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A STUDY OF SIMULATED INSTABILITY INDICES AND ITS BEHAVIOR OVER RIO DE JANEIRO

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1. INTRODUCTION

The atmospheric instability indices have been introduced, mainly, as aid in connection with techniques or particular studies of forecasting. These indices are great utility, only when agreed, want objective or subjectively, with other data and sinoptic and mesoscale analyses (ANON, 1952; WAGNER and SANDERS, 1959).

The instability indices are calculated from thermodynamic and kinematic atmospheric profiles, that can be gotten of atmospheric soundings or numerical simulations. When calculated from numerical models and/or routines of objective analysis, where diverse regularly spaced profiles are available, the space variation of these parameters can directly be analyzed, allowing the meteorologist to identify regions more favorable or favorable to the development of the convective systems (NASCIMENTO, 2005).

Modeling Indices: A great advantage of the use of instability indices as a tool of I assist to the forecast comes of the fact on that these indices depend only on basic atmospheric variables for its calculate, not needing to use no parametric for the numerical models. These basic variables are calculated of sufficiently reasonable form for the numerical models, without the necessity of a highest resolution.

Of this form, from simulated instability indices, the numerical models can indicate regions favorable to development and the evolution of a strong storm, exactly that the precipitation parameterization of these models have not been capable to simulate rains for the same region. Many times this can happen for the fact of the model not to have enough resolution so that the precipitation parameterization function of adequate form. While this, as the indices are calculated from the simulated basic variables, them do not suffer the restriction to need a so high resolution for its calculation.

In this work, three you marry of storms with high rain and strong winds were used you study the behavior of adds instability indices (also called "severe weather indices") over Rio de Janeiro State. The convective events were simulated by the numerical model "Regional Atmospheric Modeling System" developed in Colorado State University (CSU-RAMS). The indices "K", "Total-totals" and "Lapse-Rate" were calculated using simulated data. The results show a very good agreement between simulated indices critical values and places of developed convective storms, even in very small scale storms. A new index using the combination of thermodynamics and dynamics (triggering) effects was introduced in this work, called "CK index". The understanding of the indices behavior can helps a lot in weather prediction in small scale events, even in situations when the model couldn't simulate the convective.

2. METODOLOGY

To study the behavior of the instability indices in the Rio de Janeiro State, had been used three rain cases of sufficiently intense and destructive character that had reached the Rio de Janeiro in days 31/01/2000, 21/03/2003 and 21/04/2005. Results of the first and second two cases will be presented in this extended abstract.

Sector images of the satellite GOES-8 and Aeronautics Ministry weather radar images had been used for observational evaluation of the phenomena and to compare with the simulated fields of indices.

The indices fields had been generated from the simulated variable for the Regional Atmospheric Modeling System (RAMS) in its 4.3 version, developed for the Department of Atmospheric Sciences - State of the Colorado University, U.S.A.. Them, these fields had been compared with preliminary analyze of the cases, carried through previously in MOURÃO et al. (2004) and LIMA et al. (2004).

For the 31/01/200 and 21/03/2003 cases, the RAMS were simulated using of two grids: "main" - with 27 km grid spacing, enclosing South and Southeast regions of Brazil and a nested domain - with 9 km grid spacing, centered on Rio de Janeiro State, as presented in the table 2.1.

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Table 2.1: Grids horizontal configurations and resolution of the numerical simulations.

Grid	Δx*	Δy*	Δt*	X points	Y points	Z points
1	27	27	15	80	80	30
2	9	9	5	68	44	30

*Measures of space in km and time in seconds

3. INSTABILITY INDEX

The main instability indices, also calls of "pointers of severe time", had been developed for average latitudes and they had almost not been applied for tropical latitudes, exactly being about Brazil. In our country, the instability indices have been used in several forecasting centers with regularity for identification favorable conditions to development of the severe storm only for the South and Southeastern regions. The developed works already had restricted it tests and evaluations of the real applicability of these indices for these country regions (BENETI and SILVA DIAS, 1986; FOGACCIA and PEREIRA FILHO, 2002; NASCIMENTO and CALVETTI, 2004).

3.1. K Index - K

Defined as the sum of dry bulb temperature and dew point temperature in 850 hPa, deducted from the depression of dew point temperature in 700 hPa and of dry bulb temperature in 500 hPa (Eq. 3.1), K most good tends to catch conditions favorable to the storm occurrence in humid environments in all the troposphere, as he is typical of tropical environments (NASCIMENTO, 2005).

$$K = (T_{850} + TD_{850}) - (T_{700} - TD_{700}) - T_{500} \qquad (3.1)$$

where T and TD mention the temperatures of the dry bulb and dew point to it, respectively, and the sub-indices indicate the level of pressure (in hPa) corresponding.

