Planned by the European Space Agency (ESA)

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Starting in 1982, the European Space Agency (ESA) has been involved in earth observation from space thanks to the Meteorological Satellite Programme, Meteosat, of which two flight models were launched successfully in 1977 and 1981. Since then, and in addition to the Meteosat Programme which is being continued as an operational system, other disciplines of earth observation such as remote sensing, geodesy and geodynamics missions have been studied.

The paper gives an overall summary of the different missions, programmes, developments and studies in which ESA has a role of leadership. This applies not only to approved programmes as, for instance, Meteosat and Earthnet, but also to programmes being in a detailed definition status and not far from approval by the Agency's governing authorities, e.g. ERS-1, and to tentative forward thinking.

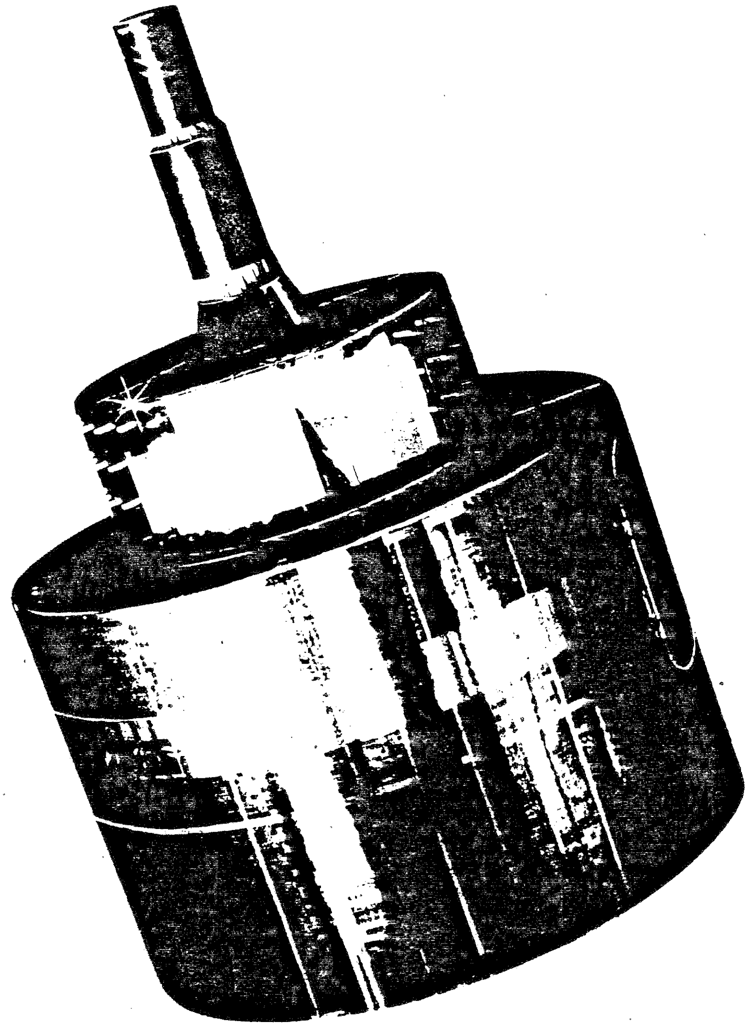
## I. THE METEOROLOGICAL PROGRAMME

In 1972, eight Member States of the European Space Research Organisation decided to embark upon a programme for the development of a preoperational meteorological satellite: Meteosat, and entrusted its execution to the Organisation which later became the European Space Agency. Subsequently, ESA was charged with the in-orbit operation of the spacecraft. The intention remained, nevertheless, to establish a meteorological community which would be responsible for setting up a system of operational spacecraft derived from the original Meteosat. The aim was achieved with the signature by 12 countries in Geneva, on 24 May 1983, of a Convention for the creation of an international organisation known as EUMETSAT, whose main purpose is to establish, maintain and operate european systems of operational meteorological satellites, the initial one being the continuation of the Meteosat preoperational programme.

