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Study of tornadoes that have reached the state of Paraná

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Abstract
Several tornadoes have solid recorded in the Midwest, Southeast and South of Brazil. The southern region of Brazil has been hit by several of them in the last decade, highlighted the state of Paraná to record three tornadoes in 2015. The work is a survey of tornadoes that caused major damage to the Paraná population, relevance those who reached the *Balsa Nova* counties, *Francisco Beltrão*, *Cafelândia*, *Nova Aurora* and *Marechal Cândido Rondon*. The main cause because it is related to *El Niño* which has caused a significant rise in temperature and water vapor present in the atmosphere in the state's regions in surroundings that influence the climate of the state. Another likely factor is the increase in global temperature of the planet, a ripple effect on the warming of Pacific Ocean waters. The meeting is the possibility of the formation of large storms that funnel and reach the states of Parana and Santa Catarina. Overall fronts storms fall into two, forming a separation channel as a wave, their crests (storms) and valleys (lull), advancing the state of Paraná.

Keywords
El Niño, Fujita scale, Global temperature, Paraná, South of Brazil,Thunderstorms, Tornadoes, Vortex, Waterspout.

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Contents

Introduction

Several tornadoes have been recorded in recent decades in southern Brazil, as well as in the Midwest and Southeast. In *Canoinhas - Santa Catarina*, May 1948; Paraná in *Almirante Tamandaré*, May 1992 [1] and *Balsa Nova*, December 2012. [2] In *Santa Catarina*: *Canoinhas*, May 1948 and *Xanxerê*, April 2015. In *Rio Grande do Sul*: *Cruz Alta*, October 2002; *Gramado* and *Canela*, September 2010; *Erebango*, April 2014. [1]

Mato Grosso do Sul is another state that has a history of tornadoes. Sao Paulo has several cases and are among the most intense ever observed in Brazil: *Indaiatuba*, in May 2005, *Itu* in September 1991 and the latest in *Taquarituba* in September 2013. [1]

You can no longer say that tornadoes are rare in Brazil, Fig. (1). With the ease that now has registration and dissemination of information, through videos and photos made on mobile phones, tablets and notebooks, severe phenomenon are increasingly known to Brazilians. The tornado is considered

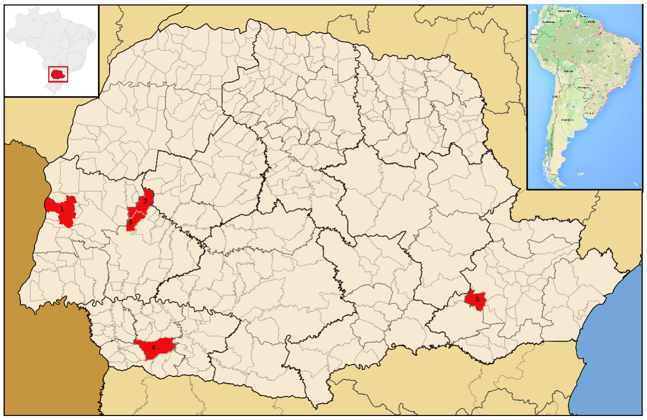

Figure 1. Map of the State of Paraná (adapted). Towns hit by tornadoes. 1. *Marechal Cândido Rondon*; 2. *Nova Aurora*; 3. *Cafelândia*; 4. *Francisco Beltrão*; 5. *Balsa Nova*. [4]

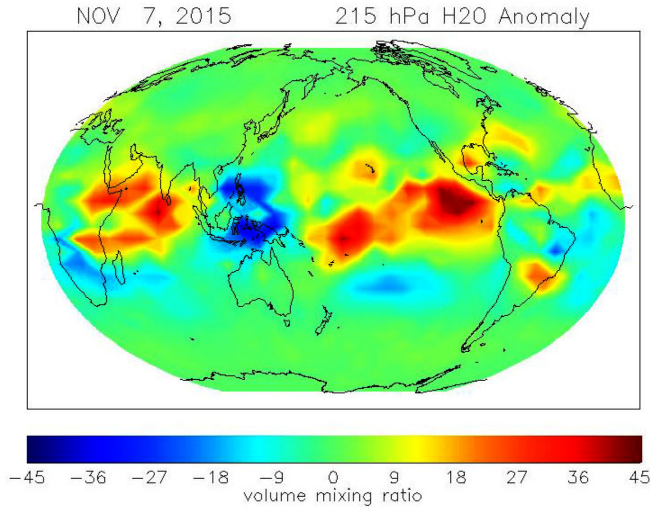

Figure 2. The map indicates humidity anomaly at 10 km as measured by Aura MLS. Blue, green, and red indicate drier, average, and wetter than average conditions. 7 November 2015 indicates a strong *El Niño* because the humidity over western Pacific is much greater than average and the eastern Pacific is much drier than average. [3]

the worst of the degree of destruction that can cause and the difficulty to predict. Every time one happens, beyond destruction, reveals the fragility of meteorologists in Brazil before phenomenon like this and others included in what is called (severe weather), which is high risk of property damage and causalities. Explain what it is, how it forms, where there are tornadoes and waterspouts does not represent any disorder for most meteorologists. But when it comes to tornadoes forecast, almost everyone feels trapped, powerless. [1]

In 2015 the state of Paraná there were several tornadoes. In January: *Pérola*; July: *Francisco Beltrão*; October: *Cafelândia* and *Nova Aurora*; November: *Marechal Cândido Rondon*.

The reason for the increase in cases of tornadoes in the state of Paraná may be related to the phenomenon *El Niño*, Fig. (2), (6) and (7). These phenomenon are significant changes in short-term (15-18 months) in the distribution of surface temperature of the Pacific Ocean water with profound effects on climate, Fig. (2). [3]

1. State of Paraná

Paraná is one of the 26 states of Brazil, Fig. (1), located in the south of the country, bordered on the north by São Paulo state, on the east by the Atlantic Ocean, on the south by Santa Catarina state and the Misiones Province of Argentina, and on the west by Mato Grosso do Sul and the republic of Paraguay, with the Paraná River as its western boundary line.

Cut by the Tropic of Capricorn, Paraná has what is left of the araucaria forest, one of the most important subtropical forests in the world. At the border with Argentina is the National Park of Iguaçu, considered by UNESCO as a World Heritage site. At only 40 km (25 mi) from there, at the border with Paraguay, the largest dam in the world was built, the Hidroelétrica de Itaipu (Itaipu Hydroelectric Dam). [5]

The state of Paraná has extreme limits west with coordinates 25°27'21.2"S 54°37'07.8"W, south 26°43'02.3"S 51°24'41.5"W, east 25°13'51.9"S 48°01'33.4"W and north 22°31'07.0"S 52°06'30.2"W.

1.1 Climate

The Paraná Fig. (1) territory covers three distinct climatic types, taking into account the temperatures and rainfall: the Cfa climates, Cfb and Cwa belonging to the Köppen classification. The Cfa climate, subtropical with good distribution of rainfall during the year and summers where it is hot, has hit area in the north, northwest, west and southwest of the state. Average annual temperatures recorded are higher than 19°C and the annual rainfall is 1,500 mm, something with great elevation on the coast than in the interior. [6]

The Cfb climate subtropical with good distribution of rainfall during the year and mild summers. Its area of occurrence is the portion of higher altitude of the state and its catchment area corresponds to the First Plateau, the Second Plateau and east of the Third Plateau. The average temperature per year is variation around 17°C [7] and the rainfall is over 1,200 mm annually. [6]

The Cwa climate, with subtropical summers where it is hot and dry winters, has occurred in the north-western end of the state. It's what is called a tropical climate because, unlike what happens with the Cfa and Cfb climates, with good distribution of rainfall recorded during the year, this is characteristically rainy with respect to tropical systems with dry winters and rainy summer, but, in Paraná, this drought is only registered for a period of two months at most. The annual temperature variation is about 20°C and annual rainfall has a range of 1.300mm. Almost the entire state is subject to a period of five days of frost per year, but in the south and in parts of greater altitude of the plateau is recorded longer than ten days. [6] The snow has less appearance in area Curitiba and, more often, in the region where they are located Palmas and Guarapuava. [?]

2. Tornadoes

A tornado is a violently rotating column of air that is in contact with both the surface of the earth and a cumulonimbus cloud or, in rare cases, the base of a cumulus cloud. They are often referred to as twisters or cyclones, [8, 9, 10] although the word cyclone is used in meteorology, in a wider sense, to name any closed low pressure circulation, Fig. (3) and (4). Tornadoes come in many shapes and sizes, but they are typically in the form of a visible condensation funnel, whose narrow end touches the earth and is often encircled by a cloud of debris and dust. Most tornadoes have wind speeds less than 110 miles per hour (180 km/h), are about 250 feet (80 m) across, and travel a few miles (several kilometers) before dissipating. The most extreme tornadoes can attain wind speeds of more than 300 miles per hour (480 km/h), stretch more than two miles (3 km) across, and stay on the ground for dozens of miles (more than 100 km). [11, 12, 13]

Various types of tornadoes include the landspout, multiple vortex tornado, and waterspout. Waterspouts are characterized by a spiraling funnel-shaped wind current, connecting to a large cumulus or cumulonimbus cloud. They are generally classified as non-supercellular tornadoes that develop over bodies of water, but there is disagreement over whether to classify them as true tornadoes. These spiraling columns of air frequently develop in tropical areas close to the equator, and are less common at high latitudes. [14] Other tornado-like phenomenon that exist in nature include the gustnado, dust devil, fire whirls, and steam devil; downbursts are frequently confused with tornadoes, though their action is dissimilar.

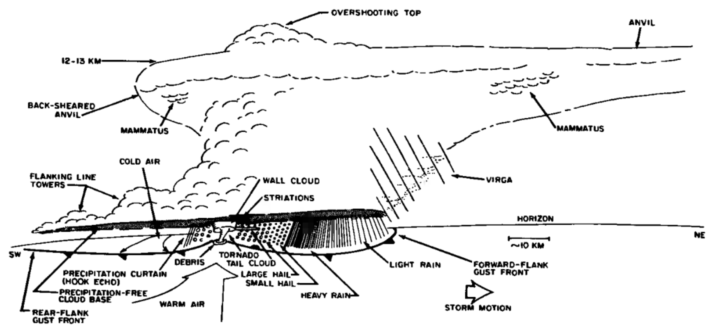

Figure 3. Schematic visual appearance of a supercell thunderstorm. [9]

3. Fundamentals

3.1 Tornado Vortex Dynamics

Consider the equation of motion for the Boussinesq flow:

$$\frac{\bar{D}\bar{v}}{Dt} = -\frac{1}{\rho_o}\nabla\bar{p}^* - f\mathbf{k}\times\bar{v} + \bar{B}\mathbf{k} + \bar{\mathbf{F}} + \bar{\mathscr{F}} \qquad (1)$$

where

$$\bar{\mathscr{F}} = -\rho_o^{-1}[(\nabla\cdot\rho_o\overline{u'\mathbf{v}'})\mathbf{i} + (\nabla\cdot\rho_o\overline{v'\mathbf{v}'})\mathbf{j} + (\nabla\cdot\rho_o\overline{w'\mathbf{v}'})\mathbf{k}] \qquad (2)$$

