

SOME ASPECTS OF THE ATMOSPHERIC BOUNDARY LAYER OVER WESTERN AMAZONIA: DRY SEASON 1994

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ABSTRACT

The evolution of temperature, humidity and wind patterns in the atmospheric boundary layer (ABL) was discussed for two types of vegetation cover, pristine forest and pasture, during the 1994 dry season. The two sites are about 80km apart and located in Rondonia State, Western Brazilian Amazonia, circa 10°S and 62°W. During the day, over the modified environment (pasture), the convective boundary layer (CBL) was 80% thicker, 2K warmer and 6g.kg⁻¹ drier than the forest CBL. The nocturnal boundary layer (NBL) was warmer and drier, the breaking of its stability was more frequent and occurred earlier than the forest NBL in the morning hours. In general, the evolution of the patterns over the two sites were quite different but there were occasions when their boundary layers behaved similarly. The results indicated that the large and meso scales dynamic mechanisms had a significant influence on the behavior of the ABL over those tropical sites.

Key words: rain forest, Amazonia, convective boundary layer, nocturnal boundary layer

RESUMO: ALGUNS ASPECTOS DA CAMADA LIMITE ATMOSFÉRICA DO OESTE DA AMAZÔNIA: ESTAÇÃO SECA, 1999

Foram discutidos os padrões de evolução de temperatura, de umidade e de vento da camada limite atmosférica (CLA) no Oeste da Amazônia (Rondônia), durante a estação seca de 1994, sobre dois sítios de coberturas vegetais distintas: floresta nativa e pastagem. A distância entre os dois sítios é aproximadamente 80km, localizados na região de Ji-Paraná, próximos a 10°S e 62°W. Sobre a pastagem, durante o dia, a Camada Limite Convectiva (CLC) foi cerca de 80% mais espessa, com 2K a mais e 6g.kg⁻¹ a menos, em média. A Camada Limite Noturna (CLN) sobre a pastagem também foi mais quente e mais seca e a quebra de sua estabilidade noturna ocorreu mais cedo e com maior frequência no período matinal quando comparada com a da floresta. Em geral, os padrões de evolução nos dois cenários foram diferentes, porém existiram ocasiões em que as duas CLCs comportaram-se de modo similar. Os resultados sugeriram, também, que fenômenos de média e grande escalas desempenharam papel importante no comportamento da CLA da região.

Palavras-chave: floresta tropical úmida, Amazônia, camada limite convectiva, camada limite noturna

1. INTRODUCTION

The Amazon region, with a area of 7 x10⁶ km², is an important source of heat for the general circulation of the atmosphere and plays a significant role in the biogeochemical cycles, particularly in the global carbon budget, being a sink of carbon presently (Molion, 1995). The changing of the pristine forest cover for another use of the soils alters the

water cycle in the soil-vegetation-atmosphere system. Simulations made with atmospheric global circulation models suggested that a large scale deforestation would lead to a 2K to 5K increase of temperature, 30% to 50% reduction in evapotranspiration and 20% to 30% reduction in rainfall totals but found no significant influence on climate outside

of the region (Lean and Warrilow, 1898; Nobre et al., 1990; Rowntree, 1991; Shuttleworth et al., 1991; Henderson-Sellers et al., 1993). Molion (1995), on the other hand, presented potential impacts that a large-scale deforestation may impose on the global climate.

The present practice is to replace the forest with crops and pasture fields. This change of vegetation cover alters the surface albedo, from 13% to 25% over the pasture (Bastable et al., 1993; Culf et al., 1995) and the energy balance as a consequence. In addition, surface parameters, such as aerodynamic roughness, leaf area index, stomatal resistance, are drastically modified, likewise the behavior of the atmospheric boundary layer (ABL), responsible for transporting of all quantities into the lower troposphere. A study comparing the evolution of the ABL over forested and deforested areas in Western Brazilian Amazonia was made with the objective of contributing to a better understanding of the behavior of this layer and to ameliorating the parameterization of the numerical modeling of the atmosphere