The basic design of the operational satellite will be that of the Meteosat F2, with two major improvements to the mission capability:

- the mission performance transponder provides 8 additional channels (2400 bits/sec) for meteorological data dissemination
- the water vapour absorption channel (5.7 to 7.1 microns) is available in parallel with visible and infrared channels.

A number of minor modifications based on F1 and F2 experience and on technology improvement are incorporated, leading, inter alia, to increased reliability.



The Meteosat Satellite

The Meteosat Operational Programme foresees the launch of three satellites, in June 1987, mid 1988 and 1990, and their subsequent exploitation until 1995. It fulfils the five following missions:

1. Earth Imaging Mission

The radiance of the Earth's surface and of its cloud cover are detected simultaneously in three spectral bands:

- the visible (VIS) image in the 0.5 to 0.9 µm region of the spectrum is made up of 5,000 lines, each containing 5,000 picture elements. The resolution at the sub-satellite point is 2.5 km. The signal-to-noise ratio will be greater than 200 for 80% albedo;

- the thermal infrared (IR) image covers the 10.5 to 12.5 µm region of the spectrum. It comprises 2,500 lines each containing 2,500 picture elements. The resolution at the sub-satellite point is 5 km. The performance, given as NE$\Delta$T, will be better than 0.65°K for a black body at 290°K;

- the water vapour (VW) absorption band image is in the 5.7 to 7.1 µm region of the spectrum. It consists of 2,500 lines, each containing 2,500 picture elements. The resolution at the sub-satellite point is 5 km. The performance given as NE T will be better then 1°K for a black body at 260°K.

For each spectral channel, the radiometric information is encoded into 256 grey levels.

2. The Dissemination Mission

Preprocessed images and other meteorological data are relayed to user stations. The transmissions are made in both digital and analogue formats (WEFAX pictures).

3. The Collection of Environmental Data

Environmental data gathered by various types of fixed and mobile data collection platforms (DCPs) are collected by up to 66 channels provided for this purpose.

4. The Extraction of Meteorological Products

The actual extraction of products is performed automatically for the region within at least 50° great circle arc (up to 55°) from the sub-satellite point. The products are:

(i) Cloud Motion Vectors (CMV)
(ii) Sea Surface Temperatures (SST)
(iii) Cloud analysis (CA)
(iv) Upper Tropospheric Humidity (UTH)
(v) Cloud Top Height (CTH)

CMV, SST, CA and UTH are encoded into WMO SATOB Bulletins and injected into the GTS (Global Telecommunications System). CTH maps are broadcast as WEFAX pictures via the satellite.

5. The archiving of digital data and image negatives

All available images are regularly archived in digital form with the extracted meteorological products (except the CTH maps). Two slots of images per day are archived on photographic film. A comprehensive catalogue will be maintained to cover all archived data.

Remote Sensing Applications of Meteosat

In spite of the low space resolution of the images, Meteosat is used experimentally as a remote sensing tool inter alia in the following application areas:

**Agrometeorology** - An experiment took place over a test period of 18 days at the beginning of the 1979 growing season in the Sahel of Africa, to map and monitor key agrometeorological parameters such as rainfall, surface radiation, evaporation and thermal inertia, with the objective of defining a germination-mapping approach. It was concluded that Meteosat had the ability to provide unique and consistent climatological surface data over large areas.

The FAO conducted a pilot project on the application of remote sensing techniques, including data from Landsat, NOAA series and Meteosat satellites for improving desert locust survey and control.

**Aid to Fisheries** - The Meteosat data have been used to increase the efficiency of fishing ships in the Gulf of Guinea by providing the fleet with accurate sea surface temperature relative and absolute values.

## II. THE REMOTE SENSING EXPERIMENTS OF THE FIRST SPACELAB FLIGHT (November 1983)

Two instruments have been developed by Germany as part of the First Spacelab Payload (FSLP): the Microwave Remote Sensing Experiment (MRSE) and the Metric Camera. Only the radiometer mode of the MRSE operated successfully during the flight. Conversely, the flight of the Metric Camera was entirely successful, in spite of the delay in the launch date which led to a modification of the exposure time 1/250 instead of 1/500 or 1/1000. The objective of the Metric Camera mission was to test the mapping capabilities of high resolution space photography. The camera is a modified version of a commercial aerial survey camera of the Zeiss RMK A 30/23 type.