The term $\mathscr{F}$ is the three-dimensional convergence of the eddy flux of momentum. The dynamics of the core region of the tornado can be examined theoretically by considering the dry Boussinesq equations written in cylindrical polar coordinates (r,Θ,z). The z-axis is vertical and centered on the vortex, which is assumed to be axially symmetric

$$\partial/\partial\Theta = 0. \qquad (3)$$

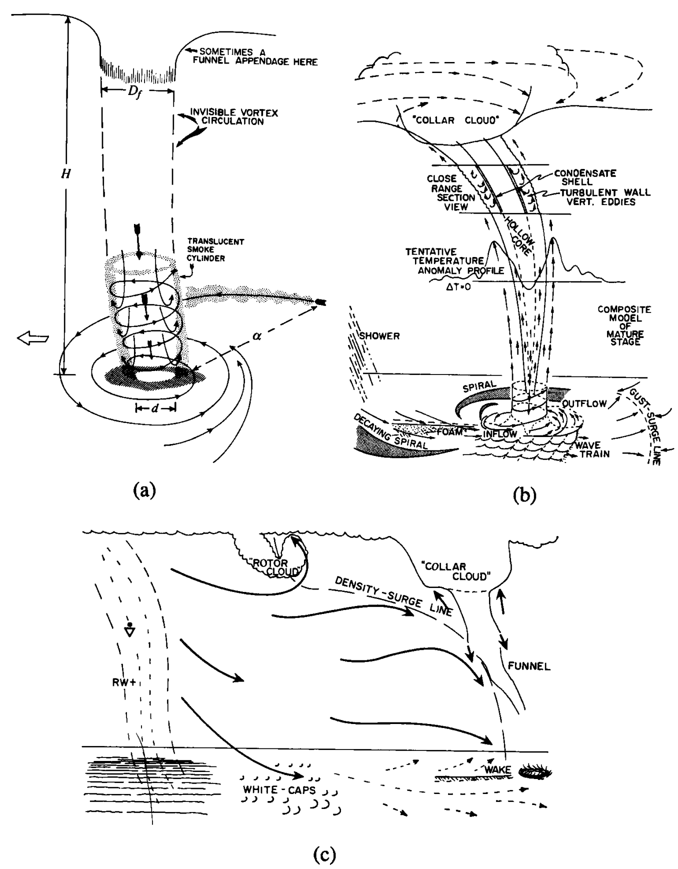

Figure 4. Empirical model of a waterspout, (a) Early stage. Cloud base height/varies from 550 to 670 m, maximum funnel diameter fly from 3 to 150 m, d = 3-45 m, a = 15-760 m. (b) Mature stage. Maximum funnel diameter ranges from 3 to 140 m. (c) Decay stage, during which the funnel cloud often undergoes rapid changes in shape and may become greatly contorted. Maximum funnel diameters range from 3 to 105 m. [8, 9, 10]

Molecular friction is ignored.

We review here the method by which the standard (Boussinesq, incompressible) HPE's for the ocean written in z-coordinates are obtained. The non-Boussinesq equations for oceanic motion are: Under these conditions, the components of the Boussinesq version of the mean-variable equation of motion (1) are

$$\bar{u}_t + \bar{u}\bar{u}_r + \bar{w}\bar{u}_z - \frac{\bar{v}^2}{r} = -\frac{1}{\rho_o}\frac{\partial \overline{p^*}}{\partial r} + \boldsymbol{K}_m(\overline{u_{rr}} + \frac{1}{r}\bar{u}_r + \bar{u}_{zz} - \frac{\bar{u}}{r^2}) \tag{4}$$

$$\bar{v}_t + \bar{u}\bar{v}_r + \bar{w}\bar{v}_z + \frac{\bar{u}\bar{v}}{r} = \boldsymbol{K}_m(\overline{v_{rr}} + \frac{1}{r}\bar{v}_r + \bar{v}_{zz} - \frac{\bar{v}}{r^2}) \tag{5}$$

$$\bar{w}_t + \bar{u}\bar{w}_r + \bar{w}\bar{w}_z - \frac{\bar{v}^2}{r} = -\frac{1}{\rho_o}\frac{\partial \overline{p^*}}{\partial z} + \bar{\boldsymbol{B}} + \boldsymbol{K}_m(\overline{w_{rr}} + \frac{1}{r}\bar{w}_r + \bar{w}_{zz}) \tag{6}$$

The mean-variable thermodynamic equation (8) and continuity equation (7) in their Boussinesq versions

$$\frac{\overline{D\theta}}{Dt} = \overline{\mathscr{H}} - \rho_o^{-1}\nabla \cdot \rho_o \overline{\mathbf{v}'\theta'} \tag{7}$$

$$\nabla \cdot \rho_o \mathbf{v}' = 0 \tag{8}$$

i.e., with the density factor ρ_o omitted are

$$\bar{\theta}_t + \bar{u}\bar{\theta}_r + \bar{w}\bar{\theta}_z = \boldsymbol{K}_\theta(\bar{\theta}_{rr} + \frac{1}{r}\bar{\theta}_r + \bar{\theta}_{zz}) \tag{9}$$

and

$$\frac{1}{r}(r\bar{u})_r + \bar{w}_z = 0 \tag{10}$$

In these expressions, u = *Dr*/*Dt*, v = *D*Θ/*Dt*, and w = *Dz*/*Dt* and the eddy-flux terms in (4)-(9) are parameterized in terms of a simplified K-theory or first-order closure, in which the values of the mixing coefficients K_m and K_θ are constant. The expressions multiplying K_m in (4)-(8) are the axisymmetric cylindrical-coordinate components of the vector $\nabla^2\bar{\mathbf{v}}$, while the factor multiplying K_θ in (9) is the axisymmetric cylindrical-coordinate form of $\nabla^2\bar{\mathbf{v}}$.

The key dynamical characteristic of the tornado vortex is its extremely large tangential wind component, which far exceeds its radial or vertical component. [9, 10]

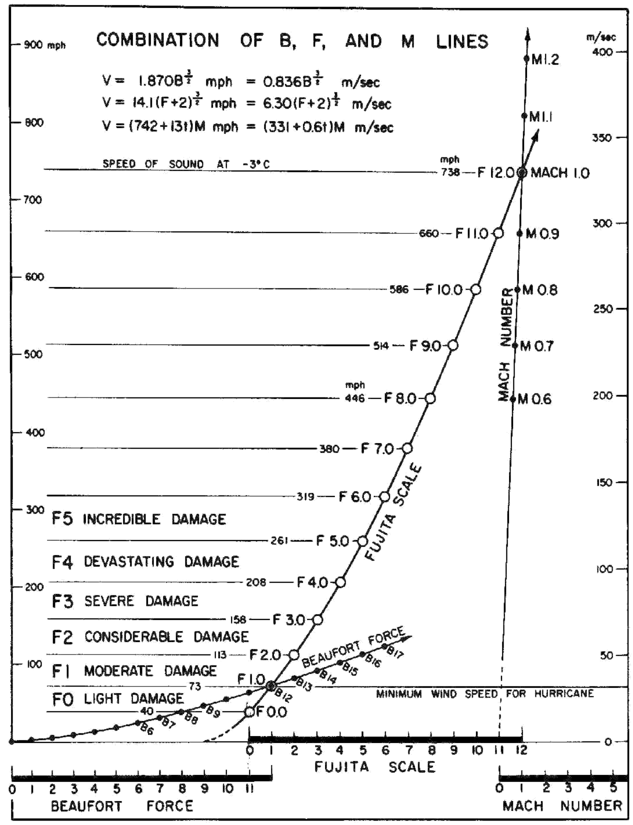

Figure 5. The Fujita Scale. Fujita's smoothly derived relationship of the F-Scale with the Beaufort Scale and the Mach Scale as explained to the right. [15]

3.2 The Fujita Scale

The Enhanced Fujita Scale (EF Scale) Dr. T. Theodore Fujita first introduced The Fujita Scale in the SMRP Research Paper, Number 91, published in February 1971 and titled, "Proposed Characterization of Tornadoes and Hurricanes by Area and Intensity". Fujita revealed in the abstract his dreams and intentions of the F-Scale. He wanted something that categorized each tornado by intensity and area. The scale was divided into six categories:

- F0 (Gale)
- F1 (Weak)
- F2 (Strong)
- F3 (Severe)
- F4 (Devastating)
- F5 (Incredible)

Dr. Fujita's goals in his research in developing the F-Scale were categorize each tornado by its intensity and its area estimate a wind speed associated with the damage caused by the tornado Dr. Fujita and his staff showed the value of the scale's application by surveying every tornado from the Super Outbreak of April 3-4, 1974. The F-Scale then became the mainstay to define every tornado that has occurred in the United States. The F-Scale also became the heart of the tornado database that contains a record of every tornado in the United States since 1950.

The Fujita Scale is a well known scale that uses damage caused by a tornado and relates the damage to the fastest 1/4-mile wind at the height of a damaged structure. Fujita's scale was designed to connect smoothly the Beaufort Scale (B) with the speed of sound atmospheric scale, or Mach speed (M). Fujita explains explicitly that (F-scale winds are estimated from structural and/or tree damage, the estimated wind speed applies to the height of the apparent damage above the ground. [15]

The Fig. (5) represent the connection of Beaufort force, Fujita scale and Mach number. In deriving the equation for F-scale wind computation, th e following considerations were made. (1) To connect Beaufort force 12 with Mach number 1 with a smooth curve, (2) To correspond B 12 with F 1 and M 1 with F 12, so that a 1 through 12 graduated scale, as in the case Beaufort force, covers the desired speed range. (3) Beaufort 0 indicates calm or no wind and Fujita O likewise denotes the wind speed causing no damage on most structures, (4) To give wider speed range as the speed increases because the faster the wind speed the under the speed range to allow a visual distinction of damage from one scale to the next, and (5) An exponent 3/2 is likely to serve the above purpose. Furthermore, the square of the speed or the kinetic energy is proportional to the cube of $F+2$. [15]

The Beaufort Scale is defined by the Glossary of of Meteorology (AMS) as a system of estimating and reporting wind speeds numerically from 0 (calm) to 12 (hurricane). The Mach scale is the speed of sound in the atmosphere. [15]

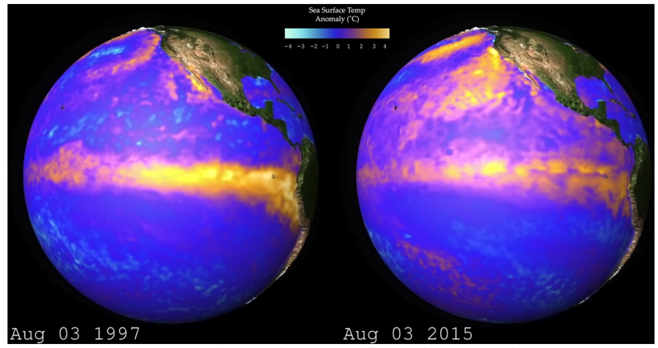

Figure 6. Comparation of anomalies of sea surface temperature due to the phenomenon *El Niño*. This snapshot illustrates of sea surface temperature (SST) anomalies (relative to the respective normal state) in the Pacific Ocean associated with the developing 2015 *El Niño*, the warm phase ENSO. SST anomalies reflect the heat content in the mixed layer (upper 50 meters). [17]

