INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392 - 1

SMR/406-22

THIRD AUTUMN WORKSHOP ON ATMOSPHERIC
RADIATION AND CLOUD PHYSICS
27 November - 15 December 1989

"Convective Clouds and Associated Precipitations"

Michel DEBOIS
L.M.D./C.N.R.S.
Ecole Polytechnique
Palaiseau
France

Please note: These are preliminary notes intended for internal distribution only.

CONVECTIVE CLOUDS AND ASSOCIATED PRECIPITATIONS

M. Desbois
Laboratoire de Météorologie Dynamique du CNRS
Ecole Polytechnique, 91128 Palaiseau, France

Summary : The capabilities of Visible-Infrared imagery from geostationary satellites for describing convective cloud systems and their life cycle are illustrated through two test studies based on the Meteosat ISCCP data set : one is concerning the diurnal cycle of tropical convective clouds, and the other the African squall lines. The relationship between these cloud systems and the precipitations, as measured from raingauges, is also investigated. It is shown from case studies and statistical considerations that this kind of satellite data can provide estimations of precipitations the quality of which decreases drastically with the space and time scales. The monthly values retrieved can be considered as satisfactory for space scales of at least 50 x 50 km, whereas daily values are not reliable, due to the very different rain efficiencies of different events.

1. INTRODUCTION

It is well known that the convective zones of the tropical regions are a major component of the climate system, as they constitute energy sources specially in relation to the precipitations they produce, associated with a large release of latent heat. As the conventional meteorological data are rather sparse and spurious in tropical regions, the representation of these phenomena in the GCMs is not always accurate, due also to the scale of the convective events. This has been principally observed from comparisons with satellite data, either for meteorological scale simulations, or for "climatological" averages. One can then question if the convective cloud observations from satellite may be useful to implement the initialization of the models, using new assimilation techniques. The introduction of precipitation rates, for example, could influence the dynamics and reduce the spin up time of the model. Suggestions have also been done to improve the initialization of the divergence (or vertical velocity) fields in the tropics from its relation to the convective cloud field deduced from satellite data (Krishnamurti and Low-Nam, 1986; Kasahara et al., 1988).

From geostationary satellite imagery animations, one of the most striking feature is the apparently complex behaviour of the tropical convective systems. This large scale behaviour can be described more quantitatively from IR imagery, specially with the ISCCP level B data set, allowing to follow the evolution of the cold cloud tops. Recent studies using this principle have shown the large amplitude of the convective cloudiness fluctuations and the large extent of the areas affected, specially in the African ITCZ *(Duvel, 1988; Desbois et al., 1988)*. In this last paper, the association of the diurnal cycle of convective clouds to orography was clearly shown : maximum cycle over mountaineous areas and over regions where breeze type circulations are likely to occur. In other areas like the flat regions of Sahel, it was noticed that propagating convective systems were also submitted to a large diurnal evolution.

The aim of the present paper is to give examples of informations on the convective clouds which can be obtained from simple processing of ISCCP data : these examples will be taken from studies done at LMD from Meteosat B2 data, in order to investigate the climatic characteristics of particular months. In a first part, we will show some results about the diurnal cycle of convective clouds over Africa, at large and regional scales, then focus on the propagating squall lines and examine the respective roles of local convection and propagating systems. In a third part, we will discuss the interpretation of these convection analyses in terms of precipitations.

2. AMPLITUDE AND PHASE OF THE DIURNAL CYCLE OF CONVECTIVE CLOUDS

The considerations presented here are extracted from Desbois et al. (1988) and Desbois et al. (1989). One of the indicators we have computed to characterize the diurnal cycle amplitude is based on the maximum difference between the frequency of occurrences of cold clouds (below -40°C), as they appear in the infrared window channel (10.5-12.5 μm) at the different hours. The knowledge of the number of events for a particular hour for a given pixel allows to control the statistical significance of the results. The maps produced are presented on figure 1, showing a close association with orography, but also large amplitudes over some other areas, with large interannual differences.

