VALIDATION OF CLOUDINESS IN GCMS USING METEOSAT OBSERVATIONS

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Abstract

Clouds are of major importance to climate simulation. Satellite observations offer a large potential for evaluating modeled distributions of cloudiness and clouds optical properties. Different approaches can be undertaken towards such an endeavor. The present report focuses on the use of METEOSAT infrared channels for validating some aspects of the models cloudiness. The emphasis is put on the so-called "model-to-satellite" technique which shares the same tools as the eventual cloudy radiances assimilation procedure in NWP models. A brief review of the literature highlights the needs and the philosophy of the method. METEOSAT "water vapor" channel characteristics are in both clear and cloudy skies as well as calibration issues are recalled. A narrow band model that simulates the infrared channels is presented and its evaluation discussed. Examples of the method at different time and space scales are detailed. The assimilation potential of the cloudy radiances of the WV channel are briefly discussed. Perspectives of improvements of the model validation direction, from a radiative simulation point of view as well as from a dataset angle are finally proposed.

1 Introduction

Modeled clouds have undergone significant improvements in the last two decades from the prescribed three levels black cloudiness of the one dimensional radiative convective models [e.g., Ramanathan and Coackley, 1977] to cloud materials prognostic formulations [e.g., Tiedtke, 1993]. This improvement in both general circulation models (GCM) and numerical weather prediction models (NWP) yields the need of dedicated diagnostics for the evaluation of these modeled clouds. Indeed despite recent and on-going efforts to better simulate cloudiness and its radiative impact, this very issue still stems as major challenge for the modeling community [IPCC, 1995].

Clouds observations suitable for models validation can be separated roughly into two categories. The first concerns the ground-based cloud climatology obtained by observers at meteorological stations and on-board ships over the ocean. Classical limitations from these source of data (sampling, human objectivity, units...) can nevertheless be overcome to some extent and provide an interesting perspective for evaluating models, especially for low level cloudiness [Norris, 1998]. The second concerns the satellite based cloud observations which suffers from different limits, for instance the detection of the low level cloudiness underneath extended anvils canopy, but contains a wide range of advantages with respect to model validation. The major satellite derived cloud climatology obtained from the ISCCP project [Rossow and Schiffer, 1991] includes cloudiness at different levels as well as some optical characteristics of the clouds in the visible and the infrared part of the spectrum together with a number of occurrence statistics at the global scale. Such climatologies are of main interest to model validation [Weare et al., 1996] even though some practical considerations of the algorithm details and overlap assumptions yield to not straightforward comparisons [Yu et al.,1996]. A third venue for evaluating the representation of cloudiness in these models concerns the radiation budget. Indeed specific radiative terms of the radiation balance, for instance comparing cloud radiative forcing from the ERBE experiment and model derived forcing, can provide an integrated perspective where both the clouds optical and occurrences properties are assessed at once [e.g., Bony et al. 1992]. Such an integrated evaluation is eventually needed. Deconvoluting the different aspects of the problem might nevertheless be of interest to cloud parameterization developers.

The aim of this paper is to present another approach concerning model clouds evaluation with satellite data. This so-called "model -to-satellite"[1] approach consists in simulating narrow band radiances from the model thermodynamic and cloud profiles to provide direct comparisons with the satellite radiances observations. Such an approach relies on radiation simulation and satellite calibration quality only. And it does not involve elaborated inversion algorithms, which could add bias to the comparison. Moreover, no ancillary data are needed. On the other hand, only part of cloudiness characteristics can be ascertain. Owing to the complexity of the problem, it would be illusive to consider that one single approach might overcome all of the others drawbacks and we shall here insist of the fact that the "model-to-satellite" technique should be consider as a complement to above mentioned approaches.

The paper is organized as follows. In Section 2, a brief review of the use of the "model-to-satellite" approach is offered. Then, we shall focus of some works performed at LMD with the emphasis on the use of the METEOSAT water vapor channel. After a short description of our data set, the narrow band radiative code used in the radiance computations is introduced. The evaluation of the code in clear and cloudy skies, as well as some sensitivity analysis are also presented. In Section 5 examples are discussed. Conclusions and perspectives of the use of this approach are finally offered.

2 A brief review on the model-to-satellite approach

Here follows a brief review of some of the model-to-satellite studies conducted in both the window channel and the water vapor channel for model evaluation in clear and cloudy skies where relevant information is summarized. This is not an exhaustive review. The aim is to brush the portrait of the available tools and their complexity, to briefly survey the expected results from such an approach in order to draw the rationale for the implementation of the approach.

2.1 The early days

In the late 80's came the first application of the model-to-satellite approach. Morcrette [1988; 1991a] investigated the representation of the diurnal cycle of convection over tropical Africa in the ECMWF analysis using METEOSAT-2 IR measurements. Geometry of view, as well as the filter function of the radiometer, is taken into account in the radiation computations. These computation relies on a broad band model spanning the 10.5-12.5 µm region with one band detailed in [Morcrette, 1991b]. These first results underscore some issues with the cloud liquid water content in the analysis. Difficulties associated with the ground emissivity are mentioned. A prognostic liquid water scheme was also assessed in a similar frame in the LMD GCM [Letreut and Li, 1988; Li et al., 1989]. In this case the radiative computation are simplified grey body computations; no dedicated radiative code is used. Completed with ISCCP derived cloudiness estimates, the comparison allows the validation of cloud emissivity dependence upon the prognosed liquid water of the new parameterization. Following a similar direction, Yu et al. [1991] showed that the LMD GCM cloudy sky radiative flux were underestimate with respect to the METEOSAT derived flux in spite of the good representation of the frequency of the mid-latitudes cloud perturbations. Issues concerning the high spatio-temporal resolution of the satellite data versus the climate model resolution are emphasized.

[1] The "model-to-satellite" expression was first coined by J.J. Morcrette [Morcrette, 1988].

2.2 More recent studies and the WV band

More recently, the spatial and temporal variability of the tropical land based convection in the ECMWF analysis were investigated through a model-to-satellite approach using METEOSAT IR observations and a cloud clustering technique [Duvel et al., 1996]. This preliminary study suggests that model and satellite should be compared at a scale large enough so that local spatial mismatch in the modeled fields is not interpreted as a model failure. We shall come back to this point later on. An exciting study was recently put forward by Rikus [1997]. In this case, the method is generalized to the whole tropics using all available geostationary observations in the IR band. Using a simple cloud detection algorithm on the top of the direct radiances comparisons, it is shown that the ITCZ simulated by the BMRC NWP model is less active than observed and suffers from some mismatch issues. Nevertheless, it is emphasized that the simulated imagery complements nicely the forecaster tools.

The so-called water vapor band has been extensively used to assess the climate/ NWP/transport models representation of upper tropospheric humidity *in clear skies* from a variety of platforms [e.g., Soden and Bretherton, 1994; Schmetz and van de Berg, 1994; Salathé and Chesters, 1995; Chen et al., 1996; Pierrehumbert and Roca, 1998]. The description of such approaches is obviously interesting but out of the scope of the present workshop. Hence, we shall here focus on the *total skies* 6.3 μm studies. Rizzi [1994] investigated the impact of the changes of the ECMWF cloud scheme from 1989 to 1993. A model-to-satellite computation in total skies in the HIRS/2 "water vapor" bands on board the NOAA satellites is performed. Using a few days of data and a simple maximum-random overlap assumption grey body like treatment of cloudiness, this prospective study indicated the strong validation potential of the WV channel and underscored the difficulties in interpreting the 6.3 μm radiances in cloudy skies. Total skies simulations of the METEOSAT WV channel were conducted at LMD in order to evaluate the representation of tropical convection of the LMD-GCM [Roca et al., 1997]. Using the broad band radiative code of Morcrette adapted to the 5.7-7.1μm spectral region, monthly mean synthetic WV images were constructed using the daily model outputs. A diagnostic cloud ice/water content from the original radiation code based on the saturation mixing ratio is used. Direct comparisons with METEOSAT observed imagery indicated some bias in the model simulation of the ITCZ characteristics: too wide an ITCZ in summer as well as a cold bias in the radiances is found. Nevertheless the model seasonal cycle was shown to reproduce well the observed evolution of the ITCZ spatial extent and of the subtropical dry subsiding branches of the large-scale tropical circulation.

