ERS-2

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# European Space Agency

# Earth Observation Scientific and Technical Advisory Group

## ERS TANDEM Mode Mission

This paper reports on the scientific aspects and applications of the TANDEM Scenario, as identified during a working session held in ESRIN on November 6-7, 1993. EOSTAG Delegates are kindly invited to comment on the content of this document and the recommendations made therein, and, if agreed, to recommend it to PB-EO.

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# EXECUTIVE SUMMARY

ERS-1 is expected to maintain its health status until end 1995. To provide continuity of service to the ERS users, it has been proposed to perform the minimum necessary upgrades of the Ground Segment in order to maintain the ERS-1 operations (as they are today) until the end of ERS-2 Commissioning. Beyond this date, simultaneous operations of the two satellites would require only marginal additional operation costs. A scenario has been devised, the so-called "TANDEM Scenario", to perform campaigns of dual ERS-1 / ERS-2 operations after the end of ERS-2 Commissioning. The purpose of this document is to summarise the benefits of this TANDEM Scenario, in terms of scientific and operational applications, as they were identified during a working session held in ESRIN on 6-7 November, 1993, with selected scientists and application users (including support from the CEC/JRC), together with a few ESA staff.

The first part of this document recalls the characteristics of the TANDEM Scenario and the corresponding limitations and constraints:

- The service for the operational satellite shall **absolutely not** be disturbed by the TANDEM operations
- Fast Delivery Service will be available only from the operational satellite
- for the non-operational satellite, HDDR recording only will be performed at the ground station. Products will be generated off-line (no real-time service).

The working group has identified that the generation of medium resolution Digital Elevation Models (DEMs) over a large part of the Earth land masses would be a major achievement of a TANDEM mission, with applications in a variety of disciplines:

- Hydrology
- Ecology
- Geology
- Agriculture
- Forestry
- Glaciology

In addition, the following applications would take advantage of the TANDEM campaigns:

- climatology studies (mesoscale wind fields, winds in coastal zones)
- plant growth monitoring, sea ice studies

Possible campaign scenarios were also identified, covering a period of about 6 months.

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# 1. Introduction

## 1.1. Background

ERS-2 is scheduled for launch in December 1994 - February 1995. ERS-1 is currently functioning well within specification and there is every reason to believe that the satellite could continue to acquire and transmit High Rate and Low Rate data well into the first year of life of ERS-2.

During commissioning of ERS-2, the assumption is that ERS-1 will remain the operational satellite, providing continuity of all current services to users. It is proposed to place both satellites on the same orbit repeat cycle, the ERS-1 35 day repeat cycle, with an offset of 1 or 8 days in the orbit phasing of the two satellites (see annex 2). With this scenario, the nominal acquisition, FD processing and product dissemination of ERS-1 from the ESA stations would be secured. For ERS-2, the operations will be limited to data acquisition, data extraction and processing required for satellite commissioning. This has necessitated a limited upgrade of the ERS Ground Segment, related to duplication of some critical equipment for mission planning and data acquisition/recording of both missions in parallel.

This opens the possibility of simultaneously operating ERS-1 and ERS-2 for a certain period of time during the Routine Phase. This simultaneous operation on a campaign basis has been called the TANDEM Scenario.

On the occasion of several ERS-1 user meetings (e.g. Principal Investigators meetings, Pilot Project Leaders meetings) and at various symposia and conferences where ERS-1 activities and results were presented, both scientific and application users have expressed a strong interest for the TANDEM Scenario. After the Second ERS-1 Symposium in Hamburg, it was decided to organise a working session with selected scientists and application users (including support from the CEC/JRC), together with a few ESA staff, to discuss further in details the potential benefits which would result from the TANDEM Scenario.

This working session was held in ESRIN on 6-7 November, 1993. The list of participants is attached as Annex 1. The contributions and recommendations of the participants are compiled in this document.

In addition, the ERS Announcement of Opportunity issued at the end of last year mentioned the possibility for a TANDEM scenario. The evaluation of the A.O. proposals is still on-going, but a preliminary analysis shows that about 23 proposals from 8 countries explicitly refer to the parallel operations scenario.

## 1.2. TANDEM Scenario Description and Capabilities

In this scenario, both satellites are operated in parallel. One satellite is supporting the full global mission and most of the SAR operations. FD products are regularly produced by the ESA stations for this satellite, and distributed to users (BDDN for SAR FD products from Kiruna and Fucino, GTS for low bit rate FD products). The second satellite is supporting complementary operations, with the SAR and low bit rate instruments, according to an agreed strategy: data acquisition at ESA stations (low bit rate and SAR) and at national/foreign stations (SAR). The baseline is that no FD products are provided from ESA stations for the second satellite, all processing being performed off-line.

### 1.2.1. Orbit phasing

A constant orbit phasing has to be maintained between the two satellites to permit control and acquisition of the data with the present ground segment. The proposed orbit repeat cycle is the 35 days as during the ERS-1 multi-disciplinary phase (Lampedusa Phasing), offering full SAR coverage at all latitudes.

The analysis has demonstrated that the following configurations are compatible with the above constraints:

- one day interval between ERS-1 and ERS-2 ground site revisiting
- eight days interval between ERS-1 and ERS-2 ground site revisiting

The diagrams attached as Annex 2 show the coverage achieved by the two satellites under these configurations, for all instruments.

### 1.2.2. Product Types and Availability

#### 1.2.2.1. low bit rate FD

Low bit rate FD service cannot be made available from both satellites. Low bit rate FD service will be therefore available only for the operational satellite. Also, ATSR (Infrared) products will be generated only for one satellite and limited to the Tromsoe capabilities (10 orbits per day).

#### 1.2.2.2. SAR off-line

The availability of off-line SAR products from both satellites will be analogous to the current availability of ERS-1 off-line SAR products. Specifically,

- PRI products can be generated at D-PAF, UK-PAF, I-PAF, Fucino, Maspalomas, ESRIN, from data acquired at ESA stations and German Antarctic and transportable stations;
- ASF (Fairbanks) and Canadian processing facilities can cope with both ERS-1 and ERS-2 SAR processing (TBC, at least on a campaign basis);

- The other stations, in particular the foreign stations, have an extremely limited processing capability (with the possible exception of Australia and Thailand).

### 1.2.2.3. low bit rate off-line

FD-type products can be generated off-line at Fucino or at ESRIN, for the non-operational satellite, from data acquired at Kiruna, Maspalomas, Gatineau, Prince Albert.

The current status of the PAFs involved in Low bit rate off-line processing (F-PAF, UK-PAF), and their upgrade for ERS-2, does not permit to anticipate a suitable throughput from these PAFs for an extensive TANDEM operation.

The acquisition and processing capabilities are summarised in the following table.

| | Acquisition | Off-line Processing |
|---|---|---|
| **SAR** | | |
| European Coverage | at ESA and National Stations | possible at PAFs |
| North America Coverage | possible | limited possibilities (campaigns) |
| Antarctica | German Station at O'Higgins, (campaigns) | at D-PAF (as of today) |
| coverage zone of Transportable Station deployment site | Transportable Station (campaigns) | at D-PAF (as of today) |
| Other Foreign Stations | limited (as of today, additional conflicts with other missions) | very limited (as of today) |
| **Low bit Rate Data** | Tape recorder dump at ESA stations | possible at Fucino (FD-type products) |

## 1.2.3. Possible TANDEM Schedule Scenario

The TANDEM operations could start after the end of the ERS-2 commissioning phase, i.e. around May/June 1995. This would allow season dependent experiments in various fields of applications: agriculture, vegetation, snow, soil moisture... These operations could be extended until end 1995 early 1996, in time for snow and ice applications. It should be noted that the ERS-1 reliability is expected to decrease notably over time from 1996 on. TANDEM operations should be therefore concentrated on campaigns held in the second half of 1995.