2. DATA AND METHOD

The data were collected during the third campaign of the Rondonia Boundary Layer Experiment (RBLE3) from August 14 to 26, 1994, corresponding to the local dry season. The forest site (forest) was located in the Jaru Biological Preserve (10.1°S; 61.9°W; 120m) and is covered with pristine tropical rainforest, with average tree height about 35m. The deforested site, a pasture field (pasture), was located in Nossa Senhora Aparecida farm (10.8°S; 62.7°W; 220m) basically covered with grass and shrubs. The distance between the two sites is roughly 80km, the pasture

being to the southwestern of the forest. The data set is composed of pressure, temperature, humidity and wind collected by simultaneous pairs of radiosoundings, a total of 148 soundings made at 05AM, 08AM, 11AM, 2PM, 5PM and 11PM (local time). The sounds used were the Vaisala RS80, with temperature sensor resolution of 0.1°C, relative humidity 1% and pressure 0.1hPa. The winds were obtained through OMEGA telemetry. Radiosound signals were recorded at 10s time interval.

The height of the ABL (Z_i) was evaluated using an analytical method where by the ABL top was determined according to the shifting from

- neutral to stable regime, during the diurnal period (Figure 1a)
- stable to neutral regime, during the nocturnal period (Figure 1b)

The variables time-height sections were made using a geostatistics gridding method, where the interpolation was made with a two variables function. The selected grid has 50 lines by 50 columns, which corresponds to a spatial resolution of 50m and a time resolution of 0.48 hours.

3. RESULTS AND DISCUSSION

The time-height sections of potential virtual temperature (θ_v), specific humidity (q), wind speed (u) and water vapor saturation deficit up to 2,500m were analyzed to compare the evolution of the boundary layers over the two sites. The synoptic conditions were typically of the dry season and a strong psychrothermic inversion at about 2,300m was observed, associated to a subsidence of large scale (Souza, 1997). This surely influenced the behavior of the ABL, mainly over the pasture, where generally the diurnal

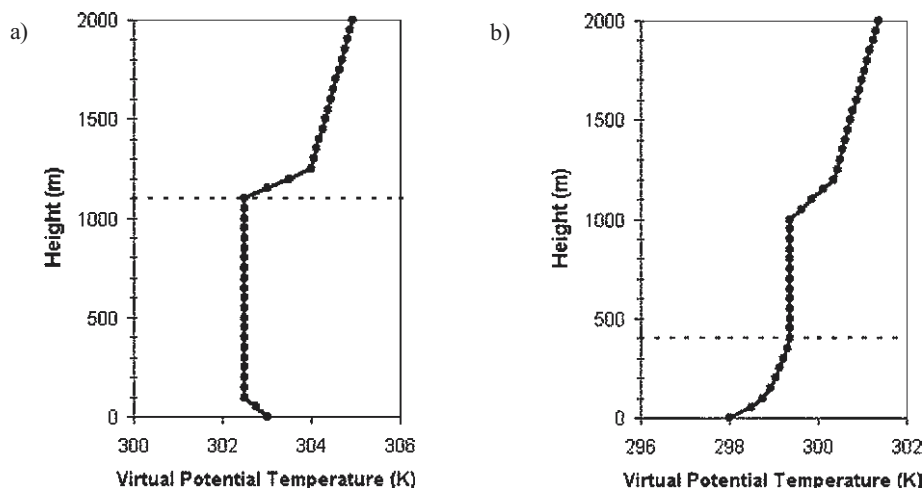


Figure 1 - a) Typical diurnal vertical profile of virtual potential temperature. The horizontal dotted line was drawn at the ABL height. b) Same as Figure 1a, but for the nocturnal period.

heating, added to the entrainment of hot and dry air at the subsidence level (SL), broke the inversion at the top of the convective boundary layer (CBL). When it happened, θ_v was uniform from the surface up to subsidence level and the CBL rose up to 2,200m. In the average, the CBL over the pasture was about 1,000m thicker than over the forest at 5PM (Nobre et al., 1996; Fisch, 1996; Souza and Lyra, 2002) where it attained a mean height of 1,200m in the average. On the daily basis, however, the CBL over the forest sometimes presented the same thickness, such as on days 15, 22 and 23. The nocturnal boundary layer (NBL) usually rose to about 200m height over the pasture and to about 300m over the forest. In the observation period, the behavior can be summarized into four classes of events:

1. The most common event was only the pasture CBL rising up to SL (Figure 2a);
2. Forest CBL grew above normal but didn't reach the SL (Figure 2b);
3. CBL of the two sites grew up to SL and the θ_v difference was only 0.5K (Figure 2c);
4. CBL of the two sites grew up to SL and the θ_v difference was about 2.0K (Figure 2d)

Studies of the CBL over tropical forest sites are scarce. Results of this work were found to be consistent with results of other experiments. In Figure 3a, the diurnal evolution of the 1994 (this work) CBL was compared with results for the Central Amazonia (Martin, et al, 1988), Congo tropical forest

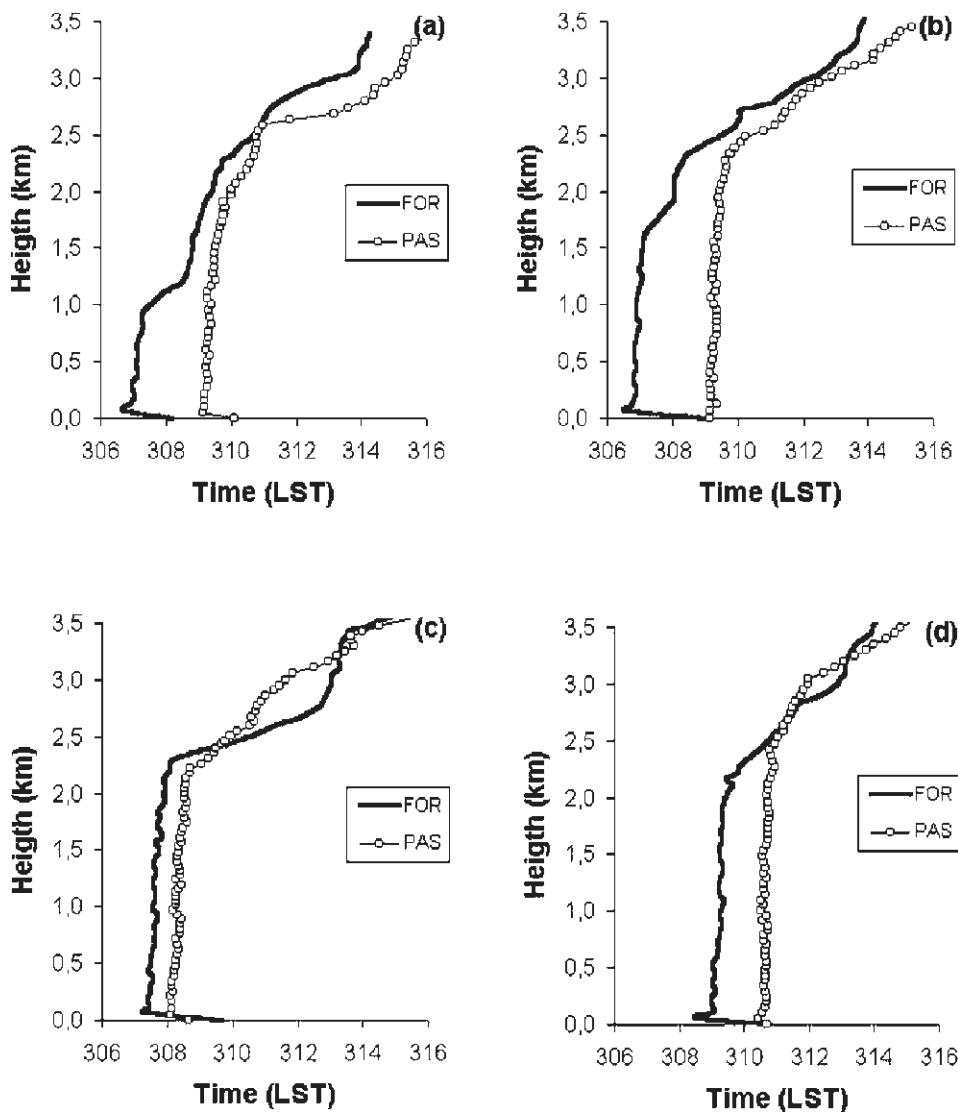


Figure 2. Virtual potential temperature profiles over the forest (FOR) and pasture (PAS) at 5PM. (a) August 20, (b) August 19, (c) August 15, (d) August 22.