2.3 Other scales, other satellites: same methods

Even though the present report focuses on climate and NWP models and METEOSAT, it seems interesting to also provide some brief perspectives on different frequencies as well as different models for which the model-to-satellite approach has been or is currently applied.

In clear skies, Shah and Rind [1995] used the Microwave Sounding Unit on board NOAA satellites to investigate the vertical distribution of temperature in the GISS GCM following a model-to-satellite approach. The water vapor band of GOES-7 was exploited towards evaluating the mesoscale model MM5 representation of upper level humidity and indicated the difficulties for the model to reproduce the observed extrema [Spagenberg et al., 1997]. Recently, the METEOSAT radiances in both the IR and WV channel in total skies were used to evaluate the simulation performed with the MESO-NH model of mid-latitude cloud systems that occurred during the FASTEX experiment. Comparisons were conducted at a 75km resolution and radiative computation performed with the code to be presented in the coming sections. The result suggests that the model produces too much cloud material s in the upper level [Chaboureau et al., 2000] (See also section 5).

2.4 Summary

In light of the different studies above mentioned, it appears that different aspects of modeled cloudiness can be assessed by comparing simulated with observed satellite infrared channels imagery (spatial distribution, temporal frequency, diurnal cycle, convective activity intensity, anvil thickness, ...). A number of complexity varying radiation code are used from the simple $\varepsilon\sigma T_{cloud}^4$ to full GCM-like radiative treatments with overlap assumptions. Contribution for the clear sky portion of the region (ground or atmosphere) under considerations has to be evaluated as well as the cloudy radiance. Filter function of the radiometer as well as geometry of view are mentioned as important items towards unbiased comparisons. Space and time scale difference between model and satellite observations deserves caution. The interpretation of the differences is not straightforward and local mismatches between models and observations might not be associated with model failure. This is not to mention the calibration uncertainties. The use of the "water vapor" channel in cloudy skies appears promising for convective cloudiness and we shall now focus on this last spectral band.

3 The METEOSAT "water vapor" channel

Figure 1 shows a 6.3 μm slot taken over the Indian Ocean in March 1999 by the METEOSAT-5 satellite. The colder areas are associated with cloudiness, for instance the Davina cyclone (85E;15S) as well as the

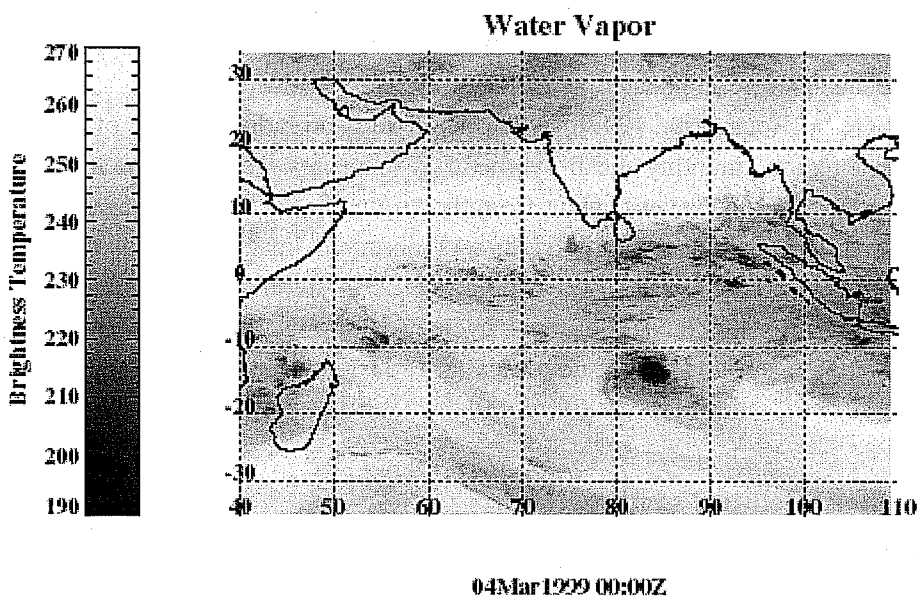

Fig 1 METEOSAT-5 "water vapor" image acquired on the 4th of March at 00:00Z over the Indian Ocean. Radiances are expressed in brightness temperature. Units are Kelvin.

classical characteristics of tropical convection (size varying clusters of cold pixels) are seen. On the clear sky side, the subtropical areas appear as extended warm regions with a fine filamentary texture. Colder clear sky areas, moist regions, are also found in the surroundings of active convection. A quantitative interpretation of these measurements is nevertheless more complicated.

3.1 Interpretation in clear sky

The METEOSAT WV channel in centered over a strong water vapor absorption band (6.27 mm). Hence, in clear sky the signal is influenced by the water vapor burden of the upper troposphere (upper 3mm [Schmetz and van de Berg, 1994]). It is usually associated with the moisture over a thick layer 200-600 hPa as presented in Figure 2. The actual layer from which the radiation is measured by the satellite depends upon the thermodynamic profile of the atmosphere as well as the geometry of the measurement (Figure 2). Many studies have aimed at quantifying this information [Poc et al., 1980; Fischer et al., 1981; Ramond et al., 1981; Schmetz and Turpeinen, 1988; Soden and Bretherton, 1993]. In short, one can relate the WV clear sky brightness temperature to the relative humidity of the 200-600 layer weighted by the cosine of the viewing angle. Warm (cold) brightness temperatures being associated with a relatively dry (moist) mid-to-upper troposphere. This implies that a successful simulation of the clear sky radiance takes into account: the filter function of the satellite (to get the proper contribution function) and the geometry of view (to correct for the angular darkening of the signal away from the nadir). It also indicates that without other information (like the temperature profile) one can only assess the *relative* humidity of the clear atmosphere.

