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Mathematical model of the convective behavior of climate variability applied to a cubic Hadley cell

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Abstract. - A mathematical model is presented to assess the impact of climatic anomalies and convective behavior on climatic variability at the Earth's surface, focusing on soil-atmosphere interaction. This model is applied within a control volume covering the Hadley cell, allowing for the verification of convective coupling and prediction of the effects of the studied climatic variation. The mathematical analysis delves into the soil-atmosphere interaction within the control volume, quantifying variations in water evaporation levels in bodies of water and soil, water vapor content in clouds, adiabatic gradient in the atmosphere, relative humidity, and condensation, taking into account average solar radiation. This developed model is a robust foundation for reproducing convective climate effects, pinpointing coupling forces, and validating models in local climate studies.

Keywords: Soil-atmosphere Interaction, Hadley cell, Climate variability, DECASAI.

Modelo matemático del comportamiento convectivo de la variabilidad climática aplicado a una celda cúbica de Hadley

Resumen: Se presenta un modelo matemático que aborda la influencia de anomalías climáticas y el comportamiento convectivo en la variabilidad climática en la superficie terrestre, con especial énfasis en la interacción suelo-atmósfera. Este modelo se aplica en un volumen de control que abarca la celda de Hadley, permitiendo la verificación del acoplamiento convectivo y la predicción del impacto de la variación climática estudiada. El análisis matemático se centra en la interacción suelo-atmósfera dentro del volumen de control, cuantificando la variación en los niveles de evaporación del agua en cuerpos de agua y suelo, la cantidad de vapor de agua en las nubes, el gradiente adiabático en la atmósfera, la humedad relativa y la condensación, considerando la radiación solar promedio. Este modelo proporciona una base sólida para la reproducción de efectos convectivos del clima, localizando la fuerza de acoplamiento y validando modelos en estudios climáticos locales.

Palabras clave: interacción suelo-atmósfera, celda de Hadley, variabilidad climática, DEACISA.

I. INTRODUCTION

Since MTC UNAM has recognized it as GLACE, the atmosphere, soil, and vegetation systems are dynamically related to the physical processes that generate the transfer of heat energy and water mass across the Earth's surface [1], as well as all processes and mechanisms of convection of atmospheric heat obey the physical laws of thermodynamics, this work is framed within the same principles and concepts.

This paper presents the mathematical model as a general development for comparing the consulted models' approaches to the atmosphere-soil-ocean interaction models and the one proposed. It shows the general methodology of the mathematical model named DECASAI in the control volume and its boundary conditions with the proposed equations. Finally, the results are presented with a case study to demonstrate the application of the relationship of the equations and quantification of the variation of the evaporation rate in a prolonged time of a climatic anomaly and Conclusions on which possibilities of lines of research of the climate change.

II. DEVELOPMENT

All processes and mechanisms of convection of atmospheric heat obey the physical laws of thermodynamics, and the interaction of these allows related mathematical equations to be formulated to study the soil-atmosphere interaction, focusing on the atmosphere as a heat engine. With this concept, it is possible to find a scientific explanation for the behavior of these effects and their relationship with climate variability. However, to date, the documentation consulted on the subject [2], [3], [4], [5], [6], [7], [8], [9], of the behavior applied so far, in the atmosphere-earth system focused on predictions and the history of the occurrence of climate variability as is the case of the models.

Atmospheric phenomena are strongly influenced by the distribution of topography and vegetation on the continent's surface. For this (climatic) model, the spatial configuration (domain: Continental and Regional) and the physics of the model and establishment of the boundary conditions and model equations, the latter being one of the objectives of this study. The physical processes considered were the surface flows between atmosphere-soil, soil hydrology, courses within the border layer, radiation, the physics of explicit humidity, deep convection, and clouds of little vertical development established within the troposphere.

A. Model definition

For the development and application of the model, the Hadley Cell [10], is taken as a control volume located within the tropics around the Equatorial zone. The climatic characteristics of the convergence zone intertropical (ITCZ) for the areas of the American continent and Monsoon for the African and Asian Continent. The representative developed model for this study is convective cells of air masses [11], and the influence of the hydrological cycle in a given region. Because atmospheric convection is often caused by variations in the temperature and humidity of the air near the surface, it is expected that convection is a phenomenon in the behavior between soil moisture and clouds.