The image scale provided is 1.820.000 which results in a ground coverage of about 189 x 189 km for a 23 x 23 cm image format. Most of the photographs taken in the visible and IR bands have been processed.

## III. THE EARTHNET PROGRAMME

Earthnet is the European network for acquisition, recording, archiving, preprocessing and distribution of remote sensing satellite data, European or otherwise. Both the Kiruna (Sweden) and Fucino (Italy) stations have been equipped with X-band reception capability and with a recording, processing and image generation system adequate for Landsat TM and MSS, while Mas Palomas (Spain) is used for acquisition of Nimbus 7 data and Lannion for the Heat Capacity Mapping (HCMM) and Nimbus 7.

As regards the future, the activities will involve:

- the continuation of on-going activities including handling of Landsat and other experimental remote sensing missions (HCMM, Nimbus 7, Seasat);
- the inclusion of new experimental missions (European, US and non-US such as MOS-1 of Japan);
- preparation of the ERS-1 mission.

## IV. THE FIRST ESA REMOTE SENSING SATELLITE (ERS-1) PROFRAMME

In October 1981, the 11 Member States of ESA, plus Canada and Norway, decided to initiate the ESA Remote Sensing Satellite (ERS-1) programme.

*Table 1 — ERS-1 main geophysical measurement objectives*

| Main geophysical parameter | Range | Accuracy | Main instrument |
|---|---|---|---|
| Wind field | | | |
| – Velocity | 4–24 m/s | ±2 m/s or 10% whichever is greater | Wind scatterometer & Altimeter |
| – Direction | 0–360° | ±20° | Wind scatterometer |
| Wave field | | | |
| – Significant wave height | 1–20 m | ±0.5 m or 10% whichever is greater | Altimeter |
| – Wave direction | 0–360° | ±15° | Wave mode |
| – Wavelength | 50–1000 m | 20% | Wave mode |
| Earth surface imaging | | | |
| – Land/ice/coastal zones etc. | 80 km (minimum swath width) | Geometric/radiometric resolutions: a) 30 m/2.5 dB b) 100 m/1 dB | SAR imaging mode |
| Altitude | | | |
| – Over ocean | 745–825 km | 2 m absolute ±10 cm relative | Altimeter |
| Satellite Range | | ±10 cm | PRARE |
| Sea surface temperature | 500 km swath | ±0.5 K | ATSR (IR) |
| Water vapour | in 25 km spot | 10% | µW sounder |

ERS-1 is expected to be the forerunner of a series of European remote sensing satellites to become operational in the 1990's. The ERS-1 mission objectives are of both an economic and scientific nature and aim to:

- establish, develop and exploit the coastal, ocean and ice applications of remote sensing data;
- increase the scientific understanding of coastal zones and global ocean processes.

Table 1 lists the various geophysical parameters to be measured by on-board instruments.

## ERS-1 Missions

### Meteorological mission

This concerns mainly short- and medium-term weather and sea-state forecasts for which near real-time data acquisition and processing are mandatory: The major limitation of current ocean and atmospheric forecasts is the lack of data over the open ocean.

Weather forecast- ERS-1 will contribute by providing wind stress at the ocean surface.

Sea-state forecast- An important benefit from ERS-1 is the ability to check and tune the models with direct measurement of wave height (Altimeter), wave spectrum (Wave Scatterometer) and wind field (Wind Scatterometer).

**Climatological mission**

This is a long-term mission based on the continuous monitoring of various ocean parameters in the meteorological mission.