3.2 Interpretation in cloudy sky

Owing to its spectral characteristics, the cloudy sky interpretation of the WV signal can be separated into 3 cloud categories where different mechanisms come into play: low level cloudiness, convective towers and cirrus clouds. The contribution function indicates that the radiation from below 700 hPa hardly contaminates the METEOSAT measurements. Hence it allows to discriminate, say with respect to the window channel, the mid-to-upper cloudiness in the model and to get rid of the surface emissivity issue. In the perspective of assimilation, this would allow to deconvoluate to some extent the influence of the different types of clouds within the model and offers an interesting angle for a dedicated tropical land based convection assimilation procedure. The clouds that actually impact the measurements can further be separated into thick (black) clouds and thin (semi-transparent) cloudiness. In both cases, it is interesting to note that observational study with an airborne radiometer indicates that the cloud emissivity in the WV channel is similar to the IR channel one with a few percent [Sjzewach, 1982]. Radiative computation of the emissivity over the 6.1µm and 11µm for ice clouds indeed confirms these observations [Ebert and Curry, 1992]. As a result, one should expect these two channels to give similar brightness temperatures. One nevertheless observes on the imagery regions where the WV channel is warmer than the IR channel as well as regions of negative differences. The warm water vapor pixels seems to be associated with cumulus convective towers (which are essentially black clouds) overshooting the tropopause where the lower stratospheric increased water vapor at a warmer temperature warms the WV signal [Schmetz, 1997]. On the other hand, it was shown that in the case of non-black cirrus clouds, the colder WV temperature arises from the fact that the contribution to the radiation from the levels below the cirrus are indeed colder (due to water vapor absorption) than in the window channel. In the latter case, the background radiation indeed emanates from the surface and the lower part of the atmosphere at a warmer temperature [Szjewach,1982]. This very principle used to be the operational

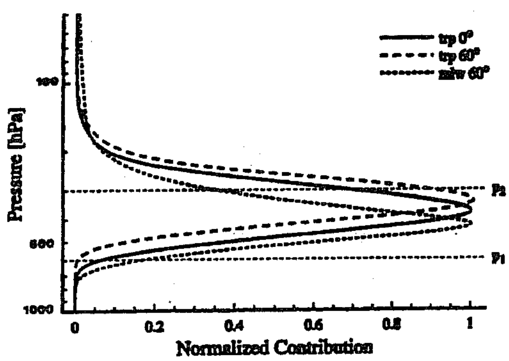

Fig 2 Contribution function of the METEOSAT water vapor channel for standard atmosphere. From Schmetz and Turpeinen (1988).

EUMETSAT technique for semi-transparency cloud height correction. It is also currently used in a more qualitative vein to discriminate the low level cloudiness from the upper level thin clouds [Roca et al., 2000]. In summary, the WV channel interpretation in cloudy sky is delicate but offers interesting perspectives to apprehend the upper level tropical cloudiness in its moist environment.

3.3 The *vicarious* calibration issue

The WV channel on board the METEOSAT series has traditionally been calibrated through a vicarious calibration approach (see Roca, 2000 for a historical perspective on the WV calibration and references). The vicarious approach consists in simulating with a dedicated clear sky radiative code and radio-sondes the radiances that the satellite is expected to measure. Owing to the good linearity of the sensor, and the knowledge of the space radiances, it is then possible to relate linearly the raw numerical count measured by the satellite to the radiative parameters over a full range of conditions including the cloudy scenes. The choice of such an approach is due to the design of the instrument for which the telescope is too large to observe any on-board black body source for reference. Furthermore part of the radiometer should be calibrated on board with the black bodies but up now to the mechanism was not operational. The latest satellite, METEOSAT-7 nevertheless benefits since May 2000 from this mechanism and first analysis indicates a good behavior of the vicarious approach with respect to the new one as well as a substantial gain in the calibration stability overt time [http://www.eumetsat.de]. Estimating the quality of the calibration of such a captor a delicate task but comparisons with other WV channel on-board NOAA satellites suggests a 10% bias in the METEOSAT calibration [Bréon et al., 2000]. The vicarious calibration nevertheless offers some flexibility and recalibration can be readily undertaken when needed [e.g., Roca, 2000] and permits long term homogenization of the METEOSAT series [Picon et al., 1999].

4 Simulating METEOSAT "water vapor" observations in clear and cloudy skies

In order to simulate from the model outputs the radiances in the METEOSAT -WV channel, we use a narrow band model. This section briefly presents the radiative model and its treatment of the above mentioned characteristics of the channel. The uncertainties arising from the use of this code in the radiation computation are then estimated in clear and cloudy skies.

4.1 The narrow band radiative code

The narrow band model (NBM) used here is a modified version of the narrow band model developed by Morcrette and Fouquart to estimate the longwave component of the radiation in a GCM. The original model is fully described in Morcrette and Fouquart [1985]. Here we rapidly mention the modification.

4.1.1 Clear sky

The modified model is a twenty bands model. Ten spectral intervals describe the window channel (10.5-12.5μm) and are evenly distributed. The water vapor continuum effect in this window region is parameterized according to Roberts [1976]. The surface emissivity as well as the surface-air temperature difference are prescribed currently to 1 and 0K. The 10 others intervals corresponds to the WV channel spectral region (5.4-7.6μm). These intervals are unevenly spread in order to better represent the strong vibration-rotation line of water vapor around 6.27μm as well as to resolve most of the filter function characteristics of the geostationary born similar instruments (see figure 3). The oxygen bands effects are supposed to have a weak influence on the radiation [Poc et al., 1980] and are then not parameterized. The absorption due to water vapor is computed with the statistical model of Malkmus. The absorption coefficients of the narrow band model are estimated using a line-by-line model. The temperature dependence of these coefficients is taken into account trough the lines characteristics [Morcrette and Fouquart, 1985].

The model does not yet account for the water vapor continuum effect over this absorption-dominated region. These effects are nevertheless important to the radiation and can reach up to 2K for the HIRS measurements [Stephens 1996]. This is not a major issue here given that the METEOSAT WV observations are highly constrained, through operational calibration for the former METEOSAT, by a radiative code developed at EUMETSAT [e.g., Schmetz and van de Berg, 1994] that does neither take into account this continuum effect.

4.1.2 Cloud sky

The treatment of the cloudy sky radiation follows the gray body hypothesis. The absorption coefficients are from the full long wave spectrum are used for both ice and water clouds [Smith and Shi, 1992]. Otherwise stated, a cloud model is also used to diagnose the cloud water/ice content from the temperature profile as a fraction of the saturation mixing ratio [Morcrette, 1991a]. The classic overlap assumptions (maximum, random and maximum-random) are available for the computation of the radiances. Radiances are computed for an overcast black cloud and then distributed through the emissivity-cloud cover product.

4.1.3 The filter function and geometry of the measurements

The previous comments were associated with the general computation of the flux at TOA that is Wm^{-2}. In order to estimate the satellite filtered radiances ($Wm^{-2}sr^{-1}$), two satellite aspects should be taken into account: the effect of the filter on the radiation and the angular dependence. The spectral radiances over the code Intervals are convoluted with the filter function of the considered radiometer response function. Examples of discretized filters from the WV channel of METEOSAT 2 and 5 are presented in figure 3. These filters indicates that the METEOSAT-5 captor (and following but also METEOSAT-4) is characterized by significant variation of the response over the spectral region. This argues by itself for the use of a narrow band model with an explicit convolution of the filter. The METEOSAT-2 filter is on the other hand, close to a hat function and a broad band model could be used for its simulation. The geometry of the measurement is simply included in the directional radiance computation by replacing the diffusivity factor set to 1.66 in the long wave flux code to the 1/cosθ value ; θ being the angle between the scene and the satellite. The last satellite specific step in the computation concerns the conversion from the radiances to equivalent black body brightness temperatures. Given that we handle filtered radiances, similar filter weighting of the Planck function should be used. Details of the approach are presented in Roca [2000].

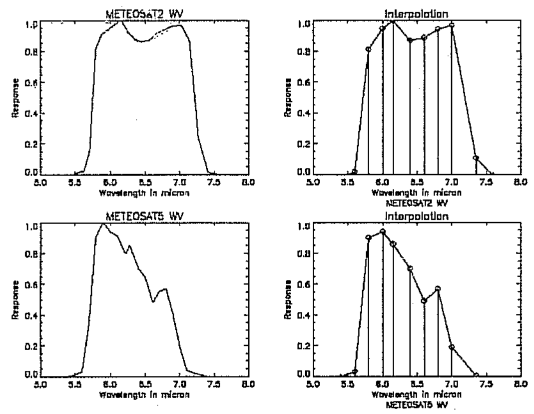

Fig 3: METEOSAT WV channel normalized filter function as a function of wavelength. Top METEOSAT-2. Bottom: METEOSAT-5. Left panels: original function. Right panels. Discretized filter on the narrow band radiative code spectral intervals.

