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Radiosounding-derived convective parameters for the Alcântara Launch Center

Abstract: Climatological features of convective parameters (K index, IK; 950 hPa K index, IK950; Showalter index, IS; lifted index, ILEV; total totals index, ITT; and convective available potential energy, CAPE) derived from 12 UTC radiosounding data collected at the Alcântara Launch Center (CLA; 2°18'S, 44°22'W) from 1989 to 2008 were computed. The parameters IK, IK950, IS and ITT (ILEV and CAPE) showed a seasonal variation coherent (not coherent) to the annual cycle of precipitation. Interdaily variability was high all year round and was comparable to the monthly average seasonal variation. For IK and IK950, the monthly fraction of days with favorable conditions for precipitation occurrence (FRAC) showed good agreement with the monthly fraction of days with precipitation greater than 0.1 mm (PRP). For ITT and IS, the seasonal variation of FRAC was lower than the seasonal variation of PRP; for ILEV and CAPE, there were marked differences between FRAC and PRP. IK seasonal variation was primarily due to the presence of a deeper (shallower) low-level moist layer in the wet (dry) season. Among the studied convective parameters, the use of IK or IK950 for assessing precipitation occurrence was recommended.

Keywords: Storms, Tropical regions, Clouds, Climatology.

LIST OF SYMBOLS

CLA	Alcântara Launch Center
IK	K index
IK950	K index for 950 hPa
IS	Showalter index
ILEV	Lifted index
ITT	Total totals index
CAPE	Convective available potential energy
T_{\bullet}	Temperature at \bullet hPa level
Td_{\bullet}	Dew point temperature at \bullet hPa level
Dep_{\bullet}	Dew point depression at \bullet hPa level
$Tp_{sfc \rightarrow \bullet}$	Temperature at \bullet hPa of an average air parcel over the first 500 m from the surface lifted to \bullet hPa by an undiluted pseudo-adiabatic process
$Tp_{850 \rightarrow \bullet}$	Temperature at \bullet hPa of an air parcel at 850 hPa lifted to \bullet hPa by an undiluted pseudo-adiabatic process
g	Gravity at sea level
T_p	Parcel temperature (for CAPE definition)
T_a	Environment temperature
z	Height
LFC	Level of free convection
LNB	Level of neutral buoyancy
FRAC	Monthly fraction of days when the convective parameter value is favorable to precipitation occurrence
PRP	Monthly fraction of days with precipitation greater than 0.1 mm

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INTRODUCTION

Radiosoundings are used to obtain vertical profiles of thermodynamic (pressure, temperature and humidity) and dynamic (horizontal winds) variables from the surface up to the lower stratosphere. From these data, convective parameters (or instability indices) can be calculated and their actual values can be compared to threshold values related to the probability of rainfall occurrence. For instance, the convective available potential energy (CAPE), which is a widely used convective parameter in theoretical, observational and modeling studies (e.g., Emanuel, 1994), measures the buoyancy force potential energy for an undiluted pseudo-adiabatic ascent of a moist air parcel from the level of free convection to the level of neutral buoyancy. Values of CAPE higher than the threshold value of 1000 J kg^{-1} are usually regarded as high (Nascimento, 2005) and associated to atmospheric thermodynamic conditions favorable to precipitation occurrence. Therefore, convective parameters provide useful information about the atmospheric column potential for deep convection and also complement the precipitation forecast from numerical atmospheric models.

There are few studies on convective parameters for regions in Brazil (e.g., Souza et al., 2001; Fogaccia and Pereira Filho, 2002; Fisch et al., 2004; Domingues et al., 2004; Nascimento and Calvetti, 2004; Barbosa and Correia, 2005; Nobile Tomaziello and Gandu, 2008; Nunes and Escobar, 2008; Silva et al., 2008). Although convective parameters are routinely used by operational weather forecasters, there is still a lack of studies to support and verify the use of standard threshold values that were not necessarily derived from atmospheric conditions similar to those found in Brazil (Nascimento, 2005).

In this work, the climatological features of some widely used convective parameters are obtained for a specific region located at the northern coast of Northeast Brazil: the Alcântara Launch Center (CLA; 2°18'S, 44°22'W), (Marques and Fisch, 2005). The climatology of convective parameters could be useful for weather forecasting and nowcasting during rocket launching missions at CLA. In CLA, surface and upper-air meteorological data are collected on a regular basis for climatological studies (e.g., Marinho et al., 2009).