**Imaging mission**

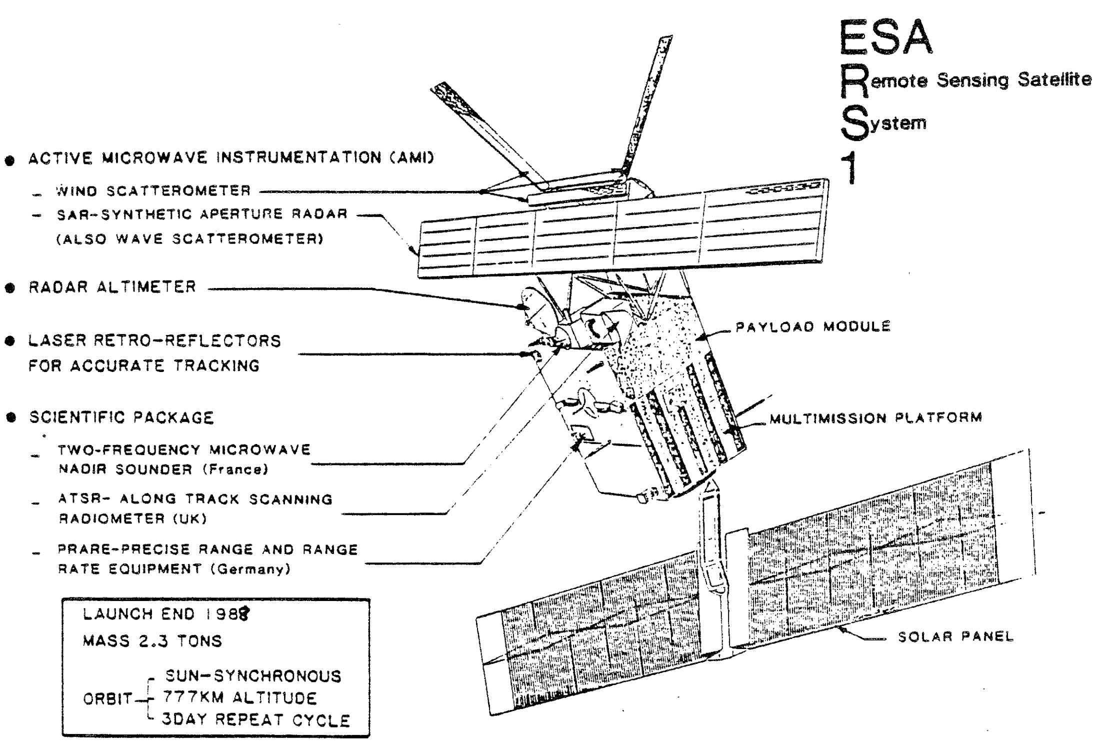
The high-resolution all-weather imaging capability provided by the SAR will be performed over polar caps to monitor land ice and sea ice features; coastal zones to monitor coastal processes; and land, as a complement to optical data.

The SAR will also operate in a sampled and reduced-power mode (called Wave Scatterometer model) over the oceans to provide small images (5 km x 5 km) from which the wave (image) spectrum will be derived.

## V. PLANS FOR FUTURE EARTH OBSERVATION PROGRAMMES

The meteorological programme is approved; the ERS-1 is still at the stage of detailed definition phase and Participating States are now discussing the conditions for entering the development phase. The present chapter describes the planning and support activities which could lead to future space missions over a broad spectrum of disciplines and applications, including:

- advanced land observation;
- advanced meteorological mission;
- climatology/atmosphere;
- physics of the "solid earth".




ERS-1 Configuration

## V.i) Follow-on Ocean Missions

It is planned to complement the ERS-1 microwave instruments by an ocean colour monitoring capability for the measurement of three principle substances:

- chlorophyl;
- gelbstoff;
- suspended sediments,

together with the sea surface temperature.

The first measurements of water quality in the oceans were made by the NASA Coastal Zone Colour Scanner (CZCS) flown on Nimbus 7. In the context of preparatory studies leading to the payload selection for ERS-1, an ocean colour monitoring instrument (or OCM) incorporating additional channels and having improved sensibility, was studied by ESA. The instrument would employ mechanical scanning and acquire imaging data between 400 and 12 000 nanometers. The swath width would be 800 km and the instaneous field of view 800 m.