In summary, the NBM model developed at ECMWF offers METEOSAT simulations capabilities including the important satellite characteristics together with the treatment of cloud effects on the radiation. This last step is done in a similar fashion as the way clouds are treated in GCMs. In the next subsection, we provide estimates of the model uncertainties in both clear and cloudy skies.

4.2 Evaluation of the code

In order to perform the comparisons a data set is built. It consists of one slot of a full resolution METEOSAT-5 in February 1996 over tropical Africa together with the corresponding ECMWF analysis of temperature and specific humidity profiles. The EUMETSAT "Climatic Data Set" [http://www.eumetsat.de] consists in the raw outputs of the EUMETSAT clouds classification algorithms. The mean radiance and coverage of different cloudy regions is provided and corrected for semi-transparency over an irregular grid of 32x32 IR pixels. A level flag (low, mid and high levels) is also available. Using the temperature profile of the analysis, a cloudiness profile is built at the resolution of the analysis. Up to 3 regions can be identified over each segment. Owing to the lack of information on the vertical structure of the cloud, we made the assumption that each cloud region corresponds to a block cloud extending vertically from the lowest level were information is available (surface or another cloud) to its given level. This assumption, in essence, does not allow us to test the difference between maximum and maximum-random cloud overlaps in the radiation computations. The total sky radiance that we eventually need to compute are composed of a clear sky part as well as a cloudy part. Hence, the good simulation of the clear sky contribution to the total sky radiation is an important aspect of the method.

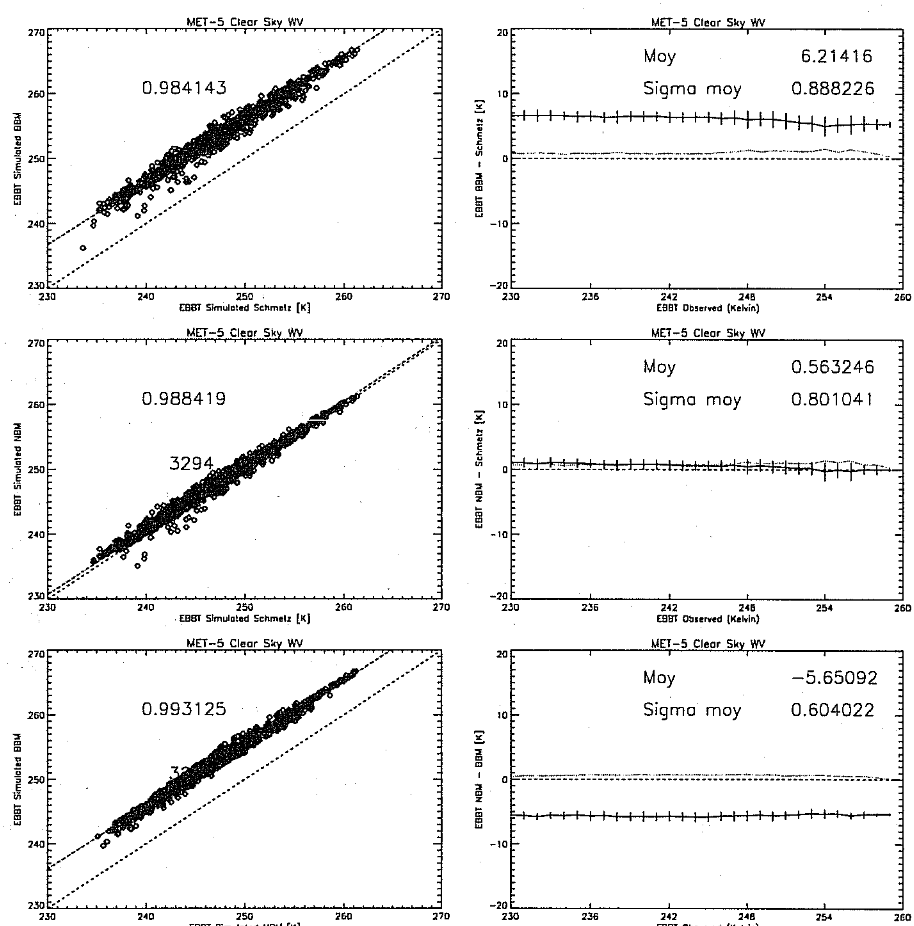

Fig 4: Comparison between the radiative code in clear sky. Left panels: scatter diagram. Right panels: bias (plain) and standard deviation (dotted). 3294 profiles are considered. Correlation coefficients are indicated in the left panels.

4.2.1 Clear sky

Figure 4 shows the comparison using the above data set (around 3000 profiles) over the full range of usually encountered clear sky brightness temperature in the WV channel between the Narrow band model and the EUMETSAT operational calibration code. The latter is a reference for the cleat sky computations by definition. A comparison with a broad band model is also provided to highlight the impact of the filter function characteristics onto the computations. The major result is the excellent agreement between the NBM and the EUMETSAT code over the whole spectrum of brightness temperature: the difference is less than 1K in clear sky. The filter function effect seen in the broad band computations were the difference can exceed 5K. In the METEOSAT-2 case, this effect is around 2K [Roca, 2000]. We now investigate the cloudy sky performances of the radiative model with the accent on the cloud overlap assumption.

4.2.2 Cloudy sky

In order to minimize the methodological bias in the estimation of the cloudy sky simulation, the METEOSAT observations were recalibrated with the clear sky temperature and humidity profiles of the ECMWF. This simple operation allows to adjust the observed radiances to the model clear sky background which contributes to the total sky simulation through partially filled grid boxes and/or semi-transparent cloudiness. Only the grid boxes where non-low clouds are present are considered in this section (around 400 profiles). Simulations are performed using the data set presented above and compared with the recalibrated image. Figure 5 shows the results of the comparisons for the two overlap assumptions maximum and random. The first important features is the fact that not taking into account cloud at all in the simulation yields an error as large as 15K * 5 on the computation. While any of the two overlap assumptions gives a bias better than 5K over the full range of observed *cloudy* brightness temperatures. In the case of the Maximum overlap, the simulations overestimate by 3K the observations for the coldest areas, while the bias vanishes to nothing as the brightness temperature warms. The Random overlap yields opposite results with bias as large as 5K in the warmer cloudy regions. The WV temperature results from the integration of many phenomena and not only the cloud characteristics. In order to shade some lights

