Journal of the Georgian Geophysical Society,
Issue B. Physics of Atmosphere, Ocean and Space Plasma, v. 12B, 2008, pp. 36-44.

Mesoscale convective complex genesis and forecast in Alagoas State of Brazil

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Abstract

Significant precipitation, thunderstorm, floods and other extreme weather events, which have caused problems in Alagoas State, were investigated. NCEP reanalysis data, HYSPLIT model trajectories, satellite images and adjacent Atlantic Ocean thermal conditions were used for the investigation. Wave Disturbance in the field of Trade Winds (WDTW) on the northwest periphery of subtropical High were associated with a different processes of clouds formation, which are possible to create both Cb and St-clouds. Periphery of the frontal zones rest were one of the causes of the WDTW formation far from other synoptic systems. The WDTW were associated with Mesoscale Convective Complex (MCC). Very height air instability (CAPE=3936J/Kg and LI=-7) was typical for these events. Extreme events forecast were elaborated by instability indexes and a convective available potential energy (CAPE) calculated by forecasted vertical profiles using. These profiles were constructed by Air Parcels Trajectories of HYSPLIT model. The ocean surface heating near Alagoas and baric trough at low levels were associated with the thunderstorm development in some MCC events. In other MCC a very weak jet stream at high levels near Alagoas was identified as a principal process for ascendant motion formation. The 12h-24h antecedent forecasted vertical profiles were helped for extreme events forecast.

1. Introduction

Some meteorological adverse phenomena, such as, significant precipitations, thunderstorms, stratus clouds, floods, etc, have caused a lot of problems in Alagoas State (North- East coast of Brazil, 10^{o}S approximately). Theses phenomena were associated with low level trough Gomes and Fedorova; Levit et. al.; Fedorova, et al. [1-5]. These troughs geneses did not well known yet.

The wave can reflect a Intertopical convergence zone (ITCZ), or a cold Low in the upper troposphere (known also as Upper Troposphere Cyclonic Vortex - UTCV), or may by associated with equator extension of mid-latitude baroclínic trough. Also, a wave was defined by Simpson [6] as a trough, or cyclonic curvature maximum, in the trade wind. The barotropic wave may reach maximum amplitude in the low or middle troposphere.

The first kind of wave, which was described in the Tropics, was Easterlies Waves in the Caribbean area (Barry and Chorley [7]). There are some weak barotropic troughs in the tropical regions. These troughs axis are usually inclined eastward with height. Frequently, Cumulonimbus clouds develop and thunderstorm occur in these weak troughs behind their axis passage. This pattern is associated with vertical and horizontal motion in the easterlies. An air convergence has occurred behind of the low-level weak trough axis and a divergence have detected in front of it.

One of the wave study problems is the detection difficulty of exact beginning of the wave formation. This is especially true in the tropic regions because of restrict meteorological data, insufficient knowledge of a synoptic systems development and absence of the numerical meteorological models suitable for this region (Riehl; Tenorio et al. [8,9]). It is sure that many waves in the Atlantic Ocean are formed over the African coast or near. Another factor, which can initiate waves in the easterlies, is a penetration of cold fronts into low latitudes (Riehl; Barry and Chorley; Tenorio et al.; Molion and Bernardo [7 - 10]). This is a common phenomenon in the section between two subtropical anticyclones.

This work aim is an investigation of intensive convection development in troughs near the Alagoas State to support the short-term weather forecast.

2. Method

The conventional data were used for adverse phenomenon identification. The identification of *Mesoscale Convective Complex (MCC)* was made according to description of Veltishev [11]. The vertical profiles were constructed by NCEP reanalysis data for Maceio city. The radiosonde data were used to complement the NCEP profiles. The synoptic situation before and during adverse events were analyzed using satellite images and different products of NCEP reanalysis: streamlines (at the levels of 1000, 925, 500 and 200hPa), surface pressure, omega, temperature and relative humidity at the 925, 850, and 1000hPa levels, thermal advection at the low levels. The software "Grads" (Doty [12]) was used to elaborate all maps.

Air Parcels Trajectories of HYSPLIT model was used to calculate forecasted trajectories for Maceio city (Alagoas State), with 12-48 h antecedence. These trajectories were used to construct of the forecasted vertical temperature and humidity profiles. The strong convection forecast was made using K, TT, LI indexes and positive CAPE (Convictive Available Potential Energy), calculated by forecasted vertical profiles.

3. Results

Three extremely adverse meteorological events with different formation processes are presented below. Significant precipitations, thunderstorms and floods were associated with these MCCs development.

The first MCC was observed 12 June 2002. An infrared satellite image (Figure 1a) shows a convective cloud system (MCC) near Northeastern of Brazil (NEB). The trough at the low levels, which is a wave disturbance in the field of trade winds (WDTW), near Alagoas State, was an important reason for the MCC devolvement (Figure 1b). The trough motion to westward at 500hPa level is presented at the Figure 2. This trough axis was over Alagoas State on 11 June, 00 UTC; its rearguard was over Alagoas State on 12 June, 00 UTC, on the MCC developed day. Therefore, a weak trough at the low and middle levels was considered as the first cause for very strong convection and consequently MCC development.

