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# "Satellite Measurements of Cloud Cover for Climatological Purposes"

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# Satellite Measurements of Cloud Cover for Climatological Purposes

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## Abstract

The need of a good description of cloud cover at large scales is outlined, specially for General Circulation Models. Conventional data available from ground are shown to be insufficient for the 3D restitution of the required parameters. Satellite data provide a better coverage, but require specific algorithms to infer useful cloud quantities from radiance images. Recent developments in cloud retrieval techniques are presented, as well as the principles of the International Satellite Cloud Climatology Program algorithm. The limitations of these techniques are shown, but the usefulness of the ISCCP results as they stand is also outlined. Finally, the need of further developments of algorithms, specific validation experiments and new instruments is stressed out.

## 1) Introduction

During the last years, there has been an increased demand for better cloud amount and cloud properties descriptions, leading to the concept of the International Satellite Cloud Climatology Program *(Schiffer and Rossow, 1983)*. As it stands out from the name of this experiment, the climatic problems are mostly at the origin of that demand. Indeed, even if a good description and parameterization of different cloud types is of great importance in weather prediction models, it is still more crucial in climate models, where cloud cover and properties interact in each climatic process, by means of two major mechanisms :

1°) radiative interactions, i.e. effects of clouds on longwave and shortwave radiations and on radiative budget at different levels, but also effect of radiation on clouds,

2°) water vapor cycle, including water transport, relation of clouds to precipitations, and release of latent heat inside clouds.

Then, the effect of clouds has to be taken into account in all the climatic simulations, f.e. simulations of the effect of doubling CO2 (*Sommerville and Remer, 1984*), of changes in sea surface temperatures (*Fennessy et al., 1985*), of changes in the land surface properties (*Laval and Picon, 1986*). That can be done only if one is able to simulate properly all the cloud types, with correct radiative and hydrologic properties : relectivities, transmissivities and emissivities in shortwaves and longwaves domains, temperature and height of the cloud top, of the cloud base, liquid water content... The first use of a good cloud data base will then be to validate cloud parameterizations on individual short term simulations. But, even if the parameterizations are improved at this time scale, there will still be necessary to validate the cloud distribution produced on larger time scales (f.e. the month or the season).

In this paper, we review the main solutions which have been proposed for cloud cover and cloud parameters determination at large scales, including conventional cloud climatology, satellite algorithms and ISCCP.

## 2) Cloud climatology from conventional data

It is possible do describe the cloud climatology from the conventional observational data of synoptic stations or ship reports. Parameters like fractional cloud coverage in oktas, cloud type, cloud base height, are indeed estimated by observers all around the world. Despite the uncertainties due to human errors and the disparity of the data sets produced by different countries or different stations, it has been possible to built cloud climatologies from these data (*London*, *1957*; *Van Loon*, *1972*; *Berlyand*, *1975*). The most famous one is the *London* climatology, giving mean latitudinal cloud distributions which were intensively used in most of the climate models in the next decades. This climatology has been updated recently by *Hahn et al.* (*1982*, *1984*) and by *Warren et al.* (*1986*). It gives, on a monthly or seasonal basis computed from a decade of observations, basic quantities like the total cloud cover, cloud types amounts and frequency of occurence, but also quantities more specific of the ground observations, like cloud base height, or derived parameters like the conditional probability of occurence of such cloud type when another one is present, zonal averages, mean diurnal cycles, mean interannual variations. An example of the results given in *Warren et al* (*1986*) for zonal averages of the different cloud types over land in summer, are given in Fig.1.

At the present time, this set of results still constitute the more complete cloud climatology on a sufficiently long period of time. Moreover, it gives indications, like the cloud base height, that are still impossible to obtain from satellite data. However, it suffers from some defficiencies due to the nature of the basic data :

- space and time inhomogeneity of the initial data set : the most striking problem is over oceans, where the data are very sparse, but there are also problems over land, where the density of synoptic stations is highly variable. Also, nighttime data are much more dubious than daytime ones. All these inhomogeneities lead to the fact that it is difficult to produce representative cloud distributions for time scales smaller than the 10 years monthly averages given in *Warren et al*. In particular, it is impossible to get cloud coverages for a given day over the whole globe, or even cloudinesses for 10 days or monthly periods. That is a severe drawback, as this kind of analyses are highly demanded for the validation of General Circulation Models at synoptic and climatic scales.

- no description of the high clouds when they are hidden by lower layers, no information on the cloud tops. Clouds are seen from the bottom, whereas they will be see from the top by satellites. That may seem an identical drawback for satellite and ground observations; however, one can argue that the knowledge of the cloud top is more useful from the climatic point of view, as it governs the radiative budget at the top of the atmosphere, then the radiative budget of the planet. On another hand, the knowledge of the cloud base is necessary to infer the radiative budget at the surface level.

- no quantitative values for cloud optical properties : that results from the observational character of the data, which are not linked to radiative measurements. In this kind of climatology, one has to assume average properties for the different types of clouds (optical thicknesses, emissivities, cloud top temperature...). The same is true for the liquid water content of the clouds.

Other more quantitative parameters more or less directly related to the cloudiness are measured from the ground, like insolation duration or radiation at ground level, or even, in the water cycle domain, precipitations. But these measurements are either very scarce, or difficult to interpret in terms of cloud properties. It has to be noted however that they can be used as ground validation measurements for satellite derived parameters.

### 3) Satellite cloud climatologies

The potentiality of satellites for the study of cloud cover became evident as soon as the first meteorological satellites were up : Even simple visible images at relatively low resolution were able to describe the cloud systems, in an homogeneous way over the whole planet. The image character of the data, together with the experience of synoptic systems of meteorologists, allowed an identification of the cloud types according to their structure and their relations with well known meteorological phenomena. That visual analysis led to the definition of a qualitative cloud classification called "nephanalysis", related to the previous definition of clouds as seen from the ground.

At the same time, the first satellite cloud climatologies were built from series of VIS pictures taken by low orbiting satellites *(Sadler, 1969; Miller and Feddes, 1971; Sadler et al., 1976; Avaste et al., 1979)*. But these climatologies, mainly produced by visual and optical processes, remained spatially partial and gave only the total cloud cover. Also, as they were obtained from low orbiting satellites, they could not describe the cloud cover diurnal cycle.

