PREPRINT

Prof. Dr. Luiz Adolfo de Mello

FLUENDO CRESCIT

UNIVERSIDADE FEDERAL
DE SERGIPE

A model to predict the movement of cold front in South America

Um Modelo Dinâmico para Prever o Movimento de Frente Frias na América do Sul

Prof. Dr. Luiz Adolfo de Mello
ladmello@ufs.br

Abstract – We propose a very simple physical model to predict cold front flow and penetration through the Brazilian Midwest. This physical model is based on eight hypotheses about the generation, dynamics and dissipation of cold fronts. Unlike dynamic models that rely on many parameters and numerical simulations, this model is a dynamic phenomenological model and only relies on information on average velocity and range of cold fronts. We use Google weather as a source of information, which in turn uses data collected by NASA satellites. We propose here that, in addition to the five air masses that operate in Brazil, we have to consider the existence of a stationary hot air mass in the central west of Brazil in the winter period and fires that act to curb the cold fronts that reach the center west . Through the accumulated data of the last twenty years it is possible to predict the braking force or deceleration of the cold fronts as it penetrates the Brazilian center west. This model is intended to provide information about the future of grain crops in the cerrado and in the wetlands (pantanal).

Resumo - Propomos um modelo físico muito simples para prever o fluxo e penetração de frente fria através do centro oeste brasileiro. Este modelo físico está baseado em oito hipóteses sobre a geração, dinâmica e dissipação de frentes frias. Ao contrário dos modelos dinâmicos que dependem de muitos parâmetros e de simulações numéricas, este modelo é um modelo fenomenológico dinâmico que só depende das informações da velocidade média e do alcance das frentes frias. Usamos como fonte de informação o Google weather que por sua vez usa dados coletados pelos satélites da NASA. Propomos aqui que, além das cinco massas de ar que atuam no Brasil, temos que considerar a existência de uma massa de ar quente estacionária no centro oeste brasileiro no período de inverno e de queimadas que atua no sentido de frear as frentes frias que chegam ao centro oeste. Através dos dados acumulados dos últimos vinte anos é possível prever a força de desaceleração das frentes frias à medida que esta penetra o centro oeste brasileiro. Este modelo pretende fornecer informações sobre o futuro das safras de grãos no cerrado e no pantanal.

INTRODUCTION

The relevance of studying the genesis, propagation and penetration of cold fronts (CF) across the continent lies in the fact that these are a source of transport and generation of rainfall over the continent. At the present time this is vital due to the fact that there is a sharp decline in the frequency and volume of rains in the southern hemisphere of the American continent. This decrease is much more accentuated in the winter period, between April and August, but it is also noticed in the rest of the year. The immediate consequences are the shortage of water in the dams, resulting in a shortage of drinking water in cities, lack of water for electricity generation in hydroelectric plants, lack of water for plantations, etc. Due to the fact that, in order to carry out two cereal crops in the center west, in the cerrado, we have that prolonged drought would cause crop failures with disastrous impacts on the economy and agriculture [Zavattini, 2009].

For decades scientists have been poring over the problem of understanding the dynamics and physical, astronomical and meteorological conditions that determine the seasonality of periods of rain and drought on the SA continent [Satyamurty, 1998]. There are some hypotheses and explanatory models for the possible causes of FF blockages [Rodrigues, 2004 and references] and humidity currents coming from the Amazon Forest [Rao, 1990; Rebound, 2010; Figueroa, 1990].

Let's make some definitions and approximations to create this model. A cold front (CF) does not have a well-defined shape. In general, this is an enormous mass of air generated in the vicinity of the south pole and that acquires different types of movements. Among these we have that its center of mass can move linearly. This can also rotate or spin in relation to some fixed point belonging to your body. In our study we are interested only in its linear displacement. The dimensions of the CF are enormous and, in general, they may be larger than the territory of Uruguay.

Due to the extremely powerful oceanic air currents that do not mix with the continental air currents, both from the Atlantic and from the Pacific, we have an imaginary corridor that directs the movement of FF over the South American continent (SA). When it is stationary over some southeastern region making an overlap with the ocean, after some time, ocean air currents split the FF into two or more parts. See figure below.