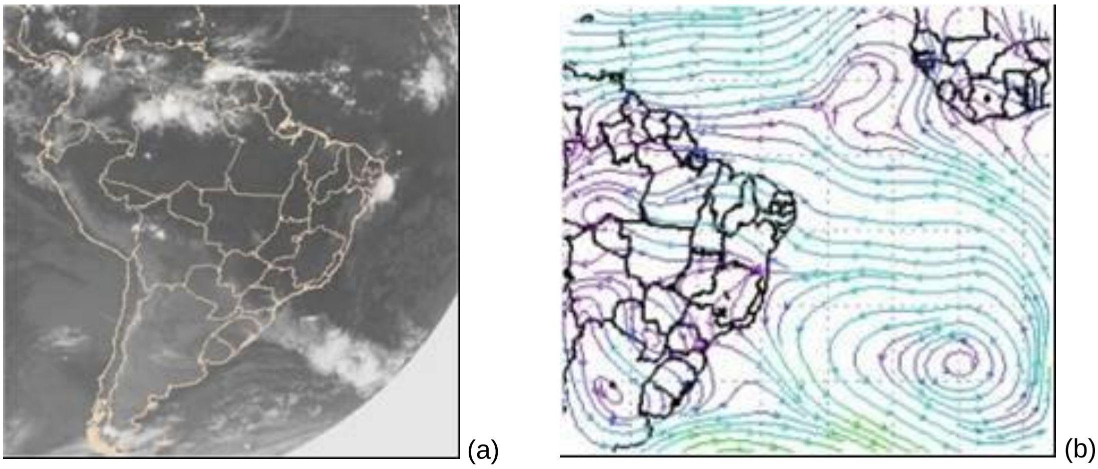


Figure 1 – (a) METEOSAT Satellite IR image and (b) streamline at 1000hPa level for 12 June 2002 at 12UTC. Source: CPTEC/INPE, NCEP.

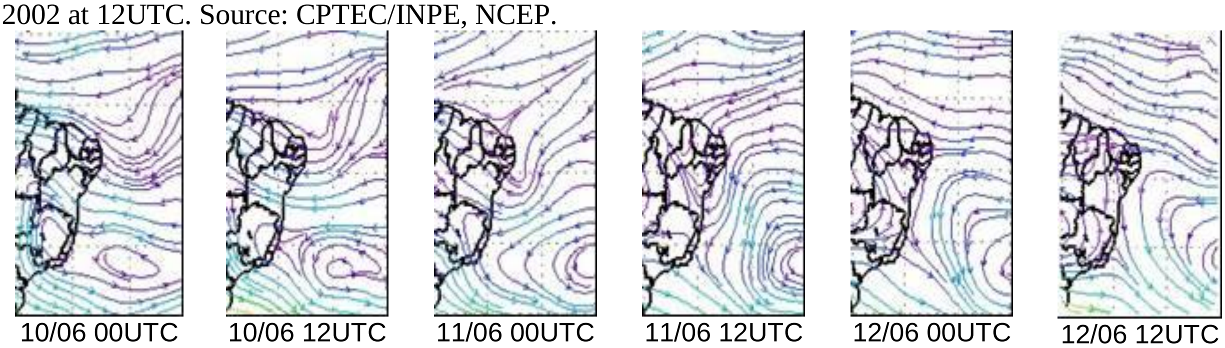
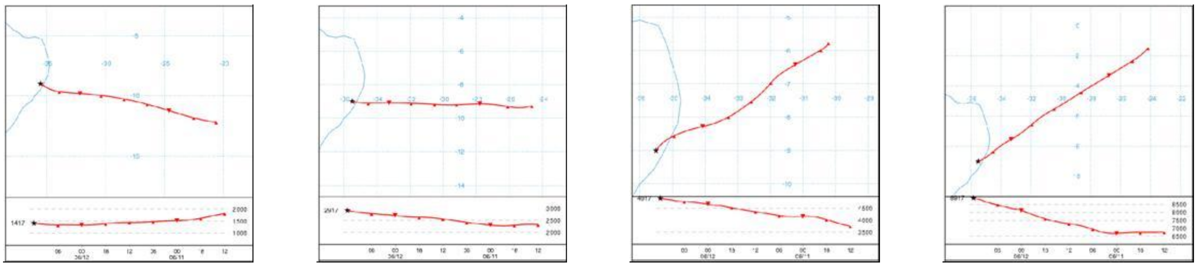


Figure 2 – Streamline at 500hPa level for 10-12 June 2002. Source: NCEP

The trajectories show the connection between the MCC development and the trade winds at the low levels and the trough at the middle levels (Figures 2 and 3). Also, some warm thermal wave at low levels and cold thermal wave at the middle levels were detected by the trajectories analyses (Figures 3 and 4).

