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ESA ACTIVITIES IN THE USE OF MICROWAVES FOR THE REMOTE SENSING OF THE EARTH

D. Maccoll
European Space & Technology Centre (ESTEC)
Noordwijk, The Netherlands

ABSTRACT

This paper discusses the programme of activities under way in the European Space Agency (ESA) directed towards Remote Sensing of the oceans and troposhere. The initial project is the launch of a satellite named ERS-1 with a primary payload of microwave values in the C- and Ku-bands. This payload is discussed in depth. The secondary payload include precision location experiments and an instrument to measure sea surface temperature, which are described.
The important topic of calibration is extensively discussed, and the paper continues with a review of activities directed towards improvements to the instruments for future satellites. Some discussion of the impact of the instrument payload on the spacecraft design follows and the paper concludes by emphasing the commitment of ESA to the provision of a service of value to the ultimate user.

1. INTRODUCTION

The European Space Agency has initiated a Remote Sensing programme with several elements. The major element is the launch of a satellite dedicated to remote sensing of the oceans (ERS-1) in 1987. It is planned to follow this launch two years later with a second (ERS-2) which will be similar to the first. Later satellites in the 1990 decade will be considerably larger and likely dedicated to Land Observation. In parallel with the satellite programme there is an existing data dissemination network Earthnet which currently handles Landsat data but has also disseminated Seasat data and will of course be used for the ERS-1 data. There is also planned a series of campaigns, on-ground and aircraft which will be used to confirm the models and assumptions behind the instrument design, to aid the in flight calibration of the instruments and to promote user interest and understanding.

2. ERS-1 PAYLOAD

The payload comprises three primary instruments: a Synthetic Aperture Radar (SAR), a Scatterometer, and a Radar Altimeter (R.A.). The first two are combined in a single microwave package operating in C-band with three operation modes; full SAR imaging, small area SAR imaging (wave mode), and scatterometer. This C-band package is known as the Active Microwave Instrument (AMI).

2.1 AMI

The AMI comprises four antennas, one SAR antenna and three wind scatterometer antennas, a high power transmitter and low noise receiver common to all modes, and various low frequency, low power components exploit commonality between modes as far as possible. The SAR antenna is 10m x 1m, and the two fore and aft looking scatterometer antennas are 4m x .35m. The central scatterometer antenna is not deployed and is 2.3m x .35m. The high power amplifier is a pulsed tube with 4.8kW peak power, with an average power varied by changing the pulse length and repetition frequency.

In the full SAR imaging mode this instrument will have a swath width of 80 km, and will have a ground resolution of 100m and radiometric resolution of 1dB at -18dB backscatter coefficient. It will be possible to produce images with 30m spatial resolution, but the radiometric resolution will be degraded since there will be few "looks" available. This mode will only be used when the spacecraft is within sight of a ground station since the data rate (100 Mb/s) is too high for onboard storage to be feasible. Also the D.C. power requirements in this mode are too high for continuous operation throughout the orbit. The D.C. available will allow approximately 10% operation which is compatible with the visibility from the planned ERS-1 ground stations, but much of that time the SAR will be imaging land.

Over the oceans the SAR will be used in a low power mode (100W average R.F.). This wave mode will be interleaved with the wind mode which is discussed later. In the wave mode the SAR is operated with a reduced pulse length at the full peak power, thus the energy per pulse and the average RF power are reduced while operating the power amplifier at its optimum peak power. The wave mode is operated for approximately 1.4 seconds every 14 seconds which allows imaging of a 5 km strip each 100 km. The radar returns are sampled over a short part of the total return sufficient to image 5km out of the available 80km swath. Thus only the data from a 5km square patch is retained, and the data rate is sufficiently reduced for storage on a tape recorder, and global coverage of the oceans can be achieved. The objective of this so called wave mode is to measure ocean wave spectra, but the specifications have been expressed in terms of image spectra. It is clear that peaks in the two dimensional spectra correspond to ocean wave and swell patterns, however the modulation transfer function between ocean wave and image spectrum is not well developed so the ocean characteristics cannot make a sound foundation for the instrument specification. In particular there is some doubt whether wave trains in certain directions or under certain wind conditions will appear at all on the image spectrum.