DATA AND METHODOLOGY

The climate in CLA is tropical humid (IBGE, 2002). Monthly precipitation shows a marked seasonal variation (Figure 1): austral autumn (spring) is the wet (dry) season, and austral summer and winter are the transition seasons (Pereira et al., 2002; Barros, 2008). Maximum (minimum) values of monthly precipitation are found in March and April (September and October).

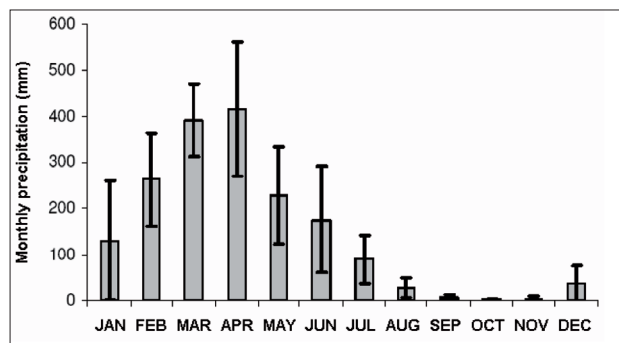


Figure 1: Average and interannual standard deviation of monthly precipitation at CLA (mm) from Sep 1993 to Mar 2007. Source: Barros (2008).

Daily 12 UTC radiosounding data collected at CLA from 1989 to 2008 were used. The raw data undergo a pre-processing procedure to filter out spikes (data is regarded as spike when the absolute change between adjacent levels is greater than a prescribed variable-related threshold value), vertically interpolate the data (regular 25 hPa spacing between adjacent levels) and remove radiosoundings with less data than needed to appropriately calculate the convective parameters (e.g., radiosounding terminated prematurely, lack of humidity data, etc.).

For each pre-processed radiosounding, the following convective parameters are calculated: K index (IK), K index for 950 hPa (IK950), Showalter index (IS), lifted index (ILEV), total totals index (ITT) and CAPE. The definition of these parameters is given in Table 1, and follows Nascimento (2005) and Corrêa (2007). CAPE and ILEV are calculated by considering the ascent of an average air parcel over the first 500 m from the surface (instead of using an air parcel at the

surface). This procedure aims at attenuating the excessive sensitivity of CAPE and ILEV to small variations in surface values (Manzato, 2003). The pseudo-adiabatic ascent is based on unsaturated potential temperature conservation from the surface to the lifting condensation level (LCL) and on equivalent potential temperature conservation (as defined by Bolton, 1980) from the LCL upwards. Equivalent potential temperature conservation is attained iteratively from two initial limit ascents: dry adiabatic and isothermal.

The time series of the convective parameters have gaps due to missing radiosoundings or removed radiosoundings in the pre-processing procedure; no gap filling procedure is used.

The standard and commonly used threshold values for rainfall occurrence (i.e., favorable conditions for rainfall occurrence) are given in Table 1. They are based on Comando da Aeronáutica (2004) and Nascimento (2005). For IK950, no threshold value has yet been proposed in the literature; so, it is assumed that the IK950 threshold value is 10°C higher than IK's, since IK950 is on average 10°C higher than IK (Corrêa, 2007).

CLIMATOLOGY

The annual cycle of the convective parameters is shown in Figure 2. Seasonal change from wet to dry season is found for all parameters, although only IK, IK950, ITT and IS exhibit coherence to the precipitation cycle (Figure 1). The values for ILEV and CAPE are almost constant throughout the wet season, i.e., no expected maximum (CAPE) or minimum (ILEV) is found in March or April (when precipitation is maximum). For all parameters, interdaily variability is high all year round and comparable to the monthly average seasonal variation.

Validity of the threshold values given in Table 1 could be preliminarily evaluated by considering that the convective parameters' annual average is a natural threshold value candidate because it splits the convective parameters distribution into two equal portions (one portion related to the wetter months; the other, to the drier ones). For IK950 and IK, a slightly lower threshold value (than that given in Table 1) could be more suitable; for IS and ITT, higher; and for ILEV and CAPE, much lower.