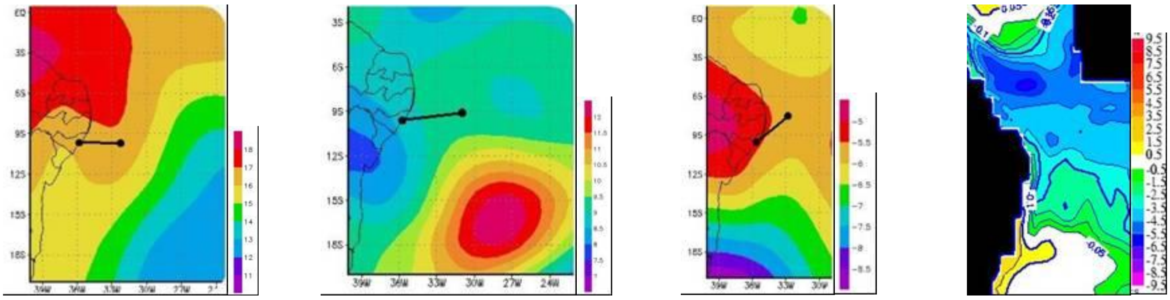


(a) (b) (c) (d)

Figure 3 - Air Parcels Trajectories of HYSPLIT model in vertical and horizontal outline at about 1500, 3000, 5000 e 9000m.

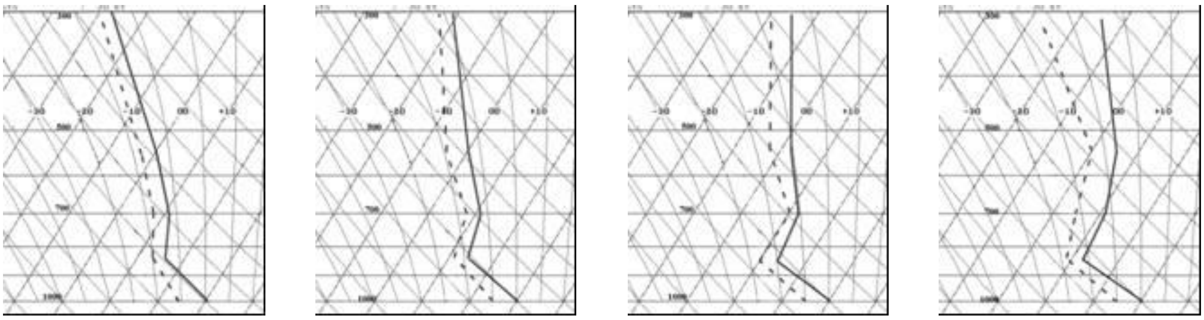
The Air Parcels Trajectory with 12 antecedence superimposed on temperature field show an influence of positive thermal advection from the warm wave at 850hPa level, from the warm center at 700hPa level and negative advection at 500hPa (Figure 4a, b and c, respectively). This thermal advection vertical distribution creates the perfect conditions for the instability development and the MCC formation. In this MCC case, the sea surface temperature was cold and did not influence to the latent heat liberation (Figure 4d).

The forecasted vertical profiles for the Maceio City are presented (Figure 5). The K (K=29 and 26, to 12 and 24hr forecasted profiles, respectively) and LI (LI= -4,5 and -3,5, to 12 and 24hr forecasted profiles, respectively) indexes were used to showers forecast with 12 and 24h antecedence (indexes interpretation by Djuric [13]). The positive CAPE values permitted to predict the strong convection with 12h antecedence.



(a) (b) (c) (d)

Figure 4 – Air Parcels Trajectory with 12h antecedence inside temperature field for 12 June 2002 at 00UTC at the levels: 850(a), 700(b) and 500hPa(c); (d) weekly sea surface temperature anomaly between June 10 and 16 2002. Source: NCEP; ECMWF



(a) (b) (c) (d)

Figure 5 - Forecasted vertical profiles calculated by Air Parcels Trajectories of HYSPLIT model with 12h (a), 24h (b), 36 (c) and 48h (h) antecedence.

The second MCC was developed on 15 June 2003. Satellite images show the MCC near the Alagoas State and jet steam cloudiness (Figure 6). This very weak jet steam (with wind velocity near $30ms^{-1}$) was confirmed by streamlines at 200hPa level (Figure 7b). This atypical weak jet steam near NEB had already identified before by Gomes [14] near the UTCV. In this present case this jet stream causes a very strong ascendant motions and MCC formation (Figure 6b). The WDTW near NEB at the low levels (Figure 7a) and direct ageostrophic circulation around the jet stream contributed to ascendant motion development.

