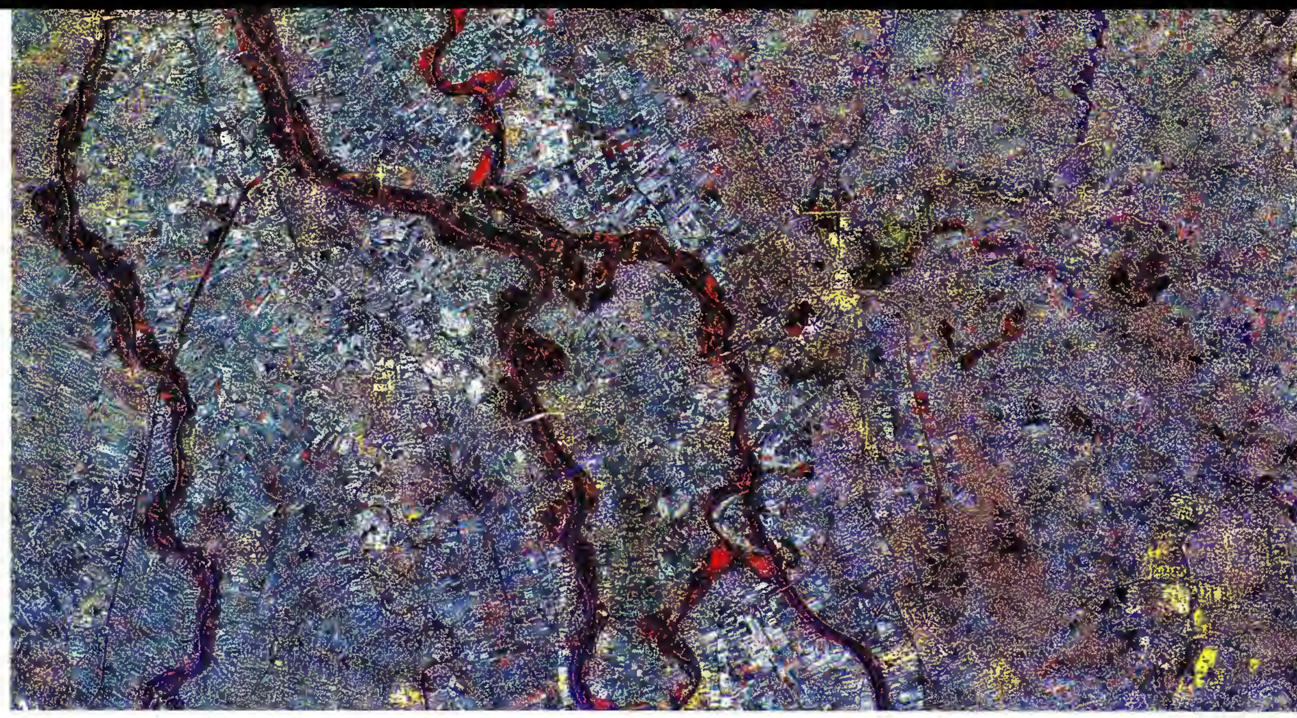
Cloud cover is frequent in the northern latitudes. Radar images from space, totally independent from weather conditions, provide a unique tool to monitor damaged areas during and immediately after a flood.

In late 1993, when the Rhine, the Rhône, the Danube and smaller rivers in northern Europe flooded, the ERS-1 satellite recorded some impressive images of the inundated regions when the floodwaters were still rising.

Satellite data of the Cologne (Germany) metropolitan area and the Camargue region in France were received at various ESA Satellite Stations throughout Europe. Shortly after data reception and processing, the information was distributed via electronic networks so that interested users were given the opportunity to access the images and observe the phenomena in near real time.



Dramatic effects of the great floods in Cologne, Germany, Christmas 1993.



Flooding in the Netherlands, 30 January 1995. From left to right (north to south), the rivers Rhine, Waal and Maas with the flooded areas shown in magenta. Multi-temporal composite image from ERS-1.

Technical Note

The ERS satellites scan the Earth with microwave swaths 100 km wide. Image resolution is 25 by 25 m. For flood monitoring, reduction to resolution cells of 100 m or more can be considered, depending on the extent of the inundated area and other factors. On the other hand, flood relief efforts require more accurate information and higher resolution data.

Under moderate wind conditions it is possible to discriminate between inland bodies of water and the surrounding land; however, it is sometimes difficult to distinguish between flooded and saturated flat terrains. Accurate differentiation may also be limited for swamped terrain which is covered by a dense forest of tall trees.

When superimposing two images acquired before and after the flood, the selection criterion for the images should be based on the fact that only significant changes (due to the presence or absence of inundated areas) need be detected. As a consequence, the images must be acquired within a short time of one another in order to reduce the influence of climatic changes, plant growth and other factors.

Contact Addresses:

S. Dautrebande
M. Badji
Faculté des Sciences Agronomiques de Gembloux
Unité d'Hydraulique Agricole
2 Passage des Déportés
B-5030 Gembloux (Belgium)
Tel: (+32) 81 62 2187
Fax: (+32) 81 62 2181

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)

- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
- ERS Help Desk
  Tel: (+39) 6 941 80 600 or 711
  Fax: (+39) 6 941 80 510

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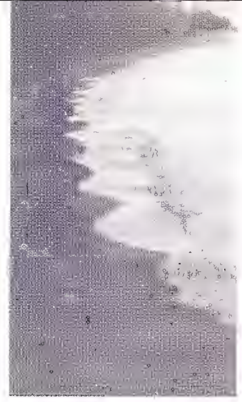
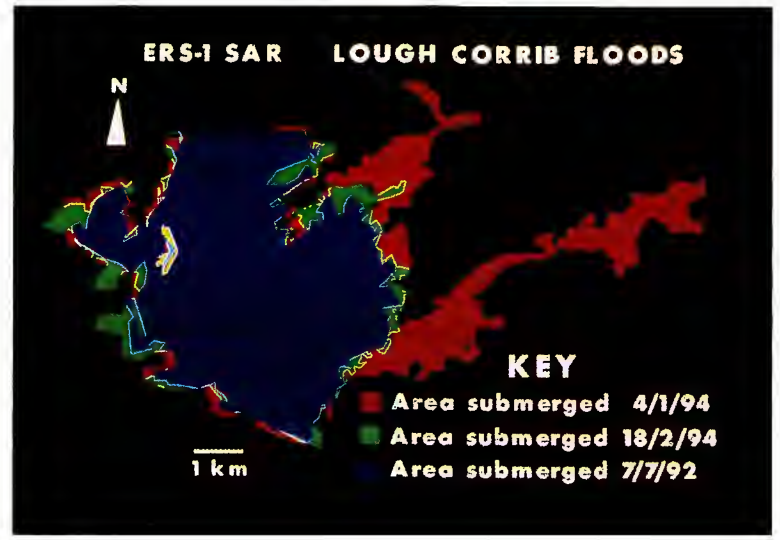
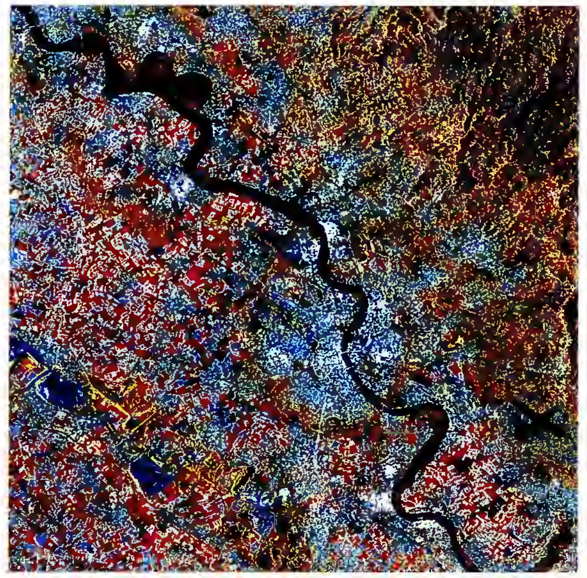
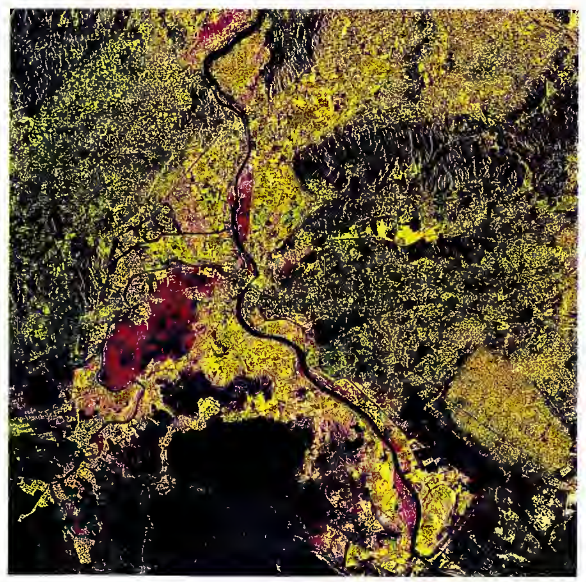




Variations in the surface area of Lake Corrib (Ireland). This composite of three ERS-1 images, shows graphically the extent of the lake shore flooding.
No flood (dry summer period) on 7 July 1992 (blue), major flood on 4 January 1994 (red), and post-flooding on 18 February 1994 (green).



ERS-1 composite image of the Rhine River flowing through the towns of Cologne and Bonn (Germany). Satellite data were acquired on 25 and 31 December 1993 and 3 January 1994. The magenta colour depicts the flooded areas along the banks of the river or hills covered by fresh snow.

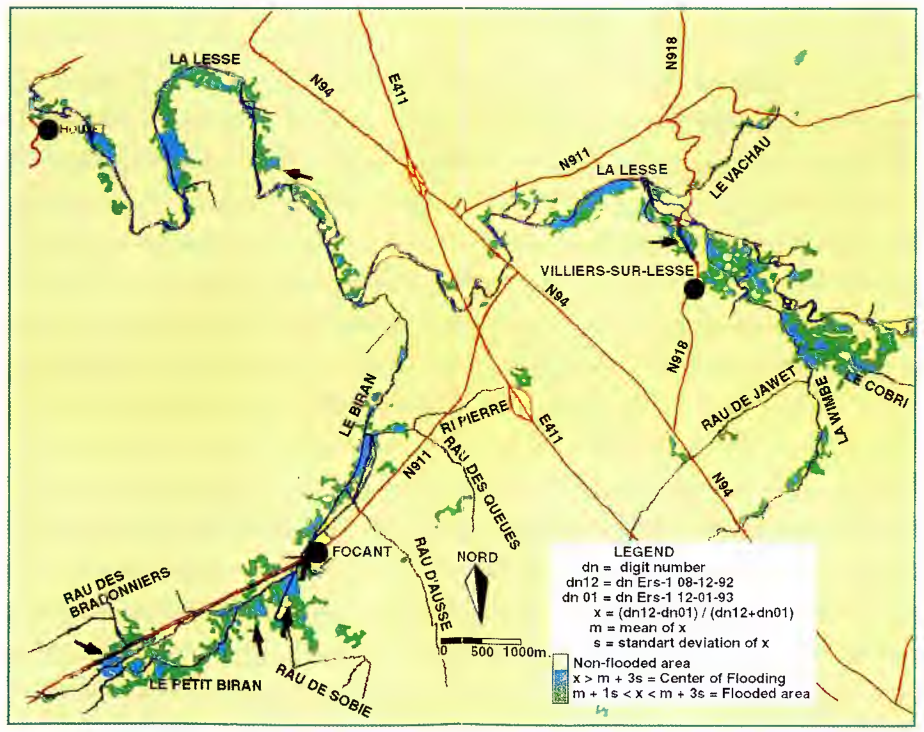


ERS-1 composite image of the Rhône Delta in Camargue (France) acquired on 3 and 6 January 1994. The magenta colour represents the extent of flooding.

Flood Relief in Belgium

In the Wallonia region, which was particularly affected by flooding in late 1993, local authorities have implemented a Geographic Information System (GIS) suitable for floodplain management. In this context, specific efforts are devoted to make use of ERS-1 satellite imagery in monitoring high risk areas and in mapping the flood relief onto the GIS.

A comparison of two ERS-1 images, acquired before and after the flooding, reveals the significant changes caused by the inundation. This information is then used in conjunction with regional maps to determine what types of areas were inundated and whether highways and railroads have been affected or are usable. Other important information useful for developing comprehensive relief efforts may be gleaned from these images.



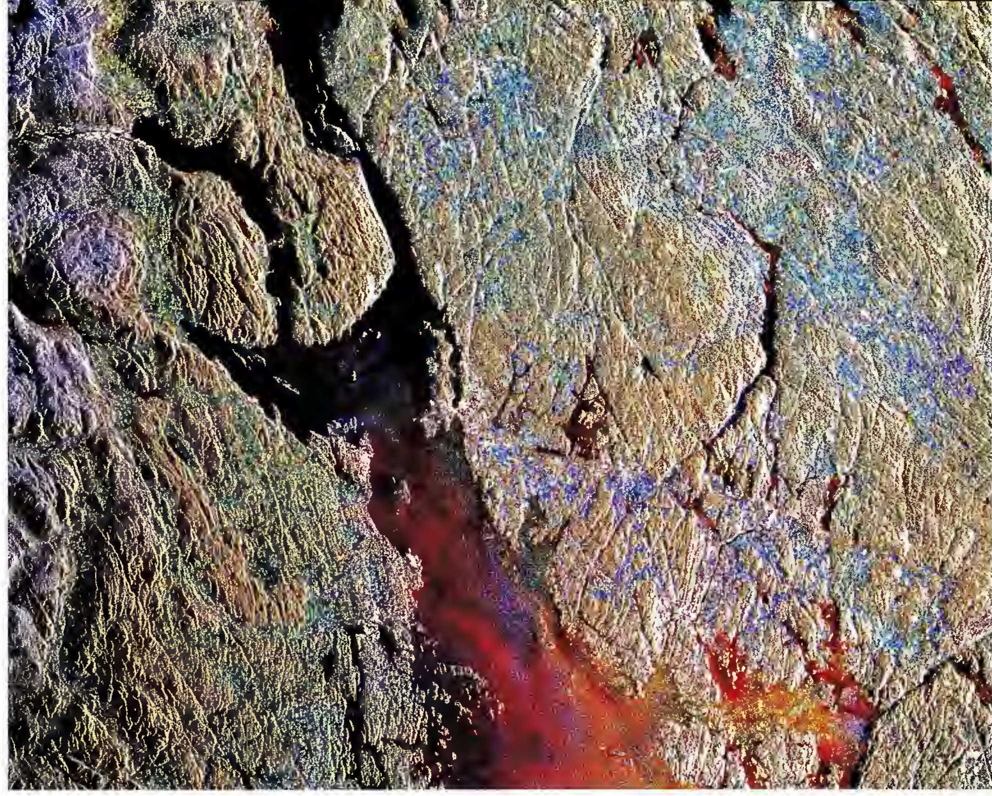
Lake Flooding in Western Ireland

In Ireland, continuous monitoring of pollution levels in lakes is done by aircraft. Unfortunately, bad weather conditions often hamper the monitoring of flooding events. Heavy rainfall and extensive cloud cover are very frequent in the British Isles, especially in winter. Weather-independent ERS-1 imagery has contributed greatly to solving this problem of regular monitoring.

Beginning in early 1994, satellite information was used to assess the impact of flooding around Lake Corrib in western Ireland. The receding floodwaters were monitored and an inventory was made of the flooded areas where water persisted, the so-called "water retention areas." In this specific case, considerable tracts of farmland were affected.

Local authorities can take advantage of this satellite technology to limit damage caused to cultivated crops by standing water.

Map of the Lesse River valley between the cities of Han-sur-Lesse and Houyet in Wallonia (Belgium). Submerged areas are shown in green and the source of the flood in blue.



ERS-1 composite image of Oslo, Norway showing topographic relief.