(Lyra et al., 1992) and for the same Rondonia site (RBLE2) in the previous year (Souza, 1997). The CBL growth major differences occurred in the morning hours whereas the CBL heights were similar in the afternoon, attaining an average value of 1,200m at the end of the afternoon. In Figure 3b, the RBLE2 (1993) height evolution of the CBL over the pasture was compared with the RBLE3 (1994). Results were very similar for the two dry season experiments, suggesting that CBL grew higher over the pasture than over the forest with a height difference of about 1 km at the end of the afternoon. It is noticed that the RBLE2 results are the only ones reported in the literature for tropical deforested sites in the dry season.

Figure 4 shows the daily cycle of the ABL over the two sites. Initially, θ_v was smaller in NBL over the forest than over the pasture. Although the humidity was higher, both the diurnal solar heating and the nocturnal cooling due to longwave loss made the daily amplitude of the pasture θ_v larger. Another difference was a clear height separation between the CBL and NBL over the pasture (Figure 4b), that is, it was easier to identify the afternoon-night transition in the variables diagrams due to the growth of CBL up to SL at the end of the afternoon. Sometimes this occurred over the forest also, as can be seen on day 22 (Figure 4a). On the other hand, it was difficult to identify the night-morning

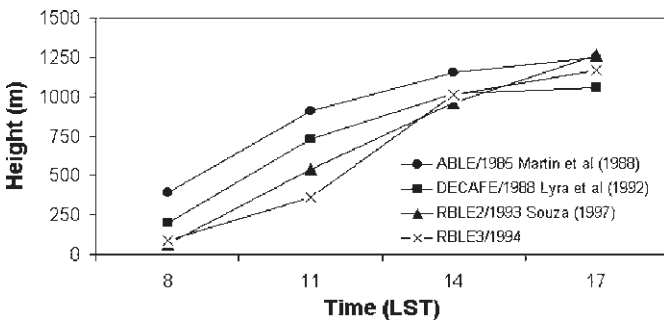


Figure 3a. Evolution of the diurnal Convective Boundary Layer over the tropical forest during the dry season for different sites: Western Amazônia (RBLE), Central Amazonia (ABLE) and Equatorial Africa (DECAFE).

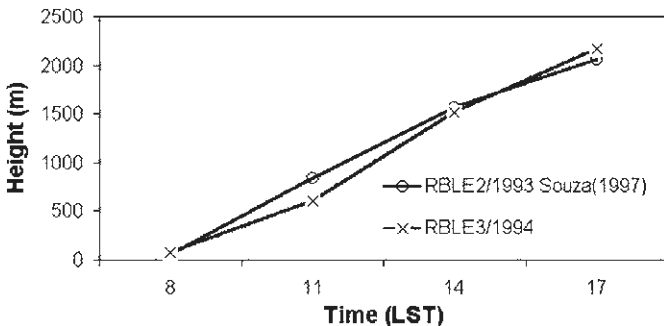


Figure 3b. Evolution of the diurnal Convective Boundary Layer over the pasture during two dry season experiments over the Western Amazônia (RBLE) .

transition since the NBL persisted during a significant portion of the morning. The persistence of the NBL was observed in the two sites but it was more pronounced over the forest because of the slower surface heating (Fisch, 1996). Silva and Lyra (2000) showed that the surface boundary layer over the forest is more unstable at 2 PM and 5 PM. In Figure 4, beginning on day 21, the subsident air can be seen clearly entraining at 2,000m over both sites. On days 22, 23 and 25, for example, the 309K isotherm, generally observed above 2,000 m over the forest, was near 250 m height (Figure 4a). On the same days, over the pasture, a warm air layer extended from the surface up to 2,500 m with temperature around 310K (Figure 4b).

