

# ASSIMILATION EXPERIMENTS WITH LOW LEVEL CLOUD MOTION WINDS AT ECMWF

Mariella Tomassini

European Centre for Medium-Range Weather Forecasts  
Shinfield Park, Reading, RG2 9AX, UK

## ABSTRACT

The low level Cloud Motion Winds (CMW) increase significantly the data coverage over oceanic regions. In order to assess their impact on the European Centre for Medium-Range Weather Forecasts (ECMWF) analysis and forecast system, assimilation experiments were performed during the summer of 1995. In addition to the well-established infrared CMW, high resolution visible winds from METEOSAT were included in the assimilation process. The experiment results showed that all the low level CMW have a substantial positive impact on the short-range forecast of the circulation over the tropical and southern oceans and a positive impact in the global medium-range forecast of the Southern Hemisphere. The impact of CMW during the development of tropical storms was also investigated.

The degree of improvement from the CMW on the wind field analysis at low level can be assessed using the surface wind data from the ERS-1 scatterometer as a reference. The results indicate that the agreement between model and scatterometer winds is closer when the CMW are used.

## 1 INTRODUCTION

In general the aim of an Observing System Experiment (OSE) is to estimate the information content of individual components of the global observing system as measured by their impact on an analysis and forecast system. There are two main categories of OSE:

- Different types of observation are progressively added in different combinations to a minimum system. These experiments are useful to understand the possible redundancy or contrast between observations, their global impact and eventually to contribute to the design of a “best-mix” operational assimilation system. The OSE can either run for a prolonged period and be repeated in different seasons (*Uppala et al.*, 1985; *Kelly*, 1993) or can focus on specific data impact events (*Graham and Anderson*, 1995).
- One type of observation is withheld from the complete observing system. With this approach, a neutral impact indicates that the observation withheld is redundant, while a degradation of the forecast performance indicates that the observations withheld have an effective information content not available from the rest of the system. This type of OSE is particularly useful to assess the impact of newly available data and/or to ensure their correct operational implementation. An example is the recent work carried out at ECMWF on the scatterometer wind data from ERS-1 (*Gaffard and Roquet*, 1995; *Stoffelen and Anderson*, 1996).

In this study an OSE of the second type is discussed. The impact of the low level CMW from geostationary satellites derived either from infrared or visible channel data is investigated by comparing the ECMWF analyses, short-range and medium-range forecasts with and without the CMW data.

## 2 QUALITY OF LOW LEVEL CMW

The basic assumption of the CMW product that clouds are passive tracers is reasonably justified at low level and over the sea. Small marine cumulus are smoothly advected by the wind and have a lifetime which is long enough compared to the time interval between successive satellite images (*Desbois, 1984*). Under these conditions the tracking part of the CMW algorithm accurately describes the local wind field. The height assignment can also be accurate: the low level clouds tend to move with the wind field at their base which can be estimated from the histograms of their brightness temperatures in the infrared channel (*Le Marshall et al., 1994*). Monitoring results confirm that at low level, i.e. below 700 hPa, the CMW have a small error and are not affected by any relevant bias. Several improvements in the CMW extraction technique have made their quality reach the level of the conventional observations: in the case of METEOSAT, the RMS vector error for low level winds has been estimated as 2 m/s (*Schmetz, 1993*), a value close to that of radiosondes operating in good conditions.

Monitoring statistics against the 6-hour forecast of the ECMWF model, used as the First Guess (FG) for the analysis (Table 1), show that winds derived from different satellite systems and from different channels have very similar characteristics. The INSAT data are the only exception, having larger RMS vector differences. Surprisingly no difference is noticed between different height assignment methods: GOES and GMS winds are assigned to a fixed level, 900 hPa and 850 hPa respectively, while METEOSAT uses the cloud base estimate. The minor negative bias in the case of the GOES is a constant characteristic of that system (*Thoss, 1991*).