For a given convective parameter and month, FRAC is defined as the fraction of days when the convective parameter value is favorable to precipitation occurrence (according to the threshold values given in Table 1). To further check the validity of the threshold values given in Table 1, the annual cycle of FRAC for all convective parameters is compared to the annual cycle of PRP, defined as the fraction of days of a given month with precipitation higher than 0.1 mm (Figure 3). The results obtained show that:

Table 1: Convective parameters definition and threshold values for rainfall occurrence (see list of symbols). Source: Comando da Aeronáutica (2004), Nascimento (2005) and Corrêa (2007).

Convective Parameter	Definition	Condition for rainfall occurrence
K index (IK)	$T_{850} - T_{500} + Td_{850} - Dep_{700}$	$> 30^{\circ}\text{C}$
950 hPa K index (IK950)	$T_{950} - T_{500} + Td_{950} - Dep_{700}$	$> 40^{\circ}\text{C}$
Showalter index (IS)	$T_{500} - T_{p_{850 \rightarrow 500}}$	$< 1^{\circ}\text{C}$
Lifted index (ILEV)	$T_{500} - T_{p_{sfc \rightarrow 500}}$	$< 0^{\circ}\text{C}$
Total totals index (ITT)	$T_{850} + Td_{850} - 2 \times T_{500}$	$> 40^{\circ}\text{C}$
Convective available potential energy (CAPE)	$g \int_{LFC}^{LNB} \frac{T_p - T_a}{T_a} dz$	$> 1000 \text{ J kg}^{-1}$

