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INSIGHTS OF MESO AND MICRO-SCALE PROCESSES FOR THE CAXIUANÃ FOREST REGION FROM HIGH RESOLUTION SIMULATION

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ABSTRACT

Meteorological data and high resolution numerical simulations were used to estimate spatial fields in eastern Amazonia where is located the Forest and the Bay of Caxiuanã. The study were performed for the period of November 2006, when occurred the field experiment *COBRA-PARA*. Analysis of the MODIS sensor from the Terra Satellite images show the occurrence of various phenomena such as local cloud streets, precipitating convective systems and an important influence of the interfaces between the forest and water surfaces. Numerical simulations for November 7, 2006 showed that the model represented well the major meteorological processes. The results show that the Caxiuanã Bay causes significant impact on adjacent meteorological fields mainly through advection by the northeast winds that induce to colder canopy temperature to the west of the bay and convective rainfall. Simulations with high resolution (LES) produced spatial patterns of temperature and humidity aligned with the winds during the daytime, and at nighttime the patterns are influenced mainly by the presence of the bay. Correlations between the mid-level winds and the latent heat fluxes showed that there is a change from negative correlations for the early hours to positive correlations for the afternoon and early evening.
Keywords: Caxiuanã, BRAMS, LES, local circulations

RESUMO: ESTUDO DOS PROCESSOS DE MICRO E MESO-ESCALA PARA A REGIÃO DA FLORESTA DE CAXIUANÃ A PARTIR DE SIMULAÇÕES DE ALTA RESOLUÇÃO
Dados meteorológicos e simulações numéricas de alta resolução foram usados para estimar campos espaciais na região leste da Amazônia onde se situam a Floresta e a Baía de Caxiuanã, no Estado do Pará. O estudo foi feito para o período de Novembro de 2006, quando foi realizado o experimento de campo COBRA-PARÁ. Análises de imagens do sensor MODIS mostram a ocorrência de vários fenômenos locais como avenidas de nuvens, sistemas convectivos precipitantes, e importante influência das interfaces entre a floresta e as superfícies aquáticas. Simulações numéricas para o dia 7 de novembro de 2006 mostraram que o modelo representou bem as principais variáveis meteorológicas. Os resultados mostram que a Baía de Caxiuanã provoca importante impacto nos campos meteorológicos adjacentes, principalmente, através da advecção pelos ventos de nordeste que induzem a temperaturas do dossel mais frias a oeste da baía. Simulações de alta resolução (LES) produziram padrões espaciais de temperatura e umidade alinhados com os ventos durante o período diurno e mudanças noturnas causadas principalmente pela presença da baía e chuvas convectivas. Correlações espaciais entre os ventos de níveis médios e os fluxos verticais de calor latente mostraram que existe uma mudança de correlações negativas para as primeiras horas do dia passando para correlações positivas para o período da tarde e início da noite.
Palavras-chave: Caxiuanã, BRAMS, LES, circulações locais

1. INTRODUCTION

The Amazon is a major ecosystem of the Earth. Its mechanism on the water recycling is very important for the global climate system. For instance, the evapotranspiration of the forest is fundamental for the strength of the precipitating squal lines (Ramos da Silva et al., 2008). Otherwise, biogenic particles emitted by the forest is an important component as cloud condensation nuclei that induces to rainfall formation (Pöschl et al., 2010). Furthermore, the region is habitat of a large number of species and possible environmental changes could cause irreversible impacts on the ecosystem biodiversity, depending on the resilience of the biota (Walker and Salt, 2006). For instance, land-cover and climate changes could lead to a permanent savanization of parts of the region (Oyama and Nobre, 2003). Other recent studies have point out to an increase on the forest net productivity by elevated carbon dioxide in the atmosphere, but the response can diminish with time mainly due to the nitrogen cycling (Norby and Zak, 2011).

The eastern region of the Amazon is now under careful monitoring and investigation. For instance, at the Caxiuanã region in the state of Pará, the Large Scale Biosphere-Atmosphere Experiment in the Amazonia (LBA) program installed meteorological towers to record several micro-climate variables (Andreae et al., 2002). In addition to micro-climate monitoring, the regions is now part of the *“Programa de Pesquisa em Biodiversidade”* (PPBIO), which is monitoring the local biodiversity changes. Recent studies in this region shows that environmental conditions such as severe drought can cause impoverishment of the local biodiversity, such as on the spiders population (Ruivo et al., 2007). Despite significant advances obtained by field experiments, there is a difficulty in obtaining continuous meteorological data at various points in the region, often due to the limitations of accessibility.