**Table 1: Low level CMW minus First Guess statistics for period 24/08/95-09/09/95.**

	rms vector diff. (m/s)	speed bias (m/s)	mean abs. dir. diff. (°)	mean FG speed (m/s)	No. of data
MET. IR	2.8	0.1	10.3	10.1	22724
MET. VIS	2.8	0.0	11.2	9.5	68349
GOES	2.8	-0.5	13.0	7.8	29091
GMS IR	3.1	0.2	15.0	8.3	13643
GMS VIS	3.0	0.4	14.6	8.4	11837
INSAT	6.7	2.3	25.5	8.3	11571

## 3 ANALYSIS AND FORECAST IMPACT

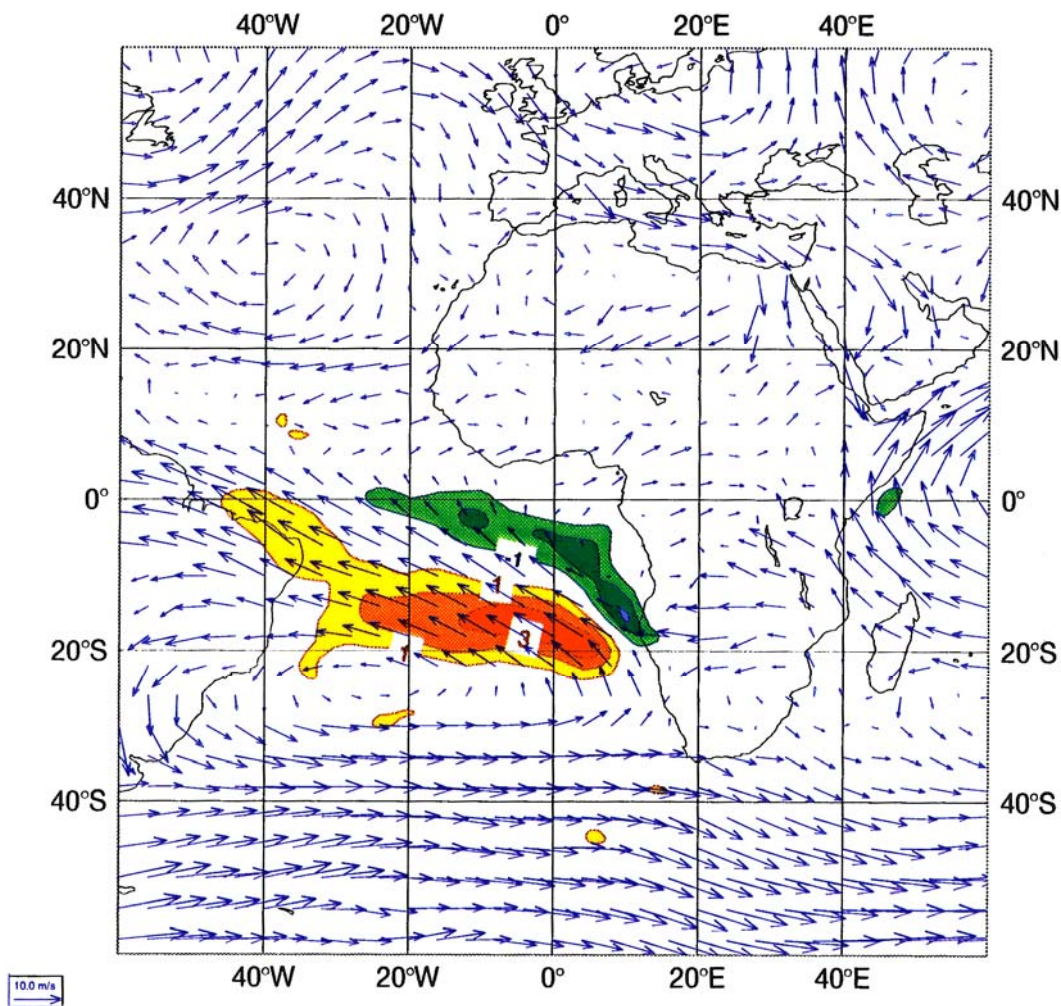
The operational ECMWF analysis system routinely assimilates the CMW derived by the geostationary satellites METEOSAT, GOES, GMS and monitors in passive mode those from INSAT. Before being assimilated an observation has to pass several quality checks, including comparison against the FG value. In the case of the low level CMW, the system rejects only a small percentage of the total data, normally less than 2%.

In order to evaluate the overall impact of the low level CMW in the ECMWF assimilation system, two experiments were run using the operational model at the T106 (~125km) resolution and the Optimal Interpolation (OI) data assimilation scheme. The first experiment, hereafter called LOW, included all observations as in the operational code, i.e. conventional and satellite measurements, while the second experiment, NOLOW, used no low level CMW. The experiments ran from 24 August '95 to 9 September '95 and the results which will be discussed are all based on mean quantities computed over this 16 day period.