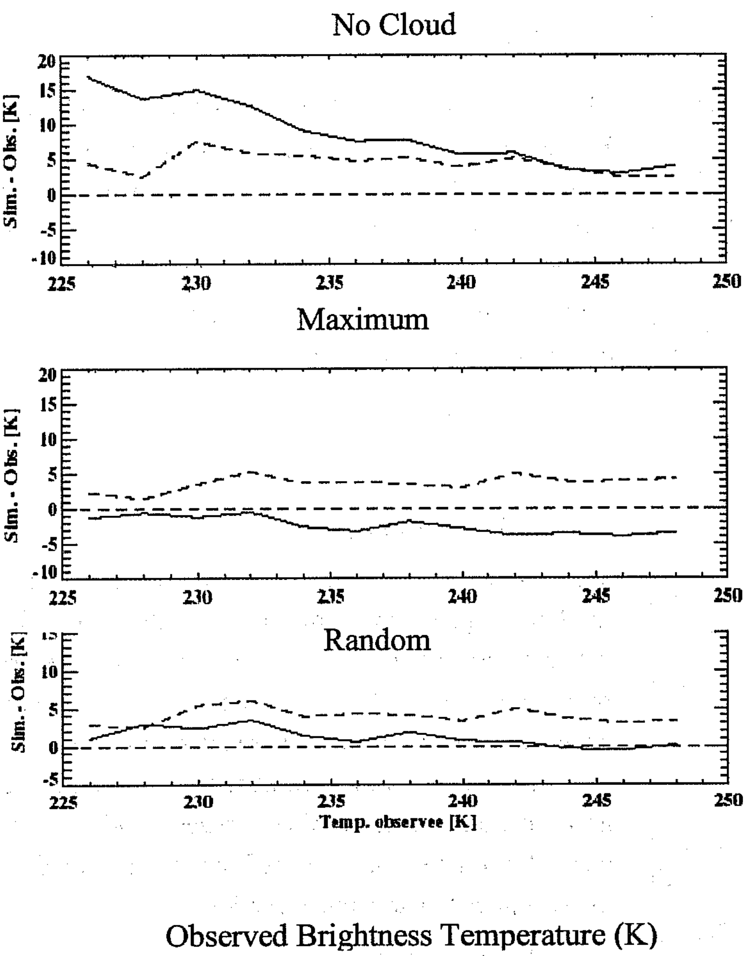

Fig 5: Difference simulation-observations as a function of the observed brightness temperature. Top: no cloud parameterization. Middle: Overlap Maximum. Bottom: Overlap Random. Difference in plain line. Standard deviation are in dashed line. Units are Kelvin. Only grid boxes with mid-to-upper cloudiness are considered.

on the behavior of the simulation with respect to other cloud parameters, Figure 6 presents the same comparisons for a set of other parameters. For the Maximum overlap, the simulation is warmer for the cold and high cloud top but slightly underestimated in the warmer cases. The dependence of the bias on the top cloudiness does not exhibit any particular trend. When the bias is estimated as a function of the cosine of the viewing angle (over a limited region), no particular trend appears indicating a good representation of the geometry of view. For the Random overlap, no trend is seen in the top cloud temperature dependence of the bias. A worsening of the bias is nevertheless revealed as a function of the top cloudiness. The behavior as a function of the cosine of the viewing angle is similar to the previous one. As mentioned above, the overall agreement between the simulation and the observations is good. The Maximum overlap assumption yields a bias around 3K in any configuration. The choice of an overlap assumption to conduct the computation should nevertheless tend to increase the consistency between the treatment of cloudiness in the long wave radiation code of the model and the METEOSAT simulation. Morcrette [1999] underscores the need to have consistent overlap assumptions between the radiation and the precipitation parameterization in the model. In the same vein, we shall here insist on the need to follow the same assumption than the radiation code in the model.

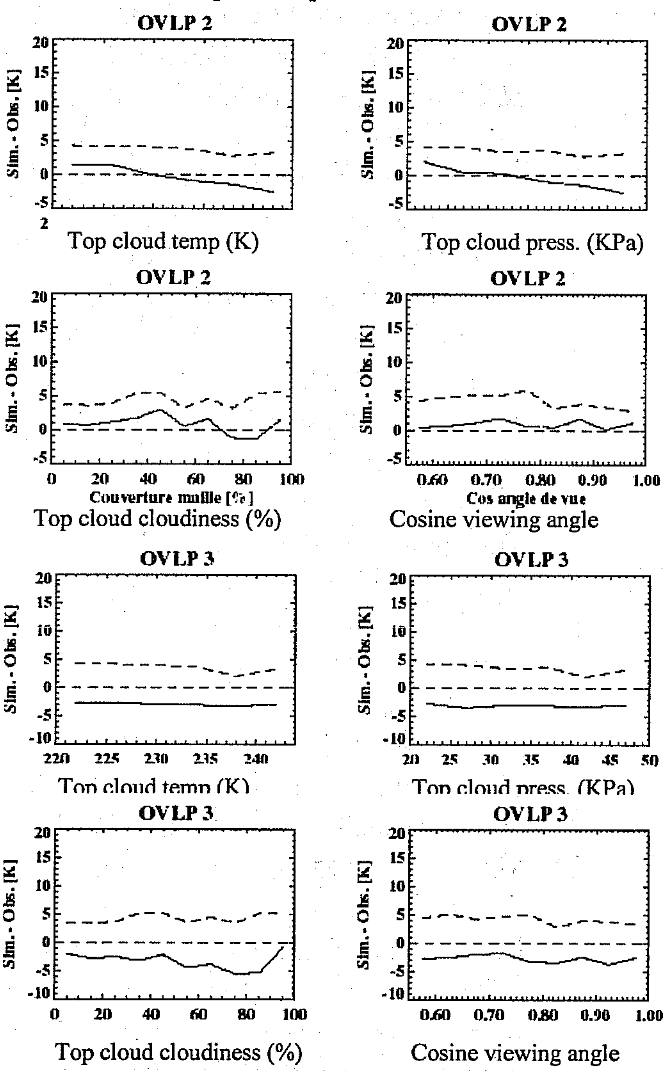

Fig 6: Same as previous figure but the differences are now expressed as a function of different clouds parameters. Overlap 2 corresponds to Maximum. Overlap 3 corresponds to Random Overlap

The narrow band model developed at the ECMWF hence stems as a well adapted radiative model to simulate METEOSAT WV radiances with uncertainties of less than 1K in clear sky and around 3K in cloudy skies. These estimates provide a reference for estimating the significance of the model-satellite differences in the following comparisons.

5 A few examples

This section briefly presents a few examples of the method applied onto different models and for different objectives. Even though the present report highlights the direct comparisons between observed and simulated imagery, it should be beard in mind that these comparisons should be accompanied with further issues and model dedicated diagnostics. The references presented in the text goes towards this direction.

5.1 In the WV band

A ensemble run of 10 members of the LMD GCM is used. The simulation is performed with prescribed climatological SST and corresponds to the control run of a 2xCO^2 climate simulation. The LMD model is detailed in a number of publications [e.g., Sadourny and Laval, 1984; Polcher and Laval, 1994]. The LMD GCM is a grid point model with a full package of parameterizations. Convection is simulated with a combination of a Kuo and a Manabe scheme. This version of the model has a diurnal cycle and an elaborated land surface scheme. The integration was performed at the resolution (3.75° x1.6°) and daily mean outputs of temperature, humidity and cloudiness profiles are used in the radiative transfer computation. Note that the prognostic cloud liquid/ice water profiles are not used to generate the cloudy brightness temperatures but the former ECMWF diagnostic scheme is used instead. This ideal seasonal cycle is compared with a five year averaged seasonal cycle derived from the 1983-1987 METEOSAT-2 observations. This data set was inter-calibrated with respect to METEOSAT-5 along the lines of Picon et al.[1999]. The inter-annual variability of this observed data set is less than the model and satellite differences. More details are provided in Roca [2000].