Technical Note

The ERS-1 satellite's Synthetic Aperture Radar (SAR) scans the Earth with a microwave swath 100 km wide. Image resolution is 25 by 25 m. For mosaicking, data reduction to resolution cells of 100 m or more can be considered, depending on the end-product scale. Although geocoding with respect to a reference height is accurate to better than 100 m, there may be considerable geometric image distortion in high relief areas. A digital elevation model can compensate for this effect. Such models can be computed by applying interferometry techniques to successive ERS SAR acquisitions. The radiometry is generally influenced by the local angle of incidence, the ground surface roughness, and vegetation and soil moisture. Differences in radiometry between adjacent strips can be overcome by using histogram-matching techniques.

Contact Addresses:

J.P. Rudant
Universite Pierre et Marie Curie
Dep. de Geotectonique
4, Place Jussieu
F-75252 Paris (France)
Tel: (+33) 1-44 27 50 87
Fax: (+33) 1-44 27 50 85

M.F. Perlant
ISTAR
Parc du Canal
3, Avenue de l'Europe
F-31400 Toulouse (France)
Tel: (+33) 62 19 19 20
Fax: (+33) 61 73 81 81

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)
- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
- ERS Help Desk
  Tel: (+39) 6 941 80 600 or 711
  Fax: (+39) 6 941 80 510

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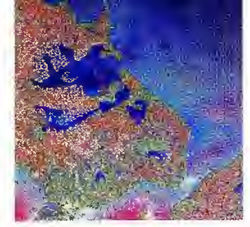
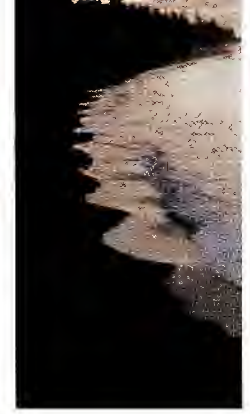


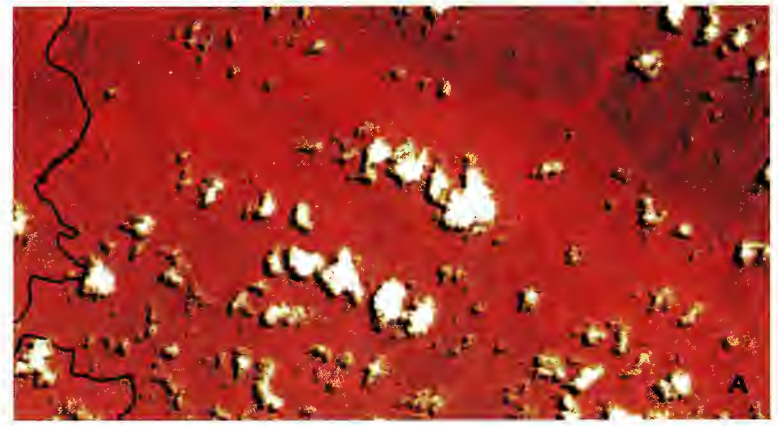


MAPPING

The Tradition

Topographic maps are an important tool in land-use planning and administration, especially for large communities and land areas. In many countries these maps are also very popular for outdoor activities.

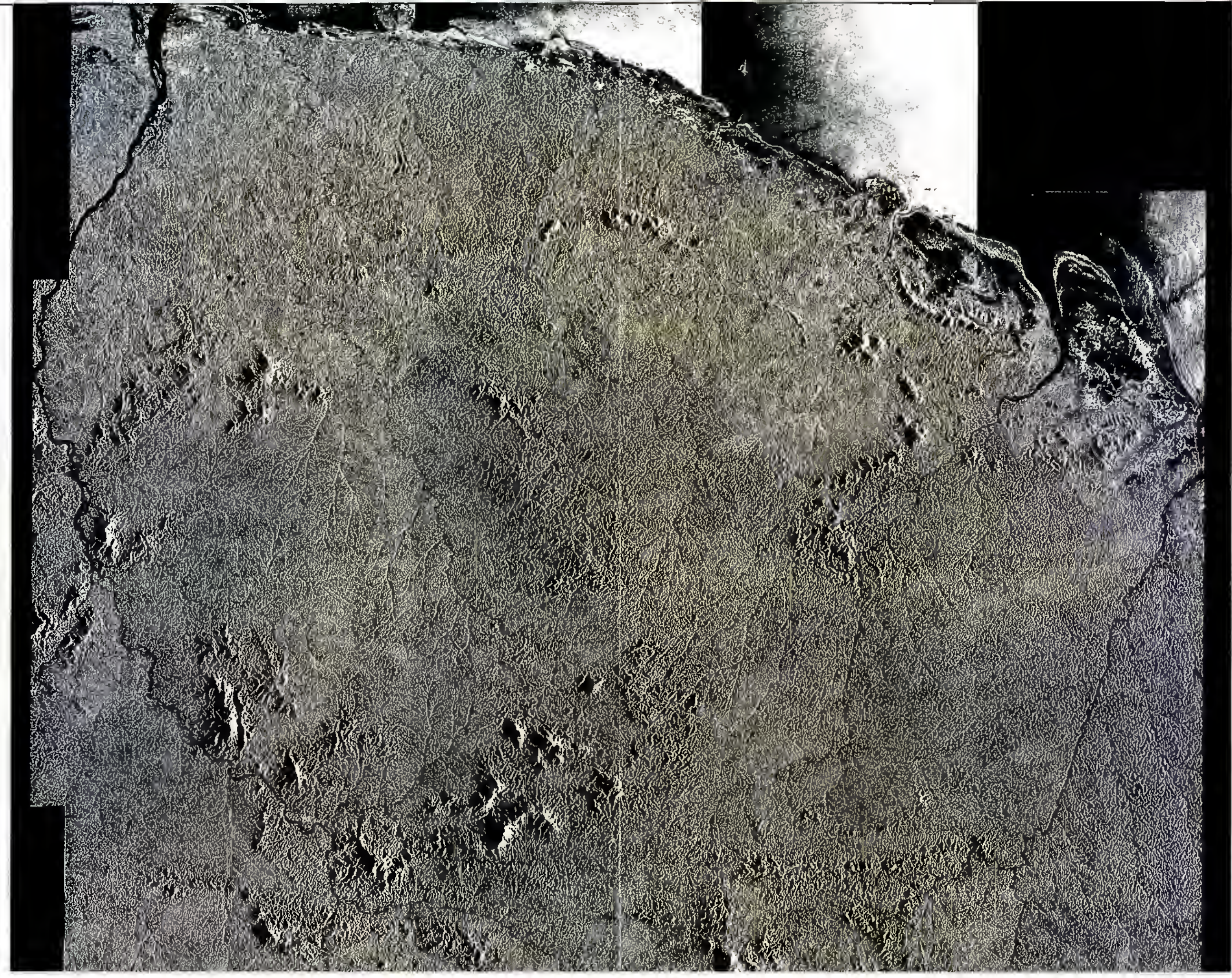
Thematic maps can show us much in terms of complex surface or point information combined with topographic features, thus allowing a global view on past or present situations. For instance, a combination of soil type, rain fall and slope angle leads to the appreciation of erosion and an estimation of land slide potential in high-risk areas.



However, when even more complicated cartographic work is involved (e.g., the development of different possible scenarios) or whenever frequent map updating is required, the need for more advanced tools becomes evident.

SPOT and ERS-1 SAR Satellite Images of French Guyana
A. A false-colour satellite image from SPOT showing the Sinnamary River and the Montagnes Piomb in French Guyana. Even during the dry season, optical satellite imagery is of limited use due to cloud cover.

B. The same scene imaged by ERS-1 radar. Thanks to the radar's ability to "see" through clouds, ground visibility is perfect. Topographic features stand out clearly as a result of the oblique viewing.



Mosaic of French Guyana composed of 18 ERS-1 SAR images, images were acquired between April and December 1992 (Copyright Telecom, Universite P. et M. Curie, Paris, and ESA.)

The New Opportunity

A prerequisite in obtaining a detailed knowledge of the landscape is to rely on as many space and ground data sets as possible. This target is achieved mainly through aerial photographs, but also, nowadays, with the aid of satellite imagery. It must be said, though, that the availability and quality of such information is not homogeneous throughout the world. The situation is even worse in the case of frequent map updating. Air surveys are very expensive and photographic surveys from space platforms, although providing wider and, thematically, more accurate views, are often hampered by cloud cover.

Radar sensors overcome obscuring clouds and haze by using the microwave spectral bandwidth for collecting surface information independent of weather and viewing conditions. These radar sensors operate in an oblique attitude which enhances topographic detail and represents an interesting and significant advantage over conventional systems.

In traditional satellite images, smaller topographic effects are not visible, in spite of vertical differences of up to 200 m. In contrast, landscapes are shown already "hill-shaded" in oblique-viewing radar images.

A Photo-Mosaic of French Guyana

Large area mosaics can be obtained by combining adjacent strips of satellite images. As satellite-borne radars are practically unaffected by the atmosphere's influence, it is easy to obtain geographic coverage using a combination of data obtained at different times. Here, five strips, each depicting a region 100 km wide, form the mosaic. The strips were derived from 18 scenes taken by ERS-1.

The topography is enhanced considerably and details are revealed which have never been observed before on a global scale. Immediate and potential applications of satellite data 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.

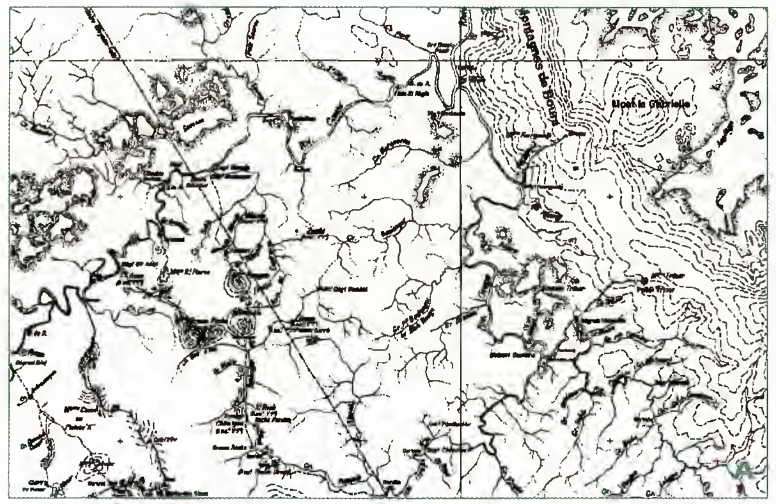
The ERS "Image Maps"

In tropical areas where conventional (optical) satellite information is unavailable, "image maps" generated from satellite radar data are precious tools. Such image maps are terrain-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 formats only. Interesting features such as topographic relief and hydrological networks (including special features such as rapids) are visible in ERS image maps.

Information on land cover, i.e., forested areas, clear-cuts, agricultural fields and settlements, is also retrievable. Image maps are gridded 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).

For some applications in thematic cartography (e.g., geology and forestry), radar image maps can be used in conjunction with traditional maps and optical satellite imagery in order to show the required information.



Cartographic product of ERS-1 for tropical forests.

A. Traditional map of French Guyana at 1:100 000 scale.

B. Image map of the same area (30x22 km), same scale as above. The precision to which landmarks are located ranges from 20 to 100 m, depending upon the quality of the Digital Terrain Model used

North Sea oil rig. (Photograph courtesy of Schreiner Airways and Conoco.)

In areas with strong currents, drilling can be hampered by surface eddies and current shears. Therefore, proper information and forecasts are required to ensure safe and cost-effective operations. ERS-1's Altimeter provides a picture of the distribution of eddies at regular intervals.

Technical Note

For mosaicking SAR images, data reduction to resolution cells of 100 m or more can be considered, depending on the scale of the desired end-product. Although the geocoding is accurate to better than 100 m, with respect to a reference height, the geometric image distortion in high-relief areas can be considerable. A digital elevation model is needed to compensate for this effect. Such models may be computed by applying interferometry techniques to successive ERS-1 SAR acquisitions.
The radiometry is, in general, influenced by the roughness of the ground (lithology, soil, vegetation type), by soil and plant moisture, and by the slope-angle and exposure with respect to radar illumination. The different radiometry between adjacent strips can be overcome using histogramme-matching techniques.

Contact Addresses:

C.D. Clark
Sheffield Centre for Earth Observation Sciences
Department of Geology
The University of Sheffield
Winter Street, Sheffield S10 2TN
(United Kingdom)
Tel: (+44) 0114 282 4749
Fax: (+44) 0114 279 7912

E.K. Biegert
GOSAP Director
Pecten International Company
200 North Dairy Ashford Road
Houston, TX 77079 (U.S.A.)
Tel: (+1) 713 / 544-4690
Fax: (+1) 713 / 544-4873

G.J. Wensink
Delft Hydraulics
Postbus 152
NL-8300 AD Emmeloord
(Netherlands)
Tel: (+31) 52 74 29 22
Fax: (+31) 52 74 35 73

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)
- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
- ERS Help Desk
  Tel: (+39) 6 941 80 600 or 711
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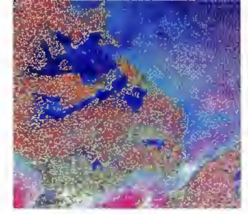
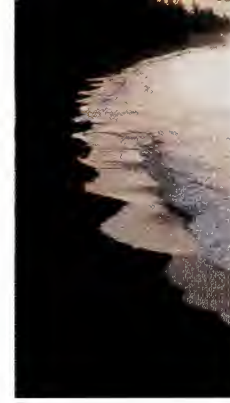




MINERAL AND HYDROCARBON EXPLORATION

The growing demand for energy and raw materials has narrowed the gap between available resources and future needs. As a consequence, mining and oil companies throughout the world have to direct their exploration activities towards remote areas, rough seas, deep oceans and the polar regions.

Working under severe conditions requires the implementation of particularly rigourous safety measures and the adoption of new, advanced techniques. In addition, the ecological impact of these activities must be taken into account.

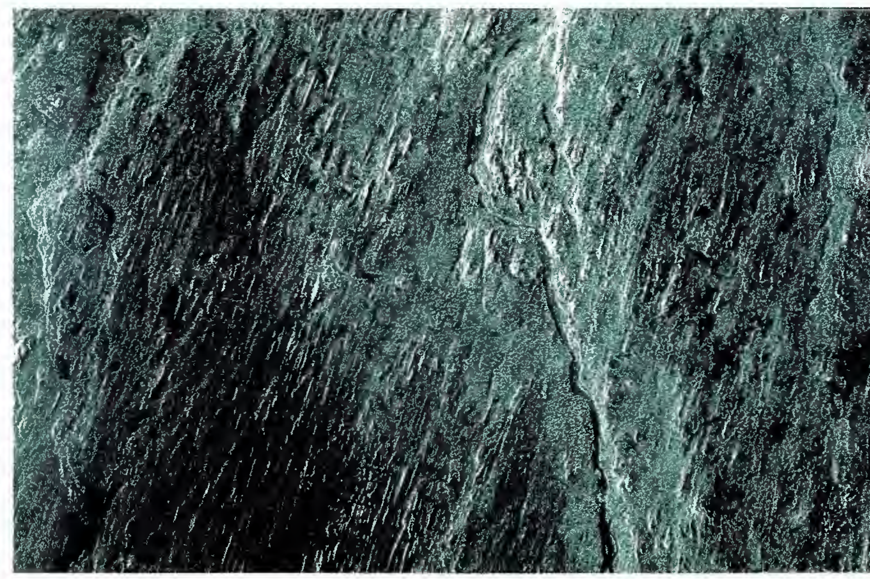
Mineral Prospecting Following Glacial Streamlines

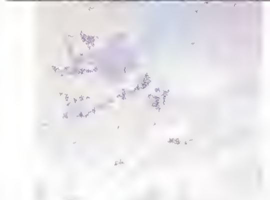
In land-based mineral exploration, both airborne and satellite remote sensing techniques are already well established. Radar imagery adds further information: the oblique viewing of the radar enhances the morphology of a landscape considerably, enabling the detection of drainage patterns, fractures and other features (gullies, moraines, etc.).

Until recently, the geological community could only rely on relatively expensive airborne radar surveys. Now, ERS-1 has the potential of providing cost-effective regional mapping and can optimise site-specific airborne reconnaissance.

