Revue des Energies Renouvelables Vol.15 N°4 (2012) 671 – 679

Simulation of a clear sky satellite image in water vapor and infrared satellite M.S.G channel's

K. Bouchouicha [1*] and N.I. Bachari [2†]

[1] Unité de Recherche en Energies Renouvelables en Milieu Saharien, URERMS
Centre de Développement des Energies Renouvelables, CDER
B.P. 478, Route de Reggane, Adrar, Algérie

[2] Université des Sciences et de la Technologie Houari Boumediene, USTHB
B.P. 32, El-Alia, Bab Ezzouar, Alger, Algérie

(Reçu le 28 Novembre 2012 – accepté le 28 Décembre 2012)

Abstract - *Radiative transfer models are an important tool for the scientific community. Such models simulate the radiative transfer processes of the atmosphere at a given wavelength or spectral region for a given set of surface and atmospheric conditions. It is used to simulate the radiances and brightness temperatures of various satellite sensors. RTTOV stands for 'Radiative Transfer for TIROS Operational Vertical Sounder' and refers to the computational efficient algorithms that have been developed by Eumetsat within the framework of SAF to meet the requirements of the operational data assimilation system. The aim of our work is to allow a simulation of infrared image of MSG2 satellite, by the RTTOV model, starting from the temperature and humidity profiles resulting from a weather forecasting model. The results are satisfactory, the evaluation have shown that the RTTOV model is effective enough for water vapor channels, while it appears less effective for the rest of the channels.*

Résumé - *Les modèles de transfert radiatif sont d'importants outils pour la communauté scientifique. Ces modèles simulent les processus du transfert radiatif de l'atmosphère à une longueur d'onde donnée ou à une région spectrale pour un ensemble donné de conditions de surface de l'atmosphère. Il est utilisé pour la simulation des radiances et des températures de brillance de divers capteurs satellitaires. Le modèle RTTOV est synonyme de 'Transfert Radiatif pour le Sondeur Opérationnel Vertical Tiros' et renvoie à des algorithmes de calcul efficaces, qui ont été développés par Eumetsat dans le cadre du SAF, afin de répondre aux exigences du système d'assimilation de données opérationnelles. Le but de notre travail est de permettre une simulation de l'image infrarouge du satellite MSG2, par le modèle RTTOV, à partir des profils de température et d'humidité résultant d'un modèle de prévision météo. Les résultats sont satisfaisants. L'évaluation de ces résultats, a montré que le modèle RTTOV est efficace pour les canaux de vapeur d'eau, même s'il semble très peu efficace pour le reste des canaux.*

Key words: Brightness temperatures - MSG2-SEVIRI - Radiance - Radiative transfer models - RTTOV.

1. INTRODUCTION

The radiative field emitted by the system Ground-Atmosphere, observed from the space by a radiometer of type SEVIRI results from a complex interaction between the radiation and the vertical distribution of temperature, moisture and the atmospheric composition, which represent key parameters of the modeling of the atmospheric

* k.bouchouicha@gmail.com
† bachari10@yahoo.fr

radiative transfer. This allows us through a radiative transfer model to simulate the radiances as they are collected by the radiometers on board satellites. The simulation of infrared radiances and brightness temperature by these models allows indirect access to input information extremely interesting for the scientific community.

In order to test this capacity, EUMETSAT 'European Organization for the Exploitation of Meteorogical Satellites' developed within the framework of SAF 'Satellite Application Facility' the RTTOV model 'Radiative Transfer for TIROS Operational Vertical Sounder', which in the beginning is developed with the ECMWF 'European Center for Medium Range Weather Forecast' in the years 1990 for sounder TOVS 'Tiros Operational Vertical Sounder', which allows us to simulate the radiances and brightness temperatures (T_b) of various satellite sensors.

The aim of our work is to allow a simulation the radiance and brightness temperature of infrared MSG2-SEVIRI sensor, using the RTTOV model, starting from the profiles of temperature and humidity resulting from the model of weather forecasting ALADIN 'Aire Limitée Adaptation Dynamique Développement InterNational', used into operational at the Office National Weather 'ONM'.

In order to evaluate RTTOV model performance, we use the infrared image of sensor MSG2-SEVIRI, also received on the level of the Office.