The humidity time-height sections were depicted in Figure 5. The humidity was higher near the forest surface, particularly within the NBL(Figure 5a). This happened because the diurnal temperature inversion, existing at the canopy level, broke after 4PM and the moist air of the forest interior rose. Contrary to what was expected, the vertical mixing over the pasture was found to be stronger, that is, there was a more efficient vertical moisture transport due to a higher development of the CBL. Thus, the air over the pasture was generally moister above 1,000m when Figures 5a and 5b are compared. Silva and Lyra (1998) stated that the

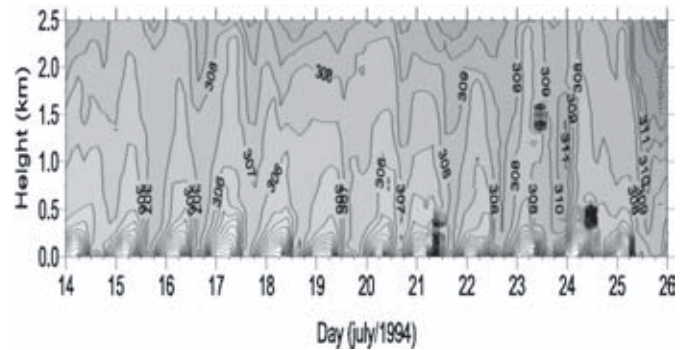


Figure 4a. Time-height section of virtual potential temperature (K) over the forest from August 14 to 26.

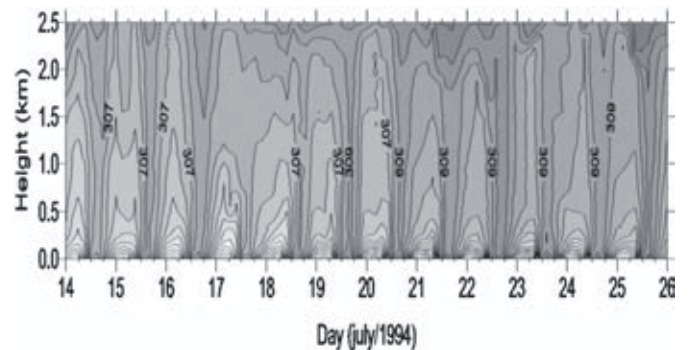


Figure 4b. Time-height section of virtual potential temperature (K) over the pasture from August 14 to 26.

CBL was moister over the pasture generally after 2 PM. The deforested area seemed to act as a heat island and one expects to have horizontal convergence of moisture and other chemical species. However, it cannot be stated if there is in fact a local forest to pasture circulation once the large scale winds blow from forest to pasture predominantly. A drier layer appeared clearly above 200 m over the two sites, similar to what happened with the temperature.

The time-height section of the wind was presented in Figures 6a for the forest and 6b for the pasture. Near the surface, the wind was weaker because forest surface roughness is higher (Figure 6a). The growth of CBL was observed to remain near 1,200 m when relative calm large scale conditions prevailed. On day 15, however, it was observed a jet at about 2,200m over the two sites, a larger scale phenomenon evidently. It was noticed that, when jets occurred at these heights, the CBL over the forest grew up to 2,000m at the end of the afternoon of the same day or the day after. The maximum wind speeds tended to occur near the base of psychrothermic inversion where the vertical mixing is damped out. At these heights, the jets may cause diffluence in the flow and produce stronger than normal vertical motion. A strong low level jet, with intensity of $18\text{m}\cdot\text{s}^{-1}$, was observed at 250m height on day 14 at the end of

the afternoon over the forest (Figure 6a). On that day, the CBL was thicker over the forest than over the pasture, 1200m versus 1000m high, and the lapse rate stable. This jet was a result of a local afternoon storm downdraft (“microburst”), as it could be seen in the time loop of METEOSAT half-hour images for the period of the field experiment. However, less intense jets were observed over the pasture in many days, either at the end of the afternoon or at night. In Figure 6b, it is noticeable that the low level jets, in fact, extend up to the top height scale, though less intense. These jets were more frequent over the pasture and might have been produced by the collapse of the CBL in the afternoon that allows the large-scale winds to sink to lower heights, once the NBL is maintained at low heights, usually between 200m to 300m. The METEOSAT images loop revealed also that, in some days, the large-scale wind field was modulated by a train of gravity waves (traveling disturbances lines) that had a wavelength of about 10° of latitude and propagate at about 10° per day. These instability lines produced pulses in the wind field at regular time intervals, as it is apparent in the time-height section. Over the forest, low-level jets were observed, such as the ones on days 17 and 18 (Figure 6a), but were less frequent. Low level jets were found over African tropical forest ABL also (Lyra et al.,1992).

