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PÓS-GRADUAÇÃO DINÂMICA DOS OCEANOS E DA TERRA UFF

EVALUATION OF A CASE OF INTENSE SUPERFICIAL NOCTURNAL AIR HEATING IN THE STATE OF RIO DE JANEIRO

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ABSTRACT

On the night of August 2 and dawn of August 3, 2011, a nocturnal warming was observed at several weather stations in the city of Rio de Janeiro - RJ. This warming occurred suddenly and intensely, with an increase of up to 5°C in one hour at Tom Jobim International Airport (SBGL) and Santos Dumont Airport (SBRJ), and 3.9°C at the Forte de Copacabana weather station. Normally, the diurnal temperature cycle is well characterized, so that the lowest and highest values are observed in the early morning and mid/late afternoon, respectively. However, some meteorological phenomena can cause changes in this cycle, most commonly when a cold front passes through. Through reanalysis and a numerical simulation of the event using the Weather Research and Forecasting (WRF), a regional numerical weather prediction model, characteristics were identified in the atmospheric column, such as a layer of drier air at medium levels, just below a wetter layer, as well as a thermal inversion near the surface. These results are similar to those pointed out by Johnson (1983) for heat burst events, which are characterized by a sudden increase in air temperature simultaneously with a decrease in humidity at the surface. Heat bursts can be associated with the dissipation of storms and are typically nocturnal in nature, when a stable boundary layer develops during this period and plays an important role to its development.

Keywords : Nocturnal heating , *Heat burst*, Rio de Janeiro.

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INTRODUCTION

The air temperature has an average daily cycle in which the maximum value occurs around two hours after the time when the incident radiation is maximum, and the minimum value occurs moments before sunrise. However, the action of meteorological systems can disrupt this cycle, so that the maximum and minimum temperatures occur at other times (Varejão-Silva, 2006).

One of the most common meteorological systems to cause such disturbances in the southeast of Brazil is a cold front, in which, in its pre-frontal phase, winds from the northern quadrant cause temperatures to increase for a few hours. South Atlantic Convergence Zones - SACZ events also cause changes in air temperature in the region where the system is influenced, due to the increase in cloudiness and, consequently, the lower incidence of solar radiation on the surface.

However, besides the more classic meteorological systems, there is the heat burst, characterized by a sudden increase in air temperature, with a simultaneous decrease in humidity and strong winds, typically occurring at night. (Williams, 1963; Johnson, 1983; Bernstein e Johnson, 1994; Mcpherson *et al*. 2010).

On August 2, 2011, in the city of Rio de Janeiro, a rapid nocturnal warming of around 5°C in one hour was recorded simultaneously at some weather stations, reaching around 8.3°C in four hours at another. The maximum temperature of the day at many of these locations was observed at night.

As this is a phenomenon that has not yet been widely studied, especially in Brazil, the general aim of this work is to review the literature on the phenomenon and, as a specific aim, to study the case that occurred on August 2, based on observations by weather stations and reports from airports, as well as seeking a physical understanding with the help of numerical modeling.

Heat burst

Heat burst is associated with the dissipation of storms and is typically nocturnal in nature, and the stable boundary layer that develops during this period plays an important role in its development.

The development of heat bursts can occur through two different processes: the one proposed by Johnson (1983) (**Figure 1**) and another proposed by Bernstein e Johnson (1994) (**Figure 2**). The first process is due to the evaporation of raindrops or the cloud itself in a dry layer at mid-levels, cooling a parcel of air, which begins a process of subsidence through a dry adiabatic process. During the movement, the parcel heats up until it reaches a thermal inversion layer near the surface which, with sufficient negative buoyancy, penetrates this layer and continues to heat up until it reaches the surface, with a temperature higher than that of the environment.

In the Bernstein and Johnson (1994) study, a strong mid-level inflow related to the storm enters the stratiform region and descends towards the surface, bypassing the main rainfall area and deforming the stable surface layer.

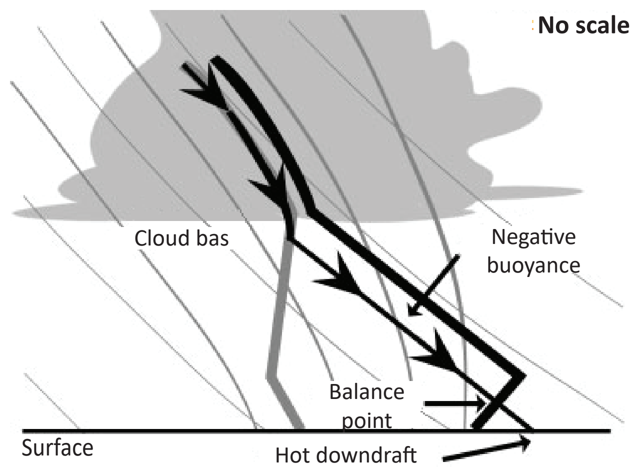

Figure 1. Conceptual heat burst model proposed by Johnson (1983)

Source: Adapted from McPherson *et al*., (2011)

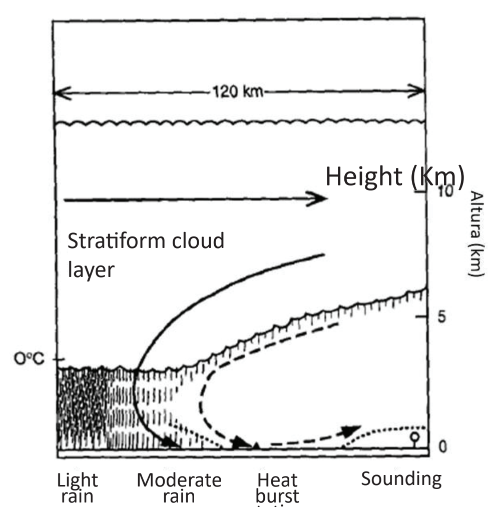

Figure 2. Conceptual model proposed by Bernstein e Johnson (1994)

Source: Adapted from Bernstein e Johnson (1994).

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DATA AND METHOD

To identify surface heating, observations were made at the four meteorological stations available in the city of Rio de Janeiro at the National Institute of Meteorology (INMET), three from the AlertaRio system network and five aerodromes from the Aeronautics Command Meteorology Network (REDEMET), as shown in **Table 1.**

Table 1. Source of meteorological data

Source	Stations	Interval
REDEMET	Rio de Janeiro International Airport (SBGL) Santos Dumont Airport (SBRJ) Afonsos Airforce Base (SBAF) Jacarepaguá Airport (SBJR) Santa Cruz Airforce Base (SBSC)	60 minutes
AlertaRio System, from city of Rio de Janeiro	Alto da Boa Vista Guaratiba São Cristóvão	15 minutes
INMET	Copacabana Fort Vila Militar Marambaia Jacarepaguá	60 minutes

The synoptic characterization of the event used satellite images in the water vapour and infrared channel of GOES 12 from CPTEC/INPE and ERA5 reanalysis data from the European Center for Medium-Range Weather Forecasts (ECMWF), with a horizontal resolution of 0.25° x 0.25° and a temporal resolution of 1 hour. To complement the analysis, a numerical simulation was conducted with the WRF model - Weather Research & Forecasting Model - with a horizontal resolution of 3 km and a temporal resolution of 1 hour.