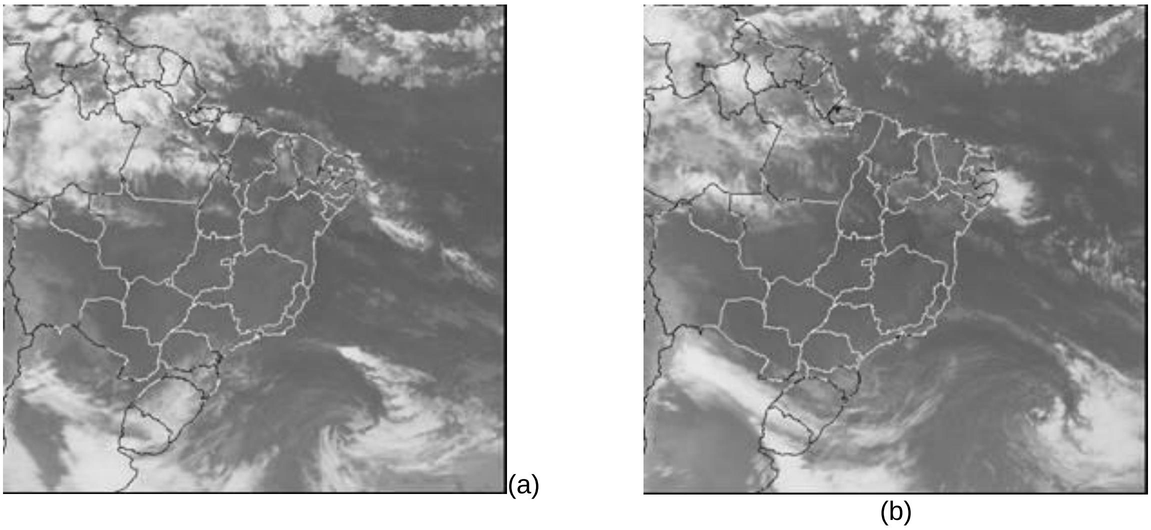


Figure 6 - METEOSAT Satellite IR image for 15 June 2003: (a) 00 and (b) 12UTC. Source: CPTEC/INPE

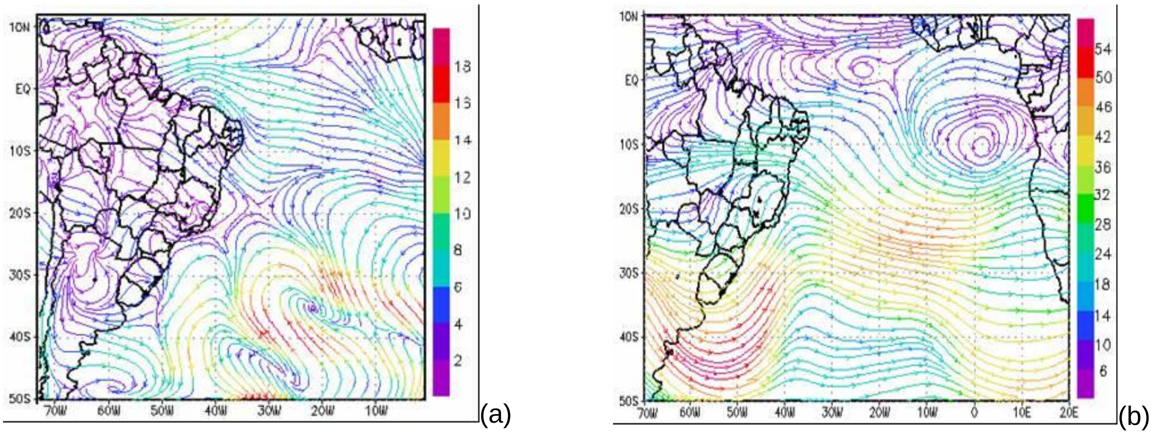


Figure 7 - Streamline for 15 June 2003 at 00UTC: (a) 1000 and (b) 200hPa.
Source: NCEP

The Air Parcels Trajectories (Figure 8) were used to elaborate the forecasted vertical profiles (Figure 9). By the using of the K, TT, LI indexes and positive CAPE values it was not possible to forecast the intensive convection development: the positive CAPE were less than 1000 J/Kg and LI index was more than -2 for 12-48h antecedence. Therefore, the strong convection could not be forecasted by theses vertical profiles.

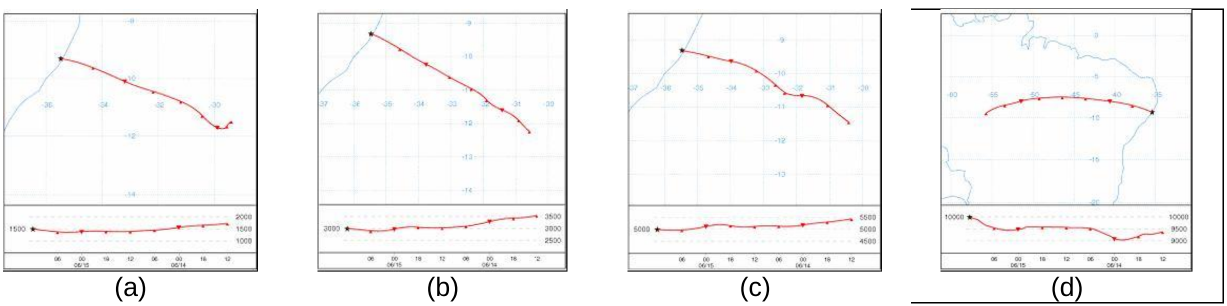


Figure 8 - Air Parcels Trajectories of HYSPLIT model in vertical and horizontal outline at about 1500, 3000, 5000 e 10000m.