On a parallel way, numerical objective methods began to be developed, applying cloud feature extraction techniques on visible images *(Rosenfeld et al., 1965)*. During this period, the satellites became more and more sophisticated, with new instruments providing more and more information in different channels. That led to the development of quantitative cloud algorithms based on the assumption that different cloud types correspond to different spectral signatures, specially in the Visible-Infrared space *(Barnes and Chang, 1968; Lo and Johnson, 1971)*. Among these methods, simple threshold cloud detection techniques working on individual pixels were largely developed, as also statistical techniques working on image segments. Some other introduced information on the spatial variability and texture of the radiance images *(Booth, 1973; Parikh, 1977)*. Interesting ways to reproduce objectively the nephanalyst methods have been prospected, like in *Rochard and Brard (1978, 1980)*.

Cloud cover techniques which have been used as well for operational purposes than for building partial cloud climatologies were mostly bi-spectral methods: for example, the European Space Operation Center in Darmstadt developed a statistical technique for Meteosat *(ESA, 1980)*, as the "Centre de Météorologie Spatiale" from Lannion (France) for AVHRR pictures *(Phulpin et al, 1982)*. *Reynolds and Vonder Haar (1978)* developed a bi-spectral technique to produce climatology from NOAA satellites; *Minnis and Harrison (1984)* studied the diurnal variations of cloudiness using an adaptative threshold method on GOES images of 1978; *Rossow et al. (1987)* provided global information on cloud parameters extracted from NOAA data for some monthes of 1977.

Interesting statistics on the global cloud cover were deduced using completely different satellites and methods, for example by *Stowe et al. (1984)*, using Nimbus 7 data, or by *Woodbury and Mc Cormic (1986)*, infering high clouds occurence from limb scanning on Sage 2. An example of their results on cirrus clouds is given in Fig. 2. Some cloud fields properties can also be deduced from satellite sounders data like in *Susskind et al., 1987*.

Another source of global cloud analysis is the so called "3 Dimensional / Real Time Nephanalysis" of the US Air Force, which is using satellite data together with surface or aircraft measurements all around the world *(Fye, 1978; d'Entremont et al., 1982; Mc Guffie, 1987)*. This analysis has the advantage to be operational since several years, but has to be used carefully, as the cloud cover inferred comes from different kinds of measurements depending on space and time.

Finally, one can also mention specific cloud studies intended to estimate precipitations over tropical areas, based on the frequency of occurence of cold cloud tops, like the analysis of the *Climate Diagnostics Bulletin* of NOAA, or the one of *"la Veille Climatique Satellitaire"* produced in Lannion.

This brief review, which does not pretend to be complete, gives an idea of the dispersion of the efforts for retrieving cloud cover from satellite data up to the early 80's. Despite of these efforts, no cloud climatology satisfactory for the needs of weather and/or climate models has been produced. Two major problems were responsible from this result :

- the difficulty to handle a huge amount of data from various satellites, with different formats, navigations and calibrations,
- the lack of agreement about a particular cloud algorithm, as validations were not possible and intercomparisons of methods had not been undertaken systematically.

These considerations led to the concept of an international program able to solve both these problems : the International Satellite Cloud Climatology Program (ISCCP).

## 4) ISCCP related research

The aim of the ISCCP *(Schiffer and Rossow, 1983)* is to produce a global cloud climatology from all the available operational meteorological satellites, polar orbiting and geostationary, over a period of 5 years (which may be extended if estimated necessary), beginning in July 1983. The data specifications for this program are summarized in table 1. To achieve these objectives, it was at first necessary to answer the two questions raised at the end of § 3: standardisation and reduction of the data coming from the different satellites, and definition of a commonly accepted cloud retrieval algorithm. The first point was a question of "data management" at the international scale for the collection, navigation, intercalibration of all the satellite data, from which a reduced radiance data set had to be built (the "B3" data set, *Rossow et al., 1985a*), the second one required intercomparison experiments between some representative algorithms. This study was performed in 1982-1985, and its results were published in *Rossow et al. (1985b)*.

To summarize, the intercomparisons were done on a test data set, composed of very different cloudy scenes taken in different areas of GOES VIS and IR images. All the methods in presence consisted of two steps. The first step, cloud detection, determines the percentage of cloud cover. The second step, analysis, determines the properties of the clouds found in the first step. These methods can be separated into two groups : 1) threshold methods where the cloud detection and analysis are performed on individual pixels using VIS and IR radiances and physical thresholding; and 2) statistical methods where these two steps are not performed on each pixel but globally on image segments using the statistical properties of the VIS and IR radiances. Table 2 shows the different algorithms which were used, whith their main characteristics :

| | |
|---|---|
| VIS or IR thresholds : | applied on full resolution images (VIS-1 km, IR-8 km), using composite "clear sky" images; |
| Radiative thresholds : | use of a radiative transfer model and composite images to determine the thresholds on the VIS and IR images *(Rossow et al.)* |
| Hybrid thresholds : | using VIS and IR images, surface and atmosphere model with statistical determination of the thresholds *(Minnis and Harrisson)* |
| Assymetric Gaussian : | fitting VIS and IR histogram shapes with Gaussian curves *(Simmer, Ruprecht and Raschke)* |
| Dynamic clusters : | clustering on VIS-IR bi-dimensional histograms. *(Seze and Desbois)* |

**Table 2 : cloud algorithms intercompared for ISCCP**

The intercomparison was done on the total cloud covers produced by the different algorithms and a good general agreement was found for most of the cases, but discrepancies appeared in some circumstances, with particular types of cloud covers :

- semi-transparent clouds, specifically cirrus clouds,
- small clouds producing partial coverage of the pixels, specifically cumulus,
- clouds over ice or snow surfaces, specifically polar clouds.

Other problems were noted for the detection of dust clouds, for regions with persistent cloudiness or for the identification of clouds in multiple layers situations.

Attempts to solve the problems of thin clouds and partial coverage were presented during the algorithm definition stage of the ISCCP. One approach, already suggested by *Platt (1983)*, was presented by *Arking and Childs (1985)*. It consists in the radiative interpretation of the VIS-IR histogram shapes in terms of optical thickness and partial coverage variations, once the homogeneous cloud classes have been recognized by some kind of clustering (Fig. 3). Another completely different suggestion was first done by *Coakley and Bretherton (1982)*, using plots of the IR local variance against the IR radiance (Fig. 4) ; in that technique, originally developped for the study of stratocumulus, the spatial inhomogeneity of the images is related to the partial coverage of the pixels.