The parameterization characteristic used was the Tropical Suite, i.e. WSM6 microphysics. (Hong e Lim, 2006), shortwave and longwave radiation RRTMG (Iacono *et al*. 2008), Tiedtke cumulus convection scheme (Zhang e Wang, 2017), YSU PBL scheme (Hong *et al*., 2006), MM5 surface layer scheme (Zhang e Anthes, 1982), and the Noah land surface model (Chen e Dudhia, 2000).

ERA5 reanalysis data from the European Center for Medium-Range Weather Forecasts (ECMWF) was used as initial and boundary conditions, with a horizontal resolution of 0.25° x 0.25° and a temporal resolution of 1 hour.

RESULTS

Observational data from August 2nd and 3rd, 2011

The 9pm sounding for Galeão (SBGL) (**Figure 3**) initially showed that the atmosphere near the surface (1000 - 980 hPa) was dry and conditionally stable. The middle troposphere was very dry and there was a thermal inversion near the surface.

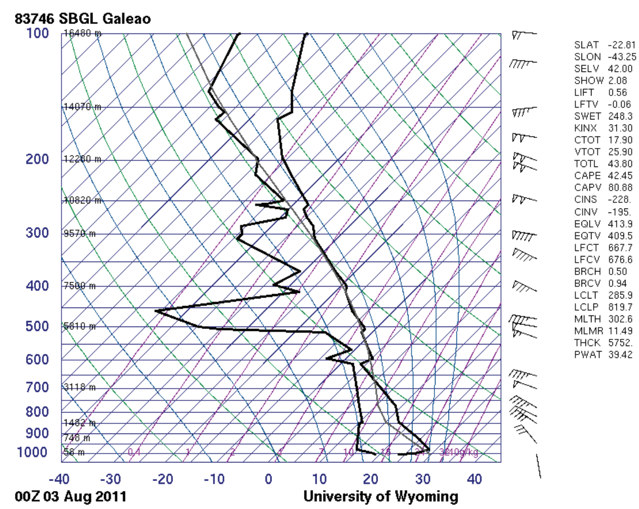

Figure 3. Sounding for Tom Jobim airport for August 3rd, 2011 00Z, 9pm on August 2nd

Source: University of Wyoming

Figures 4 and **6** show the evolution of air temperature (T) and dew point temperature (Td), as well as the variation in temperature over a 1-hour period for INMET weather stations and REDEMET aerodromes. With the exception of Santa Cruz Airforce Base, all the observation points recorded an increase in air temperature (T) at the same time as a decrease in Td, especially between 9pm and 00Z.

Figures 5 and 7 show the temperature and relative humidity (RH) and the heating rate over 15 minutes. It is known that relative humidity is a direct response to temperature variation, however, it is the only variable available measured at Alerta Rio stations that allows analysis of this nature. In all locations, it was possible to notice night-time warming of up to 4.9°C in 2 hours in São Cristóvão, reaching a rate of 1.8°C/15min in Alto da Boa Vista between 8:15 PM and 8:30 PM. The RH also dropped, as expected, from around 70% to 40%.

At the Alerta Rio network stations, the Td value is not observed, which is why the relative humidity (RH) value was used, even though it is a direct response to air temperature.

Table 2 lists the 12 observation points, classified from the highest to the lowest warming. Of note is Copacabana Fort,

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with a warming of 8.3°C between 20Z and 00Z, lasting a total of 4 hours. Santos Dumont Airport, with a warming of 7°C in just 3 hours, and Rio de Janeiro International Airport, with a warming of 6°C in 2 hours. In the latter two locations, the temperature warmed by 5°C in 1 hour.

Heating frequency

There were 2012 cases in which the temperature increased by at least 0.1°C in 1 hour, and in 88% of cases the heating was up to 1°C. Heating above 3.5°C occurred 7 times in 1 hour, representing around 0.35% of the sample (**Figures 8 and 9**).

Table 2. Observed heating

Station	Starting time (utc)	Initial temperature (°C)	Peak hour (utc)	Peak temperature (°C)	Duration (hours)	Heating (°C)
Copacabana Fort	8 PM	21.6	12 AM	29.9	4	8.3
SBRJ	9 PM	23	12 AM	30	3	7
SBGL	11 PM	23	1 AM	29	2	6
Vila Militar	10 PM	23.4	12 AM	29	2	5.6
SBAF	11 PM	22	1 AM	27	2	5
São Cristóvão	9H45 PM	24.6	11h45 PM	29.5	2	4.9
Guaratiba	9H30 PM	24.3	10h45 PM	28.6	1:15	4.3
Marambaia	9 PM	24.5	11 PM	28.5	2	4
Jacarepaguá	8 PM	22.8	12 AM	26.8	4	4
SBJR	9 PM	23	11 PM	27	2	4
Alto da Boa Vista	8H15 PM	24.9	10 AM	28.4	1:45	3.5
SBSC	-	-	-	-	-	-

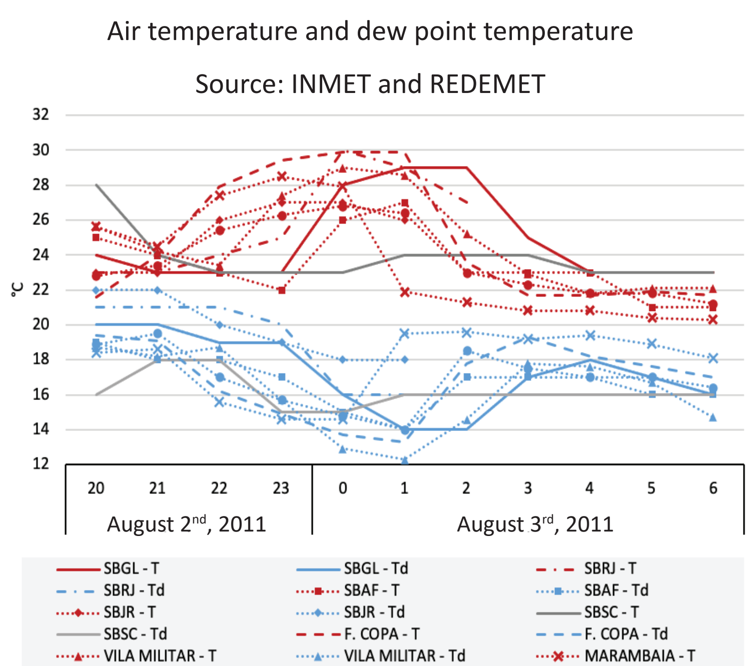

Figure 4. Air temperature (red line) and dew point temperature (blue line), in Celsius, observed between 20Z on August 2 and 06Z on August 3, 2011. SBGL, continuous line; SBRJ, dashed and dotted; SBAF, dotted with square marker; SBJR, dotted with rhombus marker; SBSC, continuous gray; F. Copa, dashed; Vila Militar, dotted with triangle marker; Marambaia, dotted with X marker; Jacarepaguá, dotted with circle marker.