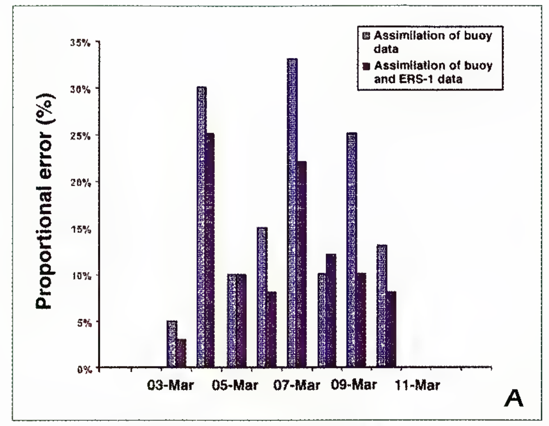
As an example, ERS-1 imagery is currently being used to reconstruct the streamlines of former glaciers in eastern Canada (Quebec). Such streamlines are useful in tracing back deposits of important minerals (uranium, gold, etc.) to their original mineral veins. The results of imagery interpretation are displayed in an ice-flow Geographic Information System, which represents an ideal database for archiving and managing different sources of information collected over large areas.

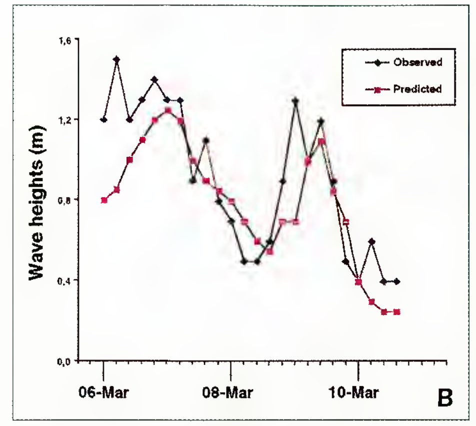
ERS-1 image of glacially-moulded landscape in eastern Canada (Quebec).





MINERAL AND HYDROCARBON EXPLORATION



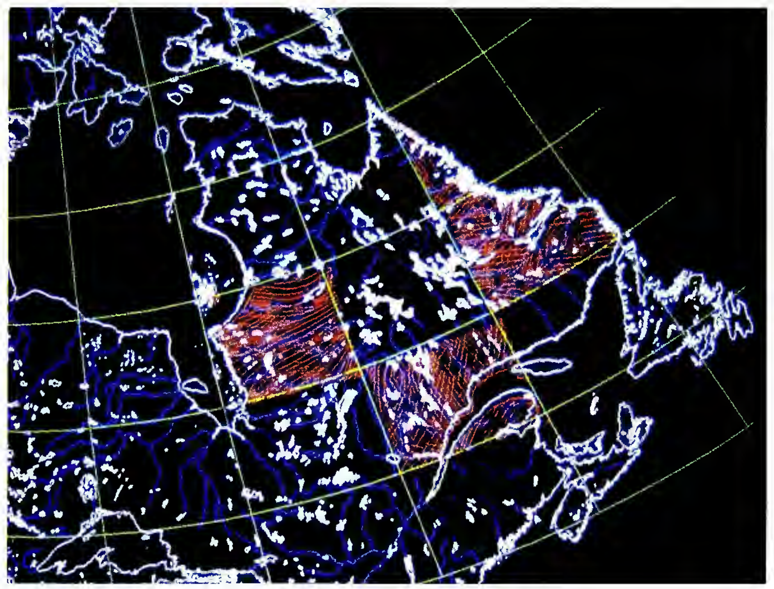


Radar image of the Gulf of Mexico with a multitude of slicks. The larger dark features are slicks from natural seepages.

New Frontiers for Offshore Activities

Today, feasibility studies for oil exploration and exploitation are based on wide-ranging information, concerning not only geology and related disciplines, but also, increasingly, geophysics, oceanography and statistics on sea-state and wind conditions. Here is where space imagery can play a crucial role by substantially reducing the costs. In fact, it can provide complementary environmental information on potential drilling sites and help to quantify risks for offshore platforms.

Selected flow patterns displayed in an ice-flow Geographic Information System.



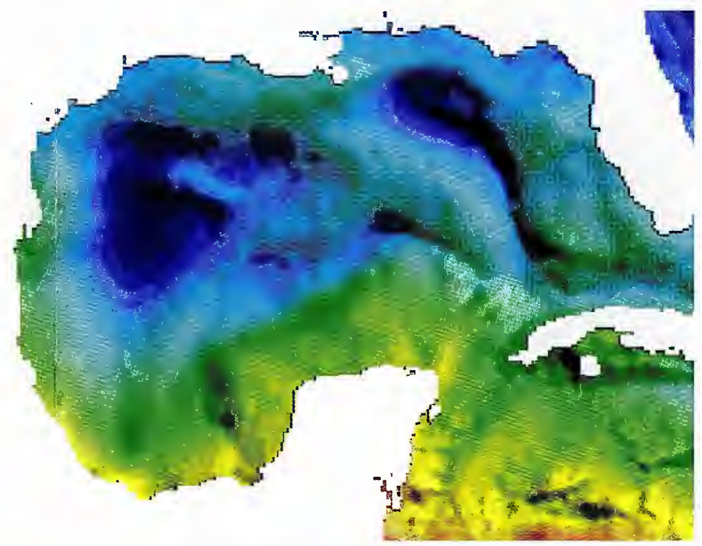
Natural oil seepage is a phenomenon which has been observed for ages. Promising oil fields may be located by finding such seeps. Thanks to the weather-independent Synthetic Aperture Radar (SAR) sensor onboard the ERS-1 satellite, in-orbit prospecting for oil by locating oil seeps is now possible and more affordable.

Under light to moderate wind conditions, oil films or slicks on a water surface may become visible in a radar image. However, slicks of different origin, whether from local concentrations biogenic material, geologic oil seepage or oil slicks caused by man, may differ in their shape.

The sporadic appearance of natural oil slicks is related to near-by seepage from the sea floor. In one project, a consortium of petroleum companies, government agencies and research centres used radar data from the ERS-1 satellite to explore the Gulf of Mexico, where such seepages frequently occur. Data collected from regular satellite passes were processed in near real time. A team of specialists analysed the images, located possible seep sources and requested detailed, on-site inspections by submarine.

Detection of Gravity Anomalies

Potential oil exploration sites may also be found by locating gravity anomalies at the Earth's surface. The presence of oil reservoir formations causes a marked change in the crust density, and hence, in the "local" gravity field. These changes in gravity are manifested as deviations of the sea surface from mean sea level. Accurate measurements of the mean sea level are made by the ERS-1 Altimeter. Over a period of time, sufficient datasets may be combined to generate geoids and gravity anomaly maps. Large geologic structures and formations of exploratory significance can be located accurately using these maps.

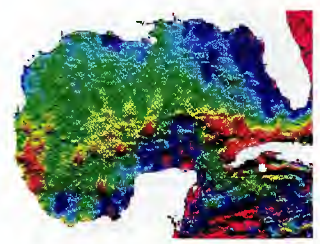


Safe Drilling in Shallow Waters

A basic requirement for planning, constructing and operating platforms is having access to timely data of extreme values (singularities) for wave heights and windspeeds. ERS-1 measures these values worldwide. The relevant information is made available and can be obtained from various databases hosted in different countries.

It has been shown that assimilation of both ERS-1 and buoy data into a wave forecast model provides a more accurate analysis of the state of North Sea waves than using buoy data alone.

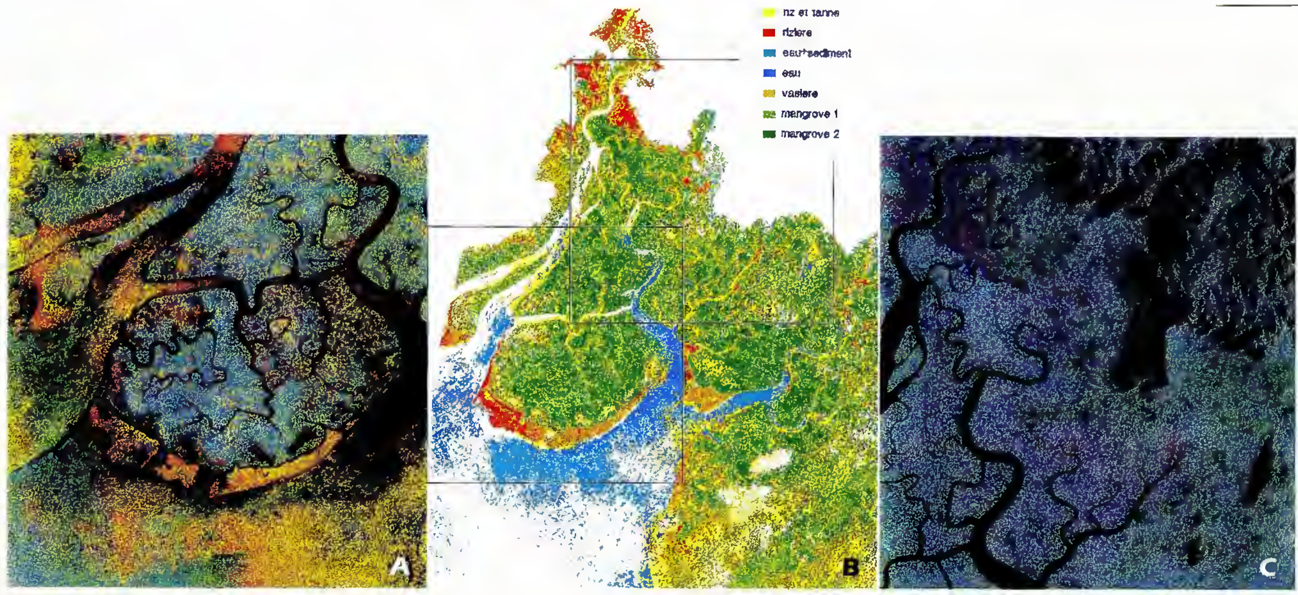
In the North Sea this information is extrapolated to generate forecasts for up to two days. Starting from the analysis of the present sea state, the forecasters make use of the latest data gathered by ERS-1 and the buoys, and derive predictions for periods from 12 to 48 hours. These results show a fair correlation between predicted and observed wave heights.



A. Assimilation of wave data collected over the North Sea into a wave forecast model. Incorporation of ERS-1 data reduced the proportional error when compared to bouy data alone versus observations

B. Comparison between observed and predicted wave heights in the North Sea.

Geoids of the Gulf of Mexico; these depict the surface of constant gravitational potential. The deviations in sea level may be used to derive the local gravity fields. (Courtesy of University of Texas at Austin and the Geosat Committee Inc.



ERS-1 composite images of mangrove forests.
A. Photo-interpretation of wooded areas (turquoise)
B. Final classification
C. Photo-interpretation of rice fields (magenta)

Technical Note

The ERS-1 satellite scans the Earth with a microwave swath 100 km wide. Image resolution is 25 by 25 m. Radar can penetrate a forest to differing degrees: the microwaves are reflected or "backscattered" from the canopy surface, from the vegetation volume and from the ground. Texture analysis, using a digital image processing technique, allows mapping of forested areas, determination of forest density and discrimination of basic forest types. This information is needed particularly in tropical areas.

Multitemporal SAR data (images acquired over successive time periods) are equally useful for visual interpretation. However, analysis of mountainous regions can be difficult, due the SAR imaging geometry.

Mangrove forest

Contact Addresses:

S. Kuntz
Kayser-Threde GmbH
Wolfratshauserstrasse 48
D-81379 Munich (Germany)
Tel: (+49) 89 59 02 442
Fax: (+49) 89 59 02 450

I. Pons
GEOSYS
Parc Technologique du Canal
3 rue Hermès
F-31520 Ramonville (France)
Tel: (+33) 61 75 12 10
Fax: (+33) 61 75 87 22

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)

- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
- ERS Help Desk
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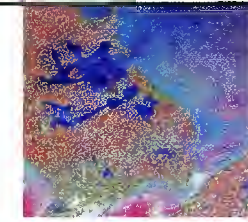
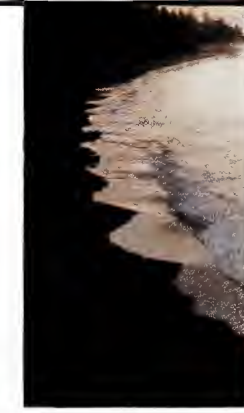
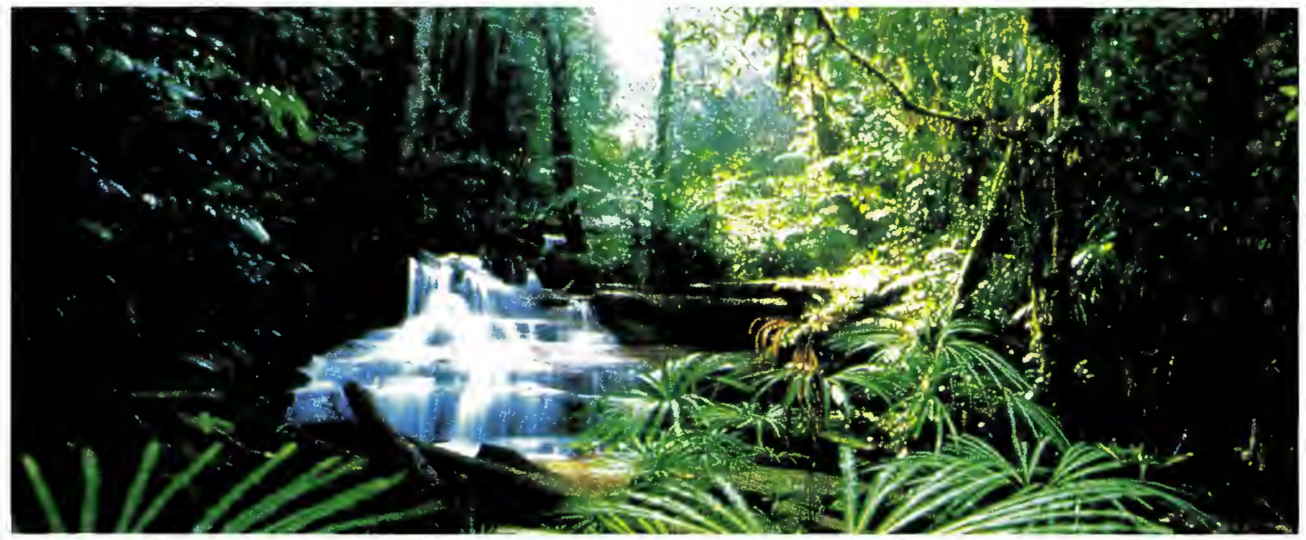




TROPICAL FORESTRY

Today's Situation

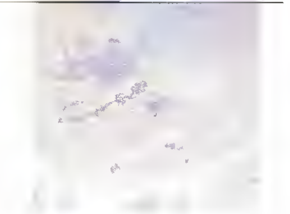
Tropical forests play an important environmental role in the global ecosystem. Their uncontrolled exploitation at an increasing rate constitutes a major threat for the countries concerned and the world. Long-term programmes to monitor tropical forests can provide the information required to assess the environmental impacts of deforestation and conversion, thus helping to preserve them.



A New Source of Information

Monitoring tropical forests by ground surveys is costly, time-consuming and geographically limited. Aerial surveys are more effective, but are also expensive. In contrast, by using satellite-borne, high-resolution, remote sensing instruments, large regions of the tropical forests can be monitored at regular intervals.

The dense cloud cover in tropical regions prevents optical instruments from observing the forests regularly. ERS satellites use radar instruments which are able to pierce the cloud cover and obtain unobscured images over large areas. Changes in the forest environment may be readily identified in these images.