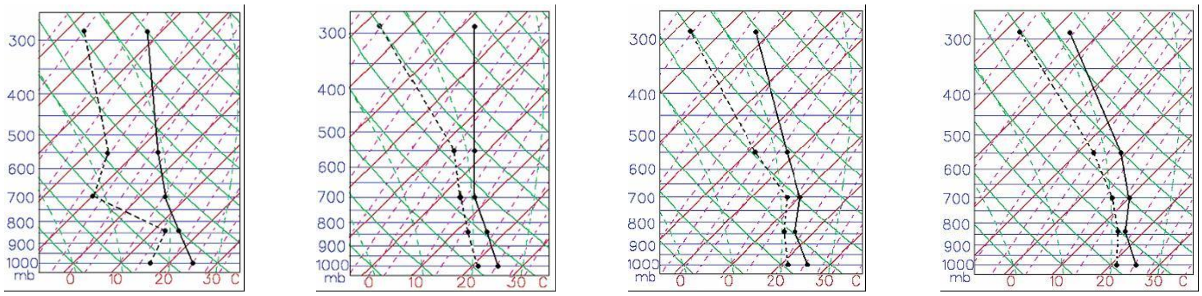


Figure 9 - Forecasted vertical profiles calculated by Air Parcels Trajectories of HYSPLIT model with 12h (a), 24h (b), 36 (c) and 48h (h) antecedence.

At the same time, the jet stream and intensive vertical ascendant motions were registered by vertical sections (Figure 10a, b, and c). This jet stream was shallow, localized at high levels up to 400hPa and formed by a very deep and strong latitude jet stream component. The jet stream and low levels trough near NEB have formed two circulations: one at the high and another at low levels, respectively (Figure 10b). Both circulations have created an ascendant motion column close to Alagoas State and sequentially were responsible for the MCC formation on 15 June 2003.