For the boundary conditions of the control cube, the convergence of the trade winds is considered, considering the climatic anomalies as a case study of the ENSO (El Niño Southern Oscillation) phenomenon [12], [13]. Physical parameterizations, including temperature, wind speed, and variables, to study the relative influence of convection and soil hydrology aim to improve vulnerability studies of a particular region. The following considerations inside the Hadley cell are visualized for model definition purposes, as shown in Figure 1, including air flows over a water body air profile. In open spaces such as seas, rivers, and lakes, natural or artificial, such as dams, although generally accepted to be turbulent flows above surface waves, are not well known yet.

As infinitesimal waves are studied, it is an excellent approximation to consider mean flow profiles above flat plates [14]. The wind blows over the water's surface. The air viscous effects induce a shear velocity profile in the water. This effect is considered to generate boundary layers with high shear to develop immediately the air-water interacting zone. Consequently, this air-water interacting zone, not quantified in this work, is unstable, leading to small waves on the water surface. Friction stresses are not considered; neither is the Coriolis Effect nor air velocity.

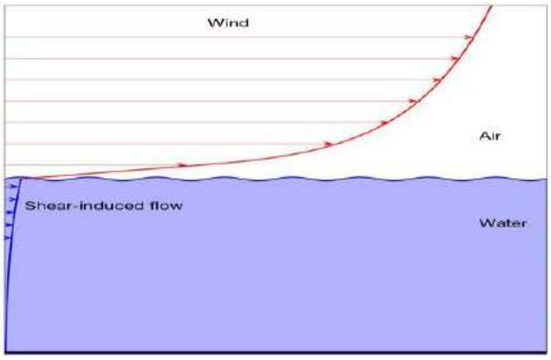


Fig. 1. Coupled shear flows. The air-water interface is unstable with the wind-blowing effect, and small water waves are grown in the wind-blowing direction [15], [16].

The theoretical study of the generation of water waves by wind relies on the hypothesis that the mean velocities and profile shape are in the turbulent air and the water interactive zone. Thus, it is regarded as a parallel shear flow, as shown in Figure 2.

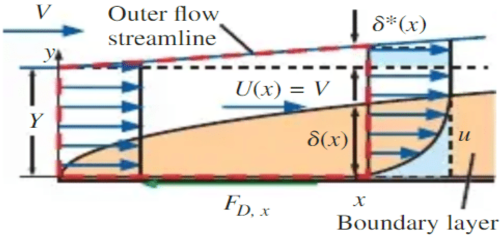


Fig. 2. Wind blow stream effect on a flat plate surface acting in the boundary layer [17].

Therefore, the velocity profile shape is considered as an independent variable. In the model application section, values concerning the mean flows used for air and water are given and used. These depend on the local environmental characteristics. In the present work, the model developed by van Driest is considered suitable for the case study analysis below. The analogy is made assuming the following aspects, as shown in Figure 3:

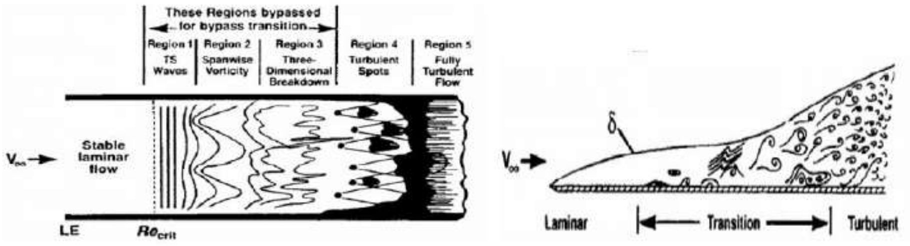


Fig. 3. Schematic of boundary layer transition with the different phases indicated. Copied from [18], [19].

The boundary layer displacement thickness $\delta *$, which quantification is not considered in this work, is given by:

$$\delta *(x) = 1.72x\sqrt{Rex} \quad (1)$$

The boundary conditions can be applied for flow over a flat plate, considering the soil surface layer of -5cm to 10cm above and establishing standardized soil porosity values.

III. METHODOLOGY

Considering thermodynamics, for the developed model, the thermodynamic and kinetic relationships of thermal imbalances in the atmosphere, as well as semi-empirical parameterizations. Viewing the data of the averaged climatic variables, the laws of hydrostatic balance and continuity equation, and the energy balance model.

A. *Experimental methodology of the DECASAI model development*

The methodology consists of establishing the control volume within the Hadley Cells as a reference base configuration and the boundary conditions or changes in the parameterizations used to evaluate the effects of said changes on the regional climatology. The first step is establishing the configuration of the domains, continental and topography, and the conditions inherent to the study area, its geographical and spatial location. The second concerns boundary conditions and the climatic data involved in each face of the assumed control volume. The third is the base configuration for the representation of the climatology of the area. The fourth is establishing the related equations following the thermodynamic and kinetic parameters.