The model has been tested under different atmospheric conditions, but however showed a strong potentiality of infrared radiances simulation of SEVIRI sensor. The results are satisfactory, the evaluation have shown that the RTTOV model is effective enough for water vapor (W_v) channels, while it appears less effective for the rest of the channels.

2. DATA USED

We chose initially to validate the simulated radiance and brightness temperature of RTTOV model using as observation the MSG2-SEVIRI data, in this context, we have prepared the following data:

2.1 The ALADIN model data

ALADIN is a short range NWP 'Numeric Weather Prediction' hydrostatical model developed in 1992 by a consortium of European country (French, Belgium, Hungry,.) [1]. In 2005 Algeria became a member ship of the consortium and the ALADIN version used in this work is the operational version of. The model centred on Algeria covers an area of 2800×2800 km^2 at a horizontal resolution of 0.1×0.1 deg, the vertical discritization is 60 levels and boundary conditions are taken from French meteorological global model 'ARPEGE: Action de Recherche Petite Echelle Grande Echelle'. [2]

2.2 The satellite data

Meteosat Second Generation 'MSG' is a new generation of the geostationary satellite developed by European Space Agency 'ESA' and EUropean organization for the exploitation of METeorological SATellite 'EUMETSAT'. MSG2 main payload is the optical imaging radiometer, the so called Spinning Enhanced Visible and Infrared Imager 'SEVIRI'. SEVIRI has 12 spectral channels covering from visible to infrared [3], and provides measurements of the Earth-disc every 15 minutes at fixed view angles, [making it particularly suitable for validation of simulated radiance and Brightness temperature.

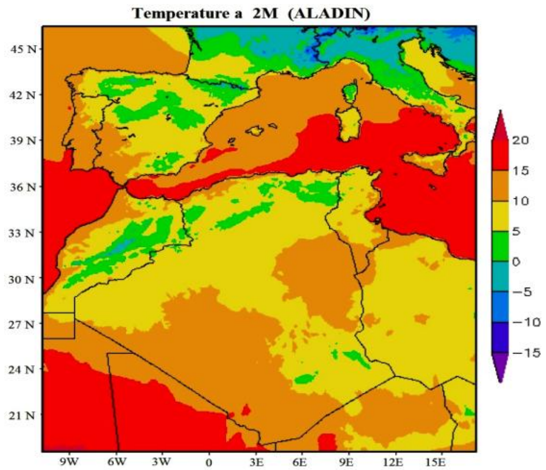

Fig. 1: Sample of 2M Temperature (°C) output ALADIN/Algeria model

In first time, we are particular interest by validation of four channels: Water Vapor (W_v) 6.2 and 7.3 µm, and the InfraRed (IR) 12.0 and IR 13.4 µm.

The following image is the observation brightness temperature in the two infrared channels.

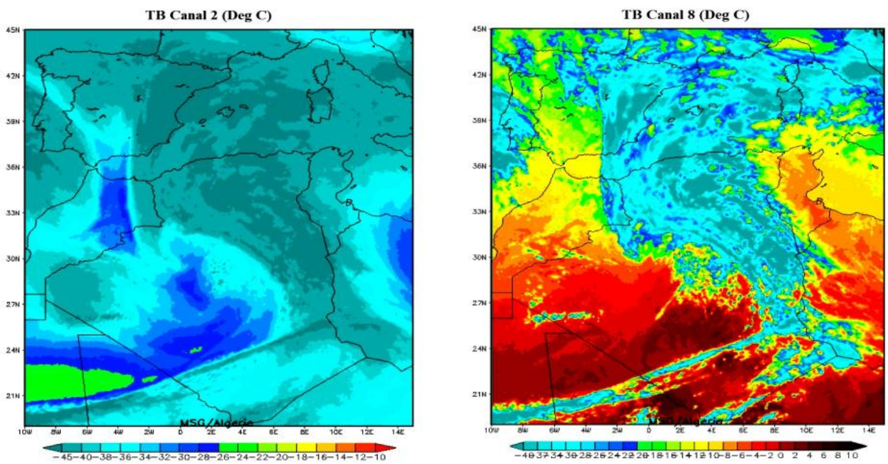

Fig. 2: T_b observed in order W_v 6.2 and T_b IR 12.0 µm channel

3. RTTOV MODEL

RTTOV9.1 is a development of the fast radiative transfer model for TOVS, RTTOV, developed with the ECMWF 'European Center for Medium Range Weather Forecast' in the years 1990 for sounder TOVS 'Tiros Operational Vertical Sounder', which allows us to simulate the radiances and brightness temperatures of various satellite sensors. Its source code developed in Fortran 90 language. [4]

