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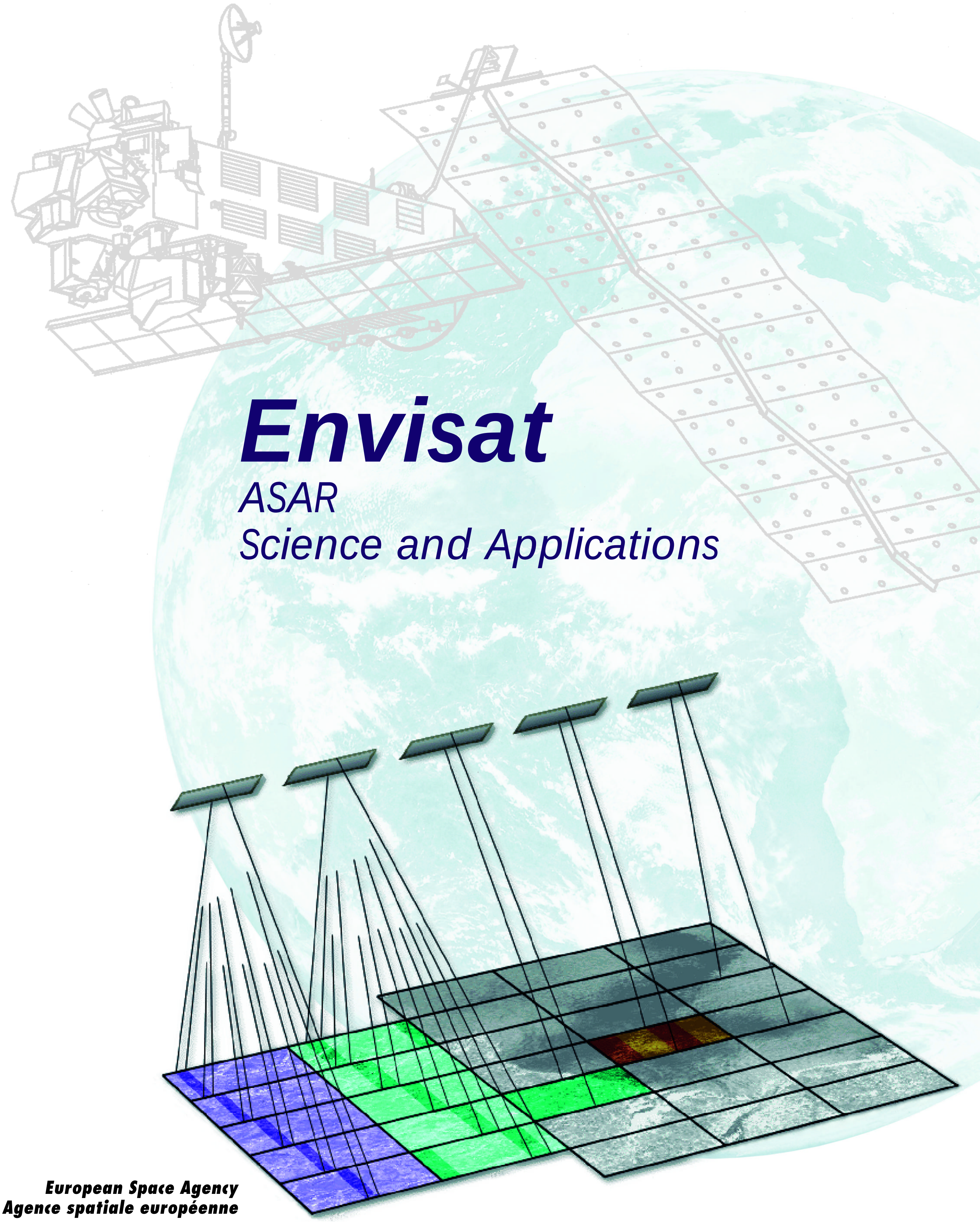

Envisat

ASAR Science and Applications

European Space Agency
Agence spatiale européenne

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ASAR SCIENCE AND APPLICATIONS

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Contents

Acronyms & Abbreviations

AATSR	Advanced Along Track Scanning Radiometer
ACSYS	Arctic Climate System Study
AMI	Active Microwave Instrument
AO	Announcement of Opportunity
ASA	Antenna Sub-Assemby
ASAR	Advanced Synthetic Aperture Radar
AVHRR	Advanced Very High Resolution Radiometer
CESA	Central Electronics Sub-Assembly
DINSAR	Differential Interferometric SAR
DEM	Digital elevation Model
EMAC	European Multi-sensor Airborne Campaign
ERS	European Remote Sensing Satellite
ESOV	Envisat Swath and Orbit Visualisation Software
GCOS	Global Climate Observing System
HH	Horizontal transmit - Horizontal receive polarisation
HR	High Rate data
HV	Horizontal transmit - Vertical receive polarisation
ICE	Instrument Control Equipment
IGBP	International Geosphere-Biosphere Programme
InSAR	SAR Interferometry
IR	Infra-red
ISn	(Envisat) Imaging Swath n (1-7)
JERS	Japanese Earth Resources Satellite
JGOFS	Joint Global Ocean Flux Study
LOICZ	Land-Ocean Interactions in the Coastal Zone programme
LRAC	Low rate Reference Archive Centre
MARS	Monitoring Agriculture with Remote Sensing
MERIS	Medium Resolution Imaging Spectrometer
NSES	National earth Station providing ESA Services
PAC	Processing and Archive Centre (prefixed by country, e.g. F-PAC)
PDAS	Payload Data Acquisition Station
PDCC	Payload Data Control Centre
PDHS	Payload Data Handling Station
PDS	(Envisat) Payload Data Segment
SAR	Synthetic Aperture Radar
ScanSAR	Scanning SAR imaging technique (for wide swath coverage)
SIR-C	Shuttle Imaging Radar - Mission C
SLC	Single Look Complex (image)
T/R	Transmit-Receive
TCIU	Tile Control Interface Unit
VH	Vertical transmit - Horizontal receive polarisation
VV	Vertical transmit - vertical receive polarisation
WCRP	World Climate Research Programme
WOCE	World Ocean Circulation Experiment

1. INTRODUCTION

1.1. Measurement Objectives

The Advanced Synthetic Aperture Radar (ASAR), to be launched on Envisat, is a new tool for mapping and monitoring the Earth's surface (ESA, 1998). Following on from the very successful ERS-1/2 SARs, it is an all-weather, day-and-night, high resolution imaging instrument which will provide radar backscatter measurements indicative of terrain structure, surface roughness and dielectric constant. Important new capabilities of ASAR include beam steering for acquiring images with different incidence angles, dual-polarisation and wide swath coverage.

The ERS programme, beginning with the launch of ERS-1 in July 1991 and continuing from 1995 with ERS-2, created exciting new opportunities for scientific discovery within the international science community and initiated commercial applications of SAR data. The main results of ERS-1 are summarised in a series of ESA publications: "New Views of the Earth: Scientific Achievements of ERS-1" (ESA, 1995), "Applications Achievements of ERS-1" (ESA, 1996) and "Technical Achievements of ERS-1" (ESA, 1997a). The original focus was on oceans and ice monitoring and an impressive range of scientific investigations has been carried out in oceanography, polar science, glaciology and climate research. These include measurements of ocean surface features (currents, fronts, eddies, internal waves), directional ocean wave spectra, sea bottom topography, snow cover and ice sheet dynamics. Operational systems have been developed for mapping sea ice, oil slick monitoring and ship detection. Additionally, a large number of land applications have emerged, several based on the important developments which have been made in the field of SAR Interferometry (ESA, 1997b). SAR data are being used for agricultural monitoring, forest mapping, geological exploration and flood mapping, while SAR interferometric measurements of topography and small topographic changes are making major contributions to environmental risk assessment involving earthquakes and land subsidence.

During the 1990s these results from the ERS programme have been augmented by those from the JERS-1 and Radarsat missions and SAR data are now seen as an important management tool for the 21st century. ASAR has extended observational capabilities in comparison with the ERS SAR, but it has also been designed to provide continuity and build on the results from ERS and these other SAR missions. Operating in concert with other Envisat instruments, MERIS and AATSR, ASAR provides essential surface roughness and land cover information for the determination of land surface processes and air-sea interaction for climate studies.

The Envisat mission is an important element in providing long-term, continuous data sets that are crucial for addressing environmental and climatological issues. It will, at the same time, further promote the transfer of applications of remote sensing data from experimental to pre-operational and operational exploitation. The mission has both 'global' and 'regional' objectives, which make it necessary to provide data to scientific and application users on various timescales.

Important contributions of ASAR to the global mission include:

- measuring sea state conditions at various scales,
- mapping ice sheet characteristics and dynamics,
- mapping sea-ice distribution and dynamics,
- detecting large scale vegetation changes,
- monitoring natural and man-made pollution over the ocean.

ASAR will also make a major contribution to the regional mission by providing continuous and reliable data sets for applications such as:

- off-shore operations in sea ice,
- snow and ice mapping,
- coastal protection and pollution monitoring,
- ship traffic monitoring,
- agriculture and forest monitoring,
- soil moisture monitoring,
- geological exploration,
- topographic mapping,
- predicting, tracking and responding to natural hazards,
- surface deformation,

Some of the regional objectives (sea-ice applications, marine pollution, maritime traffic, hazard monitoring, etc.) require near-real-time data products (within a few hours from sensing) generated according to user requests. Some others (e.g. agriculture, soil moisture, etc.) require fast data turn around (a few days). The remainder can be satisfied with off-line (few weeks) data delivery.

As well as using ASAR to satisfy specific operational and commercial requirements, major systematic data collection programmes will be undertaken, to build-up archives for scientific research purposes.

1.2. Key Technical Features

In comparison with the ERS SAR, which is a single-channel, fixed geometry, instrument, ASAR represents a step forward in terms of both system flexibility and the scientific value of its data sets. The main new technical features are:

- Instrument enhancements include a digital chirp generator (programmable from 200 kHz to 16 MHz) and an improved linear dynamic range.
- Flexible swath-positioning; offering the choice between several image swath positions at various distances from the sub-satellite track, with different incidence angles.
- Dual polarisation; offering horizontal (HH) & vertical (VV) or cross-polarisation (HH&HV or VV&VH) operation.

- Wide swath coverage; 405 km swath with 150 m or 1 km resolution.
- Enhanced wave mode with imagettes acquired at 100 km intervals along track
- Extended operating time at high resolution (30 minutes of operation; 10 minutes in eclipse).
- Global SAR coverage possible using the solid state recorder or data relay satellite.

ASAR will provide continuity of the ERS SAR Image and Wave Modes, but with the opportunity for better temporal frequency of coverage. The nominal 30 m spatial resolution and swath coverage of ASAR Image Mode (100 km) and Wave Mode (5 km) are the same as the ERS Image Mode, and ASAR will also be on a 35 day repeat orbit. However, using beam steering, it will be possible to obtain images of the same area on the ground from different orbits. This gives a revisit frequency varying from daily coverage near the poles to weekly coverage at the equator.

ASAR has dual polarisation capabilities and a special Alternating Polarisation Mode has been implemented which permits half of the “looks” at a scene to be acquired with horizontal and half with vertical polarisation, thereby considerably increasing the target classification capability (especially if used in conjunction with multi-temporal imaging).

Wide area coverage will be achieved by switching between different swaths using the ScanSAR technique. This will enable 405 km coverage at resolutions of either 150 m or 1 km. At the 1 km resolution the data rate is low enough for tape recording onboard the spacecraft and the recording capacity will be sufficient for downloading low resolution global coverage through a single receiving station.

Compared to ERS, the Envisat mission offers much improved data recording and transmission capabilities for the high resolution data from ASAR. The Artemis Data Relay Satellite (with a Ka-band link) will enable direct reception of data at ESA (ESRIN) from a large part of the Earth’s surface (i.e. Europe, Africa, Asia, South America, Arctic, Antarctic and parts of North America and Australasia). Additionally, a 60 Gbit solid state recorder will allow 10 minutes continuous recording of SAR data, for downloading when in visibility of ESA ground stations.

Special attention has been focused on the Envisat ground segment, to provide consistent high quality data products and rapid turn-round times. Data services will include on-line data search, browsing and ordering. A system will be put in place for delivery of large near-real-time data products.

2. INSTRUMENT AND PRODUCT SPECIFICATIONS

2.1. The ASAR Instrument

The ASAR instrument provides a number of technological improvements compared with the ERS-1/2 SAR. The most challenging is the replacement of the passive radiator array by an active phased array antenna system using distributed elements. Transmit/Receive (T/R) modules are arranged across the antenna such that, by adjusting the gain and phase of individual modules, the transmit and receive beams may be steered and shaped. The design uses an active array antenna with 320 T/R-modules, and achieves selectable positioning of the imaged swath and a larger swath coverage (405 km), by using beam steering in elevation and the ScanSAR technique at medium resolution (150 m) or low resolution (1 km). H or V polarisation can be selected on transmit and receive, or a combination of both can be used, and there is also a more versatile wave measurement mode.

The radar antenna beam illuminates the ground to the right side of the satellite. Due to the satellite motion and the along-track (azimuth) beamwidth of the antenna, each target element only stays inside the illumination beam for a short time. As part of the on-ground processing the complex echo signals received during this time are added coherently. In this way a long antenna is synthesised, with the synthetic aperture length being equal to the distance the satellite travelled during the integration time. In principle the along-track resolution obtainable with SAR is about half the real antenna length. However, to enhance the radiometric resolution, multi-look azimuth processing is employed and consequently the along-track resolution will be reduced by a factor equal to the look number. The across-track or range resolution is a function of the transmitted radar bandwidth. Pulse compression techniques are used to improve ASAR performance, taking into account the instrument's peak power capability. The fact that the system works coherently from end-to-end means that both the amplitude and the phase relationships between the complex transmitted and received signals are maintained throughout the instruments and the processing chain. This facilitates aperture synthesis as well as multi-pass radar interferometry using pairs of images taken over the same area at different times.

The instrument comprises two functional groups, the Antenna Sub-Assembly (ASA) and the Central Electronics Sub-Assembly (CESA), with subsystems as shown in the functional block diagram (Fig. 2.1). The ASAR instrument is controlled by its Instrument Control Equipment (ICE), which provides the command and control interface to the satellite. Macro-commands are transferred

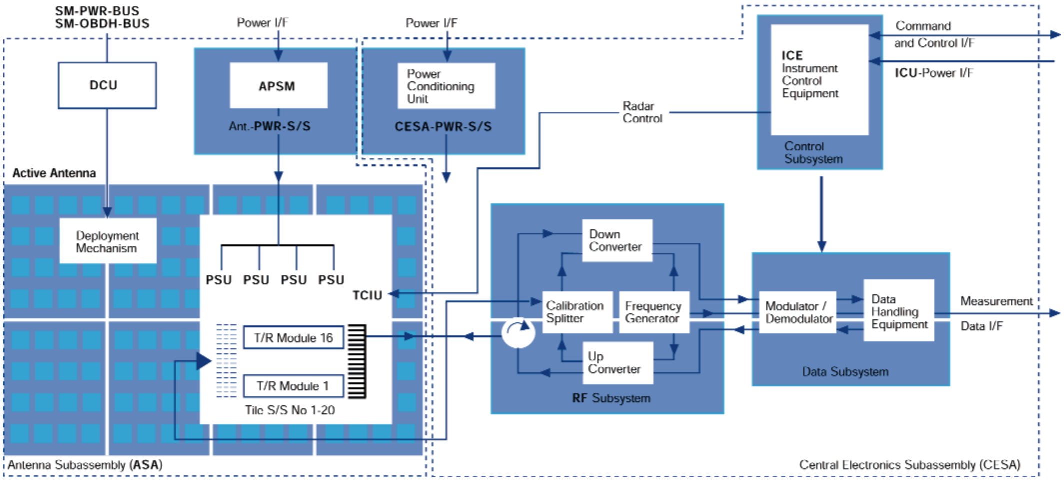


Fig. 2.1: ASAR Instrument Diagram

from the Payload Management Computer to the ICE, where they are expanded and queued. The ICE maintains and manages a database of operational parameters such as transmit pulse and beam characteristics for each swath of each mode and timing characteristics like pulse repetition frequencies and window timings.

The transmit pulse characteristics are set within the Data Handling Equipment by coefficients in a Digital Chirp Generator which supplies In-phase (I) and Quadrature (Q) components. The output of the Data Subsystem is a composite up-chirp centred at the IF carrier frequency.

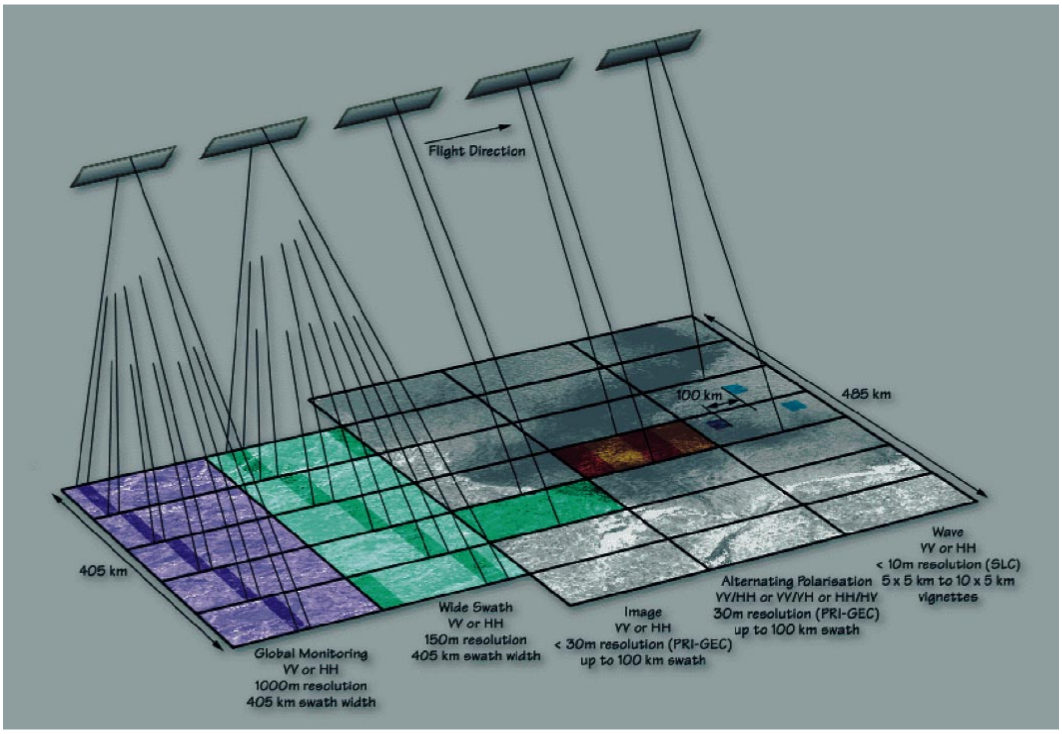
The signal is then passed to the RF Subsystem where it is mixed with the local oscillator frequency to generate the RF signal centred on 5.331 GHz. The upconverted signal is routed via the Calibration/Switch Equipment to the antenna signal feed waveguide. At the antenna the signal is distributed by the RF Panel Feed waveguide network to the antenna tile subsystems. The T/R modules apply phase and gain changes to the signal, in accordance with the beamforming characteristics which have been given by the Tile Control I/F Unit (TCIU), taking into account compensation for temperature effects. The signal is then power amplified and passed via one of two feeds (V or H) to the Tile Radiator Panel. The signals are received through the same antenna array, passed to the T/R Modules for low noise amplification and phase and gain adaption to determine the received beam shape. The outputs from each module are routed at RF via the corporate feed to the antenna RF distribution system which acts as a combiner, effectively adding signals coherently and noise inputs incoherently.

Coherent RF/IF conversion of the RF echo signals is performed in the Downconverter. I/Q detection of the IF echo signal is accomplished in the Demodulator of the Data Subsystem. The resulting baseband I/Q signals are further processed in the Data Handling Equipment, which performs digitisation, compression and filtering of these data. After buffering and packetising, the echo data are transmitted to the measurement data interface.

2.2. Calibration

Calibration will build on the well established methods used for ERS, but include additional elements necessitated by the ASAR active array architecture and multiple mode capability. The principal engineering challenge for ASAR calibration is

Fig. 2.2: ASAR Operating Modes



presented by the active antenna. The antenna includes 320 T/R modules, each of which is connected to a radiating array. Each T/R module includes transmit and receive chains of active components which provide amplification and programmable amplitude and phase adjustment. Instabilities in these will distort the antenna gain pattern and potentially cause a radiometric error in the SAR image.

The radiometric calibration of ASAR will involve three different operations:

- Internal Calibration
- External Characterisation
- External Calibration.

Internal Calibration
The ASAR instrument internal calibration scheme has been designed to determine the instrument's internal path transfer function and to perform noise calibration. Special pulses are fed through dedicated signal paths, measured by the sensor, and used by the ground processor to perform corrections. A calibration loop includes all relevant factors within the calibration process. The loop is used to characterise: the instrument transfer function during measurement modes; the individual T/R modules (enabling correction for rapid temperature fluctuations or errors due to ageing and module failures); and the special external characterisation mode of the sensor. The internal calibration scheme monitors drifts in the transfer function of the majority of the instrument, but does not cover the passive part of the antenna, the calibration loop itself and the mechanical pointing of the antenna.

External Characterisation
As part of the overall calibration strategy to monitor the instruments, a dedicated ASAR mode called External Characterisation Mode is used, nominally every six months. A sequence of pulses is sent by each antenna row, then sensed by the antenna calibration loop and recorded on the ground by a specially built ASAR transponder ground receiver.

Image Swath	Swath Width (km)	Ground position from nadir (km)	Incidence Angle Range (°)	Noise Equivalent Sigma (°)
IS1	104.8	187.2 - 292.0	15.0 - 22.9	-20.4
IS2	104.8	242.0 - 346.9	19.2 - 26.7	-20.6
IS3	81.5	337.2 - 418.7	26.0 - 31.4	-20.6
IS4	88.1	412.0 - 500.1	31.0 - 36.3	-19.4
IS5	64.2	490.4 - 554.6	35.8 - 39.4	-20.2
IS6	70.1	549.7 - 619.8	39.1 - 42.8	-22.0
IS7	56.5	614.7 - 671.1	42.5 - 45.2	-21.9

Table 2.1: Specifications for ASAR Image Mode Swaths (for satellite altitude of 786.18 km).

These data enable a comparison of the phases and amplitudes from each antenna row. This is then used to characterise the row of radiating sub-arrays and the calibration path from the row.

External Calibration
Based on the successful methodology used for ERS-1/2, the external calibration scheme aims to derive an overall scaling factor correction. Three specially built high precision transponders will be deployed across the ASAR swath to provide measurements which can be used to provide across swath correction, derived from the radar equation, and calibration for the final image products. There will be a comprehensive calibration exercise to cover all the operating modes.