These two techniques were introduced in the last stages of the ISCCP algorithm intercomparisons. However, it was not possible from these intercomparisons to found a method working better than the other ones for every kind of situation, but the advantadges and defficiencies of each experimental algorithm were pointed out in order to define the operational ISCCP algorithm. The basic method chosen at first was the radiative transfer threshold method, which was the more complete one at the time of the intercomparison. Then, it was largely implemented by contributions coming from other algorithms, and by new developments. Figure 5 , from *Schiffer and Rossow, 1985*, shows the scheme of the operational algorithm.

This algorithm is applied to the so called "B3 data" which are constituted from a reduction of the original satellite data set, sampled to 30 km and 3 hours for the geostationaries. The results constitute the "C level analysis", giving parameters required in the ISCCP specifications (fractional cloud cover, cloud top temperature, pressure, cloud optical thickness), but also additional information, as shown on table 3. Examples of preliminary results are given in Fig 6, for the Meteosat area. The operational production of these analyses has begun in 1987, for all the satellite data available since july 1983. It has to be noted that these results are provided with quality flags, indicating the degree of confidence which can be attributed to each one, depending on how the algorithm reacted at each step.

However, the progress of the definition of the ISCCP algorithm and products did not stop the research towards better satellite cloud discrimination. On the contrary, the evidence of many remaining problems for particular situations and the set up of validation experiments encouraged new developments, which are summarized in the next section of this paper.

## 5) Recent developments in satellite cloud algorithms

As it is outlined in section 4, some new ideas were pointed out to improve the methods during the ISCCP algorithm intercomparisons : the radiative interpretation of the VIS-IR bidimensional histograms, for example, gave rise to new developments in order to introduce it in automatized procedures *(Happ et al.,1983)*.

In the same way, the use of spatial variances first suggested by *Coakley and Bretherton (1982)* was developed not only in the team of the authors *(Coakley and Baldwind, 1984)*, but introduced in different ways in other algorithms : in some of them, spatial variances are used as an auxiliary test for cloud detection, *(Saunders, 1985, 1986; WCRP, 1987)*, in other ones, they are considered as a supplementary parameter processed in the same way than the radiances *(Seze and Desbois, 1987)*. In this last paper, IR and VIS local standard deviation images are used, together with the original images, to built multidimensional histograms on which a clustering technique is applied.

ISCCP has also shown that histogramming techniques were often producing scene dependent classes, and then cannot be used easily for climatology. It has been proposed in *Seze and Desbois (1987)*, to increase the climatic representativity of these classifications by working on time cumulated histograms, producing distributions characteristic of regions and time periods. The possibility of characterization of climatic cloud regions by this way has been emphasized in *Seze and Rossow (1986)*.

Some progress has also occured in the use of the spatial structure of the images, which is a fundamental element for the visual recognition of the clouds : indeed, mathematical morphology techniques *(Serra, 1982)* allow now to obtain segmentation of the images by some kind of contouring; then, the segments can be classified both from their radiances information and from expert rules like the ones used by nephanalysts (f.e. vicinity of other cloud systems). This kind of techniques has been experienced in the thesis of *F. Kermel (1987)*. Other techniques of pattern recognition at larger scales *(Burfeind and Weinman, 1986)* have also been experienced. Another approach has been investigated by *Garand and Weinman, 1986*: characterization of cloud textures for different cloud systems using a Markov model of texture (technique developed for image synthesis).

The use of more spectral channels than 1 VIS and 1 thermal IR has also been developed, especially with the AVHRR imager *(Saunders, 1986; Phulpin, 1987)* : the thermal split window can help to deduce cirrus properties *(Inoue, 1987)*, whereas the 3.7 $\mu$m channel allows to separate ice clouds from water clouds *(Arking and Childs, 1985)*. Other specific uses of this last channel have also been proposed, like the detection of warm low clouds during the nighttime *(d'Entremont, 1986)*.

In the same time, intercomparisons of methods have been pursued *(Ruprecht, 1985; Coakley, 1987)*, and the effect of threshold choice has been further studied *(Chou et al., 1986)*. The effect of the satellite spatial resolution has also been studied, as well in the case where original images have been degraded (as in ISCCP) *(Shih et al., 1986; Seze and Rossow, 1986)*, as by comparisons with data of higher resolution radiometers *(Baldwind et al., 1986)*. Related to that topic, models of scale dependence of cloud spatial variability have been proposed *(Gabriel et al., 1986)*.

Comparisons with cloud data from meteorological stations have also been pursued, but they cannot be considered as validations due to the very different observation conditions *(Henderson-Sellers et al., 1987)*.

The only way to validate properly sophisticated cloud algorithms is then to design specific in-situ experiments with adapted instrumentation : surface and aircraft radiometry, lidars,...; different satellite instruments can also be associated to these validation experiments: microwave radiometers for liquid water content, high resolution VIS and IR radiometers (Landsat, Spot) for partial coverage problems. Such experiments have been designed for specific cloud studies, f.e. the First ISCCP Regional Experiment (FIRE: *Cox et al., 1987)* on stratocumulus and cirrus clouds in the U.S., the International Cirrus Experiment (ICE) in Europe, devoted to cirrus, the Western North Pacific cloud radiation experiment on stratocumulus in Japan *(WCRP, 1986)*.

## 4) Conclusion

Despite all the interrogations which remain regarding precise cloud properties description from satellites, the ISCCP experiment furnishes for the first time an homogeneous climatological data set on the cloud cover, using all the available satellites. This data set has been elaborated very carefully and constitutes the best that can be done at large scales at the present time. It can be used either at the level "B" of reduced and intercalibrated radiances (see for example monthly averages of IR radiances on Fig 3), or at the level "C" of analysed cloud parameters. The test data set which has been distributed to some potential users has already been used for model comparisons *(Le Treut, 1987; Morcrette, 1987)*. No doubt that the complete data set will be very useful to modelists.

Nevertheless, it cannot be said that ISCCP will answer all the questions about cloud/radiation interactions (cloud fraction, size statistics, cloud emissivity, cloud base level) or role of cloud in the water cycle (liquid water content, precipitations).

It cannot be said neither at the present time that satellite cloud algorithms have reached their limits : many new ideas have been suggested in the last years, but they urgently need validations. Validation experiments, like those which are already planned (FIRE, ICE...), have to be conducted for specific clouds (stratocumulus, cirrus, cumulus, deep convection...) in specific situations (polar clouds, tropical clouds...).