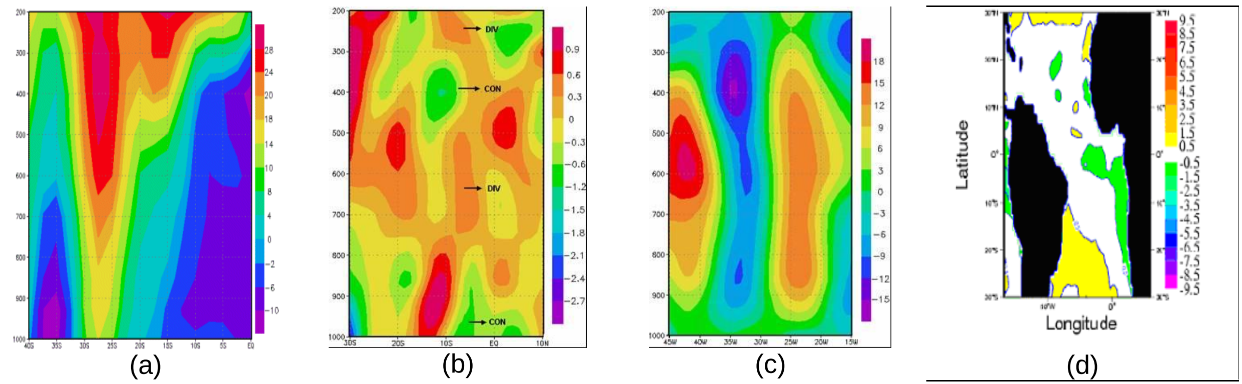


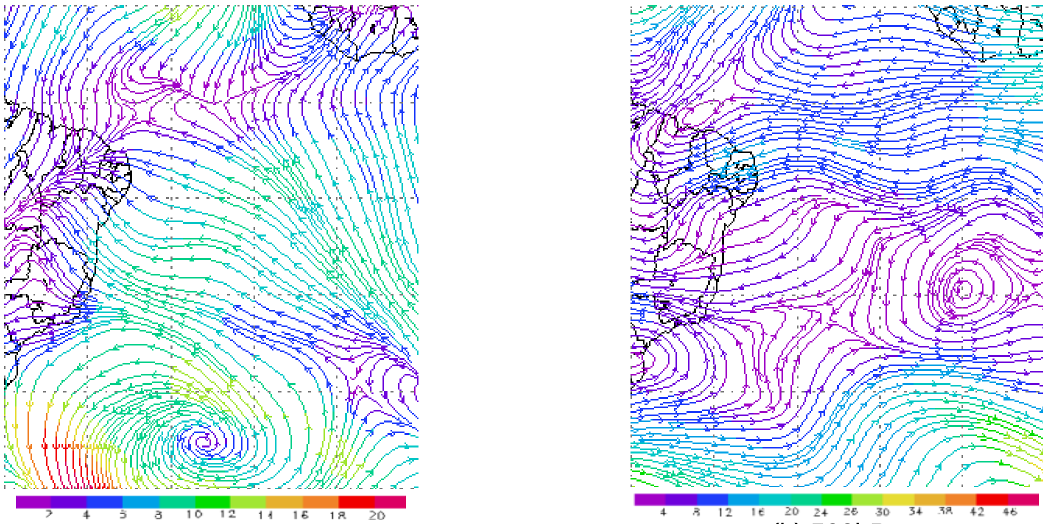
Figure 10 – Vertical sections along 36°W: (a) **u** component wind vertical section, (b) divergence vertical section, (c) omega vertical section for 15 June 2003 at 00UTC. Weekly sea surface temperature anomaly between June 8 and 15 2003 (d). Source: NCEP; ECMWF

The third MCC was observed 4-5 March 2002. Extremely intensive precipitations, above average values, have been registered from 4 to 5 March 2002 in the State of Alagoas and were associated with MCC development. The precipitations of more than 100mm/24h were observed by four meteorological stations, more than 70mm/24h by 11 stations and more than 50mm/24h by 19 stations on 4 March. The highest precipitations of 130 mm/24h and average precipitations of 42,8 mm/24h were detected on the same day. The maximal precipitation intensity was 6.2 mm/1h on 4 March, 16h and 8.6mm/1h on 5 March, 1h (local time). The conventional meteorological 10 min observations show that the maximal precipitation intensity on 5 March was registered at 16h (local time) immediately after maximal solar radiation increase and relative humidity decrease.

Table 1 – Average and maximal (max) precipitation (mm/24h) in the ambient regions of Alagoas State on 3, 4 and 5 March 2002.

Region	**precipitations**					
	Day 3		**Day 4**		**Day 5**	
	average	**max**	**average**	**max**	**average**	**max**
Litoral	2,08	13,0	66,71	123,0	12,5	36,0
Zona da Mata	6,27	22,8	60,2	130,0	8,83	27,0
Sertão	0,24	1,2	27,0	48,0	5,4	27,0
Sertão do São Francisco	0,05	0,2	5,8	23,0	27,2	56,4
Agreste	1,1	2,2	49,9	95,8	34,0	68,0
Baixo São Francisco	2,65	5,2	46,95	93,6	5,17	12,6
Average in the State	**2,07**	**7,43**	**42,80**	**85,57**	**15,50**	**37,83**

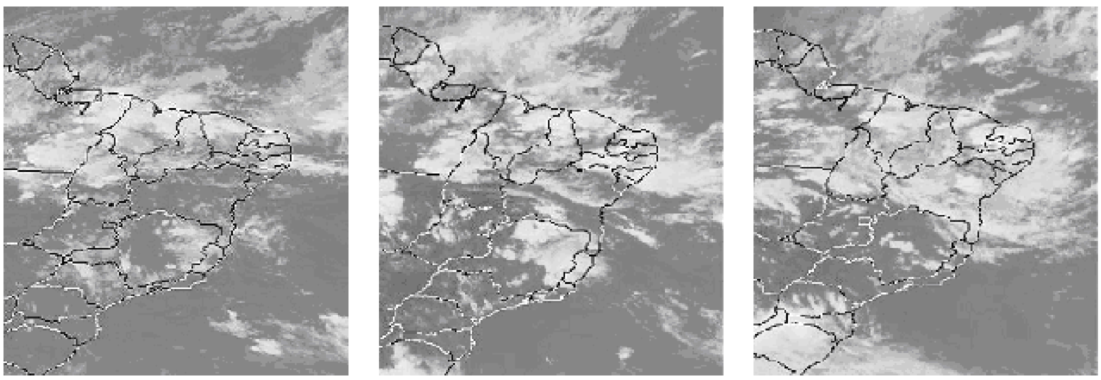
The MCC development was associated with WDTW, which was formed between both hemispheres trade winds near the Intertropical Convergence zone (ITCZ) (Figure 11a). The WDTW was observed only at the low levels (up to 850hPa) and above the anticyclonic air current was predominated (Figure 11b). The divergence current in ITCZ near equator and air convergence to south from Alagoas State at the high levels were accompanied by the MCC development. These synoptic scale currents have created the convergent air current at the low levels and the divergent current at the high levels and as a consequence have created favourable conditions of ascendant motions and MCC formation.