2.3. Operating Modes

ASAR has five different operating modes: Image Mode, Alternating Polarisation Mode, Wide Swath Mode, Global Monitoring Mode and Wave Mode (Fig. 2.2).

Image Mode
In Image Mode the ASAR will generate high spatial resolution products similar to the ERS SAR: images, with a 30 m spatial resolution and a swath coverage of up to 100 km (depending on incidence angle). New, flexible swath positioning will allow imaging of seven different swaths (IS1 to IS7) located over a range of incidence angles from 15° to 45°, with HH or VV polarisation. Table 2.1 provides details of the swath widths, ground position and incidence angle range for each of the 7 imaging swaths.

Alternating Polarisation Mode
The Alternating Polarisation Mode provides vertically and horizontally polarised imaging of the same scene by interleaving looks in each polarisation along track within the synthetic aperture. The echo measurement is made within repetition cycles containing two transmission bursts on each polarisation. In addition there are two cross-polarised modes, in which the transmit pulses are all H or all V polarisation and the receive chain operates alternately in H and V as in the co-polarisation mode. Possible dual channel combinations are therefore HH&VV, HH&HV or VV&VH. There is no capability for full quad-polarisation operation. Any of seven different swaths is selectable, the same as for Image Mode.

Wide Swath Mode
The Wide Swath Mode, using the ScanSAR technique (which achieves swath widening by the use of an antenna beam which is electronically steerable in elevation), provides medium resolution images (150 m) over a swath of 405 km, at HH or VV polarisation. ASAR transmits bursts of pulses to each of five sub-swaths in turn, in such a way that a continuous along-track image is built up for each sub-swath.

Table 2.2: Summary of ASAR characteristics

Mode	Spatial res (m)	Swath (km)	Polarisation	Equivalent no. of looks	Incidence angle (°)
Image	30	56 - 105	VV or HH	>3.9	15 - 45
Alt. Polarisation	30	56 - 105	VV and HH HH and HV VV and VH	>1.9	15 - 45
Wide Swath	150	405	VV or HH	~11.5	17 - 42
Global Monitoring	1000	405	VV or HH	~7-9	17 - 42
Wave	10	5	VV or HH	1	15 - 45

Global Monitoring Mode
The Global Monitoring Mode provides 1 km resolution images over a 405 km swath, using HH or VV polarisations. The mode has a low data rate, due to a slightly reduced along-track duty ratio and the use of analogue filtering and subsampling for data reduction in the across-track direction. ASAR operates independently of ground station coverage, offering a tool for global monitoring of features such as snow and ice, deforestation, desertification or soil moisture. The same sub-swaths are used as for the Wide Swath Mode.

Wave Mode
In Wave Mode the ASAR instrument will generate a minimum imagette size of 5 km × 5 - 10 km, similar to ERS SAR, spaced 100 km apart along track, with HH or VV polarisation. The position of the imagette across track is selectable as either constant or alternating between two across track positions over the full swath range. Similar to the Wave Mode on ERS, this will provide global sampling of ocean wave spectra.

Table 2.2 provides a summary of ASAR imaging specifications together with the predicted in-orbit performance in each operating mode.

2.4. Coverage

The orbit selected for Envisat will provide a 35 day repeat cycle, the same as the ERS-2 mission. Since the orbit track spacing varies with latitude (the orbit track spacing at 60° latitude is half that at the equator) the density of observations and/or revisit rate is significantly higher at high latitudes than at the equator. The flexible swath positioning in Image Mode greatly increases the potential temporal coverage frequency in comparison with ERS. Coverage is affected also by the different swath widths of IS1 to IS7. Table 2.3 shows the repeat coverage capability as a function of latitude and incidence angle variation (N.B. only for

Table 2.3: Average revisit frequency per 35 day orbit cycle as a function of latitude and incidence angle variation to illustrate ASAR revisit time capability (only for descending path).

Incidence Angle	Latitude			
	0°	45°	60°	70°
No Constraints	5	7	11	16
± 5°	3	4	6	9
± 2°	1	1.4	2	3
Exact repeat	1	1	1	1

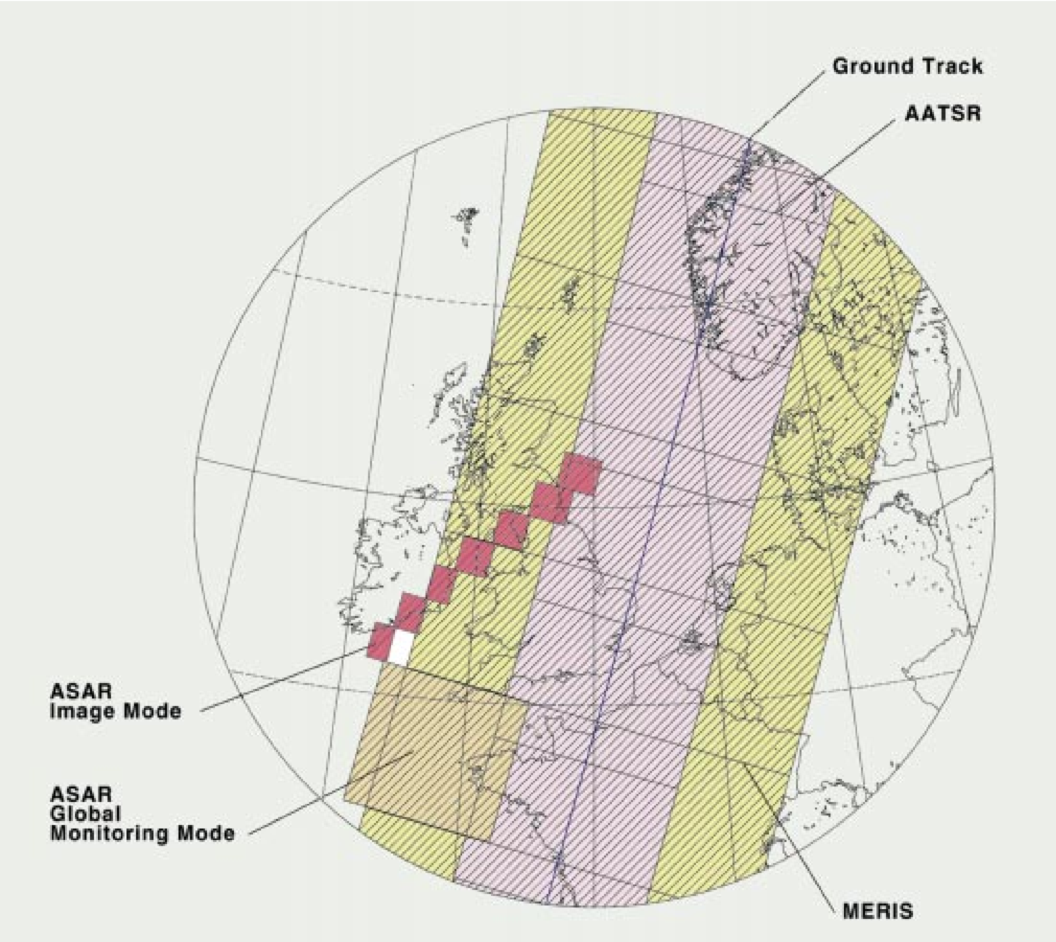


Fig. 2.3: Comparative simultaneous coverage of ASAR (Image (red); Wide Swath - Global (orange), AATSR (light brown) and MERIS (yellow).

descending tracks). If there are no incidence angle constraints, average revisit will be 7 days at the equator, improving to nearly every 2 days at 70° latitude.

ASAR will operate simultaneously with the other Envisat instruments. Fig. 2.3 shows the swath positioning of ASAR together with AATSR and MERIS coverage. Overlap with AATSR is seen to be quite limited, but ASAR IS1 to IS5 and most of Wide Swath/Global Monitoring Mode coverage fall within the MERIS cover.

The Envisat Swath and Orbit Visualisation (ESOV) software provides visualisation of the Envisat orbits, instrument swaths and ground station visibility. It is a free tool available to any user involved in Envisat data acquisition planning.

2.5. Data Products

Specifications for the standard ASAR data products are shown in Table 2.4. Many of the product types and definitions are similar to those used for ERS. For instance, Precision, Ellipsoid Geocoded and Single Look Complex images have the same nominal resolution and pixel spacing as their ERS equivalents.

Level 0 data products are the raw data suitable for image processing on other processing sites. These products would be required by remote sensing scientists for the testing of SAR processors and for research institutes interested in full SAR data processing.

Level 1b data products are geolocated engineering calibrated products.

Level 2 data products are geolocated geophysical products.

Precision, Ellipsoid Geocoded and Single Look Complex images are generated on request, but all other products are generated routinely when ASAR is acquiring data in the relevant mode. Stripline processing of

Table 2.4: ASAR data products

Product ID	Product Name	Nominal Resolution (m)	Nominal Pixel Spacing (m)	Approx. Coverage (km)	Equivalent No. of Looks
IMP	Image Mode Precision	30 x 30	12.5 x 12.5	56-100 x 100	> 3
IMS	Image Mode Single Look Complex	9 x 6	natural	56-100 x 100	1
IMG	Image Mode High Resolution Ellipsoid Geocoded	30 x 30	12.5 x 12.5	56-100 x 100	> 3
IMM	Image Mode Medium Resolution	150 x 150	75 x 75	56-100 x 100	40
IMB	Image Mode Browse		225 x 225	56-100 x 100	80
APP	Alternating Polarisation Precision Image	30 x 30	12.5 x 12.5	56-100 x 100	> 1.8
APS	Alternating Polarisation Single Look Complex Image	9 x 12	natural	56-100 x 100	1
APG	Alternating Polarisation Mode High Resolution Ellipsoid Geocoded	30 x 30	12.5 x 12.5	56-100 x 100	> 1.8
APM	Alternating Polarisation Mode Medium Resolution	150 x 150	75 x 75	56-100 x 100	50
APB	Alternating Polarisation Mode Browse		225 x 225	56-100 x 100	75
WSM	Wide Swath Mode Medium Resolution	150 x 150	75 x 75	400 x 400	11.5
WSB	Wide Swath Mode Browse		900 x 900	400 x 400	30 to 48
WVI	Wave Mode Imagette and Imagette Power Spectrum	9 x 6	natural	5 x 5	1
WVS	Wave Mode Image Spectra			5 x 5	
GMI	Global Monitoring Mode Image	1000 x 1000	500 x 500	400 x 400	7 - 9
GMB	Global Monitoring Mode Browse		1000 x 1000	400 x 400	11 - 15

browse, medium and low resolution data will produce products for up to 10 minutes data acquisition in Image, Alternating Polarisation and Wide Swath Modes, and up to a full orbit for Global Monitoring Mode.

Image Mode Products
The Precision Image product is a multi-look, ground range, digital image (in either HH or VV polarisation) suitable for most applications. It is intended for multi-temporal analysis and for deriving backscatter coefficients. Engineering corrections and relative calibration are applied to compensate for well understood sources of system variability. Absolute calibration parameters are provided in the product annotations.

The Ellipsoid Geocoded Image product is similar to a Precision Image, but with the best available instrument corrections applied for precise location and rectification to a map projection.

Single Look Complex (SLC) image data are intended for SAR image quality assessment, calibration and interferometric or wind/wave applications. A small number of corrections and interpolations are performed on the data in order to allow freedom in the derivation of higher level products.

A Medium Resolution Image product will be available at 150 m resolution, which is specifically aimed at sea ice and oceanography applications.

Alternating Polarisation Mode Products
These products are similar to Image Mode, with the addition of a second image at different polarisation combinations. The polarisation combinations are:

- the co-polarisation sub-mode (one image HH and one image VV)
- the cross-H polarisation sub-mode (one image HH and one image HV)
- the cross-V polarisation sub-mode (one image VV and one image VH)

Products contain two images corresponding to one of the three polarisation combination sub-modes, at reduced radiometric resolution in comparison with Image Mode.

Wide Swath Mode Products
The standard product available for Wide Swath Mode will be a 150 m resolution image with the full 405 km swath width.

Global Monitoring Mode Products
The Global Monitoring Mode product is a 1 km resolution image with a 405 km swath width, suitable for dissemination by electronic links in near real-time.

Wave Mode Products
ASAR wave mode products are based on small high-resolution, complex images of ocean scenes also called imagettes. These are processed to derive spectra of the ocean backscatter and consequently the wavelength and direction of ocean waves.

An SLC Imagette and Imagette Power Spectrum is the basic Level 1b product from the ASAR Wave Mode. A minimum number of corrections and interpolations are performed on the SLC data in order to allow freedom in the derivation of higher level products. Absolute calibration parameters are provided in the product annotations.

ASAR Wave Mode Spectra are available as a Level-2 product.

3. Technical Capabilities

3.1. Selectable Incidence Angles

The incidence angle is the angle between the radar beam and a line perpendicular to the surface at the point of incidence. Microwave interactions with the surface are complex and different scattering mechanisms may occur in different angular regions. Returns due to surface scattering are normally strong at low incidence angles and decrease with increasing incidence angle, with a slower rate of decrease for rougher surfaces. Returns due to volume scattering from an heterogeneous medium with low dielectric constant tend to be more uniform for all incidence angles. Thus, radar backscatter has an angular dependence, and there is potential for choosing optimum configurations for different applications.

In contrast to the ERS SARs, which had a fixed 23° incidence angle, ASAR Image Mode will provide data acquisition in seven different swath positions (i.e. IS1 to IS7), giving incidence angles ranging from 15° to 45°. The incidence angle range for each of the Image Mode swath positions and the slightly narrower range of incidence angles for Wide Swath and Global Monitoring Modes are shown in Table 2.1.

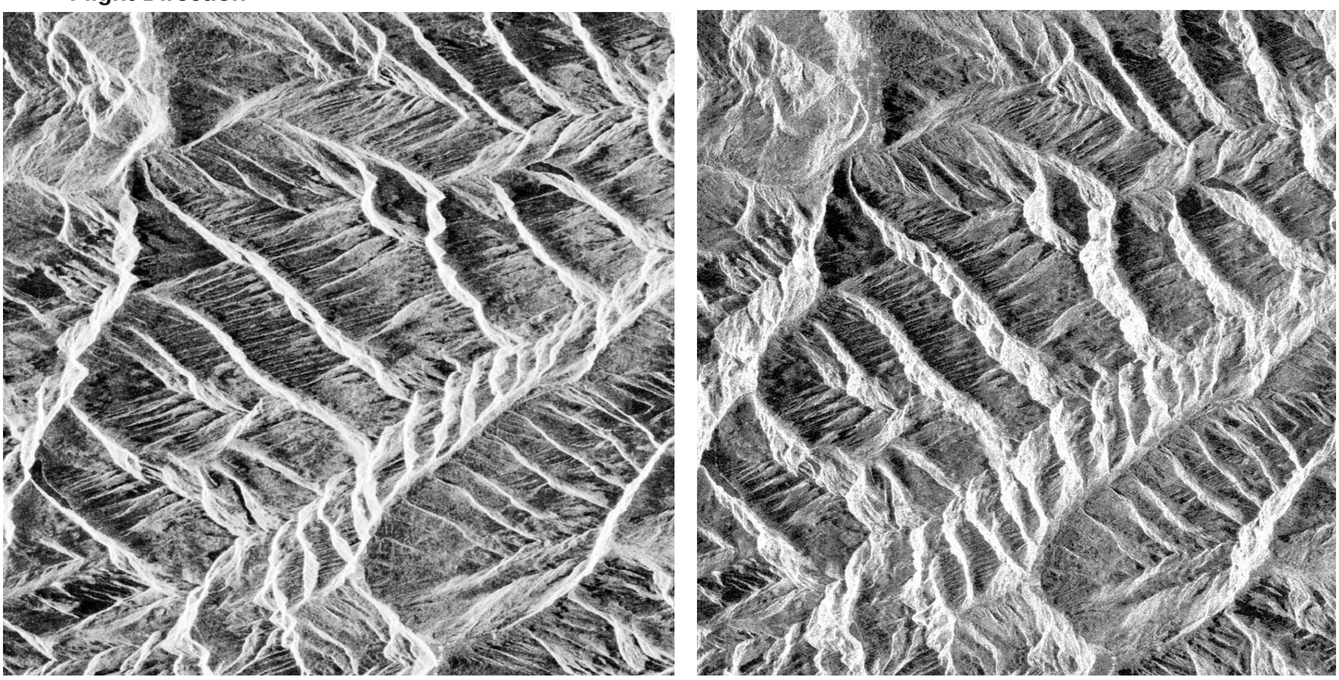
Fig. 3.1: Terrain distortion effects on SAR images obtained with different incidence angles: Zillertal Region, Austrian Alps. Area covered is approx. 35 km × 40 km. (Acknowledgement: H.Rott, University of Innsbruck)

Look Direction →

↑ Flight Direction

a. ERS-2 image acquired on 27/1/97, with incidence angles 24° - 26°

b. Radarsat fine beam image acquired on 2/2/97, with incidence angles 41° - 44°



One significant advantage of higher incidence angles is that terrain distortion is reduced. This is well illustrated by a comparison of ERS-2 and RADARSAT images of the Zillertal region in the Austrian Alps (Fig. 3.1). This region includes narrow valleys which range from 600 m at Mayrhofen, up to 3500 m on the highest peaks; up to about 1900 m, the slopes are partly forested, with alpine vegetation (grass, sedge, etc.), rocks and moraines at higher levels. The two images were obtained within a few days of one another, with a very similar viewing direction. Looking first at the ERS-2 image, obtained with incidence angles of 24° to 26° from near to far range, one sees extreme terrain distortion, in the form of severe foreshortening and layover (and brightening) of slopes facing the radar, combined with significant lengthening of the slopes facing away from the radar. In contrast, these distortions are seen to be much less in the Radarsat image where the incidence angle varies between 41° and 44° from near to far range on this image extract. One clear benefit of the higher incidence angle is the extra information which can be observed on the bright steep slopes facing the radar, and this has been found to greatly improve the value of the image for classification of surface classes such as moraines, bare soil and vegetation types.

With a range of different incidence angles available, it becomes possible to select optimum angles for different applications, or to use acquisitions from two separate passes for multi-angle analysis. In the context of vegetation and soil applications there are some general points which can be made, based on previous research results:

- for soil moisture and soil roughness studies, the combination of different incidence angles is of interest, with the condition of short time intervals between acquisitions
- for agriculture, the use of particular incidence angles will improve selective observation of vegetation (high incidence angles) or underlying soil (low incidence angles)
- for forestry, the use of low incidence angles enhances the sensitivity to biomass, whereas the use of high incidence angles enhances the discrimination of forest types through interaction with forest structure.

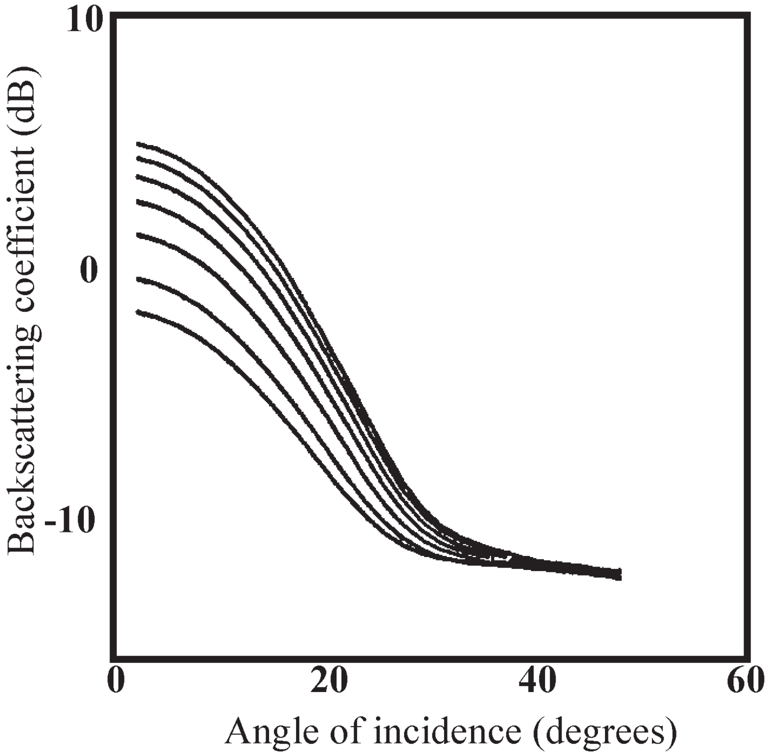


Fig. 3.2: Simulated backscatter for a soybean canopy showing increased sensitivity to soil moisture at low incidence angles. (Acknowledgement: Nghiem et al., 1993)

Fig. 3.2 illustrates the importance of the incidence angle in isolating the radar response due to the vegetation canopy from that of the underlying soil. Each curve represents the simulated response, with C-band VV polarisation, of a soybean canopy for

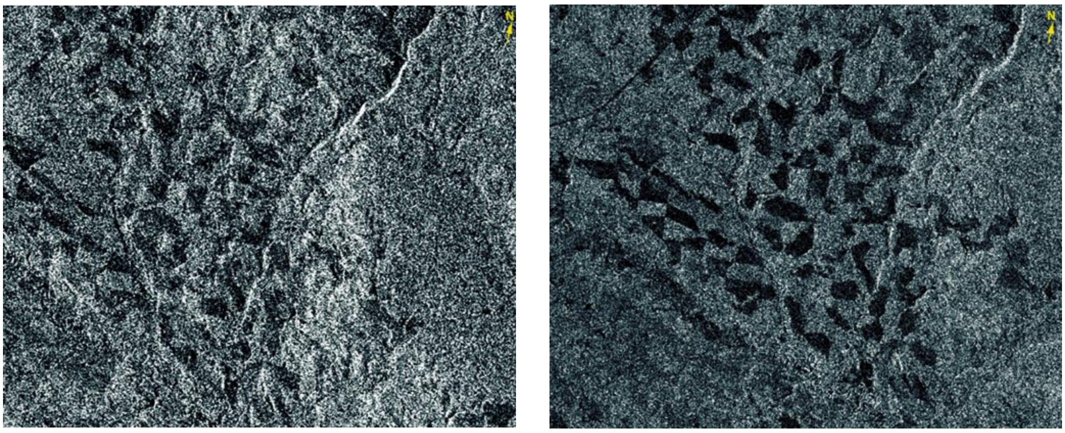


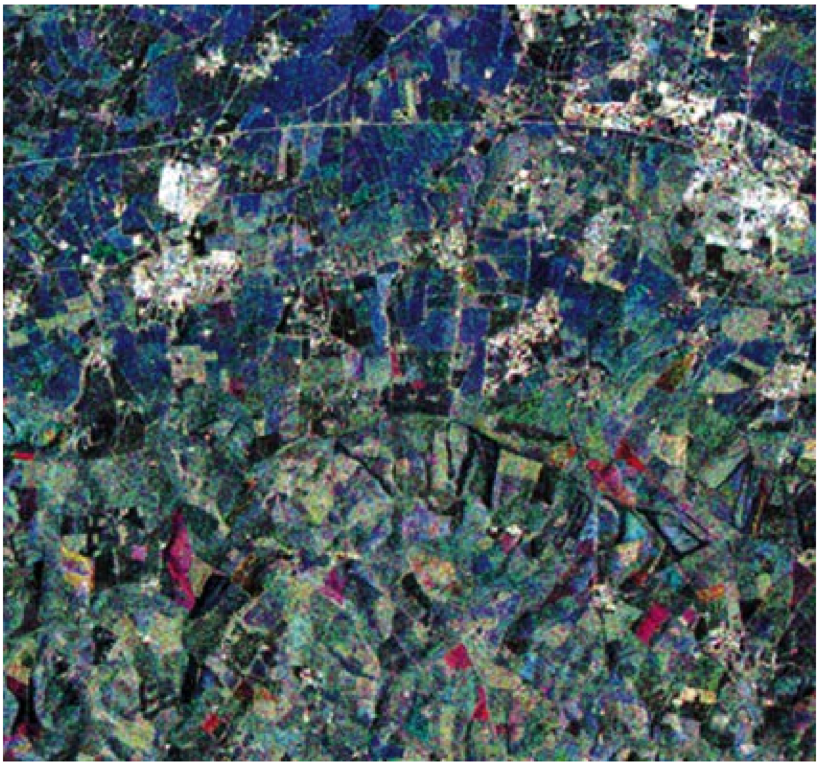
Fig. 3.3: Radarsat images acquired at different incidence angles (a. 20°-27°, b. 45°- 49°), showing Forest Clearcuts in Alberta, Canada. (Acknowledgement: L. Gray, CCRS, Canada)

varying gravimetric soil moisture ranging from 2% to 30% (from bottom to top). Whilst the backscatter at 20° incidence angle is still sensitive to underlying soil conditions, that at 40° is stable and invariant with respect to soil moisture.