3.2. Total Totals Index – TT

The Total Totals Index was defined by MILLER and MADDOX (1975), as presented in Equation 3.2.

$$TT = T_{850} + TD_{850} - 2 * T_{500} \qquad (3.2)$$

where T and TD mention the temperatures of the dry bulb and dew point to it, respectively, and the sub-indices indicate the level of pressure (in hPa) corresponding.

As well as K, the TT biggest limitation is the dependence of the humidity in 850. Therefore the humidity in low levels can be below of this surface. When the air mass is hot and humid, these indices (K and TT) give similar interpretations, but when air is more cold and dry the TT present better results, because it gives one bigger weight to the cold air presence in average levels (BENETI and SILVA DIAS, 1986).

3.3. Lapse Rate Index – LR

Index LR represents the variation dT/dz (eq. 3.3) for one determined atmospheric layer, in way that how much bigger LR is for one given layer, greater will be the atmospheric instability for deep convection.

$$LR = \frac{-dT}{dz} = \frac{(T_{500} - T_{700}) \times 1000}{geo_{500} - geo_{700}} \qquad (3.3)$$

4. CK Index – CK

So that the formation of deep convection exists, producing of intense rains, it is necessary that it has a combination between the atmospheric instability and the “trigger” for detonation of the determined convection in one local one.

To if analyzing the variables "K Index", that it represents a thermodynamic condition of the atmosphere and "convergence in low levels", that can be a sufficiently efficient “trigger” for the air survey and consequence convection triggering, of combined form, was possible to generate resulted excellent in terms to characterize the regions of formation of the convective systems associates the studied cases.

Therefore, a new "pointer for convection" was introduced (or new index), that it represents a combination of these effect: dynamic (“trigger”) and thermodynamic. This new index is calculated from a simple product between K index and the divergence in low levels, 925hPa. This was called, "CK Index”, which is defined in the equation 3.4 (de Lima, 2005).

$$CK = K \cdot \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) \qquad (3.4)$$

where: u – zonal component of wind;
v – meridional component of wind;
K - K Index.

As K it is a positive number and "convergence" (that it is the trigger) is represented by the negative values of the divergence, then the CK way to denote situations favorable to the convective triggering cells is when this presents negative values. And how much lesser (more negative) they will be these values, more favorable will be the situation.

5. RESULTS

5.1. The January 31st 2000 case

In the early night of January 31st of 2000, a very intense storm developed and displaced over Rio de Janeiro, causing several serious upheavals, as overflows in diverse points of the city (causing sets of ten of kilometers of heavy traffic), lack of electric energy, stoppage of the railroad net and closing the two main airports of the city. The associated rainfall rates were very high, over of 80mm.h^{-1} during about 30 minutes (Silva Paiva, 2000).

The upheavals was caused by a squall line storm type, with orientation WSW-ENE. This line of storms formed next to the mountains “Serra da Mantiqueira” (one of the most important topographical chains of the Southeastern region of Brazil) and went southeastward, reaching the Rio de Janeiro city.

At 21 GMT the storm had its strongest intensity over south portion of Rio de Janeiro, near Baía de Guanabara, as observed in radar image (Figure 5.1).

The moment where the line had its bigger intensity over Rio de Janeiro was around 21 GMT as it can be observed in the radar image (Figure 5.1). This line of storms was not forecasted by the operational numerical models neither by the operational forecast centers.

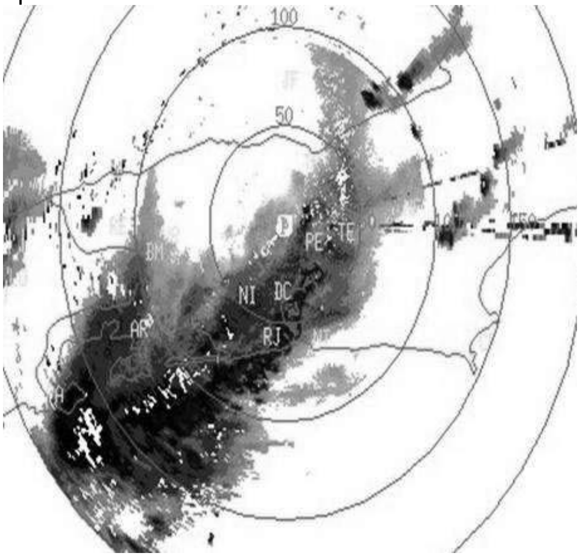

Figure 5.1: Image of pico do couto radar at 21 GMT (2000/01/31).