The low level CMW adjust the wind field analysis especially over the South-East Pacific and South Atlantic. The largest impact occurs in the Tropical belt over the Atlantic ocean. In Fig.1 the contour of the speed difference LOW minus NOLOW is plotted on top of the LOW wind field at 850 hPa. It is evident how the CMW from METEOSAT, which are the major data source over the Atlantic, modify the easterlies circulation. In particular they intensify the trade winds between 10°S and 20°S (orange contour) and form a large calm wind area west of the African coast and below the equator (green contour).

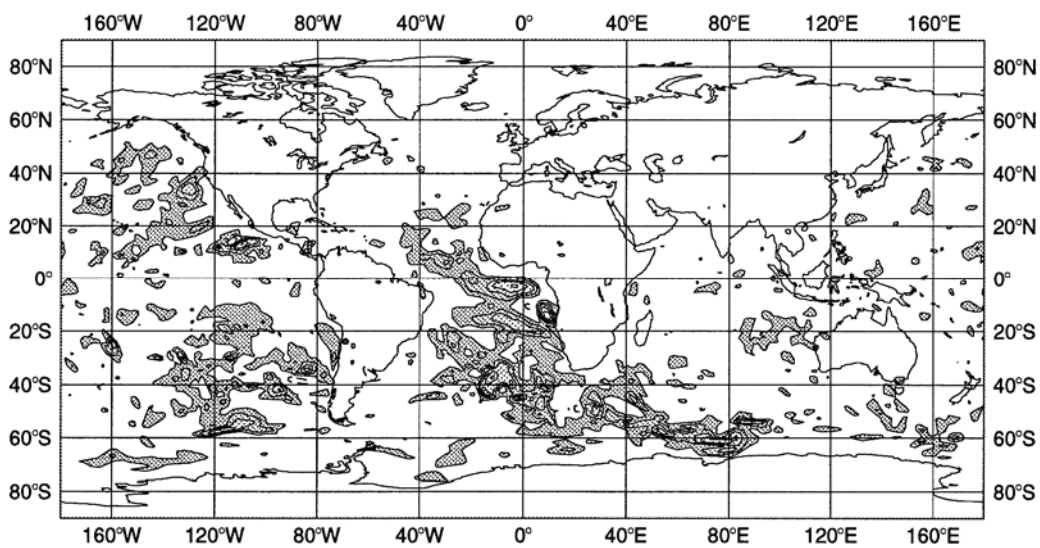
The higher accuracy of the analysis assimilating the CMW is demonstrated by the better fit of its First Guess (FG) field not only to the CMW themselves but also to an independent set of observations, the ERS-1 scatterometer winds (see section 4). For this reason the LOW analysis is taken as the “best possible” and used as the verifying analysis of the forecasts from both, NOLOW and LOW, experiments.