More recent studies have addressed the use of linear detector arrays in the imaging plane of suitable optics to eliminate the scanning mechanism. Further activities will determine whether this concept should replace the baseline mechanically scanned OCM as the candidate for a possible second flight unit of ERS-1.

## V.ii) Advanced Land Observation

The Landsat programme has shown the potential of multispectral observations of the land surface in the visible and near infrared portions of the spectrum. The more recent Landsat D has demonstrated an improved spatial resolution of 30 m, more applicable to the smaller and more randomly-shaped fields in Europe. The French programme named SPOT will continue to monitor the Earth in the visible spectrum from 1985 onwards. The Agency is examining the role which all-weather microwave techniques could play.

A land satellite would have to address the areas of:

- agriculture
- forestry
- land use management
- water resources (including snow and ice) and land surface processes
- geology
- cartography

In the early stages of defining ERS-1, the Agency also studied a candidate Land Applications Satellite System (LASS) consisting of a C-band SAR (similar to that of ERS-1) and an Optical Imaging Instrument (OII) based on pushbroom linear arrays imaging in the visible and near infra-red as far as 3 micrometers. Further work is underway aimed at realising a thermal infra-red push broom capability in the 8-14 micrometer region, but it is not yet certain whether this could meet a launch date in the early 1990's. Likewise, preliminary work has started aimed at expanding the performance of the ERS-1 SAR for future missions, specifically by adding a second channel and by widening the swath.

### V.iii) Second Generation of Geostationary Meteorological Satellites

In Europe, the user requirements have matured since the first Meteosat was launched and the key future requirements for space meteorology can already be stated as:

- regional images of much higher resolution for "nowcasting" tracking of severe weather);
- imaging atmospheric sounder to provide vertical atmospheric profiles;
- imaging atmospheric sounder to yield water vapour profiles;
- data collection;
- data dissemination.

A first study has already examined how the above requirements could be met. In particular, three sophisticated instruments would be needed:

- a highly performant 7 band visible/infra-red imaging instrument with:
  - 1km revolution in the visible/near infra-red;
  - 4 km resolution in the middle and thermal infra-red,
- a 20 channel infra-red imaging radiometer, covering principally the edges of the $CO_2$ absorption band for measuring vertical temperature profiles. Two modes are foreseen:
  - whole earth disc with 25/50 km resolution;
  - European region with 8/16 km resolution,
- a 14 channel imaging microwave radiometer to measure water vapour profiles with 50 km horizontal resolution. 10 channels would be centred around the 118 GHz oxygen line, a window channel at 90 GHz and 3 channels centred around the water vapour line at 180 GHz.

### V.iv) Climatology

Beyond ERBE (**Earth Radiation Budget Experiment**) carried out by the USA from 1984 to 1987, there are no plans for systems to monitor the earth radiation budget. The international community is of the opinion that a future satellite system will be needed, but that it can only realistically be realised by embarking appropriate instruments on satellites planned for other purposes.

Studies of the necessary instruments will help to prepare for the possibility of embarking such instruments on satellites in an internationally coordinated manner (as well as employing the planned meteorological instruments where appropriate).

### V.v) Physics of the Solid Earth

The Earth changes shape in at least two different ways:

- on short time scales: the solid earth tides;
- on long time scales: the tectonic plates forming the crust drift around.

In addition, the earth's axis of rotation moves in a cyclical manner with a period of slightly more than one year. The rotational speed of the earth also varies. Finally, the gravity field of the earth differs from that of a point mass by virtue of the uneven distribution and density of the material constituting it.

The investigation and monitoring of the above effects by ground based techniques is limited and two basic space techniques can be considered:

- precise point position;
- precise gravity determination.