In this work, numerical simulations of the indices of instability (described in previous section), was developed. Results show that the field of K index, simulated at 21 GMT (Figure 5.2), configured a tongue of maximum values of K over most of Rio state, including the Rio city, with orientation WSW-ENE, like the observed orientation pattern of the storm. This simulated field evolved to the 23 GMT pattern (Figure 5.3), when the maximum values of simulated K were found (plus than 40^{o}C) with the most critical values located over the city of Rio de Janeiro and Baía de Guanabara (Figure 5.3), very close to the places of maximum rainfall rates (Figure 5.1).

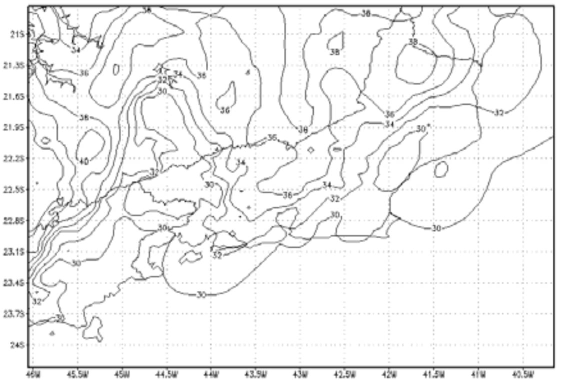

Figure 5.2: K index simulated by RAMS at 21 GMT.

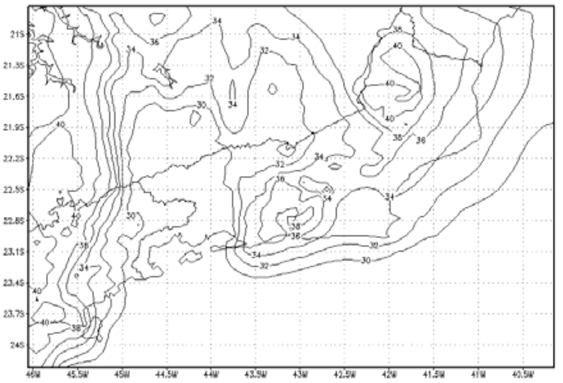

Figure 5.3: K index simulated by RAMS at 23 GMT.

The simulated TT index field, had similar behavior to the one of the previous index (K), with the TT presenting maximum values (above of 49° C) over the city of Rio de Janeiro, in coherent times to the actual storm (Figures 5.4 and 5.5).

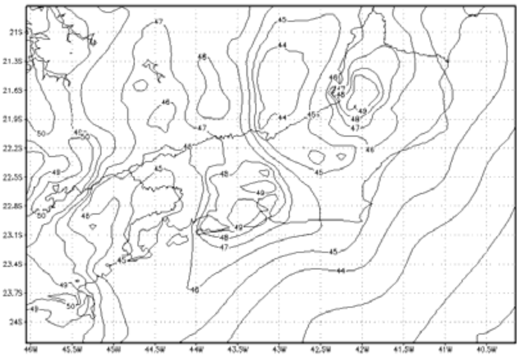

Figure 5.4: TT index simulated by RAMS at 22 GMT.

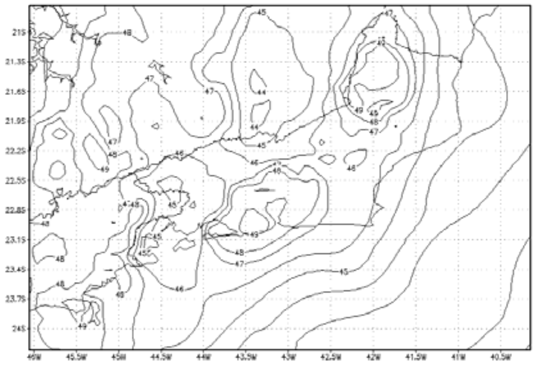

Figure 5.5: TT index simulated by RAMS at 23GMT.

Figure 5.6, shows the lapse rate index (LR) field at 22 GMT, simulated by RAMS. The simulated index also shows a reasonable agreement between the places with critical values of LR and those with more intense observed rain. However, the results of this index are not as good as the previous indices (K and TT).