(a) 1000hPa (b) 500hPa

Figure 11 - Streamlines for 4 March 2002 at 12UTC at the levels 1000 (a) and 200hPa (b).
Source: NCEP

The intensive convection development was observed in cloudiness by infrared satellite images above the whole Alagoas State (Figure 12). Also, theses images show that this convection is associated with the south part of the ITCZ cloudiness.



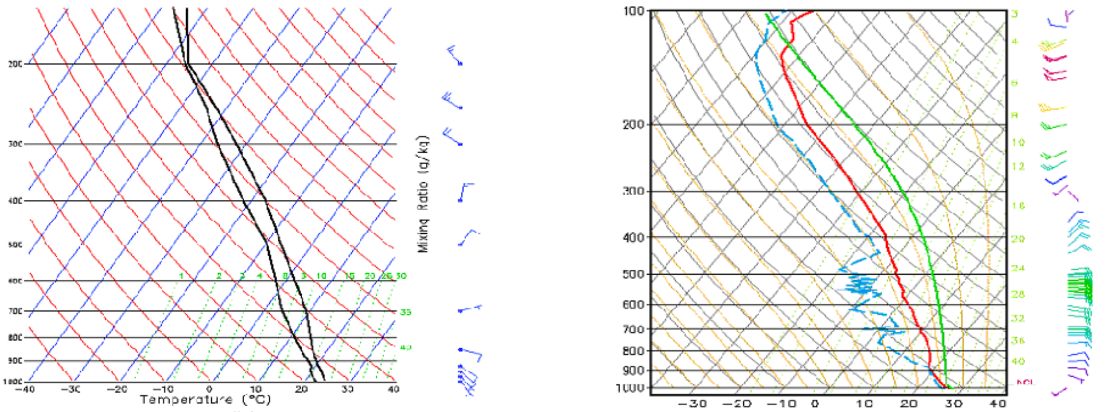
(a) 4 March, 00 UTC (b) 4 March, 19:30 UTC (d) 5 March, 20:30 UTC

Figure 12 - GOES Satellite IR image for 4 and 5 March 2002. Source: CPTEC/INPE

The intensive instability was calculated by vertical profiles, constructed by NCEP reanalysis for Maceio city, and by radiozond data in Natal (Table 2, Figure 13). The highest values were obtained for intensive precipitation time in Maceio and reached LI = -3 e CAPE = 1139J/Kg. The convection in Natal was more intensive and instability parameters by radiozond have reached extremely high values (CAPE = 3936J/Kg e LI = -7). It is important to note, that calculated instability parameters by NCEP reanalysis were 3 times less than calculated by radiozond data. The highest vertical temperature gradient at the low level up to 970hPa and high humidity at all troposphere levels up to 350hPa were responsible for extremely intensive convection development. The precipitation stopping was associated with superficial instability decreasing.

Table 2 – Instability parameters (indexes K, TT, LI and CAPE, J/Kg) by NCEP reanalysis for days 3, 4 e 5 March 2002 in Maceio city and by radiozond in Natal. Source: NCEP, CPTEC/INPE.

Day / hour / city	**K**	**TT**	**LI**	**CAPE**
03/ 00UTC / Maceio	27	40	-1	344
03/ 12UTC / Maceio	27	41	-2	847
04/ 00UTC / Maceio	30	43	-2	542
04/ 12UTC / Maceio	25	40	-1	990
05/ 00UTC / Maceio	34	44	-3	1139
05/ 12UTC / Maceio	32	43	-3	1078
03/ 12UTC / Natal	29	45	-7	3380
04/ 12UTC / Natal	25	44	-7	3936



(b) (c)

Figure 13 - Vertical profile calculated by NCEP reanalysis data for Maceio city, 4 March, 12UTC (a) and vertical profile by radiosonde in Natal, 4 March, 12UTC (b). Source: NCEP, CPTEC/INPE

The wind direction variation with height increase, obtained by radiozond and NCEP reanalysis profiles, promoted the convection intensification. All these data show the wind direction variation to left at low levels and to right at the high levels (Figure 13). Theses wind variations are associated with warm advection at the low levels and with cold advection at the high levels. Consequently, this thermal advection height distribution has increase instability and convection.

The principal results of this investigation show that difficulties of such events forecast are the result of restrict meteorological data, insufficient knowledge of a synoptic systems development and absence of verification of the numerical meteorological models suitability over this region. The WDTWs on the north-western periphery of subtropical High were associated with all events of MCC development. Peripheries of the frontal zones rest were one of the causes of WDTW formation which were localised far from other synoptic systems. The weak jet stream near NEB have created the direct ageostrofic circulation, which intensified vertical motions and MCC formation in other case. At the third case, the vertical distribution of thermal advection (warm advection at the low levels and cold advection at the high levels) have increased increases instability for extremely intensive MCC development.

