Mapping Solar Radiation By Meteorological Satellite

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ABSTRACT

The estimation of solar radiation at the earth's surface from cloud pictures taken by geostationary meteorological satellites is reviewed. Details are given of several different methods based variously on empirical correlations between satellite radiometer data and measurements of insolations on the ground, and on physical models of the transfer of solar radiation through the atmosphere. Operational systems using modest equipment for receiving and processing satellite data to this end are described, and potential applications in meteorology, agriculture and solar technology are mentioned.

BASIC CONCEPTS

Solar radiation falling on the surface of the earth in the visible and near infra-red wavelength range (0.3 - 2 μm) is measured on the ground by means of a pyranometer. The response time of a good instrument is rapid, so the output can easily be recorded and analysed with a resolution in time of the order of minutes. This is important when rapid variations take place in the intensity of solar radiation due to the passage of clouds and changes in the weather.

Besides a fine resolution in time, a detailed knowledge of the variation of solar radiation over areas of the earth's surface is also important because of the influence of coastlines, mountains, lakes and large cities on local climates. Studies of these effects would require a closely spaced network of pyranometers measuring solar radiation over each area of interest. Unfortunately, reliable pyranometers have been developed only recently. They are still expensive and special skills are needed to operate and maintain them. As a result solar radiation is not yet one of the elements of weather routinely observed at meteorological and climatological stations, and pyranometric data from remote areas will remain sparse or non-existent in the foreseeable future.

Fortunately, an alternative solution to this problem has recently appeared. It is now possible to observe the distribution of solar radiation incident on the surface of the earth through the analysis of images from meteorological satellites. The pictures of the earth taken in the visible spectrum by these satellites show the brightness of the reflected solar radiation at each point of the image. Where there are no clouds the brightness depends on the reflectivity, or albedo, of the earth's surface. The albedo of water surfaces is very low, so oceans and lakes appear dark on the image. Over land the albedo varies with the nature of the surface. Green forests, which have a low albedo, appear moderately dark, while sandy deserts are somewhat lighter. Thick and continuous clouds, on the other hand, have a very high albedo and appear white.

The brightness of the reflected solar radiation at a particular point in a particular image depends on the amount of cloud present when the picture was taken, and on the albedo of the underlying surface. The difference between the observed brightness and the brightness that would have been observed in the absence of cloud is therefore a measure of cloudiness. Since cloudiness is the main factor determining the amount of solar radiation reaching the surface, relations between the above measure of cloudiness and the insolation at the surface form the basis of all methods of studying solar climatology with the help of meteorological satellites. One problem that may arise is the difficulty of distinguishing snow on the ground from cloud. Fortunately, this problem does not arise in the tropics, where solar climatology is likely to benefit greatly from satellite methods.

The size of the picture elements, or pixels, in meteorological satellite images typically corresponds to a distance of 1-10 km on the ground. Each satellite image thus provides a detailed picture of the distribution of cloud over a large area. The images are taken at intervals throughout the day, and although it may take many minutes to scan and transmit the whole picture back to the earth, each portion of the image is an essentially instantaneous representation of the brightness of reflected solar radiation over the area covered.

Thus a network of pyranometers provides records that are continuous in time at individual locations distributed over the study area several hundred kilometres apart, while satellite images provide records that are continuous over the area but distributed in time at intervals of at least 30 minutes. Comparisons between ground-based pyranometric measurements and insolation values derived from satellite data therefore require careful treatment.

It is important in this connexion to find the exact correspondence between points in the image and locations on the ground, a process called navigation. The accuracy with which navigation can be performed greatly influences the quality of the results.

METEOROLOGICAL SATELLITES

There are two kinds of meteorological satellite at present in operation: polar orbiting satellites and geostationary satellites (Fig. 1).