Numerical model is an important tool for improving the understanding of meteorological and climate processes. These models have been used on several studies for the Amazon region such as on the regional impacts of deforestation (Ramos da Silva et al., 2008, Gandu et al., 2004); studies of the local hydrometeorological processes (Ramos da Silva and Avissar, 2006); global climate impacts (Nobre et al., 1991) and local weather predictions (Ramos da Silva et al., 2007). In areas with more restricted and difficult access, the numerical models can be applied with high resolution to improve the spatial knowledge and to better understand the physical processes. Silva Dias et al. (2004) used the BRAMS (Brazilian Developments on Regional Atmospheric Modeling System) to demonstrate the importance of the river breeze in the region near the confluence of Rio Tapajos and Amazonas; Gandu et al. (2004), simulated the atmospheric effects of substituting forest for pasture in eastern Amazonia. In another study, Ramos da Silva and Avissar (2006) used the same model to study aspects of mesoscale to a deforested region of the Amazon rainforest showing that high-resolution models are needed to represent more complex the performance of Amazonian mesoscale meteorological processes.

This study uses a high resolution model approach that allows to represent aspects of meso and micro-scale of the study area, enabling the understanding of meteorological phenomena in the region of Caxiuanã National Forest, and also the region of the PPBio Project where studies related to biodiversity have been developed.

2. DATA AND METHODS

The Caxiuanã National Forest is a conservation unit consisting of a primary forest area in the municipality of Melgaço in central-western state of Para, approximately 400 km west of the capital Belém. The grid of the PPBio, in which the project has developed its research and data collection relating to biodiversity, is located at 1º57 ‘36.7920”S and 51º36’55.0800”W, within the limits of Caxiuanã National Forest (Figure 1).

2.1 Numerical model BRAMS

In this study we used the numerical model BRAMS (Brazilian Developments on Regional Atmospheric Modeling

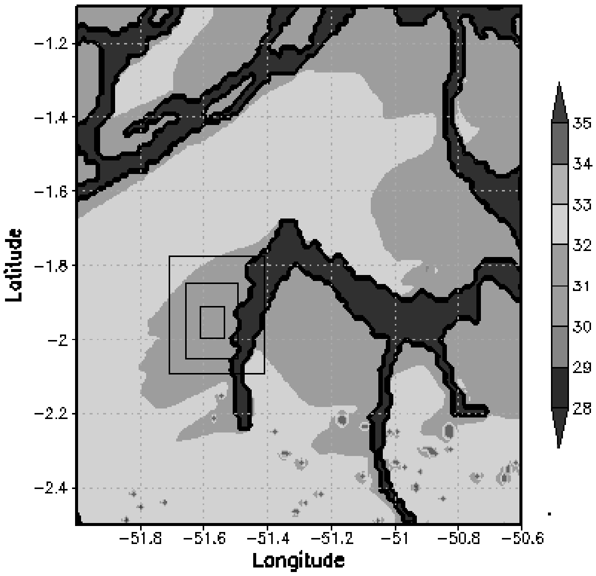


Figure 1 - Domain grids in BRAMS and model results for canopy temperature (° C), on November 7, 2006 at 14:00 UTC. The cooler surfaces represent the Caxiuanã Bay in the center and the Amazon River in the north-west of the domain.

System), version 4.2. This model version, adapted to Brazilian surface characteristics, is derived from the atmospheric model RAMS (Regional Atmospheric Modeling System) (Pielke et al. 1992; Cotton et al., 2003). This regional model has been widely used to study climatic and environmental processes in the Amazon region (Silva Dias et al, 2002a, 2004; Gandu et al., 2004; Ramos da Silva and Avissar, 2006; Cohen et al., 2007; Ramos da Silva et al., 2008). Its multiple applications allow simulating the atmospheric phenomena of meso and micro scale with different resolutions and can be used to understand the operation of convective systems and storms, estimating precipitation, wind, and temperature, and the study of interactions between regional atmosphere and biosphere. The BRAMS has several modules (sub-models) that simulates interacting processes such as the heat exchange between water and soil-vegetation-atmosphere (Walko et al, 2000a), the turbulent processes in the surface layer and boundary layer (Mellor and Yamada, 1974; Deardorff, 1980), the exchange of solar and thermal radiation (Harrington, 1997), and the microphysics of clouds and precipitation (Walko et al., 2000b).