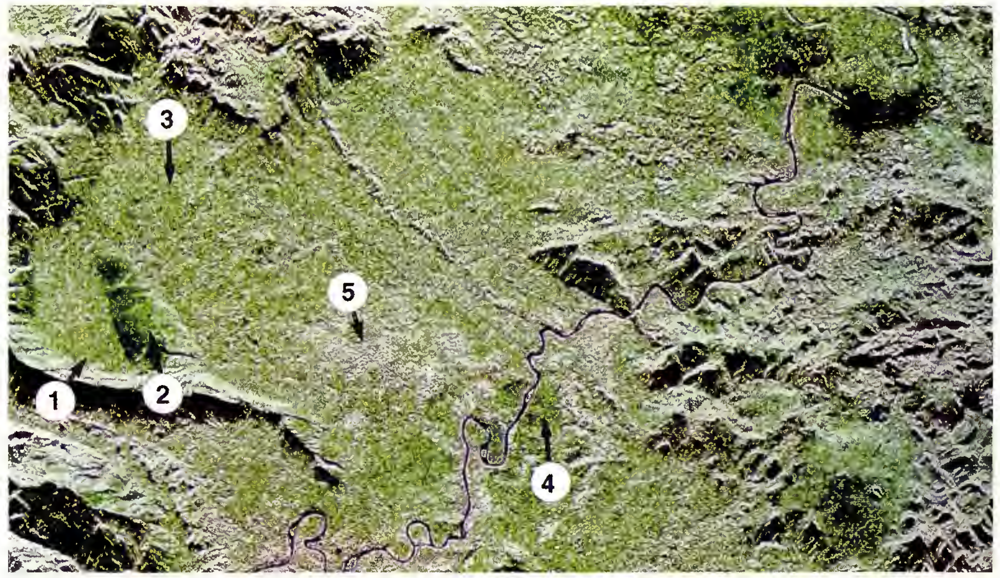
Monitoring the Indonesian Rain Forest

Long-term changes caused by human activities in the tropical rain forest are monitored in a programme which makes use of ERS-1 data.

Deforested areas, where the forest has been totally or partially cleared by logging activities, can be readily seen. Also evident are the burnt-out fields used by the local inhabitants for agricultural purposes and regions where secondary forest growth has reclaimed those fields that have been left fallow. ERS-1 images also show natural features, such as rivers, and man-made features, like roads, settlements and logging camps, that are often associated with logging and agricultural activities. Land-use maps of the region are derived from the interpreted ERS-1 images and can be used for monitoring the changes that are occurring in the rain forests.

Using these radar images, it is even possible to distinguish between the two classes of forest existing in the tropical rain forest: the dense *Dipterocarp* forest with a wide range of tree heights, and the sparse *Heath* forest where the tree heights are lower and more homogeneous.
Heath forest grows on poor soil not suitable for agriculture, so identification of this forest type proves important in land use planning and development.

Deforestation in Indonesia.



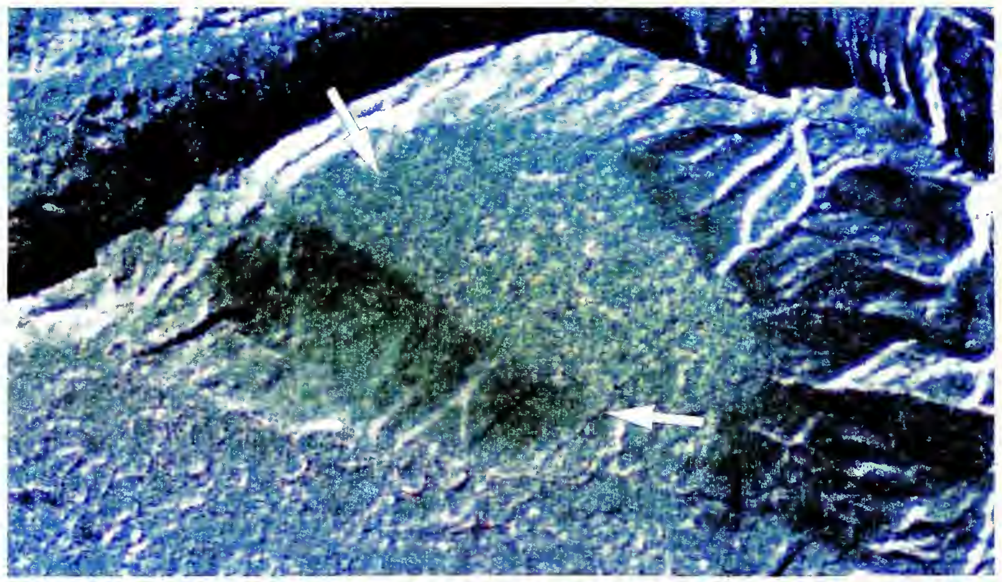
SAR image showing clear-cuts .
1. Old secondary forest
2. New secondary forest and small agricultural areas (magenta and white spots)
3. Selectively logged forest (white spots)
4. Settlements
5. Clear-cuttings

Monitoring Guinean Mangroves

Mangrove forests are being mapped and their evolution monitored by using ERS-1 radar images in conjunction with ground surveys and optical satellite images.
The mangroves in the region of western Africa are being converted into areas of intensive rice cultivation as well as being logged for their timber.

The different land use classes shown on land use maps of the study area can also be identified in the ERS-1 radar imagery. 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. The rice fields that have been planted in earlier clear-cuts are also evident. Waterways and mudbanks 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.

By using a number of ERS-1 images taken at regular intervals one can observe the degeneration and regeneration of the mangroves, and monitor and map the extent of deforestation activities.



Processed SAR image showing different forest types:
- *Dark green: Virgin "heath" forest, not yet disturbed by human activity*
- *Light green: "Dipterocarp" forest. Disturbances of the forest canopy due to selective logging are visible as magenta and white spots, and show a rougher texture.*

December 1992,
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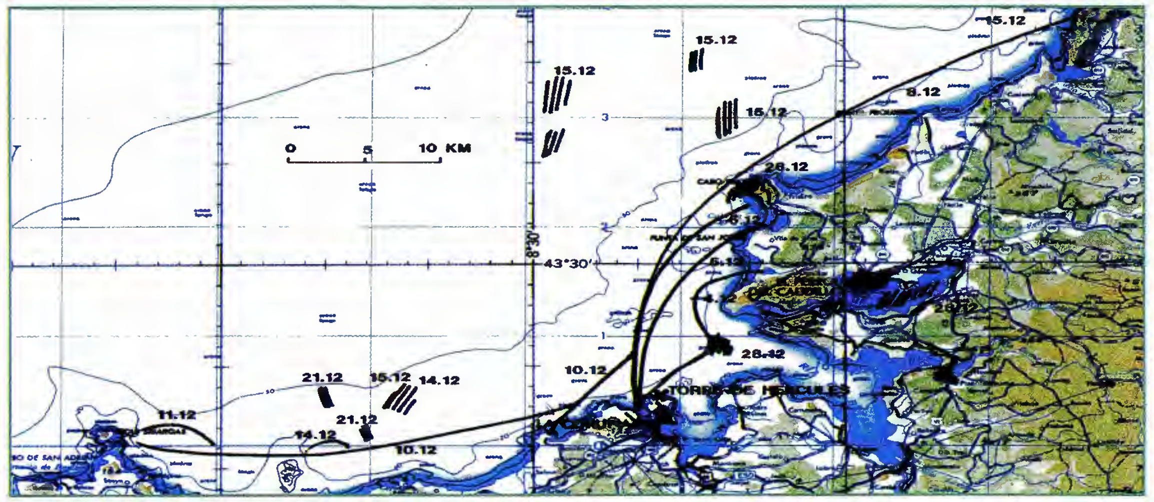

December 1992 oil spill near La Coruna, Spain. Daily, detailed reports were collected from patrolling aircraft beginning on the day the accident occurred. Reports through 28 December are summarised.

Technical Note

The ERS satellites observe the Earth with microwave radar swaths 100 km wide. Nominal image resolution is 25x25 m. For oil spill detection, "low" resolution images of 100x100 m are used; this reduces the data content of each image from 64 Mbytes to 2 Mbytes or less. Oil spill detection is possible under wind speed conditions ranging from 6 to around 23 knots (3-12 m/sec). Within this range, the wave damping action of an oil film is most effective. The microwave backscatter is greatly reduced in these areas as compared to the surrounding oil-free waters. However, to distinguish natural from man-made slicks requires special expertise.

Contact Addresses:

Tromsø Satellite Station
Norwegian Space Centre
Prestvannveien 38
N-9005 Tromsø (Norway)
Tel: (+47) 77 68 48 17
Fax: (+47) 77 65 78 68

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)

- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
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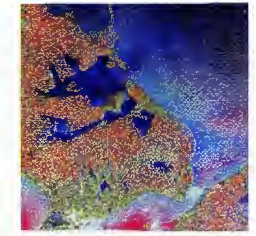


OIL SPILL MONITORING

The Situation Today

As a consequence of man's actions, oceans in general and coastal areas in particular suffer from ever-increasing exploitation and contamination. Although some water pollution is natural (plumes of suspended matter, algae blooms- both harmless and toxic, oil seepage from the sea floor, etc.), it is recognised that the great majority of stress to the marine environment is a result of man's activities.

This has led to the implementation of various national and international measures, laws and regulations, such as the total ban on oil discharges in the Mediterranean Sea. However, in spite of public awareness of these problems and the rigourous controls imposed locally on those shores dependent upon tourism, the deterioration of water quality, especially of those waters with heavy ship traffic, continues at a high rate.

Patrol ships and aircraft ensure continuous monitoring of coastal waters. Because of the high costs involved in patrolling extensive areas, these surveys require careful planning. (Courtesy of Swedish Space Corporation.)

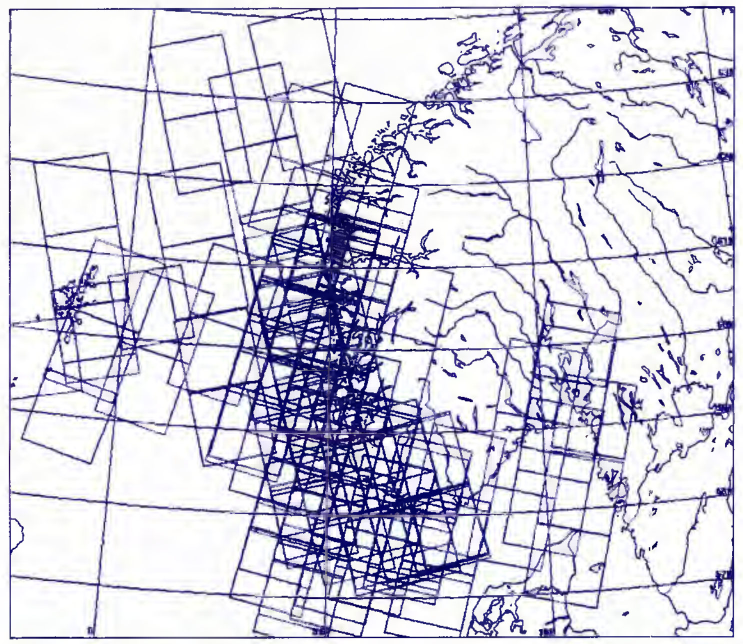
OIL SPILL MONITORING

Using Modern Technology in Operational Services

The Norwegian coasts have been monitored routinely by satellite since 1991. This observation pattern shows the ERS-1 satellite coverage of the Norwegian coast. Each square represents an area which is imaged every 35 days. Taking advantage of adjacent orbits, a specific area can be covered more than once a week, if so requested.

Until recently, large-scale monitoring was possible only by using aircraft; but this method was and still is very expensive. Few countries can afford routine airborne surveys so, to minimise costs, their geographic coverage is limited.

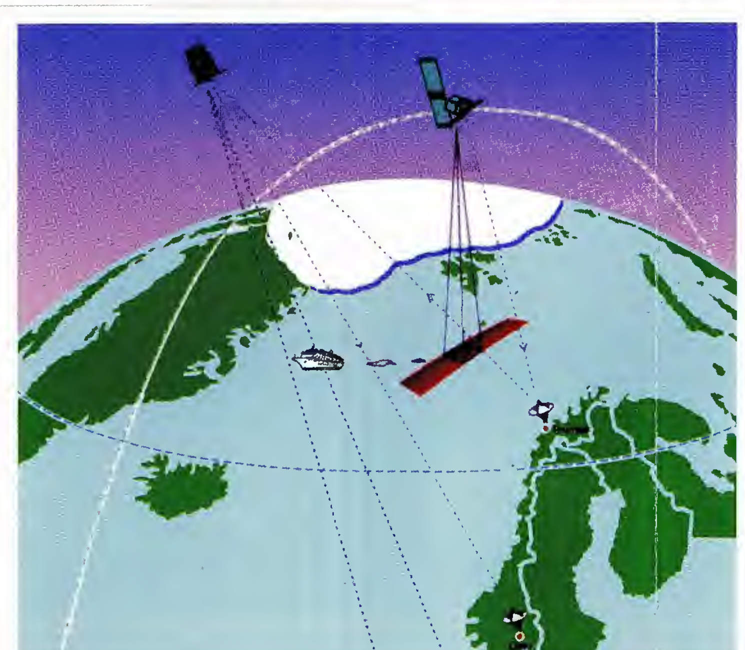
With the advent of earth observation satellites, extensive and repetitive surveys have become possible. When compared with similar airborne systems, space-based radars can provide more cost-effective monitoring.

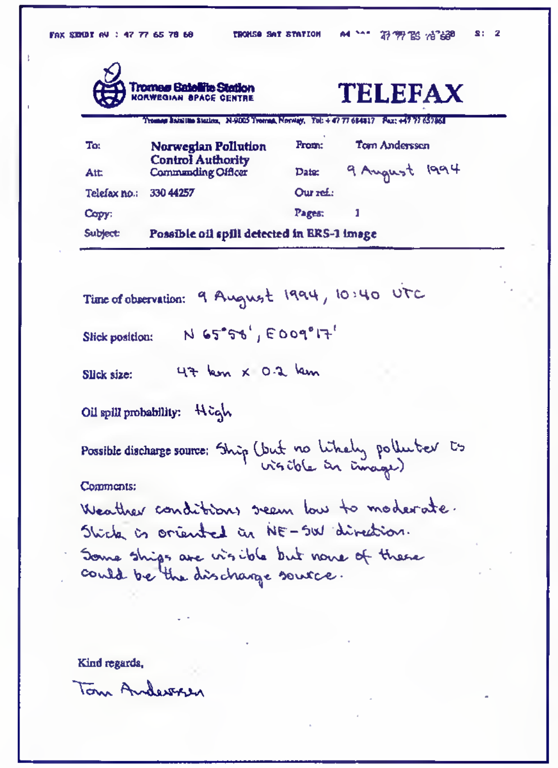


ERS-1 images are already used for monitoring oil spills. Maintaining surveillance of large areas with the help of satellite imagery means that not only can occasional small spills be identified (whether accidental or intentional), but also that their spreading and displacement can be monitored.

Such information is fundamental for coordinated intervention and clean-up operations. This information may also be used as evidence for insurance claims and legal actions.

The Tromsø Satellite Station receives and processes SAR data. When an oil slick is detected, a facsimile message is sent to the Norwegian Pollution Control Authority in Oslo. A "quick-look" image can also be transmitted either via "land-line" or telecommunications satellite link. (Courtesy of Norwegian Space Center.)