# 2. Benefits from TANDEM Scenario

## 2.1. Introduction

The potential advantage of the TANDEM configuration is that data over a given area (i.e. land, ocean, ice surface/masses) could be acquired

- more frequently for a given instrument (e.g. SAR) or
- acquired first by one instrument (e.g. SAR) on-board the first satellite and then later (with a delay of the order of a few days) by another instrument (e.g. ATSR) on-board the second satellite.

More precisely, the benefits from the TANDEM Scenario have been explored according to the following four broad categories:

- *interferometry potential* where the AMI SAR on ERS-1 and the AMI SAR on ERS-2 are used to achieve better interferometric conditions than with only one AMI SAR;
- *relaxation of instrument operation exclusivity* where the availability of the second satellite permits simultaneous operations with instruments which are exclusive (in terms of operability) on a given ERS satellite (e.g. altimeter modes, scatterometer during descending passes);
- *Space/Time sampling* significantly increased for a given instrument, as shown in Annex 2. The consequences of data availability are twofold:
  - — for a given date, the spatial coverage is doubled, especially with the 8-days offset, where the ground tracks of one satellite are regularly interleaved with the ground tracks of the other satellite;
  - — for a given site, the interval between two observations is reduced (1 day or 8 days within each 35 days cycle).
- *synergy* i.e. observation of the same area by different instruments at short time interval (of the order of a few days), in particular at high latitudes.

## 2.2. Overall summary of TANDEM benefits

They are summarised in the table below, and detailed in the following paragraphs.

| | Interferometry | Exclusivity | Sampling | Synergy |
|---|---|---|---|---|
| Hydrology | flood forecasting water cycle research | | soil moisture variation | |
| Agriculture | surface change | | plant growth | |
| Vegetation / Forestry | deforestation | land cover (ATSR-2) | | |
| Snow and Climatology | | | snow cover variation | |
| Ice Sheets | mass balance and dynamics | RA tracking modes | | |
| Sea Ice | | | ice dynamics ship routing | |
| Geoid | | | | dual laser tracking data, PRARE |
| Atmospheric studies | | | | ATSR orbit perturbation |
| Ocean Circulation | | | dealiased measurements | |
| Wind fields | | coastal regions | mesoscale wind fields | |
| Catastrophic Events | land slides, earthquakes | | oil slicks, pollution | |

## 2.3. The potential of Interferometry for Geoscience applications

Many geoscience disciplines could benefit from the data that can uniquely be acquired during a proposed TANDEM mission. The main interests in terms of Geoscience lie in:

1. the capability to generate medium accuracy Digital Elevation Models (DEMs) on a large fraction of the land surface.

2. the improved detection capability of changes on the land surface.

A medium resolution DEM over a large portion of the land surfaces of the Earth is one of the key requisites in many global and local research and application fields in the following disciplines:

- Hydrology
- Ecology
- Geology
- Agriculture
- Forestry
- Glaciology

Today moderate resolution DEMs (500 m) are available only for a small portion of the land surface (app. 20%). The extrapolated cost of this product, which is not adequate for most Geoscience applications in terms of the resolution it offers, is app. 6 MAU for the whole land surface of the Earth. The costs for these DEMs have prevented many institutions from including them in their projects, even though the quality of the results could be greatly enhanced.

The quality requirements for a medium resolution DEM to meet many Geoscience requirements on the local and global scale can be defined as follows:

| | |
|---|---|
| x - y accuracy: | 30 m |
| z accuracy: | 10 m |

### 2.3.1. Digital Elevation Models (DEM's)

DEM's are important for many disciplines and practical applications as well as for the Global Change programme. The SAR interferometry is a very powerful tool to acquire them with medium accuracy, very efficiently and on a large fraction of the land surface. For cloudy areas or for regions with extremely low textural surface features it is even the only feasible method.

The generation of DEMs on a large scale requires, however, the TANDEM mission as various constraints have to be met, which are not met by just one SAR in operation:

1) Temporal coherence between the SAR image pair must be high. For many parts of the Earth's land surface, which are affected by fast surface cover changes through vegetation development the 35 days repeat cycle is too long (there are various other effects deteriorating coherence for interferometric processing. Among those are ionosphere, troposphere, rain, and soil moisture changes.). For some regions, investigations have shown that correlation degrades by as much as 10% in 5 days.

The 3 days repeat orbit offers good coherence but covers only limited parts of the land surface. This option has proven to be of value for DEM production during the Commissioning Phase and the Ice Phases of ERS-1 but it will not meet user requirements for large-area DEMs.

For the production of large-area DEMs a one day equivalent timeline is preferable to a 3 days repeat cycle.

2) Spatial coherence must be high as well for interferometric DEM production. In addition, the ambiguity problem must be solved. The preferred interferometric baselines should be about 50 and 150 meters. This is much easier achieved with the TANDEM mission as the orbits of the two satellites will be affected by similar forces. Precise orbit determination is essential for interferometry. ERS 2 will have PRARE on board, which might be beneficial for the ERS 1 and 2 TANDEM.

The TANDEM experiment would therefore permit generation of DEMs over a large fraction of the land surface.

It would be possible to achieve simultaneously:

a) higher coherence due to the relatively short delay between the interferometric takes (1 or 8 days)

b) wide coverage.

Without the TANDEM experiment, it would be possible to achieve a) or b) but not both goals together: with the 3 days cycle one would get high coherence but no global coverage, whereas with the 35 days cycle one would achieve global coverage (within the ground stations visibility) but lower coherence. In addition, the number of couples of images in 35+1 (or 35+8) days of TANDEM would be five times larger. This would lead to a reduction of the dispersion of the elevations.

### 2.3.2. Surface Change Detection

Surface change can be observed in interferograms either through decorrelation in the interferometric phase, or coherent phase shifts caused by locally uniform motion of the surface. Random changes in the surface cause random decorrelation of the interferometric phase. In contrast, uniform displacements of the surface cause coherent phase shifts detectable using differential three passes interferometry. Interferometric correlation maps made from ERS 1 data have revealed decorrelation patterns which are related to the amount of vegetation and soil moisture in most scenes processed. These results have been demonstrated by several presentations at the Second ERS-1 Symposium.

Short term changes could be very well monitored with a TANDEM operation using a **1-day** or a **8-days** offset.

The potential benefits of a medium resolution DEM, available on a large fraction of the land surface, derived from a TANDEM mission are different for the different fields of application. Among the many possible applications there are a few worth mentioning to show the impact of the availability of this product in scientific, environmental and commercial terms.

### 2.3.3. Hydrology

Three fields can be identified, in which medium resolution DEMs are necessary on a global basis:

1) **flood forecasting**: Since the development of floods is strongly determined by the hydraulics of the watersheds, a DEM, which reflects the major influencing factor in watershed hydraulics can greatly improve the forecasting of floods through modelling. Especially in developing countries, where stream flow data is rare, a considerable amount of damage can be avoided through improved flood forecasting, which will be possible as soon as the appropriate DEMs are available.

2) **Determination of water availability**: The local topography determines the direction of water flow, ground water recharge and snow melt. These factors strongly affect the amount of water that is available for irrigation, power production, industry and agricultural production. Including medium resolution DEMs in water availability models can greatly improve their accuracy and create a considerable benefit for large parts of the land surface.

3) **Basic water cycle research**: Within research programmes in the frame of Global Change and GEWEX the climate investigations of the water cycle gain increased interest since the transport of water is the single most important distribution path of energy on the land surface. Global GEWEX experiments (for example BALTEX: modelling the Baltic Sea and its watershed; LAMBADA: modelling the Amazon basin) can hardly be conducted without the availability of a medium resolution DEM since the distributions of irradiance (sun-shade) and water flow have to be known on the local scale to adequately model land surface evapotranspiration and stream flow on a large scale.

In addition to the above mentioned field, there are important applications that depend on the detection of changes on the land surface, which can greatly improve the interferometric processing of the data available through the TANDEM mission. Among the many fields of potential applications, the following should be mentioned because they most stringently rely upon the short repeat cycle offered by the TANDEM mission.