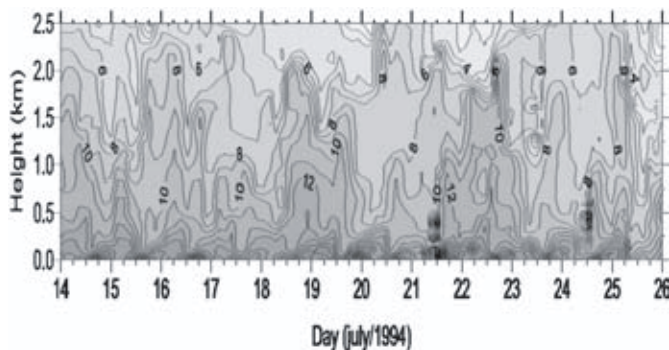


Figure 5a. Time-height section of specific humidity ($\text{g}\cdot\text{kg}^{-1}$) over the **forest** from August 14 to 26.

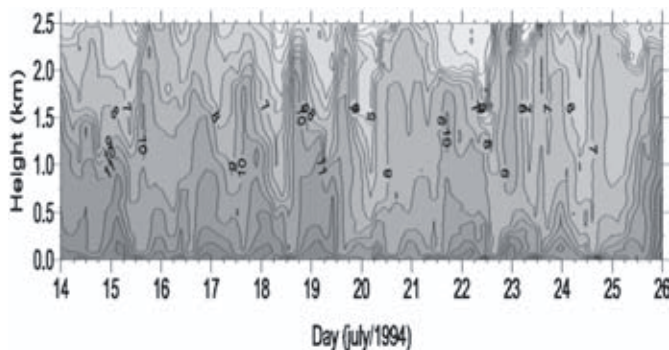


Figure 5b. Time-height section of specific humidity ($\text{g}\cdot\text{kg}^{-1}$) over the **pasture** from August 14 to 26.

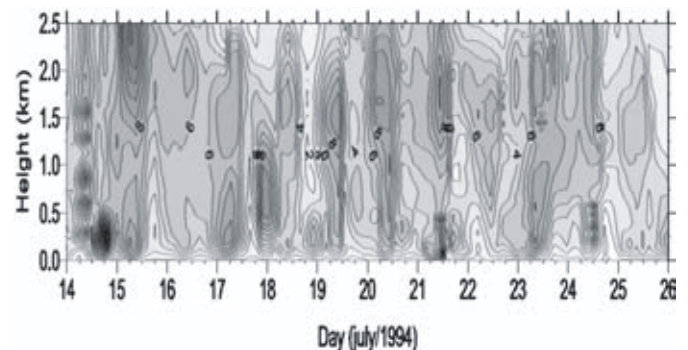


Figure 6a. Time-height section of wind ($\text{m}\cdot\text{s}^{-1}$) over the **forest** from August 14 to 26.

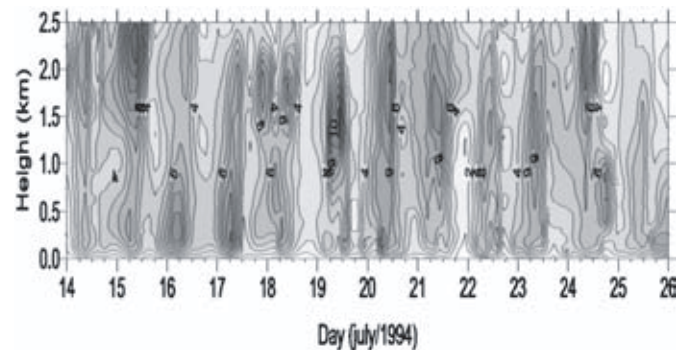


Figure 6b. Time-height section of wind ($\text{m}\cdot\text{s}^{-1}$) over the **pasture** from August 14 to 26.

The water vapor saturation deficit (Δe) evolution was presented in Figures 7a and 7b for the forest and pasture sites, respectively. The intention was to identify conditions favorable for fog formation since fog is important condensation mechanism not only for the vegetation water balance but also for the balance of some chemical species, as they act as condensation nuclei and fall out. According to Silva and Lyra (1998), fog was observed every day over the forest. In fact, it can be seen in Figure 7a that, at low levels, Δe was nearly zero over the forest in all nights of the observational period. In the column up to 2,500m, the Δe was over 10hPa most of the time. Over the pasture (Figure 7b), Δe was nil at low levels only during the nights of the first half of the period and the whole column, up to 2,500m, was relatively wetter up to day 19. After that, Δe reached values above 30hPa (e.g., day 24 afternoon) and the dryness extended throughout the column. The drying of the ABL in the second half of the experiment was caused probably by entrainment of the dry air from the subsidence aloft due to the breaking of the top of CBL by traveling disturbances, as it can be seen starting on day 18 but quite remarkably on days 22 and 23. But horizontal divergence associated with low level jets within the CBL also produce descending