Source: INMET and REDEMET

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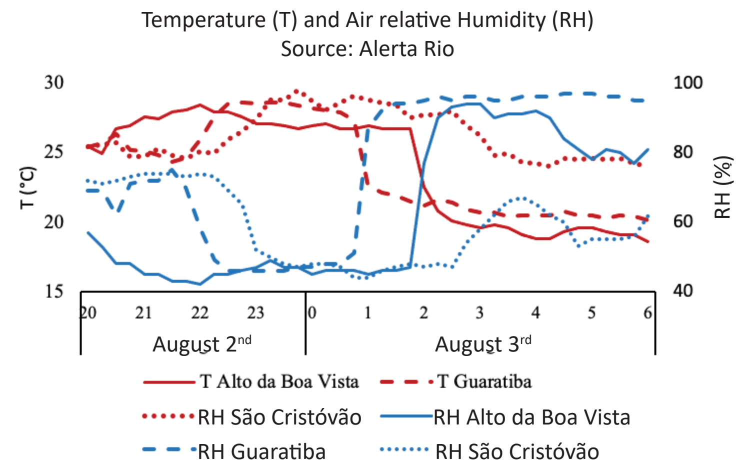

Figure 5. Air temperature (°C), in red, and Air Relative Humidity (%), in blue

Source : Alerta Rio

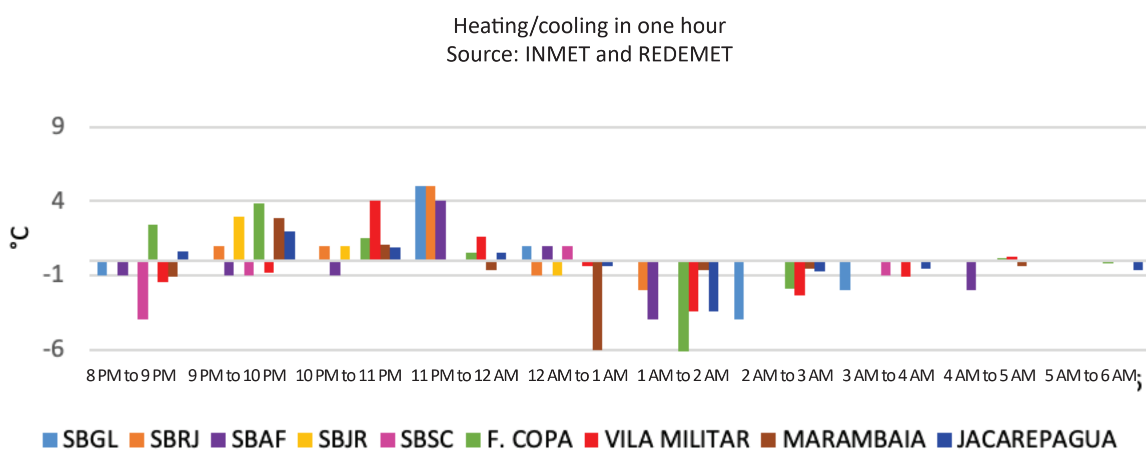

Figure 6. Heating and/or cooling rate, in degrees Celsius, in one hour

Source : INMET and REDEMET

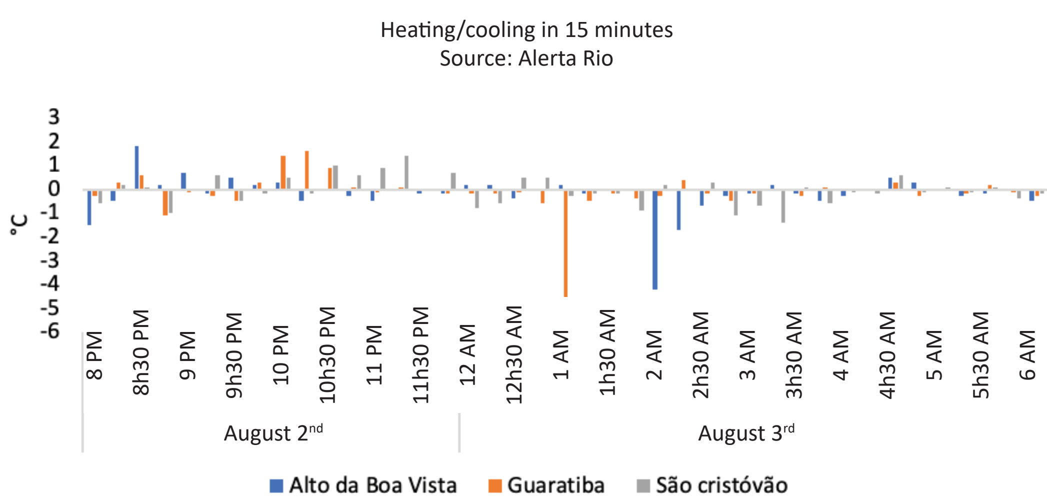

Figure 7. Heating and/or cooling rate, in Celsius, in 15 minutes

Source: Alerta Rio

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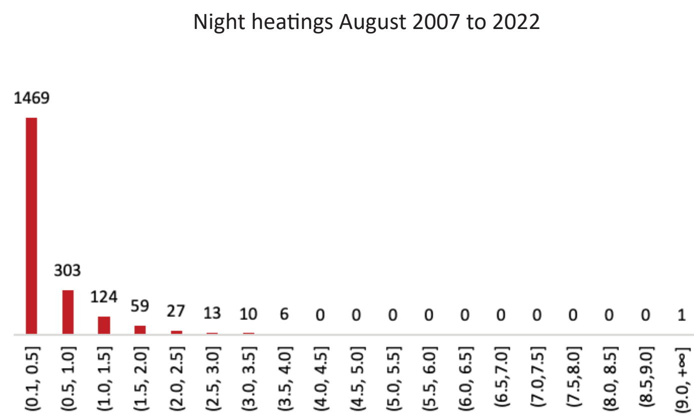