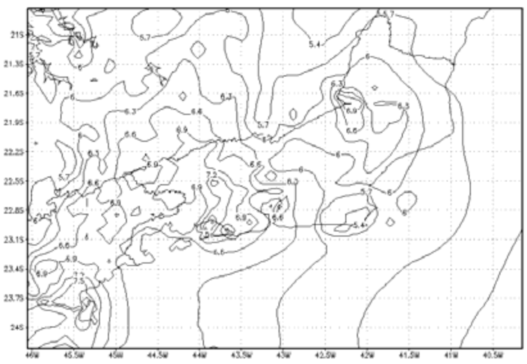

Figure 5.6: LR index simulated by RAMS at 22 GMT.

Index CK presented critical values in coherent positions with the formation places and evolution of the storm. However in this in case, where the purely thermodynamic indices already had registered satisfactory results, index CK does not add any new information over the results presented for the other described indices. Figures 5.7 and 5.8 they show index CK simulated field for 19 and 20 GMT.

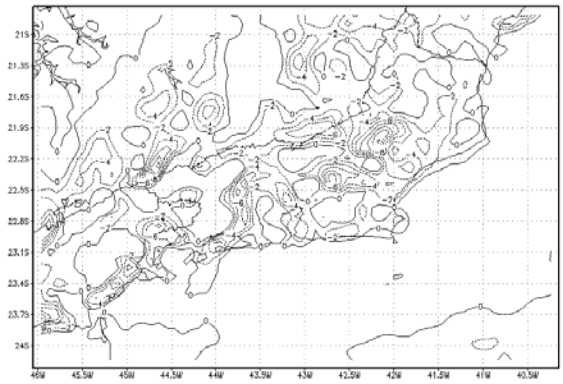

Figure 5.7: CK index simulated by RAMS at 19 GMT.

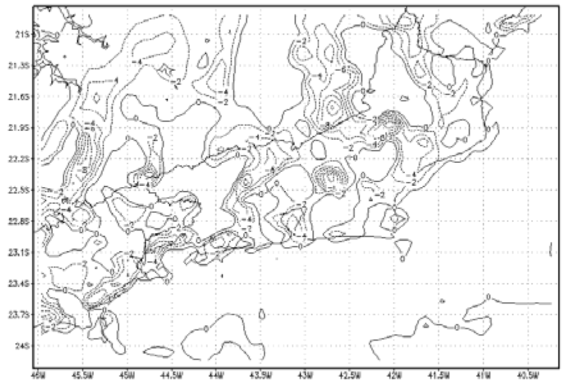

Figure 5.8: CK index simulated by RAMS at 20 GMT.

5.2. The March 21st 2003 Case:

In the Friday night of March 21st 2003, another strong storm developed and arrived in Rio de Janeiro, causing a lot of upheavals in city life and also for the population. Heavy rain caused damages and difficulties in several portions of the city, being south and west portions the most affected by the damages. In Tijuca, a small river overflowed dragging a car, leaving three people with no exit during more than 1 hour. In Copacabana many streets had been completely flooded and several cars floated through the traffic.

Rain started around 18h30min (Local Time - LT) of march 21st , according to periodical newspaper "O Dia" of Saturday, 2003/03/22. The maximum rainfall rates were in Copacabana, Tijuca and Barra exceeding 100mm.h^{-1}, according to registers of the GEORIO pluviometer net (Mourão et al 2004).

The storm was caused by several vigorous and deep convective cells found in the front flank of a frontal system that was penetrating in the State of the Rio, as it can be seen in the image of satellite of 20:45 GMT (Figure 5.9)

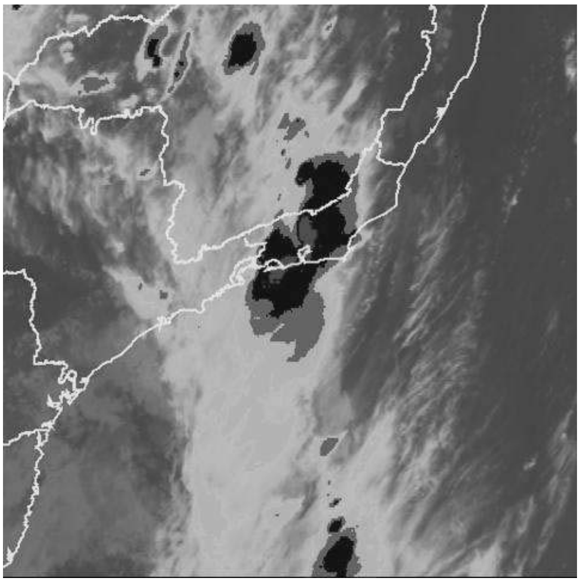

Figure 5.9: Satellite image at 20:45 GMT (2003/03/21).