### 2.3.4. Forestry

Through determination of forest stand height and its change using TANDEM interferometry, clearcuts can be clearly identified. Equally important is the monitoring of the plant development on these clearcut areas. Reforestation, fallow land as well as the development of natural vegetation can be monitored using TANDEM interferometry. The 35 day repeat cycle is less adequate to perform the necessary interferometric processing because of strong decorrelation effects within the forests.

### 2.3.5. Ice Sheet And Glacier Research

The polar ice sheets are key elements of the global climate system, strongly influencing atmospheric and oceanic circulation. In addition, polar ice cores are able to provide unique information on climate and atmospheric composition of the past several hundred thousand years. Mountain glaciers are important indicators of climate change and - in many regions- are valuable resources of fresh water. For these reasons, improved information on mass balance and dynamics of ice sheets and glaciers is of great interest for climate monitoring and research in the context of global change. Due to the remoteness of polar areas and glaciers, the high percentage of cloud cover in these regions, and the sensitivity of radar backscattering to snow and ice properties SAR systems show high potential for monitoring and mapping ice sheets and mountain glaciers and for studies of ice dynamics. Significant advancements for these applications can be expected from the ERS-1/ERS-2 TANDEM mission.

The highest gain of the TANDEM mission for ice sheet and glacier applications would result from the improved capabilities for interferometry. Ongoing research indicates significant potential of interferometry for determining topography over ice sheets and glaciers and for deriving ice motion. Whereas radar altimetry is the optimum sensor for determining surface topography over the level parts of Antarctica and Greenland, topographic information cannot be obtained by means of altimetry over surfaces with inclination of more than about 2 degrees, which include many of the fast flowing ice streams draining the central parts of the ice sheets. Interferometry should be able to fill these gaps, as well as to improve the very limited knowledge of the ice reserves of the mountain glaciers all over the world. Improved knowledge of ice motion is needed for modelling of ice sheet/climate interactions and for studying the impacts of climate variability for glacier extent and mass balance. Among the techniques available to derive motion vectors, SAR interferometry indicates the best potential for deriving fields of surface motion over large areas with high spatial resolution.

A basic problem for the application of interferometry over ice sheets and glaciers is temporal decorrelation. This problem can be significantly reduced if the time difference between the acquisition of image pairs is small. Decorrelation may result from changes of snow and ice backscattering properties due to weather events (wind, temperature, snowfall) or from deformation of the surface and near-surface layers due to ice motion. Examples for decorrelation within three days for the first case have been observed even over permanently dry snow in Antarctica, examples for the second case have been reported for fast flowing ice streams in Antarctica, Greenland, and Alaska. Daily surface motion of the most dynamic ice streams is up to 24 m in Greenland and up to 10 m in Antarctica. Significant improvements of coherence can be expected if the time lag between two observations is reduced to **1-day**, as enabled by the ERS-1/ERS-2 TANDEM operation.

## 2.4. Benefits from increased sampling frequency

### 2.4.1. Agriculture

In the field of agriculture an improved detection of soil moisture changes can lead to better input parameters for models for plant water use. A considerable amount of irrigation water can be saved if on the basis of improved soil moisture information the irrigation water consumption can be managed more intelligently and efficiently.

A short revisit interval will vastly improve the determination of plant growth since single frequency, polarisation and incidence angle operation of ERS-1 and ERS-2 has to be compensated by a multitemporal coverage. This multitemporal coverage of presently 35 days is not fully adequate to monitor the most important phases of plant growth (shoot and maturation) since they occur within 2 to 3 weeks each. An **8-days** interval between data acquisitions, as planned within the TANDEM mission, will enable a more accurate determination of plant growth because the observation cycle is much better adapted to plant growth dynamics. This will improve the accuracy of agricultural land use classifications. Together with the exploitation of the night orbit for the observation of plant height development and biomass build-up through interferometry this will enable an improved harvest estimation, with respect to what can be achieved within the 35 day repeat cycle.

### 2.4.2. Snow Melt Hydrology And Snow Climatology

The capabilities and uniqueness of SAR for monitoring melting snow areas have been demonstrated at the 2nd ERS-1 symposium. SAR-derived snow cover maps are able to provide basic information for water management, hydrological modelling and monitoring, as well as for climate research. Due to the high temporal dynamics of snow cover during the melt period, improved temporal SAR coverage is able to result in considerable benefit for these applications. Typically, the duration of the snow melt period in alpine drainage basins is of the order of 2 to 3 months. In lowland basins, which include smaller altitude ranges, the duration of the snow melt period is shorter. Pairs of images at **8-days interval** would clearly improve the measurement of the variation of snow cover in comparison to SAR coverage by a single satellite.

For stream flow forecasting, flood warnings, and hydrological research, extent of snow-covered areas is a basic input parameter of snow melt-runoff models. During the peak snow melt period daily changes of snow extent in alpine basins are of the order of 1 to 2 percent of total basin area. This results in significant variations of runoff contributions due to snow melt if time intervals of more than about 10 days are considered.

### 2.4.3. Sea Ice

Large areas of the oceans are covered by sea ice every winter (in average 13% and 10% of the oceans in the northern and the southern hemisphere, respectively) with large variations in extent seasonally and annually. Since sea ice effectively cuts off the heat flux from the ocean to the atmosphere, the formation and drift of sea ice are important elements of the regional and in

view of the large areas involved most likely also the global climate. Extensive research of sea ice has therefore been carried out for many years presently supported to a great extent by remote sensing and microwave remote sensing in particular - the latter due to the independence of daylight and clouds and haze. In some areas sea ice prevents or hamper economically important shipping, and operational services of routing of ships and icebreakers have been established exploiting remote sensing in almost real time.

Sea ice is a very dynamic medium. During the winter large areas of the polar oceans become covered by ice, often at a high rate; with the boundary between the ice-canopy and the open-ocean shifted by 100 km per day, for instance. Similarly, large areas of sea ice may melt at a high rate, one example being the melt of an area of first-year ice of about 100 km by 500 km in the course of one week.

Sea ice is influenced by wind and ocean current so that large areas of sea ice are moved from one location to another at velocities which may range from zero for shore-fast ice to 60 km per day in pack ice with average velocities of the order of 17 km per day. Techniques have been developed to determine more or less automatically the velocity field of an ice canopy from a time series of SAR observations, for instance.

Consequently, the advantage of the proposed TANDEM Operation lies in the increased observation rate from which a better understanding of the ice dynamics may accrue. This dynamic is an indicator of the geophysics of polar oceans reflecting the air-sea-ice interaction attracting much attention presently. Thus, the velocity vector field of an ice canopy is used in connection with numerical modelling, now being performed to a scale of 15 km and time scales of days (in specific cases) to a week, for instance. The increased repetition rate may assist in understanding the short-term variability that is experienced at all times of the year. One example is the observation of the central pack ice where one six-day winter period showed a movement of only 7 km whereas the following six-day period experienced a movement of 65 km.

With an increased observation rate the chances of observing special phenomena such as the convection processes associated with the formation of deep water of importance to studies of climate change increase accordingly. This is related to the so-called chimney effect with an areal extent of about 10 - 30 km which shows up as a special signature in a sea ice canopy.

Data from the radar altimeter and ATSR (I-R and microwave) are spatially and temporally coincident, providing the opportunity for synergistic studies. This has proved particularly useful for developing the understanding of the response of the altimeter to complex surfaces such as sea ice.

It would be very valuable to be able to compare the altimeter data over a variety of surfaces with SAR imagery and wind scatterometer data. However, because the swaths of these instruments are offset to one side of the ground track, there is no overlap with the altimeter footprint. Thus, spatially coincident measurements can only be achieved at ground track crossover points, which generally occur after substantial time delays. If the surface is temporally variable, little useful information can be obtained.