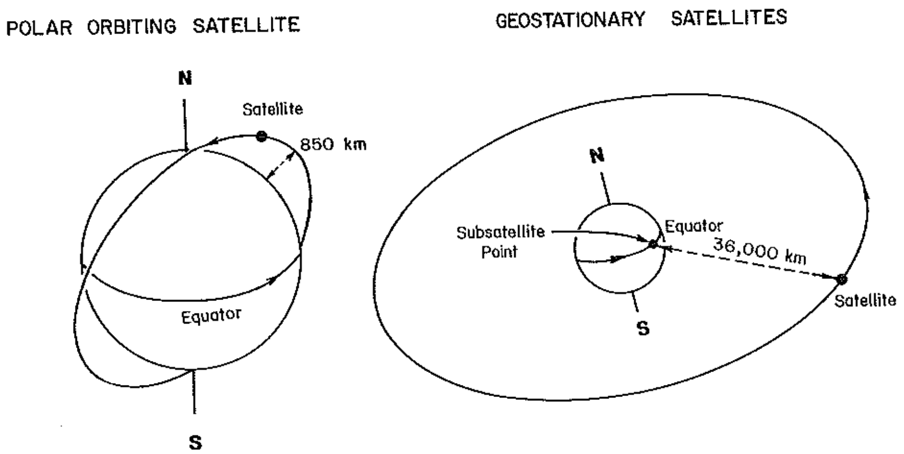

Fig. 1 Meteorological satellites.

A polar orbiting satellite rotates around the earth approximately 850 km above the surface passing close to the north and south poles. It makes 14¼ revolutions per day, each passing over a different part of the earth's surface. There are two American polar orbiting satellites now in operation: a morning satellite crossing the equator at 7:30 a.m. local time each orbit, and an afternoon satellite crossing the equator at 2:00 p.m. local time each orbit. These satellites provide data covering the whole of the earth.

A geostationary satellite has a circular orbit with period 24 hours obtained by placing it at a height of 36 000 km. The satellite is located exactly over the equator moving east. This causes it to remain stationary over the same point on the earth's surface, called the sub-satellite point. It thus provides a continuous view of the same side of the globe at all times. This continuous viewing capability, which is not possessed by the polar orbiting satellites, makes geostationary satellites suitable for solar radiation studies.

At present there are five geostationary satellites in operation covering the globe: GOES-E and GOES-W (U.S.A.),[1] METEOSAT (Europe), GMS (Japan)[2] and INSAT (India).[3] Their sub-satellite points and areas of coverage are shown in Fig. 2. The smaller ellipses drawn for GMS and INSAT, which give views of Asia, show the areas sufficiently close to the sub-satellite points for the data covering them to be of good quality.

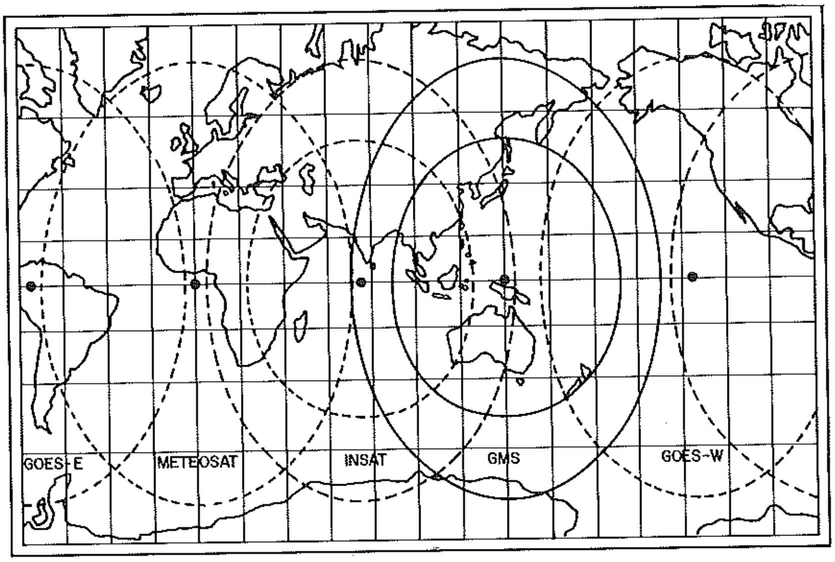

Fig. 2 Sub-satellite points and coverages of geostationary satellites.

It is the common practice for geostationary satellites to take two full-disc images every half hour. One is at visible wavelengths for showing cloud cover in the daytime. The other is at far infra-red wavelengths for temperature sensing during the daytime and at night. The image at visible wavelengths is the most important for solar radiation studies. The image data are sent to ground stations for processing, analysis, dissemination and archiving. Preprocessed image data are returned to the satellite for transmission as facsimile broadcasts at 1.7 GHz in standard formats that can be received by any ground station within range. The cost of the basic equipment required to receive low resolution image products in analog format is of the order US$10 000. Unfortunately these broadcasts are not made from INSAT, but users in east Asia can receive them from GMS.