FAX SENDT AV : 47 77 65 78 68 TROMSØ SAT STATION

Tromsø Satellite Station NORWEGIAN SPACE CENTRE

TELEFAX

Tromsø Satellite Station, N-9005 Tromsø, Norway. Tel: +47 77 684817 Fax: +47 77 657861

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

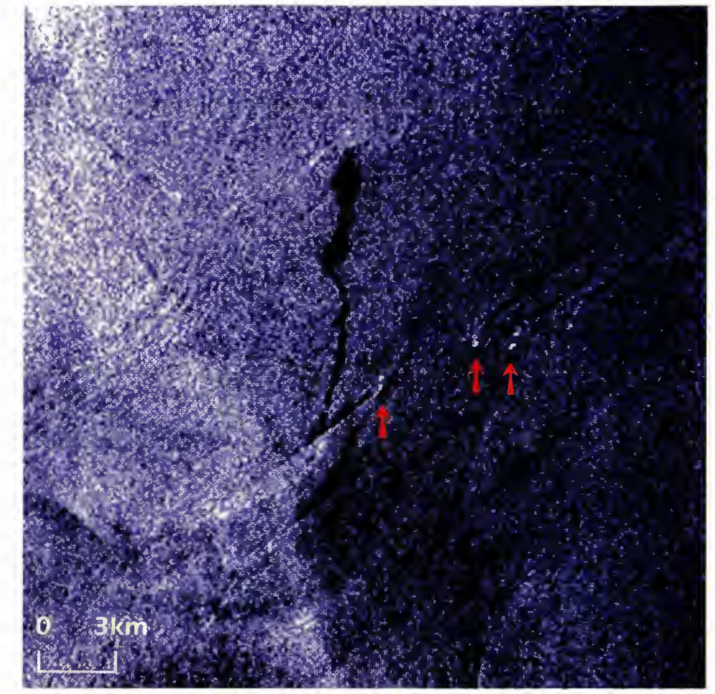
Possible discharge source: Ship (but no likely polluter is visible in image)

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

A typical facsimile message sent from the Tromsø Satellite Station to the Norwegian Pollution Control Authority. The position of the slick and other useful observations are stated.



A 12.4 km long oil slick and ships with their wakes (arrows) are imaged in the Oslo Fjord on 5 August 1991. This is one of the various oil slicks detected using ERS-1 satellite imagery. Upon receiving this satellite information, the Pollution Control Authority in Norway directed one of their aircraft to the area. Detailed on-site inspection revealed the origin and quantity of oil released.

An Example in Norway

Combining airborne observations with ERS-1 imagery has already shown good results in some countries. Norway, for instance, has set up a data processing and distribution system capable of acquiring and then quickly analysing data on the spot. This processed information is then transmitted to a specialised centre for further evaluation and analysis.

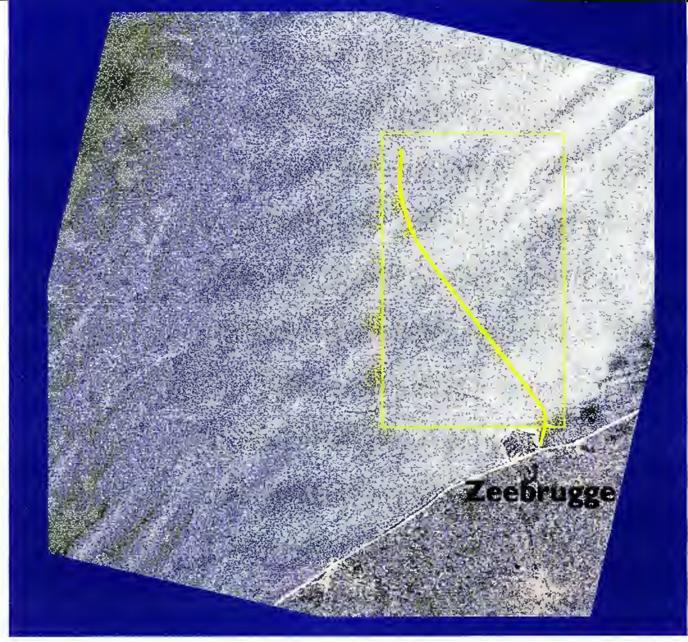
When a slick is detected in or near Norwegian waters, the responsible authority, in this case the State Pollution Authority, is alerted. Immediately, a plane is directed to the area indicated. The crew observes and estimates the extent of the spill and attempts to determine its origin. Most slicks are caused by discharges from tank cleaning operations on ships. Other discharges may originate from either oil rigs or fish processing plants. Once the source and extent of an oil slick are determined, the required actions are promptly taken.

An Example in Spain

The oil tanker disaster near La Coruna in December 1992, in which 80,000 tons of oil were released into the sea, represents a very significant case.

Detailed and daily reports from surveillance aircraft were vital in coordinating the clean-up operations. The radar data and images from ERS-1 provided wider, though less frequent, synoptic views of the area, thus offering complementary information.

By superimposing satellite images onto maps, precise information on the location and extent of oil slicks is easily seen. For longer-term monitoring, the complementary use of satellite data and aircraft checkpoints represents a cost-effective solution in meeting the requirements of governmental authorities, industries and environmental organisations.



ERS-1 image of Holland's North Sea coastal waters off Zeebrugge, September 1, 1993. Yellow box denotes mapped area

Technical Note

Data products utilised in each of the projects were provided by the following instruments (a part of ERS-1's complex payload):

- Imaging Radar (Synthetic Aperture Radar-SAR). Operates in high-resolution *imaging* mode and in low-resolution *sampling* mode. Capable of detecting wave patterns on the sea surface.

- Radar Altimeter. Measures at nadir the significant wave height and wind speed.

- Scatterometer. Measures the backscattered energy of a discrete area from three different directions. The wind field is derived from this information.

SAR coverage and data availability are limited to the receiving station acquisition areas, while other ERS-1 sensor data of all the oceans are available worldwide. Information is processed and disseminated usually within three hours of satellite acquisition (fast-delivery data). The standard SAR product is the precision image (PRI).

Altimeter, Scatterometer and SAR wave mode data are released as fast-delivery products and delivered via the Global Telecommunications System.

These products are also available off-line (i.e., as historical data for use in climatology studies).

Contact Addresses:

G.J. Wensink
Delft Hydraulics
Postbus 152
NL-8300 AD Emmeloord
(Netherlands)
Tel: (+31) 52 74 29 22
Fax: (+31) 52 74 35 73

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)

- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
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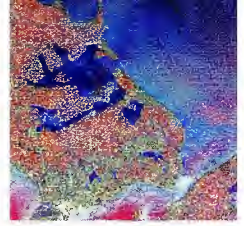


SEA BOTTOM TOPOGRAPHY

Traditional and Modern Techniques

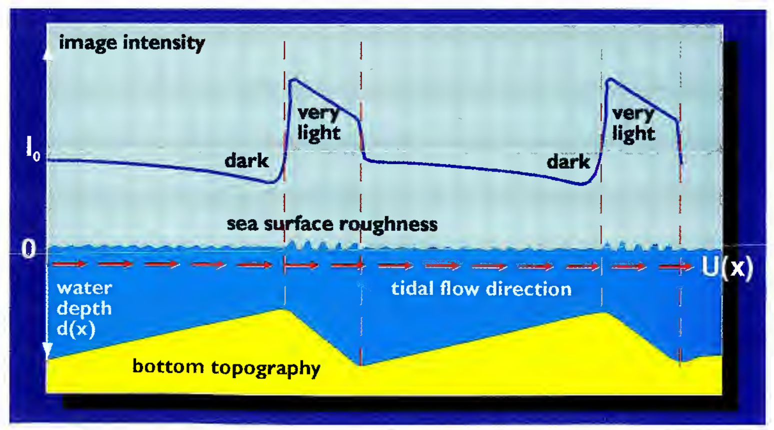
In many marine activities, ranging from navigation to fishing, and from offshore platform construction and pipeline laying, a thorough knowledge of the sea-floor topography (bathymetry) is vital.

Mapping the seabed with ship-based echosounders is expensive. However, if this traditional method is used in conjunction with space techniques, such as satellite radar imaging, the costs for gathering such bathymetric information may be reduced substantially. In fact, data from each of these techniques complements one another. Echosounding provides very accurate depth measurements along a line, whilst satellite radar images offer synoptic, two-dimensional overviews. Combining the data provides detailed information too costly to obtain from echosounding alone.

Radar images, such as those derived from the ERS-1 satellite, "show" the bottom topography in shallow waters, when currents are present. This is accomplished using the Synthetic Aperture Radar (SAR) instrument onboard.

Three factors permit mapping of the ocean bottom using this technique:

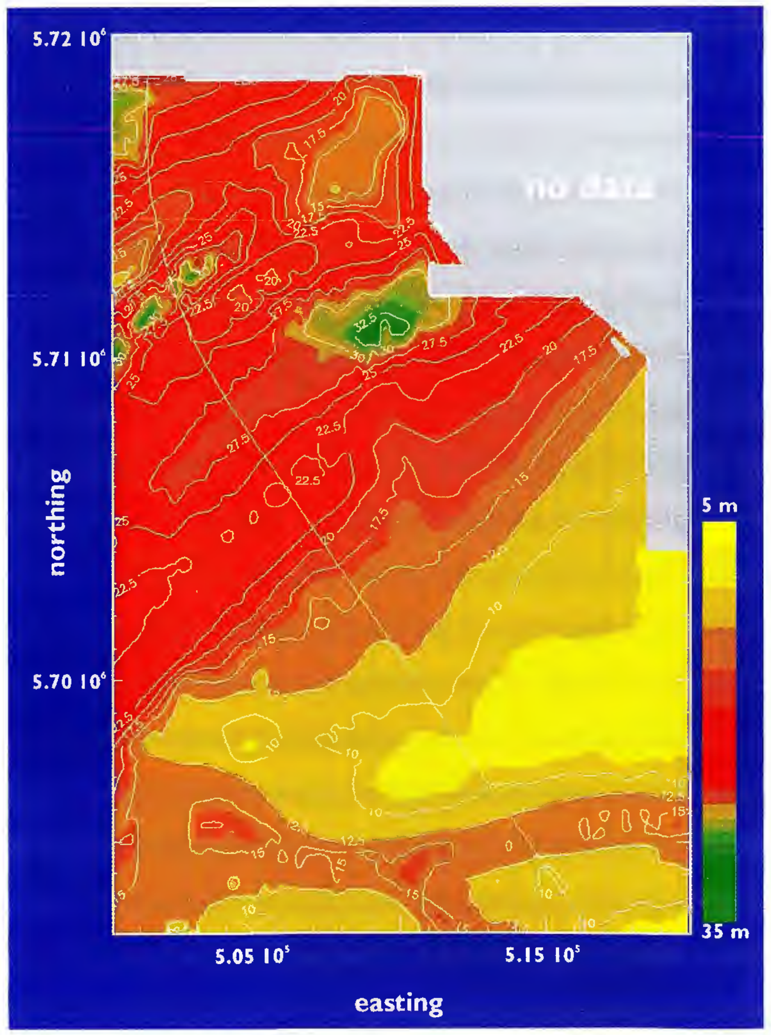
- interactions between tidal flow or currents and the bottom topography cause changes in the speed of surface water flow;
- variations in the surface flow's speed cause variations in the surface waves;
- variations in the surface waves create changes in the surface response to radar impulses.



Bathymetry by imaging radar. The intensity of the returning radar signal indicates the sea surface conditions, which are influenced by the underlying topography.

SEA BOTTOM TOPOGRAPHY

Admiralty chart showing the bottom topography in an area of the North Sea. These charts are developed from echosounding data.



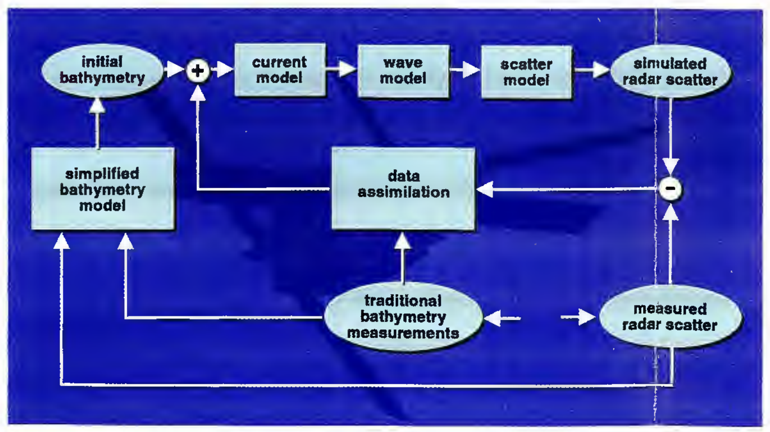
Using Satellite Data in Pipe Laying Operations

Traditionally, pipeline laying operations follow these steps:

- selection and survey of the most suitable track, based on available charts ;
- survey of additional tracks on both sides of the main one, up to several hundred metres in width;
- definition of the final pipe route corridor;
- execution of a single survey after pipe laying to confirm that the pipeline has been laid according to design criteria.

(The surveyed strip is generally 1 km wide, with a depth accuracy of about 20 cm.)

Today, tradition merges with modern techniques. One example is the Bathymetric Assessment System, developed in Holland, which combines echosounding and ERS-1 SAR observations.

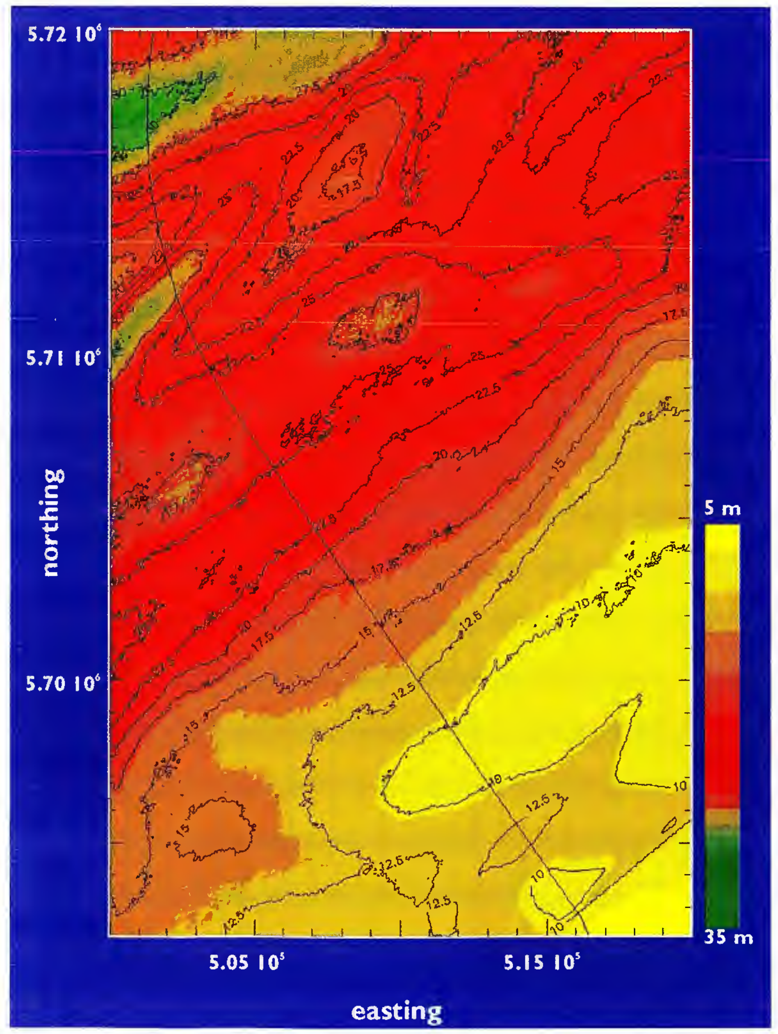


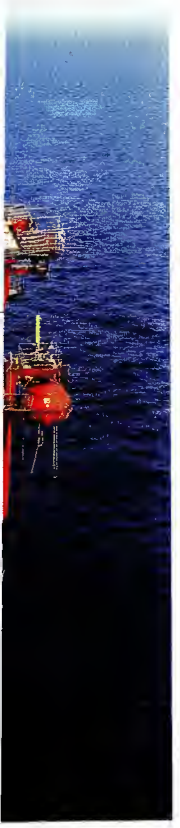
Bathymetry Assessment System. Mathematical models, integrating from traditional sources (echosounding) and satellite radar, are used to generate contour maps of the sea bottom topography.

Starting from radar imagery, a "first-guess" of depth is made using a relatively simple imaging model which describes how the radar can "read" the bathymetry. Based on this depth estimate, a detailed, conventional survey is planned. The imaging model is used to reconstruct the final depths from radar imagery and using the conventional depth observations as standards.

The system has been used successfully in surveying an area northwest of Zeebrugge, off Holland's North Sea coast. The site includes a corridor 32 km in length and 200 m in width. Pre-route contour (depth) maps were prepared, which were similar and comparable to admiralty charts. An absolute accuracy in the order of 30 cm has been achieved, which is comparable to that obtained by most standard echosounders. Similar systems can be used in other shallow water regions of the world.