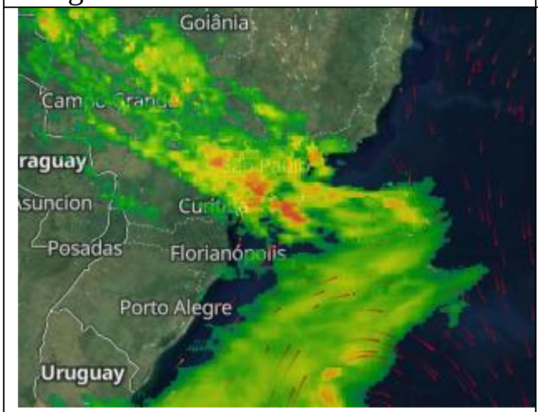
Imagem de Satélite em 10-09-21	Imagem de Satélite em 13-09-21
	

Figura 1 – Imagens de Satélite mostrando uma FF estacionada na região sudeste do Brasil e se separando devido as forças de convecção sobre o oceano Atlântico [Google Weather].

In order to be able to talk about surface of contact between a CF and a hot air mass and about forces between air masses we have to remember that different air masses when they come into contact do not mix. In the region between the two air masses portions of air heat up and others cool. Those that heat up acquire upward movement (up) and those that cool down descend and are incorporated by the hot and cold air masses respectively, causing a chaotic and turbulent movement in this region (wind). They fight each other, moving and pushing each other, in such a way that the one that advances with the greatest impetus makes the other go back. When a cold front advances over the continent, the cold air mass penetrates underneath the warm one and pushes it upwards, forming an inclined contact surface whose angle depends inversely on the propagation speed of the CF. See below figures 2 and 3. All these movements cause changes in the weather [CPTEC-INPE, 2021]. The contact or separation zone between two neighboring air masses is called FRONT. The contact surface between both air masses is like a huge, sloping, invisible membrane that extends from the ground to approximately 5000 meters in altitude. This separating surface is called the front surface. The front that is drawn on the maps is the line of intersection of the front surface with the ground. See reference [Varejão-Silva 2000, Vianello, 2000]

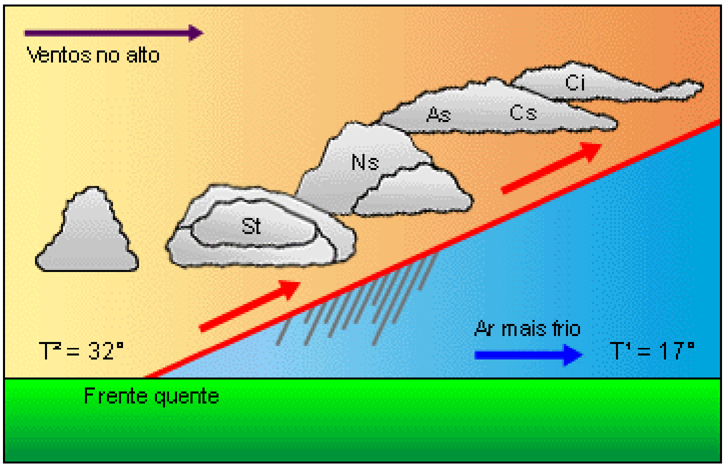


Figure 2 – Schematic model of the separation surface between a hot and a cold air mass.

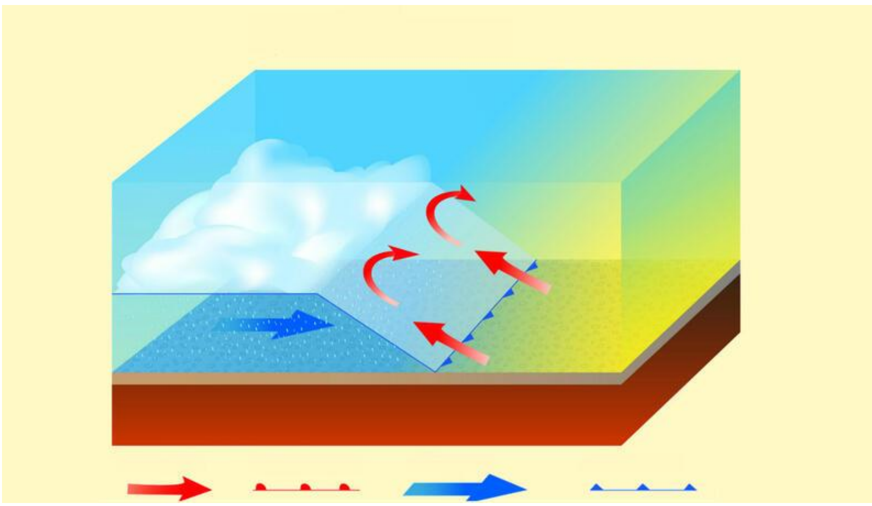


Figure 3 – Schematic model of propagation of a cold front with convection currents illustration.