**Figure 1** Mean speed difference LOW minus NOLOW (contour interval 1 m/s) and LOW wind field at 850 hPa

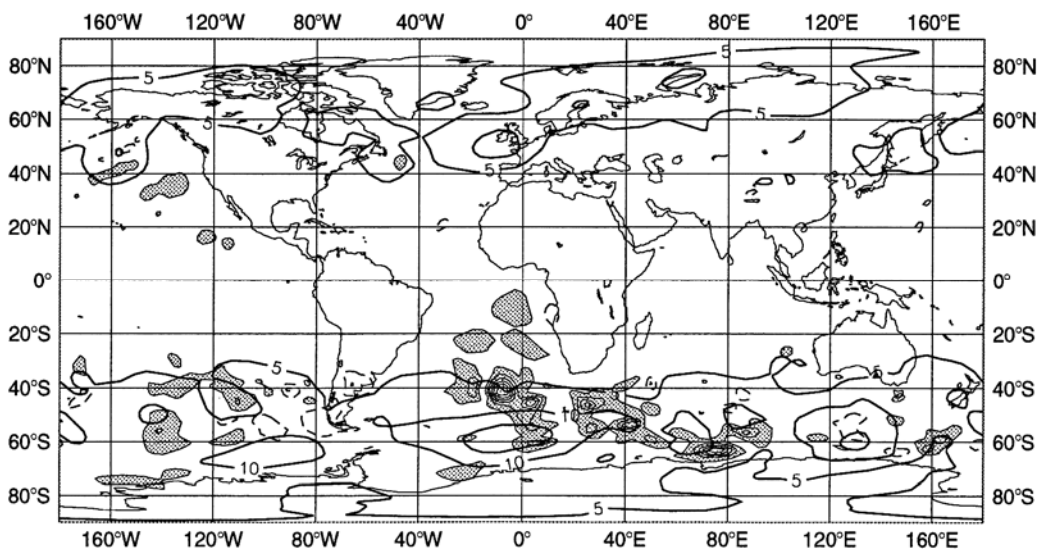


The impact of low level CMW on the short-range forecast is globally positive, with improvements especially in the Tropics and in the Southern Hemisphere. In these regions the RMS wind vector error of the 24 hour forecast and at 850 hPa is typically of the order of 3-4 m/s. The reduction of this error by the CMW is given by the mean difference of the RMS wind vector error of the LOW experiment minus NOLOW. The geographical distribution of this difference is shown in Fig. 2: the contour shading starts below -0.5 m/s and indicates areas where the LOW forecast is closer to the analysis (at least 20% of error reduction). There is also evidence of an improvement in the geopotential field. Fig. 3 shows the same error difference as Fig. 2 but for the 850 hPa geopotential height plus the temporal variability (thick contours in std. dev.). The error of the 24 hour forecasts decreases especially in correspondence with those areas in the Southern Atlantic where the synoptic activity was more intense and thus the forecast more difficult. It is in these situations of larger uncertainty that there are also larger margins for improvement by the data.

**Figure 2** Mean difference of 24h forecast RMS error of 850 hPa vector wind LOW minus NOLOW taking the LOW analyses as reference (shaded contour below -0.5 m/s).

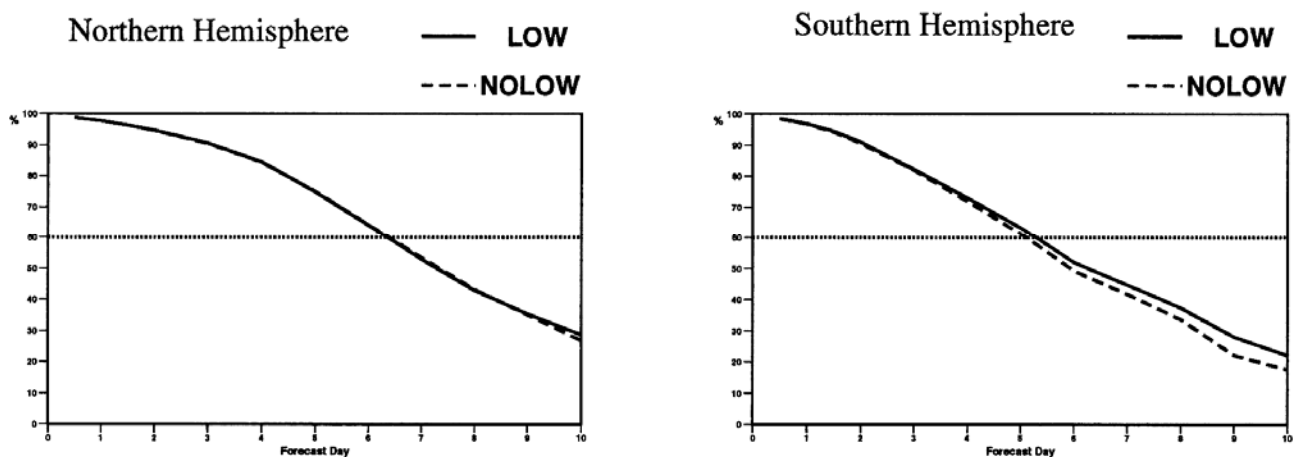


**Figure 3** Mean difference of 24h forecast error LOW minus NOLOW (shaded contour below -0.25dm) and temporal variability (thick contour at 5 dm interval) of 850 hPa geopotential



The better performance of LOW can still be noticed in the two day forecasts but for longer ranges it becomes rather weak. This phenomena has been discussed already in previous work (*Uppala et al., 1985*): in the medium-range the model error starts to grow rapidly and eventually swamp the positive effects of a reduced analysis error. However it is still important to verify the behaviour of the forecasts beyond two days, to be sure that spurious data have not introduced any noise degrading the performance of the whole system. The scores of the forecasts are measured in terms of anomaly correlation, i.e the correlation between the forecast and the operational analysis at higher resolution (this time not the LOW one) averaged over the whole period of the experiment (Fig. 4). The scores are always very close indicating a general neutral impact of low level CMW in the medium-range forecast. The slightly better performance of LOW in the Southern Hemisphere indicates that where the data have modified the analysis they have also improved the performance of the medium-range forecast system. In the Northern Hemisphere, where the synoptic activity during the period of the assimilation was relatively weak, the impact is neutral: a winter experiment may have produced more distinction between the cases with and without CMW data.