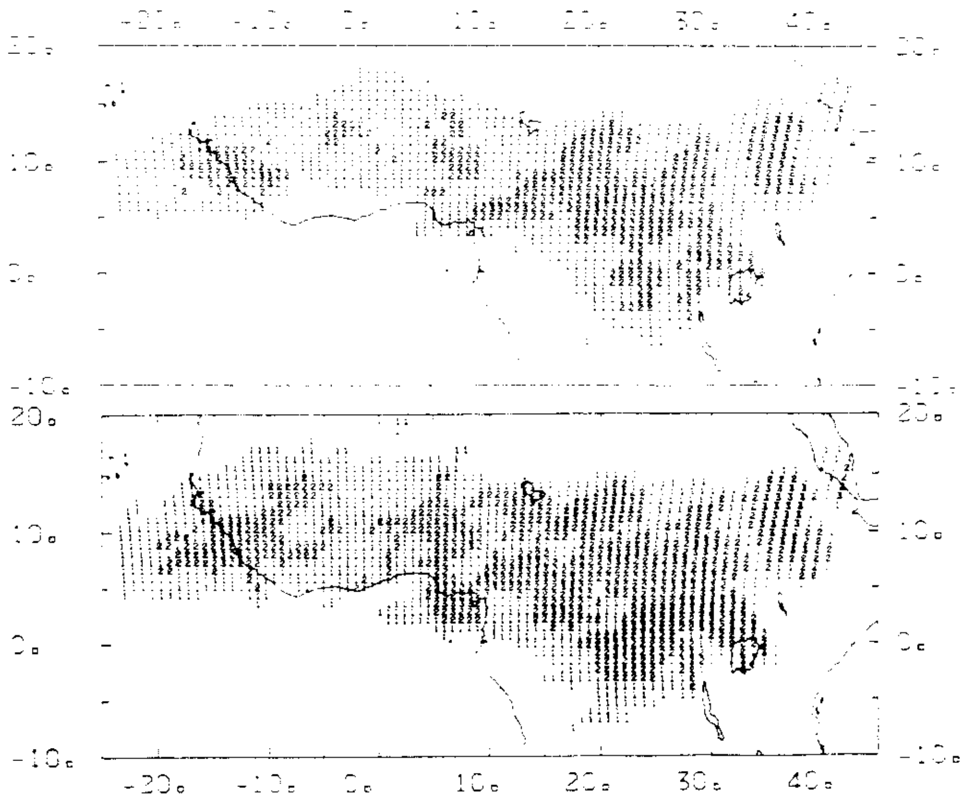

Fig. 1. Amplitude of the cycle for July 1983 (top) and 1985 (bottom). Moderate: 1; Medium: 2; High: 3.

From the hourly maps of the monthly number of occurrences of clouds colder than -40°C, maps of the hour of maximum "cold cloudiness occurrence" can be constructed to characterize the phase of the cycle (Fig 2). Mountain regions can be distincted by a cloud growth maximum occuring in the beginning of the afternoon, i.e. earlier in the day than for other regions. Downwind of these regions, there is often a delay of the phase of the cloud cycle from East to West corresponding to phase speeds of the order of 10-15 m/s, similar to the one of squall lines, but not far neither from the wind velocity in the upper troposphere.

