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WEATHER FORECASTING FOR EASTERN AMAZON WITH OLAM MODEL

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ABSTRACT

The OLAM model has as its characteristics the advantage to represent simultaneously the global and regional meteorological phenomena using the application of a grid refinement scheme. During the REMAM project the model was applied for a few case studies to evaluate its performance on numerical weather prediction for the eastern Amazon region. Case studies were performed for the twelve months of the year of 2009. The model results for those numerical experiments were compared with the observed data for the region of study. Precipitation data analysis showed that OLAM is able to represent the average mean accumulated precipitation and the seasonal features of the events occurrence, but can't predict the local total amount of precipitation. However, individual evaluation for a few cases had shown that OLAM was able to represent the dynamics and forecast a few days in advance the development of coastal meteorological systems such as the squall lines that are one of the most important precipitating systems of the Amazon.
Keywords: Weather forecasting, OLAM, Amazon

RESUMO: PREVISÃO PARA O LESTE DA AMAZÔNIA COM O MODELO OLAM
O modelo OLAM tem como característica a vantagem de representar simultaneamente os fenômenos meteorológicos de escala global e regional através de um esquema de refinamento de grades. Durante o projeto REMAM, o modelo foi aplicado para alguns estudos de caso com objetivo de avaliar o desempenho do modelo na previsão numérica de tempo para a região leste da Amazônia. Estudos de caso foram feitos para os doze meses do ano de 2009. Os resultados do modelo para estes casos foram comparados com dados observados na região de estudo. A análise dos dados de precipitação mostrou que o modelo consegue representar a distribuição média da precipitação acumulada e os aspectos da sazonalidade da ocorrência dos eventos, mas não consegue prever individualmente a acumulação de precipitação local. No entanto, avaliação individual de alguns casos mostrou que o modelo OLAM conseguiu representar dinamicamente e prever, com alguns dias de antecedência, o desenvolvimento de fenômenos meteorológicos costeiros como as linhas de instabilidade, que são um dos mais importantes sistemas precipitantes da Amazônia.
Palavras-chave: Previsão numérica de tempo, OLAM, Amazônia

1. INTRODUCTION

Rainfall prediction at the tropical regions is very difficult because these regions are characterized by high downward solar radiation and atmospheric moisture producing strong turbulent fluxes and convection that are highly non-linear phenomena (Cotton et al, 2011).

Remote effects are constantly modifying the tropical weather. For instance, the seasonal migration of the Inter-tropical Convergence Zone (ITCZ) sets an important large scale variability that modifies the local meteorological conditions. In addition, the Madden-Julian Oscillation (MJO, Madden and Julian, 1972) can have important effects on the local precipitation (Souza and Ambrizi, 2006). Further climate variability may occur driven by the Pacific and Atlantic sea surface temperature conditions. For example, during the El Niño conditions, when the west Pacific is anomalously warm, precipitations usually are lower over the eastern Amazon (Grimm, 2003; Marengo, 2004). In addition, data analysis shows that a warm tropical Atlantic can be associated with weaker wind shear and less precipitation over the region (Nobre and Shukla, 1996).

Furthermore, the surface heterogeneity has an important effect on the local atmospheric circulations and rainfall distribution. The eastern Amazon is bounded by the Atlantic Ocean; the region is crossed by large rivers; it has a landscape covered by heterogeneous vegetation; and it is covered by topographic hills. These surface heterogeneities can produce horizontal temperature gradients that develop local atmospheric circulations affecting the convection and precipitation. Examples of these circulations are the river breeze (Silva Dias et al., 2004), the effects of topography on the convection development (Silva Dias et al., 2002), the cloud streets formation (Ramos da Silva et al., 2011); and the sea breeze and its influence on the squall lines formation (Cohen et al., 1995).

In general, the global models don´t have enough spatial resolution to represent the mesoscale meteorological systems. Otherwise, the limited area models have better spatial resolution, but are slave of atmospheric boundary conditions from the global models. To fully represent the local mesoescale features and to account for the influence of remote and large scale systems simultaneously, a new modeling approach has to be applied.

The new Ocean-Land-Atmosphere Model (OLAM) has this capability. This model can represent the global atmospheric circulation using a hexagonal (or triangular) coarser icosahedral grid and simultaneously have an improved regional resolution through a grid refinement (Walko and Avissar, 2008a, b; Ramos da Silva et al., 2009). Recent studies with OLAM for the South America and the Amazon had shown good results on representing the regional climate variables (Medivgy et al., 2008, 2011).

During the project REMAM (*Rede de Monitoramento e Pesquisa de Fenômenos Meteorológicos Extremos na Amazônia*) a series of modeling experiments were performed with OLAM to evaluate its forecasting skill for the eastern Amazon.

The main goal of this study was to evaluate the OLAM model performance for several environmental conditions. First, the region of study, the model characteristics, and the numerical experiments are briefly described. Then, the results for all the case studies are evaluated trough a comparison with observed data. Finally, the model characteristics and performance are discussed.

2. METHODOLOGY

2.1 Region of study

The eastern Amazon region is located near the equator at the east of the South America (Figure 1). The Amazon River crosses the region and reaches the Atlantic Ocean at the east of the domain. The major land cover is rainforest, but urbanization and deforestation is modifying the landscape of the region. Topography of the region can reach about 700 meters over the north and south of the domain (Figure 1b). Dynamically, the atmospheric region is dominated by the trade winds that transport moist air from the Atlantic Ocean into the continental areas. The interface between land and the ocean sets local breeze circulations and convection producing squall lines that can propagate westward over the Amazon basin (Cohen et al., 1995). These squall lines are the major systems that produce the precipitation distribution over the Amazon basin (Cohen et al., 1995).

