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Environmental Studies Using Satellite Imagery

The 1970s will be remembered as the decade which saw the birth and development of an environmental conscience, now spread quite widely but in various forms and with various implications. Developed as a reaction to excess growth and accidents often due to badly-oriented human activities, that conscience gave rise to a search for remedies, in which increased knowledge and information clearly formed a necessary condition for improved decision-making.

Whether the question concerns the entire natural heritage of a single country or, with all the more reason, the undivided regions between nations, such as the atmosphere or oceans, the information-gathering undertaking appears to be gigantic particularly from the point of view of its practical as well as its periodic realization.

However, the 1970s also saw the launching and first experiments with civil Earth observation satellites, i.e. remote sensing satellites. Examining their characteristics, which are quite often praised, one is naturally tempted to see in that innovation the solution to all the new problems arising from the desire to understand the environment better in order to manage it more effectively.

Remote sensing principles

Remote sensing is a term which normally covers the collection by satellite of information concerning the different physical components of the environment, particularly the natural heritage. Those methods are based on techniques which generalize those of normal aerial photography.

As with those direct techniques, satellite remote sensing records 'in flight' the electromagnetic radiation emitted or remitted by objects on the ground. However, contrary to aerial photography, these operations are based on an artificial satellite, make use of a different process and are sensitive to a much wider range of radiation.

These three last remarks summarize the conditions which give satellite remote sensing its originality as well as its potential for solving certain problems mentioned above.

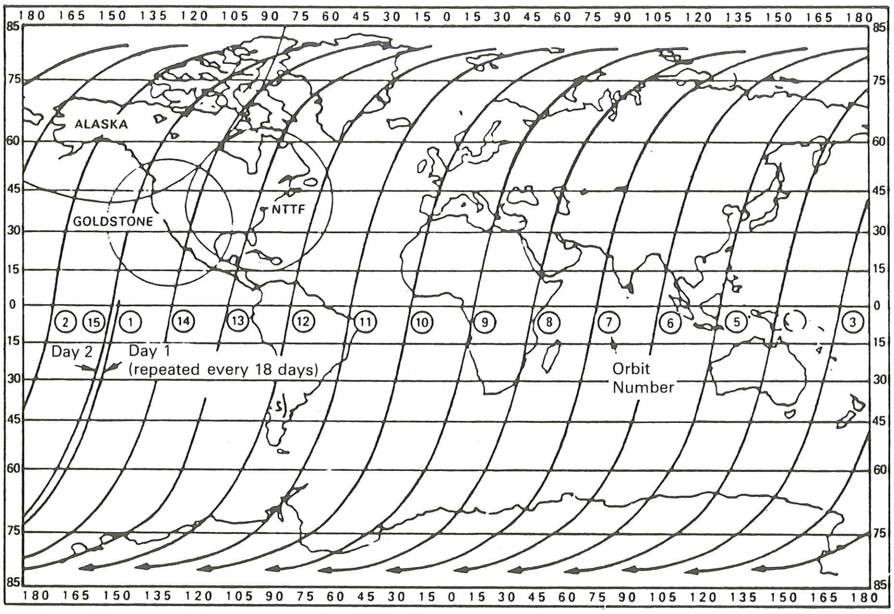
The laws of celestial mechanics make remote sensing satellites faithful periodic observers. For example, every 18 days US satellites pass over the same zones at the same times of day. In addition, their distances above the ground (900 km.) give an observed zone dimension such that it overlaps part of the image observed the previous day (towards the east) as well as that to be observed the following day (towards the west). Total coverage of the planet is thus possible every 18 days and likewise, in theory, all France can be completely recorded in a 10-day period (FIG. 1).

The onboard recordings are transmitted to the ground by radio and are available a few days later. One can thus imagine having homogeneous and up-to-date information covering large areas, systematically and very rapidly available.

Each of the words in the previous sentence emphasize the originality of satellite remote sensing with respect to aerial methods, which, confined to low altitudes, are limited to the observation of much smaller areas in the same periods of time. This results in a considerable lengthening of the time required for the aerial observation of a given area, a period which may amount to months or even years, whilst one speaks of only minutes or days for an equivalent satellite remote sensing operation. Consequently, the information obtained from aerial surveys of large zones is spread out in time. The French national forestry inventory, compiled every 10–15 years in this way, does not provide a global instantaneous picture of French forests, but is rather like a puzzle in which each piece (large administrative unit) is labelled with a different date in that period and then is only available 2 or more years after the aerial survey operations.