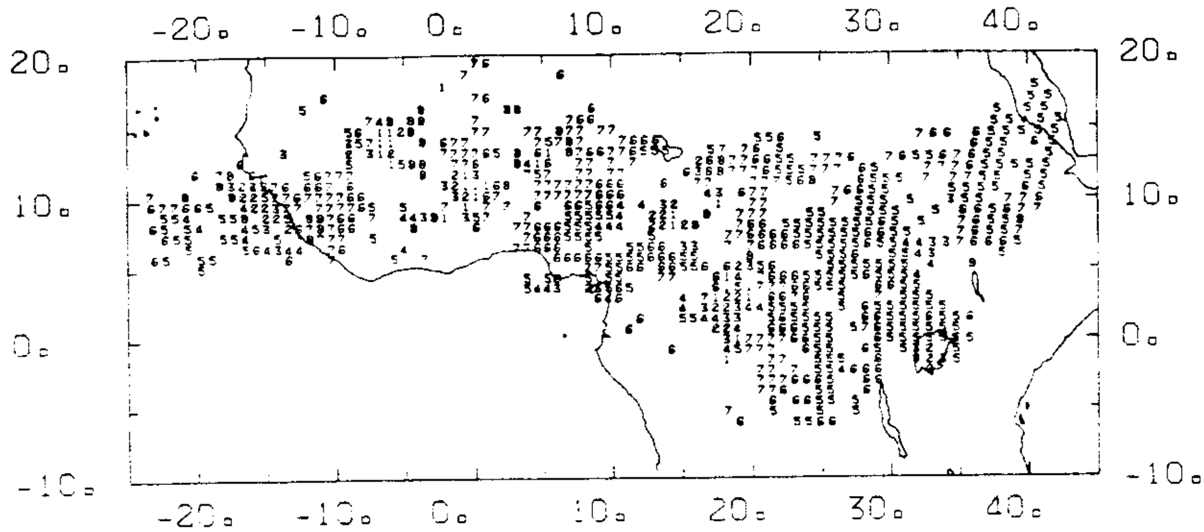

Fig. 2 : Map of the hour of maximum "convective cloudiness" for July 1983, defined as the hour of maximum monthly occurrence of clouds with tops colder than -40°C. Numbers 1 to 8 refer to the successive times of the ISCCP B2 images of Meteosat (UT) : 2:30, 5:30, 8:30, 11:30, 14:30, 17:30, 20:30, 23:30. Places with multiple maxima or no cold cloud occurrence are left blank.

Most of the large scale interannual differences appear to be related in a complex way to the position relative to the mean ITCZ and the orography, the coastal effects and the occurrence of squall lines. But no general rule appears, and a regional examination of the interannual differences is necessary. The case of the crossing of the West African coast with the ITCZ is presented below :

This area is marked by a North-West to South-East coastline, backed by a moderately high moutain range, composed from the Fouta-Djalon in the North and the Guinean ridge in the South. The low layers of the atmosphere are characterized over the sea by a South Westerly to Westerly flow (monsoon flow). This mean flow weakens over the continent, specially near the mountain range. The Easterly wind at 700 hPa (described from the ECMWF analyses) is on the average stronger in 1983 (≃ 10 m/s) than in 1985 (≃ 5 m/s). On the contrary, at 200 hPa, the Easterlies are stronger in 1985. The diurnal amplitude of the cycle (Figure 3) appears to be the highest over the Fouta-Djalon for both years. But the remaining distribution is very different : in 1985, a band of maxima lies just beyond the coastline from Senegal to Liberia, and the oceanic maximum occurs more South than in 1983, but significant values are found over a much wider area, facing the

