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METEOSAT - A MULTI-PURPOSE SATELLITE ?

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The title of my speech is a question. This does not mean that the answer isn't yes and isn't known. If it was anything but yes, the European Space Agency would have produced a failure. However, there is a question mark, because, is the satellite limited to meteorology only?

The satellite was launched in November 1977 and forms part of the biggest experiment undertaken by mankind until now, namely the Global Atmospheric Research Programme, GARP. It is one out of five satellites, all operating around the earth spaced about 72° apart.

What is Meteosat ?

It is a satellite with a payload which, in prinicple, is a multi-spectral radiometer. This provides for basic data of the Meteosat system as visible and infrared radiances producing images of the full earth disk, visible from the geostationary orbit. The three-channel radiometer includes two identical adjacent visible channels in the 0.4 to 1.1 micrometer band, and an infrared (water vapour) channel in the water vapour absorption band (5.7 to 7.1 micrometers) which can be operated in place of one of the two visible channels.

Each picture is composed of 2500 lines and 2500 elements which gives a resolution at the sub-satellite point of 5 km, whereas in the visible, the resolution can be improved by a factor 2 down to 2.5 km at the sub-satellite point.

Radiation data from the full earth disk are acquired by line scanning during a 25 minute period, followed by a 5 minute retrace and stabilisation period, so that one set of pictures is available each half hour. Because the water vapour image replaces one of the visible channels, the possible sets of images in any one half hour period are:

- either 2.5 km resolution visible with 5 km infrared (11 micrometers)
- or 5 km resolution visible with 5 km resolution infrared (11 micrometers) and 5 km resolution water vapour (6 micrometers).

The data from the satellite is received at the ground station in Odenwald, transmitted to ESOC in Darmstadt via a wide band data link, then treated by the Meteosat Ground Computer System where the output are reconstituted images which are being further processed and form the basis for the extraction of meteorological parameters.

Image Dissemination

Meteosat operates with two S-band dissemination channels which are independent and can work in two possible modes:

- digital, for high resolution (for further processing by computers; main format: full disk and European area)
- analogue, for APT-compatible weather facsimile (resolution achievable, depending on recording device used, several formats covering selected parts of the full disk).

The first mode is usable by medium size user stations (PDUS: Primary Data User Stations, antenna dishes of about 4 m diameter), the second one by small stations (SDUS: Secondary Data User Stations, antenna dishes of about 2.5 m diameter), capable of direct recording on standard WEFAX recorders.

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Since these dissemination channels are separated from the image transmission stream, one has in principle 2 times 1440 "dissemination minutes" available per day. Presently some 450 formats are disseminated per day via Meteosat.

The choice of data to be disseminated is very flexible, the source can be either information stored on the main computer files of the central processing facility or even another ground station as long as it complies with the interface specifications.

The main transmissions originate from the Meteosat Ground Computer System (MGCS) of the European Space Operations Centre (ESOC) in Darmstadt. They are supplemented by transmissions from the Centre de Météorologie Spatiale (CMS) in Lannion, France. This ground station also relays image data via Meteosat from NOAA and GOES spacecraft (GOES-E and GOES-Indian Ocean). Consequently, an operator of an SDUS or PDUS has the unique possibility to regularly receive relay transmissions from the various satellites covering an area between approximately 115°W and 100°E (this covers nearly 2/3 of the earth's surface).

In addition to the data type flexibility, there is also a considerable degree of freedom in the definition of the daily schedule of items to be disseminated.

Data Collection

The spacecraft can also relay data collected from remote Data Collection Platforms situated on the earth's surface to the Central Ground Station. These sensors typically provide for environmental measurements and could be either fixed or mobile, land-based, sea- or airborne. The DCPs can be either self-timed, transmitting their messages automatically according to a predetermined time and frequency schedule or interrogated, transmitting their messages only upon interrogation by the Ground Facility of Meteosat.

Some of them may, in addition, have a warning function ("alert DCPs"), allowing them to transmit a short warning message in case a given parameter exceeds a certain threshold. The maximum potential capacity for Meteosat is 66 different telecommunication channels. The DCP data are processed on the ground and relayed to the owner via conventional landlines, mail or magnetic tapes, depending on requirements.