Figure 8. One-hour heatings at Copacabana Fort station in August, between 21Z and 9Z, from 2007 to 2022
Source: INMET

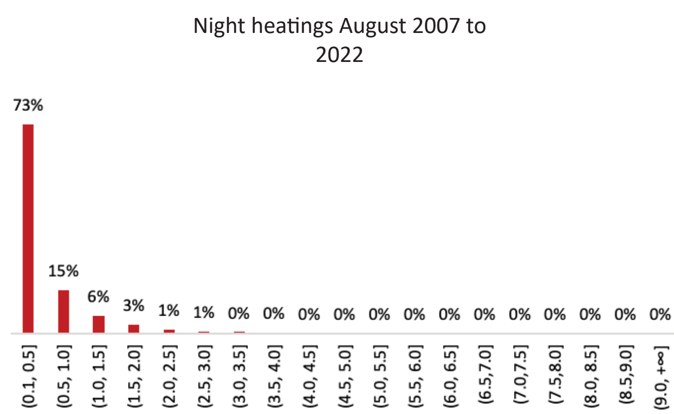

Figure 9. One-hour heating Frequency at Copacabana Fort station in August, between 21Z na 9Z, from 2007 to 2022
Source: INMET

Synoptic characterization

Figure 10 shows the geopotential height at 500 hPa in red dashed lines, mean sea level pressure (MSLP) in black lines, and wind magnitude at 200 hPa, for 21Z on August 2, and 00Z, 03Z and 06Z on August 3, 2011.

Figure 11 also shows the pressure at mean sea level (PNMM) in black lines, wind at 10 meters in barbels, and relative vorticity at 1000 hPa.

The figures show the subtropical jet at between 25 and 30°S, the extratropical cyclone centered at 35°S, with its extension associated with the cold front, and the negative relative vorticity over the sea. On the surface, the wind at 21Z on the 2nd and 00Z on the August 3rd was in the N quadrant over the state of Rio de Janeiro, and after this time, the wind shifted to the S quadrant. Therefore, it can be concluded that a cold front moving over the open sea caused the changes in wind circulation on the surface.

Figure 12 has satellite images made available by CPTEC/INPE for 00:00 on August 3 in the water vapor (left) and infrared (right) channels, showing the cloud band between the two air masses, indicating the presence of the cold front, as observed in the reanalysis.

Heating evaluation

In order to assess the nature of the anomalous warming, we tried to compare the warming under study with another event under similar synoptic conditions. To do this, we selected the case of nocturnal warming observed on August 6, 2018, when there was an increase of up to 0.7°C in 1 hour between 21Z and 22Z at Copacabana Fort station, which represents around 88% of the cases of nocturnal warming (**Figure 13**).

An analysis of **Figures 14** and **15** shows the extension of the extratropical cyclone, corresponding to the region of ne-

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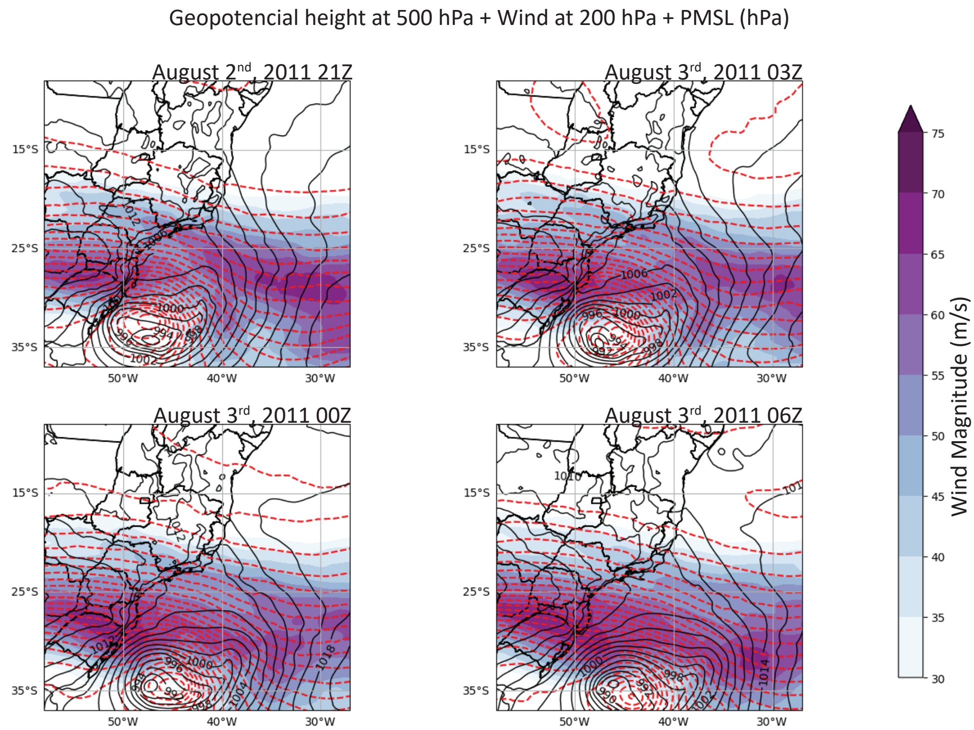

Figure 10. Geopotential height at 500 hPa, red dashed line; pressure at mean sea level (PNMM), black solid line; and wind magnitude at 200 hPa, in color.

Source: ERA5.