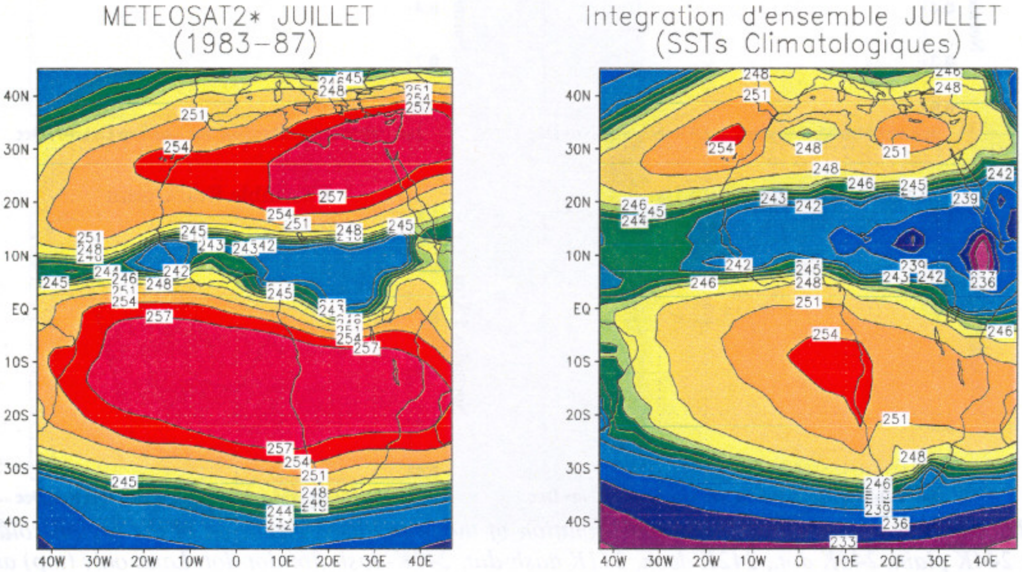

Fig 7: Comparison between METEOSAT observed brightness temperature multi-year monthly mean of July (left) with simulations from a climatological ensemble run of the LMD-GCM (right)

Figure 7 shows the result of the simulation from a month of July together with the observed references. Overall, the GCM reproduces the large-scale features of the African summer climate. The ITCZ (cold temperatures) is surrounded by two warmer regions, which are associated with the subsiding branches of the Hadley circulation. Note the darkening away from the nadir in the simulations which corresponds well with the observed one indicating a good representation of the radiances angular dependencies. The subsiding branches suffers from a cold bias in the simulations suggesting a moist (in terms of relative humidity) bias in the subtropical free tropospheric simulations. The ITCZ mean WV temperatures in the simulations are in agreement with the observations at the radiative code uncertainties. Nevertheless discrepancies are found. Over the ocean, the ITCZ is too wide in the climate simulation. Over the continent, the signature of convective activity extends too much over the Sahara (up to 20N) with respect to the observed ITCZ (12N). A patch of very cold brightness temperature is found over Ethiopia and corresponds to a well known default of the GCM: due to the orography, this very grid point is always convective and the monthly mean signature is consequently too cold with respect to the observations. The seasonal cycle of this simulation was also investigated. As argued in the introduction, the model-to-satellite diagnostic should be accompanied by a more dedicated comparison. In this vein, we here used temperature thresholds to discriminate the ITCZ in both the METEOSAT and simulated imagery and analyzed the seasonal evolution of its spatial extension. Both satellite derived and model generated indicators of the ITCZ spread were normalized independently in order to get rid of the local mismatching in the evaluation procedure. The results are presented in figure 8.

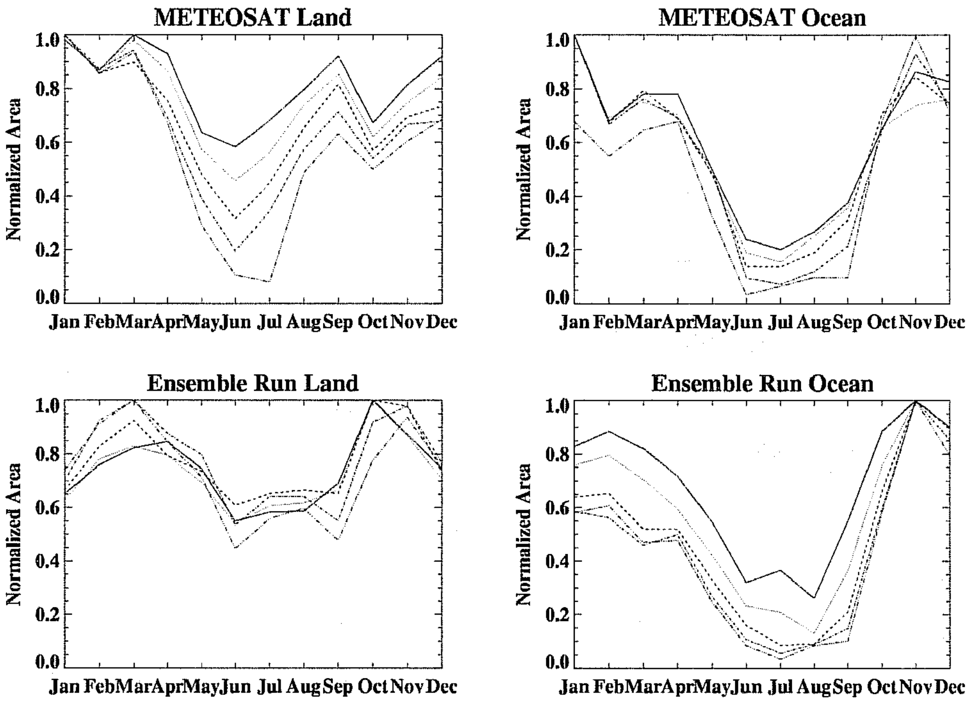

Fig 8: Observed and simulated seasonal evolution of the normalized extension of the region colder than: 244K plain, 243K dot,, 242K dash, 241K dash-dot, 240K-dash-dot-dot-dot. Land only (top) and ocean only (bottom).

The seasonal cycle of the normalized areas is better represented over the ocean than over the continent. Interesting enough, this comparison of the intrinsic behavior of the model with respect to the observations indicates that the model nicely reproduces the narrowing of the ITCZ from winter to summer, and this despite the above mentioned overestimation of the ITCZ spread. Similar comparisons with the LMD5.2 version of the LMD-GCM and a narrow band radiative model were conducted and reported in Roca et al. [1997]. The same conclusions still applies to the GCM and suggest that these discrepancies are rooted in the parameterizations which have not been updated between the two versions. The investigation of the present GCM, but in an AMIP like simulation also confirms the diagnostic and indicates that the climatological trends of the model are found in a given particular year [Roca and Picon, 1997]. This later run was further compared over an extended region including both METEOSAT-3 (over the Americas) and METEOSAT-4 (over Africa) observations. The study indicates that the observed differences of the convective clouds signature at the monthly mean scale onto the WV brightness temperature fields (deeper and colder over the

Eastern Pacific with respect to African squall lines) is not reproduced by the GCM. The land based convection issues similar to that of Africa are found over South America.

5.2 In the IR band

The wide potential of the approach is here further illustrated through a brief discussion of some works that make uses of the IR window channel measurements.

5.2.1 A mid-latitude cloud system

The NBM model was recently used to evaluate a cloud system life cycle simulated by the Meso-NH model during the FASTEX experiment [Chaboureau et al., 2000]. The Meso-NH model is a non-hydrostatic mesoscale model developed at CNRM. The resolution of the model is around 75km. In this case, the simulation does not explicitly treat the convection and runs with a cloud and convective scheme. METEOSAT-6 radiances are used for the comparisons. Two runs are considered: one with the former cloud scheme (A) and one with a more elaborated scheme including the mixed-phase processes (B). The comparisons are briefly discussed here and the reader is referred to the original paper for complement information on the model and its parameterizations.