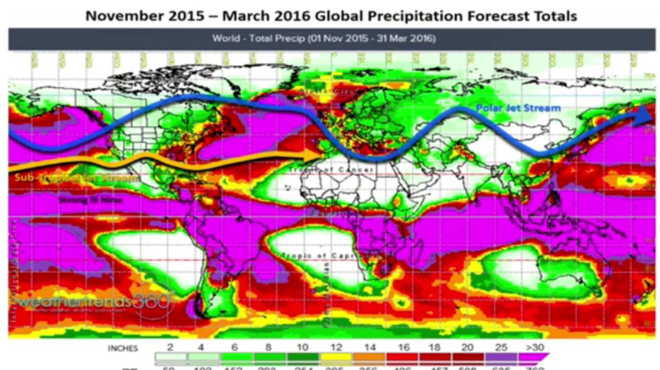

Figure 7. Snapshot with the forecast increase or reduction of rainfall for the period November 1, 2015 to March 31, 2016, with *El Niño* phenomenon influence. [18]

4. *El Niño*

El Niño Fig. (2), (6) and (7) is the warm phase of the *El Niño* Southern Oscillation (commonly called ENSO) and is associated with a band of warm ocean water that develops in the central and east-central equatorial Pacific (between approximately the International Date Line and 120°W), including off the Pacific coast of South America. *El Niño* Southern Oscillation refers to the cycle of warm and cold temperatures, as measured by sea surface temperature, SST, of the tropical central and eastern Pacific Ocean. *El Niño* is accompanied by high air pressure in the western Pacific and low air pressure in the eastern Pacific. The cool phase of ENSO is called *La Niña* with SST in the eastern Pacific below average and air pressures high in the eastern and low in western Pacific. The ENSO cycle, both *El Niño* and *La Niña*, causes global changes of both temperatures and rainfall. [3, 16] Mechanisms that cause the oscillation remain under study.

The El Niño-Southern Oscillation (ENSO) is a quasi-periodic fluctuation of ocean temperatures in the equatorial Pacific, Fig. (6). The temperatures generally fluctuate between two states: warmer than normal central and eastern equatorial Pacific *El Niño* and cooler than normal central and eastern equatorial Pacific (*La Niña*). [17]

The Fig. (6) represents the Global Precipitation Forescat Totals of November 1, 2015 to March 31, 2016. [18]

5. Paraná towns of records affected by tornadoes

5.1 Balsa Nova, metropolitan region of Curitiba

Driver records beginning tornado in the metropolitan region of Curitiba, Fig. (8) "I was a little scared," said the man who made the images, Fig. (8). In the western region, temporal reached Foz do Iguaçu wreaking havoc. The truck driver, [19] have made a video of a funnel cloud that passed Balsa Nova, the Metropolitan Region of Curitiba, on Wednesday (12). Images were recorded in the late afternoon, around 17:30 (UTC) of december 13, 2012, Fig. (8). I was a little scared and apprehensive. It's not that common here in the region.

Figure 8. Snapshot of the video [19] of a tornado that hit the south of Brazil in Balsa Nova, Curitiba, Paraná, reaching speed in excess of 115 km/h. The two tornadoes caused destruction and injured 34 people. [20]

I had only seen on television and internet. For me it was a novelty, "reported the driver. The storm in the city, according to the Simepar, lasted about 40 minutes. Also according to the Simepar a funnel cloud is the beginning of a tornado, however, for one twister, it is necessary to touch the ground. [19, 20]

Earlier on Thursday, december 13, 2012, Somar Meteorologia recorded wind gusts of up to 107 km/h in town. At the airport, at 9:20 am (UTC), 67 km/h winds were recorded. However, according to the record of the Meteorological Institute Simepar, the wind reached 50 km/h around 9:45 am (UTC). For 45 minutes from 9:30 am to 10:15 am (UTC), it rained 32.6 mm. Even as Simepar, the rain was significant because the average in the region is 120-150 mm for the entire month. The meteorologist Simepar, P. Barbieri explained that the storm was caused due to a cold front coming from Paraguay and Argentina, who is entering the state. The temperature in Foz fell from 26.2^{o}C to 18.5^{o}C after rain. The forecast is isolated showers of rain in the city later on Thursday. [20]

In Plateau in southwestern Paraná, the wind in the early morning hours of Thursday was 63 km/h, according to the Simepar. The weather station of Somar reported that the wind reached 100 km/h in the city. The Civil Defense reported that by 11 am, 30 trees fell and 12 houses were left roofless in Foz. The agency has no reports of homeless or displaced.During the storm, the offices of the Federal Highway Police (PRF) on the Friendship Bridge, the Tancredo Neves Bridge in Santa Terezinha de Itaipu, in the western state, were without power. The Civil Police Foz also was without light for an hour. [20]

Already Laudemir Neves Jail in Foz, is without power for three hours. The IRS, in Bridge of Friendship, still without power, delaying the release of trucks in the Dry Port direction Paraguay. [20]

5.2 Francisco Beltrão

Storm

Tornado leaves trail of destruction in Francisco Beltrão, Fig. (9). Winds of up to 120 km/h destroyed dozens of homes and left 51 people injured. Strong winds - which reached 120 km/h - hit the southwestern region of the state Monday night nun (July 13, 2015). The storm started around 19 hours (UTC) and caused much destruction. In total, seven municipalities were affected. However, the biggest problems were recorded in the city of Francisco Beltrão. Forecasters Simepar confirmed that the destruction was caused by a tornado.

"A supercell gained strength in Bela Vista da Carobá around 18:10 (UTC). The storm moved by Ampere at 18:30 and arrived in western municipality of Francisco Beltrão with intensity compatible extreme storm. Between 18:45 and 18:53 (UTC) the mesocyclone was set up and, in this storm, a tornado hit the rural Francisco Beltrão," said the Meteorological System of Paraná. [21]

Undoing

In the city, about 50 homes were affected, five were totally destroyed. Nineteen people were injured, but there were no casualties. 220 people were affected. Trees, vehicles and poles were ripped from the ground and dragged by the wind. Many explosions were heard. Many animals died because of the tornado.

"People who were displaced are being forwarded to shelters. We are doing an assessment in southwestern municipalities to know the actual size of the damage suffered," says the state coordinator of Civil Protection and Defense of Paraná, Captain Eduardo Pinheiro.

In heaven's southwest region, residents viewed a cloud funnel-shaped, very similar to a hurricane, but did not touch the ground. Many people believe that it was a tornado. The information was confirmed by Somar Meteorologia, but not by the Meteorological Institute Simepar. [21]

"Our radar expert will do the analysis, but what we have is that it was a very strong wind. The weather station recorded winds of 55 kilometers (km) per hour, but the damage may have passed 100 (km) per hour," said meteorologist Simepar, Tarcisio Valentine Costa.

According to Simepar, new storms moving from the southwest and should reach the region in the coming hours. Several counties are on alert. It should also be intense thunderstorms in the western, central and southern parts of the state and there is the possibility of floods and flooding in urban areas. There is no forecast of frost, but the soft rains will continue until the weekend. [21]

On Friday (10 July 2015), when the first warnings about the possibility of storms across the Paraná were issued, 37 municipalities were affected by the storms and 13,374 people were affected, and one person died (in Araruna), 51 were injured, 293 dislodged and 14 homeless. A total of 1,952 houses were damaged and six were completely destroyed. [21]

Figure 9. Photo of the tornadoes that hit the south of Brazil, in Francisco Beltrão. Strong winds - which reached 120 km/h - hit the region of Francisco Beltrão July 13 2915. [21]

5.3 Cafelândia e Nova Aurora

Tornado hits two cities in western Parana and destroys shed. Fig. (10)

A tornado went on the afternoon of Friday (October 9, 2015) by the cities of Cafelândia and New Dawn in western Paraná, according to Simepar (Paraná Meteorological System). Meteorologists said the phenomenon lasted about eight minutes, with winds that reached 115 km/h and destroyed a shed and an aviary in Central community of Central Santo Antônio in Cafelândia, Fig. (10). Technological institute reported that its radar showed severe storms, but did not anticipate the formation of the tornado. To prove the existence of the phenomenon, meteorologists have used videos that were sent by local residents. [2]

In addition to filming, photo as the vegetation was after the passage of the tornado, with twisted trees and pine trees cut in half, were also used by specialists to confirm the phenomenon, as they wind characteristics consequences that are formed with a funnel touching the ground . No injuries were reported.

Researchers at Simepar said that the phenomenon is not common in Brazil, but has happened in the Paraná this year in Francisco Beltrão, on 16 July.

It is expected that the storms continue on saturday in the western, north and northeast of the state, but there is no specific provision of new tornadoes. [2]

5.4 Marechal Cândido Rondon

A tornado with winds exceeding 115 km/h cause destruction in the region of Rondon around eighteen hours of November 11, 2015, Fig. (11). [22]

In Santa Catarina, another tornado destelhou homes and an emergency room in Treze Tilhas. In Chapecó, the wind reached 90 km/h. Four houses collapsed and 20 were roofless. Four people were injured.

Figure 10. Photo of the tornadoes that hit the south of Brazil, in Cafelândia and Nova Aurora in western Parana. A tornado went on the afternoon of Friday (October 9, 2015) by the cities of Cafelândia and Nova Aurora in western Paraná. [2]

Figure 11. Snapshot of the video of the tornado that struck southern Brazil, Marechal Cândido Rondon in western Paraná, reaching top speed at 115 km/h, around eighteen hours of November 11, 2015. [22]

In the south, two tornadoes caused destruction and injured 34 people. Within minutes, the enormous funnel-shaped cloud caused losses that will take to repair. [22]

The wind went from 115 km/h in Marechal Cândido Rondon, Fig. (11), west of Paraná. And he brought down hundreds of trees, damaged homes and snapped poles. Thirty people were injured, one in serious condition. A video shows the dread of two residents who were in the middle of the road. Through the glass you can see tree branches and roof tiles flying. The wind toppled trees and power lines.

On a street, which is one of the hardest hit, trees were uprooted, posts fell and residents came together to repair the damage. [22]

6. Analysis of climatic setting

Balsa Nova

Satellite images [21] indicate that around 15h (UTC) of December 12, 2012, Fig.(13) and (14), there is the meeting of two great masses of warm air coming from the Mato Grosso do Sul and Paraguay, with a cold air mass coming from the

Rio Grande do Sul and Argentina. There is a big storm formation that affects the states of Paraná and Santa Catarina, and *Corrientes* and *Misiones* in Argentina. Because of this occur the funneling of the fronts of air in the region of Balsa Nova, Fig. (1), the Curitiba metropolitan, heading west to east, there is the image formation of the tornado in the region, Fig. (8).

Francisco Beltrão

Satellite images [21] indicate that around 18h (UTC) of July 13, 2015, Fig. (15) to (18), there is the encounter between two air masses, the warm Mato Grosso do Sul coming and eastern Paraguay, with a mass of cold air coming from Argentina, moving westward to east, being pushed to the southeast toward the ocean. Divided in two fronts.

There is a big storm formation that reaches the southwestern state of Paraná, the western state of Santa Catarina and advancing to the east and the Rio Grande do Sul. Because of this funneling of air masses in the region of Francisco Beltrão, Fig. (1), heading west to east, there is the formation of image of the tornado in the city, Fig. (9).