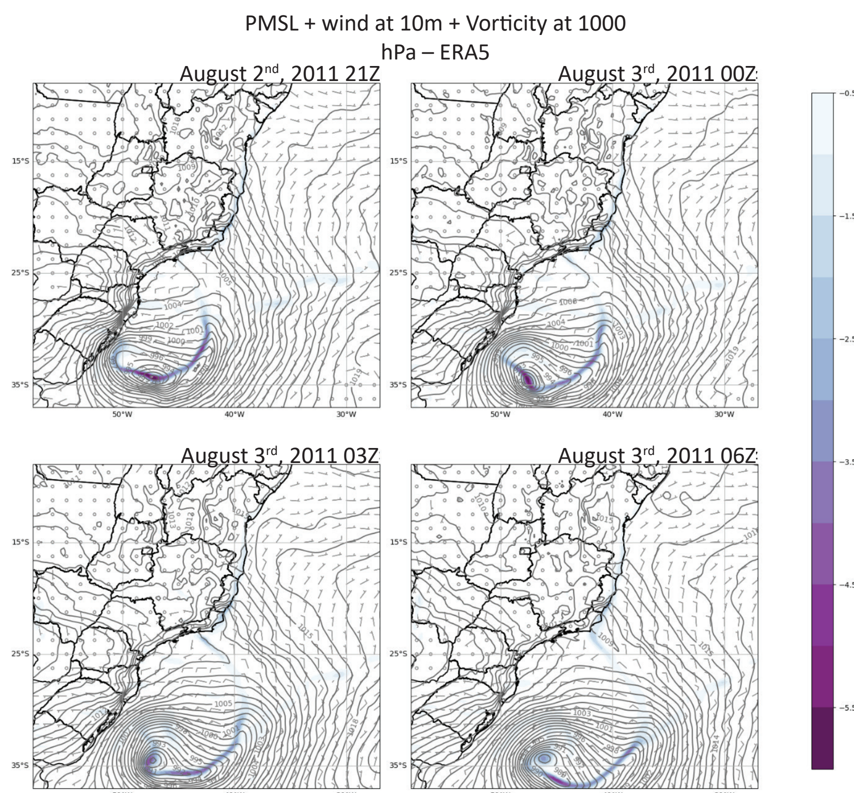

Figure 11. Wind at 10m in barbs; pressure at mean sea level (hPa) (PNMM), black continuous line; relative vorticity at 1000 hPa (s-5), in color

Source: ERA5

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Copacabana Fort station

Temperature (°C)

Heating (°C)

August 6th, 2018 August 7th, 2018

Heating T

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gative relative vorticity, the subtropical jet around the latitude of 25°C. These characteristics point to the passage of a cold front on the high seas, far from the continent, with winds from the S quadrant from the start of the warming.

Thermal advection was also assessed in both cases, 2011 (**Figure 16**) and 2018 (**Figure 17**). In the first case, positive thermal advection was observed, of up to 0.2°C/s over the city of Rio de Janeiro, and higher over the sea, of up to 0.4°C/s. In the second case, thermal advection was lower, up to 0.1°C/s.

Heat burst evaluation

Evaluating the latitude and longitude of Copacabana Fort, it can be seen that both the reanalysis and the numerical simulation identify a tendency for the temperature to rise, especially the one with a spatial resolution of 3 km with the WRF. Howe-

PMSL + wind at 10m + Vorticity at 1000 hPa – ERA5

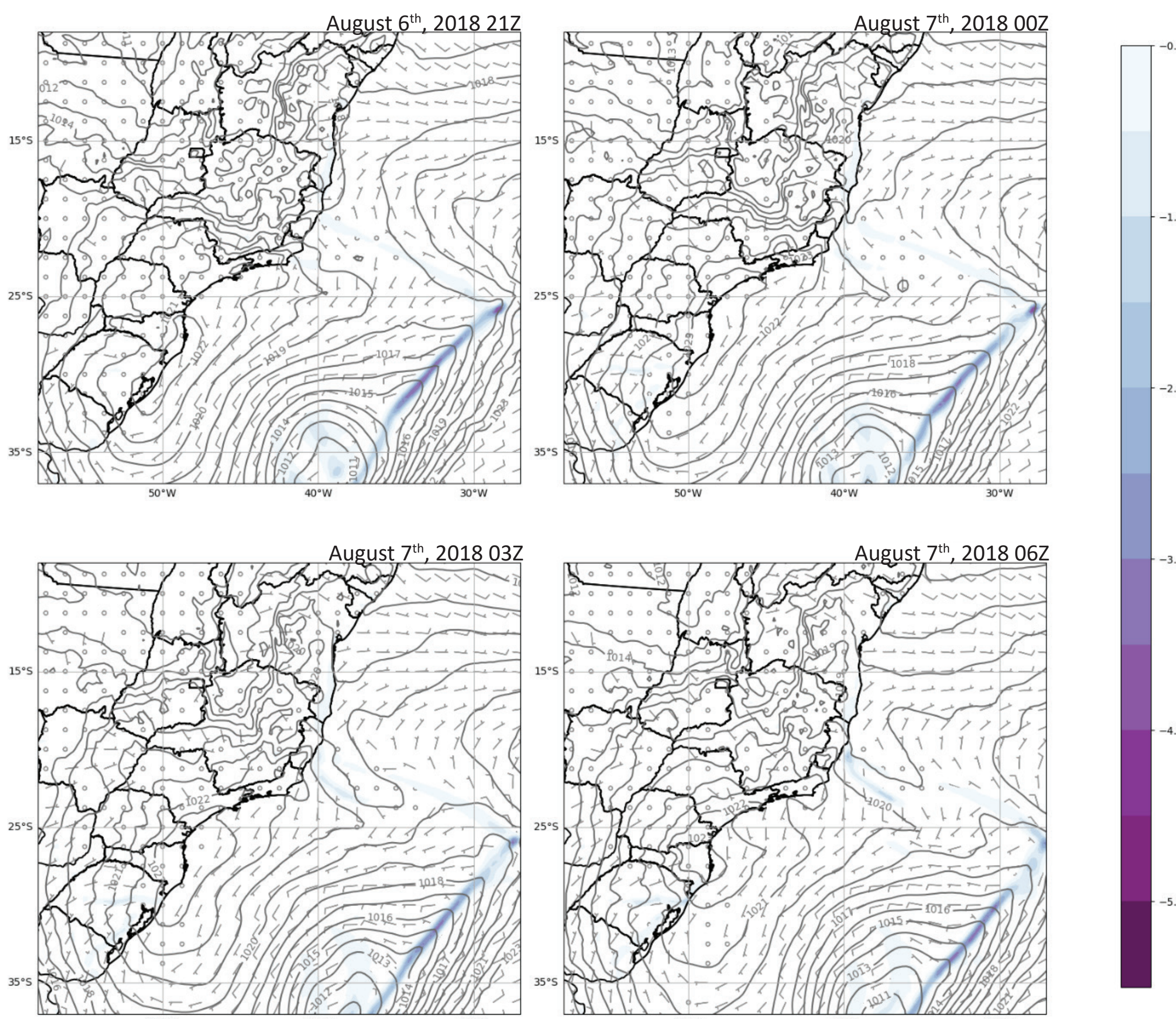

Figure 14 . Wind at 10m in barbells; pressure at mean sea level (hPa) (PMSL), black continuous line; relative vorticity at 1000 hPa (s-5), in color