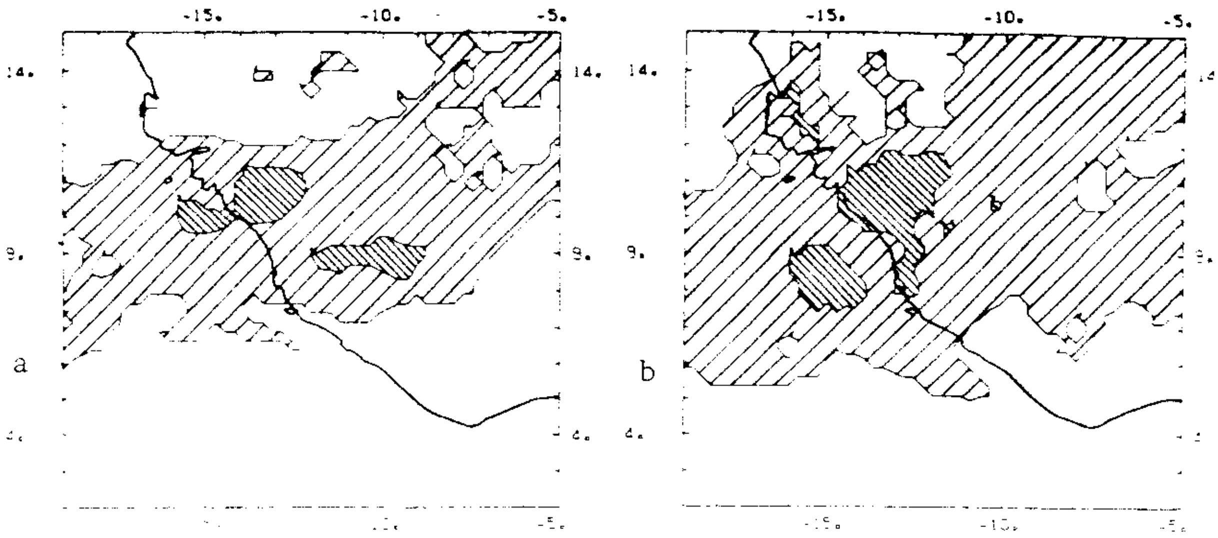

Fig. 3 : Map of the amplitude of the diurnal cycle (in terms of frequency of occurrences) for the Western African coast area. a) July 1983, b) July 1985.

coastline. Over the continent, the maximum frequency of cold clouds occurs around 18:00 local time over the mountains, but also along the coastline in 1985. Over the ocean, the areas of maximum cycle correspond to a maximum frequency time around 4:30 in 1983 and 7:30 in 1985. A westward advection of this maximum is noticed in 1983. This advection does not appear clearly in 1985.

These elements suggest the following behaviour : In July 83 (see §3.), propagating events are predominant over the area, and a land-sea breeze circulation can establish only in the zone of the highest mountains (Fouta-Djalon). Reversely, in July 85, the weak 700 hPa Easterly flow allows the development of breeze circulations along the whole coastal region.

3. SQUALL LINES

In the flat areas of Sahel and Sudan, the above studies have shown that the diurnal cycle was largely weaker than over mountaineous regions. Over these flat areas, the main convective systems, supposed to be responsible of the majority of precipitations (this is commonly admitted, but no really quantitative analysis has been done), are organized squall lines of very large extent (reaching 500 km or more), which maintain during longer time periods than diurnal events, while propagating westward.

Main characteristics of squall lines occuring in July 1983 and July 1985 have been described in Desbois et al. (1988), from the same ISCCP B2 data set than above. Individual squall lines trajectories have been tracked from interactive processing, allowing to do statistics on the source regions, propagation speeds, life time, ... of these events, in order in particular to look at their relation with general circulation parameters, as given by the ECMWF analyses. For example, it has been shown that the velocity of the squall lines was larger in the dry monthes July 1983 and 1984 (more than 15 ms^{-1}) than in July 1985, a more humid year (13.5 ms^{-1}), related to a change of same sign of the zonal speed at 700 hPa. The diurnal cycle of the squall lines was also found to be very large; the fact that this does not influence the local diurnal cycle described in § 2. being due to the different hours of passage of the squall lines in particular places.