On the other hand the aerial method has several advantages precisely because of its operational flexibility, due to its being independent of the periodicity constraints imposed on satellites by Kepler's laws, when it is necessary to investigate transient phenomena, e.g. take action at a precise instant as with flooding or pollution, and as the procedure operates nearer the ground, aerial surveying can analyse phenomena in a much more detailed manner. The high altitude of the satellite produces very integrated observations of phenomena. The radiation measured point by point is the total radiation emitted by an elementary zone which, for Landsat, for example, is one acre (0.5 hectare) in size. The information obtained from that one-acre zone is the aggregate of the entire

Only 103 minutes are required for a Landsat satellite to make one revolution around the Earth, i.e. it makes 14 revolutions each day. As the Earth also revolves during the same period, the 15th revolution is displaced with respect to the first one by 149 km westwards (at the Equator). One must therefore wait 18 days before the satellite travels along the first path once again.



group of phenomena which it contains, and it thus possesses a synthetic character, e.g. mineral-bearing zone, urbanized where necessary, with varying density, rather than an analytic one, where it is possible to distinguish between different buildings, infrastructures, etc. This integrating power is an advantage for our purposes as discussed below. In addition, the high altitude sometimes shows up relationships between widely separated elements on the ground and thus reveals unsuspected structural phenomena.

Such was the case, for example, in geology, where the satellite with its high altitude renewed normal investigation methods, drawing attention to structural elements sometimes ignored in normal geological mapping activities.

The original data are collected in the form of digital images and stored on magnetic tape, i.e. as a series of measurements concerning each of the one-acre elementary ground points. Measurements at elementary points are made by onboard radiometers which scan the ground perpendicularly to satellite paths. Images are thus produced by the double:

a) longitudinal motion of the satellite (from north to south), and
b) transversal motion of the scanning (east–west) radiometer.

Each element of the recorded image is marked on the magnetic tape by the number of the scanned line and by an order number (column) on that line; a relationship exists making it possible to pass from those line-column coordinates to the usual geographic coordinates of the ground points. Consequently, the radiometric data so collected are also given positions.

The radiometers used for satellite remote sensing are sensitive to electromagnetic radiation. As with aerial photography, they not only operate in the visible spectrum but outside that region as well, out to the far infra-red wavelengths. Satellite remote sensors thus acquire information on phenomena, invisible to the eye, that generate infra-red radiation. This is the case, e.g. for thermal phenomena occurring near ground temperatures which give rise to infra-red radiation than one can easily capture at night at that wavelength.

Satellite radiometers, instead of giving a global measurement of the energy emitted by each ground element, produce a group of measurements for each point, with each measurement corresponding to the energy contained in a different wavelength band. This is analogous to the use of filters in photography, or that procedure used in colour photography where the wavelengths of the various colours in the same luminous flux are recorded on different sensitive layers of the film. Thus, in Landsat operations, the complete signal is analyzed according to four wavelength bands corresponding to four different colours (visible and infra-red).

An advantage of this arrangement is that the ground phenomena can have emissions whose energy levels vary considerably from one channel to another depending on their physical nature. Objects are thus identifiable by their 'spectra' or the entire group of measurements in the different channels (one also speaks of 'spectral signatures').

These remarks will make clear the following characteristics of satellite remote sensing.

The original digital data supplied on magnetic tape can be processed automatically by computer, i.e. very rapidly and for vast areas, in accordance with processing hypotheses based on the relationship, assumed to be stable, between the identity or nature of a phenomenon and its spectral signature. The processing of all the recordings forming a single image (Landsat provides some 30 million digits for each square image with a 185 km. side) consists in identifying, in the first place by their signature, all the elementary recordings corresponding to the same phenomenon, then to position those data on the image by their line-column coordinates, as indicated above. Such classifications can be carried out rapidly and the results displayed on maps.

If required, digital processing can measure immediately the areas of those zones concerned by the information being classified. It is sufficient just to count the number of elements in a given classification (reputed to correspond to that information because they have its signature) and to multiply by the elementary area (1 acre) in order to obtain the total area concerned, e.g. water, forest, etc. In France, an annual inventory of the forest areas destroyed by fire in the Provence region is produced in this way. The results are available in the month following the data acquisition by Landsat and they are displayed in the form of maps and statistics for each local government area. The data so obtained are more accurate than the estimates made by the fire-fighting services whose activities, it must be admitted, leave little time for objective evaluation. The positions of the areas destroyed by fire are also determined more accurately than by the simple indications collected at the time of the disaster.

Coming back to Earth

Looking into the future using these few theoretical elements, because of insufficient experimental data concerning civil activities and the small amount of information available on military applications, most of the more popular articles concerning remote sensing have adopted an extravagant tone, e.g. 'Satellites see everything, know everything and do everything'. The truth is not so simple and in order to be realistic, one must 'come back to Earth'.

In the first place a certain number of limits are easily identifiable, e.g. those related to the weather which, in Europe, lead to the number of useful passes being nearer to 5–10 per cent than 100 per cent. The 18-day theoretical period is thus replaced on the average by a frequency of once a year for zones which are often covered by cloud. A remedy to that limitation would be to provide satellites with onboard radar equipment because those waves are not affected by clouds. However, these are medium-term projects (except for a brief US experiment in 1978). On the other hand, countries nearer the Equator can obtain images more frequently.

As satellite remote sensing has only recently become operational, delivery times are sometimes long, the products do not always have the required properties and finally the sensors mounted onboard current satellites have frequently been damaged giving rise to fairly long interruptions of their routine functioning. The 1980s will see many improvements in this situation; firstly in the USA where decisions have been taken to make space remote sensing systems more reliable and secondly in France where the SPOT satellite is being prepared for launching in 1984.