The use of BRAMS in LES mode (Large Eddy Simulations), is generally applied in grids with cells smaller than 100 meters spacing, allowing to simulate the large eddies (LES) by using the parameterization option developed by Deardorff (1980). These simulations usually are performed over small domains due to the very high resolution that implies in a large number of grid points, and time steps in the order of seconds (Avissar and Schmidt, 1998; Avissar et al., 1998).

2.2 Field experiment COBRA-PARÁ

The *COBRA-PARA* (Caxiuanã: Observations of the Biosphere River and Atmosphere of Para) field experiment, was conducted from October 30 to November 15, 2006. This field campaign aimed to make simultaneous measurements of the contributions of carbon fluxes in the atmosphere, soil and river, besides studying the role of local circulations on these measures in the region of Caxiuanã (COBRA-PA, 2006). In this study we used the radiosonde profiles data recorded during the experiment to provide the initial conditions and to evaluate the modeling simulations. The radiosondes were launched from a clearing in the Caxiuanã forest every 3-hour for the period of the experiment (Monteiro da Silva et al., 2010).

2.3 Description of numerical experiment

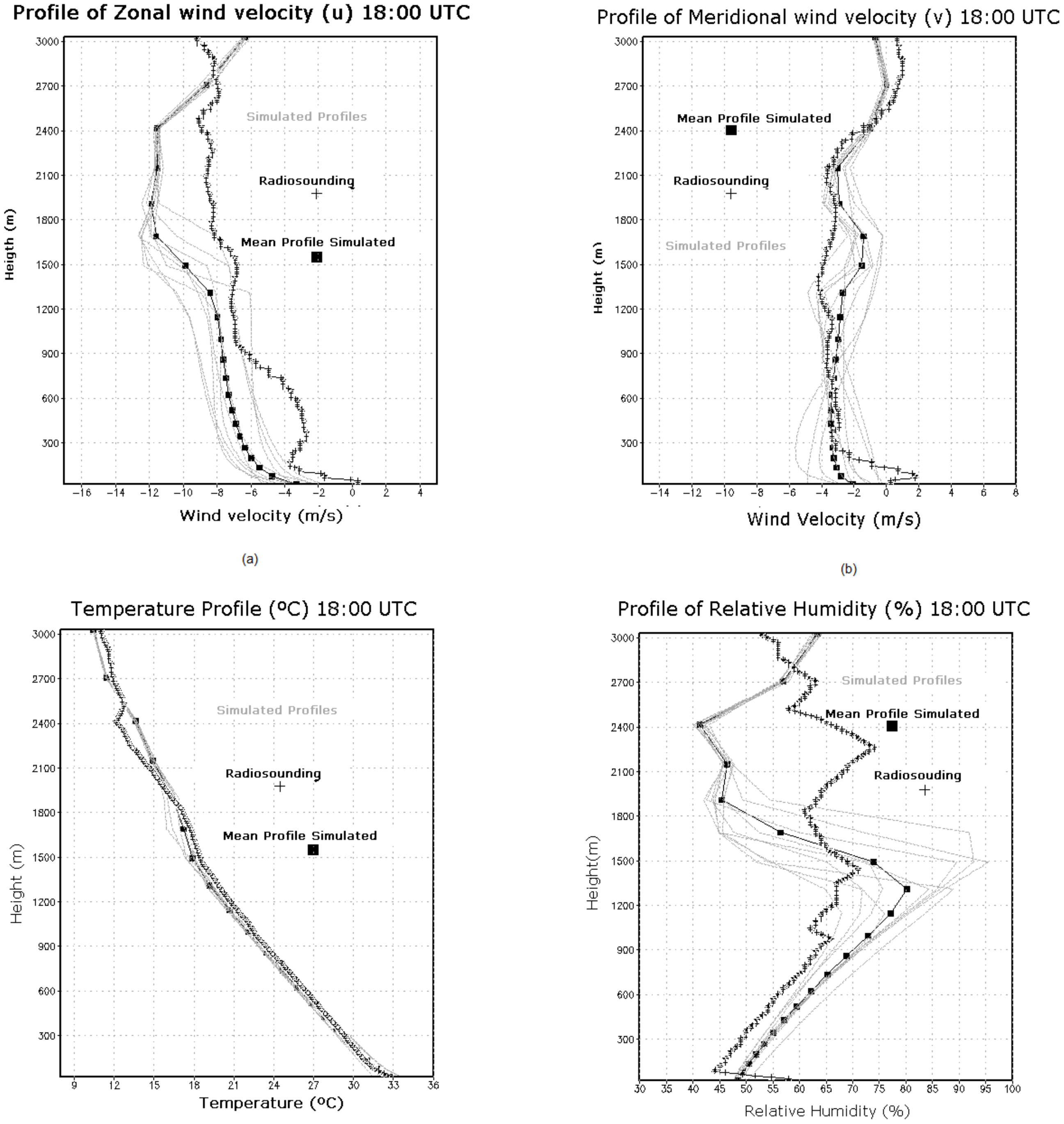
BRAMS was configured with the surface characteristics of the region such as local topography, vegetation and soil types. The model was set up with four interacting nested grids, with the large grid domain covering the limits of Caxiuanã National Forest and its surroundings, and the smaller grid domain corresponding to the site of the PPBio research program (Figure 1). The large grid domain was set up with spatial resolution of 1350 meters, and the smaller grid with resolution of 50 meters. The intermediate grids had 450 and 150 m horizontal spacing, respectively. The vertical resolution was variable with initial spacing of 50 meters in the lowest layer of the model, increasing upward by a factor 1.1 to the vertical spacing of 800 meters, which is fixed up to the top of the model. We also defined 12 soil levels having the following depths: 0.2, 0.4, 0.6, 0.8, 1.0, 1.3, 1.5, 2.0, 3, 0, 3.5 and 4 meters. The surface water temperature in the Bay of Caxiuanã was defined as constant with a value of 30.5 ° C based on measurements made during the experiment *COBRA-PARA* experiment. For the atmosphere it was adopted an initial condition based on a vertical profile obtained from a spatially homogeneous sounding collected during the Experiment *COBRA-PARÁ* for winds, temperature, and moisture. The boundary conditions adopted was an advecting type as developed by Klemp and Whilhelmsom (1978).