2.2 OLAM model

The OLAM model is an evolution of the mesoscale Regional Atmospheric Modeling System (RAMS, Cotton et al., 2003) but improves in several aspects such as with the possibility of a global grid that uses an icosahedral structure (Figure 1). Higher resolution can be achieved using a grid refinement for the region of interest. Therefore, the model is design with a unique grid and avoids problems that occur on the usual grid nesting schemes. The dynamical core for the grid structure can have a triangular or hexagonal grid mesh. The prognostic equations are solved using the finite volume technique and conserves momentum, mass and energy (Walko and Avissar, 2008a, b).

The major physical parametrizations adopted by OLAM are the same used by the RAMS model including the land-vegetation-atmosphere interaction (Walko et al., 2000a), the

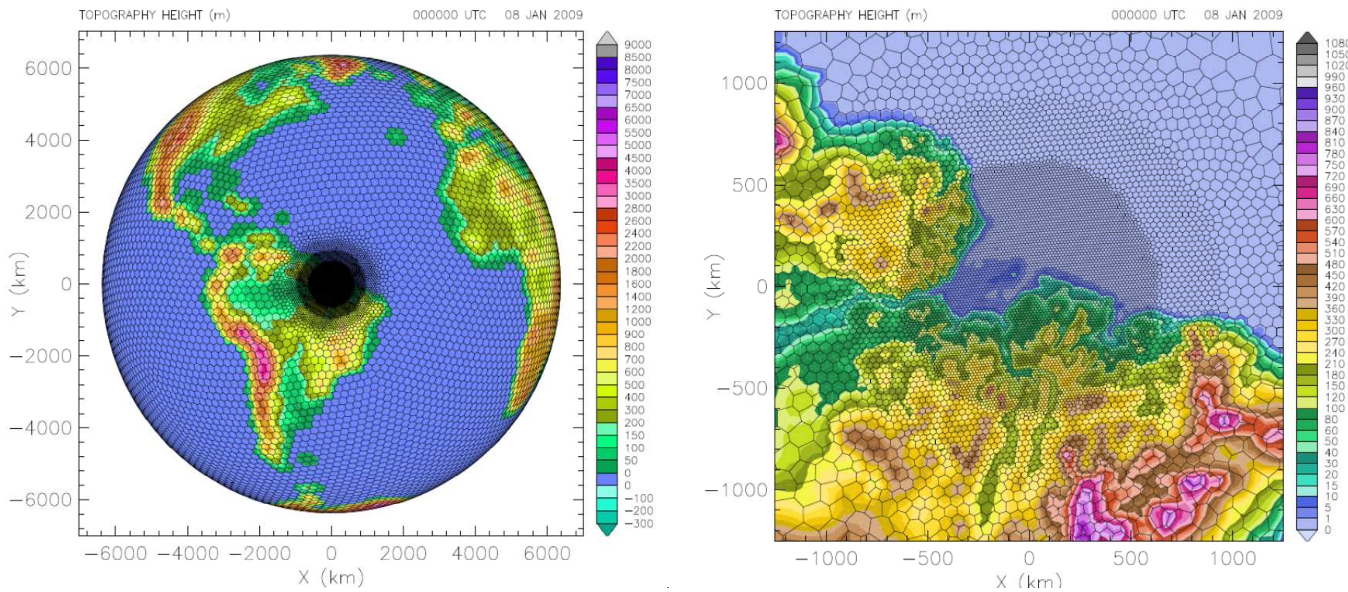

Figure 1 – OLAM hexagonal grid structure and topography (m) for (a) global domain and (b) eastern Amazon domain.

cloud microphysics scheme (Walko et al., 1995; Meyers et al., 1997; Walko et al., 2000b), the radiation transfer (Chen and Cotton, 1983; Harrington and Olson, 2001), and cumulus parametrization (Kain and Fritsch, 1990; Grell and Dévény, 2002). The RAMS mesoscale model was used in several applications for the South America studies such as on the deforestation impacts (Gandu et al., 2004; Ramos da Silva and Avissar, 2006; Ramos da Silva et al., 2008); lightning formation (Gonçalves et al., 2012), convection transport (Freitas et al., 2000), squall lines formation (Bender and Dias de Freitas, 2013), and weather forecasting (Freitas et al., 2005; Ramos da Silva et al., 2007; Longo et al., 2013).

2.3 Numerical design

In this study, the OLAM model was set with a global grid having a refined spatial resolution for the eastern Amazon (Figure 1). The global coarser grid was design having about 240 km of spacing between the hexagonal grid cells (Figure 1a). A five degree of refinement was set with the innermost grids cells having space on the order of 120 km, 60 km, 30 km and 15 km, respectively. The innermost high resolution domain was centered at 04 degree latitude South and 48 Longitude West, at the eastern Amazon (Figure 1b).

The atmospheric initial conditions for horizontal winds, temperature, geopotential height and moisture were obtained from the NCEP/NCAR (National Centers for Environment Prediction/National Center for Atmospheric Research) reanalysis project version 02 (Kanamitsu et al., 2002). Since OLAM is not a limited area model, nudging was not necessary. For OLAM, the coarser global grid produces the boundary conditions for the innermost model domain. Weekly sea surface temperature (SST) was obtained from NOAA (National Oceanic and Atmospheric Administration) as described by Reynolds et al. (2002). The SST fields were constantly updated during the atmospheric integration. Global data of topography, soil texture, and vegetation types, were used as a surface boundary condition.

To better evaluate the model, a series of case studies were performed for the year of 2009. The model was integrated for a total of seven days on twelve numerical experiments, one for each month for the year of 2009 (Table 1). These twelve cases were chosen to represent broad meteorological conditions including wet and dry periods of the year.

Table 1 – Case studies for the year 2009, simulated periods and spatial correlation between daily maps of precipitation from OLAM and TRMM satellite estimates.