The wind mode is far better understood, the basic concept having been provenon SEASAT. ERS--1 however works at C-band where though the backscatter coefficient is higher than at Ku band, the modulation by wind speed and direction is less. The principle of operation is based on the fact that the backscatter coefficient from a wind disturbed sea is dependant on both wind speed and direction with respect to the radar beam. Since there are two parameters to be measured two measurements must be made and this is done by looking at the same patch of ocean from two different parts of the orbit. Unfortunately the experience of SEASAT showed that there are ambiguities in the extraction of the wind speed and direction from the two measured backscatter coefficients, due to the inherently noisy measurement and the shape of the modulation curve which has bigger change between up-wind and cross-wind than between up-wind and down-wind. In order to help resolve these ambiguities the ERS-1 instrument includes a third measurement. Two measurements are made looking at 45° forwards and 45° aft, and the third measurement is made looking abeam.

The selection of these three look directions was made after extensive anlaysis and simulation taking account of noise, speckle, model uncertainties, and the range of incidence angles. The choice of one beam looking directly sideways lead to another change in implementation with respect to SEASAT: the doppler filterbank approach of SEASAT clearly will not work on the side looking beam since this beam looks almost exactly down the zero doppler line. The alternative approach of range gating had been under consideration and the need for a side-looking beam confirmed the choice of range gating. Since these measurements require both high accuracy and good calibration between beams the possibility of using a mixed system of two doppler and one range gated beam was not considered. In order to ease the on-board frequency tracking and also to ensure the full wind swath of 400 km can be imaged the satellite will be steered in yaw to keep the side looking beam on the zero doppler line including the effect of earth rotation.

2.2 Radar Altimeter

The ERS-1 Radar Altimeter is designed to have the same performance over the oceans as the SEASAT Altimeter. However there are improvements in two important areas: the instrument is fully redundant within approximately the same mass and power envelope, and the aquisition and tracking loops have been improved.

A trade-off peak power requirement and chirped pulse length taken together with an investment in surface acoustic wave (SAW) technology has allowed the use of a power amplifier with a peak power of 50W. Since the mass of both the tube and the power conditioner are closely linked to the peak power this relatively low peak power has effected a substantial reduction in mass and therefore a redundant system can be used. Additionally an existing space qualified tube and power conditioner can be used with some small modifications thus saving the cost and problems of space qualifying a new amplifier. Associated with this power level is a long pulse of 20 ms. SAW technology development has resulted in a single component generating the wideband (330 MHz) long pulse with a time bandwidth product of 6600.

The aquisition and tracking are both done using digital technology taking advantage of more powerful microprocessing (8086) and other processing elements than were available in the mid 1970's when the SEASAT instrument was designed. In the tracking mode the level, the position and the scope of the leading edge are followed and the backscatter coefficient, the altitude and the significant wave height can thus be estimated. The instrument uses a deramp technique in which the signal return is mixed with a delayed replica of the transmitted signal, and differences in height are converted to a frequency shift. The deramped output is then filtered using a digital fourier transform to give the return signal profile. This profile is averaged over fifty pulses and used to provide the inputs to the tracking loops. In the aquisition mode the transmitted pulse is unmodulated, and the leading edge of the return is detected with sufficient accuracy to be able to switch to a modulated pulse form. The possibility of detection of 95% is achieved after 50ms which is significantly better than SEASAT which could take 5s to reacquire after loosing lock, and over some sloping surfaces even longer.

Over the oceans the results from the SEASAT altimeter were good though occasionally it lost lock (probably over severe weather systems). The ERS-1 RA should equal this performance. Over ice the SEASAT RA often lost lock and it is expected that the improvements in the acquisition and tracking of the ERS-1 instrument will permit a more consistent coverage.