This model is based on the interaction of electromagnetic radiation with the different components of the atmosphere. Radiation is a matter of multiple processes and effects of atmospheric properties during its transfer from surface to space.

$$R_{\upsilon}^{Clr}(\theta) = \varepsilon_{\nu}(\theta) \times \tau_{\nu}^{\uparrow}(P_0,\theta) \times B_{\nu}(T_{P_0}) + [1-\varepsilon_{\nu}(\theta)] \times \tau_{\nu}^{\uparrow}(P_0,\theta) \times \int_{p_t}^{p_0} B_{\nu}(T_p) \frac{d\tau_{\nu}^{\downarrow}(P,\theta)}{dP} dP + \int_{p_0}^{p_t} B_{\nu}(T_p) \frac{d\tau_{\nu}^{\downarrow}(P,\theta)}{dP} dP \quad (1)$$

For solving the equation of RTTOV radiative transfer model, some approximations derived from statistical calculations for clear sky radiances. The transmittances are calculated through the use of linear regressions, predictors of base are defined from the temperature, pressure and the amount of gas absorbent with the direction of propagation θ [9].

The total radiance captured by the radiometer for a channel i in a wavelength range (or wave number), using the spectral response function of the channel, given by:

$$R_i = \frac{\int_{\lambda} \phi_{\lambda} \times R_{\lambda}(p_0,\mu,\varphi) \times d\lambda}{\int_{\lambda} \phi_{\lambda} \times d\lambda} = \frac{\int_{\nu} \phi_{\nu} \times R_{\nu}(p_0,\mu,\varphi) \times d\nu}{\int_{\nu} \phi_{\nu} \times d\nu} \quad (2)$$

4. RESULTS AND DISCUSSION

4.1 Resultats

In order to evaluate the RTTOV outputs model, several experiments were undertaken. A set of eight simulations was carried out, covering different weather situations, in order to have a large representation.

Synthetic IR and W_V radiances are generated using RTTOV-7.8 (Chevallier *et al.*, 2001). This RTM uses profiles of temperature, specific humidity and model surface variables.

Two dates have been selected to be presented, August 7, 2011 and January 4, 2012. The analysis of the model ALADIN is served to carry out simulations.

We try in the following paragraphs devalue these simulations, we present the results, considering a non-cloudy atmosphere under realistic conditions. All simulations were first assessed visually, then using statistical scores, after the exclusion of pixels considered cloudy, by using a cloud detection algorithm [10].

The statistical parameters computed are: the root mean square error ‘ RMSE ’, the ‘ BIAS’ and correlation coefficient ‘ R ’ according these equations [11].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - S_i)^2}{N}} \quad (3)$$

$$BIAS = \frac{\sum_{i=1}^{N}(O_i - S_i)}{N} \quad (4)$$

$$R = \frac{\sum_{i=1}^{N} (O_i - \bar{O}) \times (S_i - \bar{S})}{\sqrt{\sum_{i=1}^{N} (O_i - \bar{O})^2 \times \sum_{i=1}^{N} (S_i - \bar{S})^2}} \quad (5)$$

where, O_i, pixel values of the observed image and S_i, pixel values of the synthetic image.

1- Situation 01: August 7, 2010

The visual analysis of figures (Fig. 3) and (Fig. 4) shows that the RTTOV model reproduce with realistic way the spatial configuration both in the W_v 6.2 µm channel and the IR 10.8 µm channel, Excepting areas or model overestimate the T_b, and that corresponds to the presence of a cloud cover that is very important in these areas, the T_b observed are very cold, and are not considered T_b of land surfaces.