The TANDEM opportunity offers the prospect of much reduced delay times between the crossover of the altimeter track from one satellite and the SAR and wind scatterometer swaths of the other. Taking sea ice as an example, the motions of floes and leads will in general be less than the altimeter footprint size (20 km) during such a delay, giving an excellent opportunity to investigate in the response of the altimeter to ice-covered ocean and to develop corresponding models, in a way not possible with a single mission. Similarly, the understanding of the response of the altimeter to complex inland water surfaces, including river channels, could be improved.

The applications referred to above are related to sea ice research. The increased observation rate is also of importance for operational purposes where sea ice reconnaissance is of importance for ship routing and other support. However, since the TANDEM Operation will only be performed in a limited period it may be expected that the operational entities will use this opportunity only for obtaining experience in preparation for future satellite SARs with a more frequent coverage than those available today.

For studies of short-term variation the **1-day** repeat proposed is of importance. However, for most other applications the other proposal of an **8-days** repeat is preferable and therefore suggested from a sea ice research and operation point of view.

### 2.4.4. Geoid

The joint operation of ERS1 and ERS2 with an **8-days** offset will provide a substantially increased high quality set of laser data in a relatively short time span and at the same time PRARE microwave data from locations different to the SLR locations. The use of these data sets in global gravity field modelling will enhance the modelling of the global Geoid, required for improved orbit determination, sea surface topography extraction, etc.

On the other hand the joint operation of ERS1 and ERS2 will allow to quickly construct a joint ERS1/ERS2 ocean Geoid and to link it directly to the ERS1 ocean Geoid, derived from one or two 168 days ERS1 orbit cycles. This Geoid derived from the geodetic part of the ERS1 mission will be only very little affected by large scale oceanographic signals, from which the ERS2 generated ocean Geoid surface could directly benefit.

### 2.4.5. Orbit Perturbation Analysis For Atmospheric Studies

The TANDEM mission provides a unique opportunity to study the perturbations in the motion of two spacecrafts, having very similar geometric and physical properties and being separated from each other in space by a constant offset of only 50 minutes. Analysing the orbital perturbations of both spacecrafts short term variations in atmospheric densities at 780 km altitude and other short term phenomena related to the surface forces can be studied.

### 2.4.6. Ocean circulation

Previous studies of altimetric satellite repeat period sample rates have established that a ground track repeat period of 10 to 20 days is most suitable for studies of large scale ocean circulation for a single altimeter, while a longer cycle (35 days) is more appropriate for studies of

mesoscale ocean circulation . The proposed ERS-1/ERS-2 TANDEM scenario of 35-day repeat orbit, with a time separation of **8-days,** will provide an unprecedented measurement type for the study of ocean circulation.

The effective sampling rate for the dual ERS altimetry would be 8 days, which allows a near-optimal pseudo repeat period of 8 days, during which oceanographic features, from large-scale to mesoscale, can be observed with minimum aliasing. Having the two satellites on the same track permits the interpretation of the data using collinear tracks. The relative bias of the two altimeters can be solved for during the commissioning phase.

Remaining orbit errors, already largely reducible in mesoscale studies but not so much for large scale, could be further reduced by ERS-1/ERS-2 crossover minimisation.

In addition, since the repeat orbits for each of the ERS satellites are still 35-days, the spatial resolution will be more than four times than the case for a designed repeat orbit of 8 days. The 35-day repeat orbits are also beneficial in geophysical studies, including improving the knowledge of Geoid and oceanic lithosphere.

### 2.4.7. Wind Fields and Waves

The ERS system with a one-sided 500 km wide swath for the scatterometer provides a limited sampling rate for wind fields, except in steady regions, such as the undisturbed trade wind and tropical latitude belts. Currently using ERS-1 scatterometer winds only, we require 3 days of data in this region to produce gridded wind fields with reasonable error structures, and there remains completely unsampled regions. Some accuracy is gained already by adding the altimeter wind speed in the subtrack, which falls between the scatterometer swaths of two sequential orbits of one satellite.

With coverage from two ERS satellites representative average daily wind fields could probably be produced for the low latitude regions, and for certain purposes also for mid- and high latitudes.

The fast delivery products would not be improved, since it is not foreseen to distribute the additional data in near real time. Thus, the benefits would be for research of mesoscale wind fields and storms and for demonstration projects.

It has been shown at the Second ERS-1 Symposium that even though the ECMWF model often catches tropical cyclones very well, it may mis-locate the storm centre, and occasionally it completely misses the presence of such storms. The latter situation we blame on the lack of input data, which the scatterometer can remedy, if properly included, and when the coverage by its swaths is sufficient. The benefits due to the doubled sampling of wind and wave fields over the sea would be present regardless of whether the TANDEM mission is in a **1-day** or an **8-days** repeat orbit.

The gridded wind fields from the scatterometer for subtropical and tropical regions are used to drive large scale ocean circulation models, wave forecast models, climate models. They have also a particular application: the El Niño phenomenon.

The separation of the altimeter and AMI ground tracks also precludes direct comparisons of the altimeter and scatterometer wind speed estimates, and the altimeter and SAR/wave ocean Significant Wave Height values. The availability of spatially coincident data sets, gathered within one day, would permit useful cross comparisons of these parameters. Clearly, these would be susceptible to temporal variability of the phenomena, necessitating careful interpretation of the data sets, and possibly some averaging. Nevertheless, given some continuing concerns about the parameter extraction algorithms used for wind speed and wave height from both the altimeter and the AMI, the comparisons would be very useful.

#### 2.4.7.2. Analysis of Severe Storms with Scatterometry.

For research purposes the doubled revisit possibility for obtaining C-band wind fields in tropical, mid-latitude and polar cyclones will give a tremendous boost to the analysis of such weather phenomena over the sea. The C-band scatterometer is able to penetrate the heavy precipitation of such systems better than the SEASAT scatterometer (operating at Ku-band). Other types of data providing as a complete a picture of the mesoscale structure of the surface wind field do not exist. The evolution of such systems can be studied much better by the higher sampling by two satellites, particularly at high latitudes.

With the limited swath width, one cannot count on sampling a particular storm even with two satellites in a systematic fashion. A TANDEM mission would however increase the likelihood to acquire some well-sampled cases.

Therefore, the opportunity to work with a more complete wind field from a C-band system should be very beneficial for planning of future scatterometer missions and for the application of storm monitoring.

Recent studies with ERS-1 scatterometer data (Second ERS-1 Symposium) illustrate several cases where the ECMWF forecast model completely missed tropical cyclone development. We attribute this failure to the lack of input data, since the model often produces realistic looking cyclones, although the exact location of the centre can certainly be improved with the use of scatterometer information.

#### 2.4.7.3. Wave Analysis.

Wave fields derived from the SAR in wave mode operated on two ERS satellites benefit from the doubled coverage (in off-line applications only) similarly to the scatterometer wind fields.

Assimilation into the WAM (community Wave Model at ECMWF) for inversion may have benefits that are even greater, since the improvement in model output is likely to not be simply linearly proportional to the data coverage.

When the AMI in wave mode can be obtained looking at the same wave field from the two satellites this provides two different look directions with respect to the mean wind and wave directions. This situation allows special tests of SAR imaging and processing methods.

Similarly, the synergy of overlap between the altimeter $H_{\frac{1}{3}}$ estimates from one satellite and $H_{\frac{1}{3}}$ estimates from the SAR wave directional spectra obtained on the other satellite (either from imagettes or from the full SAR image) is also a unique opportunity to deepen our understanding of the interaction of radar signals from space with various types of wind and wave fields.

The opportunity to collect scatterometer wind fields from one satellite simultaneously with SAR imagettes or images from the other satellite close in time in coastal zones and other dynamic regions should not be missed. It would be opportune to combine a few such special satellite sampling programs with dedicated surface or aircraft measurements. Use could also be made of the existing NOAA buoy network.