Weather observations are made by GMS with the help of a visible and infra-red spin scan radiometer whose action is illustrated in Fig. 3. The field of view sweeps across the earth from

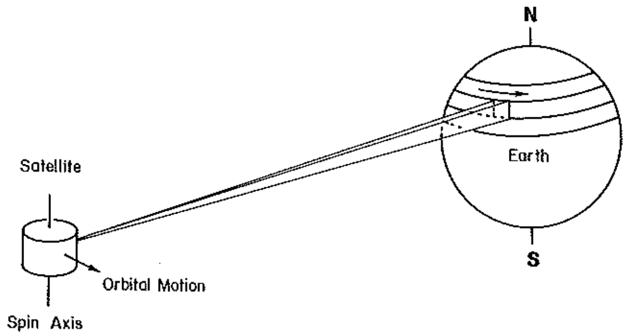

Fig. 3 The action of the spin scan radiometer.

west to east making one step from north to south in each rotation of the radiometer. About 25 minutes are required to scan the whole of the earth's disc. The wavelength range of the visible sensor is 0.55 - 0.75 μm, and the image resolution on the ground at the sub-satellite point is 1.25 km. Among the facsimile display products broadcast by GMS there is a full disc image divided into seven pictures with latitude-longitude gridding and coastlines. The sector covering southeast Asia is shown in Fig. 4. The resolution of these pictures in the visible spectrum is 4 km. Fig. 5 shows an example.

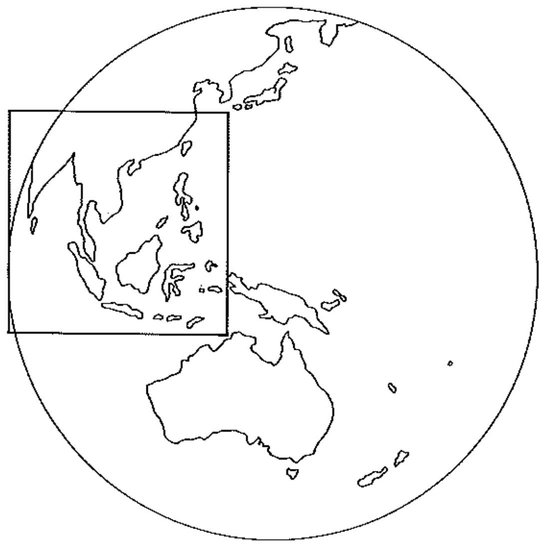

Fig. 4 The sector produced by GMS covering southeast Asia.

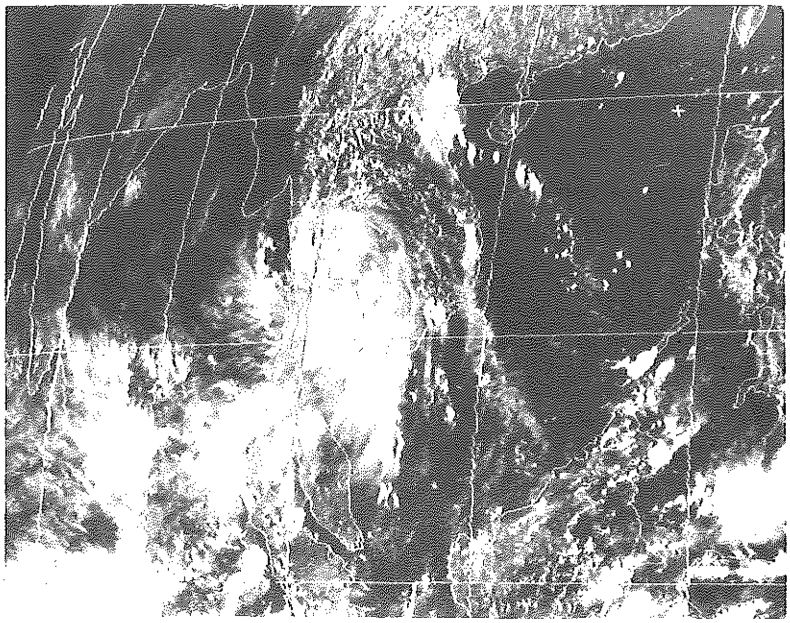

Fig. 5 GMS picture of southeast Asia in the visible channel.