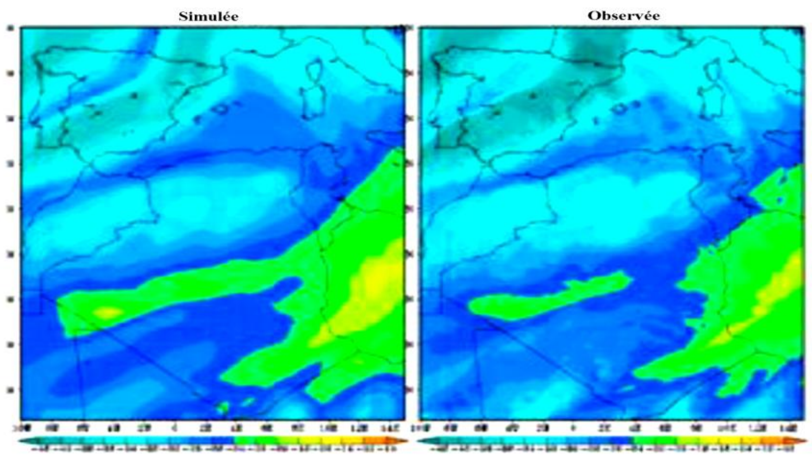

Fig. 3: T_b observed in left and simulated in right of W_v channel 6.2 µm (august 7, 2010 at 00:00)

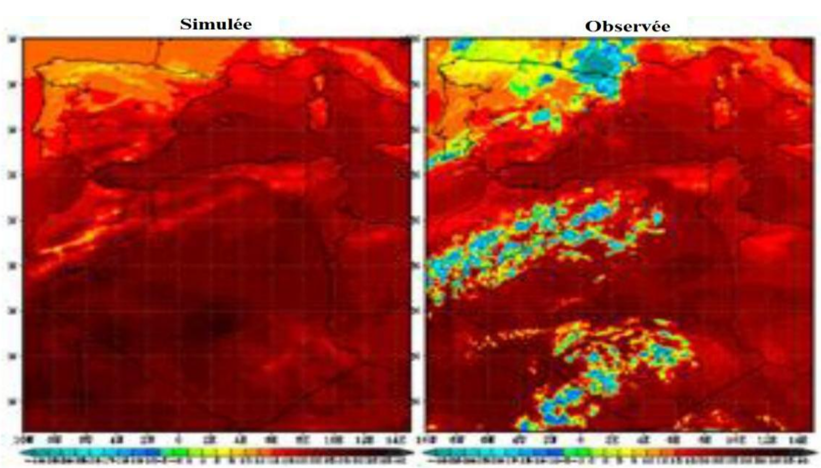

Fig. 4: Observed & simulated of IR channel 12,0 µm (august 7, 2010 at 00:00)

The statistical results shows well a good correlation greater than 0.88 between observed and simulates data for W_V and IR channel. The ‘BIAS’ varies between -0.3 and 1.5°C and an ‘RMSE’ less than 2°C for the W_V channels. Negative values of ‘BIAS’ indicate that observed values over-estimates simulated values (Fig. 5, **Table 1**).

On the other hand and the ‘BIAS’ and the ‘RMSE’ are slightly higher for IR channels l.

Table 1: The statistical result August 7, 2010

Channel	‘BIAS’	‘RMSE’	‘R’	‘N’
W_V 6.2	1.08	1.56	0.9587	31844
W_V 7.3	-0.3	1.16	0.9537	35930
IR 12.0	2.24	3.22	0.8979	49147
IR 13.2	3.68	3.94	0.9465	40700

This table resumed a result obtained for all channels. Is clear we can obtain a good image simulated but the result’s in not similarly for all channels.

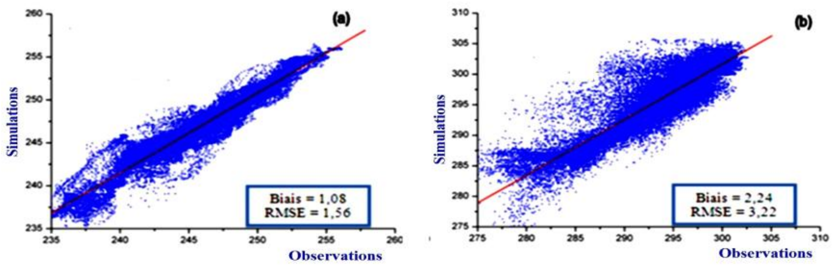

Fig. 5: Correlative analysis between real image and simulated image of W_V channel 6.2 µm and IR 12.00 channel’s (august 7, 2010 at 00:00)

In this figure, we remark the linear relation between simulated image and real image.

2- Situation 02: January 4, 2011

Such as the situation 01, the visual analyze of figures (Fig. 6) shows a good similarity between MSG observed and RTTOV simulated images.