Fig. 3.3 provides an excellent example of how vegetation mapping can be enhanced by using high incidence angle data. This pair of Radarsat images show discrimination of forest clearcuts in Whitecourt, Alberta, an active logging area in the foothills of the Rocky Mountains. On the first image, acquired at an incidence angle of 20° - 27° there is poor contrast between the clearcuts and the forest, but on the second, which was acquired at a much larger incidence angle of 45° - 49°, the dark tones of the clearcut areas contrast strongly with the brighter returns from the surrounding forest.

Images acquired with different incidence angles may be used in combination to improve land cover discrimination, but since each image has to be acquired on a different day, any composite image will also include a temporal change component.
Fig. 3.4 provides an illustration of the use of multiple incidence angles to improve land cover discrimination for an area near Oxford, UK. In this case, 3 Radarsat images taken within a period of 10 days have been combined (Blue - 23° 23rd March 97, Green - 37° 13th March 97, Red - 43° 3rd March 97). Most of the coloured areas on the image, indicative of backscatter differences related to incidence angle, are bare soil fields, while grassland, woodland and urban areas tend to have grey tones, showing a similar backscatter at the different incidence angles. In the northern half of the area, which has clay soils, practically all bare soil fields have a blue colour, indicating higher backscatter at the lowest incidence angle, as one would expect. In the southern half of the area which has chalk soils, some of the bare soil fields also have blue colours, but

Fig. 3.4: Multiple incidence angle image of Oxfordshire area, UK Composite of Radarsat images:
Blue: 23° - 23/3/97,
Green: 37° - 13/3/97,
Red: 43° - 3/3/97.
(Acknowledgement: Remote Sensing Application Consultants, UK)



some of the fields coloured red are also bare soil fields and this seems something of an anomaly. Possible explanations are that these fields have marked differences in soil roughness, or possibly that cultivation changes took place during the period over which the 3 images were acquired.

Ship detection with ERS data was limited to a certain extent by the steep incidence angles. As illustrated in Fig. 3.5, Radarsat has now clearly demonstrated the benefits of higher incidence angle data for the detection of ocean-going trawlers (typically 55 m long) and Radarsat images are already used pre-operationally for monitoring fishing activity in the Barents Sea. The pattern of trawlers seen on this image shows a marked concentration in International Waters along the boundary with Norwegian Waters. Several of the outer ASAR standard beams will be capable of detecting trawlers, although in a rather narrow swath. Also, cross polarised images from the Alternating Polarisation Mode should further improve detection capability at steeper incidence angles.

Although higher incidence angles are preferable for ship detection, wide swath and ScanSAR images (such as that shown in Fig. 3.6) can be used across most of the incidence angle range, giving excellent wide area coverage.

Fig. 3.5: Radarsat image showing fishing vessels in the Barents Sea, similar to what will be possible with ASARs higher incidence angles (25 km scene width) (Data copyright Canadian Space Agency)

3.2. Dual Polarisation

Imaging radars can transmit horizontal or vertical electric-field vectors, and receive either horizontal or vertical return signals, or both. The basic physical processes responsible for the like-polarised return are quasi-specular surface reflection and surface or volume scattering. The cross-polarised return is usually weaker, and often associated with multiple scattering due to surface roughness or multiple volume scattering. Scattering mechanisms and the returns from different surfaces may also vary markedly with incidence angle.

ASAR will provide dual channel data. In Alternating Polarisation Mode it will provide one of three different channel combinations: 1. VV and HH, 2. HH and HV, 3. VV and VH. Dual polarisation data will be important for a wide range of applications.

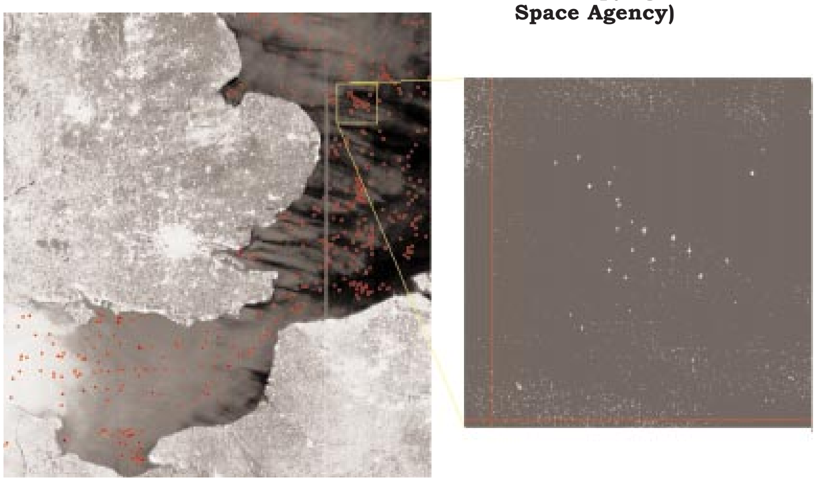


Fig. 3.6: Radarsat ScanSAR image of the English Channel and North Sea showing ship/oil rig detections. The enlarged inset shows a cluster of oil rigs in the North Sea. (Acknowledgement: Space Dept., DERA, UK; Data copyright Canadian Space Agency)

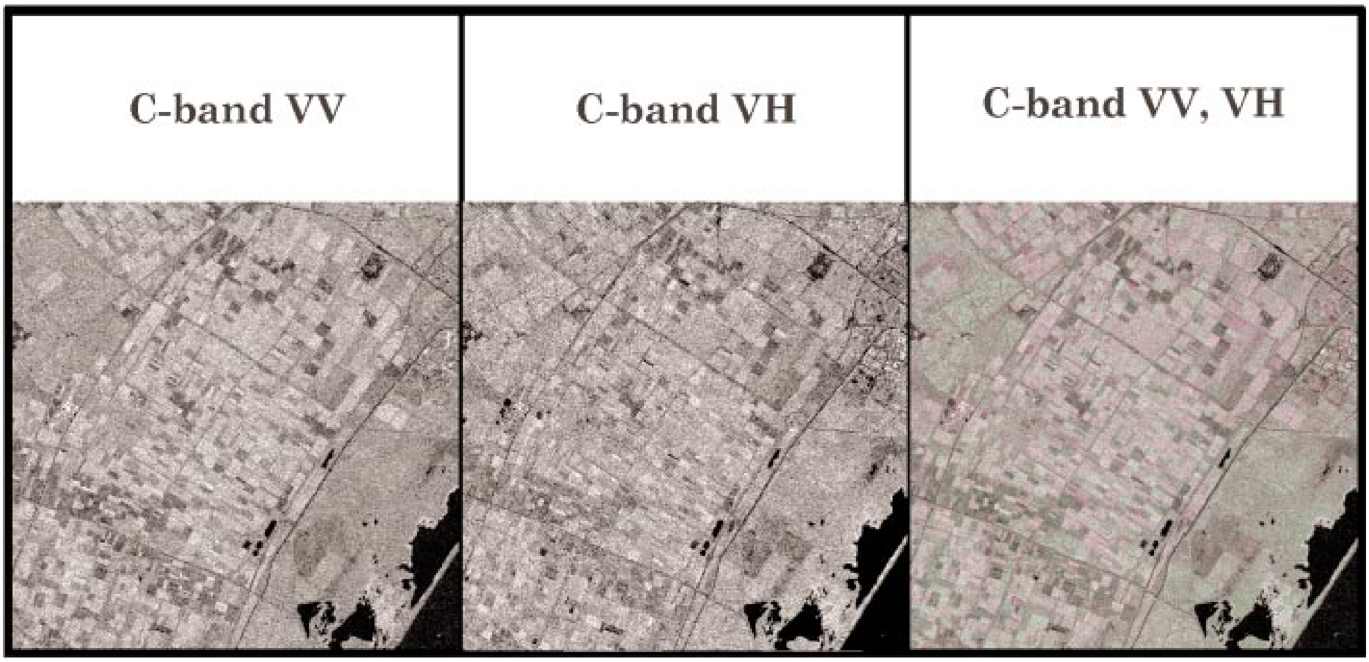


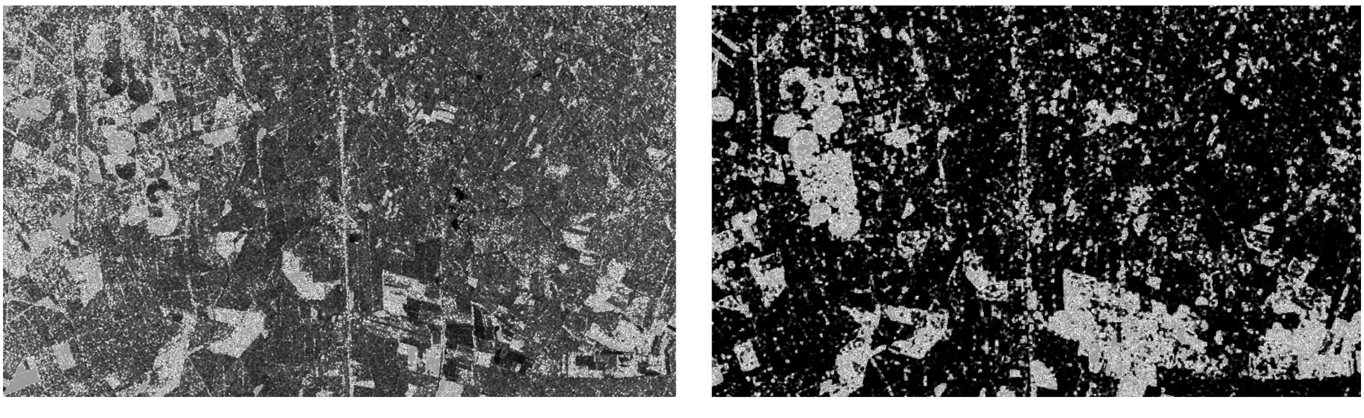
Fig. 3.7: SIR-C images of Flevoland, The Netherlands, 5/10/94
a. VV polarisation,
b. HV polarisation,
c. combination of VV (magenta) and HV (green) polarisations.
(Acknowledgement: M. Davidson & T. Le Toan, CESBIO, France)

Fig. 3.8: SIR-C data (C-band, 26.5°) over Les Landes test site, France. Left image is backscatter intensity (VV polarisation) and right image is HH/VV correlation image. (Acknowledgement: Souyris et al., 1998)

For studies of bare soil, where attention focuses on the retrieval of soil moisture and soil roughness, the use of different polarisations will improve the inversion into soil parameters. Cross polarisation will provide an important improvement for soil moisture retrieval since the radar backscatter is less sensitive to surface roughness, row direction, etc.

For many vegetation studies, the use of different polarisations, in particular cross-polarisation, will improve the discrimination between vegetation (volume scattering) and soil (surface scattering). In the case of forestry, the use of cross polarisation will improve the forest/non forest discrimination and the retrieval of low biomass values (forest regeneration, regrowth, plantation). Two examples are provided below showing how the use of dual polarisation data can improve the information content.

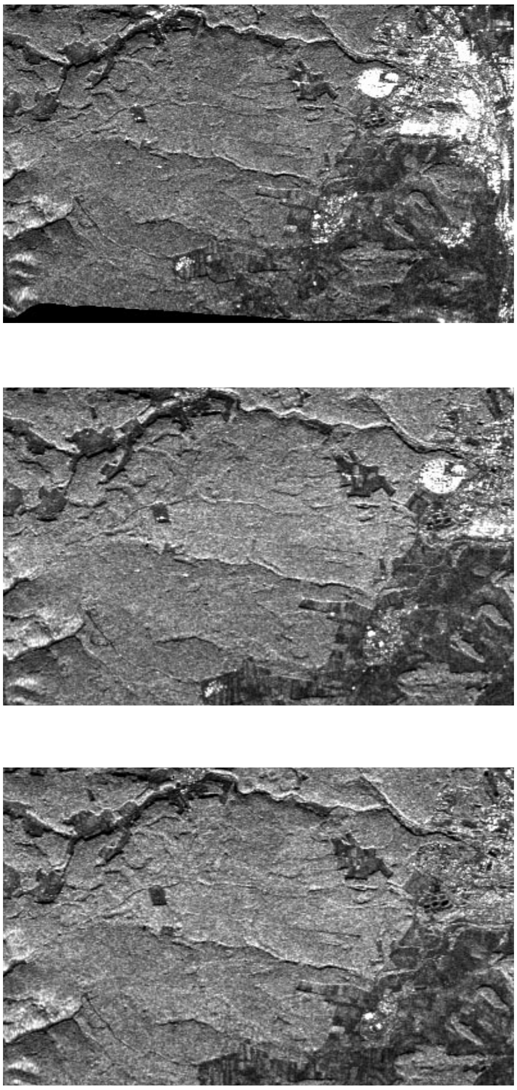
In Fig. 3.7, the combination of SIR-C VV and HV polarisation images over Flevoland, The Netherlands, is seen to greatly improve interpretability in comparison with the single channel images. Looking at the VV/VH composite image, areas with a relatively high backscatter at VH



polarisation are characterised by a green colour. These areas correspond to those having strong volume scattering, including forests (upper left and bottom right of image), crops such as potatoes, maize and sugar beet, and pasture (dark green). The different shades of green depend on crop type and condition. On the other hand, areas with relatively high surface scattering, such as bare soil fields and urban areas, have a magenta colour.

In Fig. 3.8, the SIR-C backscatter intensity image (left) shows poor discrimination between vegetated and non-vegetated areas. This is because of large variations in the backscatter of bare soil surfaces related to different soil roughness and moisture conditions and is similar for both VV and HH polarisation images. However, using both polarisations to produce a HH/VV correlation image (right), it becomes possible to discriminate between non-vegetated (high correlation) and vegetated (low correlation) areas. On this image the high correlation (bright) areas correspond to recently harvested cornfields. In contrast, the different states of tillage are seen to produce large variations in backscatter intensity in the single channel image.

Fig. 3.9 illustrates differences between like-polarised and cross-polarised images of urban areas. Three different polarisation images are shown for an area in southern Germany which was imaged by the JPL AIRSAR during the MAC Europe campaign in 1989. The area is 12 km wide, and includes forests, cultivated fields and urban areas. The two like-polarised images are seen to be very similar. However, on the cross-polarised image, urban areas are seen to be much less bright. This is because the cross-polarised return only appears through multiple scattering, while the urban areas are characterised by man-made objects that act like corner reflectors.



HH

VV

HV

Fig. 3.9: Three different C-band polarisation images for an area in southern Germany imaged by the JPL AIRSAR during the 1989 MAC Europe Campaign.

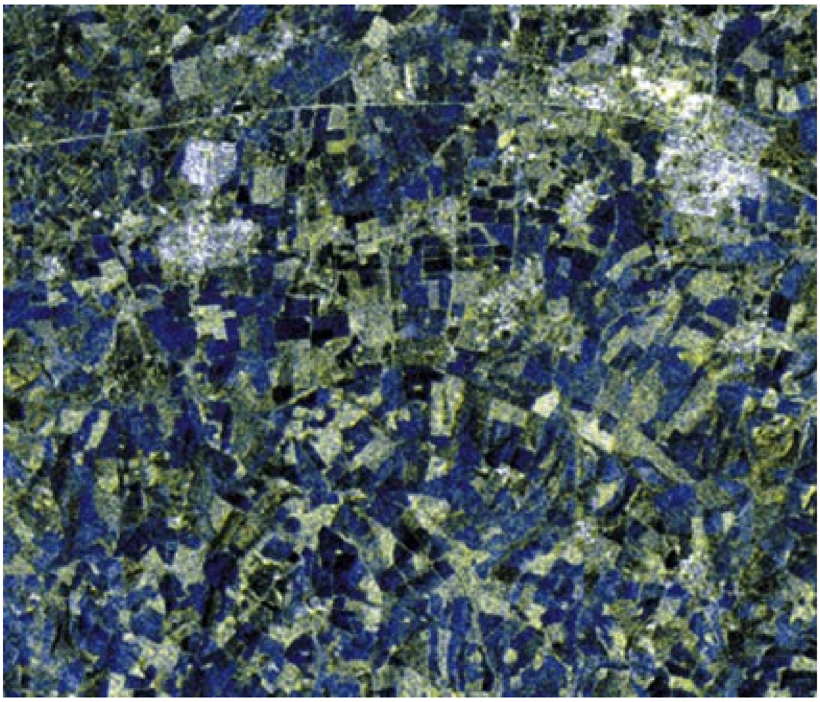


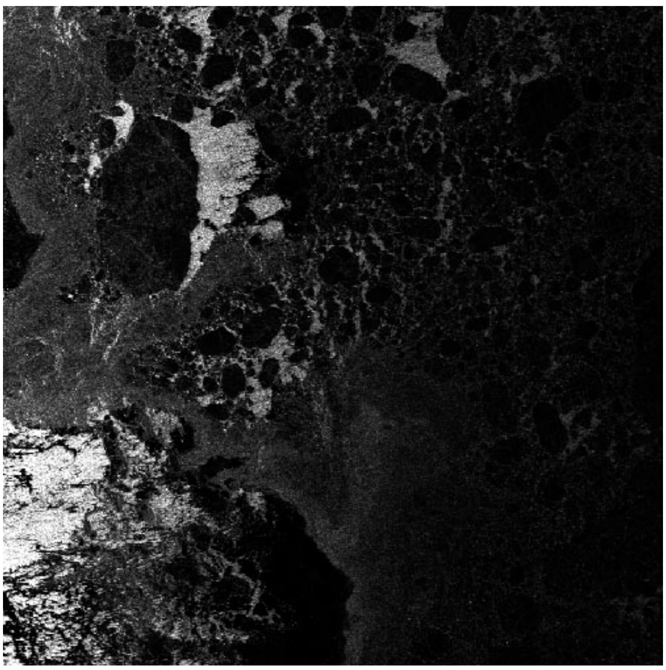
Fig. 3.10: Simulated Alternating Polarisation image (VV&HH) of an area in Oxfordshire, UK. (Red & Green: ERS 26/5/97, Blue: Radarsat 27/5/97). Acknowledgement: Remote Sensing Applications Consultants, UK

It is possible to simulate Alternating Polarisation images (VV/HH) using ERS and Radarsat data. Fig. 3.10 shows a combination of ERS and Radarsat images taken one day apart, for an area in Oxfordshire, UK. In this example a large number of agricultural fields are seen to have a blue colour which is indicative of a high backscatter in HH polarisation compared with VV. Since these fields are all cereal fields, this is a good indication of the value of alternating polarisation images for improving crop classification. Over the remainder of the image, urban areas, woodland and grassland all have grey tones indicating no significant differences in HH and VV backscatter.

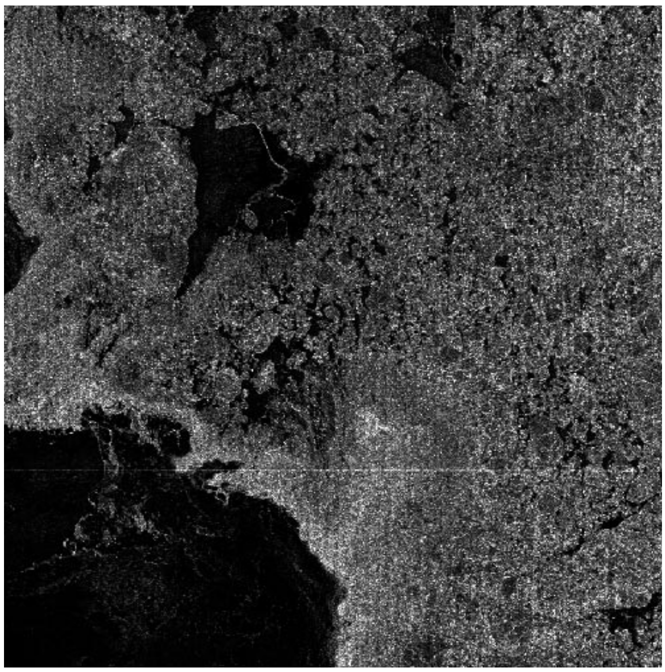
There is considerable interest in the Alternating Polarisation Mode for sea ice applications. From current research results using ERS and Radarsat data it is still not clear whether VV or HH polarisation is generally better for mapping sea ice. One of the current problems using

Fig. 3.11: Almost simultaneous ERS and Radarsat images covering 80 × 80 sq km centred around 82°N 12°E. The ERS image was acquired from a descending orbit at 12:58 and the Radarsat (which has been rotated by 90 degrees) from an ascending orbit at 14:33, both on 19/9/96. The images are averaged to the same pixel spacing and the image intensity is stretched.
(Acknowledgement: J. Askne and A. Li, Chalmers Univ. of Technology, Sweden).

a. ERS-2 (VV polarisation)



b. Radarsat (HH polarisation)



either ERS or Radarsat data at low incidence angles is that ice-water discrimination can sometimes be poor. Alternating polarisation, HH and VV data, will give improved Ice Edge/Water Discrimination. Cross polarisation data are expected to be particularly useful for mapping ice topography (ridging, rubble), and are also likely to give improved ice type discrimination.