Observing the evolution or entry of a cold front across the continent, in particular through Argentina, passing through Uruguay and then entering Brazil, we observe that it is rising (taking as a reference that the south pole is below and the north pole above[1]) from more or less uniformly way, that is, it presents a uniform movement (uniform velocity) until reaching the center-west region. In general, fast fronts can reach an average speed of up to 12 m/s, and their inclination can vary from 1º to 50º; for slow fronts that can reach an average speed of up to 7 m/s the inclination is from 1 to 100º.

In the year 2021 it was observed that the cold fronts entered the Brazilian territory with an average speed typical of the CF cataloged so far, but these ended up being parked somewhere below the 15º S parallel, causing one of the biggest droughts in history in the cerrado region and from MT. A possible explanation for this phenomenon would be the appearance of a stationary air mass during the winter season of the southern hemisphere on the Brazilian CO generated by excessive deforestation and fires. We will describe this phenomenological dynamic model below.

The information and data used here were taken from Google Weather [2021], Zoom Earth [2021] and CPTEC-INPE radar images [2021].

MODEL

Below we create a physical model based on eight (8) hypotheses, in the sense of the scientific paradigm created by Karl Popper (2005), which intends to phenomenologically describe the genesis, movement and dissipation of frontal air masses or FF.

Hypotheses

1 – The Cold Fronts are formed in some region between the South Pole and Patagonia.

2 – It will rearrange itself until it reaches the territory of Uruguay.

3 – It acquires an approximately uniform upward movement towards the Amazon.

4 – The translation movement in general does not depend on the dimensions of the CF.

5 – The oceanic air masses (from the Atlantic and Pacific oceans) create a corridor that directs the movement of the CF over the South American continent.

6 – The oceanic air masses (from the Atlantic and Pacific oceans) create a corridor that directs the movement of the FF over the South American continent.

7 - Deforested territorial regions create a warm air mattress that slows down the CF.

8 – In some region of the Southeast this is stopped and dissipated.

[1] Purely subjective criterion, as we can invert the referential.

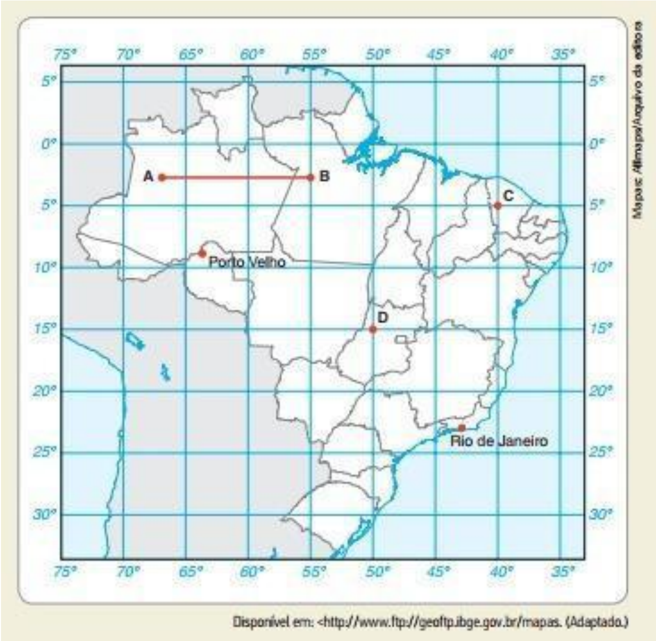


Figure 4 – Map of Brazil with latitudes.

The cold fronts we are interested in studying here are usually generated at the south pole and dynamic forces [Varejão-Silva 2000; Vianello, 2000] are pushed towards the continent. In this way they acquire two types of movement. A movement of rotation in relation to some axis belonging to it and a translation movement. In relation to the latter, CF acquires a linear moment defined by

$$P_{ff} = M_{ff} . V = d.(l.c.h).V$$

where d is the average density of air in the CF, l its width, c its length, h its height, and V its average velocity. Due to the fact that the humidity in the Amazon rainforest forms a damping mattress, see figure, the CF are braked and parked in the center west of Brazil. In this way, they undergo a deceleration ‘a’, that is, a deceleration force.

$$F = M_{ff}.a$$

Knowing the area of deforestation, fires and the average temperature over the last 20 years in the center west, it would be possible to correlate the F force with the deforested area. With this information it would be possible to estimate when the winter drought would be permanent in the CW with the respective winter crop failure. That is, it will be possible to predict the moment when this braking force will have sufficient intensity to prevent CF from reaching the wetlands and cerrado in the winter period.