Cafelândia and Nova Aurora

Satellite images [21-22] indicate that at around 18h30 (UTC) of 9 October 2015, Fig. (19) to (21), there is a large area of instability installed on the southern and southeastern Brazil. Within this area of instability in western Parana state moving in the northwest direction south-east, a low pressure system crosses the region Figures [21-22] of Cafelândia and Nova Aurora, Fig. (1). It has been the story tornadoes forming in the city, Fig. (10).

Marechal Cândido Rondon

Satellite images [21-22] indicate that at around 17:30 (UTC) of November 11, 2015, Fig. (22) to (25), there is a large area of instability that already installed in Corrientes and Misiones in Argentina, and west Santa Catarina and Rio Grande do Sul moves over southern Brazil, heading west to east. Within this area of instability in western Parana state shifting westbound east, a low pressure system forms over the region, Fig. (22) to (25), of Marechal Cândido Rondon, Fig. (1). Divided into two fronts, between the states of Parana and Santa Catarina. Images of the formation of the tornado in the city are shown in Fig. (11).

7. Conclusions

Satellite images [23, 24] indicate the dominance of the regional climate with the meeting of two great masses of air, a hot coming from the Mato Grosso do Sul and Paraguay, and another mass of cold air from the Rio Grande do Sul and coming Argentina. This meeting is the possibility of the formation of large storms that funnel and reach the states of Parana and Santa Catarina, Fig. (12). Due to this funneling of the fronts of the loaded mass air humidity in the region of the predominantly west to east direction is the formation of strong thunderstorms with a high possibility of tornado.

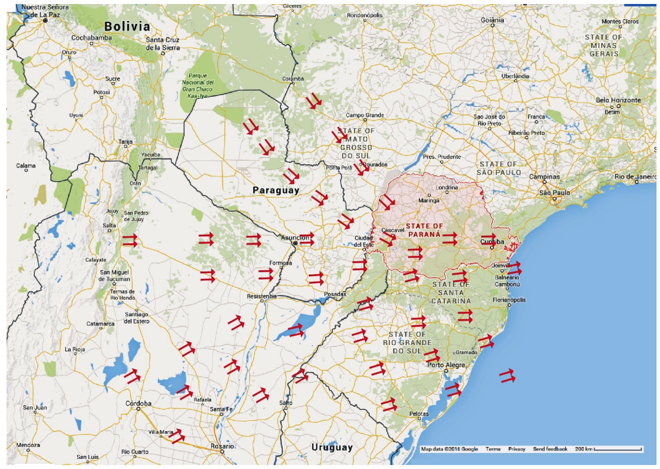

Figure 12. Map (adaptad) of the State of Paraná state with the average trajectory (double arrows in red) of hot air masses, from of Mato Grosso do Sul and Paraguay and the cold air from Argentina and Uruguay. [25]

These events are occurring more often probably due to the warming of the Pacific Ocean, *El Niño*, which bring large amounts of stemmed humidity of the Amazon region, and traverse the states of Mato Grosso and Mato Grosso do Sul, Bolivia and Paraguay, accumulating If in southern Brazil, eastern Paraguay and northwestern Argentina.

Overall fronts storms fall into two, forming a separation channel as a wave, their crests (storms) and valleys (lull), advancing the state of Paraná.

Acknowledgments

Thank GOD

8. List of Symbols

- f Coriolis parameter
- **F** molecular friction force
- $\bar{\mathscr{F}}$ three-dimensional convergence of the eddy flux of momentum
- **B** buoyancy
- $\dot{H}$ heating rate
- K_m turbulent exchange coefficient for horizontal momentum
- K_θ turbulent exchange coefficient for θ
- ω vorticity
- p pressure of air
- $\hat{p}$ reference pressure, usually representative of conditions near the earth's surface, often taken to be 1000 mb

- r radial coordinate (called range in the context of radar meteorology)
- ρ density
- t time
- Θ azimuth angle of a cylindrical coordinate system
- θ potential temperature
- u radial velocity component
- v tangential velocity component
- $\mathbf{v}$ three-dimensional velocity of a parcel of air
- w wind component in z-direction
- $\overline{()}$ an average; in discussions of atmospheric air motions, the average is usually taken over a spatial volume or area; in discussions of radar measurements, the overbar is used to indicate other types of averages (over time, over a power spectrum); in discussions of laboratory experiments, it is used to indicate a time average

$$\dot{\mathscr{H}} = \equiv \frac{1}{c_p}(\frac{\hat{p}}{p})^k \dot{\boldsymbol{H}} \tag{11}$$

$$\frac{D}{Dt} \equiv \frac{\partial}{\partial t} + \mathbf{v} \cdot \nabla \tag{12}$$

$$\frac{\overline{D}}{Dt} \equiv \frac{\partial}{\partial t} + \bar{u}\frac{\partial}{\partial x} + \bar{v}\frac{\partial}{\partial y} + \bar{w}\frac{\partial}{\partial z} \tag{13}$$

9. Images shot by Goes-13 satellite

9.1 Balsa Nova

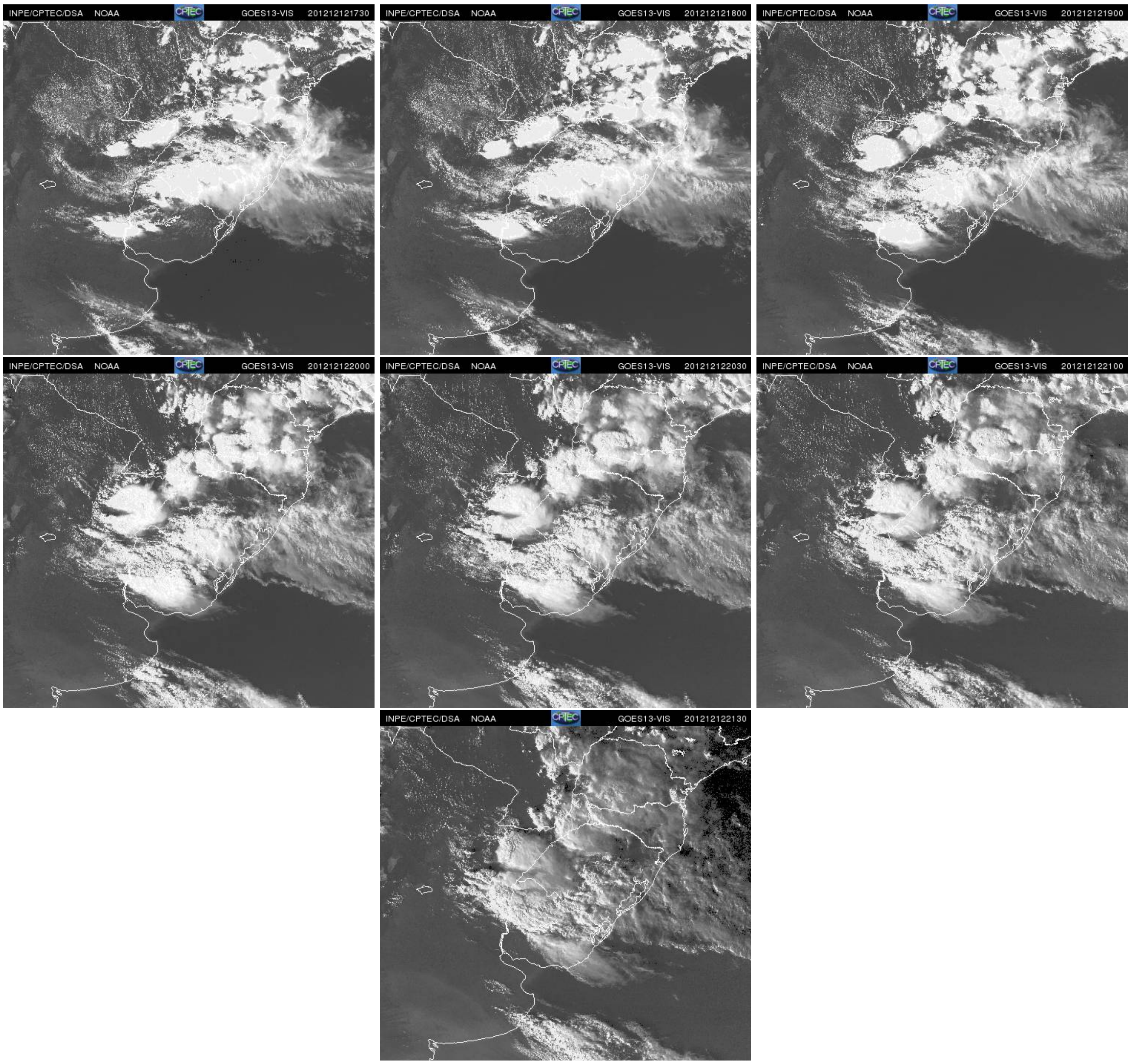

Figure 13. Following of seven images obtained by satellite GOES of the visible spectrum to the southern region of Brazil, on December 12 2012, from 17:30 to 21:30, with 30-minute intervals. [23]

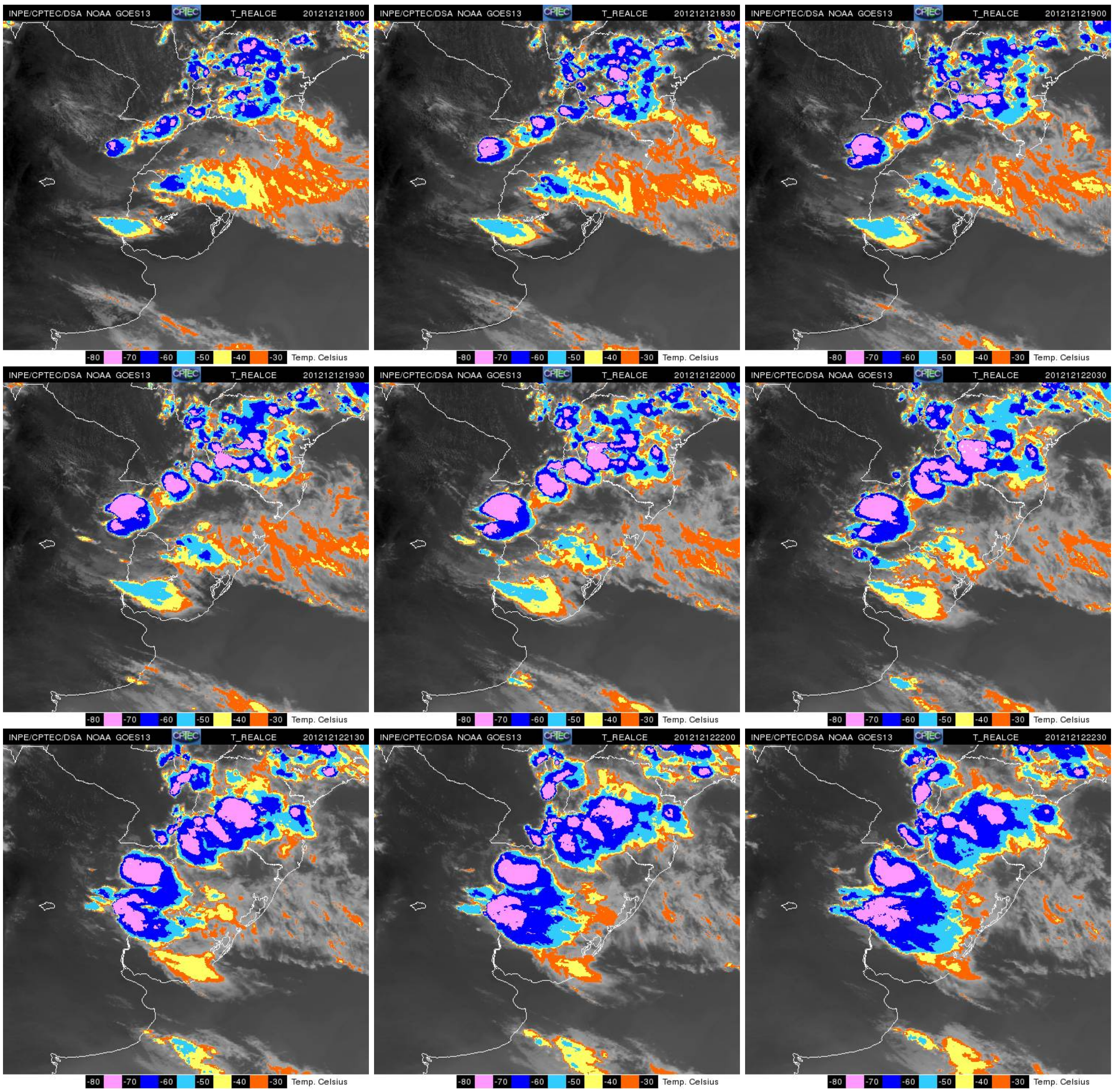

Figure 14. Following of nine images taken by the infrared spectrum of the GOES satellite highlighted, for the temperature of the south region of Brazil, on December 12 2012, from 17:30 to 21:30, with 30-minute intervals. [23]