A numerical simulation was performed for a period of 24 hours to assess a daily evolution of the micro-and meso-scales processes and their interactions. The 24 hours simulated corresponded to the period between 12:00 UTC on November 7, 2006 and 12:00 UTC on November 8, 2006.

3. RESULTS AND DISCUSSION

Model performance was evaluated by comparing the model results with those obtained with the radiosondes during the *COBRA-PARA* field experiment. The main meteorological variables evaluated were the zonal and meridional winds, temperature, relative humidity and the forest canopy temperature.

For the zonal wind (u) profiles, we observed the predominance of easterly trade winds for both the simulation and the observations (Figure 2a). The model results show strong winds (above 08 m/s) on 07 November, mainly in the layers between 1200 and 2500 meters. However, the persistence of strong observed winds were not well simulated by the model for the first hours of 08 November (not shown). These results suggest that these jets are remote phenomena that propagate into the region. In fact, simulations by Cohen et al. (2006) showed that low level jets in this region should be caused by the low drag coefficient of the water surfaces, especially over the Amazon River. Over these regions winds channel giving rise to the low level jet. Results for meridional wind (v) demonstrated a relative agreement between model and observations for levels between 300 and 1200 meters for 18:00 UTC (Figure 2b). However, similarly to the zonal wind, the model underestimated the magnitude of the winds at night, and could not properly simulate the direction (not shown). The air temperature at 18:00



(a) (b)

(c) (d)

Figure 2 - Simulated profiles and radiosonde at 1800 UTC, for 07 November, 2006, namely: (a) zonal wind profile (u), (b) meridional wind (v), (c) temperature (° C) and (d) relative humidity (%).

UTC (Figure 2c) showed a difference of 1 ° to 2 ° C between the model results and the radiosoudings. Results for relative humidity at 18:00 UTC show good agreement with the observed profile mainly for the boundary layer (Figure 2d). For the levels between 1000m and 2700m the presence of clouds causes a high moisture variability which is depicted by the nearby simulated profiles.

In general, the model simulated well the first hours of integration, but could not properly represent the meteorological behavior for the evening time. Since the model was set with an advecting type of atmospheric lateral boundary condition, it could not simulate large scale features that could be entering the simulated domain. However, the goal of this study was to better understand the convection evolution that occurs mainly during the daytime and over the PPBio site. Further studies should include a high resolution boundary condition fields to produce a nudging for this study region and allow longer integrations.