## 2.5. Improvement of Instrument Operations with TANDEM

### 2.5.1. Cross Validation Benefits

#### 2.5.1.1. Extended Geophysical Validation

Following the assumptions presented above ERS-2 will be launched in January 1995 and nominally would undergo a 3-month commissioning phase. During this period engineering calibration will take place together with the verification of the operability and performances of platform and payload. Where possible the engineering calibration of ERS instruments has been decoupled from the geophysical validation. As a consequence, once the quality of ERS-2 basic data products in terms of radar backscattering coefficient, time delay, etc. has been verified, the geophysical data products in terms of wind speed, wave height, etc. are automatically verified since the geophysical models do not depend in principle on the particular sensor used.

However, this has to be verified through comparison of time series of geophysical measurements from ERS-2 and ERS-1. Although these comparisons are part of the planned commissioning process an extended TANDEM operation might be necessary to reveal small trends and biases, which can only be observed in long (e.g. > 6 months) series of wind speed, wave height, etc.

It should be noted that such extended validations are a bonus for the Agency 's product control services, but may turn out to be essential to establish sufficient confidence in ERS-2 products (an in particular as a continuation of ERS-1 products) among the user community in operational meteorology and oceanography.

For the case of ATSR-2 validation, the **1-day** option is preferred, because it provides a rapid second opportunity when expensive or complex ground deployments are involved on an opportunistic basis (as is frequently the case). For most applications of the data, both scientific and otherwise, the improved temporal sampling of the 8-days separation is definitely preferred. Thus, the recommendation of the ATSR 1 & 2 user groups will be to use the **8-days** separation

as baseline, with the **1-day** separation used for periods during commissioning and, possibly, for subsequent validation exercises or campaigns.

Extended geophysical validation only requires nominal operation of the satellite sensors.

#### 2.5.1.2. Inter-instrument validation

TANDEM operation of ERS-1 & ERS-2 offers the unique benefit to investigate the geophysical retrieval models by comparing for example radar altimeter responses and scatterometer measurements over the same area within typically less than one hour. Similar comparisons can only be done with one satellite on the basis of time (e.g. monthly) averages.

Inter-instrument validation requires an investigation of suitable sites, which can be covered by the two satellites within a short time interval and obviously requires mission planning to ensure that the relevant instrument modes are activated over the sites. Inter-instrument validation would benefit greatly from the availability of surface data collection by ships, buoys, aircraft, etc.

During the ERS-2 three-month Commissioning Phase the altimeter height bias will be calibrated using the combination of laser and sea level measurements over the Venice tower successfully demonstrated for ERS-1. In addition, ERS-1 and ERS-2 altimeter height data from the oceans, ice, inland water and land will be compared, using both Ice and Ocean modes where appropriate, in order to detect and measure any biases between the two data sets.

The TANDEM opportunity offers the possibility of long-term monitoring of any secular drift in the relative height bias of the two altimeter instruments. This will be of especial importance for studies of ice sheet mass balance and mean sea level rise, which are very susceptible to such drift at the ~cm level. The time series of inland water and lake levels would also benefit.

### 2.5.2. Radar Altimeter

The ERS-1 radar altimeter can be operated in a specially designed "Ice" mode that provides robust tracking over topographic surfaces at reduced height precision. This is used to achieve significantly greater coverage of ice sheet and land surfaces than has been possible with previous altimeter missions. The operation strategy adopted with ERS-1 is to switch between the two modes over ice sheets and land on alternate 35-day cycles. This ensures the repeated collection of two interleaved data sets, one of which supports research studies requiring maximum spatial coverage, and the other of which supports work requiring maximum height precision, but over a more restricted set of targets. Examples of the former type of study include ice sheet topographic mapping for dynamics modelling and mass balance studies, and the mapping of land surfaces. Examples of the latter include ice shelf mapping (ice shelves are very flat and the Ocean mode performs well over them), and the monitoring of water levels in specific lakes and wetlands. Note that the Ocean Mode of operation is always used over the ocean (including major inland seas) and over sea ice.

The ERS-1 strategy is a compromise, since the different communities of researchers would prefer continuous operation over ice and land in one mode or the other. For example, a consequence of the mode switching is that all time series of height measurements over ice and

land are gathered with alternately high and low precision. Furthermore, the data must be carefully corrected for height bias between the two modes. This is a particular problem for the monitoring of inland water levels, where a uniform, high precision data set is particularly desirable.

The ERS-1/ERS-2 TANDEM Operation offers the opportunity to satisfy both communities of researchers simultaneously by operating one altimeter in Ice Mode and the other in Ocean Mode. Of the various permutations and combinations of routine Ice/Ocean mode switching which could be adopted, the simplest from the operational point of view would be to operate each instrument permanently in a fixed, complementary mode over ice and land. A more preferable option scientifically would be to alternate the instrument switched to Ice Mode between ERS-1 and ERS-2, since this would allow the detection and study of any height biases which might exist between the two data sets, either as a result of differences in the instrument performance or calibration, or differential biases in the orbit solutions.

### 2.5.3. ATSR-2

#### 2.5.3.1. Introduction

This section treats the three main classes of ATSR-2 data-products, namely SST, Clouds and the properties of Land. The potential benefits of improved sampling, the potential for synergy, as well as the issue of exclusivity, will be addressed.

#### 2.5.3.2. Space/time Sampling

All of ATSR-2 measurements of the Earth's surface will suffer from obscuration by cloud and the TANDEM mission provides an obvious second opportunity to view a previously obscured scene. In the case of land and sea observations this will greatly improve the ability to detect change. In the case of SST measurements, for example, there is much interest in the detection of mesoscale or basin-scale fluctuations and oscillations, which are now being revealed by ATSR data (as presented at the Second ERS-1 Symposium), with characteristic periods of up to 80 days. For the detection of such phenomena in the equatorial regions the 35-day repeat cycle of ERS-1 is adequate, but the loss of observations due to cloud cover can lead to ambiguities and unwelcome aliasing. In the case of land cover the TANDEM Mission will increase the probability of obtaining representative observations in any given averaging period (e.g. one month).

In the case of cloud observations, the converse advantage applies, and the TANDEM Mission will double the amount of information provided, enabling representative statistical data-bases to developed more rapidly, also revealing intra-seasonal variations.

Regarding the time-separation of observations: in contrast to the case of validation, the **8-days** option is clearly better for these applications, because major weather systems are very much more likely to have changed substantially over 8 day periods than in one day.

#### 2.5.3.3. Synergy

Many users have requested coincident ATSR and SAR images They have had to make use of data from other satellites when images of cloud fields or surface temperature patterns are needed. Examples of such applications include the study of, for example, boundary layer rolls and Lee waves, where signatures are seen in the surface reflectivity and the cloud field (as presented at the Second ERS-1 Symposium) of which the height could be uniquely determined from ATSR data if coincident data were available. The **8-days** scenario will allow a certain number of coincident images to be obtained within one day of each other. Unfortunately, the coincidences are unlikely to be close enough in time to be of relevance to cloud and boundary layer dynamics, but for SST-related scientific applications the possibility of ATSR-SAR coincidences in certain regions within one day (which would be provided by the TANDEM Mission) is of considerable scientific interest.

#### 2.5.3.4. Exclusivity

The full radiometric resolution of ATSR-2's new visible wavelength channels can not be achieved while the scatterometer is operated. This is because of data-rate limitations. When ATSR-2 was accepted for flight on ERS-2 it was envisaged that the scatterometer would be turned off over land at regular intervals, allowing ATSR-2 to collect full resolution data over land, while the baseline operating mode for ATSR-2's visible-wavelength channels would involve a reduced radiometric resolution of 8 bits. As a result of the complexity of scatterometer algorithms in coastal regions, as well as the scientific interest in examining scatterometer data over land, there is much tendency to operate the scatterometer continuously when the SAR is off and it now seems unlikely that ATSR-2 will be able to collect substantial quantities of full resolution data over land.