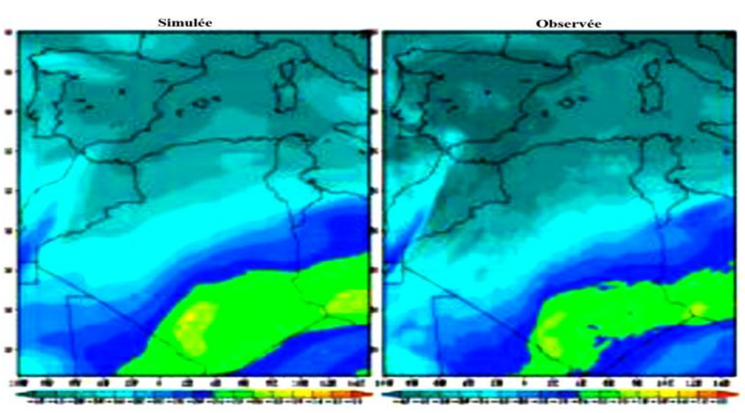

Fig. 6: Same as Fig. 3 but for January 4, 2011

The figure 6 shows a much wider area on the upper part of the map, in which the model overestimated the ‘ T_b ’, which corresponds to the presence of a vastly cloud system.

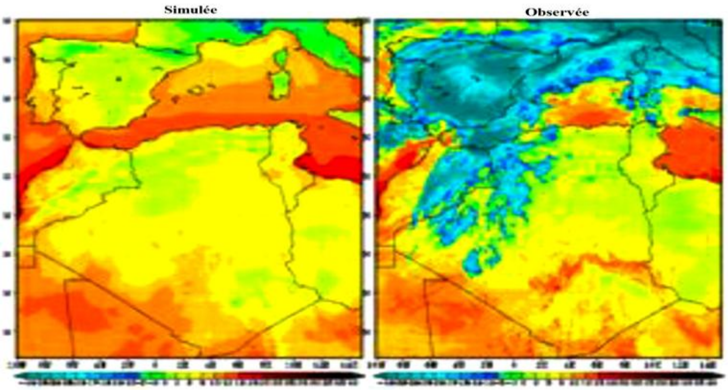

Fig. 7: Same as Fig. 4 but for January 4, 2011

We observed a best score than the situation 01 for the W_V channels. The correlation coefficient reaches 0.98.

For the IR channels, we remark a light degradation in correlation coefficient in comparison with last simulation, with a slight decrease in the ‘ RMSE ’ and the ‘ BIAS’. (Fig. 8, **Table 2**).

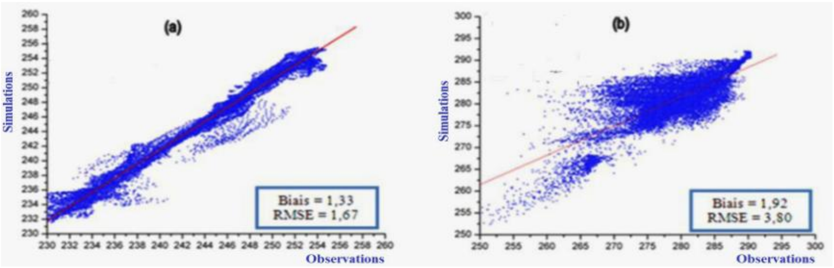

Fig. 8: Same as Fig. 5 but for January 4, 2011

In this situation we obtained a very good linear relation for water vapor channel. The simulation is better than august situation. The statistical analysis is resumed in following **Table 2**.

Table 2: Same **Table 1** but for January 4, 2011

Channel	‘ BIAS’	‘ RMSE ’	‘ R ’	‘ N ’
W_V **6.2**	1.28	1.61	0.9848	19791
W_V **7.3**	0.2	0.89	0.9879	25387
IR 12.0	1.15	2.89	0.8336	23726
IR 13.2	2.98	3.33	0.9356	29527

4.2 Discussion

On all of the results, the RTTOV model well reproduced ‘ T_b ’ maps, in terms of space thermal structure. Excepting areas or model overestimate the ‘ T_b ’, and that corresponds to the presence of a cloud cover that is very important in these areas, where the ‘ T_b ’ observed are very cold, and is not considered ‘ T_b ’ of land surfaces.

The quality of the results remains satisfactory, with correlation coefficients which are on average higher than 0.8, the biases that do not exceed the 2.5 °C and the ‘ RMSE ’ are below 4 °C.