Here, the simulated instability indices also found satisfactory results in representing the most favorable regions to the convective development, and possible storms.

The simulated K Index at 20 and 21 GMT of March 21st (Figures 5.10 and 5.11) shows a reasonable coherence with the region of bigger intensity of the system, according to the satellite images. Almost all Rio State portions, including East, NW and center, presented critical values of index K, and all this area was influenced by the convective system.

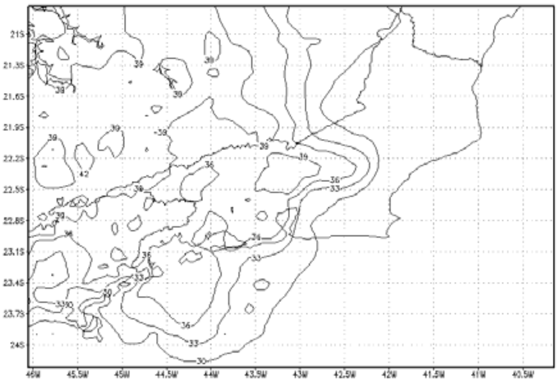

Figure 5.10: K index simulated by RAMS at 20 GMT.

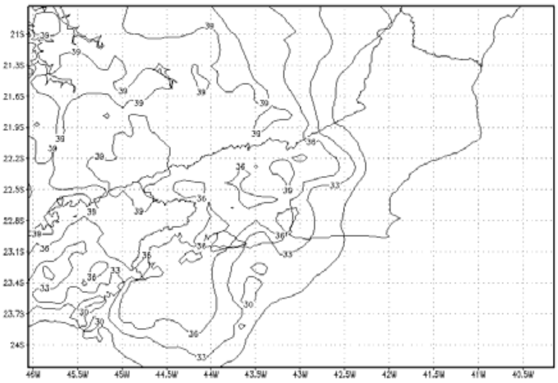

Figure 5.11: K index simulated by RAMS at 21 GMT.

TT index field also showed a reasonable behavior for the case, since its critical values were found close to Baía de Guanabara and oceanic portion southward the Rio State at 20 GMT (Figure 5.12). The simulated LR index at 22 and 23 GMT (Figures 5.13 and 5.14) presents critical values mainly over the Rio de Janeiro city and also over oceanic portion, at south of State.

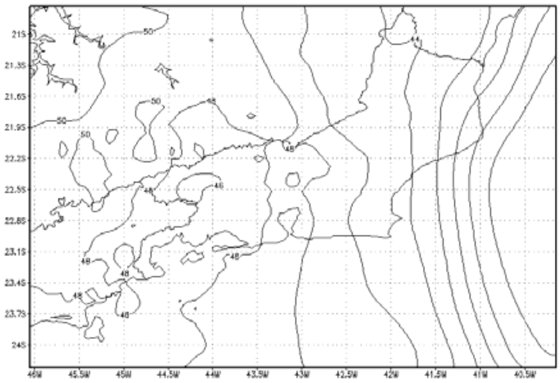

Figure 5.12: TT index simulated by RAMS at 20 GMT.

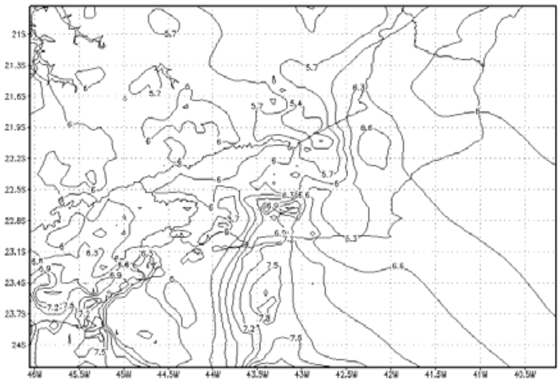

Figure 5.13: LR index simulated by RAMS at 22 GMT.