It should be remembered that, in part due to the IGBP and other related programmes, there has been much activity in the development of global land cover maps. ATSR-2 will provide substantial volume of new information and insight into this activity because of its narrower spectral bands, greater radiometric resolution as well as the superior atmospheric correction that can be provided by ATSR-2's unique two-angle view. However, while this exclusivity with respect to the scatterometer exists, it will be difficult to realise this potential within the context of ERS-2.

If, for any reason, the ERS-1 scatterometer would be used as the FD baseline and the ERS-2 scatterometer not used over land or the coastal seas, there would be a major opportunity for ATSR-2 to reach its full potential for the evaluation of such parameters as vegetation cover over land.

### 2.5.4. Wind Scatterometer

#### 2.5.4.1. Wind Fields in Coastal Regions and Inland Waters.

In the TANDEM mission, regions such as coastal zones, not now well explored due to the conflicts in operations of the SAR and the wind scatterometer, could be better sampled by scatterometer winds from one of the satellite, when the other one operates in SAR mode.

The high resolution, 12.5 km, of the scatterometer would be analysed in coastal zones together with ocean SAR and/or ATSR imagery. This would be done in a research mode to develop methods to interpret these data. This use of the scatterometer could eventually lead to short range weather forecasts and evaluation of local winds and currents of possibly great value to coastal populations.

# 3. Conclusions and Recommendations

At the close of the working session held in ESRIN on 6-7 November, 1993, the participants expressed the following conclusions and recommendations.

[1] The geometry of observations with different instruments from each satellite needs to be specified precisely, for the 1-day offset and the 8-days offset. In particular, locations where observations at minimum time interval are possible shall be identified.

[2] The benefits for the applications of the 1-day offset and 8-days offset can be summarized as in the following table:

| | 1-day offset | 8-days offset |
|---|---|---|
| Hydrology | surface coherence preserved for interferometry (DEM generation) | snow cover variation |
| Agriculture | | plant growth monitoring |
| Forestry | surface coherence preserved for interferometry (tree height) | |
| Snow Hydrology and Climatology | | snow melt measurements |
| Ice Sheets | surface coherence preserved for interferometry (DEM and ice dynamics) | |
| Sea Ice | short term variation studies | ice dynamics |
| Geoid | | global gravity field modelling |
| Atmospheric studies | ATSR-2 validation | cloud cover variation |
| Ocean Circulation | | measurement de-aliasing |
| Wind fields | | increased sampling |

[3] The participants to the working session in ESRIN discussed a possible strategy for the TANDEM campaign and recommended the following:

- 2 x 35 days cycles at **8-days** delay and short baselines ( < 50 m).
- 2 x 35 days cycles at **8-days** delay and intermediate baselines ( < 100 m).

- 2 x 35 days cycles at **1-day** delay and large baseline ( <300 m).

The following advantages for the DEM calculation would ensure:

- with the shorter baselines it could be possible to overcome the effects due to the lower coherence for the longer delay. At the same time, one could profit of the relative stability of the two orbits and could operate with few phase ambiguities.
- with longer baselines one could profit of the higher coherence for the higher sensitivity. Many problems due to phase unwrapping would have been solved already by using the low baselines passes.

A possible scenario is to perform two TANDEM campaigns:

the first campaign should take place immediately after the end of the Commissioning Phase for a duration of four 35-days cycles:

- 2 cycles with 1-day offset, to achieve the following objectives:
  - — cross-validation of the instruments and ATSR-2 validation
  - — DEM generation over areas where the surface coherence is not preserved (tropical forest, Antarctica)
- 2 cycles with 8-days offset, to achieve the following objectives:
  - — plant growth monitoring (SAR)
  - — ocean circulation and Geoid studies (Radar Altimeter)
  - — climatologic studies (Wind Scatterometer) in coastal zones and in open ocean (increased sampling)

the second campaign should take place at the end of 1995, for a duration of two 35-days cycles with 8-days offset, to achieve the following objectives:

- — sea ice dynamics studies (SAR)
- — hydrology (SAR)
- — ocean circulation and Geoid studies (Radar Altimeter)
- — climatologic studies (Wind Scatterometer) in coastal zones and in open ocean (increased sampling)

For these two campaigns, the SAR data would be systematically acquired at ESA stations, at all National stations and at selected Foreign stations (e.g. Fairbanks, Alice Springs) having the appropriate capabilities and skills.

[4] The laser tracking of ERS-1 and ERS-2, and PRARE operations shall be continued also between and after the TANDEM campaigns, to improve the orbit(s) determination, global gravity field modelling and orbit perturbation studies.

Delegations are kindly invited to comment and express their view on the usefulness of the TANDEM scenario for Geoscience applications, to acknowledge the unique opportunities offered by the simultaneous presence of ERS-1 and ERS-2 in orbit, and to provide their recommendations for the Earth Observation Programme Board, regarding the implementation of TANDEM campaigns.

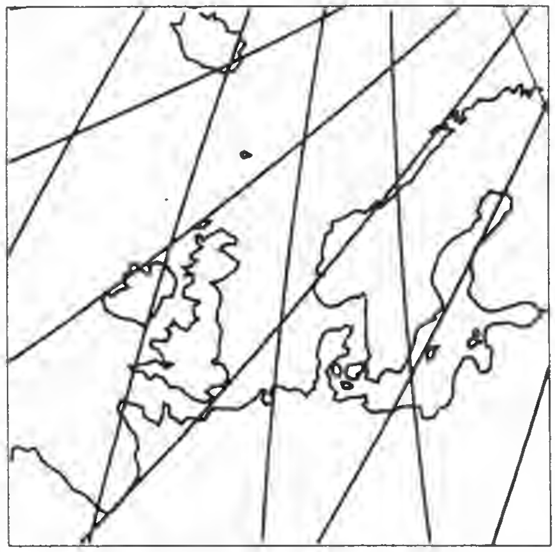
# Annexes

## Annex 1 List of Participants

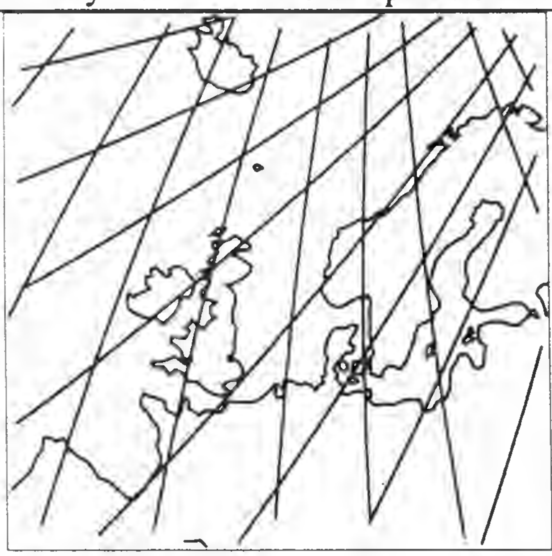
| NAME | ORGANISATION | NAME | ORGANISATION |
|---|---|---|---|
| ATTEMA, Evert | ESA/ESTEC | LECOMTE, Pascal | ESA/ESRIN |
| BENVENISTE, Jerome | ESA/ESRIN | LLEWELLYN-JONES, David | Earth Observation Science, University of Leicester, UK |
| COLIN, Olivier | ESA/ESRIN | MARTIN, Philippe | ESA HQ |
| COULSON, Steve | ESA/ESRIN | MASSONNET, Didier | CNES Toulouse, France |
| DOYLE, Eric | ESA/ESRIN | MAUSER, Wolfraus | Geography & Remote Sensing, University of Munich, Germany |
| DUCHOSSOIS, Guy | ESA HQ | NUESCH, Daniel | Remote Sensing Laboratories, University of Zurich, Switzerland |
| FRANCIS, Richard | ESA/ESTEC | RAPLEY, Chris | Mullard Space Science Lab., University College London, UK |
| GRECO, Bruno | ESA/ESRIN | REIGBER, Christoph | GFZ Postdam, Germany |
| GUDMANDSEN, Preben | Technical University, Denmark | ROCCA, Fabio | Politecnico Milano, Italy |
| GUIGNARD, Jean-Pierre | ESA/ESRIN | ROTT, Helmut | University of Innsbruck, Austria |
| HARTL, Phil | Institute of Navigation, University of Stuttgart, Germany | SHARMAN, Martin | DG XII D-4, CEC |
| KATSAROS, Kristina | Dept. Oceanography from Space IFREMER, France | SIEBER, Alois | CEC-JRC, Ispra |
| KOHLHAMMER, Gunther | ESA/ESRIN | SOLAAS, G. | ESA/ESRIN |
| LAUR, Henri | ESA/ESRIN | | |