9.2 Francisco Beltrão

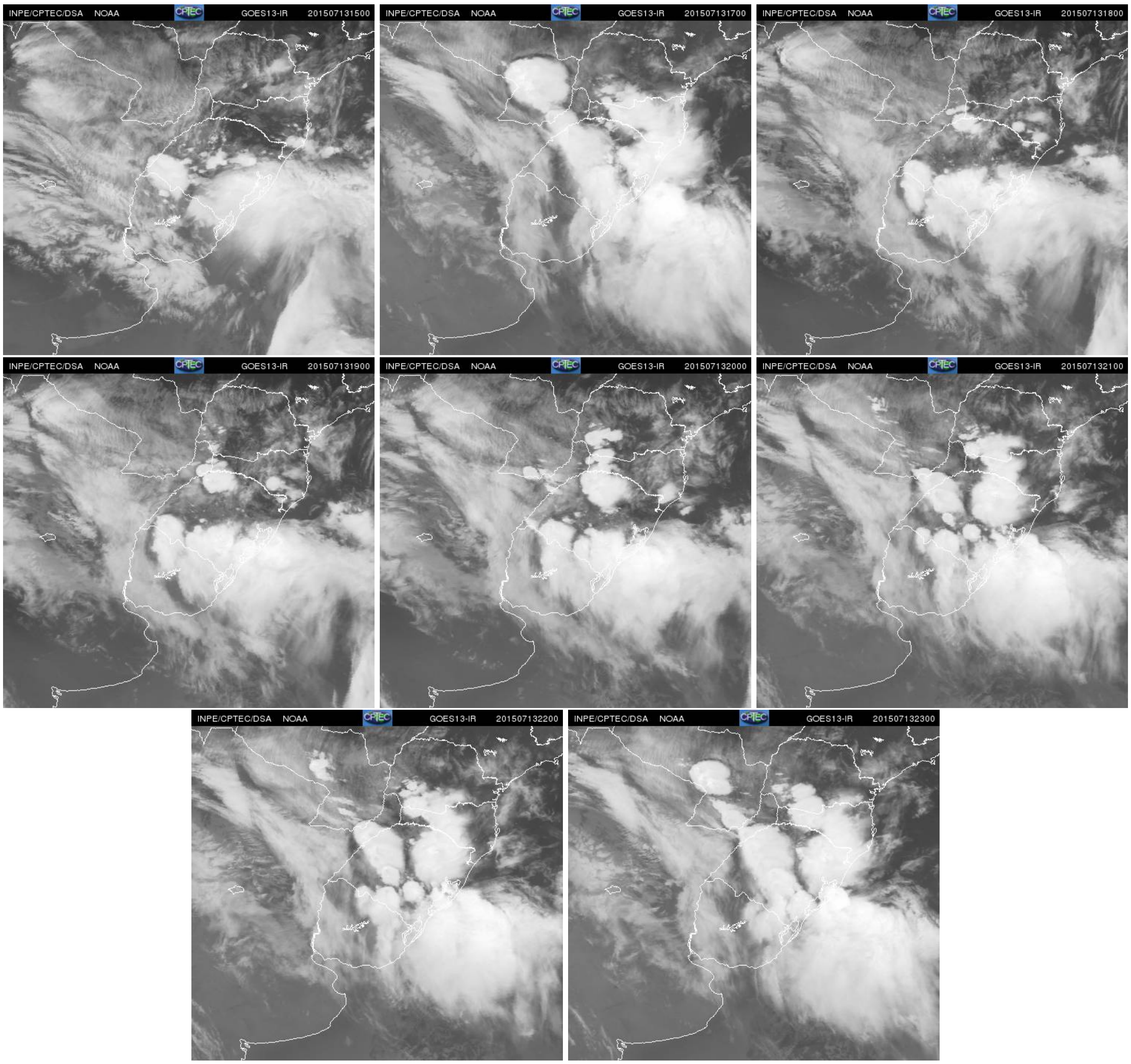

Figure 15. Following of eight images obtained by the infrared spectrum GOES satellite to water vapor, the southern region of Brazil, on July 13 2015, from 15:00 to 23:00, with one-hour intervals. [23]

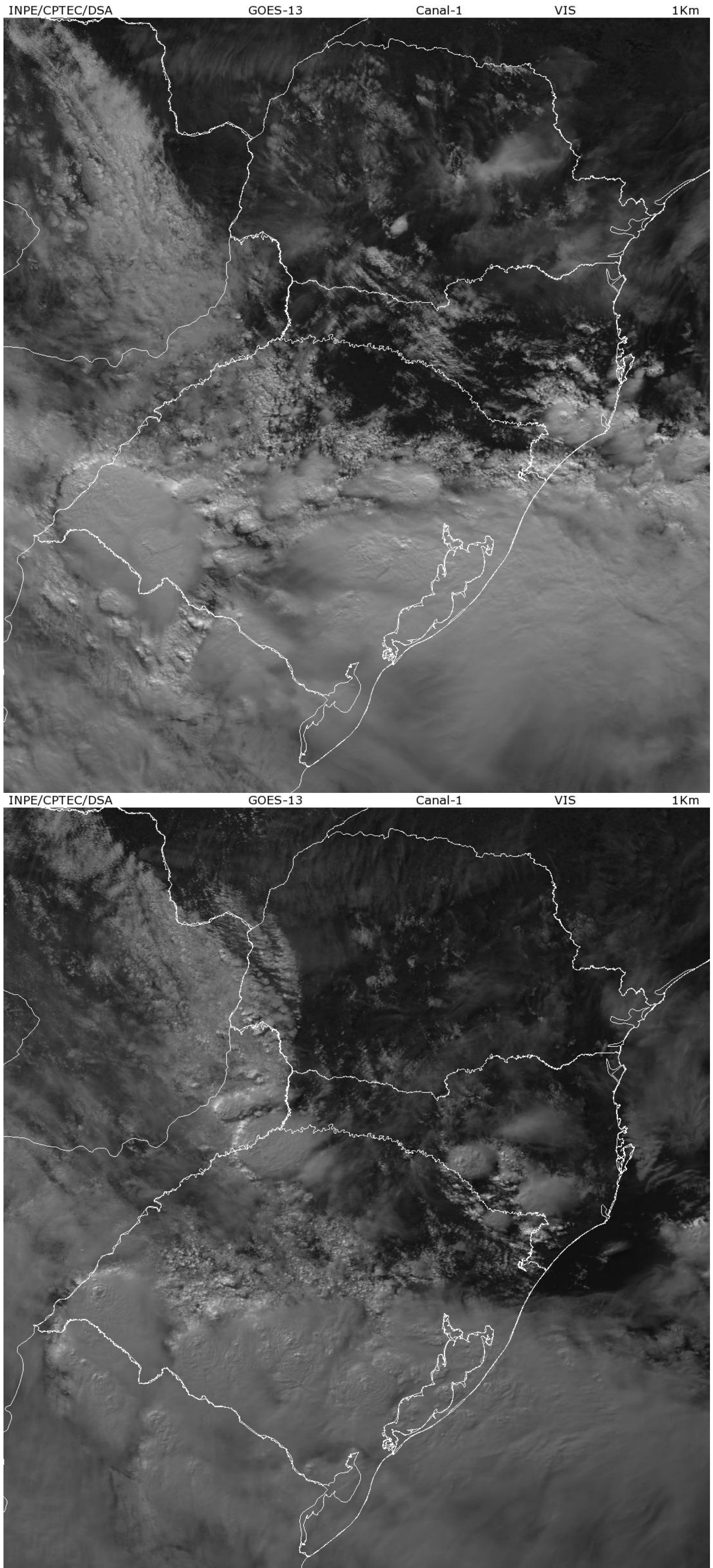

Figure 16. Following of two images taken by GOES satellite 1km visible spectrum, from southern Brazil, on July 13 2015, at 15:00 and 18:00. [23]