Since all DCP data are stored on intermediate disk files on the central computer, a considerable degree of flexibility and possibility of extension of the processing of data exists.

In principle, this can involve tasks such as translation of transmission codes to other WMO alphabets, monitoring of some critical values, calibration of data and conversion to engineering units.

Also in this case, the processing and DCP schedule is driven via data tables and corresponding software on MGCS.

Meteorological Processing

Another objective of the Meteosat system is the extraction of meteorological parameters from the basic image data. The ground system has been designed to produce six meteorological parameters:

- cloud wind vectors
- sea surface temperatures
- cloud top height maps
- cloud distribution maps
- maps of distribution of water vapour in the upper troposphere
- radiation balance data.

As an example can be mentioned that about 30 000 wind vectors are produced per month.

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Archiving

The prime Meteosat objectives are completed by the requirement to archive all images and image related data. The raw image itself comprises some 200 x 10^6 bits of information each half hour, and this data quantity is increased during ground processing so that the quantity to be archived is extremely large. The primary archive medium utilised is high density magnetic tape which can store data from one day of Meteosat operation, or about 50 times what can be stored on a standard 1600 b.p.i. computer tape. Individual images can be retrieved from the archive and copied onto computer compatible magnetic tapes, or used as input to a laser beam recorder which produces high quality photographic images of any radiometer channel and for either the full earth disk or of selected areas.

Meteorological Products

Having outlined the basic system which provides data to be processed at the Meteosat Ground Computer Centre, it is important for the understanding of the utilisation of the data to have a walk through of the process which takes place before we have arrived at our meteorological products. As a typical example, I have selected the wind extraction or wind vector calculations. The purpose of that product is to provide the meteorologists with direction and speed of winds twice a day. The technique used is a type of pattern recognition where one is searching within pre-defined areas for recognisable features like cloud tops, and to trace those from one image to another. In order to do that, it is essential to have the following steps carried out:

- Image Referencing
- Segment Processing
- Wind Vector Determination
- Height Attribution
- Manual Editing
- Final Processing.

I will briefly cover the various stages:

Image Referencing

As winds are obtained by measuring displacement of clouds across successive images, a prerequisite for accurate winds is the precise relative registration of one image on the next one. A displacement of one picture element (5 km^2) between two images one hour apart, gives an error to the wind vector of 1.4 m/sec. This precise relative registration is obtained by a software solution, using a predicting model of the image characteristics. The model is supplemented by the input of measurements made on the image by automatic detection of the earth horizon.

Segment Processing

The basic unit of processing is the segment. This is an array of 32 x 32 infrared or water vapour picture elements (64 x 64 visible picture elements) cut from the image in such a way that the centre of each segment is always at a fixed geographical location, using deformation information. For practical reasons, the number of segments are registered to 3000 segments.

Wind Vector Determination

Infrared segments from consecutive images are used to determine one wind vector by an automatic correlation process. The central image segment is the target, and the algorithms search for a similar pattern in each of the two adjacent images in turn. Only segments having suitable tracers are utilised as targets.
The first problem is to take a target infrared segment in one image, and to find the same cloud pattern in the next image. This is achieved by statistical means using correlation coefficients calculated from the image data. There are 65 x 65 possible displacements of the small target within the large search area, and for each location the correlation coefficient between the target and the search area is computed, leading to an array of 66 x 66 .

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correlation coefficients. The surface is searched for significant peaks, and the distance of the peaks from the centre indicates the cloud motion vector. However, it is usual for this surface to contain several different peaks corresponding in some cases to winds of various levels, and in other cases to spurious matching due, for example, to repetitive cloud patterns.

In order to eliminate the problem of spurious peaks in the correlation surface the next step is to repeat the entire process by comparing the image at time H with the image at time H - 1/2 hour. Exactly the same process as outlined above is repeated but, at the end, all peaks which are not symmetrical within certain thresholds between the two determinations H $\pm$ 1/2 hour are rejected.

Height Attribution

The cloud height attribution is calculated from the mean infrared radiance from the cloud cluster. The input data available are in the form of the mean cluster count. This number is converted into a radiance value and hence into a temperature by means of the Planck relatioship. The temperature can then be converted into a pressure, if the appropriate atmospheric profile is known. All these conversions are achieved by means of pre-calculated look-up tables to save time during the processing.