THE CORRELATION OF IMAGE DATA WITH INSOLATION

The simplest way of using image data to estimate insolation is to correlate the solar radiation measured by pyranometers on the ground with the reflectivity of the earth at the same locations measured by the satellite radiometer. The quantities involved in the basic theoretical model underlying this method are as follows (Fig. 6):

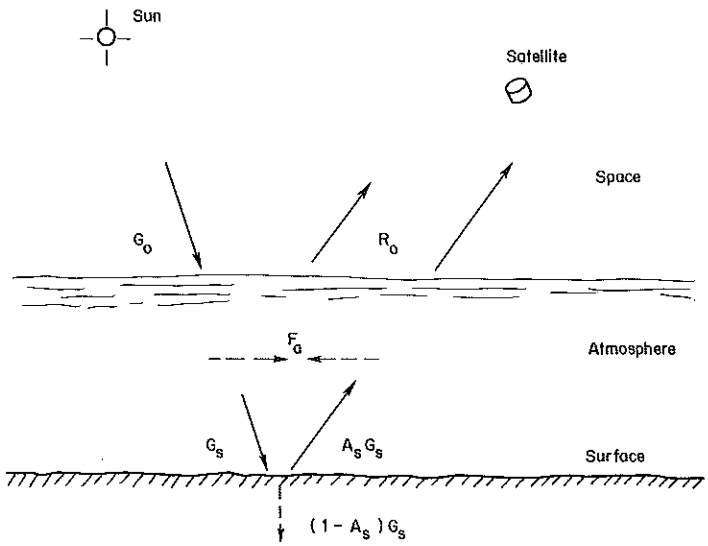

Fig. 6 Solar radiation flux densities. For definitions of symbols see text.

1) The downward global solar radiation flux density outside the atmosphere, G_o.
2) The solar radiation flux density absorbed by the atmosphere, F_a.
3) The downward global solar radiation flux density at the surface, G_s.
4) The reflectivity, or albedo, of the surface, A_s.
5) The upward reflected radiation flux density outside the atmosphere, R_o.

Since the solar radiation flux density reflected from the surface is A_sG_s, it follows that the flux density absorbed by the surface is $(1 - A_s)G_s$, and the energy balance of solar radiation in the atmosphere is represented by the equation

$$G_o = F_a + (1 - A_s)G_s + R_o.$$

The overall transmissivity of the atmosphere is therefore given by

$$G_s/G_o = (1 - F_a/G_o - R_o/G_o)/(1 - A_s).$$

If the albedo of the surface A_s and the relative absorption of the atmosphere F_a/G_o are constant, then the transmissivity of the atmosphere is a simple linear function of the reflectivity of the earth R_o/G_o thus:

$$G_s/G_o = a + b(R_o/G_o),$$

where $a = (1 - F_a/G_o)/(1 - A_s)$, $b = -1/(1 - A_s)$, and G_o may easily be computed from the solar constant, the distance of the sun from the earth, and the solar zenith angle.

The empirical parameters a and b are estimated from the linear regression of G_s/G_o on R_o/G_o, where G_s is obtained from pyranometer measurements at a number of locations in the study area, and R_o at the same locations is obtained from the satellite data. The parameters may then be used to produce maps of estimated values of G_s over the entire area from satellite images. The calibration of the satellite radiometer is taken care of in the parameter b.

This method was developed and used by Hay and Hanson[4] to map the distribution of solar radiation over the tropical Atlantic Ocean. They found it possible to estimate the hourly transmissivity of the atmosphere with a standard error of 0.1, and the daily transmissivity with a standard error of 0.05.

The success of this method depends on the stability of the parameters a and b. Over the ocean A_s is nearly constant, so the parameter b should be stable. Over land areas this is not necessarily so because variations in surface albedo may be important. The parameter a is influenced by variations in the atmospheric absorption, which is mainly due to aerosols, cloud and water vapour.

A theoretical analysis by Nunez[5] of the processes involved showed that the reflectivity R_o/G_o should normally correlate well with atmospheric transmissivity G_s/G_o provided that aerosol absorption is not dominant. His study covering land and sea areas along the coast of Queensland, Australia, found the same standard error 0.05 as that found by Hay and Hanson[6] in estimates of daily transmissivity from satellite data. A considerable part of the scatter in the results was attributed by Nunez to variations in aerosol absorption.

The transmissivity of the atmosphere under average conditions of cloudiness is typically 0.5, depending on the climate of the area. The above linear correlation method should therefore estimate hourly insolation with an average accuracy of 20%, and daily insolation with an average accuracy of 10%. Apart from the difficulty of comparing localized time-averaged pyranometer data with instantaneous space-averaged satellite data as mentioned earlier, improvements in the accuracy require improvements in the modelling of atmospheric absorption and surface albedo. The surface albedo can be found by measuring the reflectivity of the earth when the sky is clear. Determinations of the atmospheric absorption are more difficult and require the use of auxiliary meteorological data in the modelling. The following sections of this paper contain short presentations of several models that take these factors into account.