Fig. 3.11 showing ERS and Radarsat images from the Arctic, acquired less than 2 hours apart, provides a very striking example of the differences that can occur between VV and HH polarisation images, although in this case it should be noted that the radar viewing directions were virtually opposite. Over much of the area one can see large signature reversals between the VV and HH images. Differences show up primarily over open water. The wind speeds recorded onboard the icebreaker Oden, 55 km away from the scene centre, were 8 and 14 m/s respectively. The incidence angle varies between 21 and 26 degrees over the ERS-2 subimage and between 29 and 34 degrees over the RADARSAT sub-image. The different VV and HH responses to wind roughening can be used for wind determination, and the sea ice differences can help in classifying ice properties.

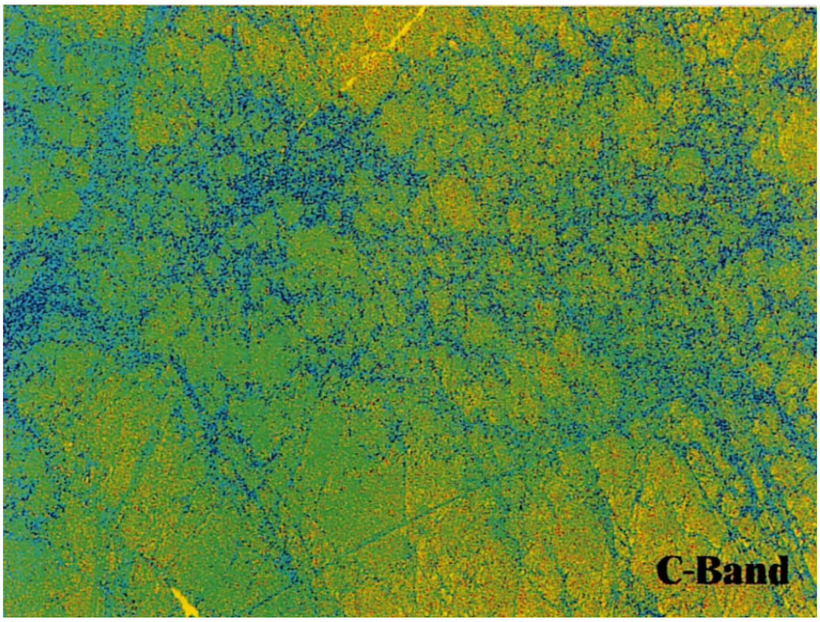


Fig. 3.12: Copolarisation ratio VV/HH image for the Baltic Sea Ice site imaged by EMISAR during EMAC-95. (Acknowledgement: Dierking et al., 1997).

The EMAC-95 airborne radar experiment demonstrated the value of dual polarised data for discriminating sea ice types. Fig. 3.12 shows an EMISAR C-band co-polarisation ratio VV/HH image covering Baltic Sea Ice (Dierking et al., 1997). The green and yellow areas on this image have co-polarisation ratios larger than 1, and correspond to level ice and thin ice/open water. The largest values (green) are associated with smooth ice surfaces. A low co-polarisation ratio around 1 (blue) is observed for highly deformed areas and ridges, where the return radar signal is dominated by coherent (specular) scattering.

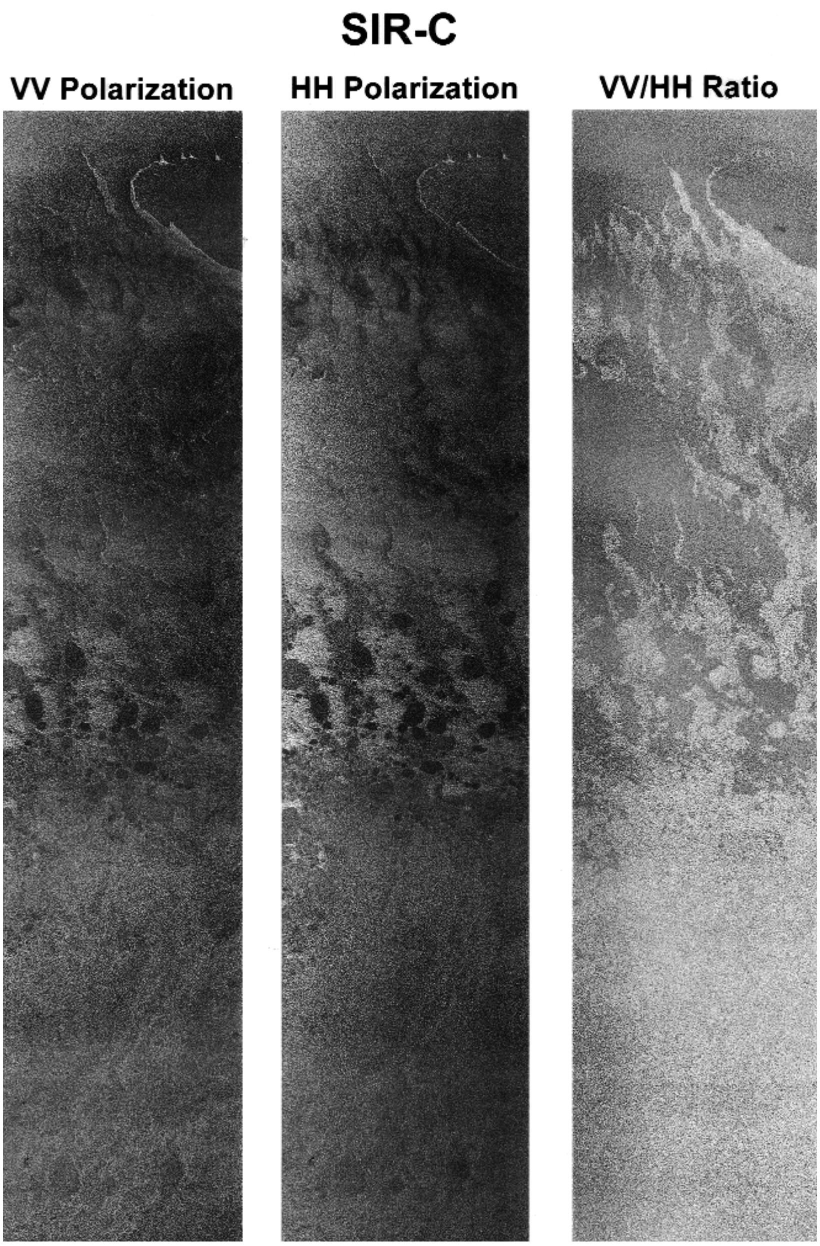


Fig. 3.13: Dual polarisation images (VV, HH and VV/HH ratio) from SIR-C for the Gulf of St. Lawrence. (Acknowledgement: L. Gray, CCRS, Canada)

Another example illustrating the value of the ratio VV/HH for discriminating ice/no ice is provided in Fig. 3.13, which shows HH, VV and VV/HH ratio images of a mixed pack ice and open water scene in the Gulf of St. Lawrence, imaged by the SIR-C radar. Discrimination of ice/water is complicated by incidence angle and wind conditions and is not always easy with either HH or VV polarisations. However, since the ratio of VV to HH backscatter is larger than 1 for open water but close to 1 for pack ice, the sea ice is seen to be much darker on the VV/HH ratio image, independent of incidence angle or wind conditions.

Over the oceans the backscattering signal is stronger with VV than with HH polarisation. Experimental results indicate that oceanic features such as internal waves, fronts and bottom topography tend to appear somewhat better with HH than with VV polarisation. Fig. 3.14 (Radarsat, HH polarisation) shows internal waves in the Straits of Gibraltar particularly well. In contrast, sea surface imprints of atmospheric features (in particular, convective cells) appear to be more visible with VV polarisation than with HH polarisation. There are many excellent examples of atmospheric phenomena seen with VV polarisation ERS images, such as those illustrated in Fig. 3.15.

The ASAR Alternating Polarisation Mode is therefore of strong interest for ocean studies. Simultaneous dual polarisation images will allow discrimination between similar signatures of oceanic/atmospheric features (e.g. fronts, internal waves). The most favourable can be chosen for detection of oceanic/atmospheric features or for special applications. Wind vector retrieval from SAR images and the tuning of imaging models (e.g. in bathymetric assessment systems) becomes easier if backscatter variations with HH and VV polarisations are known.

3.3. Wide Area and Frequent Coverage

ASAR low resolution images provided by the Wide Swath and Global Monitoring Modes open up new possibilities for applications requiring large area coverage and/or more frequent revisit. Both modes will provide 405 km swath coverage. For applications where higher resolution is necessary, better than a 5 day

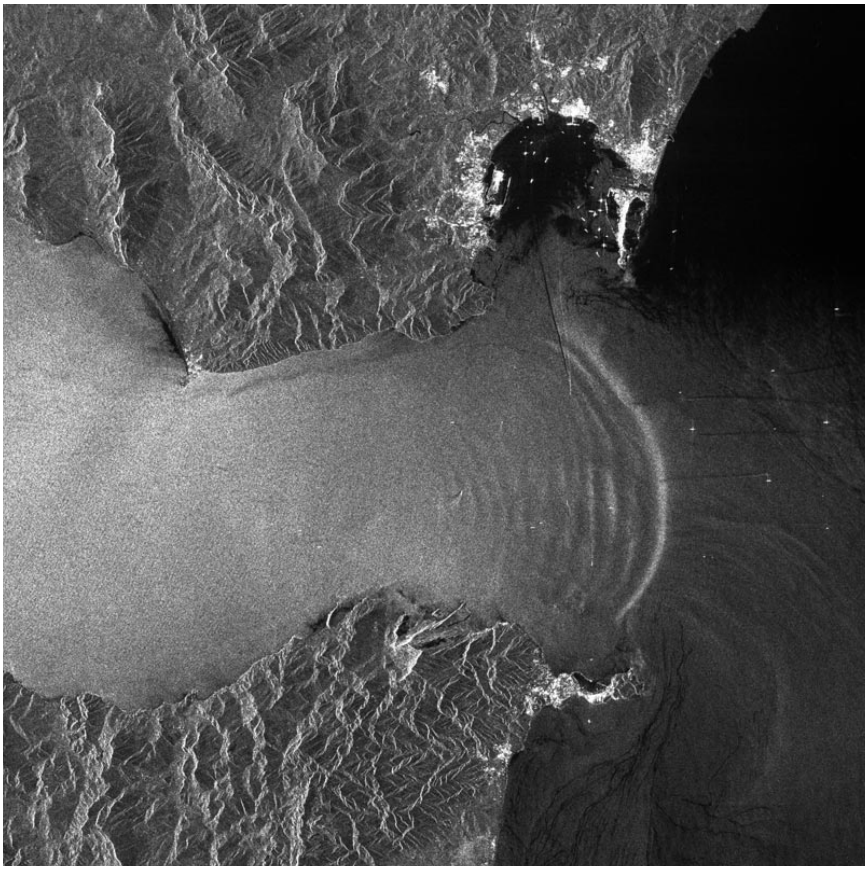


Fig. 3.14: Internal wave packet seen on a Radarsat image of the Straits of Gibraltar. (Acknowledgement: Space Dept., DERA, UK; Data copyright Canadian Space Agency)

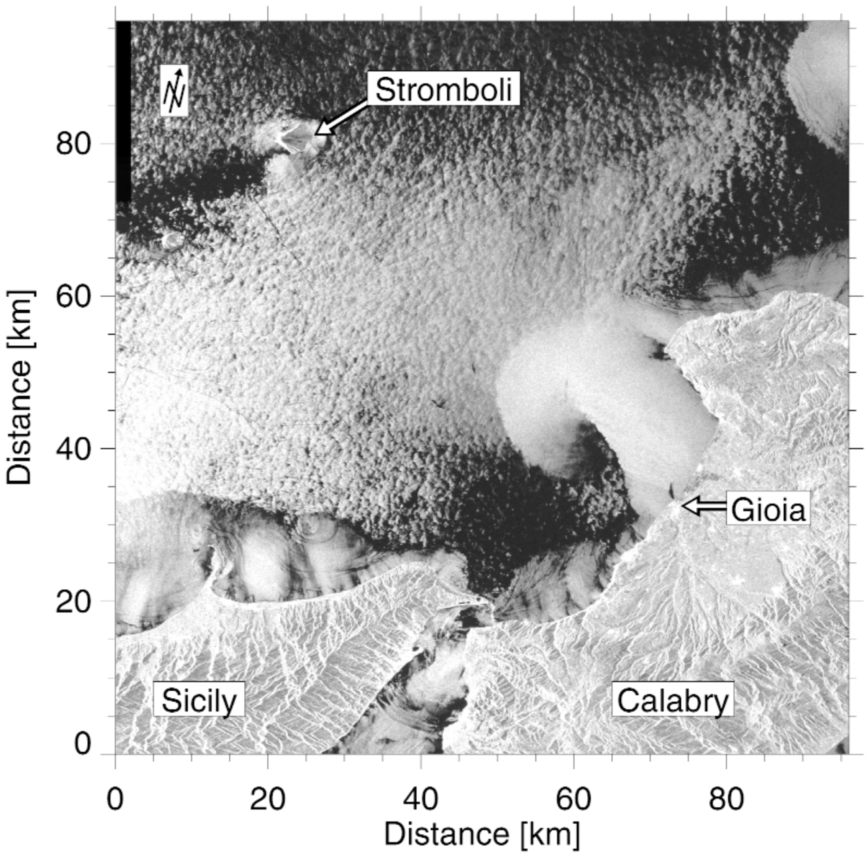


Fig. 3.15: ERS-1 SAR image (100 km × 100 km) of the Mediterranean Sea north of the Strait of Messina acquired on 8/9/92. To the north-west of Gioia there are surface manifestations of a katabatic wind (bright area). Furthermore, between the island of Stromboli and the Sicilian coast there is a granular pattern, which is interpreted as sea surface “imprints” of atmospheric convective cells. This cellular structure is destroyed in the vicinity of the Sicilian coast by the katabatic wind blowing from the mountains on to the sea. In the lower section of the image an oceanic internal wave train can be delineated propagating southwards in the Strait of Messina. (Acknowledgement: W. Alpers, Univ. Hamburg, Germany).

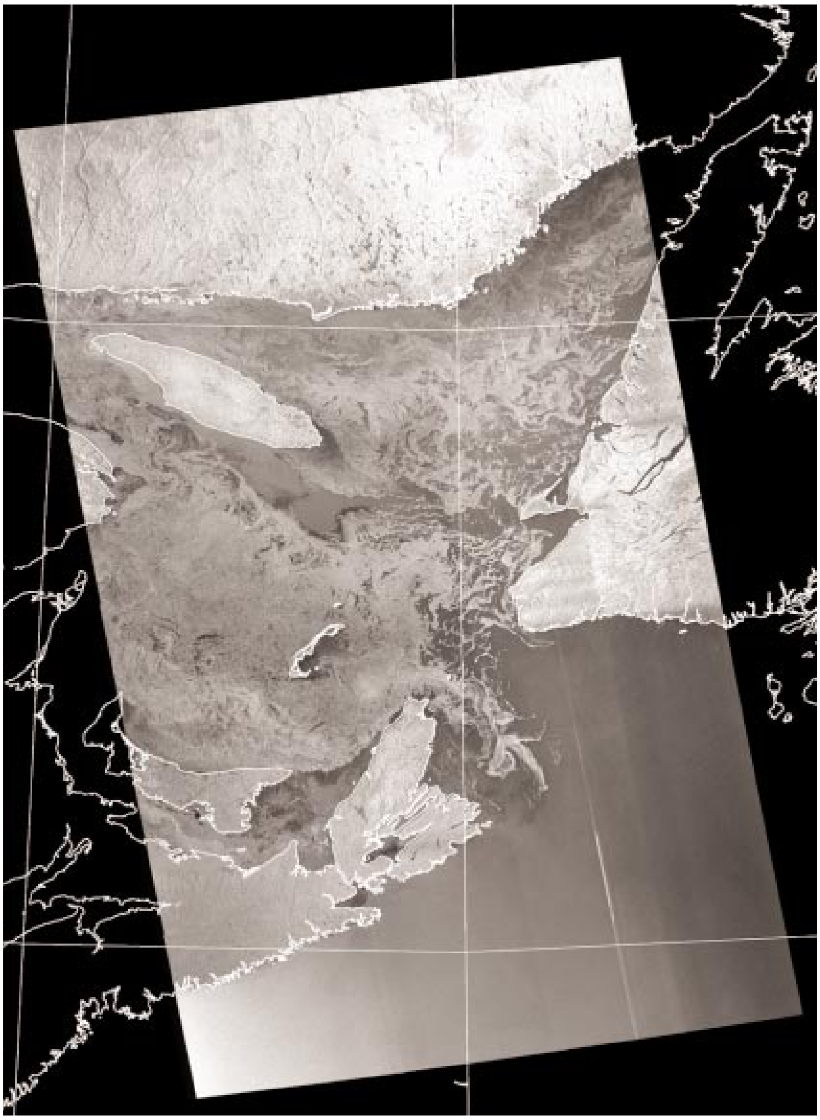


Fig. 3.16: Sea Ice Monitoring using Radarsat ScanSAR data in the Gulf of St. Lawrence, Canada, 6/3/96. Swath coverage is 450 km, with 250 m pixel spacing. (Radarsat Data Copyright Canadian Space Agency/Agence spatiale canadienne 1996. Received by the Canada Centre for Remote Sensing. Processed and distributed by Radarsat International. Imagery enhanced and interpreted by CCRS).

repeat interval is possible for approximately 100 km × 100 km areas using Image Mode (see Table 2.3).

ASAR Wide Swath is aimed primarily at sea ice and other oceanographic applications, where there is a special interest in obtaining a wide area view with high temporal frequency. Fig. 3.16 shows a Radarsat wide swath image of the Gulf of St. Lawrence on which ice types are seen in various shades of light grey, in contrast with water which has the darkest tones. Such images are now used routinely by the Canadian Coast Guard for ice breaker operations and routing of ships in the Gulf.

The ASAR Global Monitoring images, with low data rates, promise to be particularly valuable for sea ice mapping over extensive areas. Fig. 3.17 shows a simulation of an ASAR Global Monitoring Mode image for regional ice reconnaissance. The simulation is based on a Radarsat ScanSAR wide, C(HH), image of the southern Beaufort Sea. The original 100m resolution, 500 km image, which was acquired on October 11th 1996, shows the Mackenzie delta and Tuktoyuktuk peninsula to the south, the new ice and open water in the lead just north of the shore-fast ice, and the pack ice to the north occupy most of the image. The simulation was obtained by reducing the swath from 500 km to 400 km, then sub-sampling and smoothing the image to simulate both the spatial resolution (1 km) and the radiometric resolution of the ASAR Global Monitoring Mode. The simulation shows the potential value of the resulting product. Although the transition from land to shore-fast ice is not distinct, there is still sufficient detail in the ice imagery to recognise areas of slightly lower pack ice concentration (to the east), and to recognise the westward drift of the pack ice just north of the shore-fast ice. This is consistent with the normal clockwise ice movement in the Beaufort Sea gyre.

The frequent large area coverage which ASAR is able to provide is also important for monitoring ice sheets. Of course, ERS already provides frequent revisits of polar regions and the value of this has been well demonstrated in a study of the collapse of the northern Larsen Ice Shelf, Antarctica (Rott et al., 1996). Fig. 3.18 shows two ERS-1 SAR images of the Larsen Ice Shelf. The first (left image) is a strip of three 100 km × 100 km images from a descending pass on 30th January, in

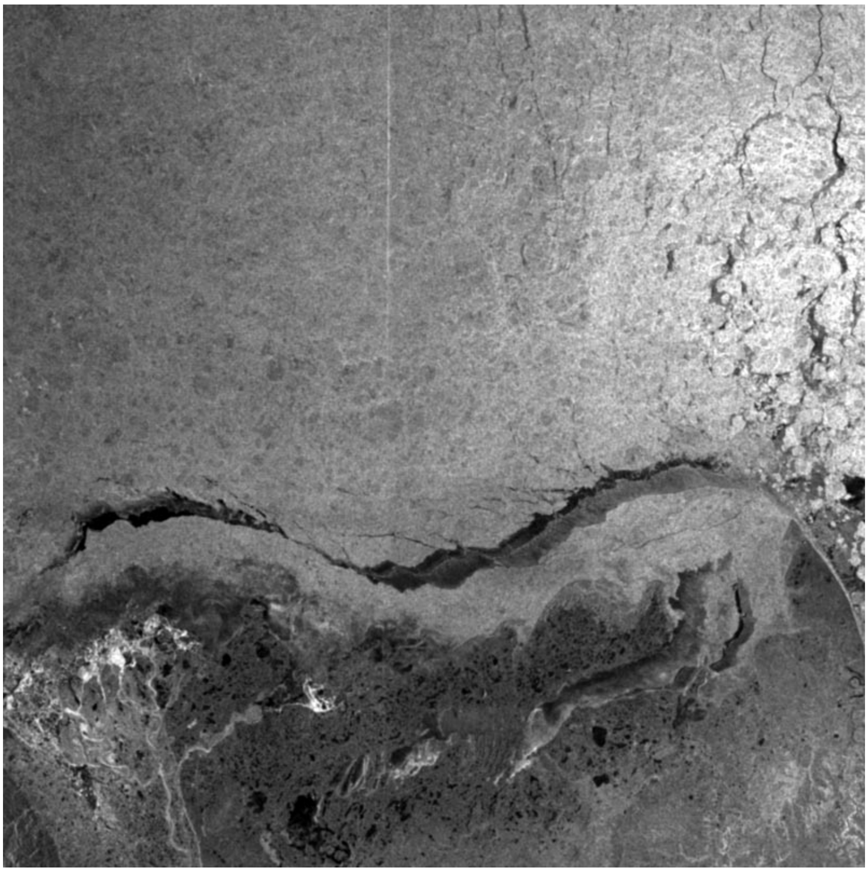


Fig. 3.17: ASAR Global Monitoring Mode simulation using Radarsat ScanSAR wide data. (Acknowledgement: L. Gray, CCRS)

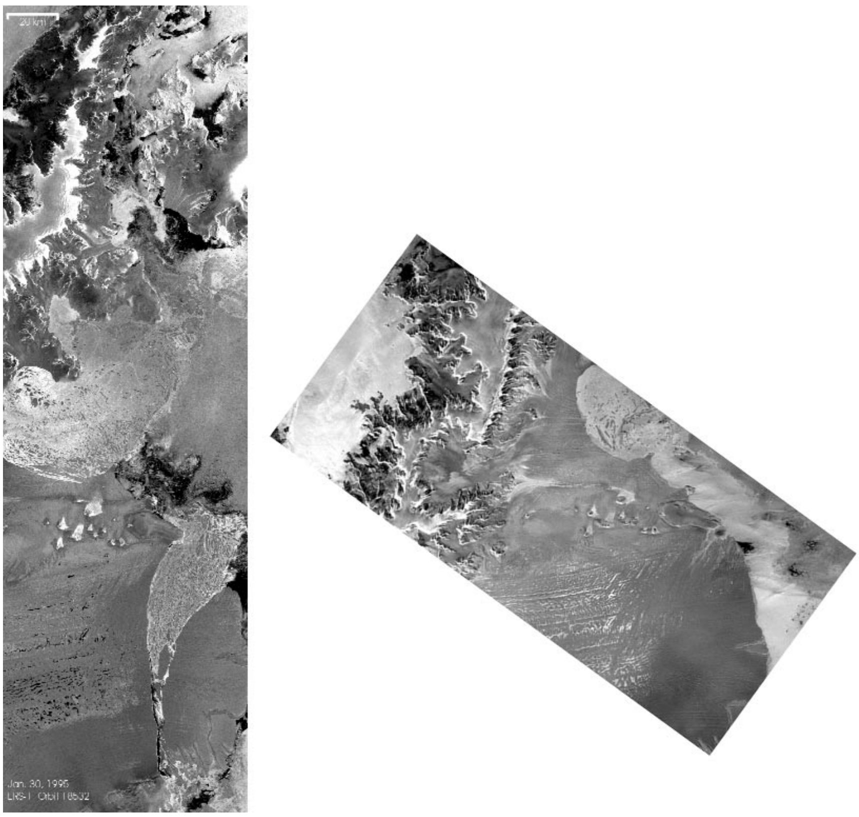
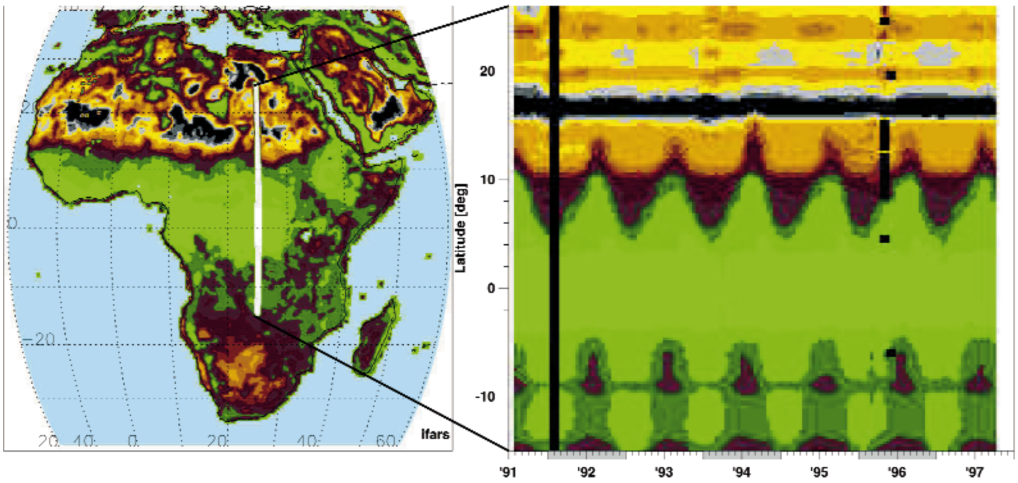


Fig. 3.18: ERS SAR images of the Larsen Ice Shelf, Antarctica. The left image is a strip of 3 standard 100 km × 100 km images (descending pass) taken on 30/1/95, showing break-up of the ice shelf. The right image is another strip of 100 km images (ascending pass) taken on 25/1/95, when the ice shelf can be seen to be largely intact. (Acknowledgement: H.Rott, University of Innsbruck, Austria).