Pre-reconnaissance depth map of North Sea topography generated by the Bathymetric Assessment System. Note the similarity to the Admiralty chart.





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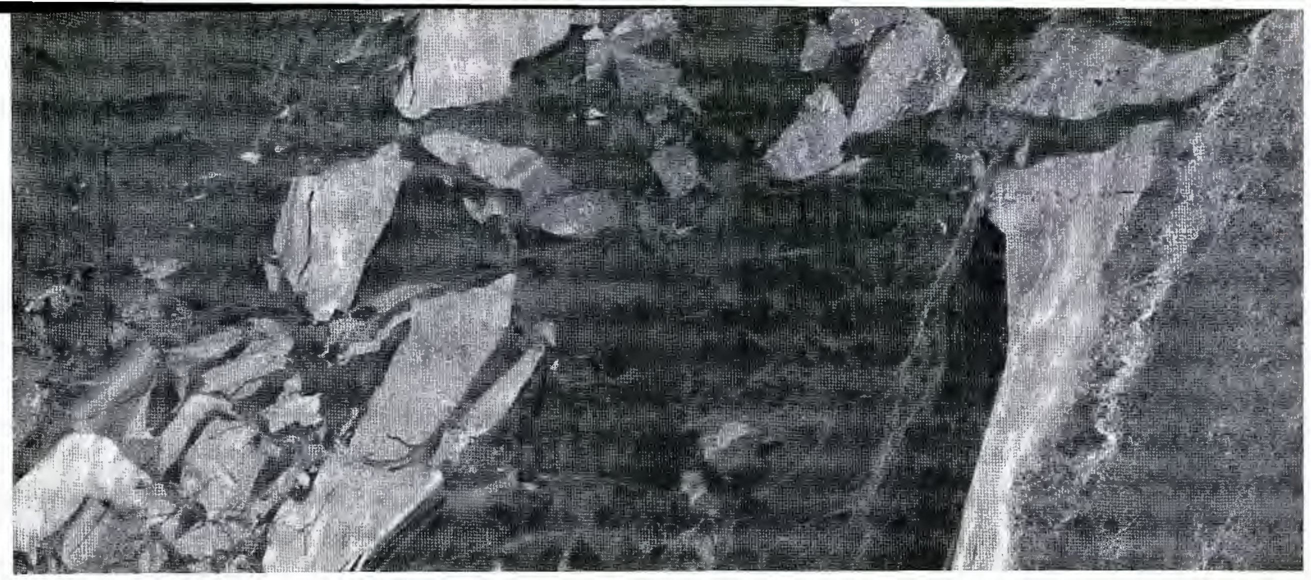

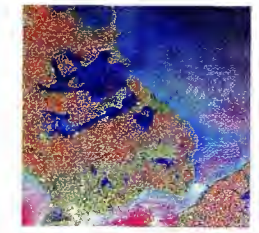

SEA-ICE MONITORING

The seasonal movement of polar sea-ice and its shifting boundaries are a constant constraint to maritime activities, both governmental and commercial.

Ice monitoring services in the Arctic regions provide real-time information to coast guards, regional icebreaking services, passenger lines and freight shipping companies. In addition, specialised users such as oil exploration and survey companies increasingly require such data as they move or expand their operations into these areas.

Ships are sent up-to-date charts of ice type and extent, as well as long-term forecasts. This information is used to locate port access routes, optimise ship routing and detect sea-ice hazards.

In the past, much of the information used in ice chart compilation was based on ground and ship observations.

These were, by their nature, limited in extent. Aircraft surveillance was therefore introduced to expand area coverage. However, due to high running costs and the need for frequent observations, the ice monitoring services searched for alternative data sources.

Today, satellites have proven their ability to provide cost-effective spatial and temporal coverage. ERS-1 in particular can monitor sea-ice during periods of darkness and through clouds. This capability represents a great advantage over more traditional techniques and that of other satellites.

The operational use of ERS-1 images for these purposes has been demonstrated by the Ice Service of the Finnish Institute of Marine Research. Based on these results, the cost-effectiveness of satellite-acquired data is being reviewed and compared with conventional data collection techniques.

Arctic ice conditions.

Technical Note

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SAR coverage and data availability are limited to the receiving station acquisition areas, while other ERS-1 sensor data of all the oceans are available worldwide. Information is processed and disseminated usually within three hours of satellite acquisition (fast-delivery data). The standard SAR product is the precision image (PRI).

Altimeter, Scatterometer and SAR wave mode data are released as fast-delivery products and delivered via the Global Telecommunications System. These products are also available off-line (i.e., as historical data for use in climatology studies).

Contact Addresses:

E. Herland
Finish Institute of Marine Research
P.O. Box 13031 (VTT)
FIN-02044 VTT Espoo (Finland)
Tel: (+358) 0 456 1 or 0 456 4799
Fax: (+358) 0 456 4496

B. Hakansson
Swedish Meteorological and
Hydrological Institute
S-601 76 Norrkoping (Sweden)
Tel: (+46) 1 11 58 000
Fax: (+46) 1 11 70 207

O. Johannessen
Nansen Environmental and
Remote Sensing Centre
Edv. Griegsv 3a
N-5037 Solheimsvik (Norway)
Tel: (+47) 55 297288
Fax: (+47) 55 200050

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)
- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
- ERS Help Desk
  Tel: (+39) 6 941 80 600 or 711
  Fax: (+39) 6 941 80 510

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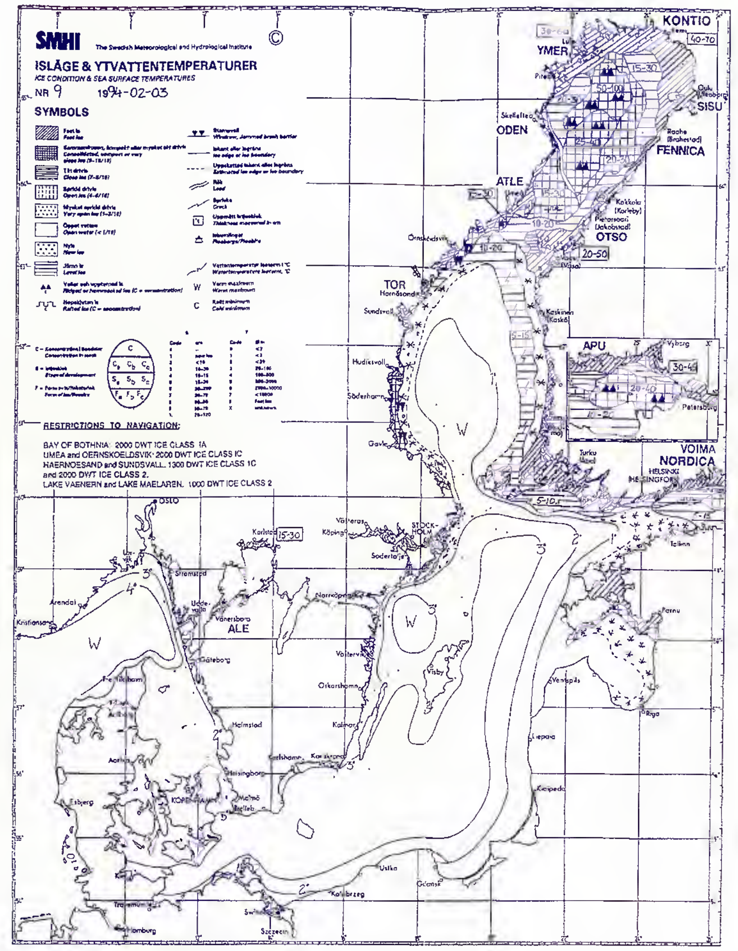
SEA-ICE MONITORING

Charting Polar Waters

Ice monitoring services of the northern European countries provide year-round information on sea-ice conditions to a variety of customers. Satellite images are received by the services usually within five hours of data acquisition. They are then combined with data from other sources and analysed to produce ice charts. The information, normally presented in the form of synoptic charts, is forwarded via marine radio facsimile directly to ships.

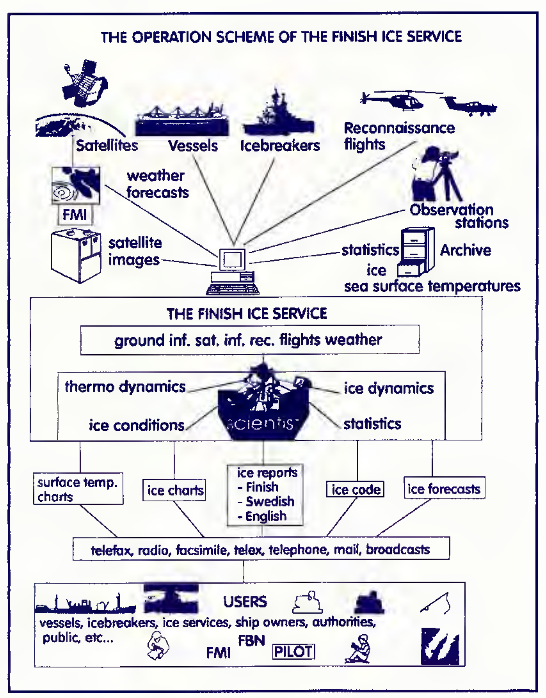


Ice Chart of the Baltic Sea.

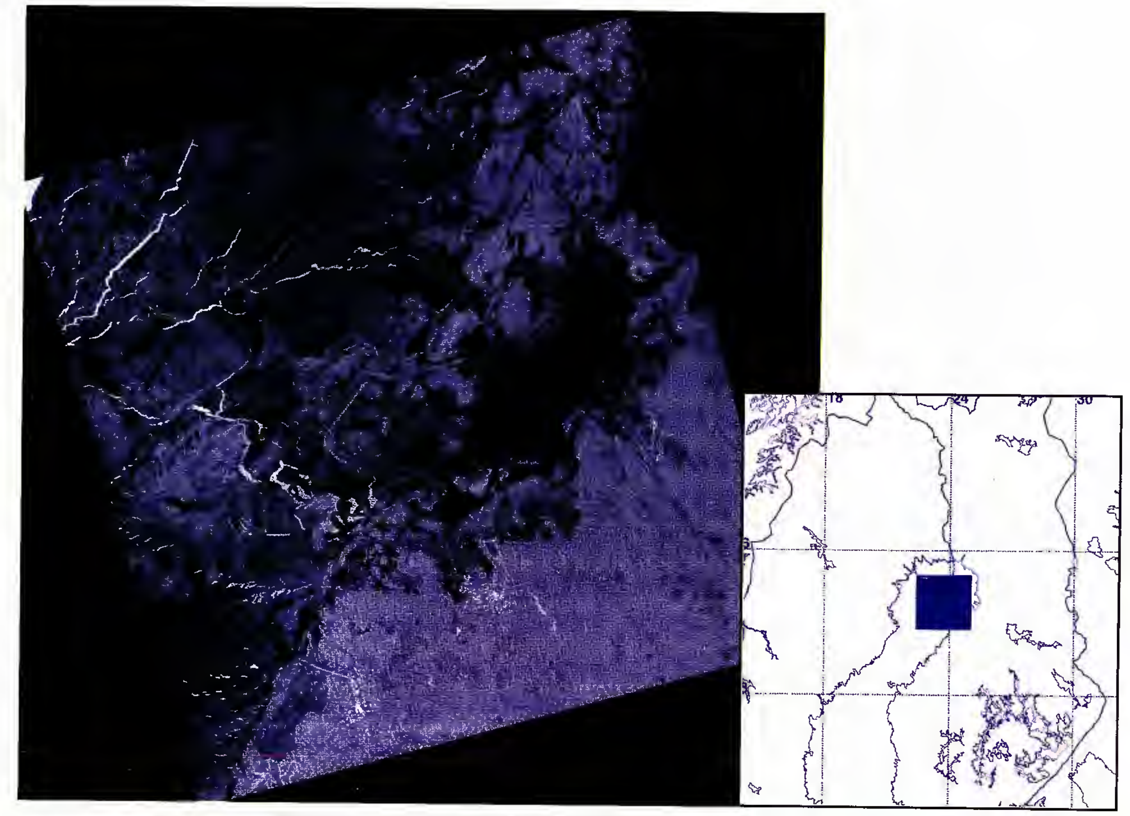
These charts show daily views of ice conditions in a standard format and provide details such as ice type (age and thickness), ice concentration, surface topography and floe size. This real-time information is used in planning access routes to ports and for avoiding difficult or hazardous areas.

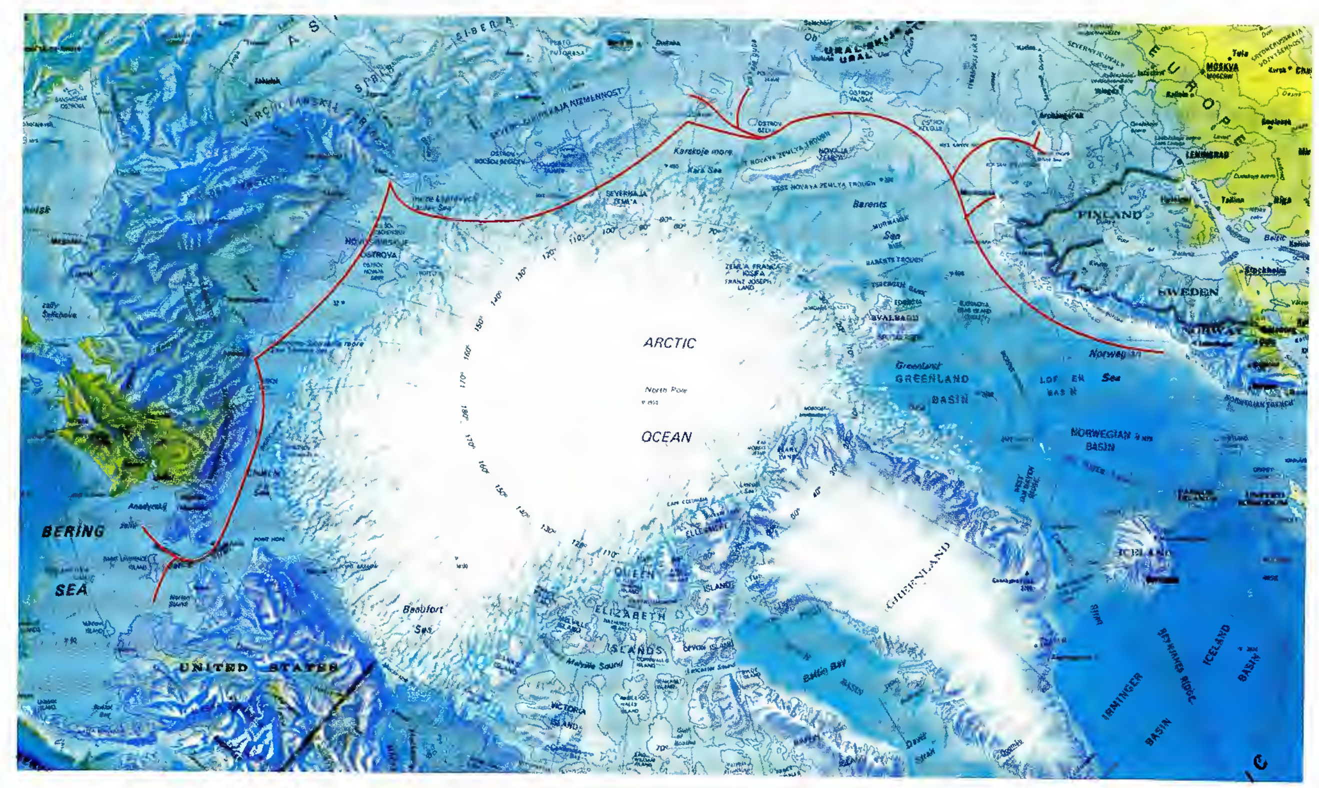
Satellite information proves in some cases to be the only usable information due to weather or operational constraints. For example, in the Great Lakes/St. Lawrence region of the USA and Canada, few other sources of information were available during the harsh winter of 1993. ERS-1 data and images provided some of the best views of ice conditions on this important waterway.