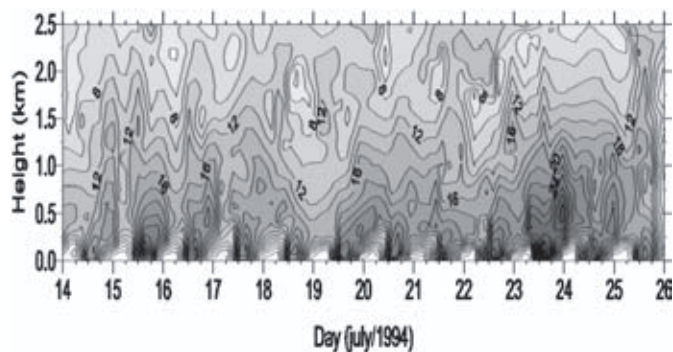


Figure 7a. Time-height section of water vapor saturation deficit (hPa) over the **forest** from August 14 to 26.

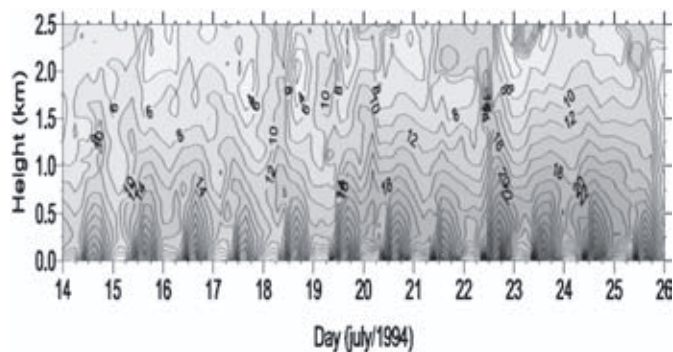


Figure 7b. Time-height section of water vapor saturation deficit (hPa) over the **pasture** from August 14 to 26.

motions, as noticed on day 14. Martin et al. (1988) demonstrated that the entrained flux across the top of the CBL must approach 600Wm^{-2} to produce realistic CBL drying rates. Over the pasture, fog occurred basically in the first half of the period. Fog was lighter and dissipated quickly after sunrise. Clouds formed before day 20 over the pasture. Due to the intense subsidence and the large relative humidity differences between the base and the top of the psychrothermic inversion layer, sometimes over 70%, clouds could not develop because they re-evaporated as they penetrated the layer.

4. CONCLUDING REMARKS

In summary, significant differences in the daily behavior of the deforested area atmospheric boundary layer have been observed when compared to the forest ABL. In general, late afternoon, the convective boundary layer was about 80% thicker over the pasture, its height reaching 2,200m versus 1,200m over the forest, and its potential virtual temperature about 2K warmer than over the forest. The CBL air was about 6g.kg^{-1} drier over the pasture due to the stronger mixing, even in days when the CBL over the forest reached the same thickness, about 1,700m height, at 5PM. The pasture nocturnal boundary layer was warmer, grew to 200m height and broke more easily in the morning hours when compared to the forest NBL that reached an average height of 300m in the average. Over the forest, the nocturnal jets were weaker and less frequent than over the pasture. Fog formed during the night over the pasture just in the first half of the period when it was observed that the whole column was wetter, whereas fog was a daily happening over the forest.

The results showed that the behavior of the ABL over the two sites was modulated mainly by dynamic mechanisms of the meso and large scales. Pulses in the large-scale wind field due to traveling disturbances and entrainment of dry air from the subsidence aloft were examples of the control exerted by these larger scale motions. The structure and behavior of the Western Brazilian Amazonia ABL seem to be rather complex and the present theory and modeling seem to be inadequate to explain it.