Fig. 3.19: ERS-1 scatterometer map of Africa and a Hovmoeller diagram for a slice through Africa from 35°N to 35°S at the longitude of 20°E. Monthly averages are plotted for 1991 to 1997. (Acknowledgement: V. Wismann and K. Boehnke, IFARS, Germany)



which the ice sheet can be seen breaking up. Looking at the second (right) image, which was taken just five days earlier, one sees the ice shelf still largely intact. Such images provide valuable information on the timing and rates of change, in this case illustrating the extremely rapid disintegration of the ice shelf over a few days at the end of January 1995. ASAR will be able to provide daily coverage of such phenomena in the polar regions and another important advantage will be the on-board storage capability. For Antarctica, the O' Higgins ERS receiving station currently operates only for two 5 week periods per year.

Over the land, interests focus on the potential of low resolution SAR data for soil moisture and vegetation monitoring.

Previous work carried out over the land using ERS Wind Scatterometer

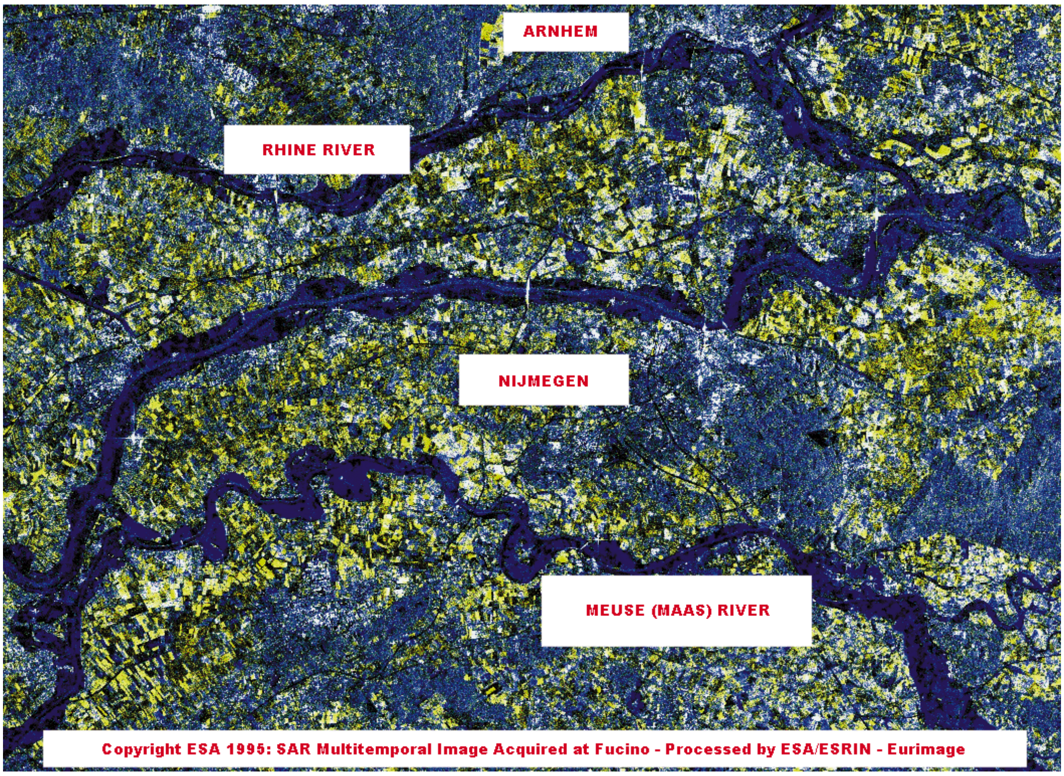


Fig. 3.20: Combined ERS SAR and Landsat Image showing flooding in the south of The Netherlands during January 1995. The flooding along the lower Rhine, the Waal and Maas, is derived from the analysis of multi-temporal ERS SAR data, with additional information provided by the Landsat image. (Acknowledgement: C. Pohl, Y. Wang & B.N. Koopmans, ITC, The Netherlands).

data has already shown that low resolution measurements, in this case 25 km spatial resolution, can provide useful information concerning vegetation dynamics and freeze/thaw on a continental and regional scale (Wismann & Boehnke, 1994).
Fig. 3.19 shows how the ERS Wind Scatterometer has been used to monitor seasonal variations over the African continent. Besides the scatterometer image for summer 1993, the so-called Hovmoeller diagram shows a slice through Africa from 35°N to 35°S extending longitudinally from 20° to 26°E. Monthly averages of the radar intensity are plotted for the period from 1991 to 1997. The predominant signal in the Hovmoeller diagram is the annual variation in radar backscatter in the savanna region north and south of the rain forest, and it can be seen how the pattern of increased backscatter in 1992 is repeated every year. The much better resolution of the ASAR Global Monitoring Mode will provide a significantly improved capability for continental or regional scale measurements.

The availability of approximately 5 day revisit coverage (in Central Europe) using Image Mode promises to be particularly important for flood mapping. For floodplain mapping and emergency management, a resolution of around 30 m is required, with frequent coverage. Examples such as that provided in Fig. 3.20 demonstrate the value of ERS data for mapping flooded areas, which is especially useful considering that flooding is often associated with poor weather conditions which restrict the use of optical sensors. The much improved temporal coverage possible using ASAR is vital for developing operational systems. In addition, the high incidence angles and HH polarisation capabilities of ASAR will give better mapping of flood extent.
For applications where this improved temporal coverage is important, the main issue then becomes the utility of data acquired at a wide range of different incidence angles. Combined use of images acquired with different incidence angles poses a new set of challenges.

3.4. Interferometry

The ERS Programme has seen particularly important developments in the field of SAR Interferometry (InSAR). InSAR provides information on topography and small topographic changes, based on measuring differential phase shifts between two corresponding pixels of the same scene imaged from two closely spaced orbits. The Tandem experiment, in which ERS-1 and ERS-2 were put in the very same orbit with 1 day separation, allowed the retrieval of interferometric images for the major part of the globe, and this huge Tandem data set will continue to be extremely useful for topographic mapping around the globe. Standard 35 day repeat ERS data are also valuable, and interferometric techniques are being applied to these data for both land cover classification using coherence differences and (using differential interferometry) to measure small differences in topography associated with, for example, earthquakes and subsidence. ASAR offers continuity with 35 day repeat images for SAR interferometry, although interferometric pairs will need to be taken with the same viewing angles. The availability of ASAR interferometric pairs acquired at higher incidence angles will be useful for improving the visibility of steeper slopes, and there will also be new possibilities for low resolution interferometry, as described below. However, since interferometry will only be possible with images taken at least 35 days apart, the capability for DEM production will be very limited

a

b

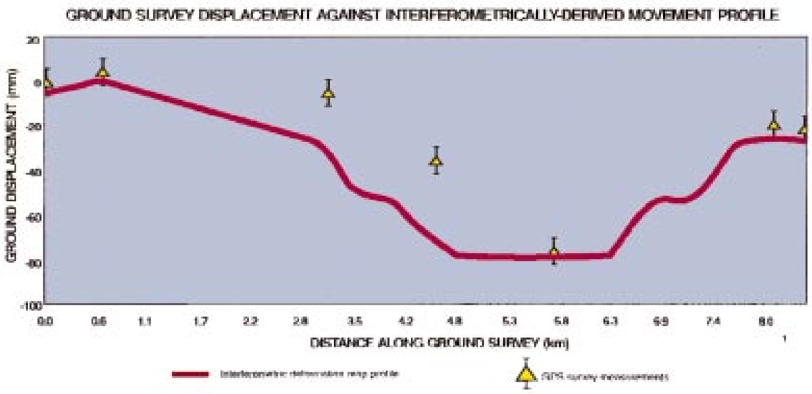


Fig. 3.21: Urban ground subsidence. (Acknowledgement: Nigel Press Associates and W.S. Atkins, UK).

a. An interferogram covering an area 12 km 16 km, from ERS images taken 2 years 4 months apart.
b. Graph comparing the interferometric results with GPS measurements made on the ground.

compared with what has been possible using 1 day repeat data from Tandem ERS data sets.

Differential interferometry
In the 35 day repeat orbit scenario, the wide swath capabilities of ASAR, combined with the predictable high reliability and repeatability of the orbits, will allow the retrieval of extremely useful data for differential interferometry (DINSAR). Another important benefit of ASAR will be the availability of different viewing angles and in particular higher off-nadir angles, that enhance the interferometric visibility of steeper slopes, which are otherwise in layover with the 23° incidence angle of ERS-1/2. As for ERS, in order that terrain can be imaged with differential interferometry the surface conditions should be sufficiently stable that more than 30-40% of the strong scatterers remain unchanged in two images acquired 35 days apart.

ASAR will be able to measure very small terrain displacements due to co-seismic motions, bradi-seismic motion, subsidence, volcanic upswelling, landslides, ice movement and possibly oscillatory effects like earth tides and the loading of sea tides on the continental shelf.

Fig. 3.21 shows a result from ERS interferometry where ground subsidence has been detected in an urban area in the U.K. Ground measurements have confirmed the 6 cm subsidence detected by interferometry.

Another excellent example of the detection of surface subsidence is shown in Fig. 3.22. The image displays an exaggerated 3D perspective view of the Belridge (middle left) and Lost Hills (lower left) Oil Fields, California, viewed from the north-west. Both oil fields are located in the San Joaquin Valley. The surface deformation derived from ERS-1 data collected in September and November 1992 (70 days time difference), shows subsidence of up to 6 cm.

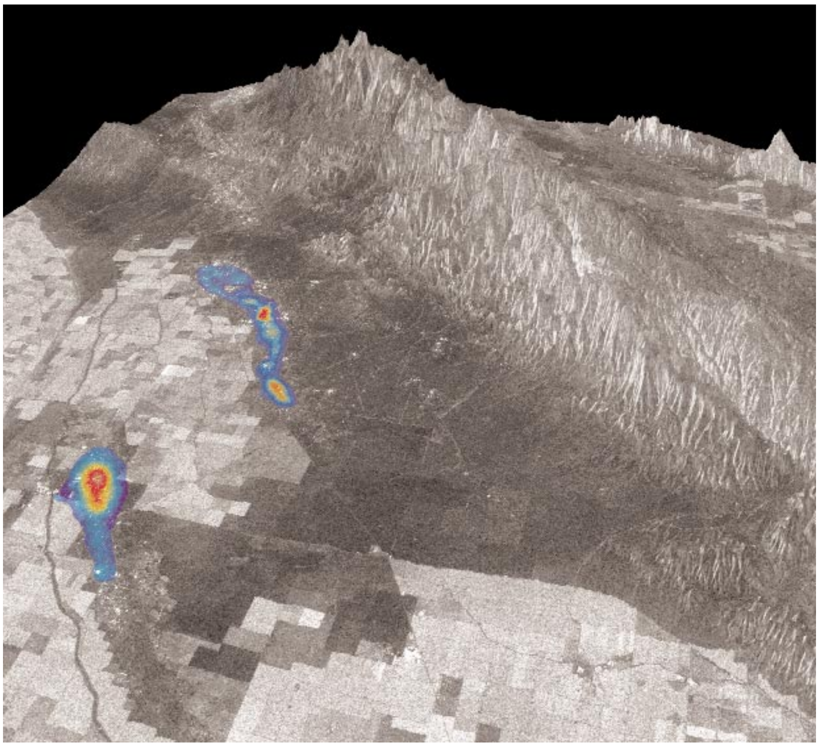


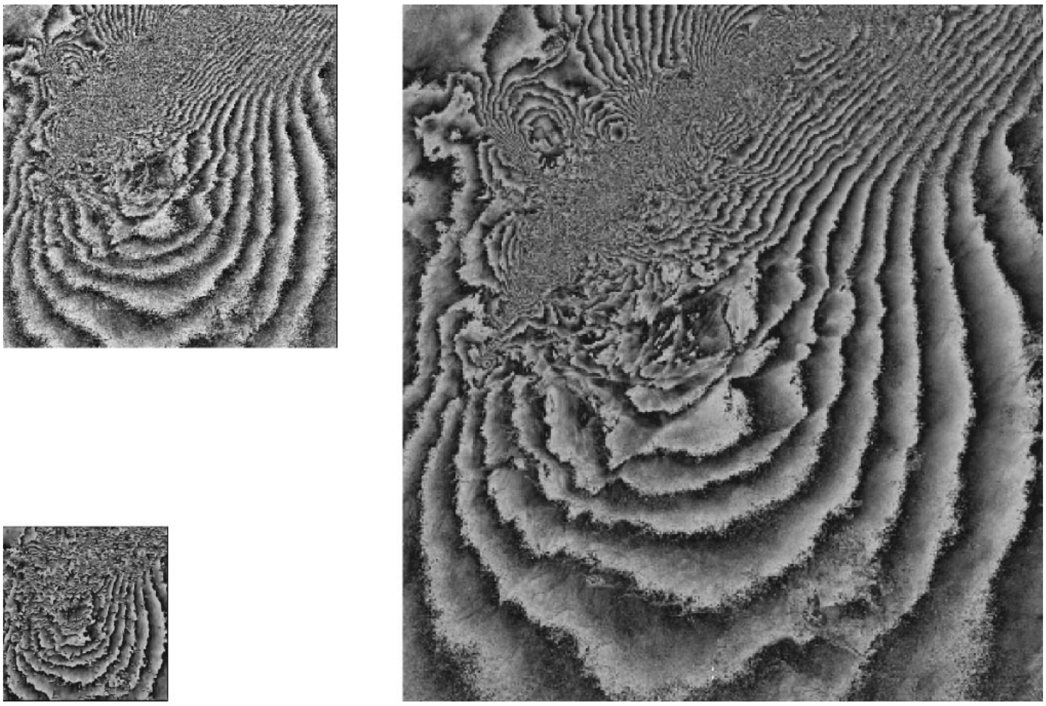
Fig. 3.22: Subsidence in the Belridge Oilfields, California. The colours derived from ERS-1 data collected in September and November 1992 (70 days time difference) show subsidence ranging from 1 cm (blue) to 6 cm (red-brown). The 3D view has been produced using the DEM generated from the ERS tandem pair, combined with a Radarsat image. (Acknowledgement: M. van der Kooij, Atlantis Scientific Inc.; Radarsat Data Copyright Canadian Space Agency/Agence spatiale canadienne 1996).

Low Resolution Interferometry
Pairs of complete Wide Swath or Global Monitoring Mode images will be unsuitable for interferometry because, in the lower resolution modes, the data are sampled in bursts along the azimuth direction. For interferometry the sampling bursts need to be spatially aligned in the two interfering frames. However, there are interesting possibilities for using low resolution images in conjunction with full resolution (image mode) images. A full resolution image with the same incidence angle as the subswath of the Wide Swath or Global Monitoring Mode image is needed.

Once a worldwide archive of Wide Swath or Global Monitoring Mode images is built-up it will be possible to obtain interferometric pairs of particular areas of interest within 35 days, by acquiring full resolution (Image Mode) data with the same

Fig. 3.23: Simulation of low resolution interferograms of the Landers 1992 earthquake, using ERS SAR data.

Image Mode (right), Wide Swath Mode (top left) and Global Monitoring Mode (bottom left), for an area of 48 km × 45 km. (Acknowledgement: F. Rocca, Politecnico di Milano, Italy).



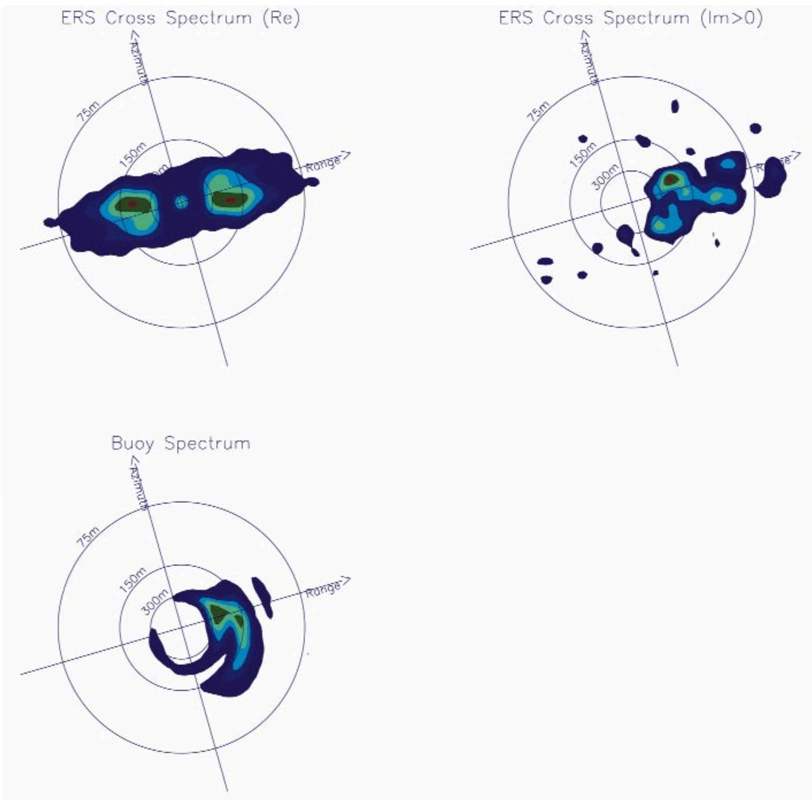


Fig. 3.24: SAR ocean image cross spectrum (real and imaginary part) processed from ERS-1 data using the Envisat ASAR Wave Mode Cross Spectra algorithm. The corresponding directional buoy spectrum is also shown. (Acknowledgement: NORUT IT, Norway)

imaging geometry as the relevant portion of the low resolution image. A lower resolution implies looks are available, and the quality of the fringes will be proportionally lower.

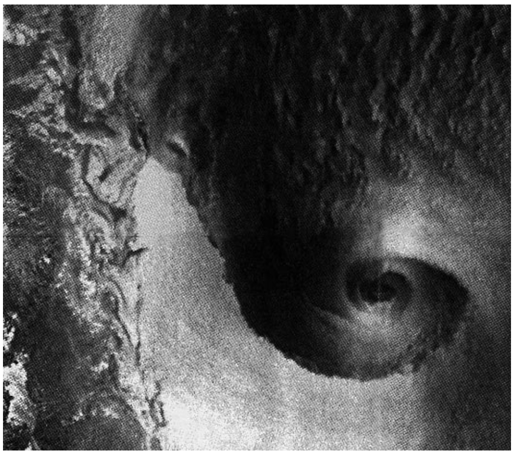
Fig. 3.23 is a simulation of co-seismic motion retrieval using low resolution differential interferometry. In this example ERS SAR images for the Landers 1992 earthquake have been used to simulate interferograms, using an Image Mode image together with either Wide Swath Mode or Global Monitoring Mode images. On these images one fringe corresponds to half a wavelength displacement along the radial direction.

3.5. Wave Spectra

ASAR Wave Mode will provide wave spectra derived from imagettes of minimum size (5 km × 5 km), similar to the ERS AMI Wave Mode, spaced 100 km along-track in either HH or VV polarisation. The position of the imagette across track can be selected to be either constant or alternating between two across track positions over the full swath width.

ERS Wave Mode products are based on image spectra (wave number and direction) estimated from SAR intensity imagettes using standard Fourier transform techniques. These products are therefore symmetric containing a 180° propagation ambiguity. Techniques involving the use of wave model predictions have been developed to solve the ambiguity problem, though this can be subject to error when opposite or near opposite wave components exist.

For ASAR, this problem will be solved by using a new wave product preserving the phase and a new algorithm called “inter-look cross spectral processing”, whereby information on the wave propagation direction is computed from pairs of individual look images separated in time by typically a fraction of the dominant wave period (Engen & Johnsen, 1995). Fig. 3.24 shows a simulated ASAR Wave Mode Spectrum, with the top left plot being the real part of the cross spectrum (symmetric and equivalent to an ERS product) and the top right plot the new imaginary part (asymmetric, giving wave propagation direction). In this example, the output from the new algorithm is seen to correspond with the wave direction provided by buoy measurements, as shown in the lower plot.