Case	Period	Spatial Correlation
01	01-07 January	.01
02	01-07 February	-0.01
03	01-07 March	0.32
04	01-07 April	-0.08
05	01-07 May	0.25
06	01-07 June	-0.09
07	01-07 July	0.17
08	01-07 August	0.02
09	01-07 September	-0.06
10	01-07 October	0.03
11	01-07 November	0.0
12	01-07 December	0.09

Precipitation data obtained from NCEP reanalysis and Tropical Rainfall Measuring Mission (TRMM) satellite estimates were used to evaluate the model results. The NCEP global precipitation data merges satellite and gauge measurement on a 2.5° × 2.5° latitude–longitude grid (Kanamitsu et al., 2002). TRMM precipitation data merges polar and geostationary satellites to provide a 0.25 x 0.25 latitude-longitude resolution dataset (Huffman et al., 2007). Meteorological images from the GOES satellite were used to identify important local precipitating systems. Also, precipitation data from the *Instituto Nacional de Meteorologia* (INMET) local weather stations were used to evaluate the local model performance.

3. RESULTS AND DISCUSSION

3.1 Precipitation forecast for eastern Amazon

The results of the 7-day accumulated precipitation simulations for each of the twelve case studies are presented at Figure 2. The model results and TRMM estimates show higher precipitation accumulation for the cases that occurred on the first half of the year (Figure 2 and Figure 3). The higher precipitation at this time of the year is caused by the presence of the ITCZ that is located over these low-latitude positions. Thus, winds and moisture converge over the region causing high frequency of convective cells. The precipitation distribution had influence not only from the presence of the ITCZ but also from local circulations caused by the local heterogeneity such as the sea-breeze and local topography. As compared with the TRMM precipitation estimates it is noted that the model was not able to fully simulate the high rainfall accumulation observed over the north of the domain including the Atlantic Ocean area. Statistical spatial correlation between the daily accumulated precipitation from the model and from the TRMM estimates shows low correlation between the simulation and the observation (Table 1). The best spatial correlations were obtained for the cases that occurred in March and May, which corresponds to a transition period when the ITCZ is moving north. However, for most of the cases, the model was able to represent the major precipitation accumulation distribution. Furthermore, the model was able to simulate reasonably well the domain averaged rainfall accumulation (Figure 3).

Figure 3 shows the forecasted mean precipitation accumulated over the domain. The results show that the model is able to estimate the 7-day accumulation of precipitation as compared with the observations from NCEP and TRMM. Between December and June there is more precipitation because the proximity of the ITCZ and the higher transport of moisture from the Atlantic Ocean. Between July and November, model and observations show very low precipitation as the ITCZ is located at far north latitudes.

To evaluate the overall domain daily rainfall rate a comparison between the model simulations and TRMM estimates are presented at Figure 4. The precipitation distribution from the model and TRMM show a similar number frequency of grid points and precipitation bins. Therefore, although the model can´t predict the local total accumulation, it can estimate reasonable well the domain average and rainfall rate distribution.

To evaluate the local model performance on the precipitation forecast, the simulated results were compared with data from local standard weather stations. Figure 5 shows the locations of thirteen weather stations from the INMET network. Data comparison between the model precipitation accumulation for the seven days and the observations from the local stations are presented at Table 2. Except for a few cases, the results show that local simulated convection is not well correlated with the recorded data from the weather stations.

3.2 Individual case studies

To evaluate the model performance on representing the dynamics of the mesoscale local features, comparison between model results and satellite images were conducted for various selected cases. Satellite images analysis show that the interface between the continent and the ocean in combination with topography were responsible for several convective cells and squall lines formation.

Figure 6 represents the model forecast for the late afternoon of the 3rd day of forecast as compared with the GOES satellite image for 03 February 2009 20:00 UTC. A comparison between the model results and satellite image show that OLAM was able to predict with three days in advance the formation of the high convective clouds observed near the coast and at the south of the domain where there is a more steep topography (Figure 2). The total spatial mean precipitation forecasted for that day was 13.4 mm, while the TRMM estimates for the same area was 13.3 mm. These results show that OLAM had a very good predictability skill for that day.

Figure 7 shows the model forecast valid for the late afternoon of the 7th day of integration (i.e. 164 hours) as compared with the GOES satellite image for 08 March 2009 at 20:00 UTC. A comparison between the model results and the satellite image shows that OLAM was able to predict with seven days in advance the formation of the squall line at the coast and the convection over the south of the domain. The total spatial mean precipitation forecasted for that day was 8.7 mm, while the TRMM estimates for the same area was 4.5 mm. These results show that OLAM was able to predict with great time in advance the precipitation for that particular day.