THE TARPLEY MODEL

This is a regression model that was developed by Tarpley for agricultural purposes using data covering the Great Plains of the United States.(7) The method was later simplified and made into an operational system to supply daily insolation estimates over a wide area.(8)

In the operational system estimates of insolation are made for targets approximately 50 km square every 1° of latitude and longitude. Each target is covered by a 5 X 5 array of pixels. The mean brightness R_o of each 25-pixel array is used to estimate G_s over the target through the regression equation

$$G_s = a + b \cos \zeta + c(R_o/B_o)^2 ,$$

where a, b and c are the regression parameters, ζ is the solar zenith angle and B_o is the cloud-free brightness of the target. The estimates are made five times a day at 7 h, 9 h, 12 h, 15 h and 17 h local time, and the results are integrated numerically to obtain estimates of the daily insolation.

The cloud-free brightness values for each target at each hour of the day were found originally by a routine that filtered out cloud-contaminated data from records extending over about one month. In the new system cloud-free brightness values are stored and updated daily to allow them to vary with seasonal changes in solar elevation and ground cover. It is noteworthy that, because the satellite data enter the regression equation for G_s only in the dimensionless fraction R_o/B_o, no calibration of the satellite radiometer is needed.

The model has given estimates of daily insolation with a standard error 12% of the mean value. It tends to overestimate insolation under cloudy conditions.

THE GAUTIER MODEL

The models described above are based on regression coefficients which require a network of pyranometers on the ground for their determination, and which may vary with geographical location and season. In contrast, Gautier's model(9) relies instead on well calibrated satellite measurements and mathematical approximations to the physical radiative transfer processes in the atmosphere. Two pairs of equations are used, one pair for the clear atmosphere and the other pair for the atmosphere with clouds.

The properties of the atmosphere that appear in the equations for the cloud-free case are as follows:

1) The reflectivity of the atmosphere for the direct solar beam, ρ_b.

2) The reflectivity of the atmosphere for diffuse solar radiation, ρ_d.

3) The absorptivity of the atmosphere for the downward path of the direct solar beam, $\alpha\downarrow$.

4) The absorptivity of the atmosphere for solar radiation along the upward path towards the satellite, $\alpha\uparrow$.

Reflection and scattering are assumed to be isotropic. The reflectivities are calculated on the assumption that they are due entirely to Rayleigh scattering by air molecules. The absorptivities are calculated on the assumption that they are due entirely to molecular absorption by water vapour using climatological surface dew points for estimating the water content of the atmosphere. The effects of scattering and absorption by aerosols are not written into the model.

The upward reflected radiation flux density outside the atmosphere is the sum of two terms, one representing radiation reflected by the atmosphere and one representing radiation reflected from the surface:

$$R_o = G_o\rho_b + G_o(1-\rho_b)(1-\alpha\downarrow)A_s(1-\alpha\uparrow)(1-\rho_d).$$

Since all the quantities on the right hand side except A_s are known, A_s can be calculated from measurements of R_o by the satellite. The downward global solar radiation flux density at the surface is then given by

$$G_s = G_o(1-\rho_b)(1-\alpha\downarrow)(1+A_s\rho_d).$$

To develop equations for the cloudy atmosphere a simple model was adopted in which the clouds were assumed to exist in a single uniform layer with separate atmospheric absorptivities above and below the layer. The new quantities that appear in the equations are as follows:

5) The absorptivity for the downward path above the cloud, $\alpha_1\downarrow$.

6) The absorptivity for the downward path below the cloud, $\alpha_2\downarrow$.

7) The absorptivity for the upward path below the cloud, $\alpha_2\uparrow$.

8) The absorptivity for the upward path above the cloud, $\alpha_1\uparrow$.

9) The absorptivity of the cloud layer, α_c.

10) The reflectivity, or albedo, of the cloud layer, A_c.

The expression for R_o now consists of three terms: The radiation reflected by the atmosphere, the radiation reflected by the cloud layer, and the radiation reflected by the surface, thus:

$$\begin{aligned} R_o = {} & G_o\rho_b + G_o(1-\rho_b)(1-\alpha_1\downarrow)A_c(1-\alpha_1\uparrow)(1-\rho_d) \\ & + G_o[(1-\rho_b)(1-\alpha_1\downarrow)(1-A_c)(1-\alpha_c)(1-\alpha_2\downarrow)\times \\ & A_s(1-\alpha_2\uparrow)(1-A_c)(1-\alpha_c)(1-\alpha_1\uparrow)(1-\rho_a)] \end{aligned}$$