Source: ERA5

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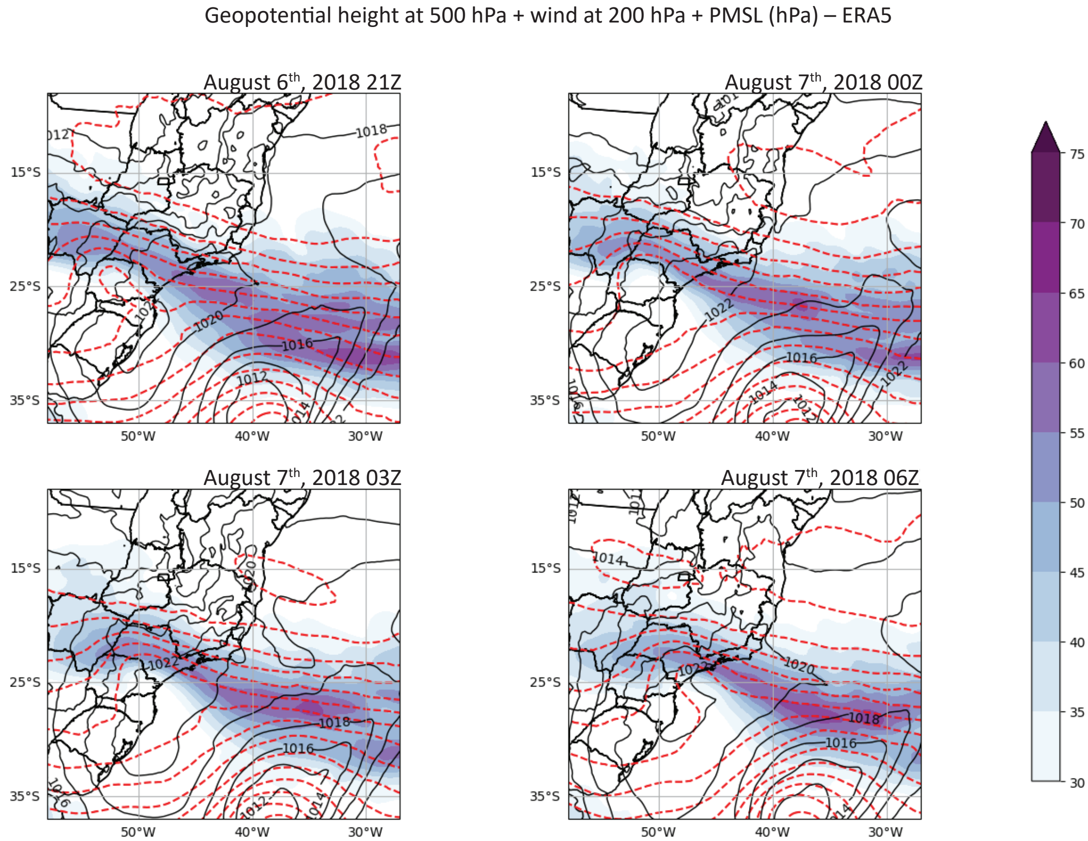

Figure 15. Geopotential height at 500 hPa, red dashed line; pressure at mean sea level (PMSL), black solid line; and wind magnitude at 200 hPa, in color

Source: ERA5

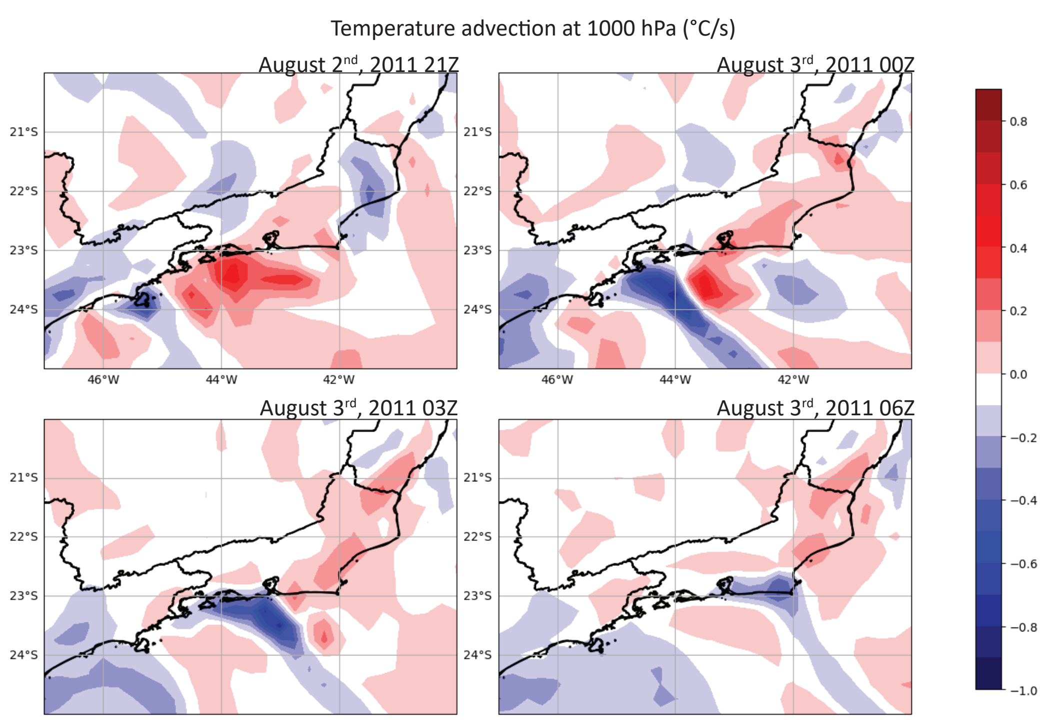

Figure 16. Thermal advection at the event on August 2nd and 3rd, 2011

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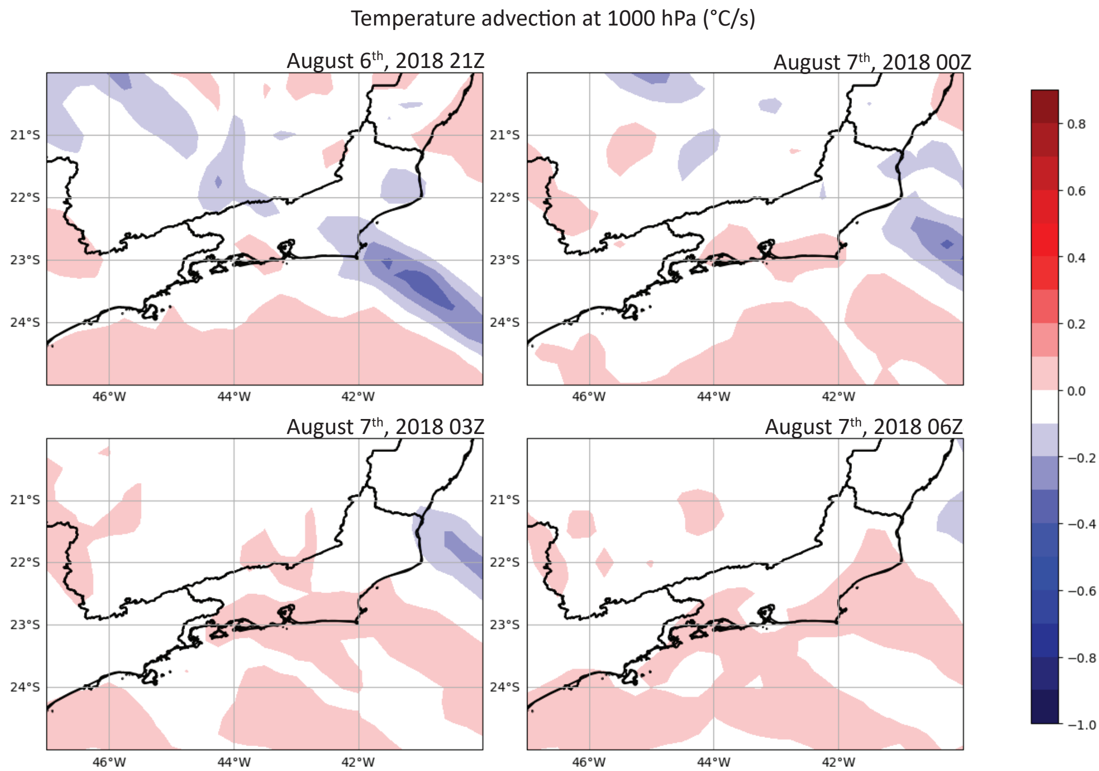