The parameters to validate at first in these experiments are the more physically related to the satellite radiance measurement (cloud optical thickness, cloud top temperature, emissivity, fractionnal coverage), but one can hope also to find more or less empirical relationships between these primary parameters and/or cloud classes determined by the satellite and other cloud properties (liquid water content, most probable cloud base height, precipitations...). For these last problems, it will be also useful to combinate ISCCP results with ground statistics. More generally, it can be said that combinations of satellite and surface data are needed at all scales.

For the large scales, however, surface and atmospheric measurements will often be too scarce, and the only solution will be to use other satellite instruments to complement the imagers, even if their space-time resolution is lower : passive microwaves, lidars and radars seem to be the most promising instruments for the improvement of cloud properties determination from space in the near future.

*REFERENCES*

Arking, A., and J.D. Childs, 1985 : Retrieval of cloud cover parameters from multispectral satellite measurements. *J. Climate Appl. Meteor.*, 24, *322-333*.

Avaste, O.A., G.G. Campbell, S.K. Cox, D. DeMasters, O.V. Karner, K.S. Shifrin, E.A. Smith, E.J. Steiner, T.H. Vonder Haar, 1979 : On the estimation of cloud-amount distribution above the world oceans. *Atmos. Sci. Paper N°309, Colorado State Univ., Ft Collins*.

Barnes, J.C., and D. Chang, 1968 : Accurate cloud cover determinations and its effects on albedo computations. *Final Report, NAS6-10478, Concord, Mass., Allied Research Associates, Inc., 82 pp.*

Berlyand, *T.G.*, 1975 : Cloud regimes over the Earth. *Trudy, Physical Climatology, 338, Main Geophysical Observatory, Leningrad, U.S.S.R.*

Booth, A.L., 1973 : Objective cloud type classification using visual and infrared satellite data. *Univ. of Md. Technical Note BN 768.*

Burfeind, C., and J. Weinman, 1986 : Classification of satellite images of extra-tropical cyclones over the ocean by means of computerized pattern analysis. *Second conference on satellite meteorology, remote sensing and applications. Williamsburg, Va., May 1986.*

Chou, M.D., J. Childs, and P. Dorian, 1986 : Cloud cover estimation using bispectral satellite measurements. *J. Climate Appl. Meteor.*, **25**, *1280-1292.*

Coakley, J.A., and F.P. Bretherton, 1982 : Cloud cover from high-resolution scanner data : Detecting and allowing for partially filled fields of view. *J. Geophys. Res.*, 87, *4917-4932.*

Coakley, J.A., and D.G. Baldwin, 1984 : Towards the objective analysis of clouds from satellite imagery data. *J. Climate. Appl. Meteor.*, 23, *1065-1099.*

Coakley, J.A., 1987 : A dynamic threshold method for obtaining cloud cover from satellite imagery data. *J. Geophys. Res.*, **92**, *3985-3990.*

Cox, S., D. McDougal, D. Randall, and R. Schiffer, 1987 : FIRE - The first ISCCP regional experiment. *Bull. Amer. Meteor. Soc.*, **68**, *114-118.*

Desbois, M., and G. Seze, 1984 : Use of space and time sampling to produce representative satellite cloud classifications. *Ann. Geophys.*,**2**, *599-605.*

Desbois, M., G. Seze and G. Szejwach, 1982 : Automatic classification of clouds on METEOSAT imagery : Application to high-level clouds. *J. Appl. Meteor.*, 21, *401-412.*

d'Entremont, R.P., R.S. Hawkin and J.T. Bunting, 1982 : Evaluation of automated imagery analysis algorithms for use in the three-dimensional nephanalysis model at AFGWC. *USAF Environ. Res. Pap. N°817, AFGR-TR-82-0397, 39 pp.*

d'Entremont, R.P., 1986 : Low and mid level cloud analysis using nighttime multispectral imagery. *J. Climate Appl. Meteor.*, 25, *1853-1869.*

ESA, 1980 : *METEOSAT system guide, Vol 5, Meteosat Management Dept., MDMD/MET,ESOC, Darmstadt, FRG.*

Fennessy, M.J., L. Marx, and J. Shukla, 1985 : General circulation model sensitivity to 1982-1983 equatorial Pacific sea surface temperature anomalies. *Mon. Wea. Rev.*, 113, *858-864.*

Fye, F.K., 1978 : The AFGWC Automated Cloud Analysis Model. *AFGWC TM-78-002, 97 pp., HQ Air Force Global Weather Central, Nebraska.*

Gabriel, P., S. Lovejoy, G. Austin, and D. Schertzer, 1986 : Radiative transfer in extremely variable fractal clouds. *6th Conf. on Radiative Transfer, Williamsburg, Va., May 1986.*

Garand, L., and J. Weinman, 1986 : A structural-stochastic model for the analysis or synthesis of cloud images. *J. Climate Appl. Meteor.*, 25, *1052-1068.*

Hahn, C.J., S.G. Warren, J. London, R.M. Chervin, and R. Jenne,1982 : Atlas of simultaneous occurence of different cloud types over the ocean, *NCAR technical note TN-201+STR, Natl. Cent. for Atmos. Res., Boulder, Co., 212 pp.*

Hahn, C.J., S.G. Warren, J. London, R.H. Chervin, and R. Jenne, 1984 : Atlas of simultaneous of different cloud types over land, *NCAR/TN-241+STR, 21 pp. and 188 maps, Natl. Cent. for Atmos. Res., Boulder, Co., 216 pp.*

Happ, S., G. Nacke, E. Ruprecht, and C. Simmer, 1983 : A method for correction of pixel cloudiness. *The fourth Meteosat scientific users meeting, Clermont-Ferrand, ESOC, Darmstadt, FRG.*

Henderson-Sellers, A., G. Seze, F. Drake, and M. Desbois, 1987 : Surface-observed and satellite-retrieved cloudiness compared for the 1983 ISCCP special study area in Europe. *J. Geophys. Res.*, 92, 4019-*4033.*

Inoue, T., 1987 : A cloud type classification with NOAA 7 split-window measurements. *J. Geophys. Res*, 92, *3991-4000.*

Kermel, F., 1987 : Estimation du rayonnement solaire au sol à partir de données météorologiques ou d'images satellitaires. *Thèse de Doctorat de l'Université de Paris VI, Paris 1987.*

Laval, K., and L. Picon, 1986 : Effect of a change of the surface albedo of the Sahel on climate. *J. Atmos. Sci.*, 43, *2418-2429.*