Figure 3 shows a comparison between simulated canopy temperature and data recorded by the radiosonde, at approximately 20 meters above the ground. The simulation of canopy temperature shows that observed values from radiosonde were within the error bar indicating that the model simulated well the canopy temperature (Figure 3). The evolution of average temperature from canopy is satisfactory throughout the simulated period, compared with the values of temperature radiosoundings.

Figure 1 shows an important result on the interaction between the mesoscale and microscale in which we observe the influence of Caxiuanã Bay and other water bodies on the canopy temperature variation near the rivers. The predominant northeast winds in this region advect the cooler temperatures toward west of bay affecting the canopy temperature at this time of the day (14:00 UTC).

Figure 4 shows model results for temperature, relative humidity, latent and sensible heat flux for 18:00 UTC. In general, these meteorological variables show spatial patterns aligned with the northeasterly predominant winds. Further analysis show that at this time of the day near surface meteorological processes and surface fluxes are highly affected by the converging winds. Above the Bay Caxiuanã and other water surfaces it is noted that wind flow is intensified, indicating the influence of the low roughness of these surfaces on the wind circulation. The fluxes of sensible and latent heat show a pattern that coincides with the locations where the wind flow is stronger. This pattern shows the formation of hot plumes above the region at the indicated time, as can be noticed in the fields of vertical motion (Figure 5a). These results are consistent with observations from the MODIS images for this particular day (Figure 5b). Lower values in latent heat flux are produced over the water surfaces indicating the important hole of the forest on the transpiration and moisture transfer to the atmosphere.

The Large Eddy simulation (LES) obtained with the high resolution grid (grid 4) shows that spatial pattern of canopy temperature is associated with the direction of wind flow that comes from northeast (Figure 6a). Analysis of model results shows that this pattern is seen until approximately 20:00 UTC. After that, the strong convection produces local storms that destroy this spatial pattern (Figure 6b).

The results also suggest a relationship between mid level wind speed and sensible heat and latent heat fluxes. The spatial correlation between wind speed at the level of 735 meters and fluxes of sensible and latent heat was analyzed for the grids 1, 2, 3 and 4. It is noted that for sensible heat fluxes (Figure 7), in the coarser grid 01, which simulates mesoscale phenomena, the spatial correlation with mid-level winds is negative. Probably this is due to mesoscale convective cells that form during the day and produce strong winds and gusts (downdrafts) with downward movements that inhibit the sensible heat flux. The correlation is highly negative at the time of 21:00 UTC when convection storms are very active. Results from the grids 3 and 4 show greater variability, but there is also a predominantly negative spatial correlation. This explains the negative correlation between the winds and sensible heat flux at this time of the day. Analysis for the latent heat flux shows a transition from negative to positive correlation over time (Figure 8). The grid shows a maximum correlation around 21:00 UTC, probably associated with mesoscale convective cells. Analysis for the LES (grid 4) shows a positive correlation especially at dawn. These results suggest an influence of the micro-scale

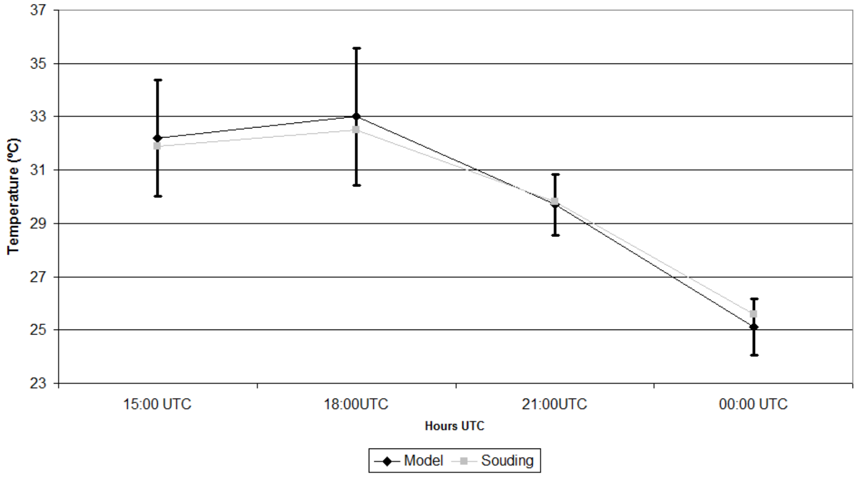


Figure 3 - Spatially mean canopy temperature from simulation and radiossonde, the bars represent the standard deviation obtained from the spatial variability.