The cloud absorptivity α_c is assumed to be a linear function of cloud brightness, ranging from 0.0 for no clouds to 0.2 for the brightest clouds. It is also assumed that 70% of the water vapour in the atmosphere is below the cloud layer. Now all the quantities on the right hand side can be calculated except A_c, which is found from satellite measurements of R_o. The downward global solar radiation flux density at the surface is then given by

$$G_s = G_o(1-\rho_b)(1-\alpha_1\downarrow)(1-A_c)(1-\alpha_c)(1-\alpha_2\downarrow).$$

Tests on the model showed that it consistently overestimated G_s for thick extensive clouds and low sun angles, probably due to shadowing effects. An empirical adjustment is therefore made in the model to correct this error.

In order to decide whether the equations for the clear or the cloudy atmosphere should be used at each data point, the measured brightness is compared with the brightness of a stored cloud-free reference image for the same time of day. The clear atmosphere equations are used if the actual brightness is sufficiently close to the minimum brightness recorded in the reference image; otherwise the equations for the cloudy atmosphere are used.

The model has been used to produce hourly and daily insolation totals within 9% of pyranometer measurements on a much finer scale than is available from the surface pyranometer network. Monthly insolation maps over large geographical areas have also been produced at a resolution of approximately 12 km.[10]

WORK IN EUROPE

Möser and Raschke have developed an operational method of determining fields of insolation and cloudiness using image data from METEOSAT.[11] The model used resembles that of Gautier in determining the insolation with the help of satellite data and calculations of the radiative transfer processes taking place in the atmosphere instead of relying on empirical correlations with pyranometer measurements. However, the method has been verified by comparison with data from a network of pyranometers in Germany. The comparison shows a root mean square discrepancy 11% of the clear sky insolation at noon, which reduces to 4% when the results are averaged over 30-day periods.

The theoretical basis of this model is as follows: Under cloudless conditions G_s has its maximum value $G_s(\max)$, while R_o has its minimum value $R_o(\min)$. These extreme values are known functions of the solar zenith angle ζ. Also, above a continuous optically thick cloud layer R_o reaches a maximum value $R_o(\max)$, which is a function of ζ and the height of the layer, while G_s is approximately zero. Normalized dimensionless variables G_n and R_n corresponding to G_s and R_o are now defined by the equations

$$G_n = G_s/G_s(\max),$$

$$R_n = (R_o - R_o(\min))/(R_o(\max) - R_o(\min)).$$

These dimensionless variables are dependent mainly on the optical depth of the cloud layer, and are nearly independent of ζ and the height of the layer. The fraction R_n, which serves as an index of cloudiness, can be measured using uncalibrated satellite data, provided that the radiometer measurements are proportional to R_o, and $R_o(\max)$ and $R_o(\min)$ are known.

In order to use the model, six maps of $R_o(\min)$ are derived from satellite data at two-hour intervals for periods of 15-30 days with the data normalized by the factor $1/\cos\zeta$, and with corrections applied when no cloud-free conditions occur. The functional relationships connecting $R_o(\max)$ with ζ and cloud height, and G_n with R_n and ζ, have been calculated theoretically for several model atmospheres, but adjustments to them have been made by statistical analysis of satellite data using cloud heights found from satellite measurements in the infra-red channel.

Another group headed by Monget[12] has developed a system similar to that of Möser and Raschke. The main difference is that, instead of calculating the ratio $G_s/G_s(\max)$ theoretically, Monget uses comparisons between the index of cloudiness R_n measured by the satellite and G_s measured on the ground to determine the parameters a and b in the linear regression equation

$$G_s/G_o = a + bR_n.$$

Tests have shown that the parameters a and b are stable over Europe. When they were used to estimate G_s from R_n using sixty-three images during April 1982, the correlation coefficient between the estimated values of G_s and the values measured at eighty ground stations was 0.89, and the standard error of the estimate was 367 kJ/m^2 per hour.

The system is now producing an insolation climatology for Europe and northwest Africa. Three low resolution visible channel images (for 9 h, 12 h and 15 h) are recorded automatically each day. There are three steps in the processing of each image:

1) Navigation to determine the exact correspondence between points on the image and locations on the ground.
2) Spatial filtering to average out random fluctuations in the data.
3) Calculation of the index of cloudiness R_n.

Monthly insolation maps are then calculated from sets of these processed images.

Fig. 7 Surface albedos of Europe in March.