Very high air instability (up to CAPE=3936J/Kg and LI=-7) was typical for two MCC events and in one MCC the high instability (CAPE ≤1000 J/Kg and LI ≥-2) didn't identified. The instability parameters, calculated by NCEP reanalysis profiles, were less than calculated by radiozond data. The ocean surface heating near Alagoas State and thermal air advection at the low levels were associated with the thunderstorm development only in some MCC events. In other MCC a very weak jet stream at high levels near Alagoas area was identified as a principal process for ascendant motion formation. The vertical profiles, elaborated by Air Parcels Trajectories of HYSPLIT model, were useful to forecast one extreme event with 12h-24h antecedent.

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(Received in final form 23 November 2008)

Генезис и прогноз мезомасштабного конвективного комплекса в штате Алагоас, Бразилия

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Резюме

Проведено изучение обильных осадков, гроз, наводнений и других экстремальных явлений погоды, которые вызвали проблемы в штате Алагоас. При исследованиях были использованы данные *NCEP*, модель траектории воздушных частиц *HYSPLIT*, спутниковые изображения и граничные температурные значения Атлантического океана. Волновые

возмущения в области пассата (*WDTW*) в северо-западной периферии субтропического антициклона связаны с различными процессами формирования облаков, и возможно, Cb и St. Периферийная область фронтальной зоны покоя была одной из причин формирования *WDTW*, далекой от других синоптических систем. *WDTW* были связаны с Мезомасштабным Конвективным Комплексом (*MCC*). Высокая неустойчивость воздушных масс (свободная потенциальная энергия конвекции CAPE=3936Дж/ кг и индекс LI = -7) была типична для этих событий. Прогноз экстремальных событий был разработан с использованием индексов неустойчивости и данными о *CAPE*, вычисленными по прогностическим значениям их вертикальных профилей. Эти профили были построены с использованием модели *HYSPLIT*. Нагрев поверхности океана вблизи Алагоаса и барическая ложбина связаны с развитием гроз при некоторых случаях *MCC*. В других случаях *MCC* очень слабое струйное течение на больших высотах рядом с Алагоас было идентифицировано как основной процесс для формирования восходящего движения.

12- и 24-часовые прогнозы указанных вертикальных профилей использовались для прогнозирования экстремальных метеорологическия явлений.

მეზომასშტაბური კონვექტური კომპლექსის გენეზისი და პროგნოზი ალაგოასის შტატში, ბრაზილია

ნატალია ნ. ფიოდოროვა, ვლადიმერ ი. ლევიტი, ლუიზ რ.ლ. როდრიგესი, საულო ბ. კოსტა

რეზიუმე

ჩატარებულია უხვი ნალექების, ელჭექის, წყალდიდობების და ბუნების იმ სხვა ექსტრემალური მოვლენების შესწავლა, რომლებმაც პრობლემები გამოიწვია ალაგოასის შტატში. გამოკვლევებისას გამოყენებულ იქნა NCEP მონაცემები, ჰაერის ნაწილაკების ტრაექტორიის HYSPLIT მოდელი, თანამგზავრული გამოსახულებები და ატლანტის ოკეანის სასაზღვრო ტემპერატურული მნიშვნელობები. ტალღოვანი შეშფოთებები სუბტროპიკული ანტიციკლონის ჩრდილო - დასავლეთის პასატის (WDTW) არეში დაკავშირებულია ღრუბლების ფორმირების პროცესებთან და შეიძლება Cb და St. სიმშვიდის ფრონტული ზონის პერიფერიული არე ერთ - ერთი მიზეზი იყო WDTW - ს ფორმირებისა, რომელიც შორსაა სხვა სინოპტიკური სისტემებიდან. WDTW დაკავშირებული იყვნენ მეზომასშტაბურ კონვექტურ კომპლექსთან. (MCC). ჰაერის მასების მაღალი არამდგრადობა (თავისუფალი ენერგია კონვექციისა CAPE = 393 ჯ/კგ და ინდექსი LI = -7) ტიპური იყო ამ მოვლენებისათვის. ექსტრემალური შემთხვევების პროგნოზი შემუშავებული იყო არამდგრადობის ინდექსებისა და CAPE - ს მონაცემების გამოყენებით, რომლებიც გამოთვლილია მათი ვერტიკალური პროფილების პროგნოსტული მნიშვნელობებით. ეს პროფილები შედგენილია HYSPLIT მოდელის გამოყენებით. ალაგოასის მახლობლად ოკეანის ზედაპირის გათბობა და ბარიული ღრმული დაკავშირებულია ელჭექების განვითარებასთან MCC - ის ზოგიერთ შემთხვევაში. MCC - ის სხვა შემთხვევებში ალაგოასის მახლობლად ძალიან სუსტი ნაკადური დინება დიდ სიმაღლეებზე იდენტიფიცირებული იყო, როგორც ძირითადი პროცესი აღმავალი დინების ფორმირებისთვის.

12 და 24 საათიანი პროგნოზები აღნიშნული ვერტიკალური პროფილებისა გამოყენებულ იქნა ექსტრემალური მეტეოროლოგიური მოვლენების პროგნოზირებისათვის.