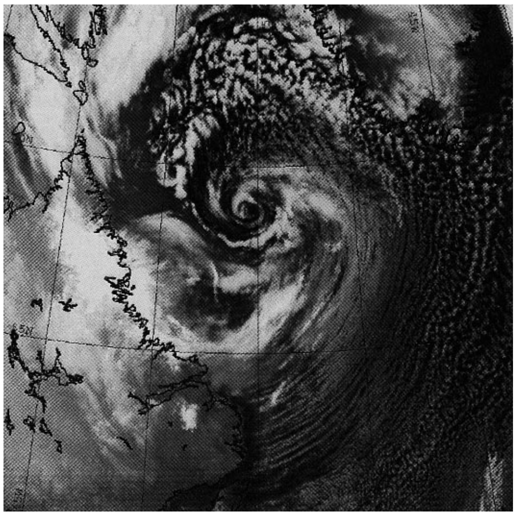


Fig. 3.25: A low pressure system seen on (a) Radarsat Wide Swath and (b) NOAA AVHRR images acquired on 30/3/97. Area shown on the Radarsat image is 500 km × 700 km. (Radarsat Data Copyright Canadian Space Agency/Agence spatiale Canadienne 1996. Received by the Canada Centre for Remote Sensing. Processed and distributed by Radarsat International. Imagery enhanced and interpreted by CCRS)

3.6. Simultaneous Observations

The Envisat Mission will offer simultaneous acquisition of ASAR and MERIS data, and this promises to be particularly valuable for ocean and coastal studies. With MERIS having a swath width of 1150 km around nadir, simultaneous data acquisition will be possible up to ASAR incidence angles of approximately 34°, therefore including IS1 to IS5 in Image Mode, and all but the outer edge of the low resolution modes (see Fig. 2.5). It will also be possible to use ASAR data together with AATSR data, but simultaneous data acquisition is restricted to a narrow overlapping swath.

Fig. 3.25 provides an illustration of the type of simultaneous SAR and optical large area data acquisition that will be possible. In this example a low pressure system is seen on both a Wide Swath Radarsat image and a NOAA AVHRR image acquired within 30 minutes of each other. On the SAR image one sees the differences in sea surface roughness associated with the depression, while on the AVHRR image the same feature is depicted through cloud patterns.

Fig. 3.26 shows the combination of a SAR image and satellite derived sea surface temperatures. The ERS and AVHRR images were acquired on 3rd October 1992, off the west coast of Norway. In the AVHRR IR image the surface temperature decreases from nearly 14°C (white) in the coastal water to 12°C (purple) in the Atlantic water offshore. The pattern of the sea surface temperature field with the curvilinear temperature fronts represents meso-scale variability of 10 to 50 km, characteristic of the unstable Norwegian Coastal Current (Johannessen et al., 1994). The ERS image, acquired 7 hours later, contains frontal features at a scale, configuration and orientation that are in good agreement with those seen in the IR image. The SAR image shows both bright and dark radar modulations of various width across the boundaries, which clearly show current boundaries including meanders.

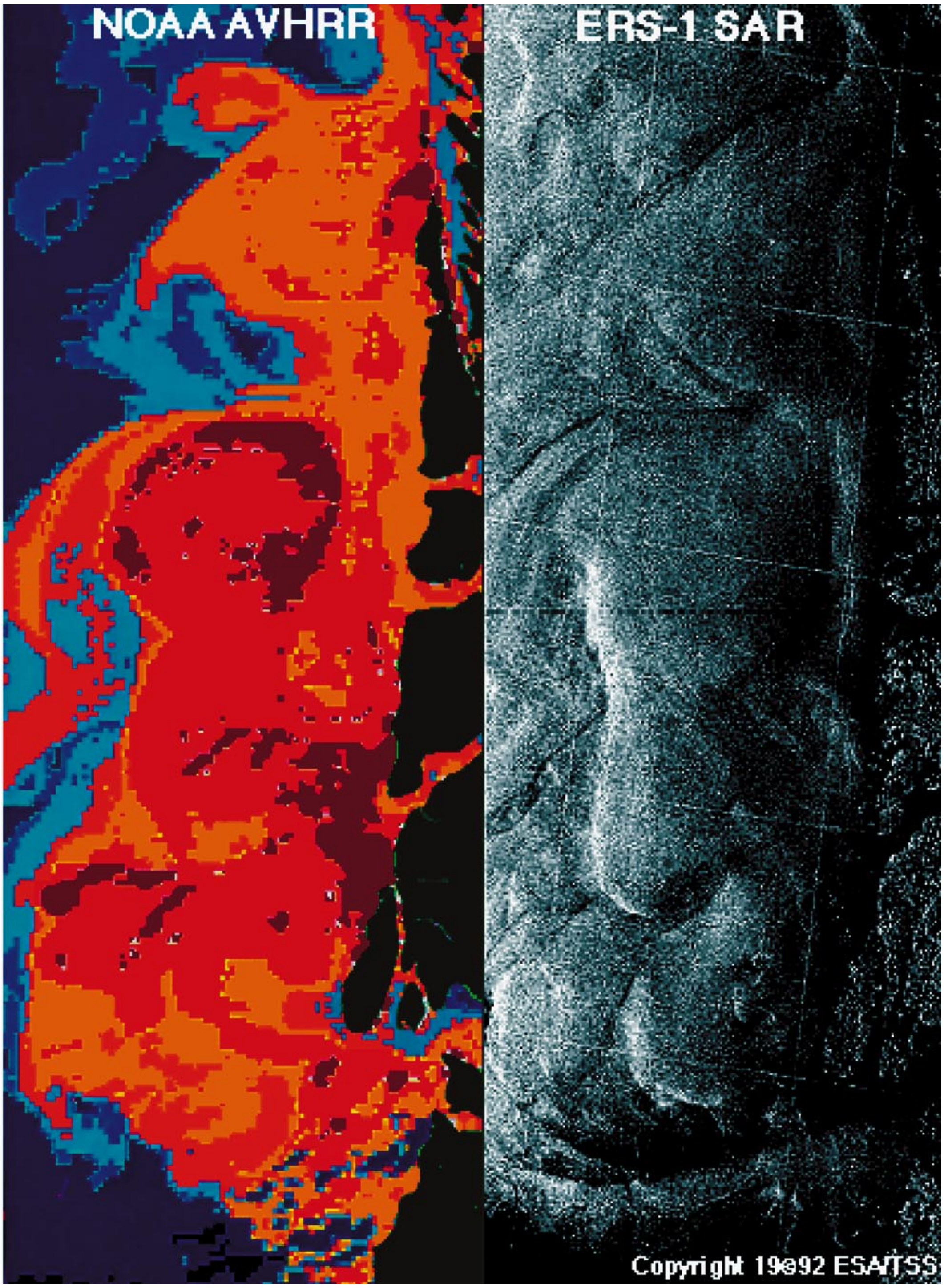


Fig. 3.26: Comparison of a 1 km resolution AVHRR image acquired at 14:20 on 3/10/92 (white is 14°C and purple is 12°C; + denotes buoy position; land is masked in green and clouds in black) and a 100m resolution ERS-1 SAR image acquired at 21:35 on 3/10/92. Both images cover the same 100 km × 300 km region off the west coast of Norway between 59°N and 62°N. (Acknowledgement: J.A. Johannessen et al., 1994).

4. SCIENCE AND APPLICATIONS

4.1. User Categories

The aim with ASAR is to build upon the success of the ERS satellites, expanding both the scientific and commercial usage of imaging radar data. Three different types of potential user of ASAR data have been identified: those involved in remote sensing science, those in earth science and those with commercial applications (Williamson, 1996).

Remote Sensing Science users are involved in the development and the testing of retrieval models and methodologies across seasons and years and at different locations. In most cases a comprehensive data set is required, covering all important dates for designated test sites, to develop retrieval models and geophysical products for different types of target, and for instrument calibration purposes. The modes of particular interest will be those which have not been available on other missions such as low resolution modes, dual and cross polarisation and the choice of incidence angle.

The **Earth Science Community** has many different requirements for data and several sectors are already developing global and regional products and data sets. Data are required to initiate or validate models and for long term monitoring at both global and regional scales as well as smaller areas which are of particular interest. The requirements will change over the next few years as models are refined and new techniques are developed for extracting physical parameters from remotely sensed data.

Many **Commercial Applications** are being developed through the ERS and Radarsat programmes. The choice of polarisations and the use of cross polarised data will increase the accuracy of many products, i.e. the reliability of identifying features will improve and the number of geophysical variables that can be measured will also increase.

4.2. Remote Sensing Science

A considerable amount of research has been undertaken into the processing and use of spaceborne SAR data from SEASAT, ERS-1/2, Shuttle Imaging Radar (SIR-C/X-SAR), JERS-1 and Radarsat. The need for further research will continue, both in data processing and analysis techniques and in the development of geophysical retrieval models. Research will be undertaken by a range of users from universities and research institutes, to value added companies and industry who wish to improve the product or service they are selling or using. The availability of multi-polarised data and those from the Global Monitoring Mode will be of particular interest.

Data Processing
Preliminary processing of data at ground stations and by value-added companies includes calibration and validation of data, feature detection, texture analysis, reduction of speckle, image registration, geocoding and radiometric corrections. Techniques are continually being developed, particularly when data from a new sensor become available. Data from all modes will be required for specific study sites over land, ocean and ice.

The availability of data from multiple incidence angles provides opportunities to develop new data processing techniques which may give new information on soil moisture, forest characteristics, geological structure, etc. Data will be required at all modes and polarisations for specific study sites covering a range of incidence angles.

Algorithm Development
Considerable ocean related research is currently being undertaken to monitor ships in busy traffic lanes and fishing boats, and by defence departments. The detection of ships and ship wakes may be improved with the use of multi-polarised data. Data will be required over a range of sea conditions for a variety of applications. In the coastal zones, research is currently being undertaken to develop methods to map shorelines and also the sea bottom in shallow areas. Some of this will continue with ASAR, although some of these applications are now operational.

Much of the basic research on classification of ice types has been carried out, and good algorithms are available. The value of multi-polarised data for ice type discrimination, especially during the ice formation and ice melting periods has been demonstrated using airborne systems, but will need to be fully tested with ASAR. Data from both the Alternating Polarisation and Wide Swath (HH and VV) modes will be required throughout the year for test areas in the Arctic Ocean.

In order to develop agricultural and vegetation products there is a requirement for multi-temporal data across the major crop and cover types from which backscatter models of crop type, area, height and condition can be developed. The analysis of multi-polarised data will be important.

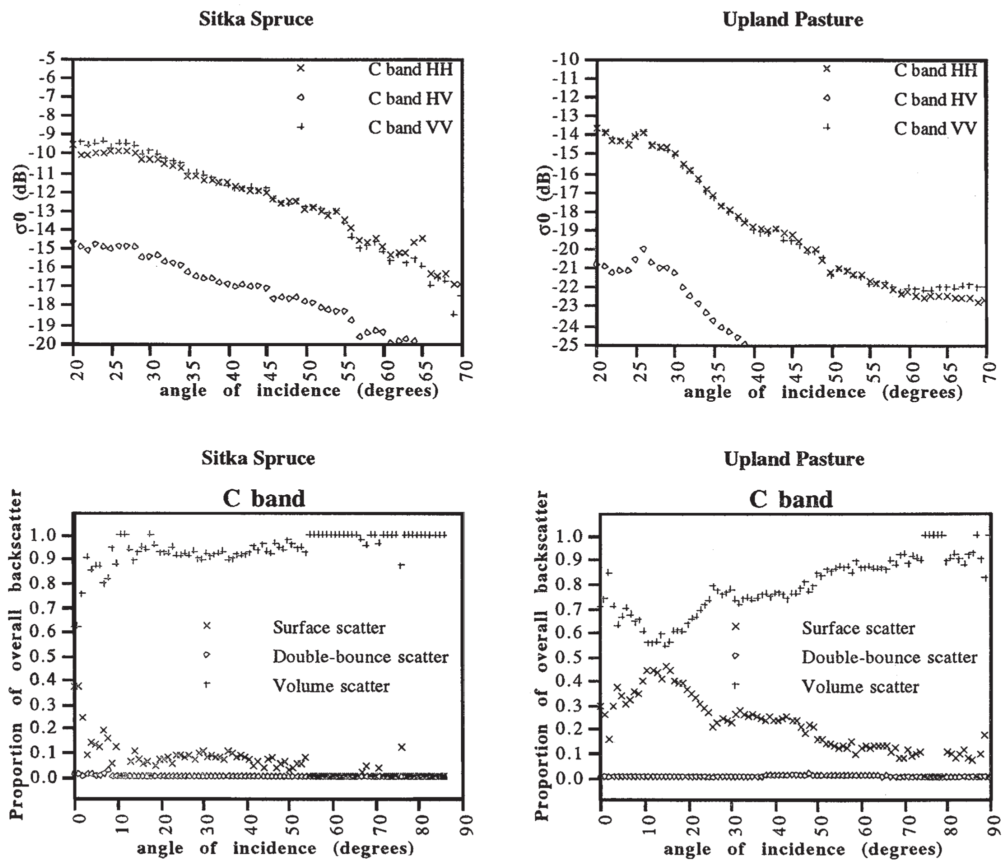


Fig. 4.1: Backscatter of Sitka Spruce and Upland Pasture at Llyn Brianne, Wales. (Acknowledgement: Luckman and Baker, 1995).

Above: Polarisation and incidence angle effects on backscattering
Below: Relative contributions of surface, double-bounce and volume scattering

Forest mapping is of particular interest in the humid tropics and other persistently cloudy areas. Important research topics include the classification of forest types, identification of burned forest, assessment of forest stress and monitoring of logging concessions. The availability of multi-polarised and variable incidence angle data from ASAR should improve on the accuracy of ERS results. For example Fig. 4.1 shows how backscatter varies with VV, HH and HV polarisations across a range of incidence angles, for Sitka Spruce and Upland Pasture, and how these measurements have been used in a decomposition model to determine the relative contribution of surface, double-bounce and volume scattering mechanisms.

Many hydrological and agricultural applications have a requirement for soil moisture data. Current research is investigating the relationship between soil moisture and backscatter across a range of soil conditions (Le Toan et al, 1994). The use of multi-polarised and multi-incidence angle data may increase the accuracy of models by reducing the effect of surface roughness and vegetation. There is a strong interest in the use of Wide Swath and Global Monitoring Modes because of the much improved temporal frequency of coverage (Zmuda et al., 1997). Snow melt and hydrology applications require information on snow cover distribution and snow-water equivalent. Research is required to measure these variables with ASAR at high incidence angles, particularly in mountainous terrain.

ASAR Data Requirements
Table 4.1 provides a list of the proposed default ASAR Modes for applications being addressed by remote sensing science. In particular, this shows a very strong demand for Alternating Polarisation Mode.

	Mode	Polarisation	Swath	Remarks
Agriculture	AP	VV/VH	IS4-6	Multi-temporal
Land cover	AP	VV/VH	IS4-6	Multi-temporal
Forestry	AP	VV/VH	IS4-6	Multi-temporal and interferometry
Soil moisture	AP	VV/VH	IS1-3	High revisit
Snow melt	IM	HH or VV	IS3-7	High revisit
Hydrology	AP	VV/VH	IS2-5	High revisit
Geology	IM	HH	IS4-7	
Urban mapping	AP	HH/HV	IS3-7	
Inland water	IM	VV	IS2-4	
Oceanography	AP	VV/HH	IS2-6	
Coastal phenomena	AP	VV/HH	IS2-6	
Sea ice	AP	VV/HH	IS2-6	
Ship detection	AP	HH/HV	IS2-7	
Marine meteorology	AP	VV/HH	IS2-6	
Pollution monitoring	WS	VV		

IM: Image Mode
AP: Alternating Polarisation Mode
WS:Wide Swath Mode
IS: Imaging Swath

Table 4.1: Proposed default ASAR Modes for Remote Sensing Science

4.3. Earth Science

The past decade has seen increasing public concern about the Earth, its environment and mankind's impact upon it. Global threats such as climate warming, stratospheric ozone depletion, tropospheric pollution and, more recently, regional events such as the very intense El Niño, the fires in S.E.Asia and the floods in Middle Europe and China, have left us more concerned than ever about the need to monitor and understand what is going on in the Earth's environment. There are many aspects of the complex evolving Earth System that we still do not understand.

These concerns have led to the establishment of the concept of a Global Climate Observing System (GCOS), including both space and surface based systems, to measure on a routine basis all major elements of the global climate system. Table 4.2 (overleaf) provides a summary of the principal observations required in support of GCOS.

Ultimately the way in which our understanding of the Earth will improve is by the development and elaboration of Earth System models into which data from various sources will be integrated. Earth observation from space is a critical tool in this task because of the unique synoptic view and high repeat frequency that it provides. Some of the earliest initiatives, including Meteosat and SPOT, have already developed into long term applications programmes integrated into regular operational use. The ERS satellites have made major contributions in areas as diverse as global and regional ocean and atmospheric science, sea ice, glaciology and snow cover investigations, land surface studies and the dynamics of the Earth's crust (seismology and volcanology). Envisat will provide new capabilities to monitor atmospheric composition and chemistry, with ASAR providing continuity and improvement upon the ocean, coastal zone and land cover monitoring capabilities of the ERS SAR instruments.

ASAR promises to be particularly important for modelling and monitoring changes in vegetation, oceans, ice sheets, snow and sea ice. Data are required in order to initiate or validate models and for long term monitoring over global to regional scales, as well as smaller areas which are of particular interest. Most of the users of remotely sensed data for Earth Science are in universities and government funded research institutes.

Vegetation Monitoring
One of the main aims of global vegetation mapping is to characterise

	PRINCIPAL SYSTEM	GCOS MISSIONS	PRINCIPAL OBSERVATIONS
THE PLANET EARTH	GLOBAL	Global Radiative Properties	Cloud Amount
			Cloud Drop Size Distribution
			Surface Fluxes (heat, water)
			Solar Irradiance
			Surface Radiation Fluxes
			Earth Radiation Budget
			Multispectral Albedo
			Aerosols
		Ocean Characteristics	Ocean Colour
			Ocean Topography / Geoid
			Sea Ice Cover
			Sea Surface Temperature
			Ocean Salinity
	OCEANS	Ocean Atmosphere Boundary	Sea Surface Temperature
			Ocean Wind Vectors / Speed
			Sea Ice Cover (as tracer)
			Ocean Wave Height Spectra
			Atmospheric Surface Pressure
		Atmospheric Thermodynamics	Temperature Profile
			Cloud Clearing
			Wind Profile
			Liquid Water / Ice
			Precipitation
			Humidity (profile / total)
	ATMOSPHERE	Atmospheric Composition & Chemistry	Constituents (total / profile)
			Atmospheric Dynamics
			Ozone (total / profile)
			Aerosols (total / profile)
		Land Atmosphere Interaction	Vegetation Characteristics
			Soil Moisture
			Snow & Ice Cover
			Land Surface Temperature
			Evaporation
	LAND	Land Biosphere Climate Response	Vegetation Change
			Land Use Change

Table 4.2: Summary of GCOS Principal Observations.

the function of biomes within the climate change models and also to quantify the extent to which changes in global vegetation distribution may affect the climate. Climate data are the main inputs for these models. ASAR products will be used, along with other remote sensing data, for initialising, parameterising and calibrating models on a global and regional scale and for the monitoring of changes in vegetation type and status. They will be required fortnightly to monthly for particular areas to characterise vegetative development cycles (i.e. growth, senescence). Cover types of interest include agricultural land, natural vegetation and forests. ASAR data and products developed from the Global Monitoring and Wide Swath Modes will be of particular interest. Currently AVHRR data are being used widely, and there is interest in improving the temporal coverage in cloudy areas using all weather data.

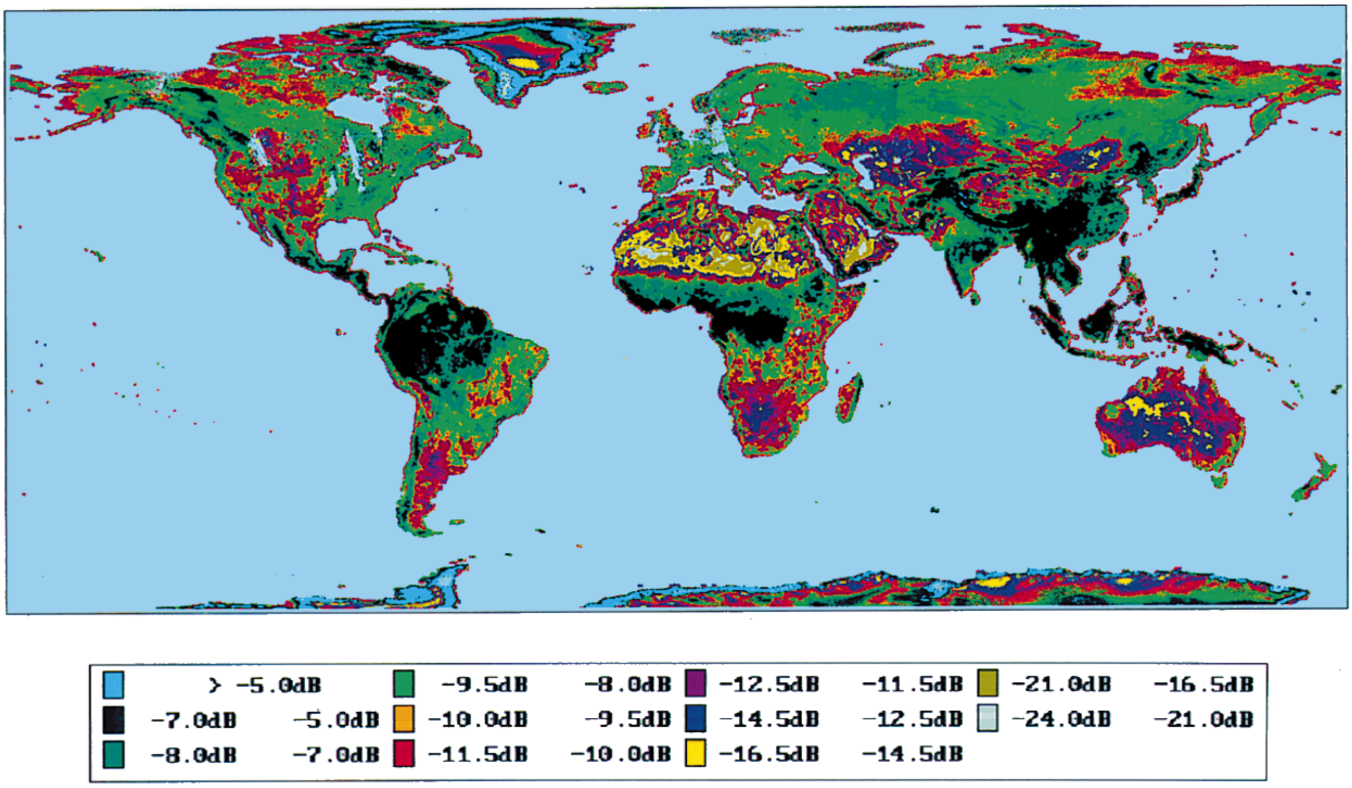


Fig. 4.2: Global backscatter data collected by the ERS Scatterometer in August 1993, showing major vegetation types and morphological units (i.e. tropical rain forest, savanna, deserts, mountain ranges, tundra).
Acknowledgement: E. Mougin, P. Frison, CESR, Toulouse; Y. Kerr, LERTS/CESBIO, Toulouse, France.