Manual Editing

Although the above processes are being quality controlled at each stage, and a threshold is set, it requires still manual editing of the various calculated wind vectors before we are satisfied that the quality is as required. The manual editing is achieved via a system consisting of a Visual Display Unit, and a meteorological operator. On the VDU, a loop, showing the three consecutive images with the wind vectors movements, is being played repeatedly, and the operator is, after some training, able to detect very fast whether some of the wind vectors calculated are dubious. It is then possible to delete such winds from the calculations via the interactive system.

As a completion of the system it can be mentioned that it is also possible to add wind vectors to those calculated by the system as mentioned above. There are situations where the computer cannot pick up the proper tracers, but where the human operator can see clear cloud movements on the screen. In those cases, he can then add wind vectors by use of the interactive system by replaying the sequence of the three images, and follow the tracers which were not picked up earlier.

Final Processing

After manual quality control, the correlation peaks in the images at times H + 1/2 and H - 1/2 are used as end points for the determination of a final wind vector, which, therefore, represents the mean cloud motion over one hour. This value is then coded into a standard WMO format for transmission over the GTS in real time. The results are also archived on magnetic tape and as plotted charts so that they can be made available for further research. The entire sequence, from the end of the central image of the triplet at time H until distribution, takes about 4 hours, and usually results in the production of some 600 cloud motion vectors twice each day.

As mentioned earlier, this is only one example of how the meteorological products are being calculated by the system.

To come to the question I asked in the beginning - Is Meteosat a multipurpose satellite ? - I will now turn to other uses which are being made of the system as it stands today.

The capabilities of the Meteosat system can be helpful in a number of other disciplines than conventional meteorology by either contributing directly new data and knowledge, or indirectly by providing essential complementary or correlative information. The applications can range from the presently quickly developing field of remote sensing to general hazard monitoring.

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In the remote sensing area. one generally aims to achieve the highest geometrical ground resolution possible, greater than that presently available with geostationary satellites. If, however, other aspects play an important role, the advantages of the Meteosat system can be usefully applied, as for example: high time resolution to study dynamic phenomena, very large scale synoptic views, need for continuous or frequent monitoring of large areas, identical viewing conditions or even the need of quick access to data or ease of processing.

For the study of most dynamic phenomena, usually the 1/2-hourly repetitive picture taking cycle of Meteosat is fully adequate (compare e.g. the repetition time for a typical earth resources satellite of up to 3 weeks). But even this time scale could be reduced letting the radiometer scan only a small portion of the earth's disc as is also used for the American GOES satellite for hurricane monitoring.

In this context it might be interesting to note that Meteosat cannot only look at the earth or parts of it, but also to other regions in space, notably the moon. By ground control, i.e. transmitting a number of telecommands to the spacecraft, the viewing direction and number of scan lines can be controlled very easily.

The successive images made by Meteosat can be put together to form a "time-lapse" movie. Examples can be seen in the film presentation. By this technique, one is able to see the variation of cloud coverage during days within a few seconds and can get a good impression on the complicated dynamical behaviour of the air masses in the atmosphere of our planet. New insights in the global circulation patterns can be found as well and a considerable contribution for more accurate short-term weather forecasting is feasible.

Another very useful feature is given by the fact that Meteosat provides practically identical viewing conditions for the observations of the earth's disc with a well-defined periodicity. This eases long trend studies considerably, such as analysis of desertification processes in the African Sahel zone or variation of lake sizes like the Tschad lake. Due to the short frequency of picture taking, it is possible to image the same surface features at different times of the day and at different seasons, i.e. at varying solar aspect angles or varying illumination, heating and environmental conditions. This can help in studies of vegetation growth or water resources.

The very large scale synoptic view permits identification of large scale features of phenomena and their variation with time as one can see e.g. in the case of the very large jet streams extending over several thousand kilometers (can be seen very well in the Meteosat cloud motion film as well).