**Figure 4** Anomaly correlation of the 850 hPa geopotential height (16 forecast average).



#### 4 VERIFICATION WITH ERS-1 WINDS

The experiments described so far are based on the ECMWF operational scheme, which at that time was for the data assimilation part the OI scheme. Wind data from the scatterometer on board the ERS-1 satellite were not used, until February'96 when they became operational with the introduction of the 3-Dimensional (3D) variational scheme. Thus the scatterometer winds can be regarded as independent information to validate the results from the low-level CMW experiments. They are especially suitable for this purpose because of their good coverage over sea areas, where the CMW are also available.

The low level CMW are representative of a cloud layer located between the surface and 700 hPa, while the scatterometer senses near-surface winds, thus a direct comparison of the two is not appropriate. But when CMW are assimilated in the analysis, the resulting FG has transferred the information from the lower-troposphere layers to surface winds. The FG wind field can then be compared with the scatterometer winds retrieved at ECMWF with the PRESCAT scheme (*Stoffelen and Anderson, 1996*).

The results from statistics computed over the whole period of the assimilation experiments indicate a global reduction in standard deviation, around 2%, between the 10 metre FG wind and the scatterometer observations when all the low level CMW are assimilated. If the same statistics are performed for the deep tropics (10°S-

10°N) over the Atlantic ocean, i.e. where the METEOSAT CMW have sensibly modified the circulation, this reduction is even more evident, as shown in Table 2. These results confirm that the LOW FG and consequently the analysis is the most accurate and the most suitable for forecast verification purposes. The conclusion is also that the two independent satellite systems can coherently provide the assimilation system with useful information.

**Table 2: Scatterometer winds minus FG from LOW and NOLOW experiments for the deep tropics over Atlantic ocean (81417 observations).**

	SPEED (m/s)		DIRECTION (°)	
	BIAS	STD	BIAS	STD
NOLOW	-0.5	1.7	3.2	19.4
LOW	-0.1	1.6	1.6	18.9

## 5 INSAT CMW

Cloud Motion Winds (CMW) from the Indian satellite INSAT are produced and disseminated on the GTS twice a day, at 0000 and 1200 UTC. Comparison against the ECMWF First Guess collected during one year (Thoss, 1991), showed that their quality was not as good as that of CMW winds from other satellites. Since then some improvements have been made, e.g the correction of the anomaly in the processing causing a large number of zonally aligned CMW (Kelkar et al, 1993).

An assimilation experiment (INS) using INSAT winds ran from 24/08/95 to 09/09/95 and the resulting analysis fields were compared to the control experiment not assimilating them (LOW). The most important result was a variation between the INS mean wind fields at 00 GMT and 12 GMT. No evidence of a similar diurnal cycle was present in the LOW analysis. The variation was found to be related to a diurnal oscillation of the INSAT winds: the mean difference between low level INSAT CMW and FG varies from 3.3 m/s to 0.5 m/s in speed and from  $-1.6^{\circ}$  to  $-19.3^{\circ}$  when computed at 00 GMT and 12 GMT respectively. During the assimilation process this spurious diurnal oscillation caused some problems, as can be seen in the observations minus FG statistics. Table 3 displays the comparison of low level INS AT (850 hPa) winds versus the LOW FG (first row) and INS FG (second row); for reference the comparison of radiosondes winds versus INS FG over the area with bounds 40S-40N/50E-100E is added (third row). The assimilation of the INSAT CMW does not improve their own fit to the FG, furthermore it leads to a slightly higher number of data rejected by the quality control check. As a result it was decided not to run any forecast. It has to be stressed that during the assimilation experiment INS, the CMW and radiosondes over the INSAT area have comparable performance in terms of wind vector RMS (Table 3). With some more improvements (e.g. solving problem discussed above) INSAT CMW would become equivalent to the conventional observations of the area with the advantage of offering a far better coverage of the Indian Ocean.