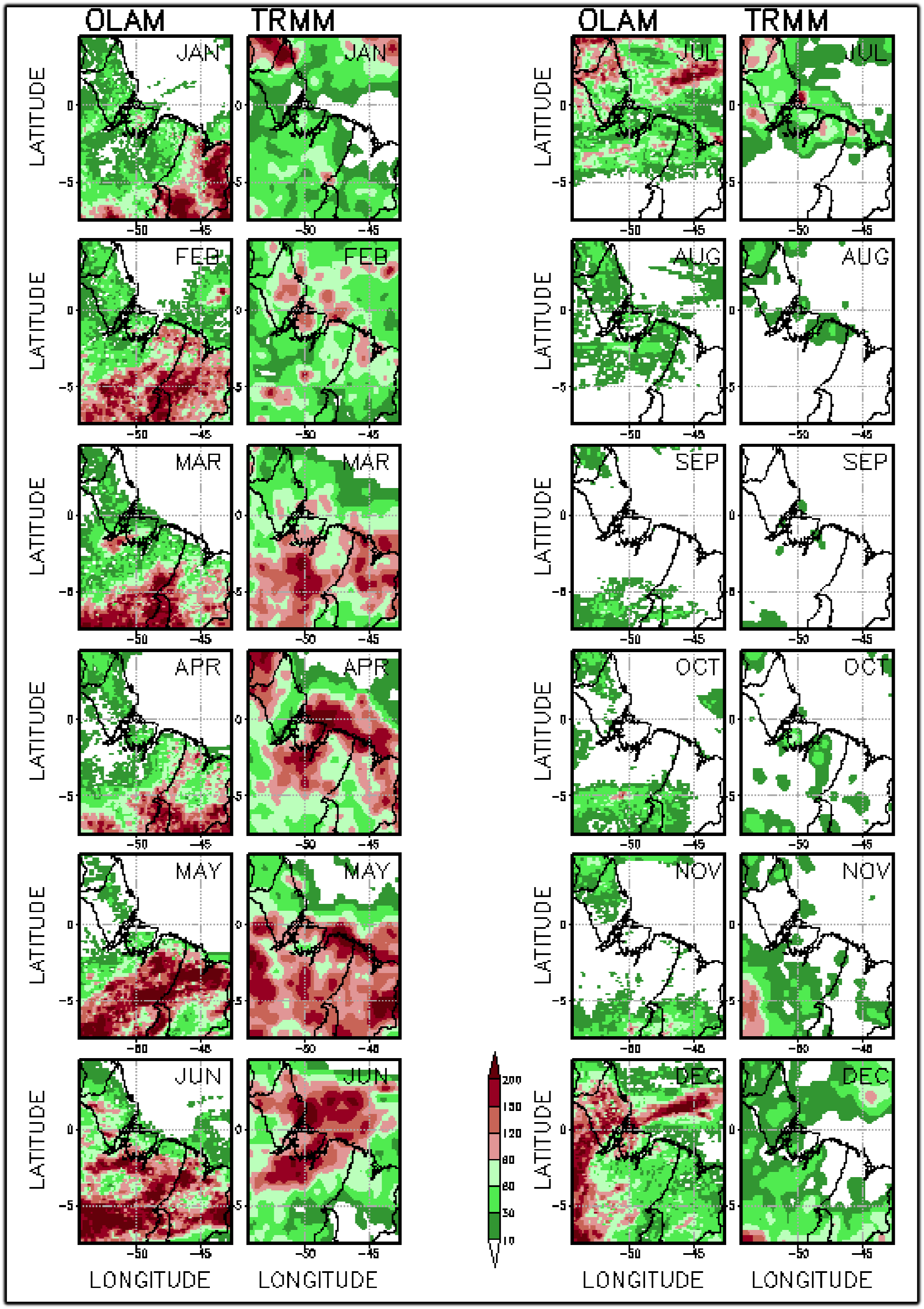

Figure 2 – OLAM 7-day accumulated precipitation (mm) maps (left) as compared with data from TRMM estimates (right) for the twelve case studies.

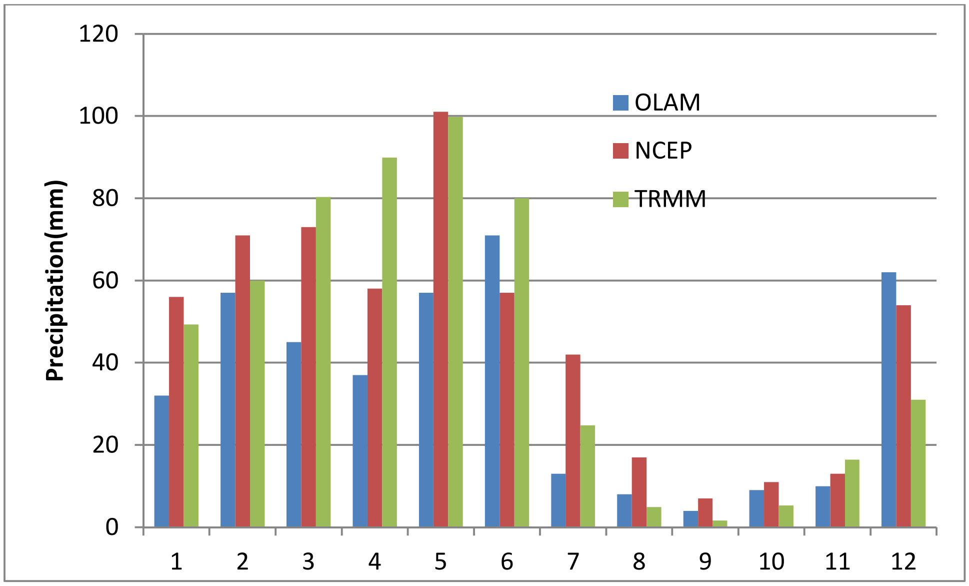

Figure 3 – Domain averaged precipitation accumulation (mm) for each case study as simulated by OLAM and data from NCEP reanalysis and TRMM estimates.