The high differences of ‘ T_b ’ simulated and observed can partially be explained by the presence of residual clouds in the observed images, That is to say that the algorithm of cloud detection is not perfect and there remain pixels where the clouds are not detected.

5. CONCLUSION

The object of this work was being to show the capacity of the RTTOV model to reproduce the clear sky radiances and the brightness temperatures of MSG2-SEVIRI sensor, by using temperature and humidity profile from the outputs of the atmospheric model of weather forecasting ALADIN, used operationally in the national office of Meteorology ‘ONM’.

A set of simulations has been launched for various weather conditions, then a statistical evaluation of each situation was realized, reported on the MSG2-SEVIRI sensor observations for water vapor and infrared channels ‘IR and W_v ’ Approved as at the ONM. The score statistics were calculated after the exclusion of pixels considered cloudy.

A set of simulations has been launched, for different weather situation, then a statistical assessment of each situation was carried out, this reported to observations of the MSG2-SEVIRI sensor for water vapor and infrared channels ‘IR and W_v channels’ also received on the level of the ONM. Statistical scores were calculated after excluding pixels with are considered as cloudy, this is applying cloud detection algorithm.

The model, however, showed a strong potential for simulation, because the results are generally satisfactory, with correlation coefficients which are on average higher than 0.8, the biases that do not exceed the 2.5 °C and the ‘ RMSE ’ are below 4 °C.

The works completed during this study showed the ability of the RTTOV model to simulate the brightness temperatures and the radiances of then SEVIRI infrared channels. As mentioned previously in chapter 5, cloudy pixels detection algorithm does not appear to remove the cloud cover in full. Therefore the cloudy pixels affect the quality of the statistical results.

REFERENCES

[1] G. Radnoti, ‘*A Spectral Limited-Area Formulation with Time-Dependent Boundary-Conditions Applied to the Shallow-Water Equations*’, Monthly Weather Review, Vol. 123, N°7, pp. 2229 - 2249, 1995.

[2] R. Bubnova, G. Hello, P. Benard and J.F. Geleyn, ‘*Integration of the Fully Elastic Equations Cast in the Hydrostatic Pressure Terrain - Following Coordinate in the Framework of the*

ARPEGE/Aladin NWP System', Monthly Weather Review, Vol. 123, N°2, pp. 515 – 535, 1995.

[3] Eumetsat, '*La Chronique de l'Organisation Européenne de Satellites Météorologiques*', Image, N°26, Mai 2007.

[4] R. Saunders, M. Matricardi and P. Brunel, '*An Improved Fast Radiative Transfer Model for Assimilation of Satellite Radiance Observations*', Quarterly Journal of the Royal Meteorological Society, Vol. 125, N°556, pp. 1407 – 1425, 1999.

[5] M. Matricardi, F. Chevallier and S. Tjemkes, '*An Improved General Fast Radiative Transfer Model for Assimilation of Satellite Radiance Observations*', European Centre for Medium-Range Weather Forecasts, Research Department, Reading, United Kingdom, Technical Memorandum N°345, May 2001.

[6] R. Saunders, E. Andersson, P. Brunel, F. Chevallier, G. Deblonde, S. English, M. Matricardi, P. Rayer and V. Sherlock, '*RTTOV-7 Science and Validation Report*', Technical Report, 1.2, Eumetsat, 2002.

[7] R. Saunders and P. Brunel, '*RTTOV-8-7 Users Guide*', NWPSAF-MO-UD-008, V 1.9, Technical Report 1.9, Eumetsat, 2005.

[8] R. Saunders and P. Brunel, '*RTTOV-8-7 Users Guide*', Met Office and Météo - France CMS, 2005. http://www.metoffice.gov.uk/research/interproj/nwpsaf/rtm/.

[9] V. Planta – Broqua, '*Intérêt des Radiances Meteosat pour la Vérification des Modèles AROME et ALADIN*', Rapport de Stage de Fin d'Etudes, DPREVI/Compas Météo-France, 2008.

[10] O. Diop, '*Détection de Nuages de Poussière dans les Images Météosat à l'aide des Attributs de Textures et de la Fusion de Segmentations: Application à la Zone Sahélienne du Continent Africain*', Thèse de Doctorat, Institut National des Sciences Appliquées, Rennes, 2007.

[11] B. Ebert, '*Verification of Spatial Forecasts*', Bureau of Meteorology Research Centre, Melbourne, Australia, 2002.