## Annex 5 TANDEM coverage

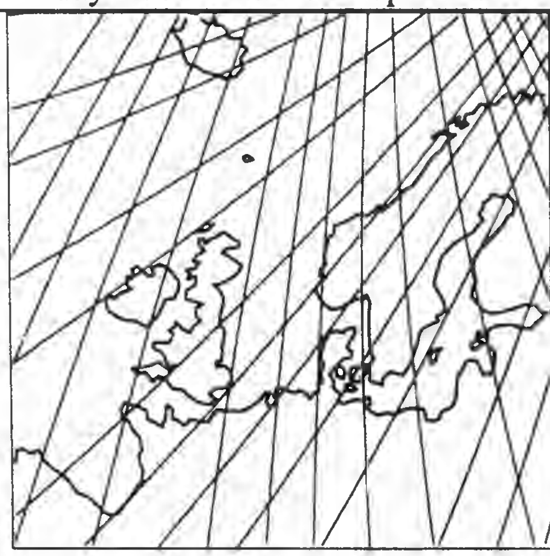
1-day offset
1 day Radar Altimeter operation



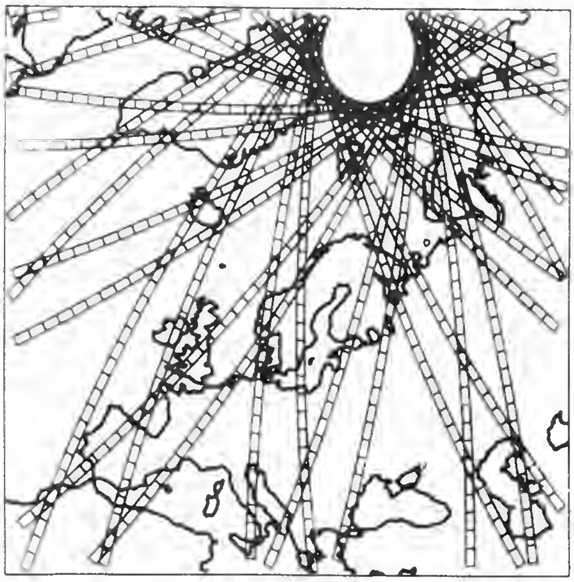
8-days offset
1 day Radar Altimeter operation



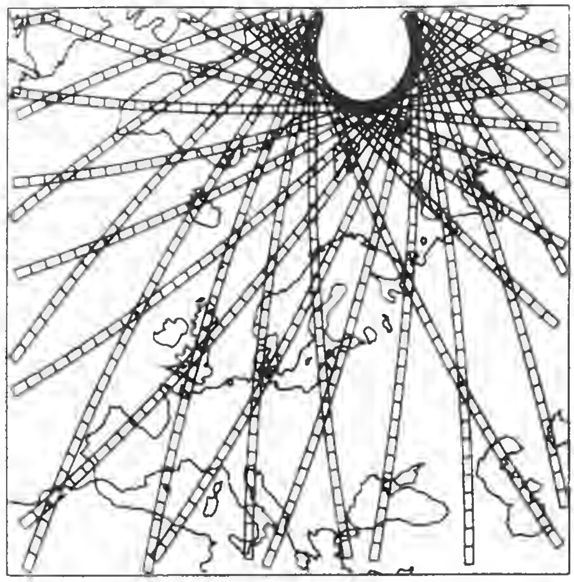
1-day offset
2 days Radar Altimeter operation



8-days offset
2 days Radar Altimeter operation



1 day offset
1 day SAR operation



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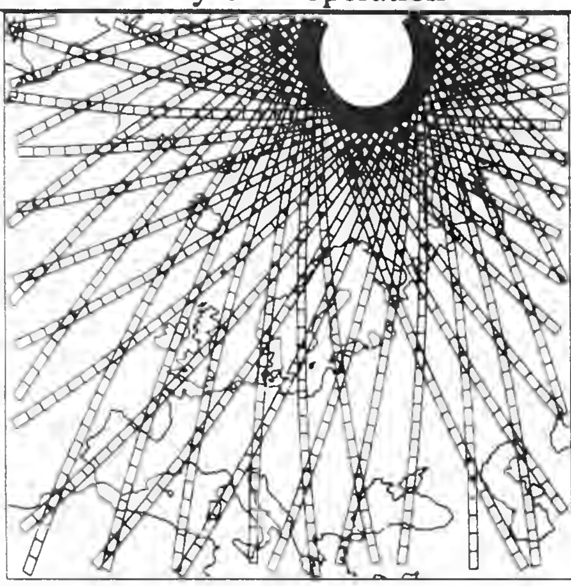
1 day SAR operation



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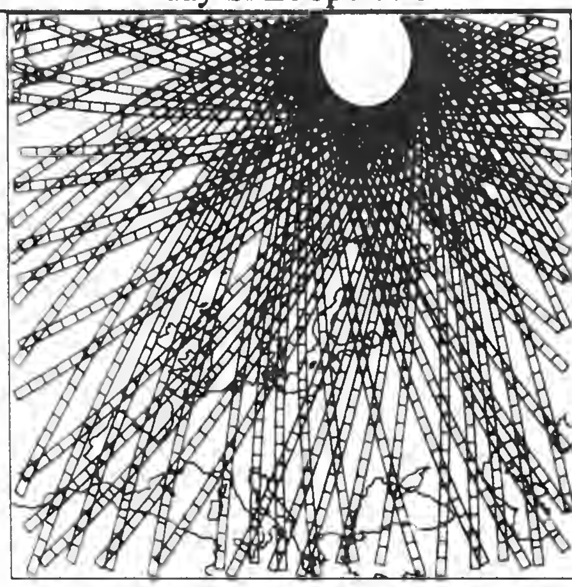
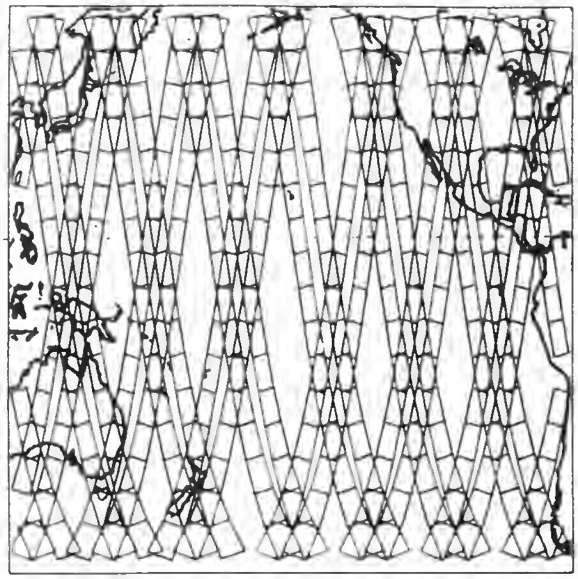
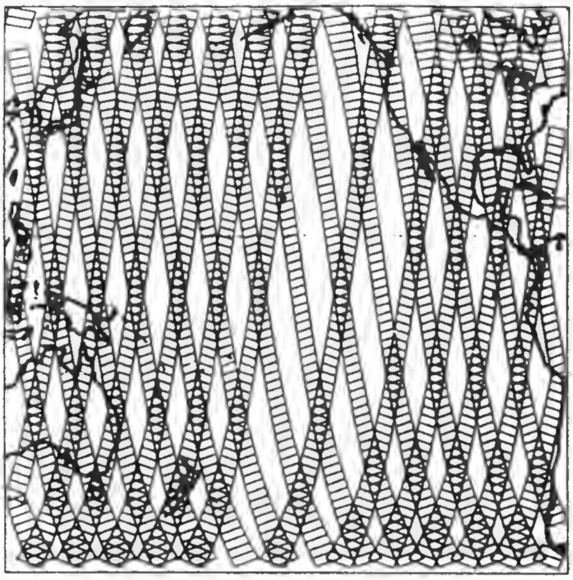
2 days SAR operation