Figure 17. Thermal advection at the event, on Augst 6th and 7th, 2018

ver, they underestimate the maximum temperature by almost 4°C, with 26.1°C being the highest temperature detected, when the observed temperature was 29.9°C (**Figure 18**).

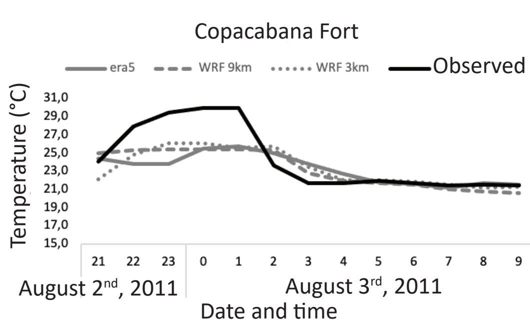

Figure 18. Comparison of the observed temperature at Copacabana Fort with the ERA5 reanalysis and the numerical simulation.

One of the hypotheses for the August 2 and 3, 2011 event is the occurrence of a heat burst and, to investigate this, we looked for results similar to those found by Johnson (1983), evaluating the temporal evolution of θe (K) isolines with height (**Figure 19**). In the case of 2011, the sinking of the θe isolines, from mid-level to the surface, are similar to those found by Johnson (1983), indicating a subsidence of air. This same pattern is not observed for the 2018 case.

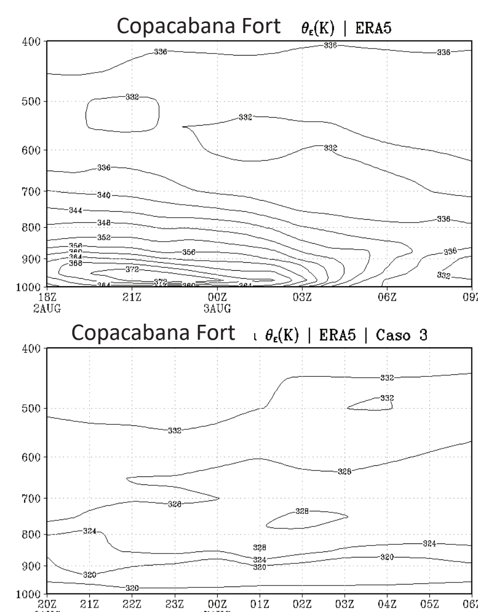

Figure 19. Temporal evolution of θe (K) Isolines with height to the heating event n 2nd and 3rd August, 2011 (upper) and 6th and 7th August, 2018 (lower)

Fonte de Dados: ERA5

Figure 20 shows the warming in one hour and the wind in barbels. There are regions of warming over the ocean, close to the state, between 21Z and 22Z on August 2nd over RMRJ. The N quadrant winds during this period stand out. An area