Other capabilities of the Meteosat system, notably the dissemination and data collection facilities, permit a number of applications generally not possible in particular on the African continent, because of lack of an adequate infrastructure. Large areas are difficult to access but need, nevertheless, either weather information for agriculture support or they lack any regular measurement of surface characteristics.

In the first case, cheap and simple stations can obtain the weather pictures as distributed by Meteosat. The significance and need of better exploitation of the natural resources, especially in the agriculture area in Africa, can be best understood if one realizes that from the more than 50 countries on the continent, less than 10 % are in a position to manage with their own resources. All other ones need external help.

In the second case, Data Collection Platforms in the form of little unattended units can provide regular measurements needed either for meteorological purposes or other applications like water level gauging.
Especially for the developing countries, systems are now being proposed, consisting of a series of DCPs and image receiving stations, supporting agro-climatological needs and crop yield forecasting. This constitutes an important contribution Europe could provide to African Nations.

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It is probably interesting to present a few typical applications to demonstrate the potential of the data one can obtain via space technology in the case of Meteosat.

When one follows over a day at a particular location on the earth's surface the emitted thermal radiation by means of Meteosat's infrared sensor, one can obtain data on the ground thermal behaviour. The behaviour in turn is a function of the soil characteristics, of the properties of the matter below the surface and of the soil moisture. By comparing e.g. the time of maximum in the heat emission with the time of maximum of solar heating over the area studied, one obtains a time difference which is indicative of the thermal "inertia" of the place. Dry soil will show surface temperature variation faster than wet soil. Also rock and sand exhibit different behaviour. Comparing not only the maximum but analysing the complete curve of radiative response versus time permits the derivation of geological and hydrological data.
A project is currently going on applying this concept to a number of areas in Africa.

Ecological studies on desert plants to find out how they can survive under extreme conditions is normally very difficult due to lack of sufficient environmental information. Usually, one has no adequate data on rainfall or humidity in desert areas. It is important to know which mechanisms desert plants develop to store or accumulate water in order to survive. If one understands these phenomena better, one can probably find better means to prevent soil erosion.

The physiological response of the "midday-flower" (it opens its flower in the early afternoon) to environmental changes, was studied in the Namib desert in South Africa.
The ground collected information was compared with Meteosat data from the same time period.

In general close agreement could be found, with the result that the group of botanists will apply the same technique for detailed studies in the Sahel zone. In addition, they plan to use DCPs in order to get also data on very localised short showers which are difficult to see from Meteosat pictures.

Another very interesting project uses Meteosat data in order to help in the control of the locust plague.
The Food and Agriculture Organisation, FAO, in Rome, uses the Meteosat images to estimate the environment in the semi-desert areas in which locusts exist and breed. Depending on rainfall and available vegetation to feed, locusts develop a different life cycle. If advantageous conditions prevail - i.e. a minimum of rainfall and sunshine must exist - the locust population density can exceed a critical threshold.
In this condition the locusts change from the harmless solitary to the dangerous migrating type within a few days. When vegetation is lacking, they will start swarming and are then a threat to basically all agricultural products they encounter.
From analysis of the images, one can obtain all necessary environmental information and is then in a position to launch a locust control operation with the aim of extinguishing the swarm.

For another application, the infrared sensor data are used to determine the temperature of the ocean surface. Temperature variation give indication on ocean currents, providing new insights into oceanography but also on areas where certain kinds of fish tend to accumulate. In areas of temperature gradients, generally water from lower levels is reaching higher levels bringing also fresh food for fish. This information can then be used by fishery fleets to improve the output.

In many more areas Meteosat data are usefully applied, such as climate monitoring, global rainfall monitoring, evaluation of atmospheric turbidity, hydrological studies, large scale geological feature evaluation, studies of movement of dust or matter generally (stand storms e.g.), desert formation and a large list of possible DCP applications, covering the important area of hazard warning as is the case for flooding, forest fire and seismic events.

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The achievements and possibilities I presented to you in a somewhat superficial way due to time constraints are the result of a cooperation between 8 European countries, members of the European Space Agency. The Agency has had the responsibility for the implementation of the overall programme. It is worthwhile underlining that the whole system, spacecraft and ground segment, has been a European effort; an effort which has been so successful that in several areas we are doing better in quality and quantity than any other meteorological satellite operator in the world.

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