Many of the ice monitoring services are currently reviewing their information sources. As a result, data and images from satellites are increasingly replacing aerial observations.



Operations of the Finnish Ice Service.





Ice-breaking supe... in Arctic waters. (Photography by ... Black © courtesy ... Times Books Ltd.)

Image from ERS-1 ... Sea-Ice in the Balt...

The Northeast Pass... (©1984 by Rand M... & Company.)

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Contact Addresses:

P. Lasnier
Meteomer
Quartier Les Barestes
R.N.7
F-83480 Puget-sur-Argens (France)
Tel: (+33) 94 45 66 11
Fax: (+33) 94 45 68 23

T. Allan
Satellite Observing Systems Ltd.
15 Church Street
Godalming
Surrey GU7 IEL (United Kingdom)
Tel: (+44) 1-483 42 12 13
Fax: (+44) 1-483 42 86 91

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)

- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
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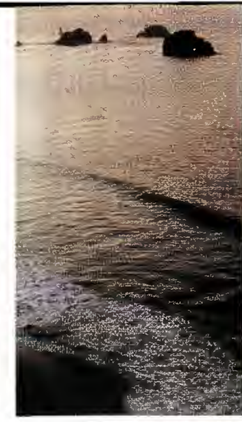
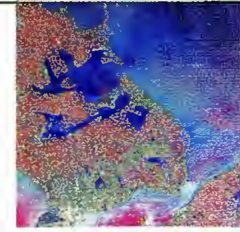


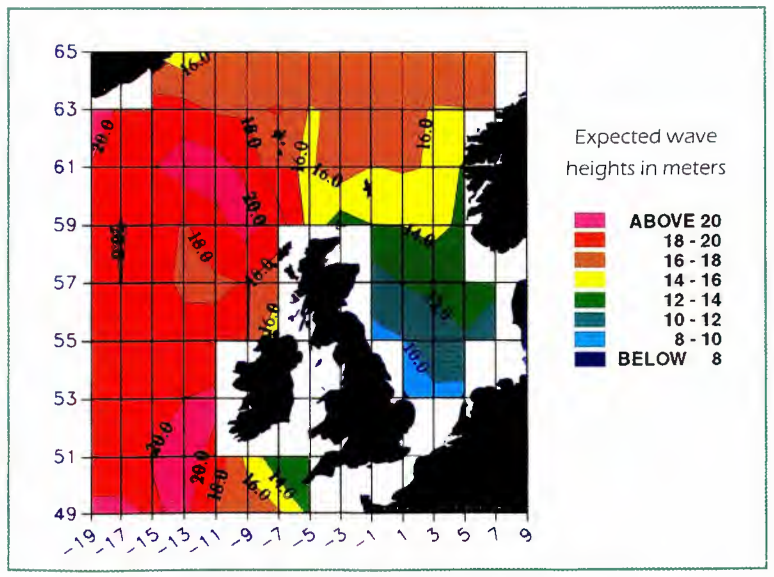


SEA STATE CLIMATOLOGY

Knowledge of the marine environment is essential for all who work at sea. Oil companies engaged in offshore drilling operations and engineering firms developing or renovating harbours need to use meteo-ocean parameters in their daily work.

Offshore exploration and drilling is now one of the most important activities of oil companies. An extensive and broad range of information about a drilling site is of fundamental importance when designing and constructing an oil platform at sea. Platform structures must also be designed to resist extremes of sea conditions, even if those conditions last for only a short while.

Expected heights of 50-year waves are mapped around the British Isles. This information is based on satellite observations.



More specifically, one of the main elements used in the planning and design of offshore structures is the value of the 50-to-100-year return wave. Practically speaking, this is the wave energy which occurs in a given area only once every 50 to 100 years.

Keeping a record of local waves for 100 or even 50 years is impractical. So the required values are normally obtained by extrapolating from available wave information. Based on climatological data, values of the highest local waves observed over a certain time are used to determine statistically the expected value of a 50-to-100-year wave.

Use of unreliable information, however, may pose a risk to the offshore operations, workers and structures. Insurance companies, for example, place great importance on accurate information. Extrapolating good, 5-year time series of data may provide more accurate results than using longer time frame (10-year) but less reliable data.

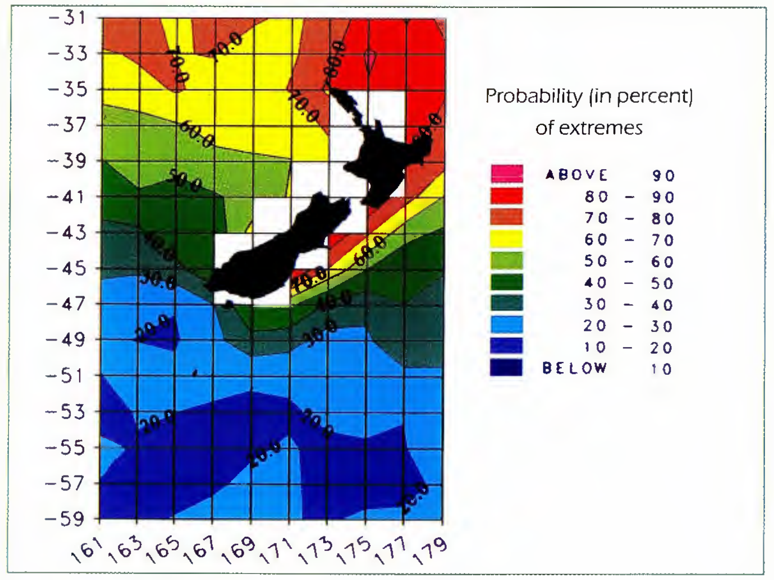
An accurate characterisation of meteo-ocean parameters based on traditional methods is limited by lack of sufficient on-site measurements, unreliable information from "ships of opportunity," high costs and delays in completing the final data restitution.

SEA STATE CLIMATOLOGY

The Satellite' s Contribution

Today's satellite measurements represent a real breakthrough in understanding the marine environment. The quality of information they provide for the characterisation of sea-state conditions is reliable and comparable to the best on-site measurements.

It may be difficult to accept that a satellite can measure sea-state parameters from space with the same accuracy as a buoy anchored to the sea bottom. However, when satellite data are used in conjunction with bouy data, the measurement errors are reduced.



Probability of encountering extremes in sea conditions.

One significant example is the measurement of wave heights by the Altimeter, a radar pointed at nadir (straight down). With a flat sea surface (no waves), the returning energy arrives at the satellite at the same time. When waves are present, the energy reflected by the wave crests arrives before the energy reflected from the wave troughs. From the distribution of the returning energy pulse, the wave height can be determined.

More than five years of Altimeter data from various satellite missions are already available. Being unaffected by weather conditions, satellite measurements prove especially useful during difficult situations, such as storms. Swell conditions are determined by utilising wave forecasting models in conjunction with data on current weather and storm conditions.

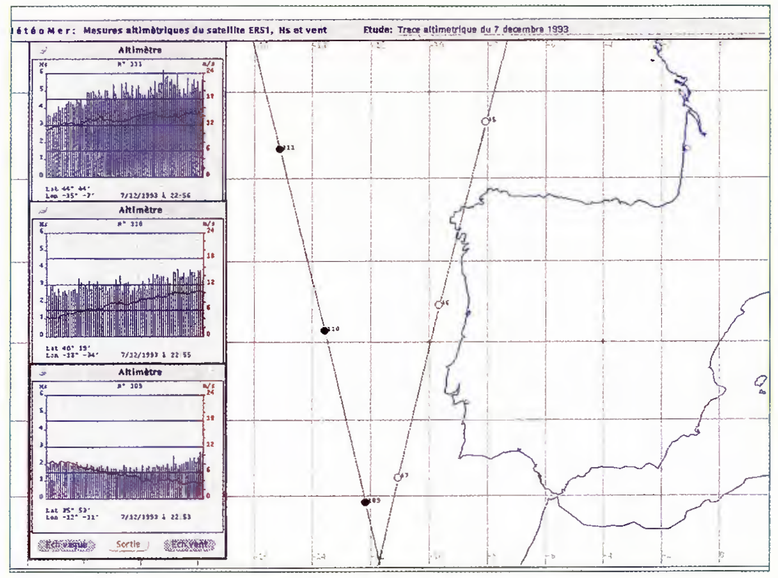
In addition, it is interesting to note that satellite information can be useful to insurance companies. In practical cases such as the sinking of a ship, satellite information can be used to establish if bad weather conditions were the cause. This information can influence the assessment of damages and assist in determining the eventual payment of claims.

Practical Results

The world-wide coverage of the oceans provided by ERS-1 since 1991 cannot be equalled by ship-board observations, especially in those areas outside the main maritime routes.

As satellite data become more available, the number of companies established in Europe to provide services and information derived from satellites is increasing.

Among the typical services offered: systematic collection of any available satellite measurements (datasets) of the seas and determination of extreme conditions in specific areas.



Measurements of wave heights (black histogram) and wind speeds (red line graph) off of Spain's Atlantic Coast made by the ERS-1 Radar Altimeter.

Datasets can be processed and converted into final, user-ready form for the customer. Important results have been achieved in this field by companies such as Satellite Observing Systems Ltd. (United Kingdom) and Meteomer (France).

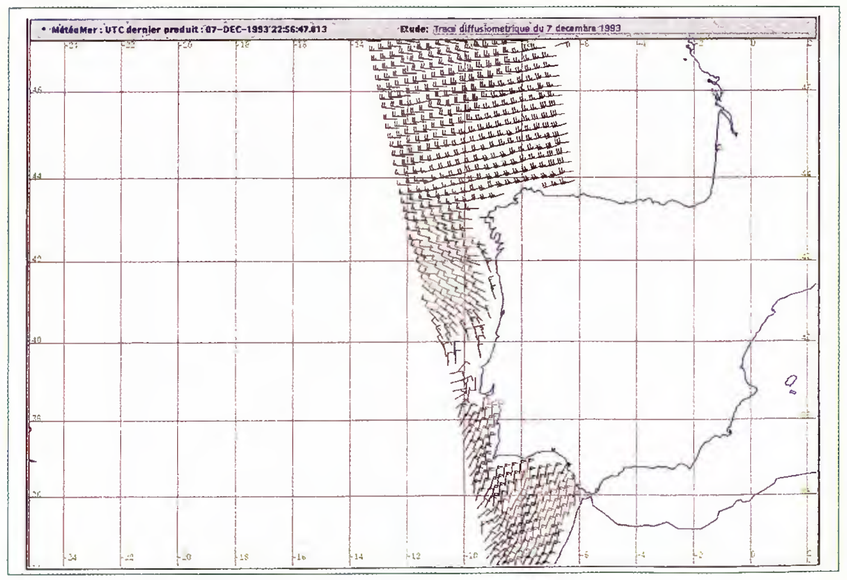
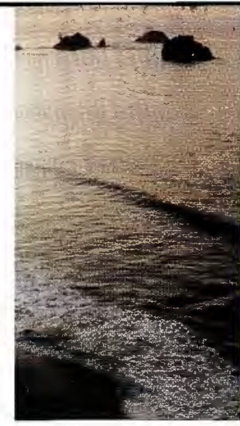
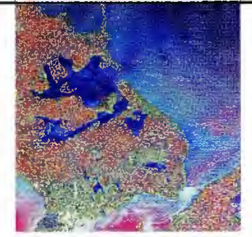


Chart of wind speed and direction off of Spain's Atlantic Coast as calculated from Radar Altimeter data.





SEA STATE FORECASTING

Sea state conditions influence all kinds of offshore activities. Forecasting conditions has always been essential for sea-faring people. Poor forecasts or unexpected storms may lead to the tragic loss of human life and of ships and their cargoes. Accurate forecasting of conditions and prediction of stormy weather therefore becomes vital for people fishing, working or travelling offshore.

Wave Forecasting for Offshore Safety

Typical offshore activities such as exploratory drilling and platform lifting require frequent wave forecasts to avoid potential risk to personnel and damage to installations.

As an example, strong vessel motions can be induced by swell (i.e., waves coming from a distant storm) even with low local wind. These vessel motions are very sensitive to the wave period of the swell. If the motion's amplitude exceeds a critical value, the vessel may be damaged or capsize.

During exploratory drilling, a "riser pipe" is connected to the drilling vessel. One parameter taken into account to determine safe work conditions during this "hooking" phase is the ship's motion, or, more specifically, the crane tip's motion. Drilling operations, lasting 12 hours or more, can continue as long as the significant wave height (SWH) remains under a safe level. If the SWH increases above the safe working threshold, vessel and pipe must be disconnected to avoid damage.

Moreover, unacceptable impacts between the lifted object and the cargo barge can occur during lifting procedures. The ship's motion can be computed from spectral wave information by modelling the motion response functions of the vessel.

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Contact Addresses:

G.J. Wensink
Delft Hydraulics
Postbus 152
NL-8300 AD Emmeloord
(Netherlands)
Tel: (+31) 52 74 29 22
Fax: (+31) 52 74 35 73

P. Lasnier
Meteomer
Quartier Les Barestes
R.N. 7
F-83480 Puget-sur-Argens (France)
Tel: (+33) 94 45 66 11
Fax: (+33) 94 45 68 23

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)

- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
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  Tel: (+39) 6 941 80 600 or 711
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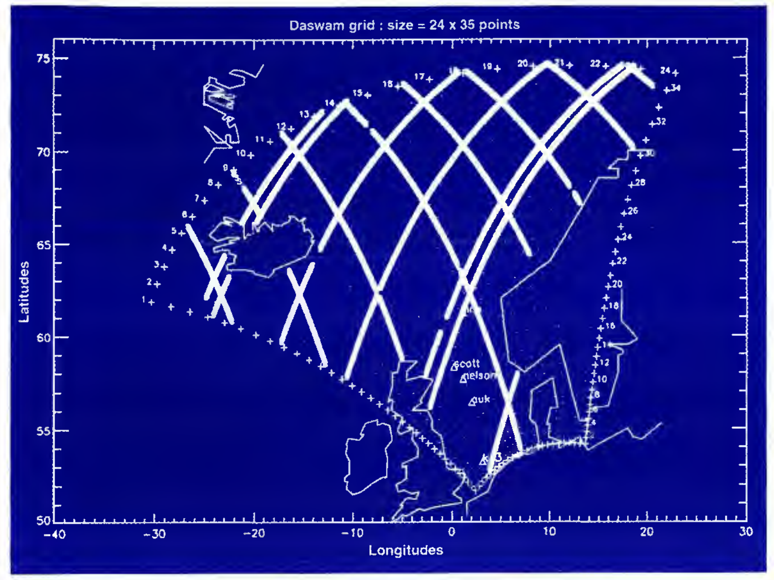
SEA STATE FORECASTING



ERS-1 surveillance tracks of the wave model grid for the North Atlantic between Iceland and Norway.

Modern Sea State Forecasting Systems

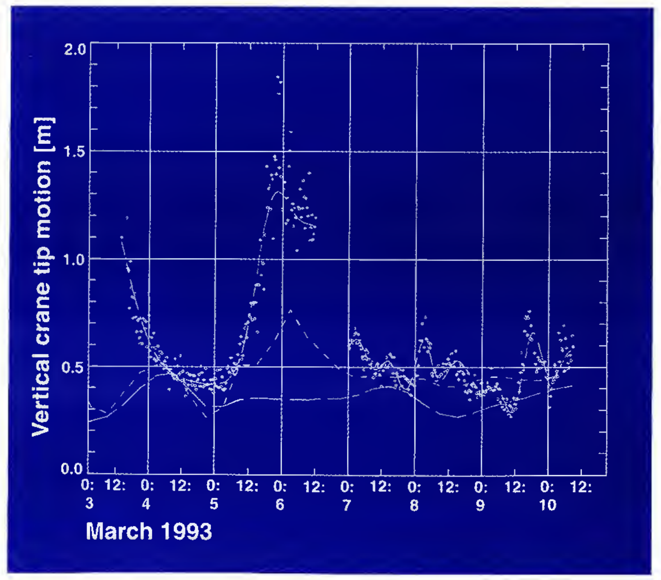
Today's modern weather forecasting systems rely on the continuous and reliable flow of data transmitted from earth-observation satellites and on the computing capability to process these enormous volumes of data. The satellites make possible the observation of remote and inaccessible regions of the Earth where information is difficult or impossible to obtain by other conventional methods.