**Table 3: Low level INSAT and radiosonde winds minus FG statistics.**

	No. total observations	No. rejected observations	RMS vector all data (m/s)	RMS vector used data	Mean FG speed (m/s)
CMW - LOW	11571	2650	6.7	-	8.3
CMW - INS	"	2764	6.7	4.8	8.4
TEMP - INS	1005	297	7.1	4.1	7.4



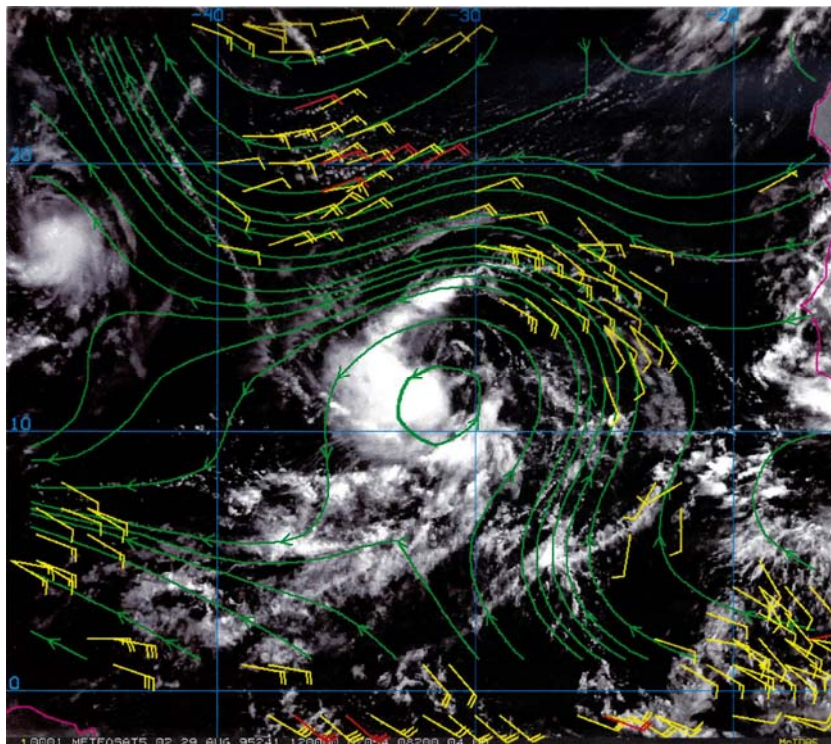
## 6 METEOSAT VISIBLE CMW

METEOSAT Visible CMW were extracted at the European Space Operational Centre (ESOC) from the full resolution visible imagery using similar techniques to the operational Infrared CMW (*Schmetz and Holmlund, 1996*). Only low clouds over sea are tracked and their height is derived from the infrared channel. An assimilation experiment using the visible winds in addition to all the other operational conventional and satellite observations was run during the same period as the LOW experiment and compared to it.

The average impact of the visible CMW in the analysis wind field is small, resulting in a small positive impact in the short-range forecast. In the South Atlantic at the lower levels there is evidence of some improvements in the 24 hour forecast, but later in the forecast the effects of the extra data are progressively lost and eventually the impact in the medium-range forecast is neutral.

Particular attention was given to investigating the visible CMW impact during the development of tropical disturbances. For the cases occurring in the assimilation period only small differences between the VIS and LOW wind fields were found. A typical example that can explain this minor impact is shown in Fig.5, a METEOSAT image of the tropical storm Luis. The extra visible winds (yellow flags) certainly produced a more detailed definition of the large scale circulation in comparison to the low level infrared winds only (red flags), however the model had already defined the overall flow in the LOW experiment (green streamlines at 850 hPa). Thus little was left for improvement by the visible CMW. In the vicinity of the storm centre the model was less accurate, i.e. the circulation was too weak, but no visible CMW were available there. This can be related to the lack of useful cloud tracers available in images at half hour time intervals. Enhanced coverage is offered by shorter imaging time intervals, of at least 15 minutes. One recent example is the visible CMW product derived from the new GOES system during the 1995 hurricane season (*Velden, 1996*). The conclusion is therefore that the use of high spatial-resolution visible images has improved the vector yield, but in the case of rapidly evolving phenomena the higher time resolution is still fundamental to provide useful information to the assimilation system.

**Figure 5** Tropical storm Luis on 29/08/95 at 12 GMT.



## 7 CONCLUSIONS

A two week OSE has proved that CMW are accurate measurements of the low level wind flow and are crucial for the tropical and southern hemisphere analyses. Their impact in the forecast has been measured as the net contribution on top of all the other components of the composite observation system. The short-range forecast over ocean areas and the medium-range forecast in the Southern Hemisphere are considerably improved. The positive impact has been confirmed by a comparison with the data from the ERS-1 scatterometer and it is encouraging that measurements from satellite systems based on very different physical principles are in agreement. Regarding the performance of tropical cyclone forecasting it has been noted that more observations are required in the vicinity of cyclones, as could be achieved with CMW derived from more frequent imagery.

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