RESULTS

For example, on 02/09/2021 a cold front approached the South American continent through Uruguay whose dimensions were 1300km by 1400 km and traveling at an average speed of ~7.2 m/s = 26 km/h. In the image below we see an approximately stationary mass of humidity on the continental shelf of Espírito Santo that has been stationary at this location for at least 3 days. We also see a stationary mass of moisture over the Amazon rainforest. On this day Buenos Aires had 94% humidity at a temperature of 14º C at 11:00 am. The next day (09/03) it was at a speed of 9 km and heading 71º East (~CM). This air mass remained stationary on 09/02/2021, the day of its formation or reorganization, and on 09/03/21 it began to ascend towards São Paulo at an average speed of 7 m/s (it walked approximately 1,200 km in 48 hours).

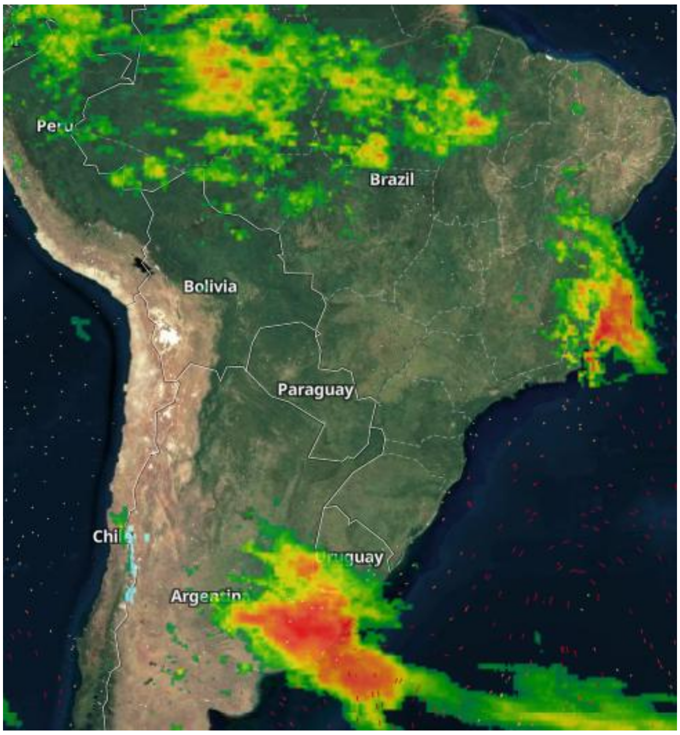


Figure 5 – Graphical animation of a cold front reaching the territory of Uruguay. [google weather]

This air mass remained stationary on the 2nd, the day of its formation or reorganization, and on the 3/09/21 it began to ascend towards São Paulo with an average speed of 7 m/s (walked approximately 1,200 km in 48 hours).

$$V = \frac{distance}{time} = \frac{1.200}{48} = 25\ km/h$$

In the next 30 hours this CF slowed down until it was stationary over the Mato Grosso do Sul region, displacing approximately 700 km. Note that it kept approximately the same shape and dimensions. So we can calculate its acceleration:

$$A = \Delta V/\Delta t = (0 - 25)/30 = -0{,}833\ km/h^2$$

This CF had an approximate mass of ρ.volume. Considering the average density of air equal to 1.2 kg/m^3, and dimensions of 1,200 x 1,300 x 5 → Volume = 7,800,000 m^3.

Therefore, mass = m = 9,360,000 kg

→ F = m.a = 7,796,880 ~ 8 x 106 N.

As this cold front was parked for more than two days over the same region until it dissipated, we can say that it suffered a deceleration and not dissipation in its path from the latitude of São Paulo to the latitude of Mato Grosso do Sul. The occurred dissipation was not the most important factor in the dynamics of its movement.

If we analyze the dynamics of propagation of CF over the last 20 years, we can verify if there is any correlation between rainfall levels in the south, southeast and central west of Brazil with frequency and reach of penetration of CF over the Brazilian territory.

It will be possible to predict the approximate time when the CW winter drought will be prolonged, resulting in the impossibility of having two harvests in the region. It will also be possible to estimate or project what would be the maximum area that could be deforested in the center west in order to guarantee a minimum rainfall frequency in order to guarantee two harvests in the region.

Conclusion

Through a simple model for calculating the deceleration force between the hot air mass parked in the CW and barred by the humidity of the Amazon forest was opened up the possibility of mathematically or dynamically predicting when CF failed to reach the Brazilian CW.

This model also allows us to estimate the minimum amount of forest that the CW should have to ensure that cold fronts reach it, and to predict how many crops we might have in the cerrado.

This model may explain the reason why CF and humid air layers do not penetrate desert regions or sparse forests.

With this model we will be able to predict the approximate deceleration and the approximate magnitude of the deceleration force that cold fronts suffer when they exceed the latitude of -23ºS over the SA continent. With this information it will be possible to estimate in which region of Brazil the CF will be stationary.

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