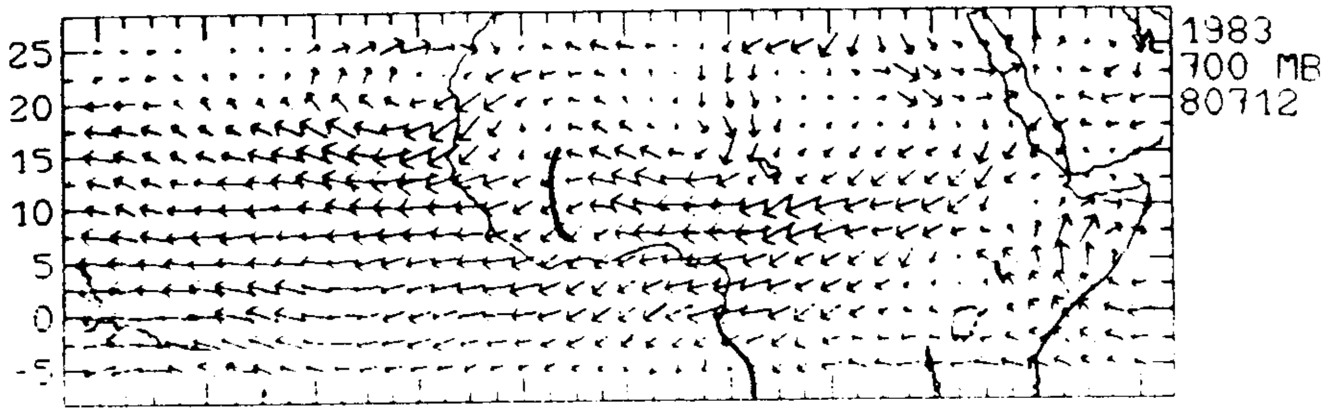

Fig. 4 : example of the positionning of a squall line front relative to the ECMWF wind field at 700 hPa.

For individual days, we have also tried to compare the position of the squall lines to the ECMWF fields at different levels. One example is given on Figure 4., where the front edge of a squall line seems to be associated with the Northerly component of the wind at 700 hPa due to an Easterly wave. More systematic comparisons show that there is a general preference for this kind of association, but one cannot tell if the reverse cases observed sometimes are real or due to a bad restitution of the field by the model analysis.

This study allowed us also to infer the proportion of convective events of the tropical Africa which can be considered as squall lines, according to our criteria (Desbois et al., 1988). The results are presented on Figure 5, for July 1985.

The number of cold clouds is characterized by maxima located over the mountains and some coastal regions. The distribution of the squall lines occurrence is very different : they are mainly concentrated from the South-West of lake Chad to Guinea mountains. The proportion of these events overpasses 50% over most of the sahelo-soudanian regions situated West of lake Chad, reaching 65% in some particular places. When comparing different seasons, the distribution of the squall lines is more variable than the distributions of cold clouds, apparently more strongly related to general circulation changes.

4. RELATION TO PRECIPITATIONS

As it is possible to characterize from satellite the presence of convective clouds and some of their characteristics (top temperature, reflectance, amount, time evolution...), it is tempting to try to relate these characteristics to precipitation rates or precipitation amounts. Numerous methods, mainly based on statistical adjustments, have been