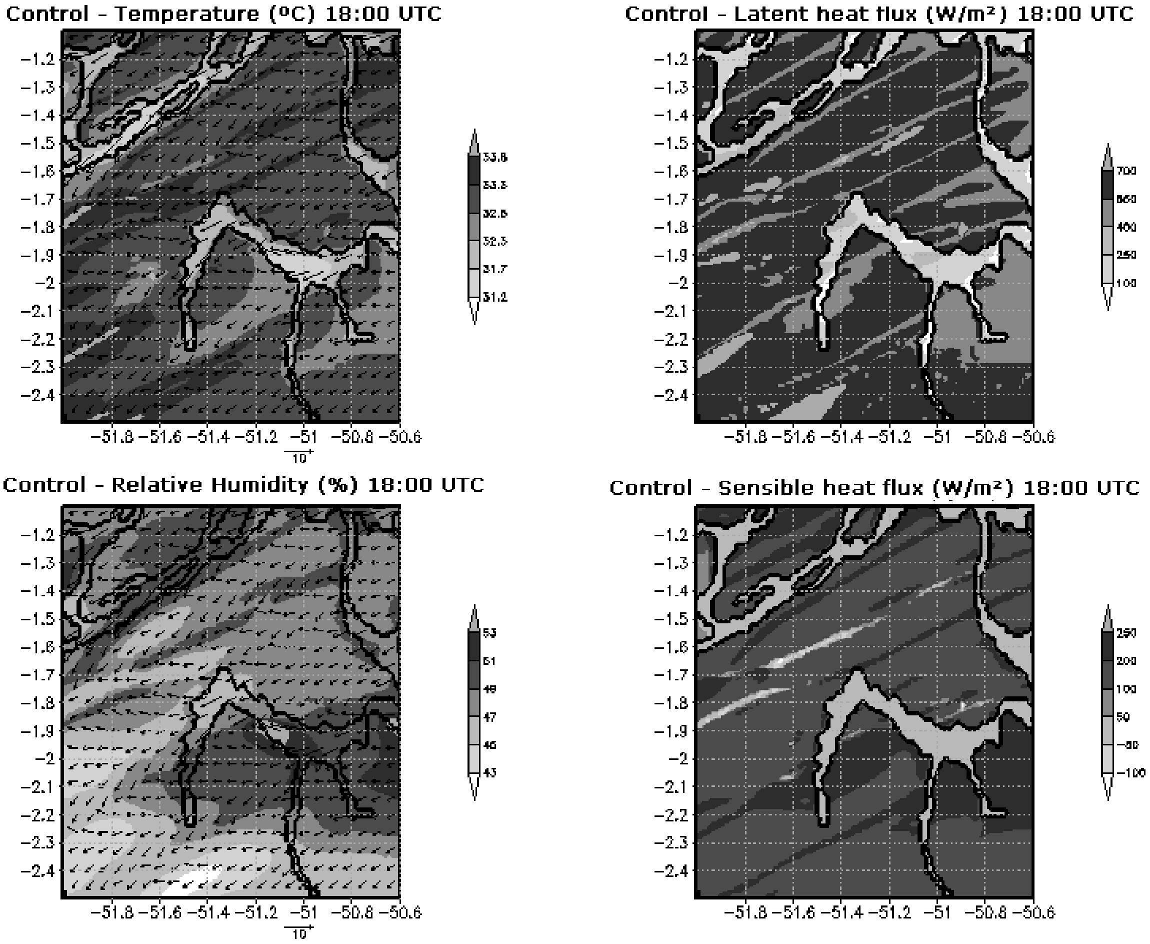


Figure 4 - Surface fields for grid 1, at the level of 24 m, at 18:00 UTC on November 7, 2006.