Fig. 7 shows as an example a map of ground albedos needed for the calculation of R_n in March.[13] The sea has a low albedo and appears dark in the image. The albedo of the land varies, being relatively high over the sandy deserts of north Africa and over the snow-covered Alps. The high albedo of the British Isles is due to the scarcity of cloud-free days during the period used to prepare the image. An example of a monthly insolation map is shown in Fig. 8, which is for April 1983.[13] Insolation is high over north Africa, Spain and most of the sea areas, and low in northern and central Europe, especially over the mountains.

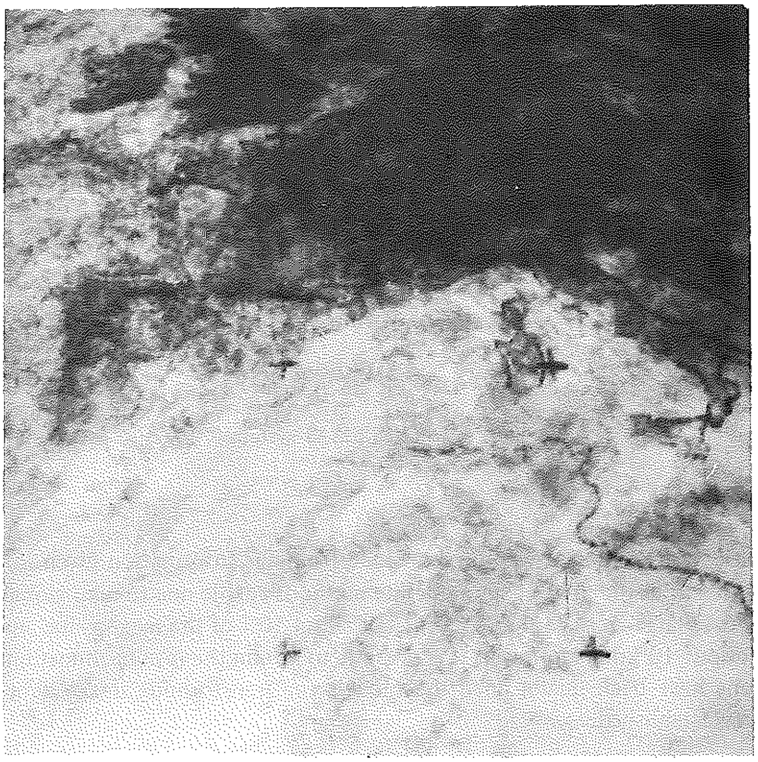

Fig. 8 Insolation over Europe in April 1983.

GROUND RECEIVING STATIONS

Geostationary meteorological satellites transmit their primary data to the ground in a high resolution digital format. The equipment required to receive and process these data is expensive. For many purposes the weather facsimile format (WEFAX) with only a selection of the original data in analog form and reduced radiometric and geometric resolution is sufficient. Receiving stations for WEFAX transmissions are much simpler, and a microcomputer is all that is necessary for station control and image processing.

In one commercial system manufactured in Germany[14] the WEFAX signal, received by a fixed dish antenna of diameter 1.2-2 m directed towards the satellite is converted to digital form, processed and transmitted to a facsimile recorder or to a video display. The picture can also be stored on magnetic tape. The system can be programmed in advance to receive selected WEFAX transmissions automatically. The operator can change the brightness and contrast of the picture to suit varying conditions. It is also possible to store eight pictures and show them in time lapse to visualize cloud movements.

A schematic diagram of the WEFAX station HELIOSAT developed in France for solar climatology is shown in Fig. 9.[12] The processing of the image data to produce insolation maps is done on the microcomputer.

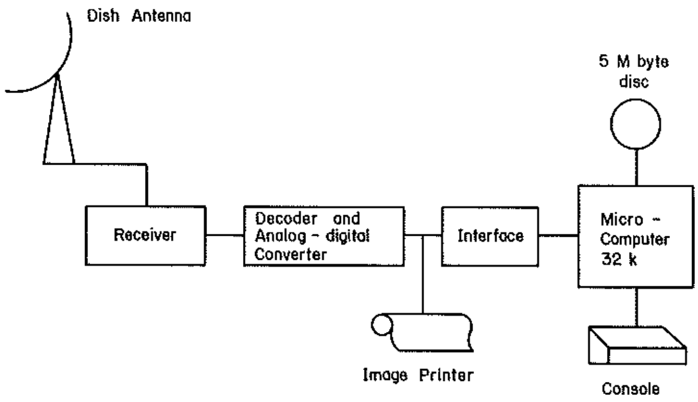

Fig. 9 The HELIOSAT system.