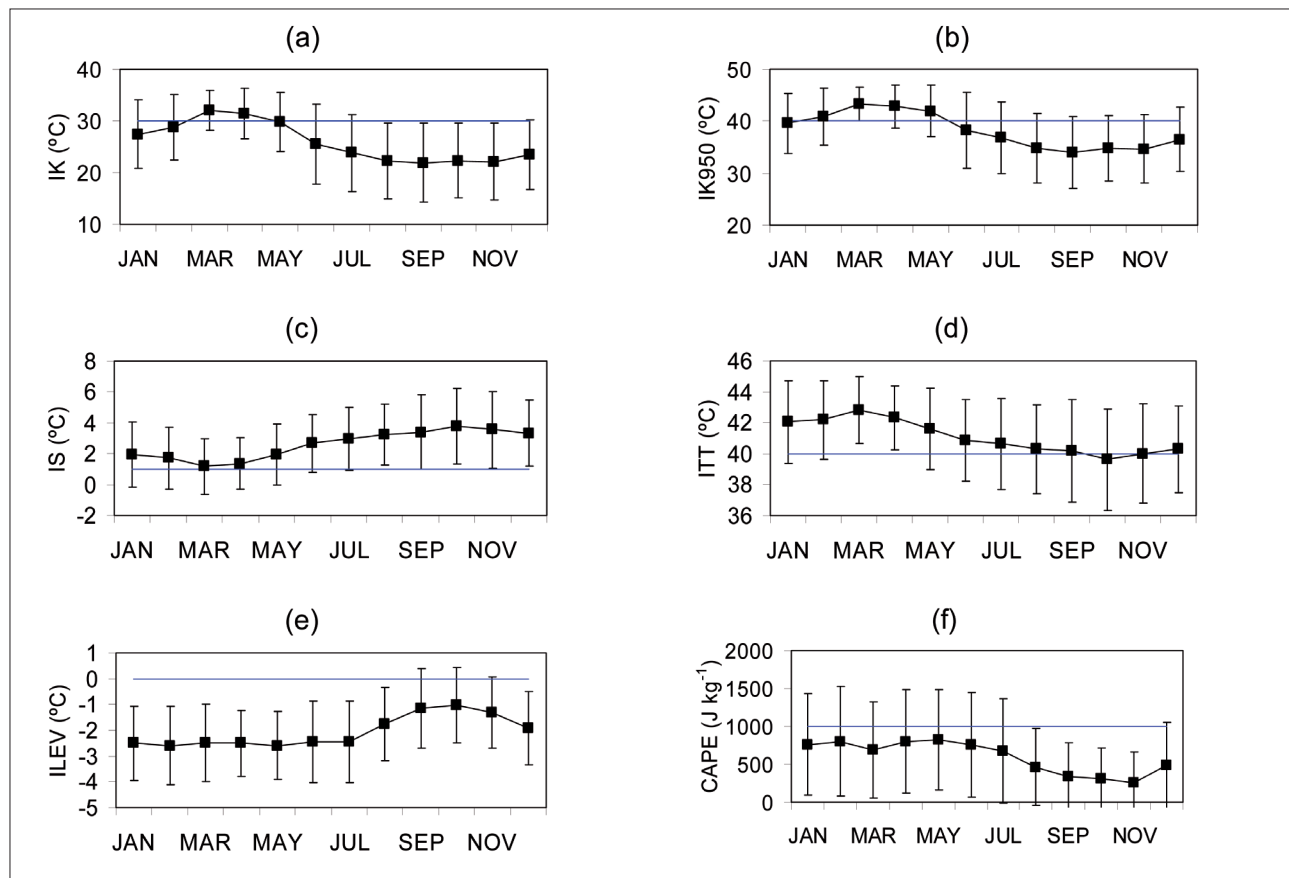


Figure 2: Monthly average and interdaily standard deviation for IK (a), IK950 (b), IS (c), ITT (d), ILEV (e) and CAPE (f). Blue horizontal line refers to the threshold values given in Table 1.

- For IK and IK950, there is good agreement between FRAC and PRP (Figure 3a). The slight underestimation of FRAC for IK (with respect to PRP) could be fully corrected if a slightly lower threshold value was used (as stated previously).
- For ITT and IS, FRAC shows good agreement compared to PRP in only one season (wet season for ITT and dry season for IS) because the seasonal variation of both parameters is not sufficiently large (Figure 3b). Threshold values changes could shift FRAC curve up or down (for instance, by using 42°C as threshold value for ITT, and 2°C for IS, FRAC curves for both parameters become almost the same) but are not able to enlarge the seasonal variation. Therefore, good agreement between FRAC and PRP would not be possible by solely changing the threshold values.
- For ILEV and CAPE, differences between FRAC and PRP are more pronounced (Figure 3c). FRAC for

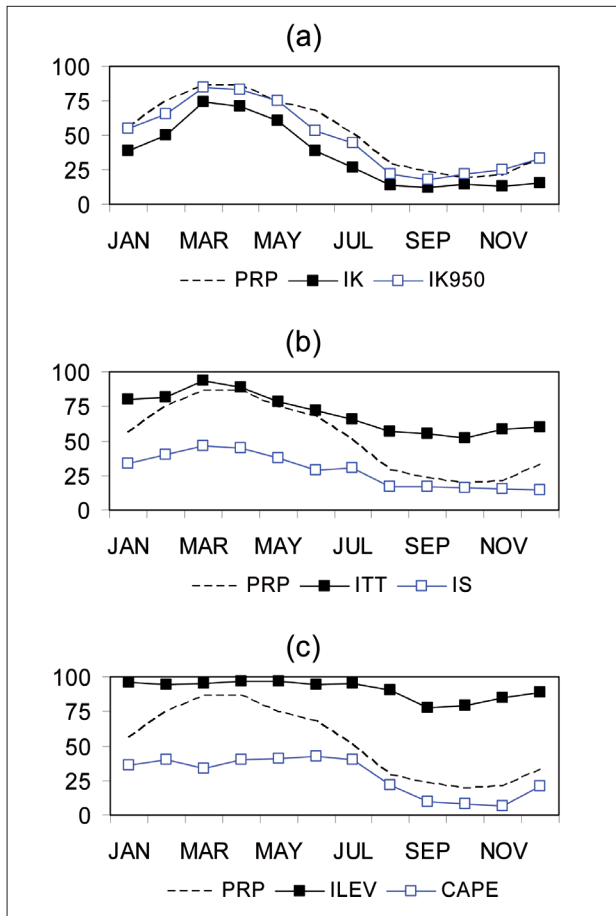


Figure 3: Solid lines: monthly fraction of days (%) when the convective parameter value is favorable to precipitation occurrence for IK and IK950 (a), ITT and IS (b), and ILEV and CAPE (c). Dashed line (PRP in all panels): monthly fraction of days (%) with daily precipitation greater than 0.1 mm (source: Barros, 2008).