The former is applicable to:

- monitoring of crustal distortion in earthquake areas,
- determination of inter and intra tectonic plate motions,
- monitoring the kinematics of the earth's rotation (including polar motion),
- precise determination of points on the earth's surface,

but the derived measurements must be accurate to a few centimetres. In principle, the former technique involves precise ranging to a satellite in a precisely known orbit from a suitable set of ground points. It is also necessary to choose an orbit far enough removed from the earth (but not so far as to make the measurement geometry poor) and to make the satellite small and dense. Even so, residual effects still have to be measured or modelled to achieve a sufficiently precisely known reference orbit. In addition, the ranging measurements to the satellite from the ground points of interest should not be restricted by time or day or by weather.

An advanced satellite concept, POPSAT (for Precise Orbit Position Satellite), has been studied by the Agency. It combines the advantages of earlier geodetic satellites without incurring their disadvantages. In particular, it employs a high altitude orbit (of 6000 - 7000 km) together with all weather two way precise range and range rate microwave tracking. (The tracking technique is planned to be tested as an experimental German national payload on ERS-1.)

For gravity missions, an interesting technique is to monitor the change in the relative position of two identical satellites chasing one another in the same orbit as each in its turn is accelerated and then decelerated by the gravity anomalies. Such a technique has been studied by the Agency and depends only on the development of a satisfactory spaceborne laser system for precisely measuring range and range rate in space. It is considered a candidate for flying in the 1990's.

Transfer of time over intercontinental distances to an accuracy of one nannosecond is a very real requirement. This was one of two missions called LASSO of the Agency's SIRIO-2 satellite which, unfortunately, was the victim of the failure of its launcher in 1982. It is feasible to accommodate the LASSO system on board the Meteosat satellites, and the possibility of implementing this on the next Meteosat (due for launch in 1986) is being examined.

The LASSO system (for Laser Synchronisation of Atomic clocks from Synchronous Orobit) would, from a geostationary orbit, measure the time difference in arrival of laser pulses transmitted from two participating ground stations at times noted on their own clocks. A retroflector array returns a portion of each pulse to a receiver at each pulse to a receiver at each station in order to allow them to determine the time for each laser pulse to propagate from its station to the satellite.

From a geostationary orbit, time sychronisation is restricted to laser stations which are in those parts of the earth seen by the satellite. A more interesting arrangement would be to remove this restriction by using a satellite in a non geostationary orbit. The optimum orbit turns out to be between 5000 and 10000 km in altitude and of at least 70° in inclination. The POPSAT orbit could not be more perfectly suited. As it would already have laser reflectors to allow cross calibration between laser and microwave tracking stations, it merely remains to fit a suitable laser detector unit connected to the existing highly accurate on board clock.

## VI. PROVISION OF FLIGHT OPPORTUNITIES

Appropriate flight opportunities are needed for instruments which fall into categories such as those that:

- are still at the experimental stage,
- seek to prove new concepts,
- need to be deployed on several satellites,
- benefit from being recovered.

Two experimental payloads, to be provided nationally, are already planned to be flown on ERS-1: the ATSR (Along Track Scanning Radiometer) for accurate measurement of sea surface temperature, and the PRARE (Precise Range and Range Rate Experiment).

More involved arrangements will be needed to provide space on future earth observation satellites, in concert with other satellite operators, to satisfy those fields which require a set of coordinated instruments to be embarked on a set of suitable satellites (e.g; the long term monitoring of the earth's radiation budget).

There are missions or experiments requiring only a shorter flight in space (e.g. mapping cameras, cryogenically cooled instruments, limited laser based instruments). Current studies are examining the practicality of adapting the EURECA (European Retrievable Carrier) concept to an earth pointing mode for use in higher inclination orbits to suit Earth Observation instruments.

## VII. CONCLUSION

This exhaustive review of present and future Earth Observation programmes and plans of the Agency demonstrate that Europe intends to play a major role in this discipline during the coming years. In many cases more detailed work is required. For this purpose, an Earth Observation Preparatory Programme has been conceived to cover:

- detailed instrument and system studies;
- measurement campaigns,
- pre-development of critical areas.

The EOPP is expected to start in 1984 and would address the new mission areas described hereabove.