Le Treut, H., and Z.X. Li, 1987 : Using Meteosat data to validate a prognostic cloud generation scheme. *12th Assembly of the European Geophysical Society, Clouds and Climate Symposium, Strasbourg 1987.*

Lo, R.C., and D.R. Johnson, 1971 : An investigation of cloud distribution from satellite infrared radiation data. *Mon. Weath. Rev.*, 99, *9.*

London, J., 1957 : A study of the atmospheric heat balance. *AFCR-TR-57-287. New York Univ. College of Engineering, 99 pp. [NTIS PB 115626].*

McGuffie, *K., 1987* : The USAF RT Nephanalysis: A current real-time global cloud archive. *12th Assembly of the European Geophysical Society, Clouds and Climate Symposium, Strasbourg 1987.*

Miller, D.B., and R.G. Feddes, 1971 : Global Atlas of Relative Cloud Cover 1967-1970. *U.S. National Environmental Satellite Service and USAF Environmental Technical Applications Center, AD739434 - Report N°1, Washington, D.C., 237 pp.*

Minnis, P., and E.F. Harrison, 1984*a* : Diurnal variability of regional cloud and clear sky radiative parameters derived from GOES data. Part I: Analysis method. *J. Climate Appl. Meteor.*, 23, *993-1011.*

Minnis, P., and E.F. Harrison, 1984*b* : Diurnal variability of regional cloud and clear sky radiative parameters derived from GOES data. Part II : November 1978 cloud distributions. *J. Climate Appl. Meteor*, 23, *1012-1031.*

Minnis, P., and E.F. Harrison, 1987 : Cloud cover over the equatorial Eastern Pacific derived from july 1983 International Cloud Climatology Project data using a hybrid bispecral threshold method. *J. Geophys. Res.*, 92, *4051-4073.*

Morcrette, J.J., 1987 : Using ISCCP data for validating ECMWF model cloudiness. *12th Assembly of the European Geophysical Society, Clouds and Climate Symposium, Strasbourg 1987.*

Parikh, J., 1977 : A comparative study of cloud classification techniques. *Remote Sensing Environ.*, 6, *67-81.*

Parikh, J., and J.T. Ball, 1980 : Analysis of cloud type and cloud amount during GATE from SMS infrared data. *Remote Sensing Environ.*, 9, *225-245.*

Phulpin, T., M. Derrien and A. Brard, 1983 : A two-dimensional histogram procedure to analyse cloud cover from NOAA satellite high resolution data. *J. Climate Appl. Meteor.*, 22, *1332-1345.*

Phulpin, T., 1987 : Exploitation des données Esther2 pour l'évaluation de la nébulosité et de la température de surface de la mer dans les spots HIRS2. *Note de travail de l'EERM, Direction de la Météorologie Nationale, Paris.*

Platt, C.M.R., 1981 : Two dimensional histograms OF GMS-1 satellite visible albedo and infrared temperature for selected cloud systems. *CSIRO Div. Atmos. Phys., Tech. Paper N° 40, 43 pp.*

Platt, C.M.R., 1983 : On the bispectral method of cloud parameter determination from satellite VISSR data: separating broken cloud and semi-transparent cloud. *J. Climate Appl. Meteor.*, 2, *429-439.*

Reynolds, D.W., and T.H. Vonder Haar, 1977 : A bi-spectral method for cloud parameter determination. *Mon. Wea. Rev.*, 105, *446-457.*

Rochard, G., and A. Brard, 1978 : Sur quelques paramètres simples de la texture nuageuse observée par satellite. *Note technique de l'EERM, n° 408, Direction de la Météorologie Nationale, Paris.*

Rochard, G., and A. Brard, 1980 : Sur une analyse automatique simple des images d'un satellite météorologique géostationnaire. *Note technique de l'EERM n° 77 nouvelle série, Direction de la Météorologie Nationale, Paris.*

Rosenfeld, A., C. Fried, and J.N. Orton, 1965 : Automatic cloud interpretation. *Photogrammetric Engineering,* 31, *991-1002.*

Rossow, W.B., E. Kinsella, A. Wolf, and L. Garder, 1985a : International Satellite Cloud Climatolgy Project (ISCCP), Description of reduced resolution radiance data. *World Climate Research Program, July 1985.*

Rossow, W.B., F. Mosher, E. Kinsella, A. Arking, M. Desbois, E. Harrison, P. Minnis, E. Ruprecht, G. Seze, C. Simmer, and E. Smith, 1985b : ISCCP cloud algorithm intercomparison. *J. Climate Appl. Meteor.,* 24, *877-903.*

Rossow, W.B., L. Garder, E. Kinsella, A. Lacis, and C. Brest, 1987 : Global, seasonal cloud variations from satellite radiance measurements. *J. Climate Appl. Meteor. (submitted).*

Ruprecht, E., 1985 : Statistical approaches to cloud classification. *Adv. Space Res., 5, 6, 151-164*

Sadler, J.C., 1969 : Average Cloudiness in the Tropics from Satellite Observations. *Int. Indian Ocean Expedition Meteor. Monogr. N°2, East-West Center Press, Honolulu, 22 pp.*

Sadler, J.C, L. Oda, and B.J. Kilonsky, 1976 : Pacific Ocean Cloudiness from Satellite Observations. *Technical Rept. of Meteorology, University of Hawaii, 137 pp.*

Saunders, R.W., 1985 : Monthly mean cloudiness observed from Meteosat-2. *J. Climate Appl. Meteor.,* 24, *114-127.*

Saunders, R.W., 1986 : An automated scheme for the removal of cloud contamination from AVHRR radiances over Western Europe. *Int. J. Remote Sensing,* 7,

Schiffer, R.A., and W.B. Rossow, 1983 : The International Satellite Cloud Climatology Project (ISCCP): the first project of the World Climate Research Programme. *Bull. Amer. Meteor. Soc.,* 64, *779-784.*

Schiffer, R.A., and W.B. Rossow, 1985 : ISCCP Global radiance data set : a new resource for climate research. *Bull. Amer. Meteor. Soc.,* 66, 1498-1505.

Serra, J., 1982 : Image analysis and mathematical morphology. *Academic Press.*

Seze, G., and W.B. Rossow, 1986 : Time cumulated VIS and IR histograms used as descriptor of cloud cover. *XXVI COSPAR, Toulouse, July 1986. (to appear in Adv. Space Res.)*

Seze, G., and M. Desbois, 1987 : Cloud cover analysis from satellite imagery using spatial and temporal characteristics of the data. *J. Climate Appl. Meteor.*, 26, *287-303*.