ILEV (CAPE) overestimates (underestimates) PRP all year round, and FRAC during the wet season is almost constant, i.e., do not show maximum values in March or April. As for ITT and IS, good agreement between FRAC and PRP would not be possible by solely changing the threshold values.

By using the degree of agreement between FRAC and PRP as criterion to single out the best convective parameters to predict precipitation occurrence, IK and IK950 could be strongly recommended; ITT and IS could be used for only one season (wet season for ITT and dry season for IS); and ILEV and CAPE should not be used.

FACTORS RELATED TO K INDEX SEASONAL VARIATION

IK is one of the most commonly used convective parameters by operational weather forecasters, and the

results of the previous section confirmed that IK (as well as IK950, which may be regarded as a small variation of IK) would be effective to predict precipitation occurrence. Since IK is able to represent the seasonal cycle of PRP, a deeper analysis of the terms that compose IK is carried out to unravel the thermodynamic conditions related to precipitation suppression during the dry season in CLA.

During the dry season, the Intertropical Convergence Zone (ITCZ) attains its northernmost position in the Northern Hemisphere, and its subsidence branch affects the northern part of Brazil (including the CLA) (Peixoto and Oort, 1992). Using Reanalysis data, Pereira Neto (2009) found that large scale subsidence strongly affects only the mid and upper levels; at the lower levels, upward motion is found and would be enough to initiate updrafts in cumulus clouds. Updraft velocities are normally one order of magnitude greater than large scale vertical velocity; thus, large scale subsidence over CLA would not be enough to inhibit updraft enhancement due to latent heat release, i.e., formation of deep cumulus clouds would be expected. However, the majority of clouds found over CLA in the dry season are shallow (stratocumulus) non-precipitating clouds; so, what are the processes that inhibit updraft enhancement and the development of deep clouds?

As shown in Table 1, IK is the sum of three terms. The first term ($T_{850} - T_{500}$) represents the low-level lapse rate. The temperature difference remains almost constant throughout the year; the values for March (wettest month) and October (driest month) are almost the same (about 23.5°C) and, therefore, could not explain the IK seasonal variation (Figure 4a). The second term (Td_{850}) is related to low-level moisture and it shows a seasonal variation of about 3°C (Figure 4b). The third term (Dep_{700}) is related to low-level moist layer thickness and it shows a marked seasonal variation of about 7°C (Figure 4c). Therefore, the 10°C seasonal variation in IK (Fig. 2a) is due to a deeper (shallower) moist layer and greater (lower) low-level moisture in the wet (dry) season. The seasonal changes in low-level lapse rate are not relevant.

Deeper moist layer (or greater moist layer thickness) aids cumulus convection by providing moister environmental air for entrainment into updrafts, thus weakening the drag effect exerted by mass entrainment in updrafts (Holton, 1992). This is an important mechanism for deep convection over oceans (Sui et al., 1997). Therefore, in the dry season at CLA, the entrainment of drier low and mid-level environmental air into updrafts could limit cloud growth and lead to the formation of shallow clouds. Mid and upper level large scale subsidence could confine moisture to the lowest levels, thus reducing the low-level moist layer thickness. This tentative explanation for deep cloud suppression in the dry season at CLA integrates both dynamic and thermodynamic aspects of convection and need to be confirmed by further studies.