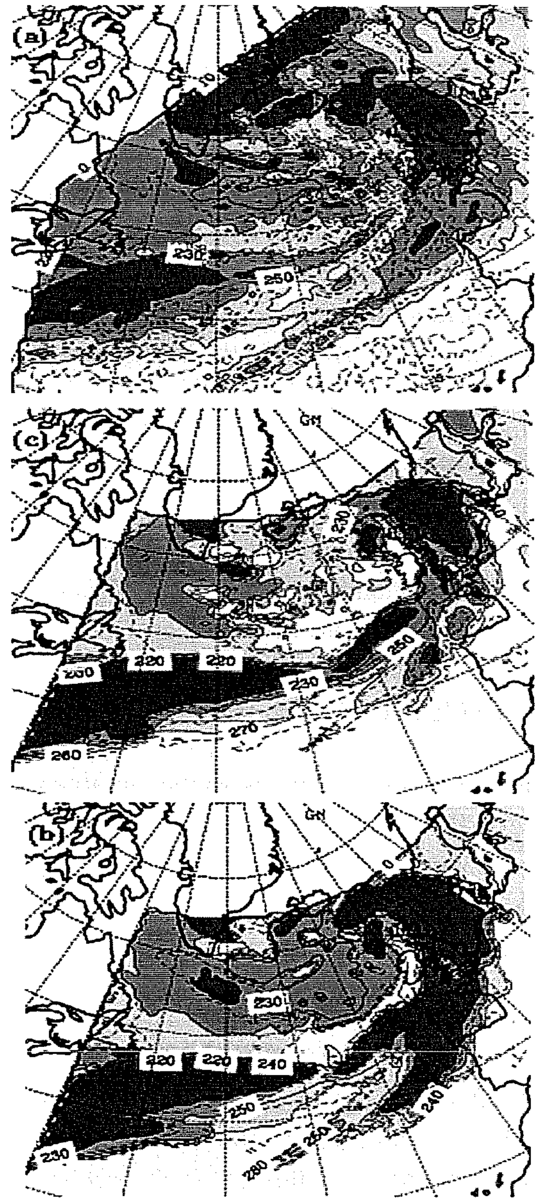

Fig 9: Comparison of METEOSAT-6 and MesoNH simulation of a FASTEX case. Top: Observed IR brightness temperature. Middle: Simulation without the ice phase. Bottom: simulation with the ice phase scheme. For the 17 Feb. 1997 18:00Z. From Chaboureau et al. [2000].

Figure 9 shows the observed METEOSAT IR image together with the two simulations synthetic brightness temperatures. The cloud patterns are well simulated. Nevertheless, over the western part of the region, the simulated temperatures are colder than the observations by around 10K. Comparisons with other clouds products indicates that the model generated temperatures agree better with the observations when the simulated cloud top pressure is close to the TOVS derived pressure. Conversely, off the west coast of the Irish coast, the simulation is too warm by around 20K. The simulation B characteristics are overall similar to the previous one but the discrepancies between the model and the satellite are smaller. For instance the inclusion of ice clouds cools the IR radiances and the temperatures overstimation is now less than 10K. Generally, the worst areas of the simulation indeed becomes closer to the observations even though the upper level cloudiness still suffers from an overestimation with respect to METEOSAT.

5.2.2 Other studies

Klein et al. [1999] investigated the representation in the ECMWF model of a rapidly deepening cyclone occurring in the Northern Atlantic during the 1989 winter. In complement of composite analysis of the cyclone structure, the direct comparisons between GOES-East IR brightness temperatures and ECMWF generated imagery reveals interesting features of the simulation. The model indeed simulates much of the large and small-scales patterns of the cyclone (general shape and location ; rain bands within the organized system). Over the coldest areas of the cyclone, the model simulates too warm IR temperatures, which is suggested to be associated with the high clouds not being optically thick enough. This seems to be the case as well in the tropical areas as shown in the last section.

Bonazzola et al. [2000] investigated the link between infrared brightness temperature, convective activity and horizontal wind divergence. A statistical relationship is established between the LMD model generated IR temperatures and the divergence profiles providing a mean to invert the METEOSAT measurements in terms of dynamics, which can aid in forcing the atmospheric model. Comparisons with METEOSAT WV derived divergence partly validate the approach. This physical-dynamical initialization is shown to improve the model short-term simulation of the Indian Ocean large-scale circulation. Comparisons with ECMWF divergence fields over this region suggest that much can be gained in the perspective of assimilating, in a form or another, the METEOSAT IR cloudy measurements.

Currently, the present radiative code is applied over tropical Africa onto the results of the non-hydrostatic mesoscale model MESO-NH. The squall line simulation benefits from the nested explicit simulation conducted at the 2.5km resolution at CNRM. Hence, comparisons with METEOSAT (in both bands) are performed at the maximum available resolution (5km). Preliminary results indicate that the model simulates well the life cycle of the convective system.

5.3 In both IR and WV channels

The last example concerns the ECMWF analysis over the Indian Ocean during the winter monsoon of 1999. Indeed the international INDian Ocean EXperiment took place in the central Indian Ocean and aimed at a better understanding of the aerosols forcing on the tropical climate. One of the objectives of INDOEX concerns the redistribution of pollutants in the upper troposphere by the convection in the ITCZ. This transport issue will at some point rely upon the quality of the analysis and so, a validation of these has been undertaken. Number of data are available and we here present preliminary comparisons between METEOSAT-5 IR and WV channels and the analysis. This is a part of a more complete satellite based evaluation of the model that will allow to highlight the impact of the increase of the vertical resolution in the operational model which took place in the beginning of March 1999 onto the representation of the hydrological cycle. Computations of the radiances are conducted using the NBM model with the filter function of the METOSAT-5 radiometer. It should be emphasized that here the analyzed temperature and humidity profiles are used together with the forecasted profiles of cloud liquid and ice water. No simplified cloud material diagnostic parameterization is used. The overlap assumption is Maximum-Random. Figure 10 shows the observed and simulated imagery in the two bands for the 4th of March 1999 at 00:00Z. At this time, the analysis ran with 31 levels. First of all, the comparison indicates the very good behavior of the model over this data void area. The major features of the observations, in both the IR and the WV channel are fully captured by the model. Few if any soundings are available over the Indian Ocean and the assimilation mainly relies upon the METEOSAT derived cloud motion winds.