Simmer, C., E. Raschke and E. Ruprecht, 1982 : A method for determination of cloud properties from two-dimensional histograms. *Ann. Meteor.*, 18, *130-132*.

Sommerville, R.C.J., and L.A. Remer, 1984 : Cloud opticall thickness feedback in the CO2 climate problem. *J. Geophys. Res.*, 89, *9668-?*

Stowe, L.L., P.P. Pellegrino, P.H. Hwang, P.K. Bhartia, T.F. Eck, C.G. Wellemeyer, S.M. Read, and C.S. Long (1985) : Use of Nimbus-7 satellite data for validation of GCM generated cloud cover. *Proceedings of the ECMWF workshop on cloud parameterization in numerical models. ECMWF-Reading. November 1984.*

Susskind, J., D. Reuter, and M.T. Chahine, 1987 : Cloud fields retrieved from analysis of HIRS2/MSU sounding data. *J. Geophys. Res.*, 92, 4035-4050.

Van Loon, H., 1972 : Cloudiness and precipitation in the southern hemisphere. *Meteorology of the Southern Hemisphere, Meteorological monographs, A.M.S.*, 13, *35, 101-111.*

Warren, S.G., C. Hahn, J. London, R. Chervin, and R. Jenne, 1986 : Global distribution of total cloud cover and cloud type amounts over land. *NCAR technical note TN-273+STR, Boulder, Co.*

WCRP (World Climate Research Programme), 1986 : Report of the fifth session of the international working group on data management for the International Satellite Cloud Climatology Project (ISCCP). *Paris, June 1986. WMO/WCP-123.*

Woodbury, G.E., and M.P. Mc Cormick, 1986 : Zonal and geographical distribution of cirrus clouds determined from SAGE data. *J. Geophys. Res.*, 91, *2775-2785*.

## Figure captions

Figure 1 : Zonal average percentage of each cloud type over land as a function of latitude for summer *(from Warren et al., 1986)*

Figure 2 : Frequency of occurence of cirrus clouds for june-july-august 1979-1981 *(from Sage results of Woodbury and Mc Cormick, 1986)*

Figure 3 : Model histogram as computed by Arking for varying optical thicknesses and partial pixel cloud coverage, from radiative transfer calculations.

Figure 4 : Plot of IR local standard deviation against local mean IR radiance, as given by *Coakley and Baldwind, 1984*.

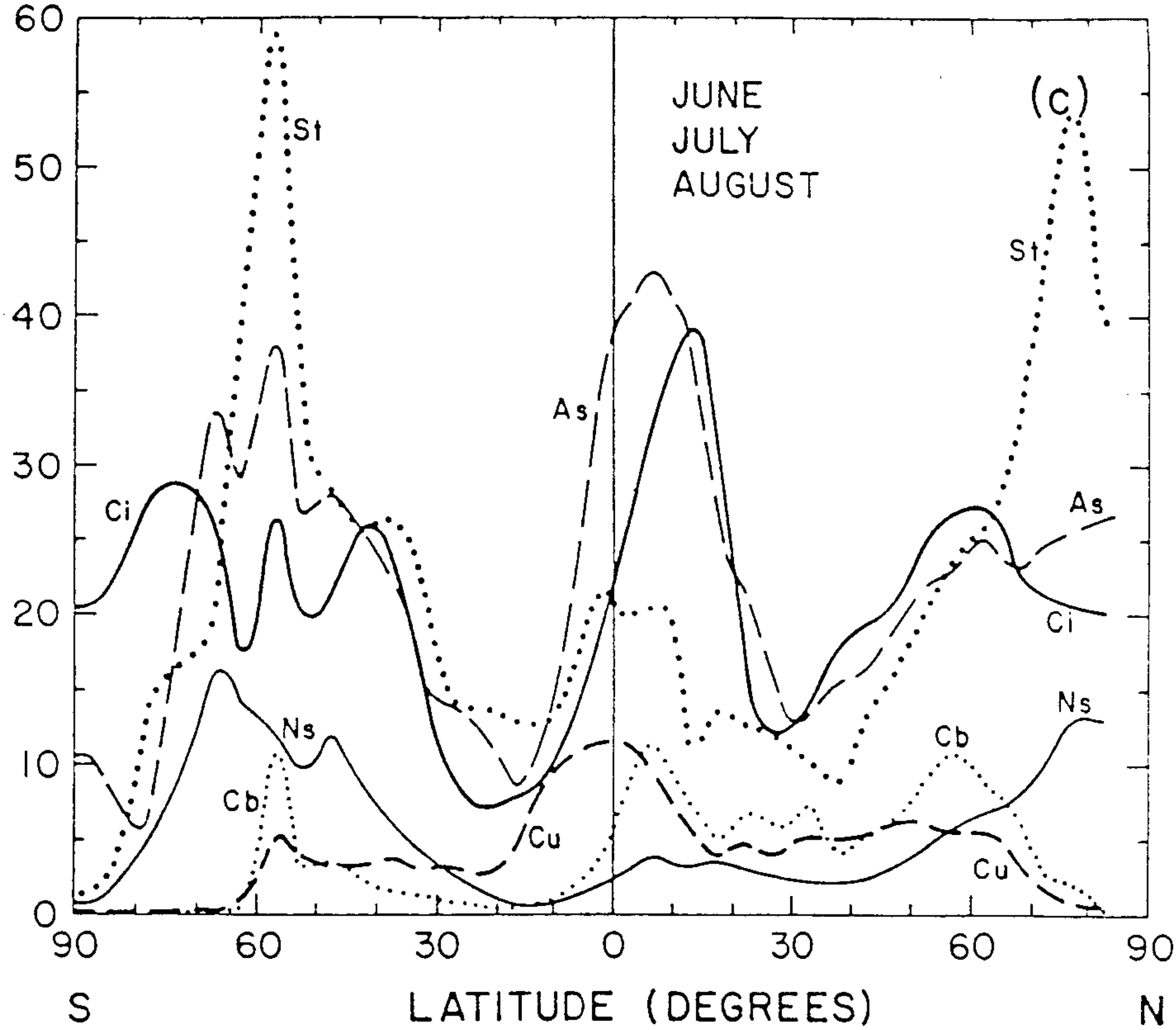
Figure 5 : Schematic of the ISCCP operational cloud algorithm.