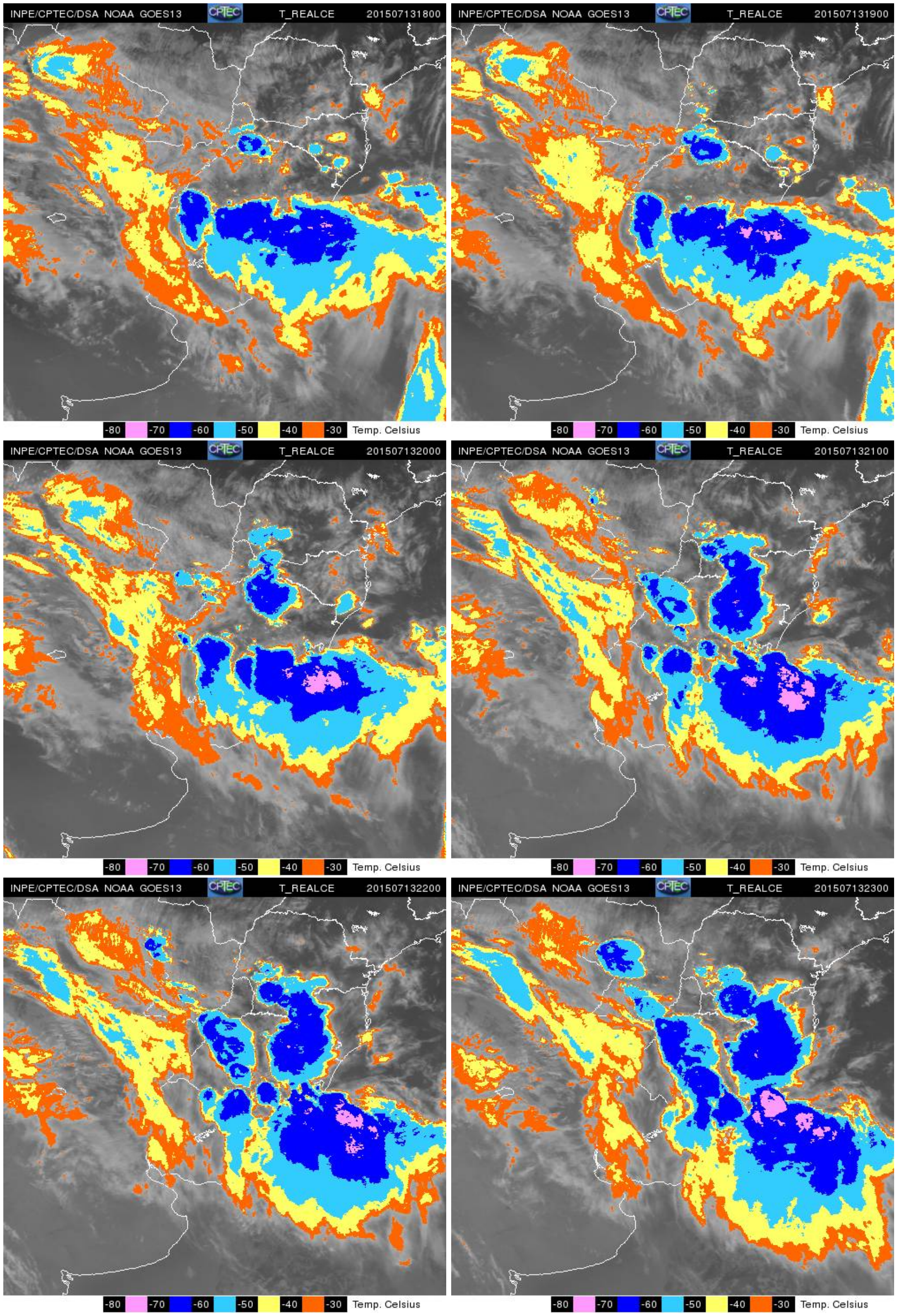

Figure 17. Following of six images taken by GOES satellite to the infrared spectrum enhanced, to the temperature of the south region of Brazil, on July 13 2015 from 18:00 to 23:00 in one-hour intervals. [23]

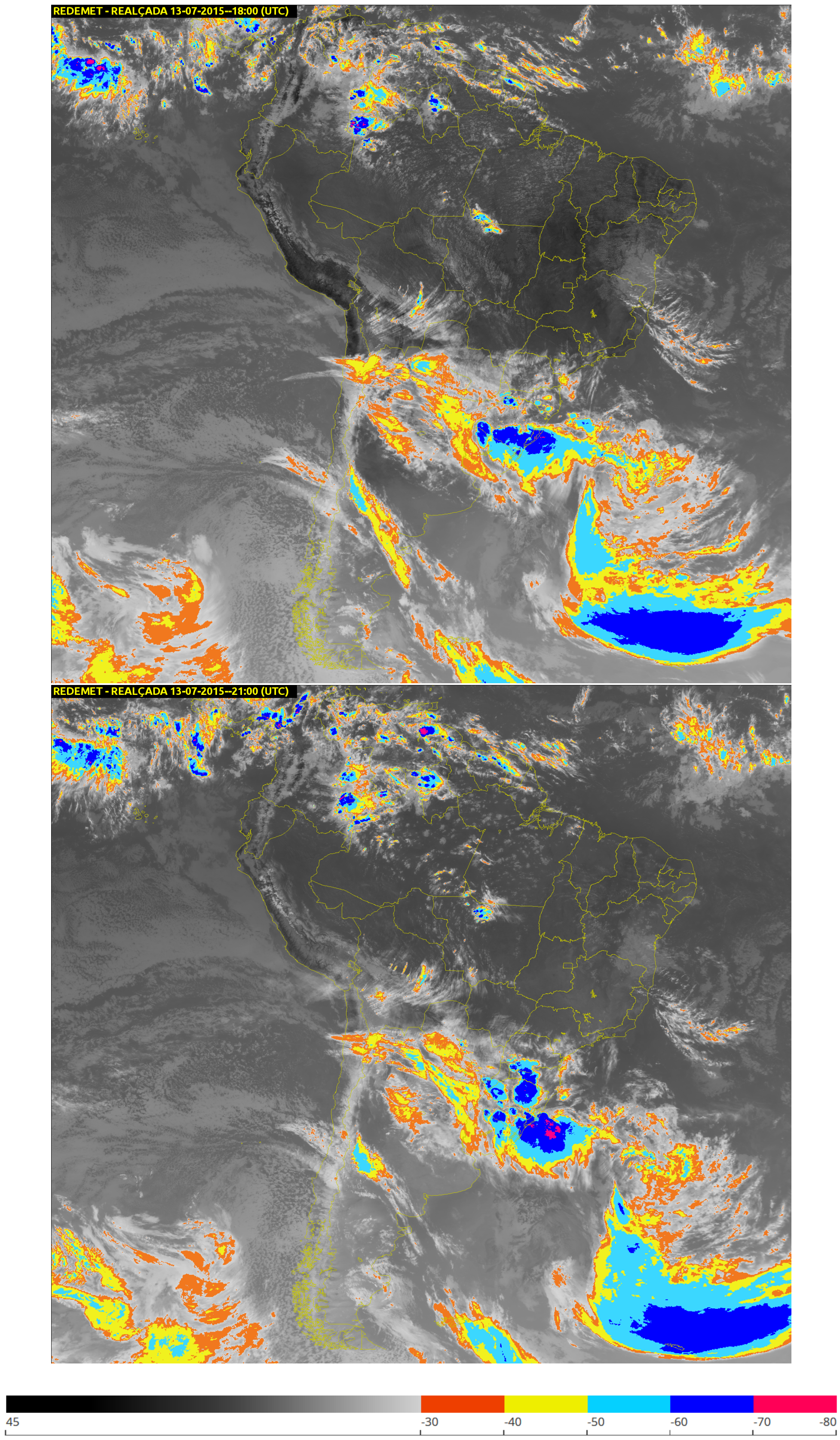

Figure 18. Following of two images taken by GOES satellite to the infrared spectrum enhanced, to the temperature of South America on July 13 2015, 18:00 and 21:00. [24]

9.3 Cafelândia e Nova Aurora

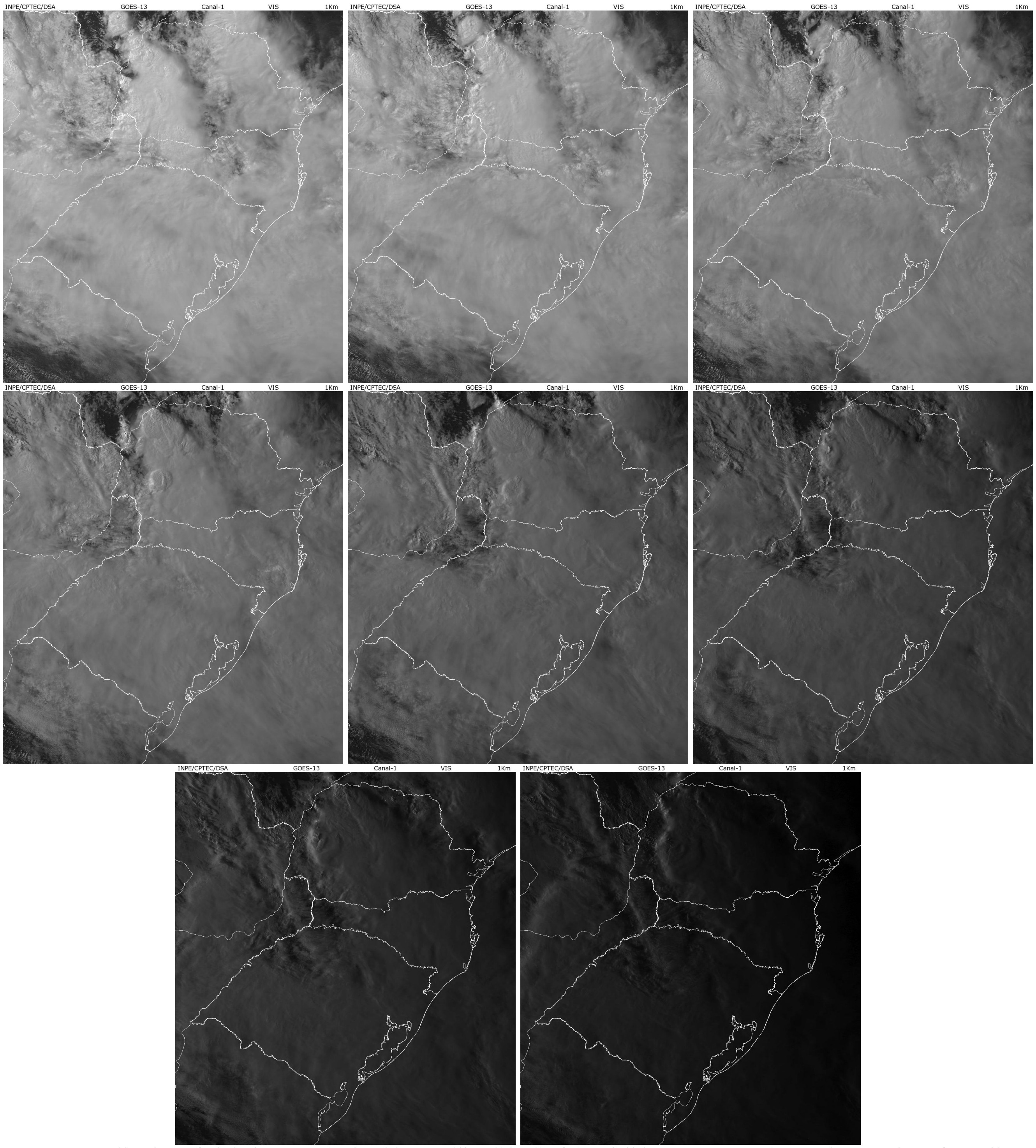

Figure 19. Following of eight images obtained by satellite GOES of the visible spectrum to the southern region of Brazil, on October 9 2015, from 17:30 to 21:00, with 30-minute intervals. [23]