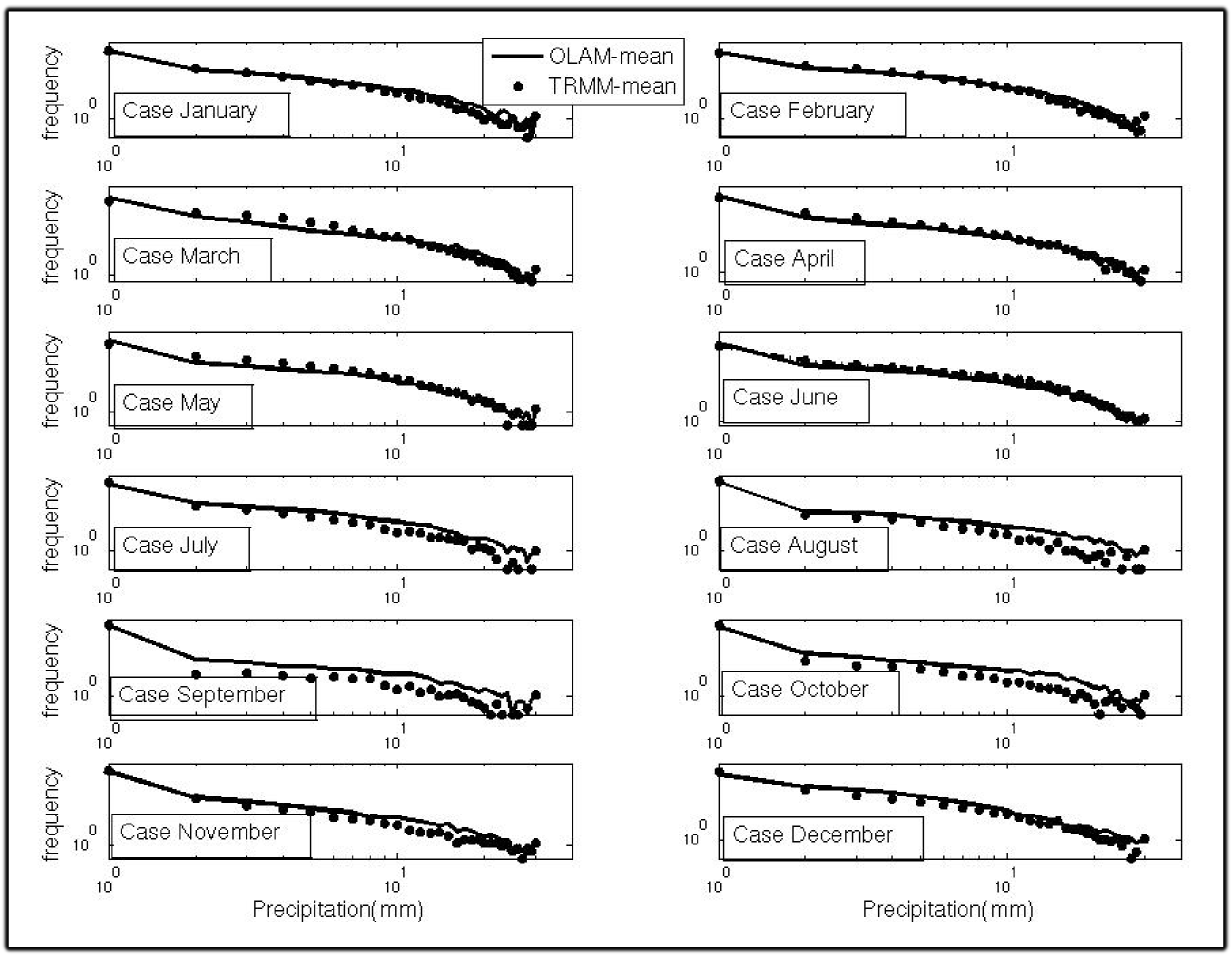

Figure 4 – Precipitation distribution for the twelve case studies obtained from maps of daily precipitation (mm) for the 7-day simulations. The model results and the TRMM maps were interpolated to the same resolution of 0.25 degree of latitude-longitude.

Table 2 – Seven-day OLAM precipitation accumulation (mm) for each meteorological station averaged around 09 neighbor model grid points and spatial standard deviation as compared with the observations (OB). Bold text highlights the instances where observations were within a spatial standard deviation of the simulations by the model.

	January		**February**		**March**		**April**		**May**		**June**	
Station	OLAM	OB	OLAM	OB	OLAM	OB	OLAM	OB	OLAM	OB	OLAM	OB
82098	44±15	23	03±04	118	01±01	150	01±01	05	01±02	57	14±04	62
82141	**09±03**	**10**	01±02	97	00±00	130	00±00	256	00±00	126	11±07	180
82145	08±03	00	29±15	105	00±00	149	00±00	55	23±17	194	**57±21**	**77**
82181	37±14	01	07±02	19	08±04	73	05±04	45	00±00	109	45±06	53
82184	08±04	18	00±00	82	34±06	180	00±00	11	00±00	99	69±18	176
82188	28±06	74	23±10	71	11±06	87	09±04	59	18±07	31	138±8	24
82191	19±11	40	43±34	125	15±11	108	06±06	71	15±12	140	42±11	100
82263	09±06	22	06±05	30	05±01	96	03±05	28	17±03	80	87±07	199
82353	03±01	26	19±08	48	08±03	65	01±01	103	10±03	50	22±08	129
82361	18±03	49	99±03	24	50±05	175	05±02	146	**124±17**	**125**	54±08	86
82562	40±06	13	119±13	24	152±13	107	117±6	55	**118±28**	**112**	189±12	19
82659	80±07	19	165±27	17	184±23	32	133±8	119	**77±10**	**83**	86±15	04
82668	**103±7**	**96**	142±10	45	189±04	131	140±14	33	127±09	107	104±12	13
	July		**August**		**September**		**October**		**November**		**December**	
Station	OLAM	OB	OLAM	OB	OLAM	OB	OLAM	OB	OLAM	OB	OLAM	OB
82098	30±07	48	05±04	36	00±00	01	**00±00**	**00**	**00±00**	**00**	44±16	27
82141	**03±01**	**03**	06±03	17	**00±00**	**00**	**00±00**	**00**	**00±00**	**00**	12±09	00
82145	**57±12**	**62**	**25±04**	**26**	**01±01**	**00**	**00±00**	**00**	07±06	00	30±02	00
82181	12±04	07	06±02	00	**00±00**	**00**	**00±00**	**00**	00±00	23	171±15	97
82184	21±09	*	**05±03**	**06**	**00±00**	**00**	**00±00**	**00**	00±00	05	37±03	02
82188	20±02	12	01±01	32	**00±00**	**00**	**01±01**	**00**	**00±00**	**00**	86±14	35
82191	23±01	71	12±01	28	00±00	58	01±00	35	01±01	20	**80±13**	**77**
82263	**10±03**	**10**	53±08	07	**00±00**	**00**	**00±00**	**00**	**00±01**	**00**	17±03	23
82353	22±03	18	**05±03**	**02**	**00±00**	**00**	**01±00**	**00**	00±00	15	73±06	89
82361	04±01	00	26±04	04	**00±00**	**00**	06±01	02	**07±02**	**09**	68±04	80
82562	**00±00**	**00**	**00±00**	**00**	**05±03**	**03**	37±03	17	09±03	42	**43±09**	**49**
82659	**00±00**	**00**	**00±00**	**00**	**01±01**	**00**	19±02	00	87±19	27	26±05	154
82668	**00±00**	**00**	**00±00**	**00**	24±02	03	07±01	19	21±02	10	127±12	39