Nevertheless, the match is astonishing: the North-South hemispheres asymmetry in the clear sky window channel is very well represented; the convective clouds signatures in the IR band seems to indicates that the Eastern Africa systems are not deep enough in the simulation. Oceanic convection is too developed in the western part of the Indian Ocean but appears to be underestimated on the Eastern flank of the ocean. In

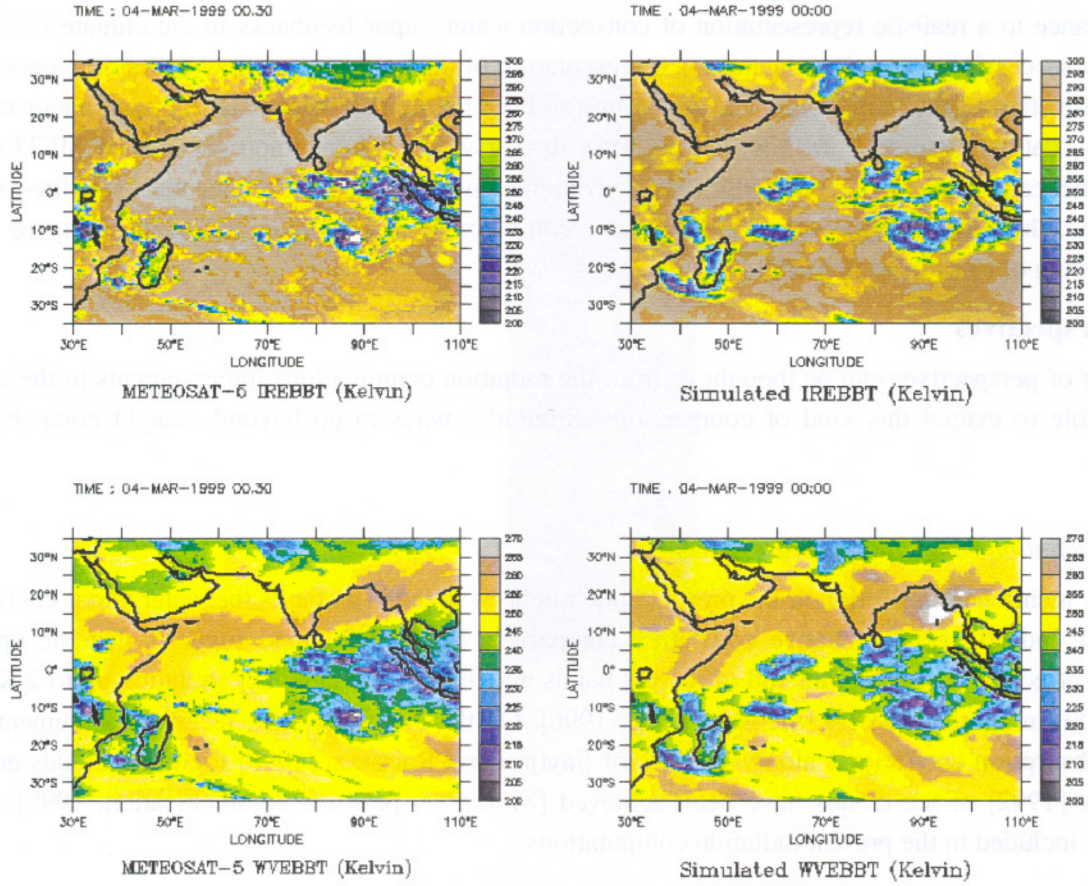

Fig 10: Comparison between METEOSAT-5 and ECMWF operational analysis over the Indian Ocean. The 4th of March 1999 at 00:00Z. Top in the Window channel. Bottom: in the WV channel

particular, the coldest temperatures observed over the Davina Cyclone in the METEOSAT images (T<200K) are not reproduced. The water vapor band allow to focus on the upper levels cloudiness are confirmed the IR based diagnostic. One can also notice the too strong and dry subsidence regions both side of the Maritime continent which deserves further analysis. In brief, the analysis performs well enough so that dedicated analysis of its representation of convective cloud clusters can be undertaken. Ways to perform it are suggested in the conclusions. The warm bias of the very deep systems in the simulation closely resembles to the issue put forth by Klein et al (see previous sub-section) and might also be associated with the high clouds not being opaque enough.

6 Summary and perspectives

To finish, we present a brief summary of the ideas expressed in this report as well as some model validation oriented perspectives. Assimilation perspective is also briefly mentioned.

6.1 Summary

The model-to-satellite approach here designed for tropical cloudiness evaluation makes use of the METEOSAT water vapor channel data. This allows to get rid of some the radiation computation problems associated with the cloud overlapping assumptions. Low level cloudiness effect being negligible on the WV signal, focus on convective systems is increased with such a channel. The WV channel further allows the documentation of the immediate moist environment of convection in the mid-to-upper troposphere which is of importance to a realistic representation of convection-water vapor feedbacks in the climate models. The need for a successful comparison includes a representation of the geometry of view and more importantly of the filter function of the radiometer. The calibration of the satellite measurements is also of major relevance is this raw data comparisons method and deserves further work. Recent improvements of METEOSAT-7 WV channel calibration are encouraging. Used in conjunction with other data source and "satellite-to-model" approaches, the kind of approach presented here complements the toolbox for contributing to a better understanding of cloudiness in models.

6.2 Perspectives

A number of perspectives can be thought of from the radiation computations improvements to the new data set available to extend this kind of comparisons. Similarly, ways to go beyond straight comparisons are proposed.

6.2.1 Radiation computations improvements

As briefly mentioned in Section 4, the present code might be updated as far as the water vapor continuum is concerned. Indeed, recent radiative code inter comparison in the VW band suggests that the up-to-now neglected effect of the continuum and of the O2 bands may impact the clear sky radiation up to 2 K [Soden et al., 2000] in agreement with [Stephens et al., 1996]. On the cloud sky side, recent improvements of the spectral absorption coefficients along the lines of Savijari and Raisanen [1998] for water clouds and Ebert and Curry [1992] of ice clouds have been achieved [Morcrette, personal communication, 1999] and will shortly be included in the present radiation computations.

6.2.2 Satellite data set perspectives

New extended data sets concerning the radiances in the window and water vapor channels have been recently built. The CLAUS european project turned the ISCCP-B3 data into a gridded (0.5° x0.5°) limb-darkening corrected, intercalibrated, spatio-temporal gaps filled, global 10.5-12.5 µm radiances data set. This source of information offers interesting perspectives for model-to-satellite based diagnostics of GCMs. The LMD in collaboration with EUMETSAT turned the METEOSAT-B3 ISCCP WV data into a gridded netCDF product at the 0.625°x0.625° resolution covering the 1983-1995 period with an image every 3 hours. Dedicated efforts were undertaken to homogenize this long term data set in terms of calibration [Picon et al., 1999]. This data set will be soon exploited towards the validation of the AMIP-2 participating models following the approach presented here [http://www.llnl.gov/amip]. The comparisons will be conducted over the seasonal cycle and the inter-annual time scale and concern both convection and upper level subtropical moisture. Owing to the rapidly increasing resolution of NWP and climate models, further tropical convection dedicated diagnosis based on synthetic satellite imagery can be thought of. Comparing the convective systems clusters properties in models and in the observed imagery appears a promising venue to tackle these specific issues [e.g,. Duvel et al., 1996] and will be pursued over the Indian Ocean. Such a perspective might offer extended understanding of the crucial parameterization issue associated with the representation of organized convective systems within increased resolution models [Moncrieff and Klinker, 1997].

6.2.3 Assimilation perspectives

Assimilationwise, this paper shows that the tools for a good representation of the radiation of the WV channel are available. The cloud sensitivity of the WV channel (high and mid level cloud only) appears as an exciting way to dedicated assimilation effort of the tropical convection, especially over land, where the IR measurements is subject of more complexity (surface temperature etc...). As discussed in the working group, the first step towards assimilating cloudy radiances from geostationary satellite is to establish the current forecast system behavior with respect to these radiances through a thorough evaluation using the model-to-satellite technique. The need for a split between precipitating and non-precipitating should accompany this effort in the perspective of extending this kind of diagnostic to the microwave instruments.

The perspective of the METEOSAT Second Generation arrival, scheduled for launch provide up to now inaccessible multi spectral very high spatio-temporal resolution (3km/15min.) observations. Of particular relevance to the present study are the much awaited two WV channels of MSG that will shade light on the vertical characteristics of the tropical atmosphere both on the moisture profiles as well as the convective clouds height distribution. The present code should be able to handle the narrower second WV channel of MSG.

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