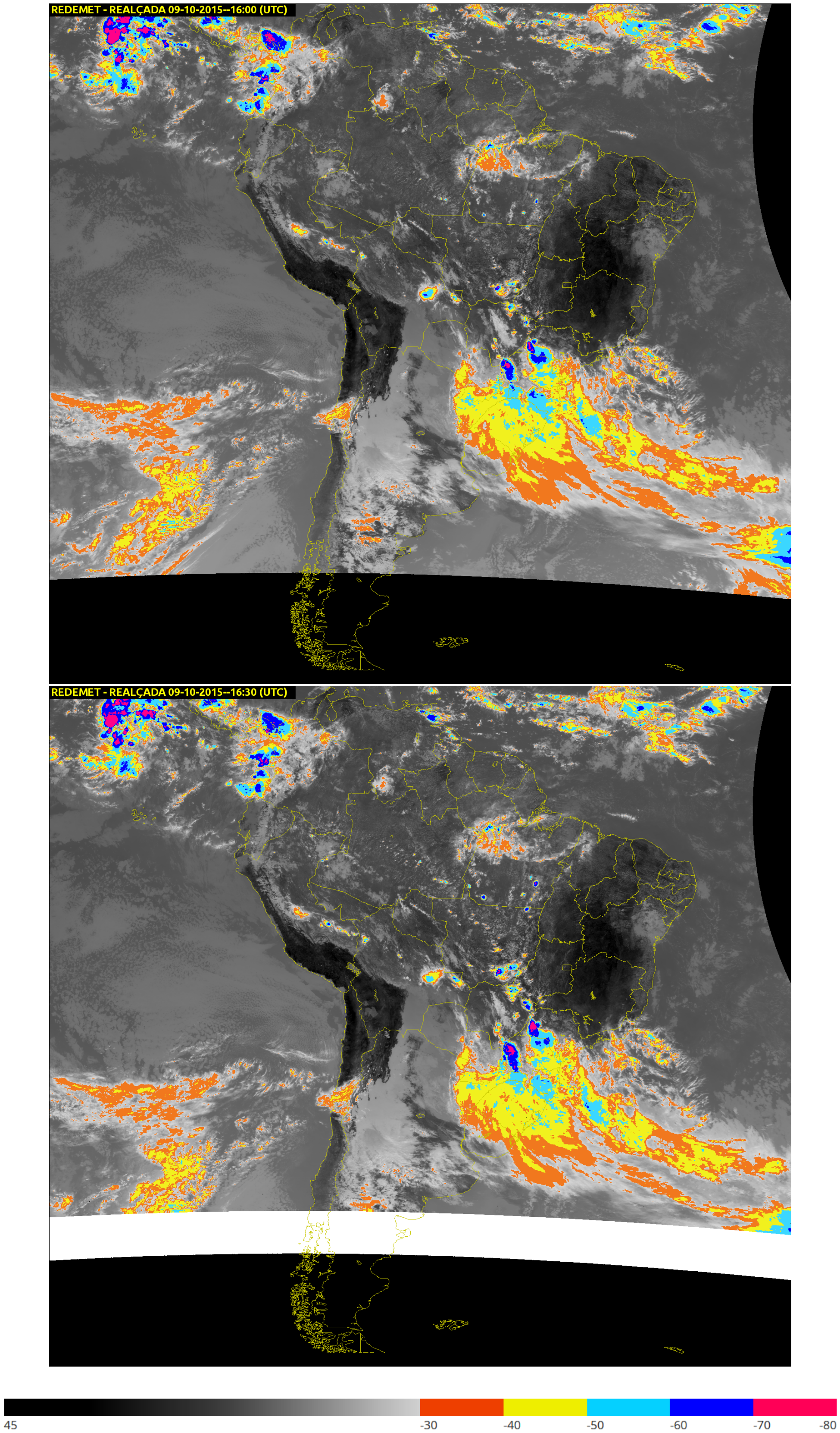

Figure 20. Following of two images taken by GOES satellite to the infrared spectrum enhanced, to the temperature of South America on October 9 2015, 16:00 and 16:30. [24]

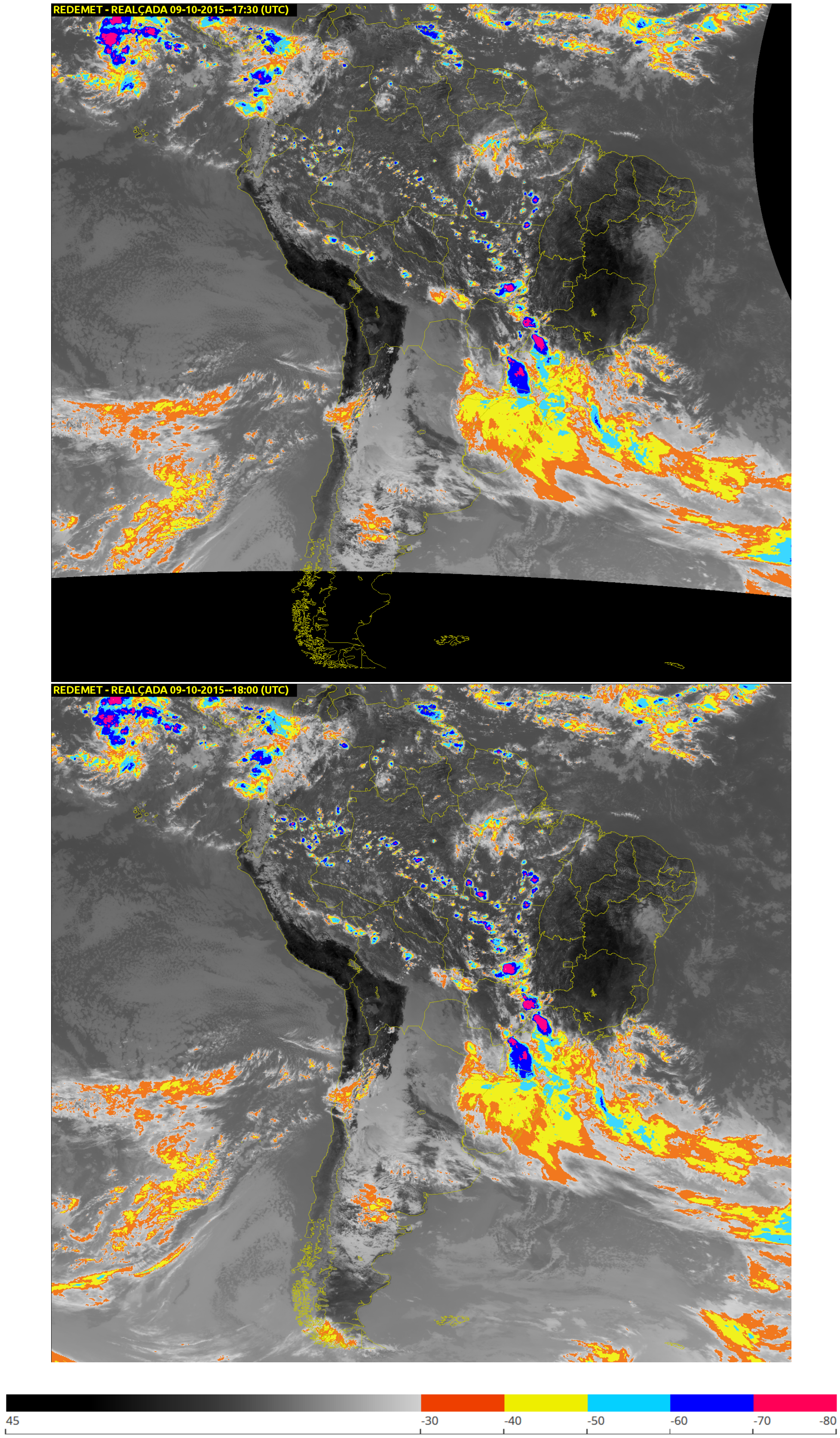

Figure 21. Following of two images taken by GOES satellite to the infrared spectrum enhanced, to the temperature of South America on October 9 2015, 17:30 and 18:00. [24]

9.4 Marechal Cândido Rondon

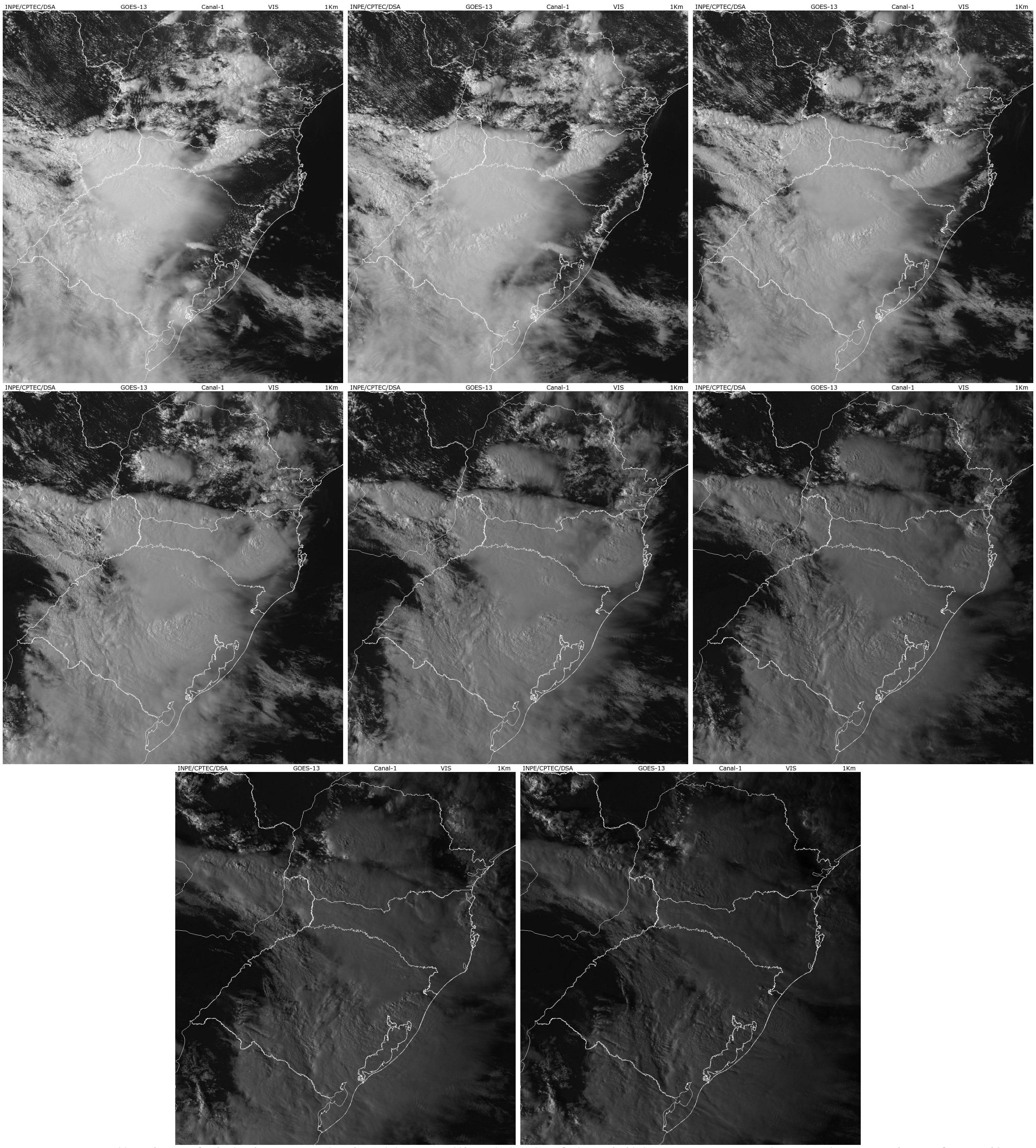

Figure 22. Following of eight images obtained by satellite GOES of the visible spectrum to the southern region of Brazil, on November 19 2015, from 17:30 to 21:00, with 30-minute intervals. [23]