The methodology is based on the logic to Determine Analysis and Method) the (DAM Pyramid) [20], starting with variables and assumed parameters, followed by the thermodynamic and kinetic laws and principles, the formulation of equations, the incremental relationship of the calculated effects, the validation of the results and their application to the real world with regards to ecosystems vulnerability.

B. *Model description*

The DECASAI model considers vertical winds, and the following variables are shown in Table 1.

Table 1. Meteorological variables considered in DECASAI.

Symbol	***Description***	***Unit***	***Symbol***	***Description***	***Unit***
Tg	Air Temperature	*°C, °F, °K*	r	Local Radiation	*W/m^2*
Ta	Water Temperature	*°C, °F, °K*	H	Local Soil Moisture	*%*
Te	Temperature Anomaly (Enso)	*°C*	Vv	Wind speed	*Km/h*
Tm	Medium temperature	*°C*	h	Reference Atmospheric Height	*mm Hg*
pa	Atmospheric pressure	*Kpa, Atm, mm Hg*	L	Length Traveled For Wind	*cm*
Pvs	Water/Soil Vapor Pressure	*mm Hg*	A ca	Body of Water Area Volume of water	km^2
Pva	Water/Water Vapor Pressure	*mm Hg*	Va	Volume of water	m^3
Vl	Specific Volume of Liquid	*cc/g, cc/mol*	Ab	Bio diverse Area	km^2
Q	Water Flow Bio diverse Area (biomass)	m^3/s	t	Anomaly Duration (Enso)	*months*

Source: Author

The characterization of the system includes part of the parameters used in the predictive models, such as the value of the thermal anomaly detected in °C, wind speed of climatic anomalies (ENSO), the value of water vapor towards the clouds, relative humidity of the selected regions (vulnerable to its impact). The thermodynamic and kinetic characterization include the corresponding parameters, such as physical characteristics of the fluids involved (air, water, water vapor), characteristics and variations of temperature conditions with height and pressure of the atmosphere, characteristics of vulnerable affected soils and their relationship with the humidity necessary to maintain biodiversity, Affected areas that host water bodies of reservoirs and water basins, biodiverse areas considered as microclimates. Formation of water droplets, the behavior of relative humidity for precipitation, and the calculation of the amount of entropy exchanged between the air masses involved. Thermodynamics of Soils for the effect of water evaporation from the bodies of water considered and the impact of moisture evaporation from the associated soils.

To define the base configuration, it was necessary to analyze the patterns of meteorological variables, such as relative humidity, air temperature, atmospheric pressure at sea level, solar radiation, and wind speed. Commonly, these variables have a daily cycle associated with changes in the winds of the intertropical ZIT zone due to their location near the equator. The intensified trade winds of the studied control volume are also induced.

C. Initial and boundary conditions

The development of the model focused on the understanding of the Hadley cells, analyzed as a convective behavior at a height of 10km-20km (at the troposphere level). Studying this effect in more detail in the Equatorial zone, presenting the domains in dry and humid regions on spatial scales of 12km x 12km x 12km (see fig. 4a and 4b).

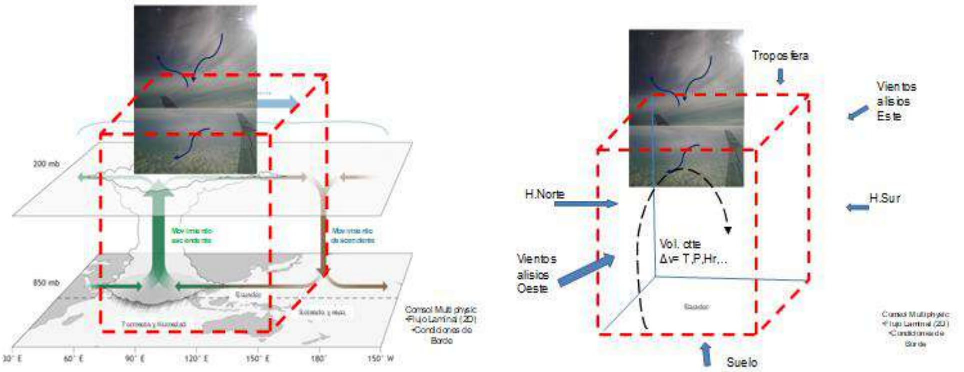
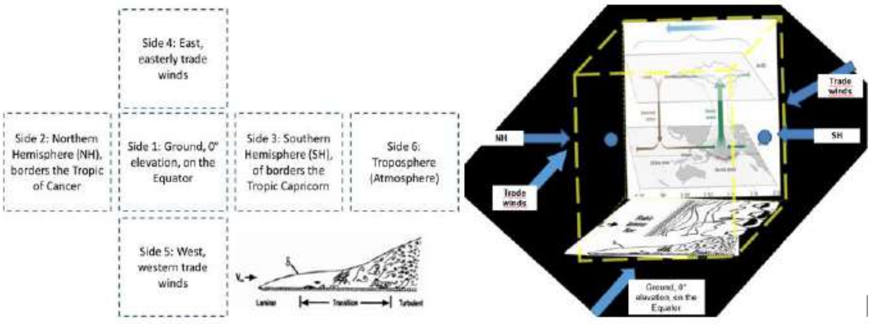