Figure 6 : Example of preliminary ISCCP result: mean cloud top temperatures for july 1983. The limits between the grey levels presented here correspond to -20, 0, 10 and 20°C isotherms.

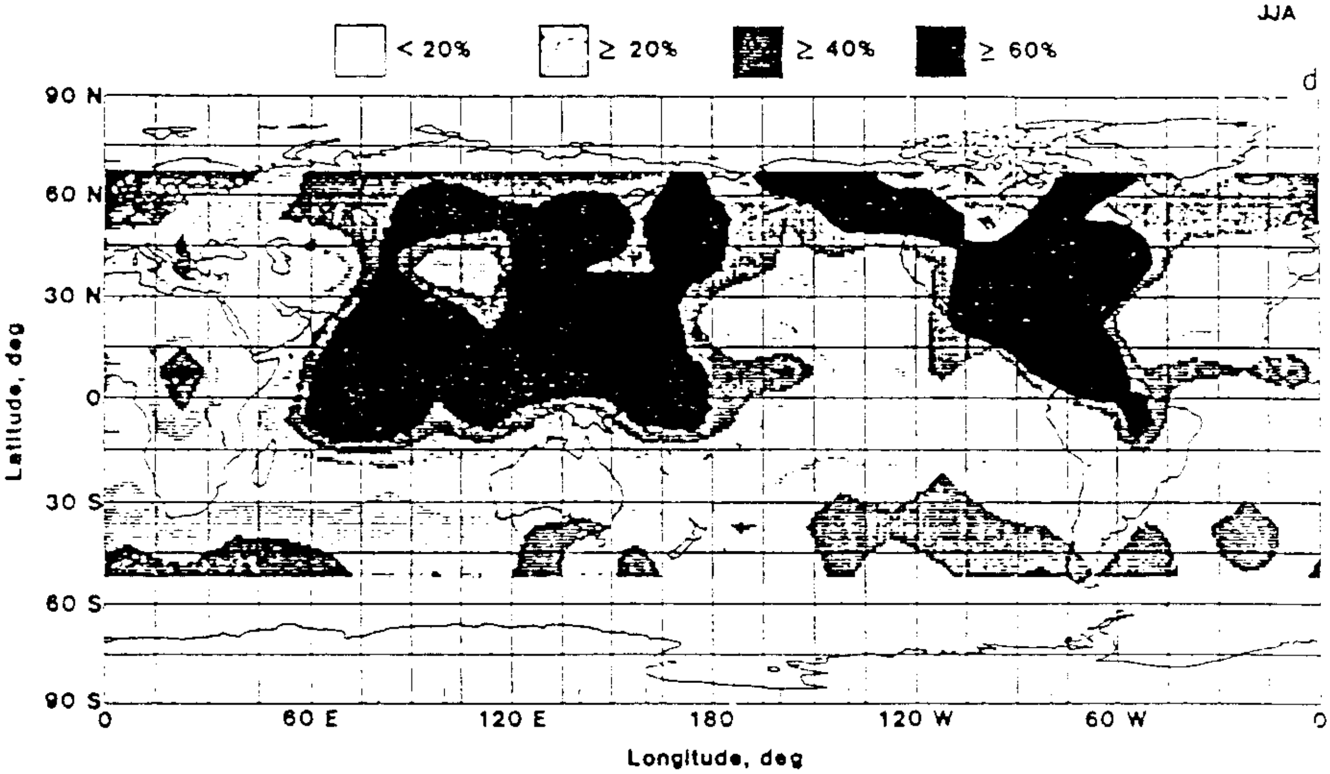
Table 1 : Data specification for ISCCP. *(from Schiffer and Rossow, 1985)*

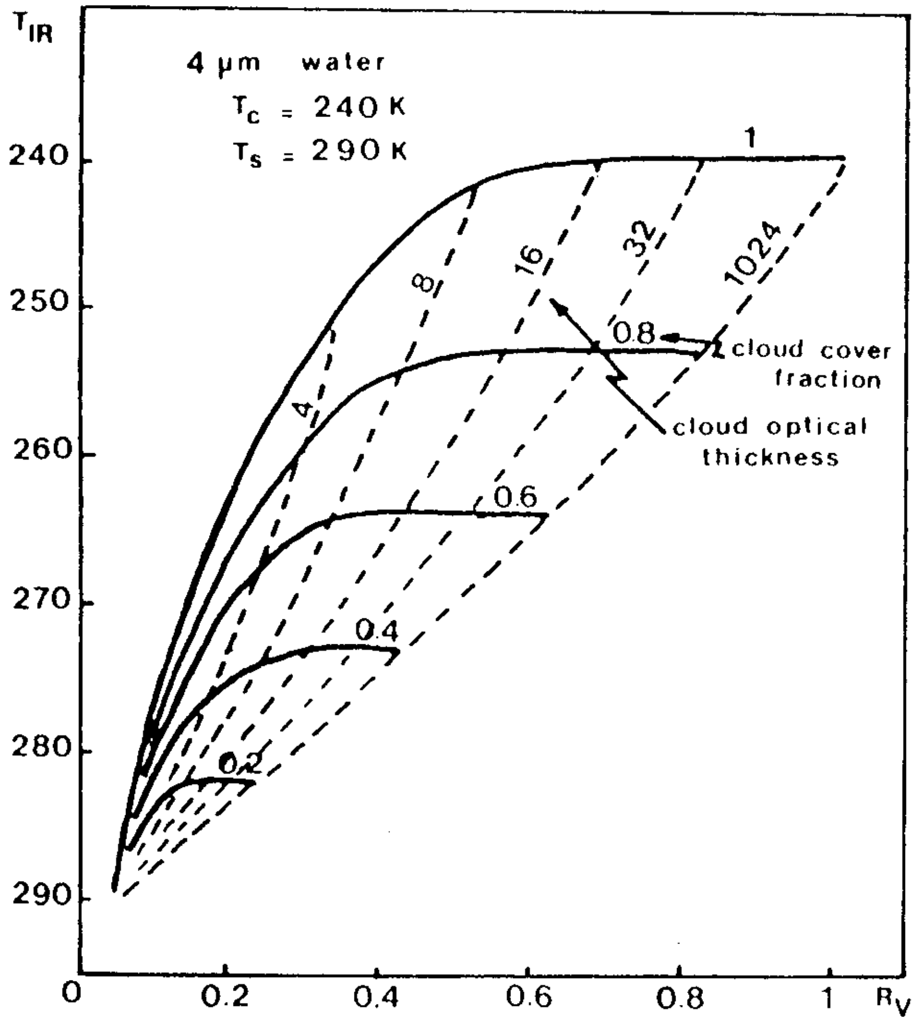
Table 2 : Cloud algorithms intercompared for ISCCP