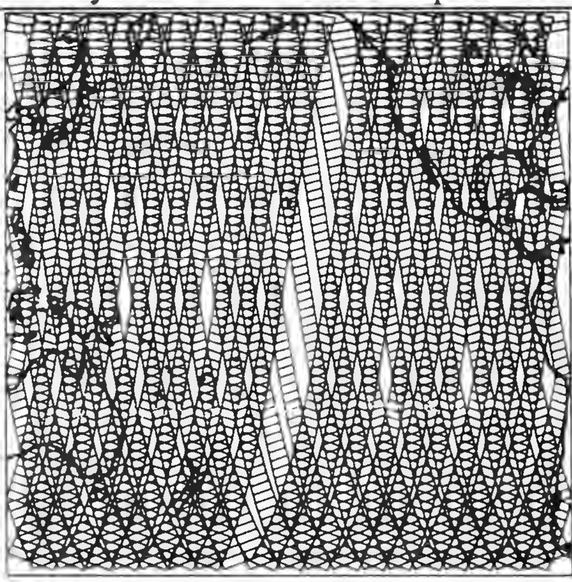
8 days offset
2 days SAR operation



1 day offset
1 day wind scatterometer operation



8 days offset
1 day wind scatterometer operation



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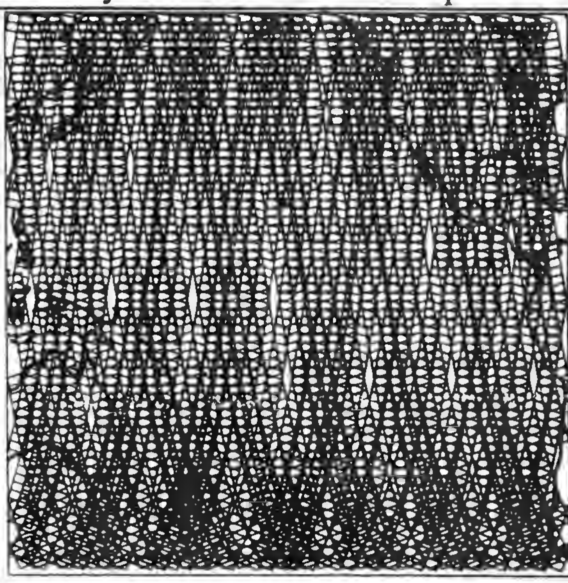
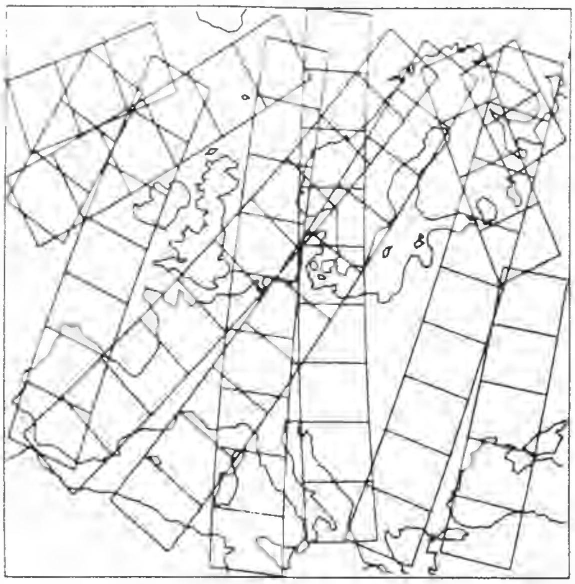
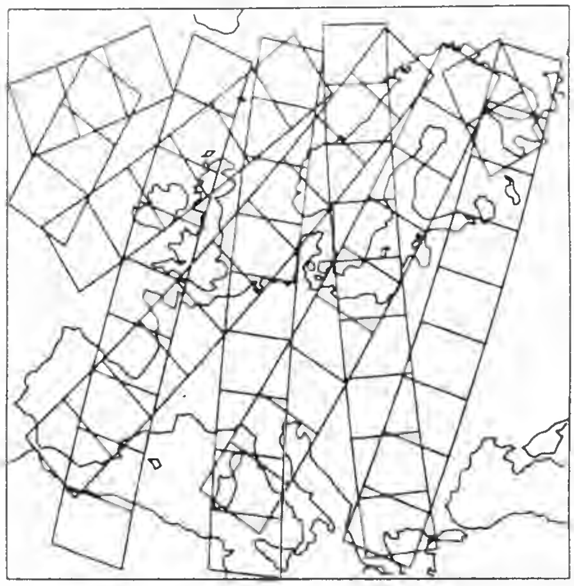
2 days wind scatterometer operation



8 days offset
2 days wind scatterometer operation



1 day offset
1 day ATSR operation



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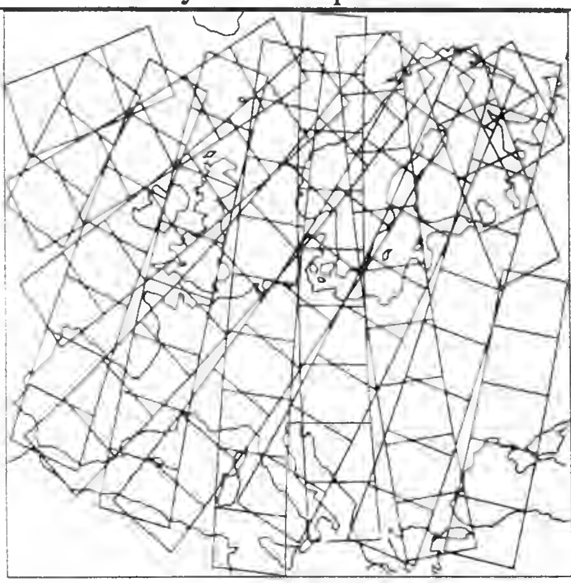
1 day ATSR operation



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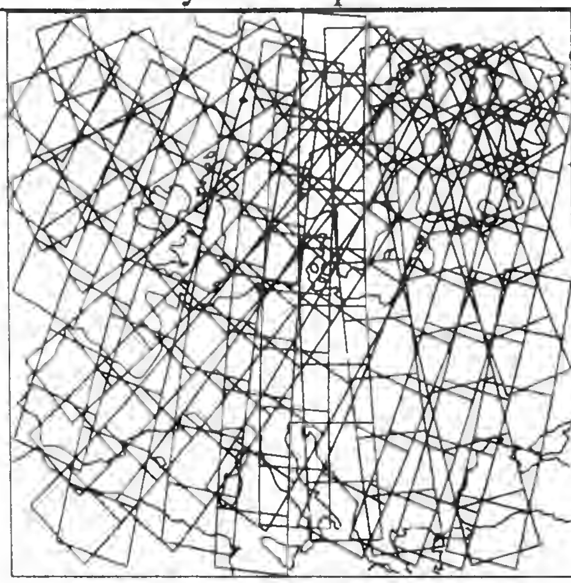
2 days ATSR operation



8 days offset
2 days ATSR operation