Fig. 4. Control volume (a) convection inside the Hadley cell; (b) Control Volume on the Hadley Cell. Source: Author.

From this control volume, the analysis was carried out during climatic anomalies such as drought or rain. Based on the Onsager model and theory, the convective aspect is incorporated into the control volume for simulation in three axes but oriented and limited to the interrelationships of the same variables within the control volume. The boundary conditions are analyzed from this control volume (Fig. 5a, 5b). Based on the model, the presence, effect, and direction of the characteristics of the six faces of the presented cube are shown.



(a) (b)

Fig. 5. Control volume (a) Control volume sides (b) Control volume established over the Hadley cell.
Source: Author

D. DECASAI geographic characteristics

The geographic information in the model and relevant meteorological meshes. These parameters are the size of the body of water (reservoirs, lagoons, dams); Biomass size (surrounding area where that body of water is located); Height above sea level (msnm); Annual average of soil temperature (it is considered that the diurnal cycle does not affect variations in soil temperature, it is assumed constant); Solar radiation (Albedo is not viewed as it is a secondary parameter that depends on land use); Wind speed (average speed under normal conditions and with anomalies-ENSO, Monsoon, among others).

E. Technical characteristics

Surface temperature; speed and direction of zonal and southern winds; Vertical wind speed and direction (m/s); Configuration of 2 domains (Continental, Regional); Surface temperature (°C, °K, °F), airflow speed, assumed about 20km/hr-22km/hr, to Northern Trades, >117km/hr as a Tropical storm.

The equations involved in the DECASAI model are the following:

F. Water bodies evaporation

Water evaporation is calculated in water bodies with increasing entropy as uncompensated energy. For this purpose, the Nusselt number (Nu) was used to measure the increase in conductive heat transmission with Nu = Nusselt number (dimensionless number); h= convection heat transfer coefficient (W/m^2K); L = characteristic length with the default value L= 1; k= thermal conductivity coefficient of the fluid (W/m.K). In the case of flat plate forced convection in laminar flow, at a distance x downstream of the plate edge, it is given by the Nusselt number represented as the function of the Reynold number (Re) and the Prandtl number (Pr), Ʊ= viscosity of air (cc/sec), in a simple way, $Re < 5 \times 10^5, Pr > 0.6$.

$$Nu = \frac{\mathrm{hL}}{\mathrm{k}} = \mathrm{f(Pr, Re)} = 0.332 * Re^{1/2} * Pr^{1/3} * \text{Ʊ} \quad (2)$$

The obtained Reynolds number is for turbulent flows, ρ= fluid density, L= length (cm), Sa= air volume (m/sec), v= air speed (m/sec), being: ρ= density of atmospheric air at water level 15°C=1225 kg/ m 3; Prandtl number "Pr" (dimensionless number) is taken Pr air = 0.71; α = thermal diffusivity heat transfer coefficient, Ʊ= moment of diffusivity, Ʊ= viscosity of air (cc/sec), The water vapor pressure above the ground (Pvs) reaches the atmospheric pressure at sea level at 760 mmHg.

$$\frac{\mathrm{Pvap}}{\mathrm{water}} = \mathrm{Pvv} = 0.2473 * \frac{\mathrm{Pv}}{0.113} \quad (3)$$

The volume occupied by air at the temperature of T_o=273.15°K is V_o=3.95.At, at this temperature, it is assumed that the amount of water vapor is minimal. We have P_v= water vapor pressure= 4.44 (gr/cc) and T in [K]. The viscosity ratio (Ʊ)/Diff) is deduced from,

$$\frac{\mho}{Diff}\left(\frac{cc}{s}\right) = Hr(\%)/Tair(°C) \qquad (4)$$

The mass transfer coefficient (hp) relates the rate of mass transfer, the mass transfer area, and the change in concentration,

$$\mathrm{hp} = \left(0.664 * (\mho)/\mathrm{Diff})^{1/3} * Re^{1/2}\right) \qquad (5)$$