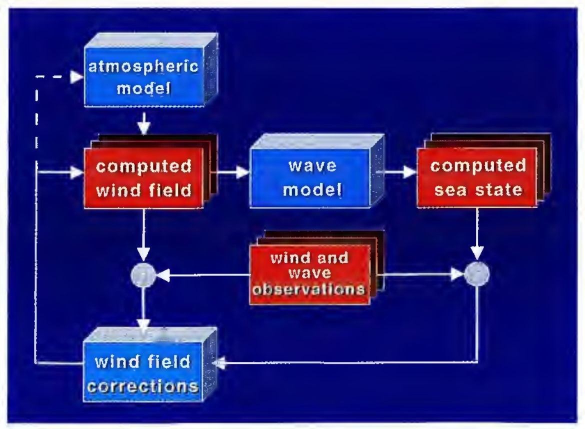
Traditionally considered a by-product of global weather forecasts, information on the ocean surface winds are used to determine the sea state. The sea state, i.e., wave intensity and direction at each point on the ocean, is calculated from physical principles using the initial wind information. The majority of numerical sea state and wave models is based on this common approach.

Measurements from earth observation satellites are integrated into the forecasting model using an iterative process, the goal being the development of more accurate predictions.

Wave model and data assimilation scheme. Data from satellite observations are used in mathematical models to compute wind fields and sea states.

Plot of a ship's vertical motion, caused by sea swells. Mathematical models which predict a ship's response to swells are compared with the observed motions.





The Satellite's Contribution

Several instruments on-board the ERS-1 satellite (in particular, the scatterometer, a radar altimeter and an imaging radar [SAR]) have been tailored specifically to provide sea state information. This arrangement was designed to overcome the time limit constraints of operational weather and sea state forecasting systems. Ground facilities have been set up which can deliver data promptly as needed by the users ("fast-delivery" products).

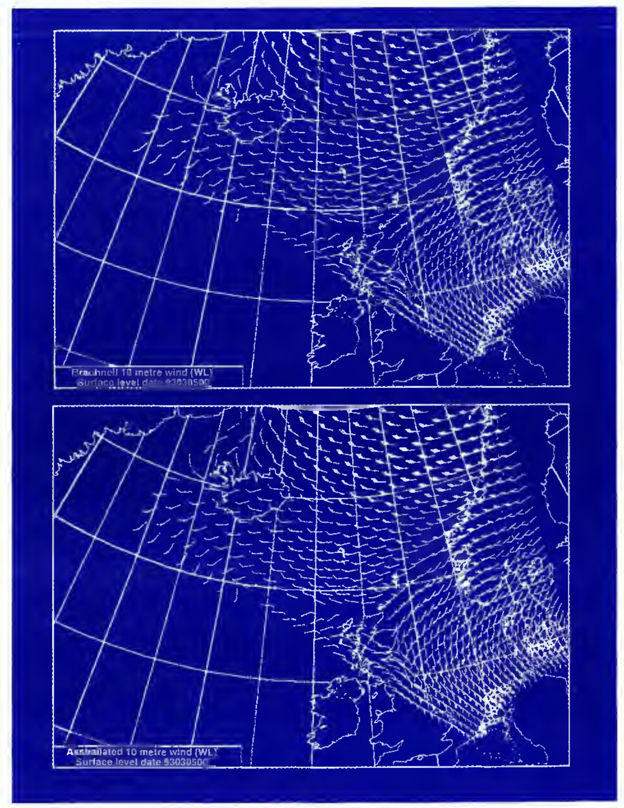
ERS-1 scatterometer information is already in use at a number of operational meteorological centres, including the European Centre for Medium-Range Weather Forecasts in Reading, United Kingdom, where the data are integrated regularly in weather-prediction systems.

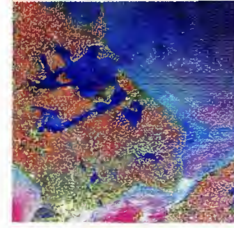
Altimeter and SAR information on ocean waves is also incorporated routinely into the operational systems at various institutes. National meteorological services are using such data more frequently in developing weather and marine forecasts. In addition, an increasing number of commercial companies has been set up in recent years to supply information in more user-oriented forms.

A Practical Case

As an example, an interesting operational wave forecasting system for the North Sea has been developed in Holland. This system makes use of radar altimeter data. Wind scatterometer and wave mode data will be integrated into the system in the near future. In France, low-bit-rate data are used operationally by Meteomer as input for their wave forecasting system.

Original and corrected wind fields in the North Atlantic Ocean as determined from satellite data. This information is then used in calculating wave conditions.





SHIP ROUTING

Ocean Transport

The conveyance of goods by sea has become a growing part of the world economy. However, long-distance transport can be expensive in terms of both fuel consumption and time. Furthermore, there are penalties for late deliveries or unforeseen stoppages. Considerable savings may be realised if ships can be routed more efficiently and through less dangerous areas. To do so, rapid, real-time knowledge of weather and sea-state conditions is needed.

Immediate access to up-to-the-minute information provides a ship's captain with the ability to continuously update an optimal route according to the most recent weather conditions and forecasts.

Modern Sea State Forecasting Systems

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Contact Addresses:

S. Lehner
DLR
WT/DA/FE Department
Postfach 11-16
D-82230 Oberpfaffenhofen
(Germany)
Tel: (+49) 81-53 28 28 95
Fax: (+49) 81-53 28 14 45

U. Frembgen
Dornier GmbH
Satellite Systems/Earth Observation
Postfach 1420
D-88039 Friedrichshafen (Germany)
Tel: (+49) 7545 85732
Fax: (+49) 7545 82206

ESRIN
Via Galileo Galilei
I-00044 Frascati (Italy)
- ERS Data Utilisation Section
  Tel: (+39) 6 941 80 419 or 371
  Fax: (+39) 6 941 80 520
- ERS Help Desk
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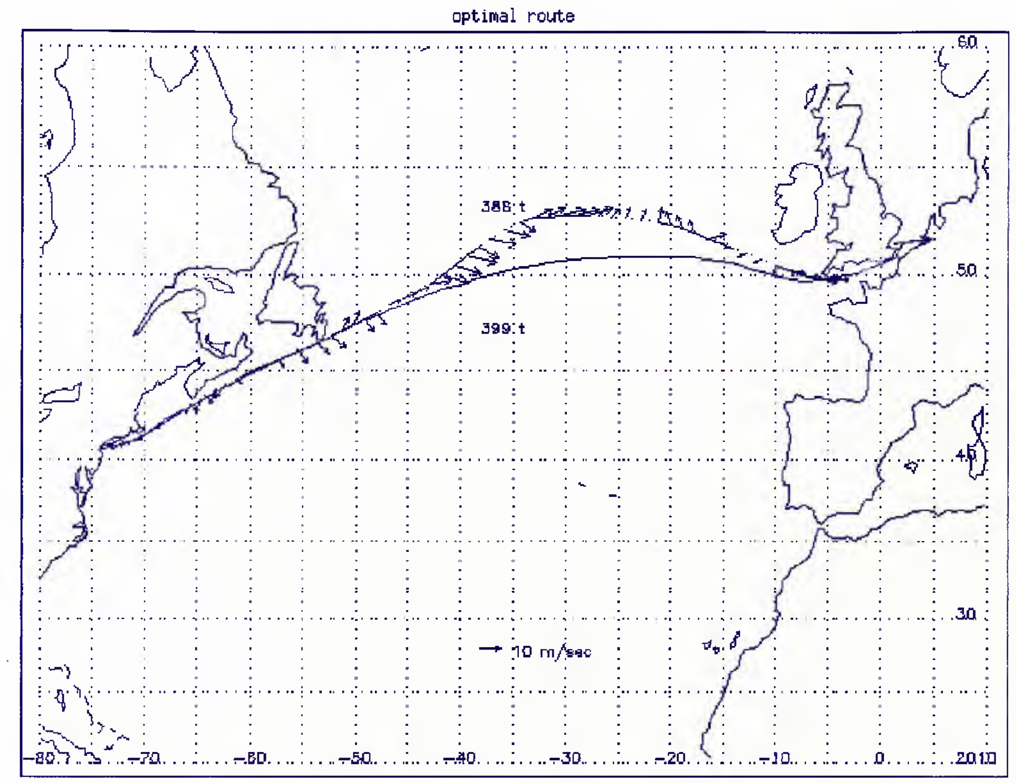
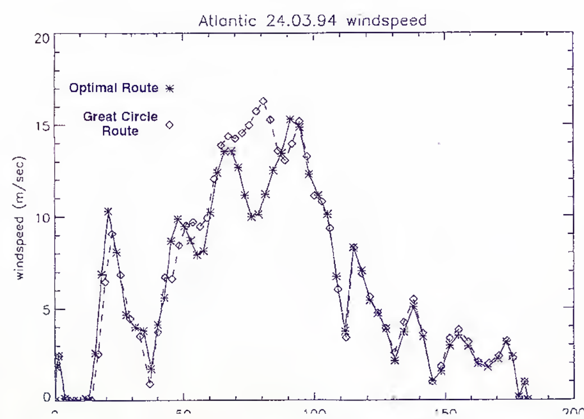
SHIP ROUTING

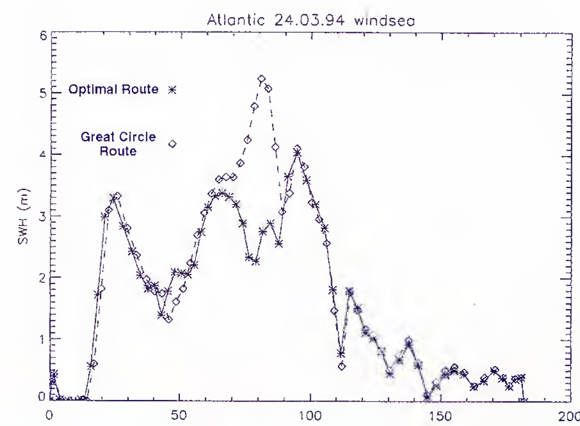


Plotting a course for the container ship *Bonn Express*, March 1994. The optimal route plotted across the North Atlantic required 11 tonnes less fuel than a crossing following the Great Circle Route, the shortest route.

Utilising Satellite Technology

Several systems make use of satellite information today. One in particular is demonstrating its capabilities in Germany. This wave analysis and forecast system enables the continuous plotting of optimal routes based on wind and sea-state data derived from ERS-1's instruments and on weather forecast bulletins issued by the European Centre for Medium-Range Weather Forecasting (ECMRW), based in Reading, United Kingdom.





Significant Wave Heights (SWH) and wind speeds on two routes across the North Atlantic Ocean. The optimal route avoids heavy seas with waves greater than five meters in height and storm winds in excess of 31 knots (16 m/s).

The system is installed on the ship's bridge. It is extremely flexible and provides the captain with timely and accurate information useful for route optimisation. He can use this information to determine any appropriate actions needed during navigation.

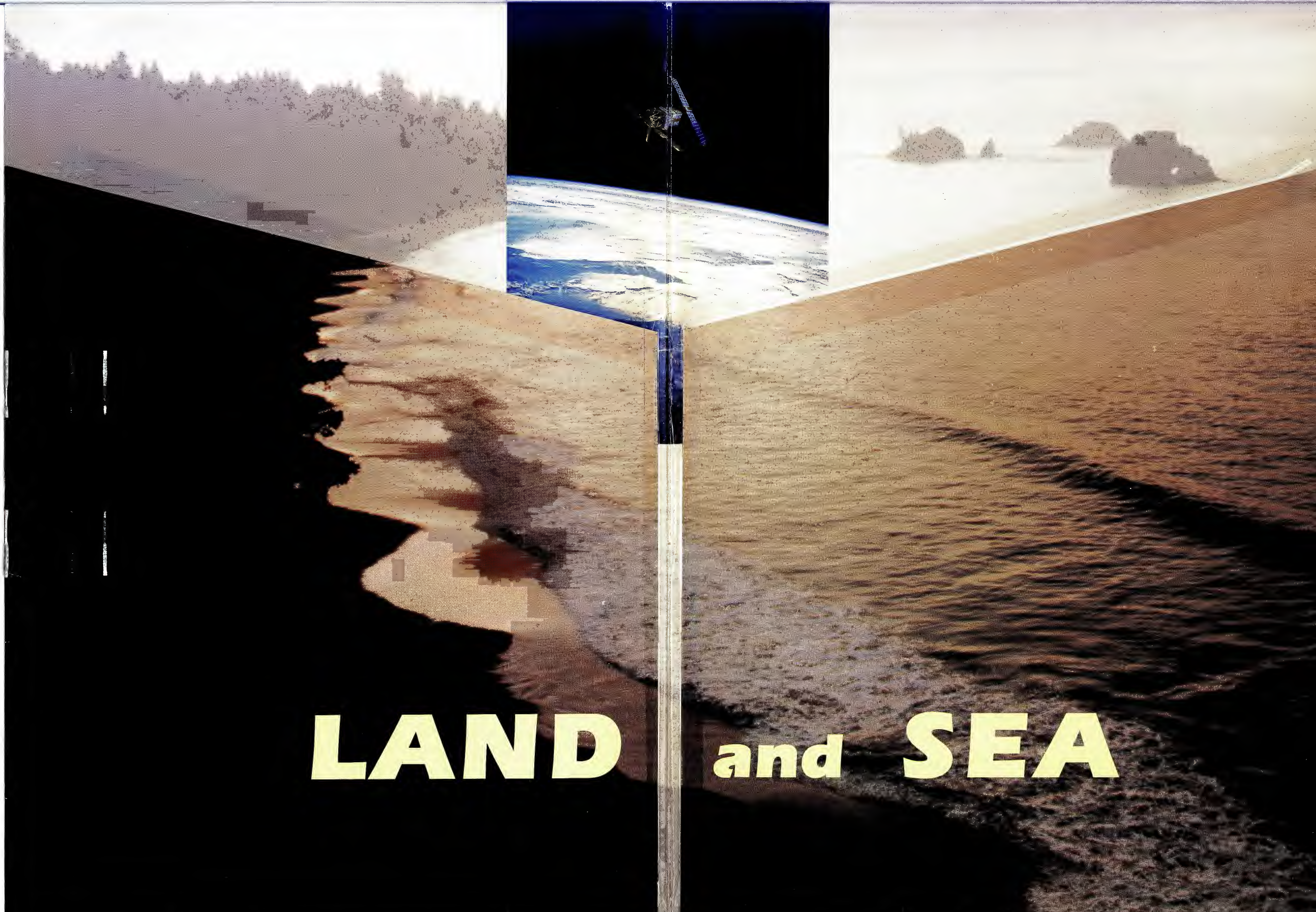
The captain enters basic information into the system, i.e., departure and arrival harbours, expected duration of the journey, etc. A communications module onboard receives the latest weather and sea-state forecast for the area of interest automatically via the Inmarsat marine telecommunications satellite. These data are transmitted to the ship every 12 hours and are used for charting course adjustments and for long-term planning purposes.

The route optimising system incorporates the ERS-1 satellite data, the ship's position and additional optimisation parameters to plot an optimal course in the form of route points. The captain then enters these route points into the ship's navigation system.

Another interesting operational wave forecasting system has been developed in Holland for use in the North Sea. This system makes use of radar altimeter data. Wind scatterometer and wave mode data will be integrated into the system in the near future. In France, low-bit-rate data are used operationally by Meteomer as input for their wave forecasting system. These forecasts may, in turn, be used in other ship route optimising systems.

The number of systems similar to the ones described here is increasing in Europe. The objective is to ensure the accurate acquisition and prompt delivery of information to ships across all oceans, now made easier by using satellite information.

Bridge of a modern ship. Telecommunications equipment enables the crew to receive timely weather observations, forecasts and routing information.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