5. REFERENCES

- BASTABLE, H.G.; SHUTTLEWORTH, W.J.; DALLAROSA, R.L.G.; FISCH, G.; NOBRE, C.A. Observations of climate, albedo and surface radiation over cleared and undisturbed Amazonia Forest. *Int. J. Climatol.*, v.13, n.7, p.783-796, 1993.

- CULF, A.D.; FISCH, G.; HODNETT, M.G. The albedo of Amazonia Forest and Ranchland. **Journal of Climate**, v.8, n.6, p.1544-1554, Mai/1995a, 1994.
- FISCH, G. **Camada Limite Amazônica**: aspectos observacionais e de modelagem. São José dos Campos, 1996. 171p. Tese (Doutorado em Meteorologia) - INPE.
- HENDERSON-SELLERS, A.; DICKINSON, R.E.; DURBIDGE, T.B.; KENNEDY, P.J.; McGUFFIE, K.; PITMAN, A.J. Tropical deforestation: modelling local-to-regional-scale climate change. **J. Geophys. Res.**, v.98, n.D4, p.7289-7315, 1993.
- LEAN, J.; WARRILOW, D.A. Simulation of the regional climatic impacts of Amazon deforestation. **Nature**, v.342, p.411-413, 1989.
- LYRA, R.; DRUILHET, A.; BENECH, B; BIONA, C.B. Dynamique above a dense Equatorial Rain Forest from the surface boundary layer to the free Atmosphere. **J. Geophys. Res.**, v.97, n.D12, p.12,953-12,965, 1992.
- LYRA, R.; NOBRE, C.; FISCH, G.; ROCHA, E.; ROCHA, H.; SOUZA, S.S. Efeitos do desmatamento sobre a termodinâmica da baixa atmosfera. *In*: CONGRESSO BRASILEIRO DE METEOROLOGIA, 8., 1994, Belo Horizonte. **Anais...** p.81-84.
- MARTIN, L.C.D.; FITZJARRALD, D.; GASTANG, M.; OLIVEIRA, P. A.; GRECO S. Structure and growth of the mixing layer over Amazonian Rain Forest. **J. Geophys. Res.**, v.93, p.1361-1375, 1998.
- MOLION, L.C.B. Global climate impacts of Amazonia deforestation. **Revista Geofísica**, v.42, p.89-101, 1995.
- NOBRE, C.A.; SELLERS, P.J.; SHUKLA, J. Amazonian deforestation and regional climate change. **J. Climate**, v.4, n.10, p.957-988, 1991.
- ROWNTREE, P.R. Atmospheric parametrization schemes for evaporation over land: basic concepts and climate modelling aspects. *In*: SCHMUGGE, T.J.; ANDRÉ, J.C., (Eds.). **Land surface evaporation, measurements and parameterization**. 1991. p.5-29.
- SHUTTLEWORTH, W.J.; GASH, J.H.C.; ROBERTS, J.M.; NOBRE, C.A.; MOLION, L.C.B.; RIBEIRO, M.N.G. Post deforestation Amazonian climate: Anglo-Brasilian research to improve prediction. **J. Hydrol.**, v.129, p.71-85, 1991.
- SILVA, M.R.G. da; LYRA, R.F.F. Modificação da camada limite noturna em função do desmatamento no Oeste da Amazônia: Projeto RBLE. **Atmosfera & Água**, v.4, p.27-31, 1998.
- SILVA, M.R.G. da.; LYRA, R.F.F. Efeitos do desmatamento nas condições de estabilidade da baixa troposfera no Oeste da Amazônia (Rondônia). *In*: CONGRESSO BRASILEIRO DE METEOROLOGIA, 10., 2000, Rio de Janeiro. **Anais...** p.2346-2351.
- SOUZA, S.S. de. **A substituição da Floresta Amazônica por pastagem e sua repercussão ao nível da termodinâmica da camada limite atmosférica**. Campina Grande, 1997. 110p. Dissertação (Mestrado) - Departamento de Ciências Atmosféricas. (CMM TD 03), Centro de Ciências e Tecnologia, Universidade Federal da Paraíba.
- SOUZA, S. S. de; LYRA, R. F.F. Características observadas da termodinâmica da camada limite atmosférica sobre Rondônia e suas relações com a substituição de áreas de florestas naturais por pastagens: Projeto RBLE. **Rev. Bras. de Meteorologia**, v.16, n.2, p.157-164, 2002.