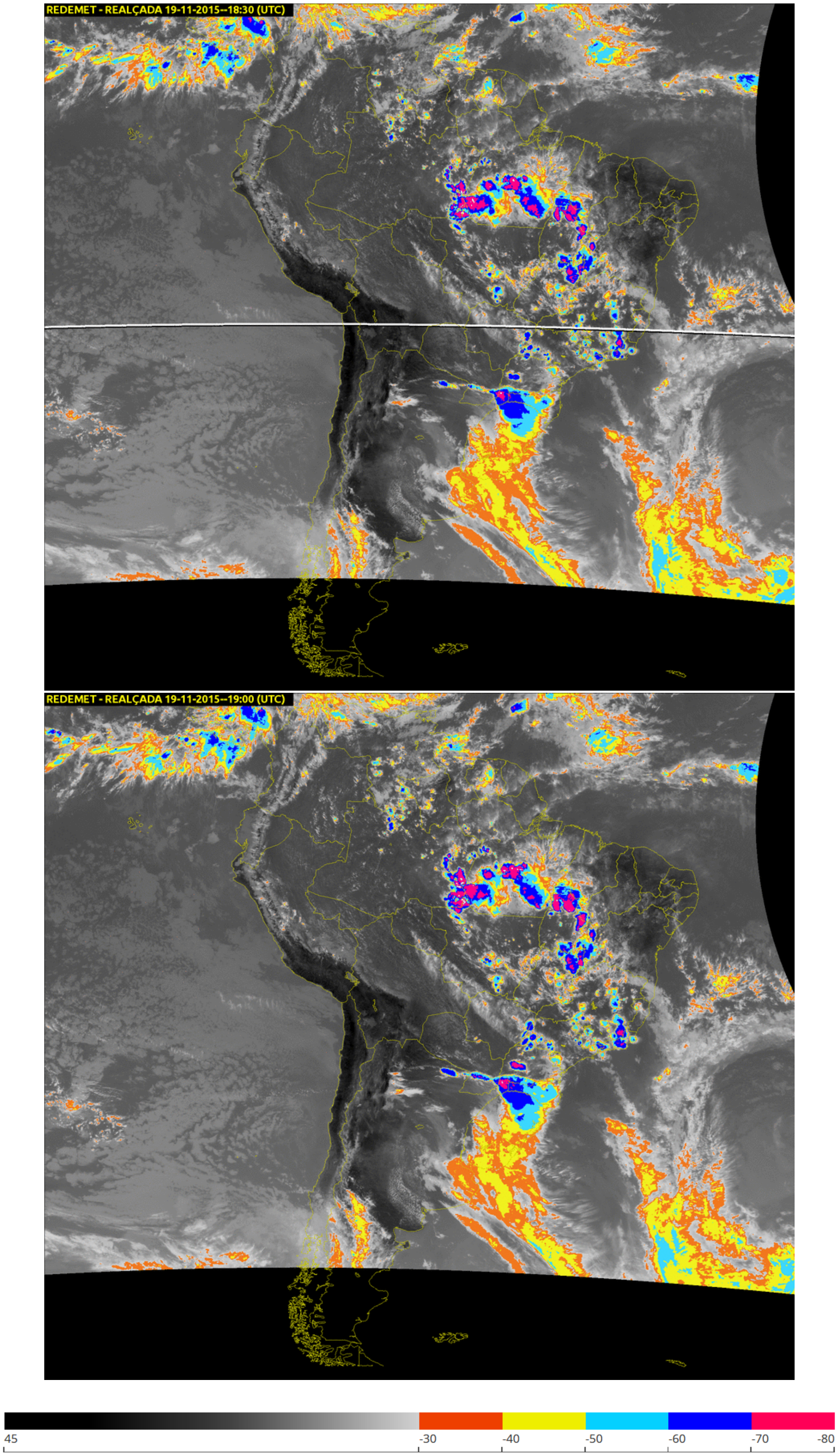

Figure 23. Following of two images taken by GOES satellite to the infrared spectrum enhanced, to the temperature of South America on November 19 2015, 18:30 and 19:00 [24]

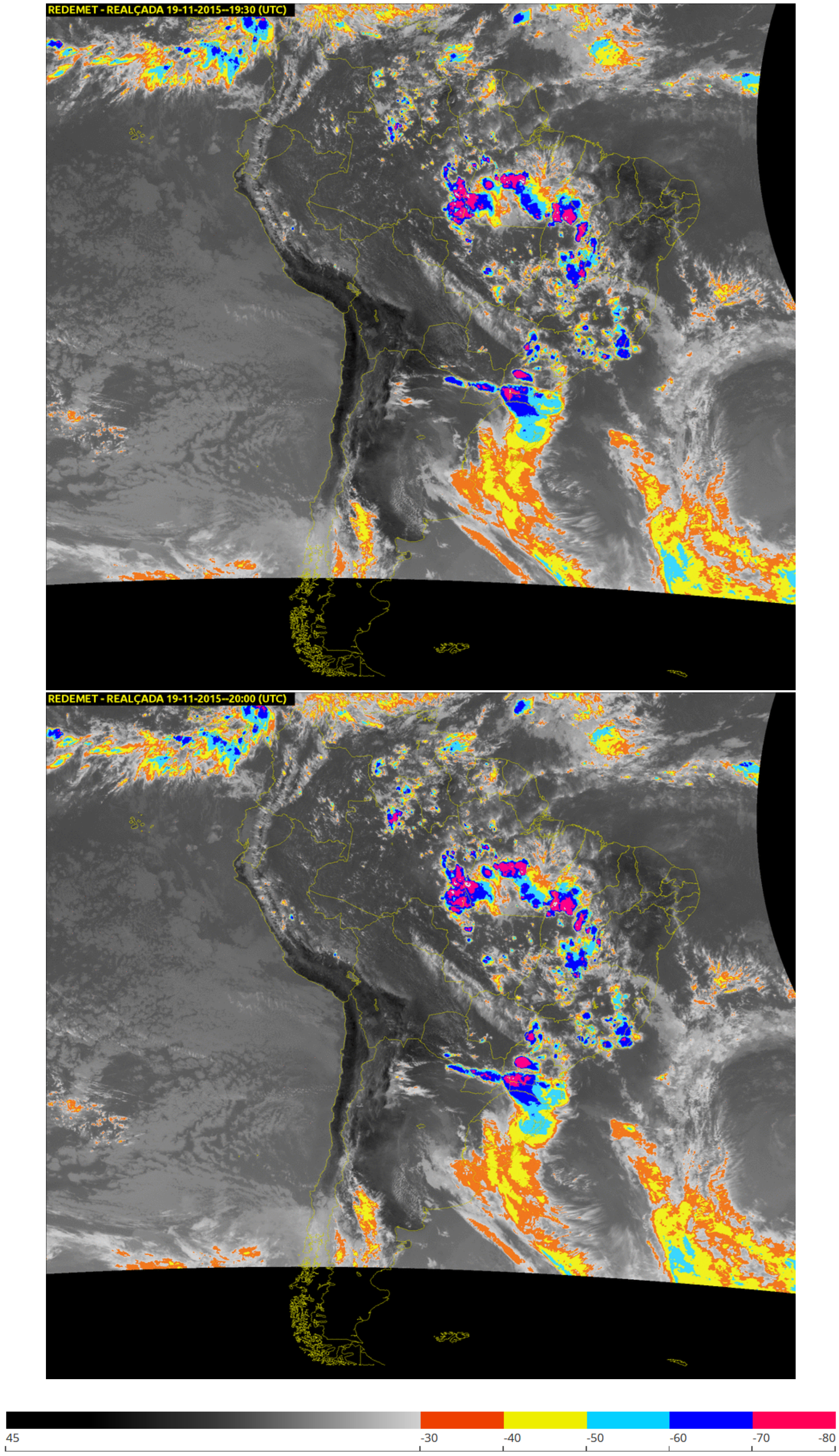

Figure 24. Following of two images taken by GOES satellite to the infrared spectrum enhanced, to the temperature of South America on November 19 2015, 19:30 and 20:00. [24]

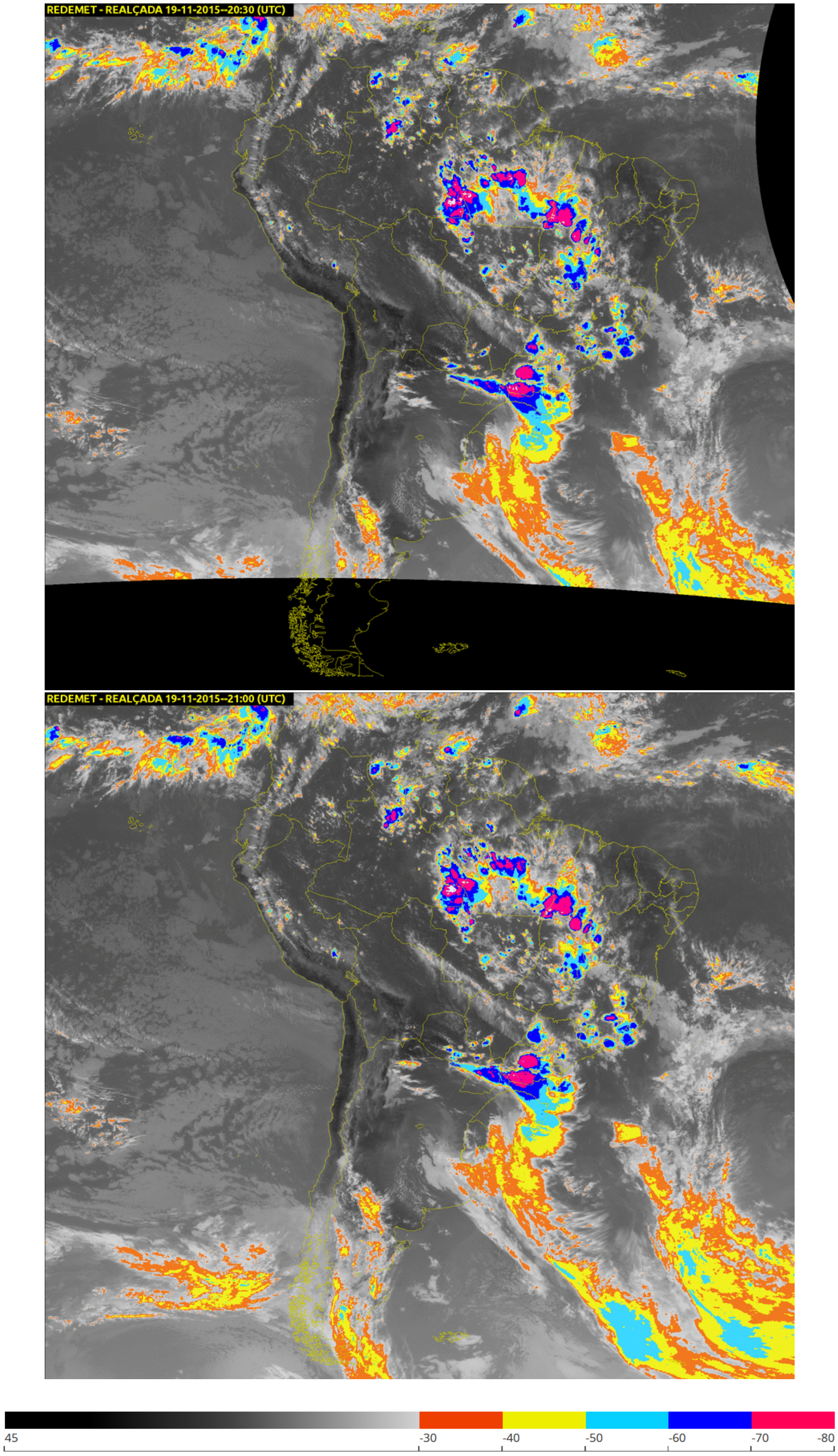

Figure 25. Following of two images taken by GOES satellite to the infrared spectrum enhanced, to the temperature of South America on November 19 2015, 20:30 and 21:00. [24]

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