Table 3 : revised content of ISCCP cloud data tapes *(from WCRP, 1986)*

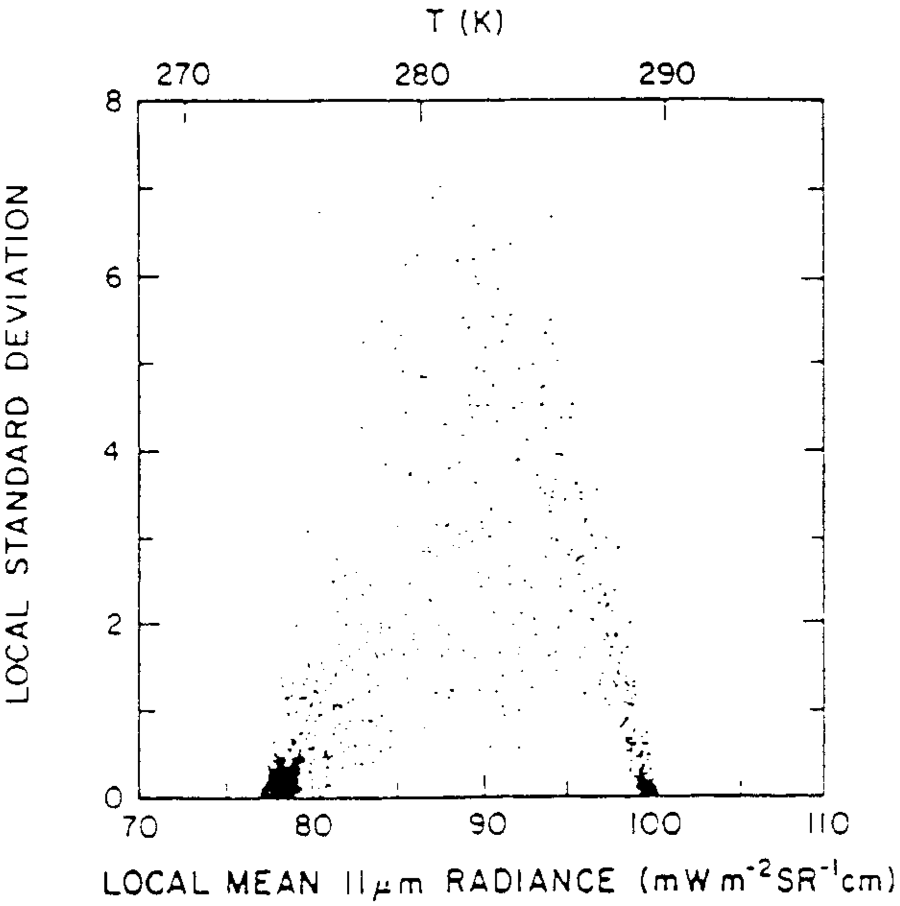


60
50
40
30
20
10
0
JUNE
JULY
AUGUST
(c)
St
Ci
As
Ns
Cb
Cu
90
60
30
0
30
60
90
S
LATITUDE (DEGREES)
N


JJA
< 20%
≥ 20%
≥ 40%
≥ 60%
d
90 N
60 N
30 N
0
30 S
60 S
90 S
Latitude, deg
0
60 E
120 E
180
120 W
60 W
0
Longitude, deg



$T_{IR}$
4 µm water
$T_c$ = 240 K
$T_s$ = 290 K
240
250
260
270
280
290
0
0.2
0.4
0.6
0.8
1
$R_V$
1
0.8
0.6
0.4
0.2
4
8
16
32
1024
cloud cover fraction
cloud optical thickness


T (K)
270
280
290
LOCAL STANDARD DEVIATION
0
2
4
6
8
70
80
90
100
110
LOCAL MEAN 11μm RADIANCE (mW m-2SR-1cm)

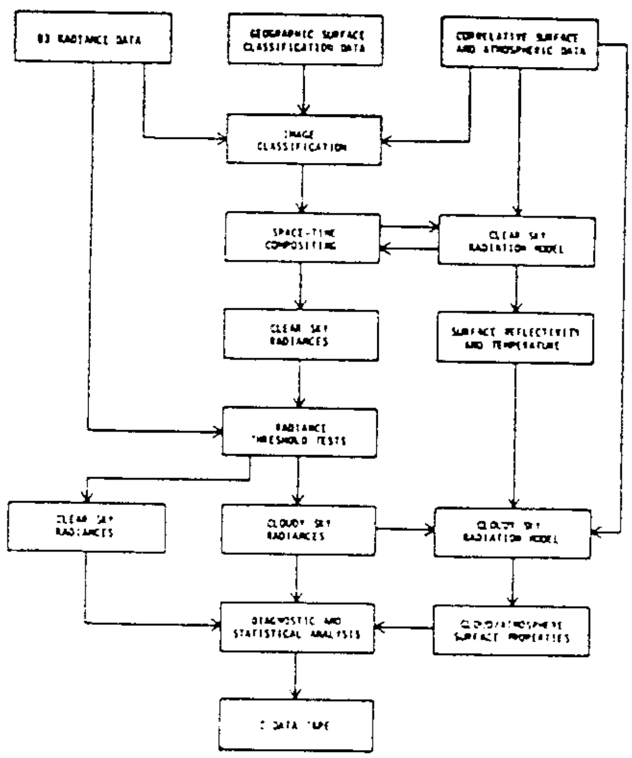

B3 RADIANCE DATA
GEOGRAPHIC SURFACE CLASSIFICATION DATA
CORRELATIVE SURFACE AND ATMOSPHERIC DATA
IMAGE CLASSIFICATION
SPACE-TIME COMPOSITING
CLEAR SKY RADIATION MODEL
CLEAR SKY RADIANCES
SURFACE REFLECTIVITY AND TEMPERATURE
RADIANCE THRESHOLD TESTS
CLEAR SKY RADIANCES
CLOUDY SKY RADIANCES
CLOUDY SKY RADIATION MODEL
DIAGNOSTIC AND STATISTICAL ANALYSIS
CLOUD/ATMOSPHERE SURFACE PROPERTIES
C DATA TAPE

Fig 5