Where (Ʊ)/Diff= air viscosity ratio (cc/sec), Re= Reynolds number. Constitutive laws of matter in equilibrium, the law of Ideal Gases. They relate the dependent variables to the independent ones. Where: P= absolute pressure (measured in atmospheres), V= volume (expressed in liters), n= moles of gas, T= absolute temperature, with a molar mass for air M= 0.029 kg/mol, R= constant universal of ideal gases (0.082 atm.L/mol.K), R = Ru, M = 287 (J/kg.K), with the universal gas constant Ru = 8.314 (J/mol.K). Convection arises naturally in the atmosphere. This process is governed by the Ideal Gas Law, which describes the relationship between the pressure, volume, temperature, and quantity (in moles) of an ideal gas such that the amount of evaporated water (ECwater) given in gr/h.\ m^2, would be:

$$\mathrm{EC_{water}}\left(\frac{\mathrm{gr}}{\mathrm{h}\ m^2}\right) = \mathrm{hp} * \frac{\mathrm{Pvv-Pv}}{0.082*(\mathrm{Tm}+273)} \qquad (6)$$

E(C water) expressed in m^3, t = anomaly time (hr), Vca = volume of body of water,

$$\mathrm{EC_{water}}\ (m^3) = \left(\mathrm{ECw} * \frac{\mathrm{Vol\ ca}}{10^7}\right) * \frac{t_{anomaly}}{10^{-5}}(hr) \qquad (7)$$

The effect of the anomaly on the body of remaining water would in m^3:

$$\mathrm{Effect}\frac{\mathrm{Enso}}{\mathrm{C}}\mathrm{w} = \mathrm{ECw}\ (m^3) + \ \mathrm{Evs}\ (m^3) \qquad (8)$$

And in this way obtain,

$$\%\, Water\ Evap\ = \mathrm{Effect}\frac{\mathrm{Enso}}{\mathrm{C}}\mathrm{w} * \frac{100}{Vca} \qquad (9)$$

G. Soil Water Evaporation

Water evaporation from the soil is important in the hydrological cycle due to its thermal regulatory role in the atmosphere and the loss of resources. Conditions assumed for the Evaporation of Water from Soils (Evsoil) and Water Vapor Condensation Temperature follow the pattern of Evaporation of water over bodies of water. The momentum conservation equations are applied to the entire porous medium, and not for each species or phase, in such a way that its result represents the behavior of the environment.

The same references are taken from the analysis of Equations (2) to (5), considering the soil conditions, where σ corresponds to the stress terms, ρ to the density of the porous medium, and g is the acceleration of gravity, at this temperature it is assumed that the amount of water vapor is minimal. Average Nusselt number = 2 * Local Nusselt number. Water vapor pressure above the ground (Pvs), reaches atmospheric pressure at sea level at a pressure of 760 mmHg.

Convection coefficient or surface transmission coefficient (h), quantifies the influence of fluid, surface, and flow properties when heat transfer occurs by convection, which is modeled €with Newton's Law of Cooling: Q=heat transfer by convection (W), h=film coefficient (W/m^2.K), A= Area of the body in contact with the fluid m^2, Ts= body surface temperature (k), T∞= Fluid temperature at a certain distance from the body $Q = h\,.A.(Ts - T\infty)$ (10).

Convection steam heat transfer coefficient (hv)= 6000 – 15000 W/(m^2 °C)= [1057 - 2641 Btu/(hr-ft^2 °F)]=0.02422(Cal/h. cm^2.°F); Vt= Total volume, Vp= Volume occupied by pores, Vs= Volume occupied by solids, Vw= Volume of water, Va= Volume of air, Ms= Mass of solids, Mw= Mass of water.

$$\text{Water density} = Dw = \frac{Mw}{Vm} = 1\ g/cc \qquad (11)$$

$$\text{Actual soil density} = Dr = \frac{Ms}{Vs} 2.65\ g/cc \qquad (12)$$

$$\text{Soil porosity} = \phi = \frac{Vp}{Vt} = 1 - \frac{Da}{Dr} \qquad (13)$$

It is assumed that the Air Pressure Pa (g/cc) = 254, the water and air temperature Ta, Tg respectively, Soil Density ρs (g/cc) = 2.2; Soil Porosity = 5 (sandy loam soil), Humidity of floor %. The weight of soil solids (g) without pores per unit volume (cc) varies from 1.3 to 1.7 g/cc in sandy soils and from 1.1 to 1.4 g/cc in clay soils, ranges from 2.6 to 2.7 g/cc in most mineral soils averaging 2.65 g/cc textural. The formula can calculate the porosity ϕ of the soil:

$$\text{Porosity} = \phi = 100 - \left(\frac{1 - \text{Bulk density Db}}{\text{particle density Dp}}\ x\ 100\right) \qquad (14)$$