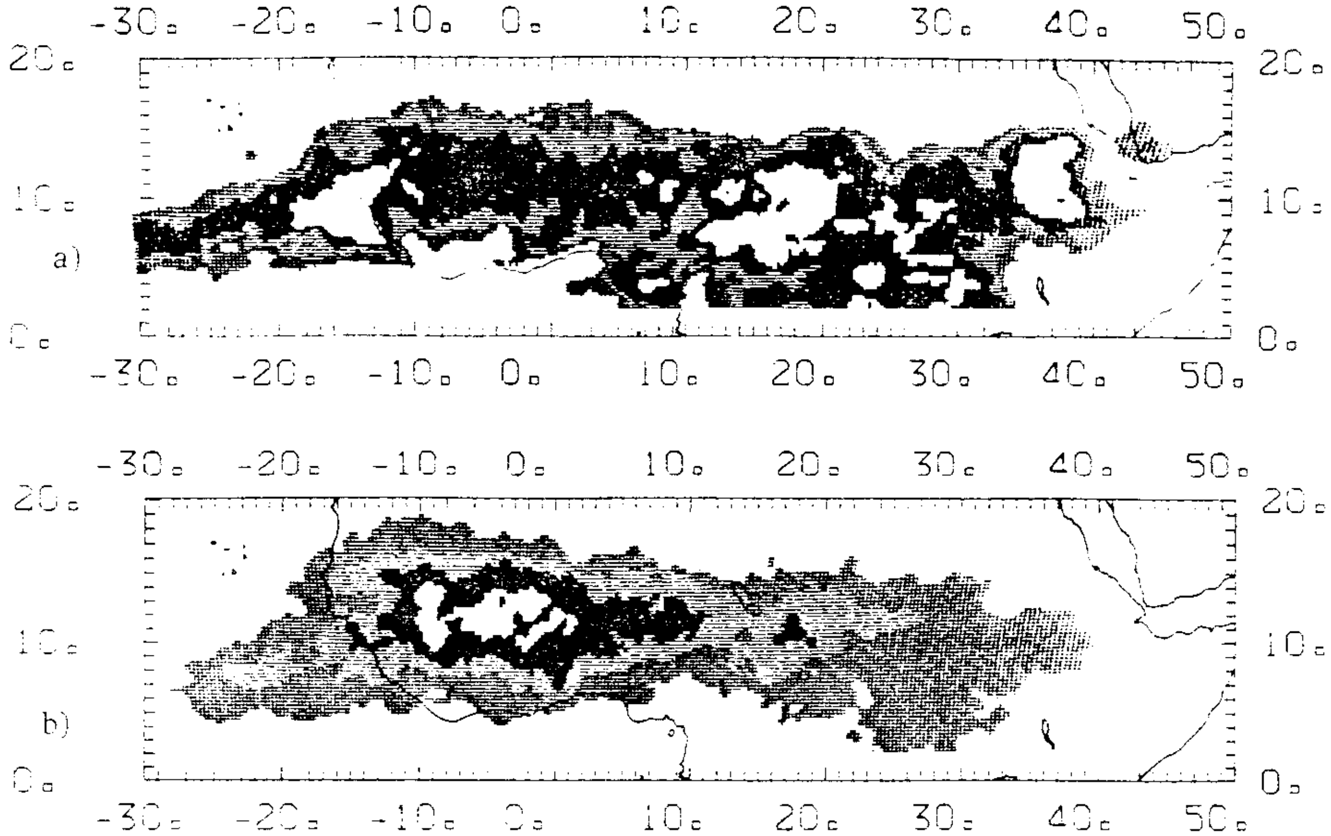

Fig. 5. a) Occurrences of clouds colder than -40°C, for July 85. Isolines: 10 to 30 ; b) Occurrences of squall lines for July 83. Isolines : 1 to 15

proposed to infer precipitation from the analysis of VIS-IR satellite imagery. It is not the purpose of this paper to review them, but rather to try to estimate their usefulness for operational GCM purposes.

These techniques have been set up for different kinds of applications : either instantaneous rain estimates for operational purposes, or more often, climatological rain estimations in regions lacking of in situ measurements. These last ones are generally the more simple, and as no one appears systematically better than the others, we (Jobard and Desbois, 1988) chosed to test the capability of a very simple one at different time scales and spatial resolutions (obtained by sampling). The satellite estimator used is the number of occurrences per pixel of clouds colder than a given threshold, taken here at -40°C. Results for the correlation coefficient between the occurrence field and the precipitation field, measured in 425 Sahelian stations, are given in table 1. It is verified that the correlation coefficients improves with increasing period of time and that it is satisfactory only for the season. Note that the correlations for the day period are significantly larger that the values that would be obtained if the no-rain case were ignored.

In fact, a large part of this decrease of the correlation is related to the difference between the spatial structures of the two fields compared, the precipitation field measured from individual stations being much more

	Full resolution 1/2 hour	Full resolution 3 hours	B2 resolution 3 hours	Sample size
Day	.42 ± .02	.40 ± .02	.37 ± .02	12750
Decade	.46 ± .04	.44 ± .04	.41 ± .05	1275
$Month_{july}$	.60 ± .06	.60 ± .06	.56 ± .07	425
Season		.89 ± .05	.82 ± .04	358

Table 1 : rain amount / cold cloud occurrences correlation coefficient

noisy at small scales that the field of cloud occurrences. In fact, the correlation computed for area values at the size of a model grid box would certainly be better, even at the daily scale; but this is difficult to verify, due to the lack of proper networks, specially in the tropical regions. We hope to estimate these values with the help of a new network of raingauge recorders associated with a digitized radar, in the vicinity of Niamey.