Fig. 4.2 provides an example of 25 km resolution global backscatter data from the ERS Scatterometer, which contains information on vegetation type, standing biomass and active vegetation. In comparison, ASAR Global Monitoring Mode will provide the much improved spatial resolution of 1 km, similar to that of AVHRR.

Sea Ice Monitoring

Sea ice research is currently concentrating on increasing our understanding of the processes operating in local areas and also on continuous monitoring to identify seasonal changes. Sea ice models, used to estimate surface flux and understand process behaviour, require information on ice extent, concentration and leads at varying resolutions appropriate to the use of Image and Wide Swath Mode data. Monthly, seasonal and annual products are required. Areas of special interest are monitored continuously, while other areas would require data only during times of fieldwork. Some large scale monitoring is undertaken for which a large swath width is required.

ASAR will have value in that it offers data similar to both ERS SAR and Radarsat, both of which are being used extensively for sea ice research. Both Wide Swath and Image Modes will provide valuable data. Products will be needed all through the year, although the information required at different times of the year will vary.

There are several co-operative projects collecting and analysing sea ice information. For example, the Arctic Climate System Study (ACSYS), a regional project within the WCRP, is a ten year programme, which began in 1994. Its objectives are to improve understanding of the processes within the Arctic Ocean, including assembling a basin-wide climatological database of sea ice extent and concentration (from satellite observations) and of ice thickness and motion (using underwater sonars) and drifting ice buoys.

Glaciology and Snow Mapping
The ice sheets of Antarctica and Greenland are the principal stores of fresh water in the Earth's hydrological system and changes in their mass balance affect the mean sea level. Changes in the height of ice sheets can indicate changes in the mass balance. Snow cover, snow accumulation and ice type information are also required for monitoring, detection of change and process studies at high latitudes and high altitudes.

Areas of glaciology to which ASAR will contribute include monitoring the ice extent and the boundaries of ice sheets and mapping the motion of ice sheets and glaciers. Fig. 4.3 provides a simple example of the use of ERS data for mapping changes in the extent of the Larsen Ice Shelf, Antarctica. There are many similar examples. SAR data are still being used on an irregular basis when something interesting happens, rather than as a monitoring tool. Interferometry and correlation measurements which show movement of the ice sheets are very important to this work. ASAR will provide valuable continuity in the supply of data started with ERS.

Mass balance and ice dynamics are the key scientific questions, with the parameters to be derived from ASAR including:

(1) Ice boundaries (every 2 weeks),

(2) Ice export due to calving (every 2 weeks),

(3) Extent of melt zones (2 weeks during summer; Greenland and Antarctic Peninsula),

(4) Snow and ice faces (1 year),

(5) Ice motion by means of feature tracking (about 1 year)

and

(6) Surface morphology (flow lines, rifts, crevasse zones etc.) (about 1 year).

Depending on the topography and the requirements for spatial detail, the ice sheets may be separated into the boundary zone (including the ice shelves) and the interior part. Baseline operation for the boundary zones is considered to be the Wide Swath Mode, for the measurement of parameters (1), (2) and (3) above. Baseline operation mode for the interior could be the Global Monitoring Mode, for the measurement of parameters (3) and (4). The preferred operation modes for selected zones (ice streams) are Image Modes at higher incidence angles

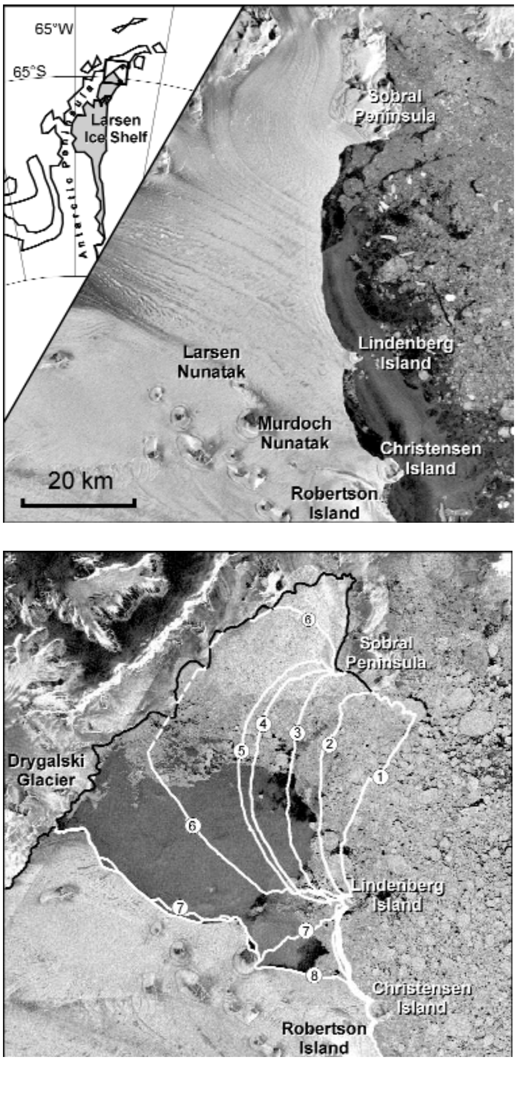
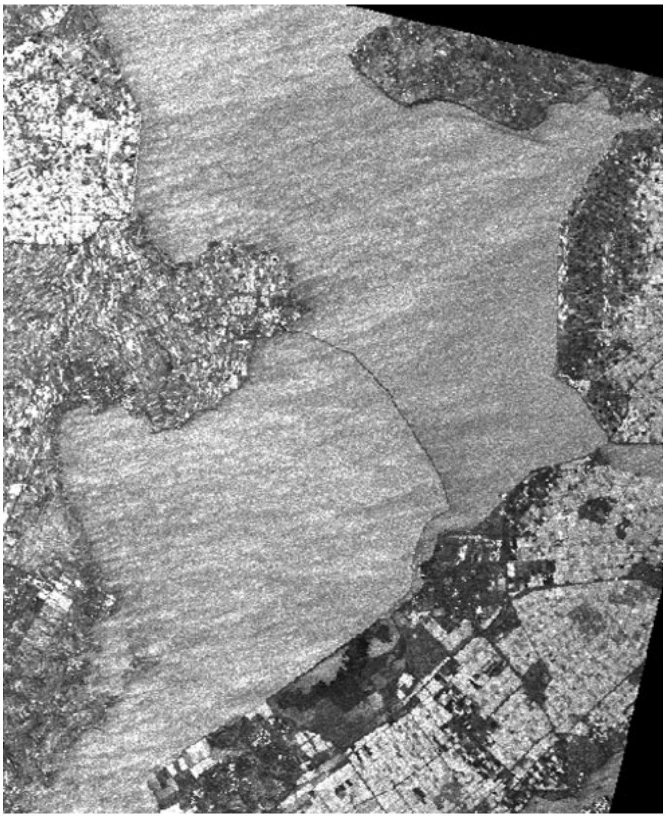


Fig. 4.3: Geocoded ERS-1 SAR images of the northern part of the Larsen Ice Shelf, (Antarctic Peninsula) from 2/7/92 (top) and 22/3/97 (bottom). White lines show ice-front positions for different dates.
1 = 1/3/86 Landsat MSS)
2 = 2/7/92 (ERS-1)
3 = 26/8/93 (ERS-1)
4 = 25/1/95 (ERS-1)
5 = 28/1/95 (ERS-1)
6 = 30/1/95 (ERS-1)
7 = 8/3/95 (ERS-1)
8 = 1/11/96 (ERS-2).
At the end of January 1995, 4200 m^2 of the ice shelf disintegrated within a few days. This collapse was observed in detail with ERS-1 SAR (published in *Science* 9/2/86, vol. 271, pp 788-792).
Acknowledgement: H. Rott, University of Innsbruck, Austria.



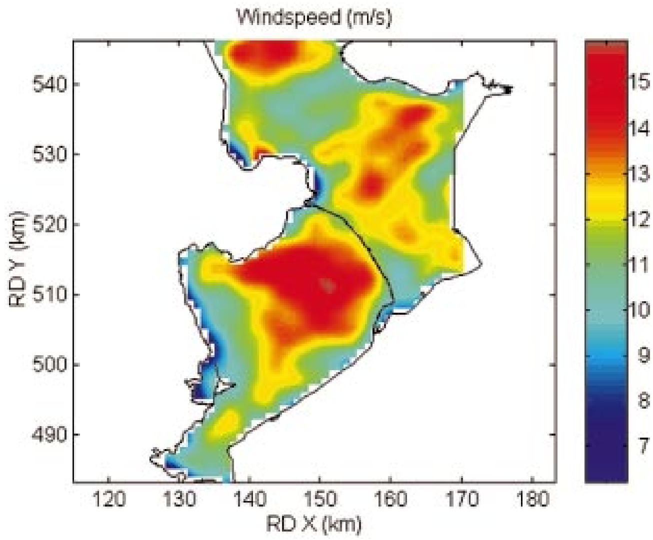


Fig. 4.4: ERS SAR image of the Ijsselmeer, The Netherlands, together with derived windspeed in m/s for 16/2/95. (Acknowledgement: K. Mastenbroek, 1998).

(IS3 - IS7), for measurement of (5) and (6) above with approximately annual repetition of observations.

The presence of snow on the ground has a significant influence on the radiative balance of the Earth's surface and on the heat exchange between the surface and atmosphere. ERS has demonstrated the value of SAR data for mapping snow cover, and the Global Monitoring Mode is of special interest for monitoring the areal extent of snow and the temporal dynamics during the melt period, on a weekly basis for climate research purposes.

Snow mapping is also important for hydrology and water management. Snow cover extent data are required every 2 weeks during the melting season, and the baseline operation in mountainous areas should be Image Mode at high incidence anges (IS4 to IS7).

Oceanography

The exchange of energy between the ocean and atmosphere, between the upper layers of the ocean and the deep ocean, and transport within the ocean all have a role in controlling the rate of global climate change and the patterns of regional change. Long continuity of measurements of sea surface temperature, winds, topography, geostrophic currents and ocean colour is essential.

ASAR products of interest to ocean scientists include wind speed and wave spectra from the Wave Mode. Other ASAR modes are of interest for wind field measurement, studies of internal waves and eddies and the detection of atmospheric phenomena, with Wide Swath and Global Monitoring Modes being of particular interest because of the larger area and more frequent coverage. An example of the retrieval of high resolution wind fields from ERS data is shown in Fig. 4.4.

The World Ocean Circulation Experiment (WOCE) is collecting information to provide a snapshot of the oceans and the World Climate Research Programme is considering how representative this is in climatic terms. There are several universities in Europe using SAR data to understand ocean processes on a local scale, and also the IGBP Joint Ocean Flux Study (JGOFS).

Coastal Zone Processes
The main areas of interest in the coastal zone are changes in sea level and in suspended sediment, carbon and nutrients. Activities are being undertaken at a range of scales using diverse data sets for ocean measurements, land use, vegetation and coastal morphology. There are numerous local, national, regional and international programmes involved in the coastal zone. Major programmes include the International Oceanographic Commission, the MAST programme organised by the EC and the IGBP Land-Ocean Interactions in the Coastal Zone (LOICZ) programme to determine how changes in the Earth's system are affecting coastal zones and altering their role in global cycles.

ASAR data will certainly be used within the range of activities in the coastal zone, although there is no underlying requirement for a particular product. Examples of current use of SAR data in the coastal zone include topographic maps of tidal flats, sea bed topography and sediment distribution in The Netherlands, an inter-tidal digital terrain model of the Wash in the U.K. and coastal erosion in French Guiana.

ASAR Data Requirements
Data from ASAR will only be able to meet a proportion of these Earth Science information requirements, but the total market is potentially quite large. Table 4.3 provides a list of the proposed default ASAR modes for some of the main applications.

The availability of multi-polarised data and data at different incidence angles or at a specific incidence angle should improve the accuracy and quality of the products for many applications. The Wide Swath and Global Monitoring Modes will provide data which are not currently available, for applications requiring large area coverage.

4.4. Commercial Applications

Although Envisat was envisaged as a pre-operational system, the growing availability of Earth observation data

Table 4.3: Proposed default ASAR Modes for Earth Science

IM: Image Mode
AP: Alternating Polarisation Mode
WS: Wide Swath Mode
IS: Imaging Swath
WM: Wave Mode
GM: Global Monitoring Mode

	Mode	Polarisation	Swath	Remarks
Vegetation maps	WS	VV or HH		Large area cover, multi-temporal
Soil moisture estimation	WS	VV		
Surface motion and subsidence	IM	VV or HH	IS2-5	Using interferometry
Oceanography	WS	HH		
Coastal phenomena	AP	VV/HH	IS2-6	
Marine meteorology	WS	VV		
Wind/wave models	WM	VV		
Glacier/ice sheet motion	IM	HH or VV	IS3-6	
Ice sheet extent and melt areas	WS	HH or VV		
Snow climatology	WS and GM	HH or VV		
Wetlands	WS	VV		
Sea ice	WS and GM	HH		

is stimulating the market and encouraging increased involvement and investment by value-added organisations and end-users. There is also an increasing political and economic emphasis on expanding the use of remotely sensed data for commercial and operational applications. Public sector users in national, European and international government are currently the primary users of Earth observation data and information derived from it. Demand from government departments with responsibility for agriculture, the environment, pollution control, meteorology, coastal protection, transport (especially coastal, marine and ice), fisheries and hazard management is providing a stimulus to the rest of the market.

The following applications are considered to be the major areas for commercial exploitation of ASAR data (based on Williamson, 1996).

Ship Routing through Sea Ice
Satellite SAR data are particularly useful for mapping the extent and type of sea ice for ship routing because of the availability of data in all weather conditions and during darkness. There can be significant benefits in improving the efficiency of offshore operations. Since the launch of ERS-1, systems have been developed which send information and images directly to ice breakers and ice strengthened ships, and images are also sent to Ice Centres which produce forecasts of ice conditions. Fig. 4.5 shows a wide swath image from Radarsat which has been used for ship routing in sea ice along the Siberian coast of Russia.

One to three day coverage is important for ice forecasting and ship routing. The temporal repeat time is of greater importance than a high spatial resolution and current use of ERS SAR and Radarsat data has shown that 100 m data will meet the product specification. Radarsat or

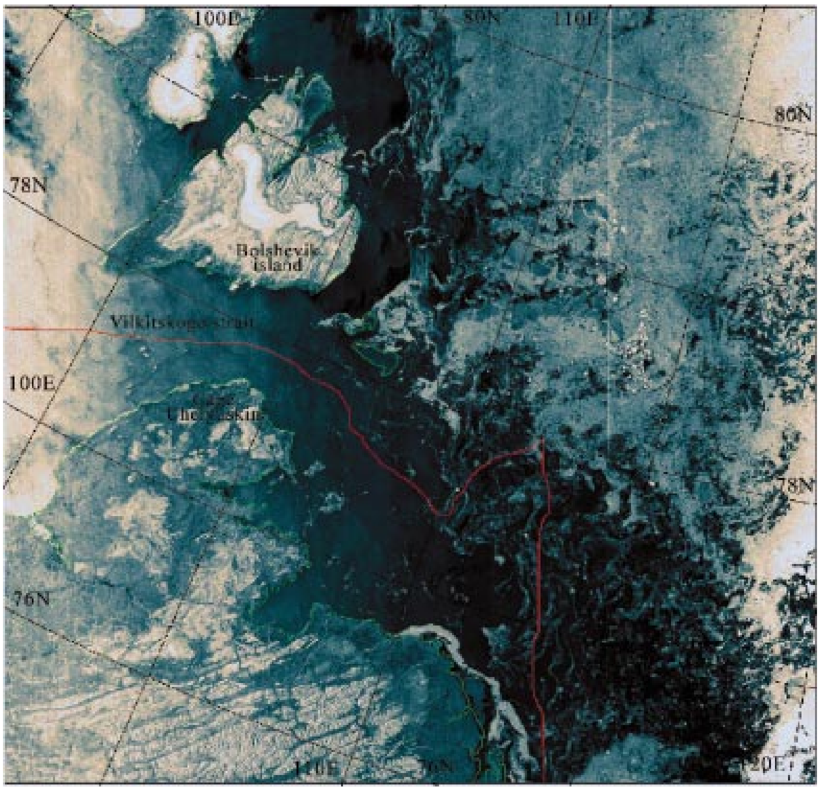


Fig. 4.5: Ship routing in sea ice along the Siberian coast, including ship track in red, September 1997. (Acknowledgement: NERSC, Bergen, Norway. Radarsat data, Copyright Canadian Space Agency / Agence spatiale canadienne 1997).

ASAR Wide Swath Mode is the obvious choice in order to have the frequent wide area coverage. This has been asked for by the community for a long time and is important in the Baltic as well as in the Arctic. However there are many unanswered questions. The ice/open water contrast will vary with wind speed, and dual polarisation images will help in distinguishing ice and water. High incidence angles will be valuable for imaging ice ridges and similar features. The cross polarised mode and the HH possibility are important complements.

Ice Services Environment Canada have an established preference for HH polarisation for ice concentration, ice movement and classification of ice types, combined with incidence angles of 25° to 50°. Cross polarised data are preferred for ice topography, preferably at greater than 35° incidence angle. Delivery to the Ice Centre, Ottawa, is required within 2 - 4 hours of data acquisition, with 1 to 3 day revisit. There is a daily mapping requirement for dissemination by chart, text bulletins, or image. Information is provided to the Canadian Coast Guard (icebreaking and vessel traffic management), fisheries, oceans, and defence organisations, commercial shipping, fishing vessels, the offshore oil and gas industry and to marine insurers.

The sea ice markets include agencies in the USA, Canada, Japan, Russia, Norway, and the Baltic countries. SAR data are combined with other sources of data to optimise sea ice forecasts, and are also transmitted directly to ice breakers and ships operating near the ice edge.

Ocean Monitoring
Several new SAR ocean applications can be expected to reach pre-operational or operational status during the lifetime of Envisat, notably in the areas of pollution monitoring, ship detection, and ocean feature nowcasting.

ERS-2 based oil spill monitoring services have already reached pre-operational status in the North Sea and some Baltic waters. Fig. 4.6 shows a map of oil slicks around the Mediterranean coast, from an analysis of 190 ERS images acquired between April 1992 and September 1993.

Oil companies are now actively using ERS SAR imagery in their search for new oil fields (oil seepage from the ocean floor is an important indicator). The ASAR Wide Swath Mode in VV polarisation will be a unique instrument for detection of oil slicks on the ocean surface, offering a very good combination of wide coverage and radiometric quality. The four-fold increase in coverage capability compared to ERS will make routine services feasible also at lower latitudes.

There is increasing interest in the maritime community in high precision nowcasting of ocean fronts, eddies and current shears. Important application areas could be: piloting of large transport ships, fisheries and fish farming, sea floor operations and autonomous underwater vehicles, acoustic sensors and acoustic communication. Also, ASAR imagery, together with data from other Envisat instruments such as MERIS and AATSR, will significantly enhance the

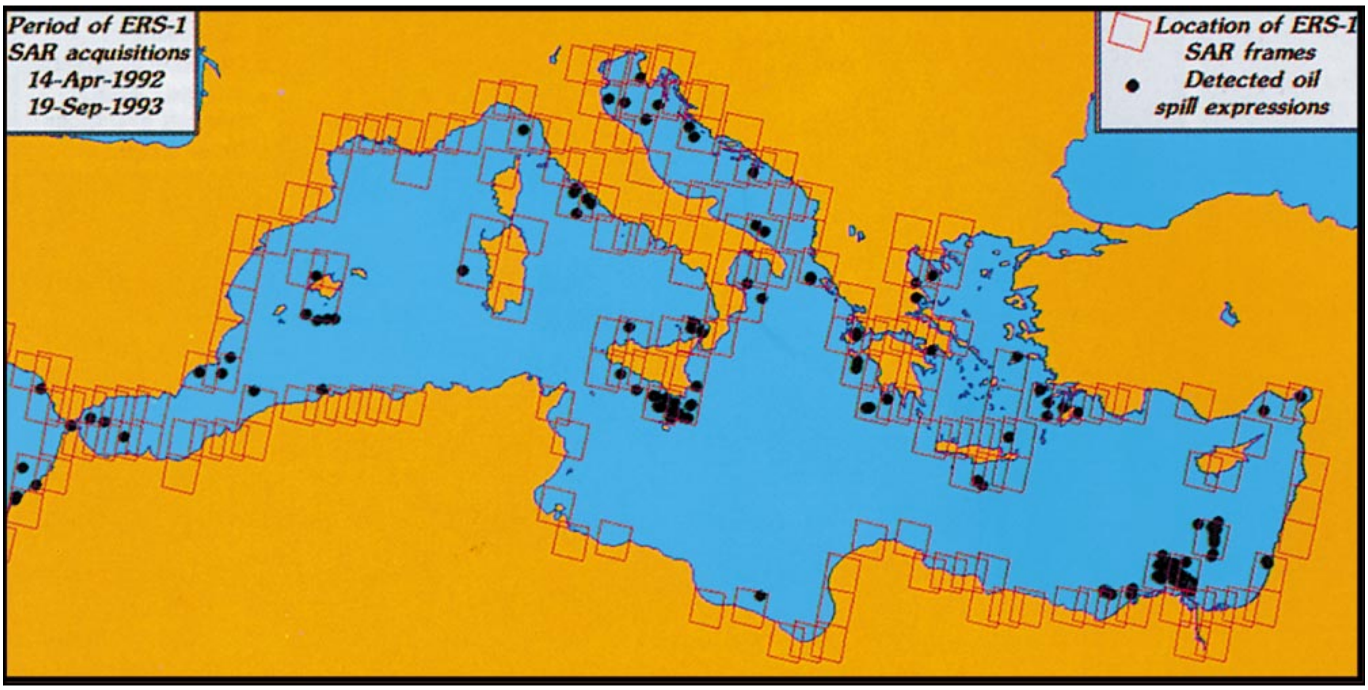


Fig. 4.6: Map of oil slicks detected around the Mediterranean coast using ERS images acquired over the period 14/4/92 to 19/9/93. (Acknowledgement: Pavlakis et al., 1996).

nowcasting of ocean features in coastal waters.

Agricultural Monitoring
The ERS programme has demonstrated the ability of satellite radars, independently of weather conditions, to identify crops, detect soil moisture and monitor seasonal land cover changes. Multi-temporal techniques are used, which involve the collection and analysis of SAR data on a series of different dates over the period of interest. Interferometric coherence has also been used to improve land cover discrimination.