This process is also governed by the Law of Ideal Gases, which describes the relationship between the pressure, volume, temperature, and quantity (in moles) of an ideal gas so that the amount of water evaporated above the soil (EC water-soil) given in gr/h. m^2, would be:

$$\text{ECw} - \text{s}\left(\frac{\text{gr}}{\text{h}\ m^2}\right) = \text{hp} * \frac{\text{Pvs} - \text{Pv}}{0.082 * (\text{Tair} + 273)} \qquad (15)$$

Where hp= transfer coefficient, water vapor pressure above the ground Pvs=6.28; Vapor pressure Pv(g/cc) =4.42; Air Temp °C. The soil humidity (gr/cc) is taken into account, comparing it with Soil humidity % (data from the region under study)

$$\text{H s}\left(\frac{\text{gr}}{\text{cc}}\right) = \frac{\text{Ds}\left(\frac{\text{kg}}{\text{cc}}\right) x\ \text{Vol.V air \%}}{100}\ x\ 18 \qquad (16)$$

E(C water) expressed in m^3, t = anomaly time (hr), Vca = volume of body of water.

$$\text{ECwater} - \text{soil}\ (m^3) = \left(\text{ECwater} - \text{soil}\left(\frac{\text{gr}}{\text{h}\ m^2}\right) * \frac{\text{Vol ca}}{10^7}\right) * \frac{t_{anomaly}}{10^{-5}} (hr) \qquad (17)$$

The effect of the anomaly on the body of water would remain m^3:

$$Effect \frac{\text{ENSO}}{\text{C}} \text{w} = \text{ECw}\ (m^3) + \text{Evs}\ (m^3) \qquad (18)$$

And in this way obtain

$$\%\ Evaporated\ Water - soil\ = Effect \frac{\text{ENSO}}{\text{C}} \text{w} * \frac{100}{Vca} \qquad (19)$$

H. Water vapor in the clouds

Water vapor condensation temperature, assumed conditions: a) between 11 and 25 km altitude the temperature does not depend on the altitude. b) Air as an ideal Gas, Height (h) m=1500, Molecular Weight (M) gr/mol=28.96; Air Temperature °C (To)=100; q vap H2O J/g=2257.104; H2O Vapor Density (kg/m^3) = 0.5977; Po Sea level kPa (J.m) =101 or 760mmHg; g (m/s)=9.81; Density Liq. water (kg/m^3)=958.31; R=0.082; T=anomaly temperature (°C)>38. The following calculations were carried out as follows,

$$dp = Dair - h\ x\ g\ x\ dh \quad (20)$$

Ideal gas then

$$ph = \left(R * \frac{T0}{M}\right) * P(h) \qquad (21)$$

$$dp/p\ = -(\frac{M}{R} * T0)\ dh \qquad (22)$$

Thus, after integration

$$p(h) = p(0) * e^{\left(-\frac{h}{h0}\right)} \qquad (23)$$

$$ho(km) = R.\frac{To}{M}.g \qquad (24)$$

Applying Clausius-Clapeyron Equation

$$\frac{dp}{dt} = \frac{A}{Tevap} \qquad (25)$$

$$A\left(\frac{j}{m^3}\right) = q\frac{Vap}{\left(\frac{1}{Dv}\right)-\left(\frac{1}{Dl}\right)} \qquad (26)$$

Then combining equations

$$d \ln Tev\ \frac{dp}{A} = -\left(\frac{po}{A} * ho\right) e^{\left(-\frac{h}{h0}\right)} dh \qquad (27)$$

$$ln\ \left(\frac{To}{Th}\right) = \left(\frac{po}{A}\right) * e^{\left(-\frac{h}{h0}\right)} - 1 \qquad (28)$$

I. Radius of water droplets in vapor cloud

A drop of water of radius r in equilibrium with its vapor in a cloud, at a given temperature T, with an internal pressure P1 and the vapor around it Pv.