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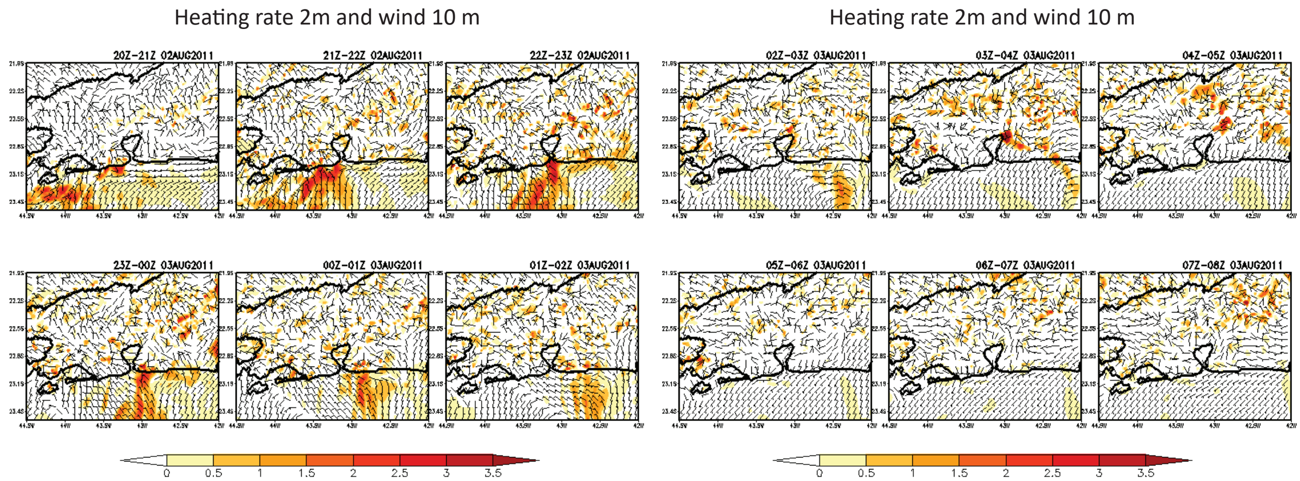
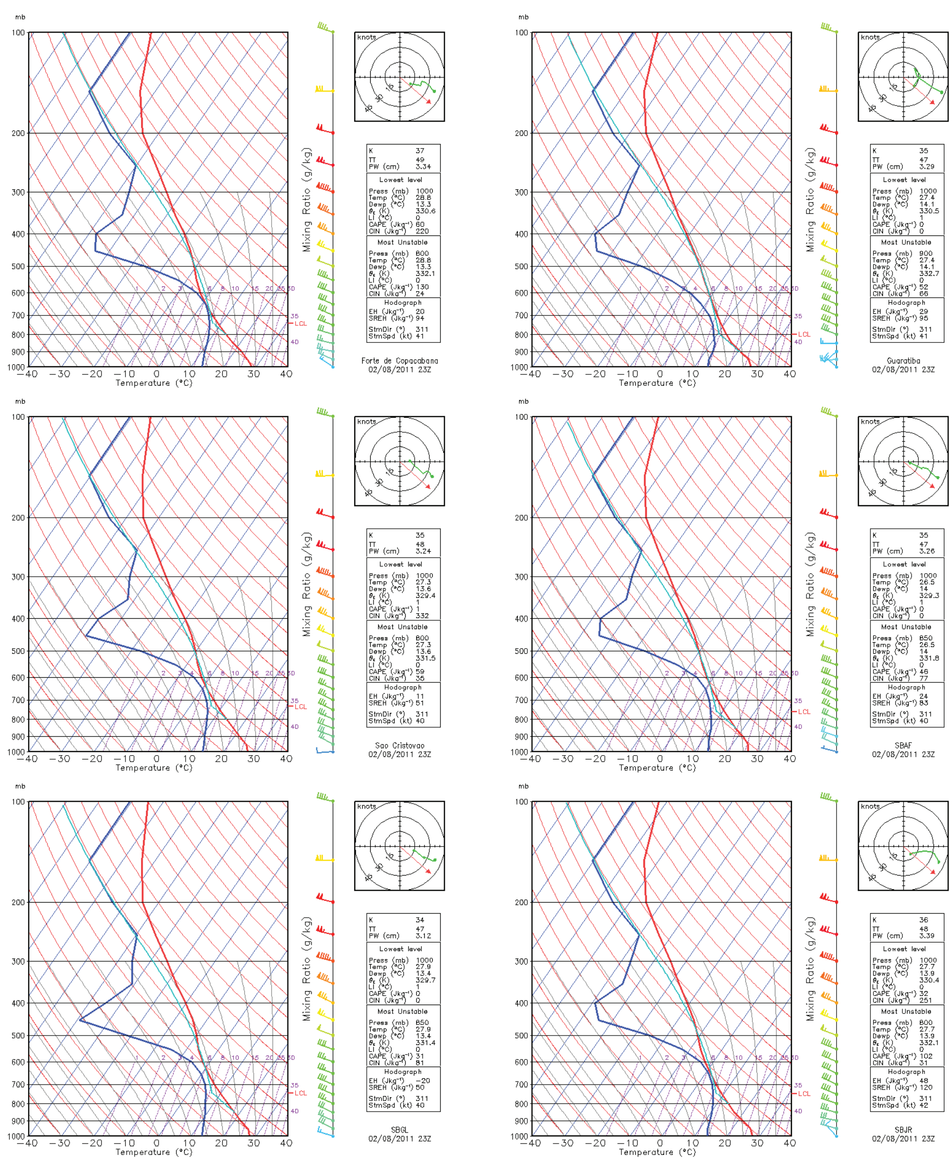


Figure 20. One-hour heating rate and wind at 10 m



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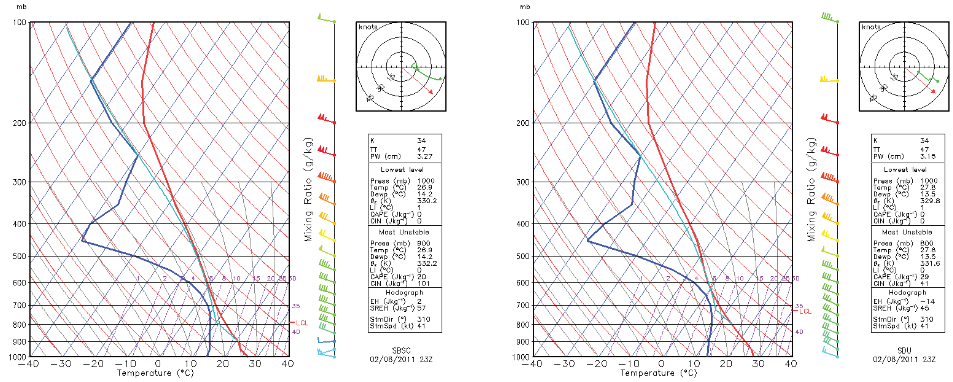

Figure 21. SKEWT on August, 3rd at 02Z

of warming on the coast of Rio de Janeiro's South Zone is very evident between 20 and 23Z. NW winds on the coast of Rio de Janeiro's South Zone are observed at the time of the most significant warming.

Looking at the SKEWT for 02Z on the 3rd, 11pm on the 2nd, we see a wetter layer around 600-700 hPa, and a drier one just below it. The thermal inversion is not as pronounced, but there is a neutral rate of heating/cooling near the surface. The skew-T's are similar to the onion sounding mentioned in the references (**Figure 21**).

CONCLUSIONS

On the night of August 2 and dawn of August 3, 2011, there was an anomalous increase in air temperatures simultaneously with a decrease in Td in the city of Rio de Janeiro. The frequency of heatings on an August night at Copacabana Fort is normally up to 1°C in one hour, and heatings of more than 3.5°C in one hour were rare, occurring less than 0.5% of the time.

In this period, the passage of a cold front through the ocean and the change in the surface wind circulation certainly contributed to the warming, an event favored by positive thermal advection. However, for another event in 2018, under similar synoptic conditions, the warming was not as significant, and proved to be common, accounting for around 88% of the cases of nocturnal warming in August for Copacabana Fort.

Analyzing the θe (K) isolines, like Johnson (1983), it is observed that a drier layer of air subsides from mid-levels to the surface in the event of August 2nd and 3rd, 2011. This result was not observed in the case of 2018.

As shown in section 2.8, a heat burst occurs when a subsidence air mass in the atmosphere heats up in the process and arrives with relatively higher temperatures at the surface. The presence of a layer of humid air at mid-levels, a drier one just below, a thermal inversion close to the surface observed in the Skew-T diagram at 9pm on August 2nd at Galeão airport, is similar to that shown by Johnson (1983), an onion-type sounding.

Also based on the numerical simulation, it can be concluded that, like the reanalysis, it was unable to represent the magnitude of the event in terms of maximum temperature reached, but the numerical simulation with the WRF detected regions of warming mainly on the coast of the South Zone of the city of Rio de Janeiro, a region close to Santos Dumont Airport and Copacabana Fort, locations where warming was observed.

Therefore, based on the results presented in this paper, it is possible to conclude that the warming observed on the night of August 2nd and dawn of August 3rd, 2011 is rare, and that pre-frontal warming alone does not justify the magnitude of the warming. This suggests that other phenomena, such as the heat burst, may have contributed to the temperatures observed that night.

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