2.3 ERS-1 Secondary Instruments

ERS-1 will also carry three other instruments which will support the altimeter, namely a Laser Retro Reflector (LRR), an Along Track Scanning Radiometer with two nadir pointing microwave channels (ATSR/M), and a Precision Range and Range Rate Experiment (PRARE). The LRR is entirely passive and will be used in conjunction with ground based laser tracking stations for accurate (10 cm) orbit measurement, and thus enhance the ability of the R.A. to measure mesoscale sea eddies. The ATSR/M is principally designed for sea surface temperature measurements, but the microwave channels will be used for atmospheric water vapour corrections to the altimeter measurement. The PRARE is a two frequency (S- and X-band) transponder system which in conjunction with a network of ground stations will be used for precision location experiments. The second frequency allows to correct for ionospheric effects. As with the LRR this experiment will also enhance the R.A. capability.

2.4 Calibration

The instruments described above will all certainly produce results: images, wind fields or profiles. It is an important aspect of the ERS-1 programme that these results will be properly calibrated in the sense that there is an assurance that the product meet certain minima in accuracy and resolution. The calibration approach of the AMI modes are the most developed, of the R.A. less so.

The final requirement is for calibration of the geophysical product, for example wind speed or significant wave height; but an important intermediate step is the calibration of the engineering product, backscatter coefficient or output from the slope tracking loop respectively. To achieve this engineering calibration all instruments are designed with internal calibration loops which, bypassing only the antenna and some of the passive output networks, provide an accurate measurement of the levels and gains of the onboard components. To include the impact of the antenna some ground sites will be provided with artificial targets which will permit calibration of the complete instrument. For the SAR modes these targets may be passive corner reflectors which can be positioned in an area of low backscatter coefficient and sized so as not to overload the receiver. For the scatterometer mode a passive target would have to be enormous to stand out against the fixed area of 25 x $10^8 m^2$. Therefore an active target is being developed which amplifies the received radar signal and retransmits it with a frequency shift. The reason for the frequency shift is to separate the artificial return from the natural return of the surroundings, and thus to establish the prop... level at the input to the radar receiver.

For the Radar Altimeter the problem of creating an artificial target is more difficult, since the RA will have to aquire and track, but the target will only be in the beam a few tenths of a second. Some work is being done on a "Return Signal Simulator" which will be used for on ground testing prior to launch. This will accept as input a radar pulse and generate a return with the shape, duration and spectral content that would be expected from a sea surface. As stated above this is being developed for on ground use prior to launch but it could form the nucleus of an artificial target for use in flight.

The geophysical calibration starts when the engineering calibration is complete. Essentially it will comprise campaigns of ground truth measurements possibly coordinated with aircraft underflights. In advance of this campaigns are planned to develop and verify models and information extraction algorithms. The first of these took place in 1981 using an aircraft SAR at X, L, and C bands. A large number of users participated but the main interest of ESA was the calibration exercise using corner reflector arrays at two sites. The next will be specifically dedicated to C-band scatterometer measurements and will take place early in 1984. Preliminary results tend to conform the models that have been used in defining the AMI instrument.

3. INSTRUMENTS FOR FUTURE MISSIONS

The instruments for ERS-1 are now well developed and receive substantial resources from industry and ESA to build, test and fly. However there are areas in which improvements can be conceived, and the ESA activities include basic technology development for next generation instruments. For the SAR the primary limitation in performance due to the instrument is the swath width. To achieve full equatorial coverage requires five hundred orbits or almost exactly one month.

The evolution of many oceanic and climate processes occurs in days so a monthly report cycle is too long to follow the developments of these processes. Of course a complete global coverage at a resolution of 30 or 100 m would swamp most users with data, nonetheless the ability to image particular areas frequently is highly desirable and some substantial improvements may be made by investigating the possibility of overcoming the ambiguity constraints. The first step is a study of the possibilities including antenna modifications, multibeam transmit and receive, squint beams, and novel pulse modulation techniques. Following this evaluation the more promising techniques will be subject to a detailed analysis and possibly breadboarding.