APPLICATIONS

As a conservative estimate we may conclude from the information given in this article that in the state of the art at the present time satellite methods enable one to map global solar radiation at the surface over large areas with an accuracy of about 10% of the mean value, and with a spatial resolution of about 10 km. Moreover, it is possible to obtain the results almost immediately after the observations have been made, once the models for transforming image data into insolation values have been established.

The exploitation of this capability will solve a number of problems hitherto associated with the collection of solar radiation data. These problems include the general lack of geographically dense networks of solar radiation measurements, the costs of operating those networks that do exist and the delays in bringing the data to central places for analysis. With the new satellite systems it will be possible to produce and archive detailed solar radiation maps daily. It will then be possible to develop and publish climatological summaries giving the statistical characteristics of the archived data in space and time in forms adapted to the needs of various users. Data covering a period of at least five years will be required for the initial stages of such a project. Discussions on the implications of this capability have been summarized by Bahm.[15]

The results will be useful in a variety of important applications. In meteorology and climatology good solar radiation data bases will improve meteorological models and our knowledge of the energetics of the atmosphere. Studies of the mesoscale variations of solar radiation over distances of the order 10-100 km, and of the relationships between solar radiation and synoptic-scale weather patterns of the order of 1000 km across persisting several days, will also become active areas of research. This will open up the possibility of issuing solar radiation forecasts, which could become important in modern agricultural and power generating operations.

In agriculture solar radiation is used in models of crop growth and evapotranspiration, and for determining irrigation needs. In marine biology a knowledge of insolation over the sea will contribute to our understanding of the growth of plankton and fish.

Finally, as solar technology matures, detailed descriptions of the solar energy resource obtained with the help of satellites will help engineers to optimize the use of water-heating and photovoltaic appliances, and (in the future) to select the best sites for solar power generating systems.

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REFERENCES

1. *NOAA Satellite Programs Briefing* (January 1984), U.S. Department of Commerce.
2. *An Overview on the Utilization of the Japanese Geostationary Meteorological Satellite* (1982), Japan Meteorological Satellite Center, Tokyo.
3. *INSAT – The Indian National Satellite System* (1984), Government of India INSAT Coordination Committee, Department of Space, Bangalore.
4. See: Raphael, C. (1983), *Models for Estimating Solar Irradiance at the Earth's Surface from Satellite Data: An Initial Assessment,* CCC Report No. 83-1, Atmospheric Environment Service, Ontario. Unpublished Manuscript.
5. Nunez, M. (1983), Use of satellite data in regional mapping of solar radiation, *Solar World Congress Perth,* Szokology, S.V. (Editor), ISES.
6. Hay, J.E. (1981), The mesoscale distribution of solar radiation at the earth's surface and the ability of satellites to resolve it, *Satellites and Forecasting of Solar Radiation,* Bahm, R.J., (Editor), 76-85. American Section ISES, NOAA, SERI.
7. Tarpley, J.D. (1979), Estimating incident solar radiation at the surface from geostationary satellite data, *J. Appl. Meteorol.* 18, 1172-1181.
8. Tarpley, J.D. (1981), Satellite-derived insolation for agriculture: an update on the NESS program, *Satellites and Forecasting of Solar Radiation,* Bahm, R.J. (Editor), 106-107. American Section ISES, NOAA, SERI.
9. Gautier, C., G. Diak, and S. Masse (1980), A simple physical model to estimate incident solar radiation at the surface from GOES satellite data, *J. Appl. Meteorol.* 19, 1005-1012.
10. Diak, G.R., C. Gautier, and S. Masse (1982), An operational system for mapping insolation from GOES Satellite data, *Solar Energy* 18, 371-376.
11. Möser, W. and E. Raschke (1983), Mapping of global radiation and of cloudiness from METEOSAT image data – Theory and ground truth comparisons, *Meteorol. Rdsch.* 36, 33-41.
12. Monget, J.M. (1984), Private communication.
13. Monget, J.M. (1984), Global solar radiation mapping from satellite – A European research programme, *Colloque Météorologie at Energie Renouvelable,* ASME/CNRS/CEE/Météorologie Nationale Plan Construction, Sophia Antipolis, 13-16 March, 1984.
14. Popp, A. (1983), APT/WEFAX station for weather picture reception. *Dournier Post* 1/83, 43-45, Munich.
15. Bahm, R.J. (1981), Summary of the satellite forecasting workshop, *Satellites and Forecasting of Solar Radiation,* 138-142, American Section ISES, NOAA, SERI.