Ec. Laplace $P^{º}1 - Pv = \frac{2Υ}{r}$ (29)
Ec. Kelvin $Pv = P^{º}v\ exp\ (2Υ.Vl.\frac{M}{R}.T)$ (30)

Considering air saturated >100% so that the drop can form and rain, drops with r<rc evaporate and when r>rc grow by condensation on the surface of the droplets.), P°v= vapor pressure of the liquid assuming a flat surface (r approx. infinite), Vl = specific volume, M= Weight/molecular mass. It seeks:

a) Represent $Pv = f(r)ΥT = 20\ ºC$ (31)
b) Estimate the radius of water drops $r = 2Υ.\frac{Vliq}{rt} ln\acute{Ø}$ (32)

$$r\ (nm) = (2\ .Υ\ .\left(\frac{N}{m}\right)Vl\ \left(\frac{cm3}{g}\right)\ .\frac{\frac{M}{R}*(T + 273.25)*LN\left(\frac{Pv}{P}{º}v\right)}{100} \qquad (33)$$

J. Adiabatic Gradient of the atmosphere

It is assumed that within the control volume, there are adiabatic processes to calculate the Adiabatic Gradient of Air (Y), rescuing the thermodynamic evolution formulated by Clausius (1860).

Applying Clausius-Clapeyron Equation

$$Ln\frac{P}{Po} = (\frac{1}{To} - \frac{1}{T}) \quad (34)$$

$$\frac{\mathrm{dp}}{\mathrm{dt}} = \frac{\mathrm{A}}{\mathrm{T}}\mathrm{evap} \quad (35)$$

$$\mathrm{A} = \mathrm{q}\frac{\mathrm{Vap}}{\left(\frac{1}{\mathrm{Dv}}\right) - \left(\frac{1}{\mathrm{Dl}}\right)} \quad (36)$$

Being A (J/m^3), then combining equations

$$\mathrm{d}\ln\mathrm{Tev} = \frac{\mathrm{dp}}{\mathrm{A}} = -\left(\frac{\mathrm{po}}{\mathrm{A}} * \mathrm{ho}\right) * e^{\left(-\frac{h}{h0}\right)} dh \quad (37)$$

$$\ln\left(\frac{\mathrm{To}}{\mathrm{Th}}\right) = \left(\frac{\mathrm{po}}{\mathrm{A}}\right) * \exp - \left(\frac{\mathrm{h}}{\mathrm{ho}}\right) - 1 \quad (38)$$

Below 11km, Using Mayer's Relation and Clapeyron's Equation

$$(\Upsilon) = -\frac{\mathrm{dT}}{\mathrm{dh}} = \mathrm{M}\frac{\mathrm{g}}{\mathrm{Cp}} \quad (39)$$

Variation of pressure as a function of height

$$\left(\frac{\mathrm{P}}{\mathrm{Po}}\right) = \left(1 - \Upsilon.\frac{\mathrm{h}}{\mathrm{To}}\right)\mathrm{e}^{(\frac{cp}{R})} \quad (40)$$

With the help of an optimization tool (DECASAI) in MS. EXCEL®, the °F and °C values are obtained that minimize the relative errors of both the saturation pressures along the Calculations applying the equations (2)-(40).

K. Thermodynamics as an Unbalanced System

For this study outside of equilibrium, the Onsager relations are proposed, as they are closely connected with the detailed equilibrium principle and followed by the linear approximation near equilibrium. Consider new variables defining the gradients or thermodynamic forces and the flux densities that are dual to the forces of the quantities specified in the Onsager reciprocity relations. From the above, it is obtained that:

$$\sigma = \sum_i J_{ij}\frac{\partial F_i}{\partial X_i}\frac{\partial F_j}{\partial X_j} \quad (41)$$

Where: σ = entropy creation rate, Jij= small flows, Fi, Fj= thermodynamic forces (very slowly), linearly related to the flows, and associated with the gradient of the forces, parameterized by a symmetric matrix of positive coefficients denoted by L, known as the Onsager reciprocity relationship.

IV. RESULTS

A. CASE STUDY: Analysis of the Meteorological Event Related to the 2017 Drought in Guri Dam-Venezuela

In this case, the largest dam in the country for generating electrical energy strongly depends on the water basins of the south, such as the Caroní River and Caura. El Niño is the reason for understanding the phenomenon itself analyzed from the thermodynamic and transport phenomena point of view. Between 2016 and 2017, The Niño anomaly caused damage to the hydroelectric generation of the country Venezuela. For the application of the model, the following parameters and values are taken (see Table 2).

Table 2. Thermodynamic variables of the system.