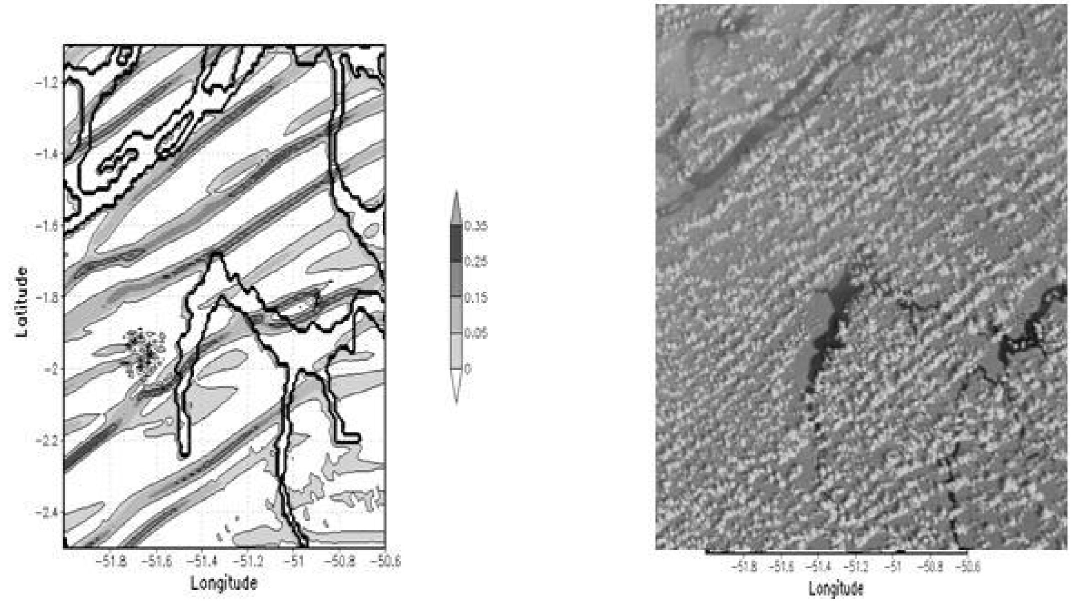


Figure 5 - (a) Vertical motion at 18:00 UTC on November 7, the level of 134.5m; (b) Image MODIS-Terra, on November 7, 2006, for the Caxiuanã Bay region. Source: MODIS Rapid Response Project at NASA / GSFC (available at: http://www.rapidfire.sci.gsfc.nasa.gov).

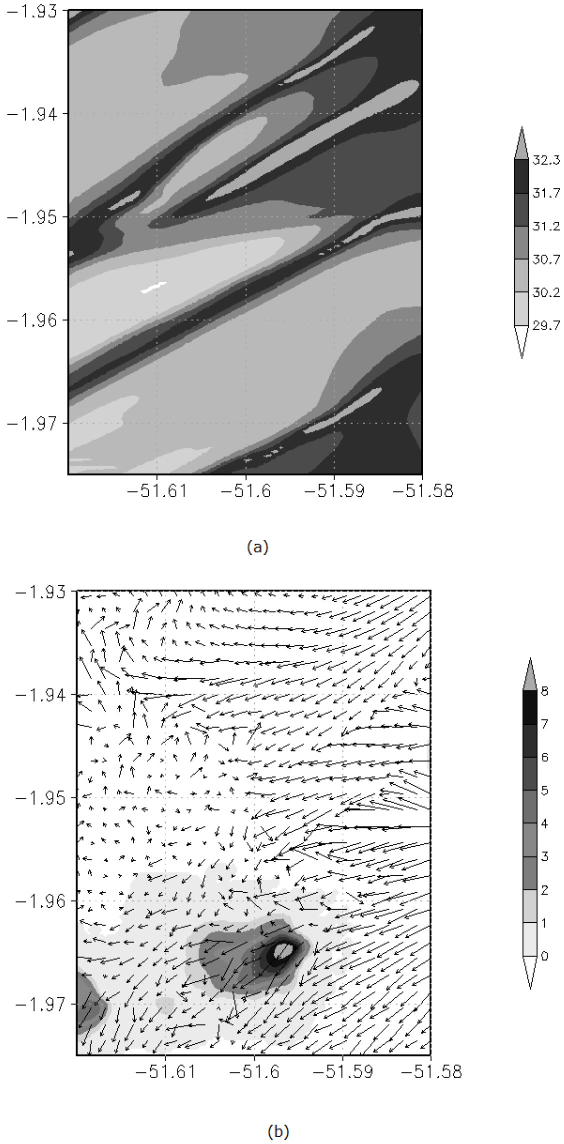


Figure 6 - (a) Canopy temperature (ºC) for grid 4 at 14:00 UTC on 7 November 2006; (b) Precipitation rate (mm/hr) and wind vectors for grid 4 at 21:50 UTC on 7 November 2006.

in the surface fluxes such as the effect of local eddies, mainly mechanically generated by the wind shear.