The scatterometer and altimeter are both required to operate over the whole oceans which cover about 70% of the earth surface. Minimising the power consumption is thus highly desirable. One technique which has been proposed for the scatterometer is to abando the fixed fan beam concept and use a scanned beam, and a very elegant way of scanning the beam is by changing the frequency of a frequency sensitive antenna. The bandwidth of the scatterometer signal is very small, a few hundred kilohertz including the doppler shift. By suitable design of the antennas the beam may be scanned over the full 40^{o} range with frequency shifts of several megahertz. By switching the full beam at the required pixel there is a significant saving in required transmitted power. Additionally the shape of the antennas, which using the conventional technique are long and narrow, became nearly circular which can relax the accommodation position. This topic is the subject of future work which should lead to a more economic scatterometer design for future missions.

The radar altimeter is characterised by a very low duty cycle (2%). Thus a power amplifier capable of delivering 50W rf power is used to deliver one watt average. It is planned to do some technology work on long pulse systems, at both instrument and component level with the objective of designing an altimeter with a peak power low enough to use solid state amplifiers. As far as solid state devices are concerned a pulse length of 20 us is the same as c.w. since the device thermal time constants are much shorter than this. Currently it is just within the state of the art of FET technology to produce 1 watt rf power, and exploiting this level in next generation altimeters is expected to simplify the front end design considerably.

The primary instruments of ERS-1 are active radars: the only passive microwave instrument is the radiometer in the ATSR/M, which has been included as an aid to the altimeter. Passive microwave radiometers can produce results which have an autonomous value. An Imaging Microwave Radiometer was studied to Phase A level as a candidate instrument for ERS-1 but was not included. Like other microwave instruments it has a great importance for all weather, night and day synoptic global coverage. This type of instrument is not particularly demanding in terms of microwave technology: it is big! Future work by ESA will include developing compact technology for the microwave receivers and developing instrument and antenna concepts suitable for large antennas, up to 10m diameter, and pushbroom systems.

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The topics of this symposium include the troposphere: the instruments described so far are directed towards measurements of the oceans and cryosphere, and the intervening atmosphere is an embarassment! The imaging microwave radiometer does contain higher frequency channels whose main objective is to allow corrections to the low frequency measurement errors which are due to the atmosphere. In the inversion process useful information about the atmosphere is also extracted. Recognising the value of atmospheric research ESA is also doing technology development for higher frequencies in the millimeter and submillimeter wave bands. The latter is mainly driven by astronomy needs, but the millimeter wave work is driven by the needs of atmospheric research.

4. SPACECRAFT REQUIREMENTS

As stated before the spacecraft resources required to support the various instruments are large. Since all these instruments are complementary each supporting the others in their contribution to earth and atmospheric observation, there is a pressure to include as many as possible. The SPOT platform used for ERS-1 has very little growth capability: the additional resources required by just one more instrument would require such modifications that there would be in effect a wholly new platform.

ESA has been studying in house the possible configurations of a large platform. This conceptual platform for an Advanced Earth Research Satellite (AERS) should exploit the full capability of the ARIANE 4 launcher. It would have accommodation for double sided SAR with a total payload mass of 2 tonnes and end of life d.c. power of 7.6 kw from the solar arrays giving a possible 5 kw available to the instruments. A topic rarely mentioned is the problem of data dissemination: the ERS-1 SAR is as much constrained by the 100 Mb/s data rate limit as by any other resource limitation. Future AERS will need a data rate in the region of 500 Mb/s and will require also a data relay capability in order to ensure the worldwide availability of the data. Data relay experiments are planned between two ESA platforms, EURECA and OLYMPUS, which may lead to the implementation of data relay on AERS.

CONCLUSION

This paper has addressed the activities under way in ESA in the field of Remote Sensing of the Oceans and Atmosphere, and attempted to demonstrate the commitment of ESA to providing the instruments required to explore this field form space. This is a complete programme including the satellite and its instruments and ground support, and the data dissemination as the nucleus but also including supporting campaigns of ground and aircraft experiment, and studies for follow-on missions with advanced spacecraft and a range of advanced instruments. While ESA does not undertake scientific and applications analysis of the data products, ESA is very concerned that the product is of maximum value to the user community, and therefore has from the inception of the project involved the users in the definition of the programme and the instruments. This involvement will continue through the development, manufacture and launch of ERS-1 and it is hoped that this cooperation will result in the product supplied being of maximum value to the oceanographic and atmospheric user communities.