ERS data are now being used operationally within major European programmes concerned with agricultural statistics (MARS STAT) and the control of agricultural subsidies (MARS PAC). Within MARS STAT the use of ERS data has improved the estimates of crop area early in the crop growing season. ERS data are used as a substitute for optical data in the MARS PAC control activity when cloudy conditions are encountered at key times during the crop growing season. The use of ERS data for rice mapping in south-east Asia is also becoming a commercially important application area. For example, Fig. 4.7 shows the use of multi-temporal ERS data for mapping the areas using different rice cropping systems in the Mekong Delta of Vietnam.

ASAR Image Mode offers continuity for these applications, enhanced by the availability of variable incidence angles. The Alternating Polarisation Mode will greatly improve crop classification and the Wide Swath and Global Monitoring Modes will be of most interest for soil moisture and large area vegetation monitoring .

Improvements in the accuracy of crop identification, in the number of crops which can be identified and in assessing crop condition, will increase the size of the market into which such products can be sold. However, this is dependent on more research to assess the use of dual polarised data for a range of crops and for key periods during the growing season.

The most likely scenario is that many of the orders will come from Europe, with the EU and national governments being the major customers who will require products during the northern summer, although increasing interest is being shown by agri-businesses and crop brokerages who would want products worldwide. Mapping the area of crops for the policing of subsidies, and the estimation of crop production are expected to continue as the main applications. SAR can contribute to

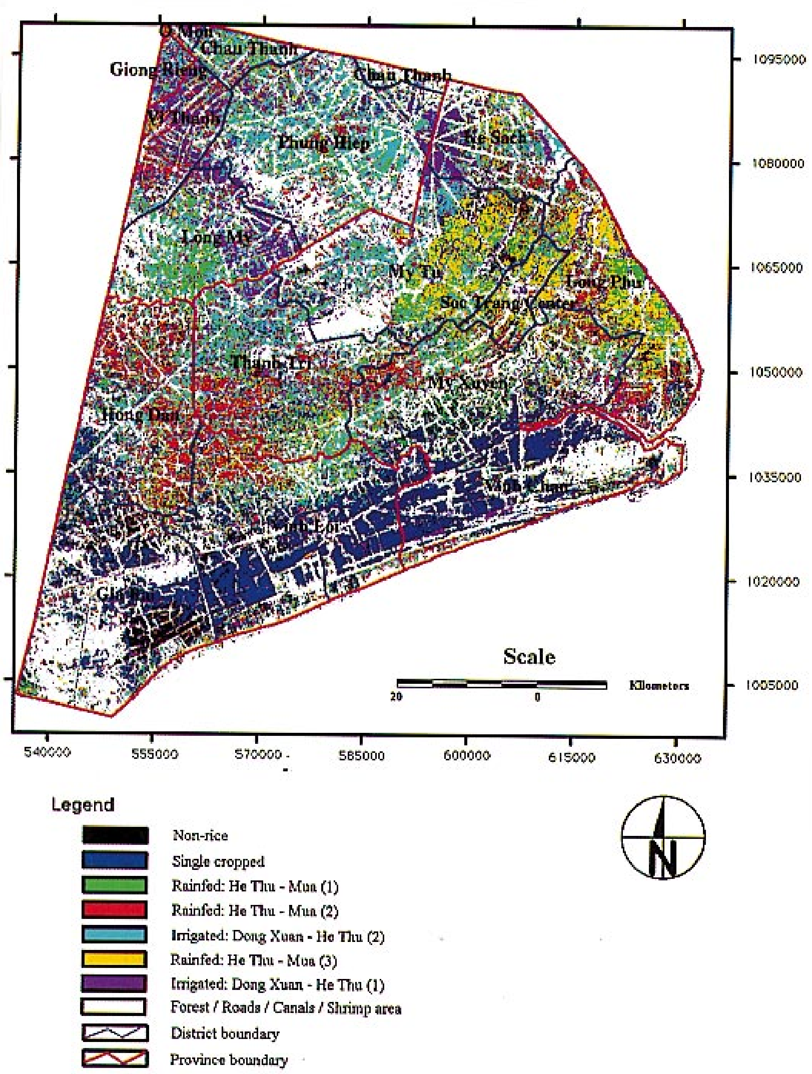


Fig. 4.7: Map of different rice cropping systems in the Mekong Delta, derived from classification of seven ERS SAR images acquired over the period May to December 1996. (Acknowledgement: Balababa et al. 1997).

crop yield estimates and the identification of stress and disease in crops, but considerable research still needs to be undertaken to prove the potential of SAR data in these areas. Currently SAR data are often not the first choice of data for many of these agricultural applications, but due to the high level of cloud cover they often provide the only source of remotely sensed data.

Forestry

Forest resources now attract unprecedented attention, because of their economic value, and of the environmental effects of deforestation. Pressures on tropical forests are increasing rapidly, and deforestation both has an impact on the carbon cycle and can be responsible for increasing soil erosion and flooding.

Many major forests are situated in tropical areas where there is cloud cover for much of the year or at high latitudes where there are long periods of darkness during the winter months. Initial results achieved using ERS data (C-band) for forest mapping were rather disappointing in comparison with what is possible using longer radar wavelengths such as L-band. However, the situation has now improved significantly using multi-temporal analysis and interferometric techniques, and ERS data are beginning to be used in operational mapping programmes.

The higher incidence angles and dual polarisation data from ASAR will further improve the potential for forestry applications. Use of low incidence angles enhances the sensitivity to biomass, whereas the use of high incidence angles improves mapping of deforestation. Dual polarisation data will improve discrimination of forest types.

There are a large number of potential customers in the forestry sector. Many international and national organisations now have deforestation monitoring programmes. The forestry industry needs forest type maps, timber yield estimates, indicators of stress or disease and maps of logged or clear-cut areas.

Hydrology and Water Management

Potential SAR-derived parameters for runoff forecasting include soil moisture, wetlands (extent) and snow cover. For medium to large basins Wide Swath Mode is recommended (high repeat), and for small basins, Image Mode.

Flood mapping is now established as an important application of satellite radar data. For example, Fig. 4.8 shows the use of ERS data for monitoring the devastating floods that occurred in China in July/August 1998. The operational requirements for improved revisit frequencies and wider swath coverage will both be satisfied by ASAR.

Oil and Gas

The oil and gas industry requires both geological maps (as part of a suite of information) to locate sites for drilling, and also topographic maps and cartographic/land cover maps for logistics planning when establishing drilling sites. Images recorded over ocean areas are being used to identify natural oil slicks which aids in the location of off-shore oil deposits.

Wide Swath and Image Mode data are required. Geological mapping with SAR data has become well established and a number of organisations offer a commercial service for mapping structure, but the effect of layover in hilly terrain prevents widespread use of the data. Image Mode with high incidence angles will therefore be of particular interest to reduce terrain distortions. Alternating Polarisation Mode may be of value for texture analysis in arid areas. Wide Swath Mode will be useful for looking at regional and continental geological structures.

Natural Hazards
The ERS mission has established SAR Interferometry as an important new tool for geologists involved in monitoring natural phenomena such as earthquakes, volcanoes, tectonics and land subsidence. Satellite SAR observations can provide high resolution maps of surface deformations. Subtle topographic changes may be observed and better observation strategies devised for predictive purposes.

The availability of higher incidence angles and more frequent (low resolution) coverage from ASAR are both significant in the context of measuring surface deformations. However, the precise value of low resolution data has yet to be established. The availability of different off-nadir angles will allow better identification of artifacts by enabling the reduction of common atmospheric effects.

Many potential customers exist in national agencies which are responsible for monitoring earthquakes and volcanoes and also amongst civil engineers interested in land subsidence. ASAR could be used to help in the creation of a global data set to allow study of the statistics of Earth motion associated with seismic phenomena. The remote sensing value-added industry will generate specialised interferometric products to address these customer needs.

ASAR Data Requirements
Table 4.4 provides a list of the default ASAR Modes for these commercial applications.

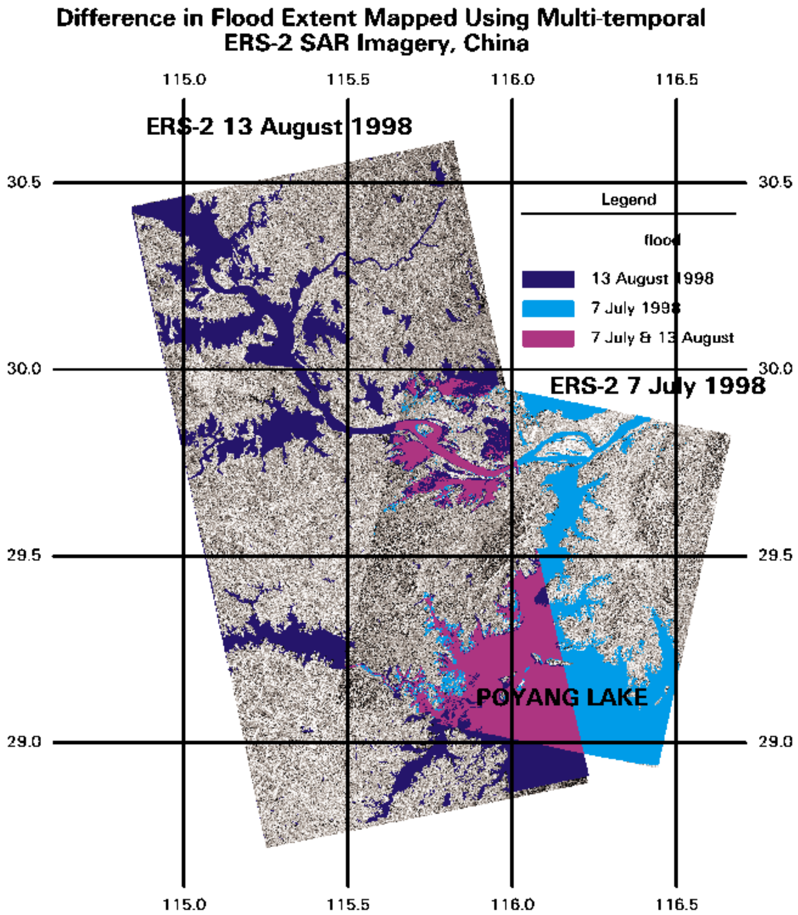


Fig. 4.8: ERS-2 SAR images showing major floods around Poyang Lake and the Yangtze River. Ascending and descending ERS-2 passes acquired on 7th July and 13th August 1998 have been used to map flooded areas, with different colours being assigned to distinguish the areas flooded on 7th July from those flooded on 13th August.

Acknowledgements: ESA - MTSC Cooperation project; Remote Sensing Technology Application Centre, Ministry of Water Resources, China; Remote Sensing Applications Consultants, U.K.; ERS-2 images acquired and processed by the China Remote Sensing Ground Station.

Table 4.4: Proposed default ASAR Modes for commercial applications.

	Mode	Polarisation	Swath	Remarks
Ship routing in sea ice				
Sea ice extent	WS	HH		
Ocean monitoring				
Surface features	AP	HH/HV	IS2-6	
Oil slicks	WS	VV		
Ship detection	AP or IM	HH/HV HH	IS2-7 IS5-7	
Bathymetry	IM	HH	IS2-5	
Agricultural monitoring				
Crop area	AP	VV/VH or VV/HH	IS4	
Crop condition	IM	VV or HH	IS2-7	
Soil moisture	WS	VV		High repeat
Forestry				
Forest area/type/condition	AP	VV/VH	IS4-6	
Hydrology and water management				
Runoff forecasts	WS	VV		High repeat
Flooding	WS	HH		High repeat
Oil and gas industry				
Geological mapping	IM	HH	IS4-7	
Natural hazards				
Earthquakes/volcanoes / land subsidence	IM	VV or HH	IS1-7	

5. OPERATIONS

5.1. Operational Data Requirements

Operational data acquisition planning for ASAR is quite complex because of the facts: that all five ASAR modes are mutually exclusive, and that there are some limitations on data collection from a single orbit. Before considering specific data acquisition strategies, an attempt is made here to bring together the likely user requests presented in the previous section. Table 5.1 provides a breakdown of the expected utilisation of the different ASAR Modes, by users and application areas.

Image Mode will be used primarily for applications which are already well established, such as glaciology, geological mapping, oil slick monitoring, interferometry and land cover mapping. The preference is likely to be for relatively high incidence angles (i.e. IS4 -IS6). There is no geographical bias and most data will be required at irregular intervals.

Alternating Polarisation Mode will be of strong interest for land applications because of the improved capabilities for crop discrimination, forest mapping and soil moisture monitoring.

Wide Swath Mode is critical to the success of sea ice mapping for ship routing. Other uses will include vegetation and hydrological monitoring.

Global Monitoring Mode data are required almost exclusively for Earth Science research. Regular coverage of regional and continental areas will be required.

Mode	Users	Applications
Image	Earth Science and Commercial	Mapping, topography, ice/snow extent, surface deformation/motion, oil/gas exploration
Alternating Polarisation	Mainly RS Science & Commercial	Especially agriculture and vegetation
Wide Swath	Earth Science & Commercial	Land cover, hydrology, sea ice, oceanography
Global Monitoring	RS Science & Earth Science	Vegetation, sea ice, oceanography
Wave	RS Science, Earth Science & Commercial	Forecast models, oceanography, coastal processes

Table 5.1: ASAR Mode Utilisation (based on Williamson, 1996)

Table 5.2: ASAR Operational Configurations

Operating Mode	Swaths	Polarisations	Configurations
Image	7	2 (HH or VV)	14
Alternating Polarisation	7	3 (HH/VV, VV/VH, HH/HV)	21
Wide Swath	1	2 (HH or VV)	2
Global Monitoring	1	2 (HH or VV)	2
			Total 39

Wave Mode data are required primarily for incorporation in ocean models for both meteorological and climate applications.

Looking at the seasonal data requirements in the major application areas for northern hemisphere users, the major requirements are for Alternating Polarisation Mode data over Europe during spring and summer, and Wide Swath Mode data over the northern oceans in winter. In addition to these commercial requirements, there are long term continuous vegetation and sea ice monitoring requirements for Earth Science. As well as these requirements which can be planned well in advance, there are potential high value products which require small amounts of data such as DEMs and maps for the oil and gas industry which are often required at short notice.

Additionally, there could be large requirements for oil slick monitoring and ship detection if national governments take the decision to put operational systems in place. The extension of the EC agricultural monitoring projects into eastern Europe and northern Africa and the adoption of such schemes by governments in other parts of the world, such as rice monitoring in Indonesia, could also impact greatly on the requirements.

5.2. Data Acquisition Strategy

Taking into account the mission objectives, operating capabilities and data recovery strategy, Envisat operations fall into two defined categories:

Global Operations: in which all low rate data, including ASAR Wave Mode and Global Monitoring Mode, can be collected continuously around the orbit, recorded on-board and transmitted to ESA ground stations, nominally once per orbit via X-band or Artemis.

Regional Operations: in which the ASAR high or medium resolution data can be acquired for up to 30% of each orbit, transmitted by direct downlink or Artemis, or recorded on the solid state recorder for later transmission to ESA ground stations (or any combination of these).

ASAR offers a total of 39 different and mutually exclusive modes in high, medium (Wide Swath) and low (Global Monitoring) resolution (Table 5.2). These modes will be operated mainly in response to user requests. Wave Mode is also mutually exclusive with respect to all other modes. The system will allow mode switching up to 10 times during an orbit. The minimum duration for the operation of an individual mode is 1 minute. ASAR has the potential to acquire up to 30 minutes of high resolution data per orbit, but the ground segment has been sized to handle approximately

15 minutes of data. For comparison, ERS-1/2 have been acquiring an average of 5 minutes of SAR data per orbit.

With so many different operating configurations, and many potential areas of conflict, careful attention will be given to the data acquisition strategy. Prioritising long term data needs together with short notice requests is a major challenge.

The operations strategy for ASAR data includes a prioritisation of “User Requests”:

Category 1: Research and application development (including ESA internal use for calibration, validation, quality assurance, AO, Earth science research).

Category 2 (highest priority): Operational and commercial use. To help the user in defining a request, certain default configurations will be proposed according to applications and/or geographic areas.

Additional data acquisition will be carried out within “Background” and “Strategic” Operations.

Background Operations will include Wave Mode over the oceans and Global Monitoring Mode over land and ice surfaces, valid over the full duration of the mission. Other activities will be added at specific times during the mission, such as full Wide Swath coverage of land surfaces or the polar regions. Background Operations will be undertaken only when there are no other requests.

Strategic Operations may include a full range of different image configurations for selected sites, the collection of specific data sets for promotional purposes and extensive coverage of areas poorly covered by the ERS missions.

5.3. Data Processing and Distribution

The Envisat Payload Data Segment (PDS) comprises all ground segment elements related to data acquisition, processing, archiving and user services.

High rate ASAR data will be acquired via one of the following routes:

- real time transmission of data via X-band link to ESA or other ground stations
- real time transmission of data via Ka-band link (Artemis Data Relay) to the ESA receiving station located in ESRIN (Italy)
- on-board recording using a Solid State Recorder (60 Gbit capacity, 10 minutes of ASAR) with data dump using X- or Ka-band when in visibility of an ESA station

Wave Mode and Global Monitoring Mode data will be recorded on-board, and downloaded every orbit when in visibility of an ESA station (Kiruna or ESRIN).

The main Centres and Stations are:

- The Payload Data Control Centre (PDCC) at ESRIN
- The Payload Data Handling Stations (PDHS) at ESRIN and Kiruna
- The Payload Data Acquisition Station (PDAS) at Fucino
- The Low rate Reference Archive Centre (LRAC) at Kiruna
- The Processing and Archiving Centres (PACs) located in ESA Member States

- The National Stations providing ESA services (NSES) located in states which participate in the Programme.

The Payload Data Control Centre (PDCC) at ESRIN will be responsible for ASAR instrument and ground segment planning. It will co-ordinate user services and provide quality control and engineering support for the products.

The Payload Data Handling Stations (PDHS) at ESRIN and Kiruna will acquire ASAR data downloaded by the spacecraft, process them and disseminate products as instructed by the PDCC. All ASAR HR data will be routinely processed in near real-time to produce 150 m medium resolution browse products.

The Payload Data Acquisition Station (PDAS) at Fucino will acquire ASAR data from the spacecraft for onward transmission to the PDHS-ESRIN for processing.

The Low rate Reference Archive Centre (LRAC) at Kiruna will archive and process the low rate ASAR Wave Mode and Global Monitoring Mode data.

The Processing and Archiving Centres (PACs) located in ESA Member States will archive and process ASAR data and generate off-line products. Responsibility for ASAR HR data will be shared between UK-PAC, D-PAC and I-PAC. ASAR Wave Mode data will be handled by the F-PAC.

The PDS will provide both Near Real-Time and Off-Line services. Near Real-Time services will provide data, within 3 hours of the overpass, for use in forecasting or tactical operations, and within 1 to 3 days for applications requiring high resolution images. Off-line services will provide data within a few days to weeks from the data take, with products benefiting from a posteriori knowledge of calibration, auxiliary data and precise orbit.

User access to the PDS will be available via the Internet to all ground stations and centres. Data services will include on-line search, browse and ordering. Data delivery will be performed using a number of different mechanisms. Multicasting and broadcasting systems will be used for near real-time delivery of large products. The Internet will be used for on-line retrieval where data volume and product size allow. Physical media will be used for the delivery of medium or large volume data products where there are no severe time constraints.

References

Balababa L., Schumann R., Adrianasolo H., & Tinsley R., 1997, "Identification of Rice Cropping Areas in the Mekong Delta (Vietnam) using Radar Imagery", ESA EOQ No. 56-57, December 1997.

Dierking W., Askne J. & Pettersson M.I., 1997, "Baltic Sea Ice Observations during EMAC-95 using Multi-frequency Scatterometry and EMISAR Data", Workshop Proceedings EMAC 94/95, "Final Results", ESA WPP-136, September 1997.

Engen G. & Johnsen H., "SAR Ocean Wave Inversion using Image Cross Spectra", IEEE Trans. Geosci. Remote Sensing, Vol. 33, No.4, pp.1047-1056.

ESA, 1995, "New Views of the Earth: Scientific Achievements of ERS-1", ESA SP-1176/I.

ESA, 1996, "New Views of the Earth: Applications Achievements of ERS-1", ESA SP-1176/II.

ESA, 1997a, "New Views of the Earth: Engineering Achievements of ERS-1", ESA SP-1176/III.

ESA, 1997b, "Fringe 96 Workshop ERS SAR Interferometry", ESA SP-406, Vol. I, March 1997 & Vol. II, December 1997.

ESA, 1998, "Envisat Mission: Opportunities for Science and Applications", ESA SP-1218.

Johannessen J.A., Digranes G., Esdedal H., Johannessen O.M., Samuel P, Browne D, & Vachon P., 1994, "ERS-1 SAR Ocean Feature Catalogue", ESA SP-1174. October 1994.

Le Toan T., Smacchia P., Souyris J. C., Beaudoin A., Merdas M., Wooding M., & Lichtenegger J., 1994, "On the Retrieval of Soil Moisture from ERS-1 SAR Data", Proceedings of the Second ERS-1 Symposium "Space at the Service of our Environment", ESA SP-361 Vol. II, pp 883 to 888, January 1994.

Luckman A.J., Baker J.R., 1995, "The Effects of Topography on Radar Scattering Mechanisms from Coniferous Forest and Upland Pasture", MAC Europe 91 Final Results Workshop Proceedings, ESA WPP-88, January 1995.

Mastenbroek K., 1998, "High resolution wind fields from ERS SAR", ESA EOQ No. 59, June 1998

Nghiem et al., 1993, “Layer Model with Random Spheroidal Scatterers for Remote Sensing of Vegetation Canopy”, Journal of Electromagnetic Waves and Applications, Vol. 7, No. 1.

Pavlakis P., Sieber A. & Alexandry S., 1996, “Monitoring Oil-Spill Pollution in the Mediterranean with ERS SAR”, ESA EOQ No. 52, June 1996.

Rott H., Skvarca P. & Nagler T., 1996, “Rapid Collapse of Northern Larsen Ice Shelf, Antarctica”. Science, Vol. 271, 788 - 792.

Souyris et al., 1998, “Estimation of Landes Forest Biomass using SIR-C data”, submitted to IEEE Transactions on Geoscience and Remote Sensing.

Wismann V. & Boehnke K., 1994, “Land Surface Monitoring using the ERS_1 Scatterometer”, Earth Observation Quarterly. No. 44, June 1994.

Williamson H.D., 1996, “Assessment of ASAR User Requirements”, DERA report DRA/CIS(CIS2)/CR/96052.

Zmuda A., Corr D., Bird P., Blyth K. and Stuttard M. J.,1997, “The Potential of ASAR for Soil Moisture Monitoring - A Simulation Study”, Proceedings of the 23rd Annual Conference of the Remote Sensing Society, University of Reading, United Kingdom, 2-4 September 1997, pp 591 to 596.