*Unavailable data.

Figure 8 shows the results from another case in which, the convective cells formed along with the coast and over the south of the domain as pictured by the satellite image from 07 April 2009 at 20:00 UTC. The model results show a 6-day prediction of these cells with great accordance with the satellite image. The mean accumulated precipitation for that day was 3.2 mm, while the TRMM data mean precipitation estimate for the same area was 6.2 mm. Again, these results show good model predictability skill.

Figure 9 shows the model forecast valid for the afternoon of 05 August 2009. During this period the ITCZ is far north and the satellite image showed that only a few convective cells formed over the continent. Furthermore, the winds are from southeast and are slightly modified by the sea breeze circulation. The forecasted mean accumulated precipitation for that day was 0.6 mm, while the TRMM mean estimates was 0.7 mm. Therefore, OLAM was able to forecast the observed system five days in advance with great performance.

4. CONCLUSIONS

A series of case studies were performed with the OLAM model to evaluate its forecast skill for the eastern Amazon region. The model had only an initial atmospheric condition and was integrated for a seven day run covering twelve cases, one for each month of the year 2009. The results showed that OLAM was not able to predict well the local precipitation accumulation, but was able to represent the dynamics of the major convective coastal systems such as the squall lines and the topographical induced convective cells. The results

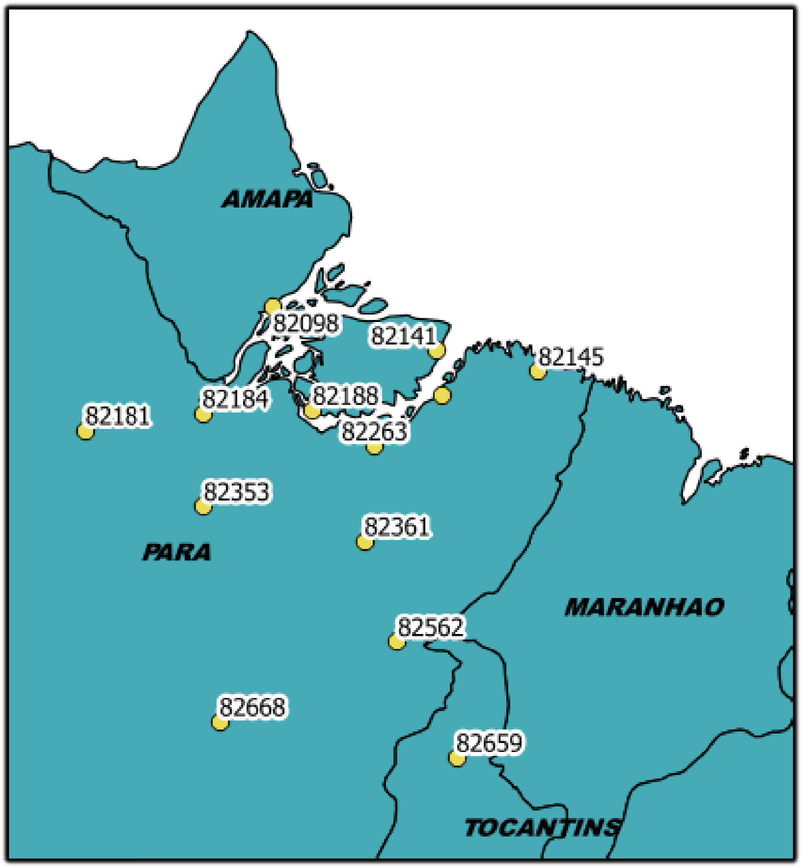

Figure 5 – INMET weather station locations.