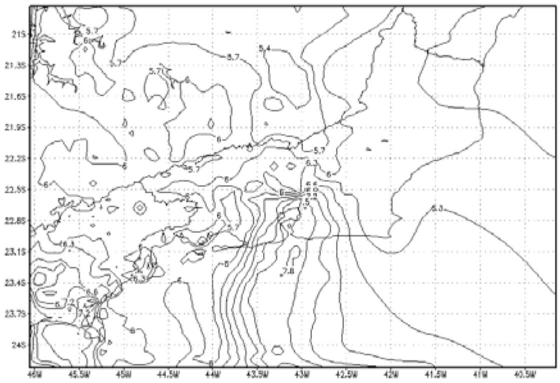

Figure 5.14: LR index simulated by RAMS at 23 GMT.

The CK index simulated fields found a good and coherent agreement between the storms developments and displacements mainly over Rio de Janeiro city, as can be observed for 19 GMT, 20 GMT and 22 GMT (Figures 5.15, 5.16 and 5.17). This result shows that the combination between unstable thermodynamic environment and convergence forcing was a good indicator for these storms evolution.

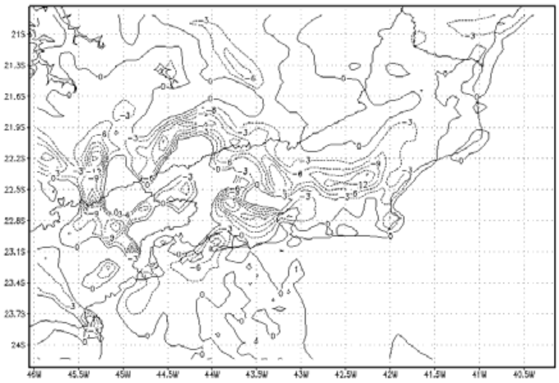

Figure 5.15: CK index simulated by RAMS at 19 GMT.

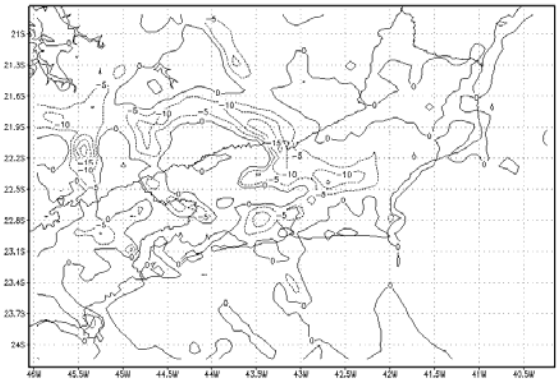

Figure 5.16: CK index simulated by RAMS at 20 GMT

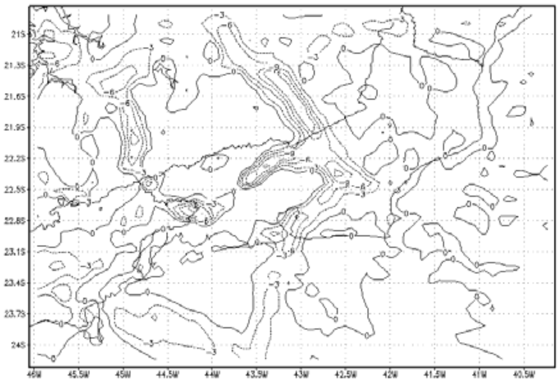

Figure 5.17: CK index simulated by RAMS at 22 GMT

6. CONCLUDING REMARKS

This work presented an analysis of the behavior of some simulated indices of instability over the Rio de Janeiro State. The study was done through numerical simulations with RAMS model of some intense storms that acted over Rio de Janeiro causing several damaging in the State, specially over Rio de Janeiro city. Two cases were presented in this extended abstract.

For the first case, a squall line occurred in January 31st of 2000, the simulated K and TT indices found quite good results, presenting its critical values over the regions of maximum observed rainfall rates. The lapse rate index field presented reasonable agreement with the high precipitation rates places, however not as good as found by indices K and TT. In this case, where the purely thermodynamic indices had good results defining favorable regions for convective development, the CK index did not show additional information, even finding satisfactory results.

For the second case, several strong convective cells in the front flank of a cold front, the K and TT indices also had good results defining the most favorable regions for deep convection development and displacement with its critical values. The lapse rate index had better results than these other indices for the Rio de Janeiro city, Baia de Guanabara and oceanic portion of the domain. The CK had a good result showing good agreement with the deeper storms evolution (displacements).

This work shows a important role of the instability indices using in the weather forecast, specially in mesoscale predictions, since the rainfall associated with the convective storms here presented was not predicted by the numerical models or operational forecast centers. Thus, simulated instability indices can represent an important tool for the operational forecasts.

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