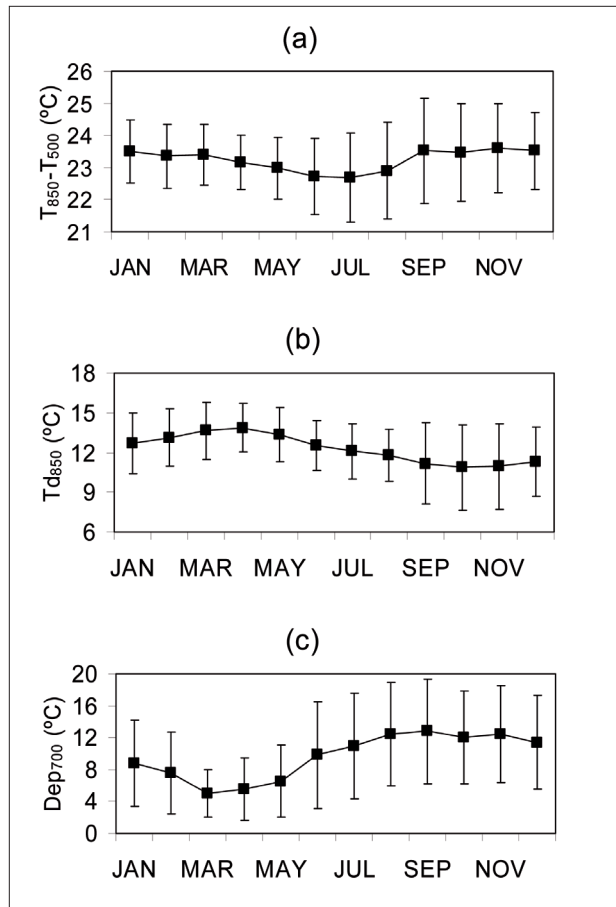


Figure 4: Monthly average and interdaily standard deviation for the terms of IK: (a) first term, $T_{850} - T_{500}$; (b) second term, Td_{850} ; (c) third term, Dep_{700} .

CONCLUSIONS

Climatological features of convective parameters (IK, IK950, IS, ILEV, ITT and CAPE) derived from 12 UTC radiosounding data collected at the Alcântara Launch Center (CLA) from 1989 to 2008 were obtained. The main conclusions of this work were:

- IK, IK950, IS and ITT (ILEV and CAPE) showed a seasonal variation coherent (not coherent) to the annual cycle of precipitation. Interdaily variability was high all year round and comparable to the monthly average seasonal variation.
- For IK and IK950, FRAC showed good agreement with PRP. For ITT and IS, the seasonal variation of FRAC was lower than the seasonal variation of PRP. For ILEV and CAPE, there were marked differences between FRAC and PRP.
- Among the studied convective parameters, the use of IK or IK950 for assessing precipitation occurrence could be recommended.

- IK seasonal variation was primarily due to the presence of a deeper (shallower) low-level moist layer in the wet (dry) season.

The climatology derived here could be useful for operational purposes and be regarded as reference values in studies for CLA. Also it may contribute to a more comprehensive characterization of the behavior of convective parameters for regions in Brazil.

In this work, only convective parameters were focused on for the sake of simplicity and conciseness. To evaluate the skill for predicting precipitation occurrence from convective parameters, a statistical analysis on a daily basis using not only radiosounding data but also precipitation data could be necessary. This issue, along with the characterization of convective parameters that use wind data information (e.g., Richardson number, Severe Weather Threat Index, etc.), will be addressed in a future work.

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REFERENCES

- Barbosa, T. F., Correia, M. F., 2005, "Sistemas Convectivos Intensos no Semi-Árido Brasileiro: o Controle da Grande Escala", *Revista Brasileira de Meteorologia*, Vol.20, No. 3, pp. 395-410.
- Barros, S.S., 2008, "Precipitação no Centro de Lançamento de Alcântara: Aspectos Observacionais e de Modelagem", M.Sc. Dissertation, Instituto Nacional de Pesquisas Espaciais, São José dos Campos, S.P., Brazil, 115 p. (INPE-15319-TDI/1362).
- Bolton, D., 1980, "The Computation of Equivalent Potential Temperature", *Monthly Weather Review*, Vol.108, pp.1046-1053.
- Comando da Aeronáutica, 2004, "Meteorologia Física I: Índices de Instabilidade", CFOE MET. 7p.
- Corrêa, C.S., 2007, "A Ocorrência de Fluxos no Perfil Vertical do Vento na Baixa Atmosfera e seu Efeito