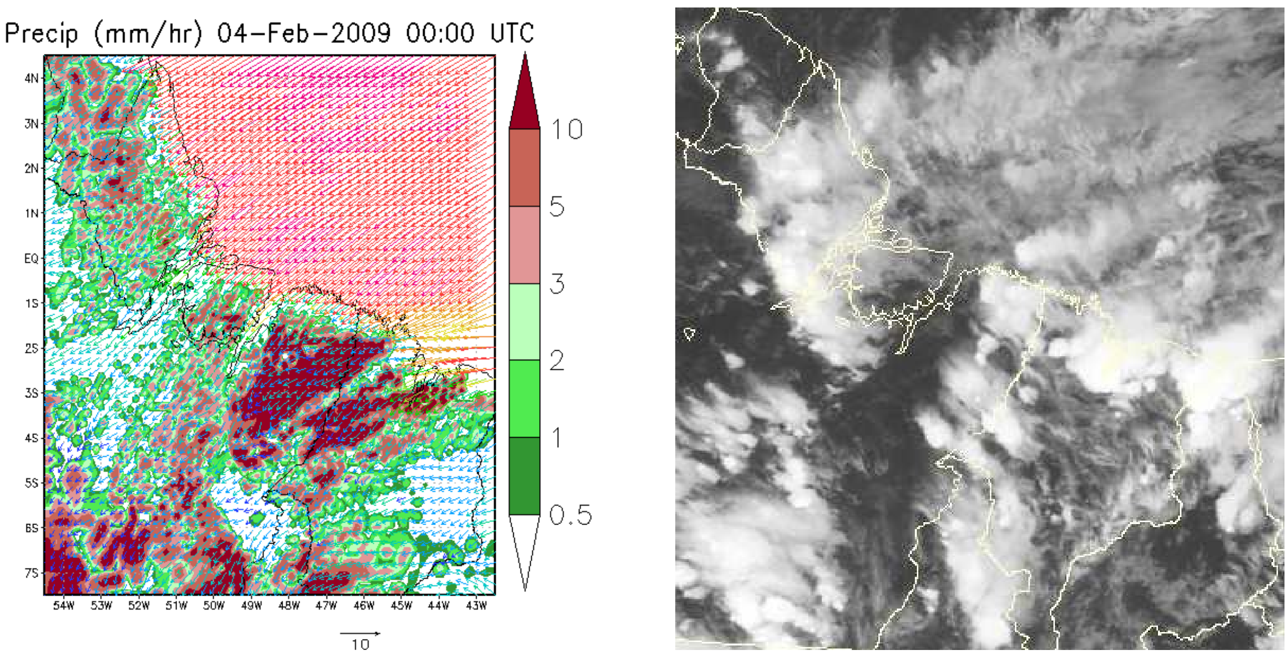

Figure 6 - OLAM precipitation accumulation forecasted between 03 February 2009 18:00 UTC and 24:00 UTC (left) and GOES satellite image for 03 February 2009 at 20:00 UTC (right).

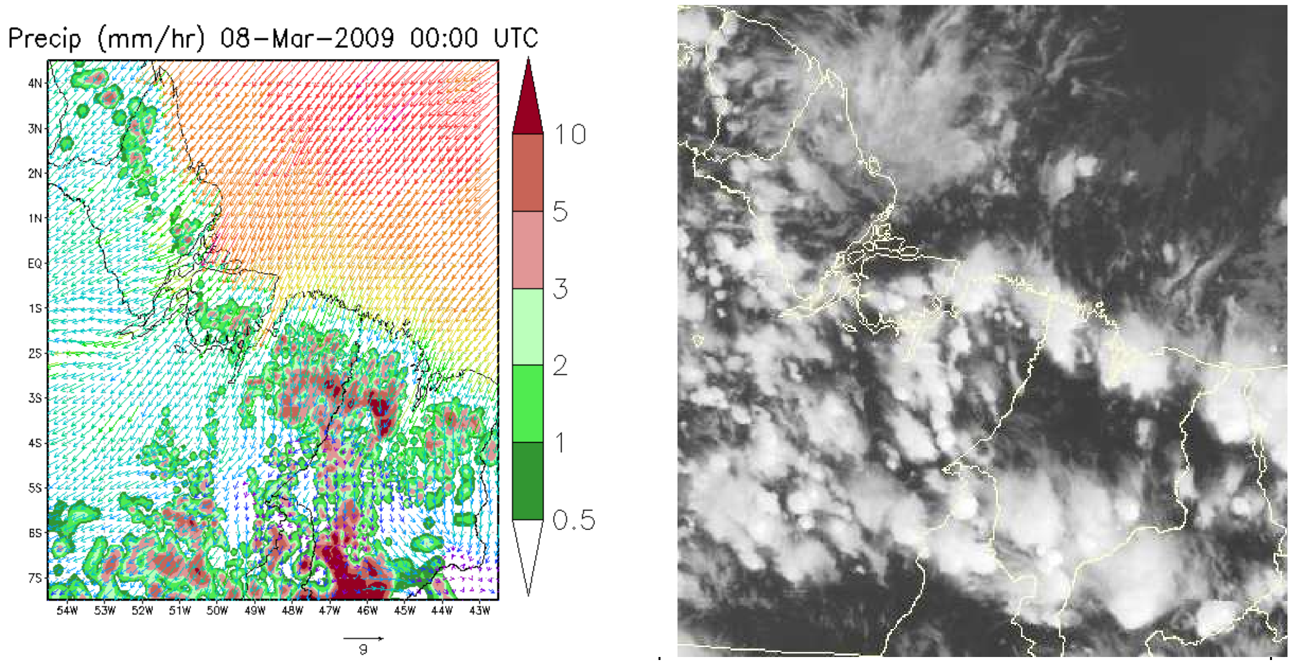

Figure 7 - Same as Fig. 06, but forecasted between 07 March 2009 18:00 UTC and 24:00 UTC (left) and GOES satellite image for 07 March 2009 at 20:00 UTC (right).