Symbol	Description	Unit	Values	Symbol	Description	Unit	Values
Tg	Air Temperature	°C	35	H	Local Soil Moisture	%	0.126
Ta	Water Temperature	°C	27	Vv	Wind speed	Km/h	8
Te	Temperature Anomaly (Enos)	°C	38	h	Reference Atmospheric Height	mm Hg	1500
p	Atmospheric pressure	Kpa	101	L	Long Course for the Wind	cm	100
		Atm	1	A	Body of Water Area	Km^2	3990
		mm Hg	760	Vol	Water Volume of the body of water	m^3	$1{,}10^8$
Pva	Water/Soil Vapor Pressure	mm Hg	6,28	A	Biodiverse Area	Km^2	5.77^{11}
Vl	Specific Liquid Volume	cc/g	1.042	Q	Water Flow Biodiverse Area	m^3/s	4000
Vl	Specific Liquid Volume	cc/mol	18	t	Anomaly Duration (Enso)	months	4
r	Local Radiation	W/m^3	1387				

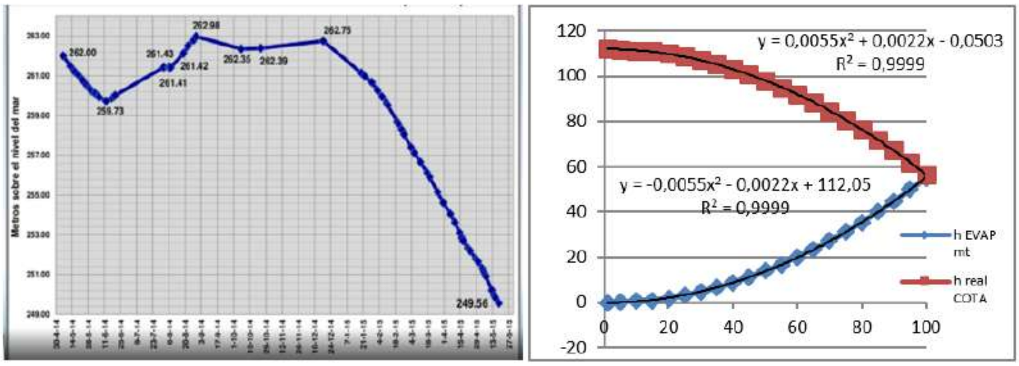
Source: Author.

As a result of the model application, the following results were obtained, as shown in Table 3.

Table 3. Results of the DECASAI Model applied in Gurí Dam-Venezuela.

Parameters	Unit	Results	Parameters	Unit	Results
Water Removal/Body of Water	g/h m^2	19,01	Relative Humidity Air	%	83.33
Water/Soil Removal	g/h m^2	31.73	Activation Energy for Droplet Formation	$J * 10^{-18}$	20.27
Temperature Steam Water Clouds	°C	96.19	Entropy	Cal/mol	17.346
Circuit Temperature Convective Mixture Enso	°C	22.16	Final Soil Moisture	gr/h. m^3	2.18
Ambient Temperature Mixing at Height	°C	7.4	The volume of Water Removed Body of water	m^3	21.846.482
Estimated Soil Temperature	°C	32.6	Volume of Water Removed Biodiversity	m^3	52.731.393
Drop Radius	nm	9.24	% Water Removed(+)	%	30.18
Critical Drop Radio	nm	4.60			

Source: Author



(a) (b)

Fig. 6. Guri Reservoir (a) Guri Reservoir Level Identification Curve 2015 (msnm), (b) Amount of water removed in the Guri Reservoir (blue) and Perception of the flow Q of the reservoir. Source: Author.

CONCLUSIONS

1. The developed model, based on the approach of deductive analysis, allowed the understanding from a thermokinetic point of view of the behavior and possible forecast of the dynamic conditions of the soil-atmosphere, during the occurrence of atmospheric anomalies.
2. The model allows the assessment of the effects on the meteorological, agricultural, hydrological, and social vulnerabilities and manages the water resources of the studied microclimates, located within the Hadley cells, considered as a control volume.
3. Because the evaporation itself is subject to various atmospheric processes, including solar radiation and turbulence processes, the inclusion of these processes required considering a control volume that covered an important fraction of the soil and at its time a strip of up to eleven kilometers of the atmosphere.
4. Due to the previous conclusion, the mass, momentum, and energy conservation equations were considered, and applied to the lower atmosphere and specifically to the atmospheric boundary layer, considering the soil-water water removal equations, since these allow the evaporation process, in which DECASAI model works.

RECOGNITIONS

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