As regards methods, it must be remembered that the detection of phenomena is based on the correspondence between a radiometric measurement (spectral signature) and the nature of the phenomenon being analyzed. The reality is evidently much more complicated; if two identical phenomena (defined as the entire group of parts contained in an elementary one-acre area illuminated under the same conditions) effectively have the same signature, the inverse is not necessarily true; two identical signatures can be quite well produced by arrangements of different elements inside the two elementary areas. In addition, the same phenomenon of interest to a user can also give rise to different signatures depending on whether or not it is associated with another phenomenon, e.g. different soils on which it is observed.

These remarks indicate that remote sensing methods are all the more effective when they are applied in the framework of well-founded a priori knowledge, e.g. at a certain growth stage, the 'corn' signature, i.e. its colour, will have that much more chance of effectively corresponding to corn if

a) that crop is frequently encountered at that growth stage during the recording period of the zone being observed,
b) it is the only vegetation having that signature at that time in that zone.

If, on the contrary, confusion arises between different phenomena because they have the same signature at the instant of recording, it is often possible to separate them using radiometric data from another period when the signatures are different. Selection of that period will depend on the knowledge that one has available about the variations of their respective signatures with time. One can thus separate the green corn zones from the green permanent grassland zones by recording the entire area in question at the sowing period: one then knows that the 'corn' signature corresponds to that of the ploughed land.

Certain easily detectable phenomena sometimes reveal other phenomena not directly visible. For example, substances in the subsoil sometimes have very special effects on the vegetation. Recording those vegetation anomalies reveals the possibility of subterranean origins, e.g. mineral veins, so long as one has accurate information concerning the possible causal links.

One thus sees how an explanatory hypothesis, or model, can orient the deciphering of radiometric measurements in different ways. Thus, during an operation carried out by a River Catchment Board during the 1976 drought in France, it was possible, in the first place, to detect clearly irrigated zones which had not been declared to the authorities or known as such. The strength of the vegetation as shown on the satellite channel 4 and 5 signatures by the characteristic quantities arising from the chlorophyllian function intensity in those zones contrasted strongly with the dried up zones because they were not irrigated.

However, in certain places, the zones so revealed, as later verified, turned out to be non-irrigated, despite the good health of their vegetation, because they were zones where the stocks of water were sufficient to make irrigation unnecessary. This is a good example of the care which must be used in making any interpretation, the 'safety barrier' consisting of theoretical knowledge of various possible explanatory models and practical knowledge about their respective probabilities. Careful checking will confirm in each case, where possible, the accuracy of the conclusions obtained.

At this stage one might legitimately be tempted to conclude that one is being asked to discover things which are quite evident. However, there are no fundamental differences between the steps described here and those implicitly practised by agronomists or forestry experts on the ground when they observe and classify phenomena based on their experience. Remote sensing makes it possible to extend over the homogeneous areas that it discovers, analyses made at a few sample points and in a manner much more accurate, sure, rapid and at a lower cost than by the arsenal of normal statistical methods.

'Neither cure-all nor gadget'

More than a science, more than a technique, satellite remote sensing thus appears as a method whose effectiveness will only develop by means of thorough information and model studies along with systematic experimentation to define the conditions for generalizing the results obtained within a particular context.

As a tool for producing information, remote sensing finds itself, for this reason, placed in a well-known problematic situation, i.e. the product obtained has no value in itself because the value depends basically on the use which is made of it. The experience acquired in the last 10 years, both in the USA as well as in France, has shown the extent to which the participation of the final user, both in the elaboration of the methodology as well as in the operational phase, is necessary to the development of that tool.

Remote sensing classifies phenomena after examination of their radiometric similarities which in turn depend on their physical natures. This leads to a physical nomenclature whilst the user has usually already developed his own nomenclatures for his activities. Correspondences between such nomenclatures do not necessarily exist. Consequently, remote sensing is not always capable of replying exactly to the a priori needs of users. On the other hand, the information that it supplies, as experience has shown, often provides increased returns that only analysis by an expert-user can discern and likewise only his initiative for innovation amongst inherited routines can activate.

This is valid at the methodology level where a continuous dialogue between the satellite remote sensing technician and the final user is necessary for the mutual adaptation of the tool and its use. Detailed knowledge of the specific conditions in each region as well as expertize in the final use of the information are also necessary in the operational mode in order to guarantee that the information so created is consistent with the project objectives and that the data will be used. In addition, American and French experiments have shown the necessity of a transfer of technology to the user, in order to secure the development of good uses.

The environment appears to be a particularly promising field for remote sensing because it is likely to benefit more rapidly than other subjects, having more rigid concepts and practices, from the potentialities pertaining to remote sensing itself. Concerned with elements spread over wide areas, defined by basically physical characteristics, it can only be understood by a high level of synthesis. Remote sensing has shown itself to be particularly well-adapted to environmental management not only for precise problems concerning, e.g., the quality of stretches of water, estimation of the biomass, but in a more synthetic manner for landscape analysis, land-use maps, etc.