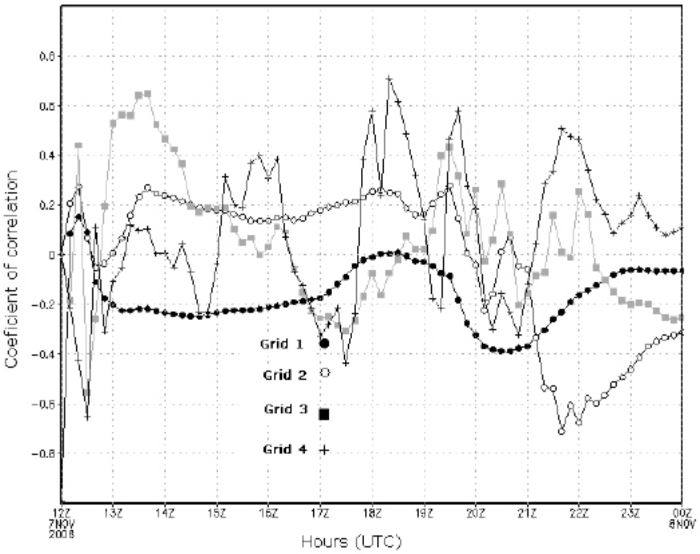


Figure 7 - Spatial correlation coefficient between the sensible heat fluxes and wind speed at the level of 735m.

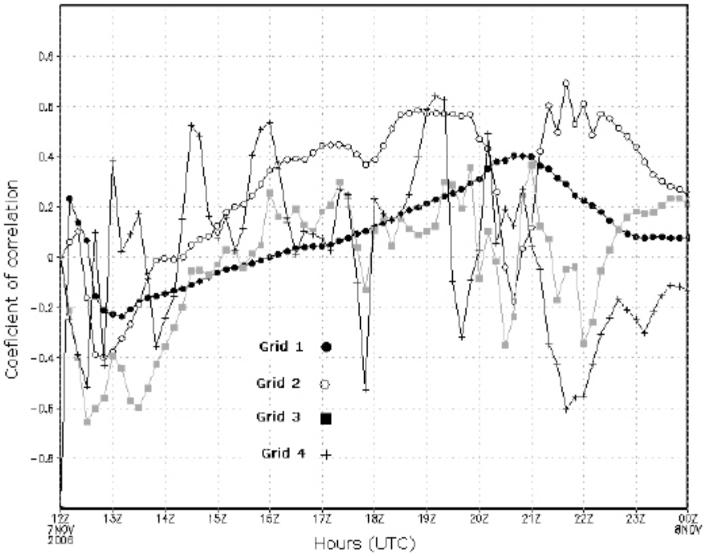


Figure 8 - Spatial correlation coefficient between the latent heat fluxes and wind speed at the level of 735m.

4. CONCLUSIONS

Meteorological data and high resolution numerical simulations were used to estimate spatial fields in eastern Amazonia where is located the Forest and the Bay of Caxiuanã and mainly near the site of the Project PPBIO experiments during the experiment COBRA-PA.

Analysis of the MODIS images show the occurrence of various phenomena such as local avenues of clouds, precipitating convective system and an important influence of the interfaces between the forest, rivers and the Caxiuanã Bay. The numerical simulations show that the model simulated well the observed meteorological processes for November 7, 2006, but could not properly represent the observed evolution of the atmosphere for the further evening time. These results show that for longer model integrations a high resolution nudging type of boundary condition should be developed. However, further analysis show that the model simulates very well the canopy temperature, which is an important variable of interest to other researchers on the project PPBIO.

The results show that the Caxiuanã Bay causes major impact in the fields of canopy temperature, particularly downstream of the wind where the PPBio site is located. The advection by winds from the northeast produces cooler canopy temperatures over the west of the Bay as compared with temperatures in the east of the Bay. Thus, this mesoscale circulation is of fundamental importance for the local micro-climate of this region.

Simulations with high resolution capability (LES) show spatial patterns of temperature and humidity aligned with the winds during the daytime. The model results also showed that stronger mid level winds cause less sensible heat flux and increased latent heat flux only in the early hours of the day. Spatial correlations for the latent heat fluxes show that there is a change from negative correlations during the early hours of the day into positive correlations for the afternoon and early evening. This shows that the descendant flows associated with gust fronts have important influences on the spatial distribution of surface fluxes.

Although this case study has provided the first micro-meteorological spatial fields for the region of PPBIO, it becomes necessary in the future to explore other cases with different meteorological conditions.

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