- na Intensidade do Índice K”, *Revista Brasileira de Meteorologia*, Vol.22, pp.129-133.
- Domingues, M. O., Mendes Jr, O., Chan, S. C., Sá, L. D. A., Manzi, A. O., 2004, “Análise das Condições Atmosféricas Durante a 2a Campanha do Experimento Interdisciplinar do Pantanal Sul Mato-Grossense”, *Revista Brasileira de Meteorologia*, Vol.19, No.1, pp.73-88.
- Emanuel, K.A., 1994, “Atmospheric Convection”, Oxford University Press. 580p.
- Fisch, G., Tota, J., Machado, L. A. T., Silva Dias, M. A. F., Lyra, R. F. F., Nobre, C. A., Dolman, A. J., Gash, J. H. C., 2004, “The Convective Boundary Layer Over Pasture and Forest in Amazonia”, *Theoretical and Applied Climatology*, Vol.78, pp.47-59.
- Fogaccia, C. V. C., Pereira Filho, A. J., 2002, “Turbulência e Cisalhamento do Vento na Área do Aeroporto Internacional de São Paulo/Guarulhos”, *Proceedings of the 12th Brazilian Congress of Meteorology*, Foz do Iguaçu, Brazil.
- IBGE, 2002, “Mapa Brasil Climas – Escala 1:5.000.000”.
- Holton, J.R., 1992, “An Introduction to Dynamic Meteorology”, Academic Press, 3. Ed. 511 p.
- Manzato, A., Morgan Jr., G., 2003, “Evaluating the Sounding Instability With the Lifted Parcel Theory”, *Atmospheric Research*, Vol.67-68, pp.455-473.
- Marinho, L.P.B., Avelar, A.C., Fisch, G.F., Roballo, S.T., Gielow, R.G., Giradi, R.M., 2009, “Studies using wind tunnel to simulate the Atmospheric Boundary Layer at the Alcântara Space Center”, *Journal of Aerospace Technology and Management*, Vol.1, N°1, pp. 91-98.
- Marques, R. F. C., Fisch, G. F., 2005, “As Atividades de Meteorologia Aeroespacial no Centro Técnico Aeroespacial (CTA)”, *Boletim da Sociedade Brasileira de Meteorologia*, Vol.29, N°. 3, pp. 21-25.
- Nascimento, E. L., Calvetti, L., 2004, “Identificação de Condições Precursoras de Tempestades Severas no Sul do Brasil Utilizando-se Radiossondagens e Parâmetros Convectivos”, *Proceedings of the 13th Brazilian Congress of Meteorology*, Fortaleza, Brazil.
- Nascimento, E. L., 2005, “Previsão de Tempestades Severas Utilizando-se Parâmetros Convectivos e Modelos de Mesoescala: Uma Estratégia Operacional Adotável no Brasil?”, *Revista Brasileira de Meteorologia*, Vol.20, No. 1, pp.121-140.
- Nóbile Tomaziello, A. C., Gandu, A. W., 2008, “Índices de Instabilidade e Tempestades Severas na Região Metropolitana de São Paulo”, *Proceedings of the 15th Brazilian Congress of Meteorology*, São Paulo, Brazil.
- Nunes, A. B., Escobar, G., 2008, “Análise dos Índices de Estabilidade dos Eventos Severos de 2006-2007 na Cidade de São Paulo”, *Proceedings of the 15th Brazilian Congress of Meteorology*, São Paulo, Brazil.
- Peixoto, J.P., Oort, A. H., 1992, “Physics of Climate”, American Institute of Physics, 520p.
- Pereira, E. I., Miranda, I., Fisch, G. F., Machado, L. A. T., Alves, M. A. S., 2002, “Atlas Climatológico do Centro de Lançamento de Alcântara”, IAE, São José dos Campos, S.P., Brazil. (ACA/RT-01/01, GDO-000000/B0047)
- Pereira Neto, A.V., 2009, Private Communication.
- Silva, L. M., Mota, M. A. S., Sá, L. D. A., 2008, “Análise da Variabilidade da Altura da Camada de Mistura (CM) e da Energia Potencial Convectiva Disponível (CAPE) Durante os Experimentos CIMELA e COBRA-PA, Realizados na Flona de Caxiuanã, Pará”, *Proceedings of the 15th Brazilian Congress of Meteorology*, São Paulo, Brazil.
- Sui, C. H., Lau, K. M., Takayabu, Y. N., Short, D. A., 1997, “Diurnal Variations in Tropical Oceanic Cumulus Convection during TOGA COARE”, *Journal of the Atmospheric Sciences*, Vol. 54, pp.639-655.
- Souza, E. P., Leitão, M. M. V. B. R., Barbosa, T. F., 2001, “Características da Atmosfera Superior, a Partir de Dados de Alta Resolução Obtidos à Superfície”, *Revista Brasileira de Engenharia Agrícola e Ambiental*, Vol. 5, N°. 3, pp. 463-468.