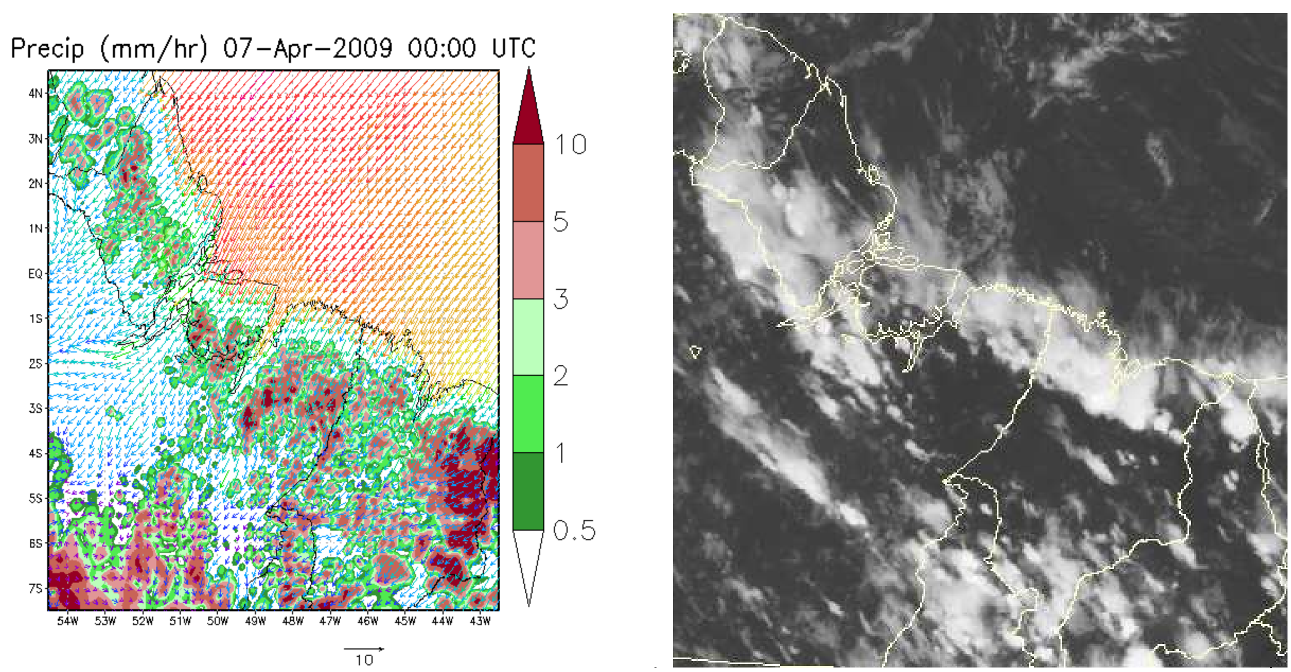

Figure 8 - Same as Fig. 06, but forecasted between 06 April 2009 18:00 UTC and 24:00 UTC (left), and GOES Satellite image for 06 April 2009 20:00 UTC (right).

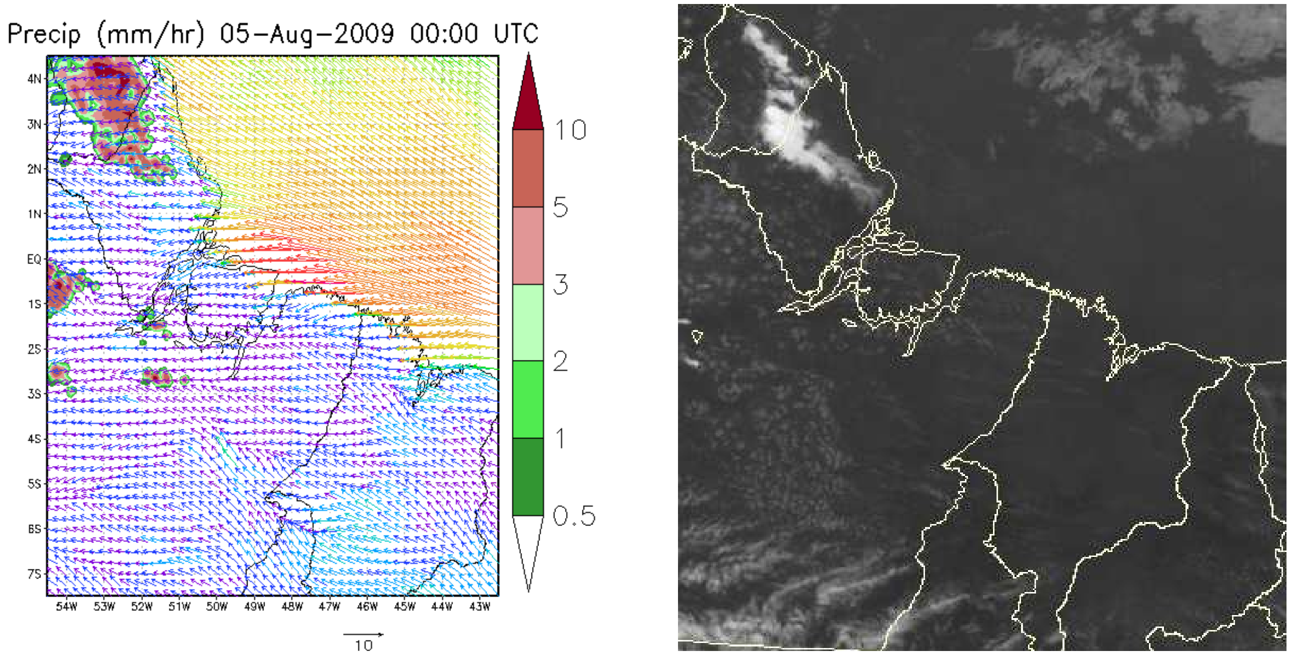

Figure 9 - Same as Fig. 06, but forecasted between 04 August 2009 18:00 UTC and 24:00 UTC (left), and GOES satellite image for 04 August 2009 at 20:00 UTC (right).

show that it is still a challenging problem to forecast well the convective cells that form in this region. Convection is itself a very nonlinear phenomenon. Indeed, a recent precipitation data measurement on several locations at the city of Belem had shown a very high variability on measurements obtained on stations very close to each other. The results suggest that new approaches such as ensemble techniques will have to be applied to improve the weather forecast for this region. In addition, better initial conditions are likely to help to improve de predictions.

In this study we used as initial atmospheric conditions the NCEP/NCAR reanalysis data that has low spatial resolution. A better initial condition based on data assimilation of meteorological observations from local stations, radar and satellite retrievals would likely improve the model predictability. This new approach is part of the next steps of this study. The Data Assimilation Research Testbed (DART, Anderson et al., 2009) is now being tested and implemented in conjunction with the OLAM and we expect to have and improved meteorological forecasting system for the region in the near future.

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