Other factors have also to be taken into account to improve these relationships; for example, for different seasons, climatic regions or orographic conditions, clouds looking similar from the satellite have not the same "rain efficiency". This quantity has to be deduced from climatologic calibrations.

The problem is still more difficult at the hourly time scale, for which many algorithms have also been designed, accounting for the life cycle of the clouds. Here again, however, the problem has not generally been adressed for the scales of GCMs, but more for individual clouds.

At the present time, IR (or VIS-IR) techniques of precipitation estimation seem to be useful mainly for climatological estimations over at least 10 days, and even in this case, they must be calibrated by a sufficiently dense network of raingauges : the satellite acts then as a spatio-temporal interpolator. Similar techniques cannot be used for operational purposes on a real time basis, as they need a still more dense network of raingauge *recorders* or radar data. However, the new passive microwave techniques will offer increased possibilities for determining more directly the precipitation rates. The geostationary VIS-IR data will still be needed, as it will be possible to calibrate them everywhere by the microwave data, to do the necessary temporal interpolation between the successive passages of the low orbit satellites carrying the microwave instruments.

5. CONCLUSION

The imagery from geostationary satellites carries much more information on the status of the atmosphere than is really used in the models assimilations (cloud winds). This information, particularly concerning cloud cover, is sometimes used, but generally only for the verification of the model simulations. However it seems that the cloud information, specially in regions where systems are very active energetically (tropical convection in the ITCZ, e.g.) could implement usefully the initialisation fields when conventional data are lacking.

We have seen above that the determination of precipitation at the model grid scale will be greatly improved from the combination of IR and microwave data. We have also mentionned in the introduction works trying to improve the divergence field from the convective clouds distribution. This kind of approach has also been tested recently in LMD (Picon and Desbois, 1989) from the analysis of water vapor images, when we tried to correlate the WV radiance field to parameters (including dynamical) from the ECMWF analyses. The results were not very convincing, due to the fact that the water vapor structures as observed by the satellite depend on several phenomena simultaneously, e.g. horizontal advection and vertical velocities. It would be better to simulate the radiance fields from the model analysis (or forecast) and to compare them with the Meteosat fields, in order to look for eventual disagreements in specific areas. If these disagreements occur preferentially in regions with bad data coverage, then the information of the satellite can be useful to improve the analysis.

How to do that is another question, but we think that the introduction of the satellite data has to be made if possible only with minor transformations, without introducing specific inversion methods : it would be better that the model processes themselves can do these inversions, e.g. by adjoint techniques.

REFERENCES

Desbois, M., T. Kayiranga, B. Gnamien, S. Guessous and L. Picon, 1988 : Characterization of Some Elements of the sahelian climate and their interannual variations for July 1983, 1984 and 1985 from the analysis of METEOSAT ISCCP data. *J. Climate*, **1**, *841-897*

Desbois, M., T. Kayiranga, and B. Gnamien, 1989 : Diurnal cycle of convective cloudiness over tropical Africa observed from Meteosat : Geographic characterization and interannual variations. *Annales Geophysicae, in press.*

Duvel J.P., 1988 : Analysis of diurnal, interdiurnal and interannual variations during northern hemisphere summers using Meteosat infrared channels. *J. Climate*, 1, *471-484*, 1988.

Jobard, I., and M. Desbois, 1988 : Remarks on the influence of time and space scales in the estimation of precipitations from satellite IR data. *METEOSAT 7th scientific users meeting, Madrid, 27-30 Septembre 1988*

Kasahara, A., R.C. Balgovind, and B.B. Katz, 1988 : Use of satellite radiometric imagery data for improvement in the analysis of divergent wind in the tropics. *Mon. Wea. Rev.*, **116**, 866-883

Krishnamurti, T.N., and S. Low-Nam, 1986 : on the relationship between the outgoing longwave radiation and the divergent circulation. *J. Meteor. Soc. Japan*, **64**, 709-718.

Picon, L., and M. Desbois, 1989 : Comparisons between Meteosat water vapour radiance fields and ECMWF analysed fields for July 1985. *Submitted to Journal of Climate.*