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Analysis of Meteorological Data for La Selva Station by Applying the Biotic Pump Theory

Análisis de datos meteorológicos para la estación de La Selva aplicando la teoría de la bomba biótica

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Abstract

This work sought to analyze the relationships among the atmospheric variables reported daily by the La Selva biological station, which is located on the mountain slopes of the Costa Rican Caribbean, covering 1614 hectares of tropical humid lowlands, through the biotic pump theory developed by Anastassia Makarieva and Victor Gorshkov, which states the importance of the participation of los forests during the process of generating winds in the intertropical convergence zone, being a dynamic and vital factor for the permanence of the hydrological cycle that fulfills the mission of delivering rains to the interior of the continents. In the biotic pump theory, Makarieva and colleagues postulate that the high rate of evapotranspiration is maintained by Tropical rainforests throughout the year and it gives way to a net force, which results from changes of the partial pressure of water vapor. These changes have a double element: first, the partial pressure of water vapor and, second, condensation. Upon combining these elements, temperature is reduced with altitude and the liberation by the vegetation of cloud condensation nuclei (CCN). The end result of the theory is a water vapor pump from the vegetation, through evapotranspiration onto the atmosphere, followed by condensation, which leads to upward acceleration, hence, on the vertical plane of the lower air mass. This work established the relationships among the thermodynamic variables insinuated by the biotic pump theory, using available information offered by La Selva station.

Key words: Biotic pump, evapotranspiration, forest, rainforest

Resumen

Este trabajo busca analizar las relaciones entre las variables atmosféricas que reporta a diario la estación Biológica de La Selva, ubicada en las faldas de las montañas del Caribe de Costa Rica, abarcando 1.614 hectáreas de tierras bajas húmedas tropicales, mediante la teoría de la bomba biótica desarrollada por Anastassia Makarieva y Victor Gorshkov, donde se manifiesta la importancia de la participación de los bosques en el proceso de generar los vientos en la zona de convergencia intertropical, siendo un factor dinámico y vital para la permanencia del ciclo hidrológico que cumple con la misión de llevar lluvias al interior de los continentes. En la teoría de la bomba biótica, Makarieva y sus colegas, postulan que la alta tasa de evapotranspiración es mantenida por los bosques húmedos tropicales a lo largo del año y da lugar una fuerza neta, que resulta de los cambios de presión parcial de vapor de agua. Estos cambios tienen un elemento doble; primero la presión parcial de vapor de agua y segundo la condensación, al combinar estos elementos reduce la temperatura con la altitud y la liberación de parte de la vegetación de núcleos de condensación (CCN, por su término en inglés). El resultado final de la teoría es una bomba de vapor de agua de la vegetación, a través de la evapotranspiración a la atmósfera, seguido por la condensación, que conduce a una aceleración hacia arriba, por lo tanto, en el plano vertical de la menor masa de aire. En este trabajo, se establecieron las relaciones entre las variables termodinámicas que insinúa la teoría de la bomba biótica, usando la información disponible que ofrece la estación La Selva.

Palabras clave: Bomba biótica, evapotranspiración, forestal, bosques húmedos.

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1. Introduction

Native Tropical forests recycle large volumes of water vapor between the surface of the earth and the atmosphere, which is quite important for the generation of precipitation. The Amazon jungle is responsible for evapotranspiration to recycle up to 50% of the precipitations on this basin [1] [2] [3] [4] [5]
Forests are among the biggest biomasses around the world and return a large portion of precipitation of water from the atmosphere through evapotranspiration. Thus, evapotranspiration of forests observed in different parts of the world [6] greatly affect the regional and global climate to the flow of rivers, which in turn impacts upon the resources of bodies of water in the transport of sediment and biodiversity from the very forests [7].

Many models have been proposed to predict spatial variation in evapotranspiration. These models are rigorously classified into two groups: simple models that employ the concept of evapotranspiration potential [8] and complex models that require formulae like the Penman-Monteith equation [9].

The dynamics performed by forests with evapotranspiration to actively transport quantities of water volumes onto the atmosphere, given that it is controlled by opening of stoma from the vegetation, could be only one of its functions according to the proposal presented through the biotic pump theory, developed by research from physicists like Dr. Anastassia Makarieva and Dr. Víctor Gorshkov from the Nuclear Physics Institute in Saint Petersburg (Russia, 2007). This theory explains how trade winds, which transport large quantities of water vapor on the horizontal plane thousands of kilometers into the South American continent and which nourish the Amazon basin with adequate precipitation for maintenance of rainforests, are suctioned by a vertical force derived from the jungle's evapotranspiration. According to the theory, without forests, the winds would not blow with sufficient strength and perseverance, thus, hindering water transport to the eastern or central part of the Andes, including its moorlands (*páramos*).

Researchers Makarieva and Gorskov show the important role of forest coverage to maintain the water cycle induced by condensation and humid air flow from the ocean to the continent. Due to the presence of the Amazon forests, the rains reach some 3000 km inland; the same does not occur when no forests exist, as is the case of east Africa where rains only reach some 440 km inland, the researchers identified how the forests attract and retain water [10].

In the first place, the forest induces inversion during the day; temperatures in the underbrush are lower than on the crown cover; thus, loss of water vapor from the atmosphere is reduced, but at night water vapor condenses above the forest canopy causing diminished atmospheric pressure over the canopy, which causes suctioning of horizontal air and can bring humid air from the ocean; this is known as the biotic pump [11]. [12]

We selected the La Selva biological station in Costa Rica because it is in the tropical zone with humid tropical climate, with mean annual precipitation of 4 meters. Although rains are present in the forest throughout the year, the months with greater rainfall are July, November, and December. This biological station is owned by the Organization for Tropical Studies (OET, for the term in Spanish), a nonprofit consortium of 63 universities and schools. The 1600-hectare property is 62% primary forest with the remaining area being secondary forest, regenerated coffee plantations, and pastures (McDade *et al.*, 1994). Under these conditions, it can be taken as a good sensor to develop the applications of the biotic pump. The meteorology services from La Selva offer through their web page the data we used for the calculations proposed by the biotic pump theory.

2. Methodology

The methodology we have employed is that presented in the proposal of the biotic pump theory, whose theoretical principles are based on classic thermodynamics of ideal gases.

The meteorological data reported by La Selva station, obtained from the land station or from the radiosonde balloon, provide temperatures and relative humidity, barometric pressure, wind speed and direction, altitude and insolation. Bearing in mind temperature and relative humidity, partial pressure of water vapor in meters at an altitude z in the lower atmosphere, it may be determined by using the law of ideal gases and the equation by Clausius-Clapeyron,

$$P_{H_2O_z} = P_{H_2O_s}\ exp\left\{-\int_0^z \frac{dz}{h_{H_2O}}\right\} \quad (1)$$

With $P_{H_2O_z}$ as the partial pressure of water vapor at an altitude of z: $P_{H_2O_s}$ the partial pressure of water at sea level or zero altitude.

Where *–dT/dz = ELR (Γ vertical gradient of temperature)*

$$\mathrm{h}_{\mathrm{H_2O}} = \frac{\mathrm{T}^2}{\left\{\frac{-\mathrm{dT}}{\mathrm{dz}}\right\}\mathrm{T}_{\mathrm{H_2O}}} \quad (2)$$

And

$$T_{H_2O} \equiv \frac{Q_{H_2O}}{R} \cong 5301\,K \quad (3)$$

Also,

$$\ln\frac{P_2}{P_1} = \frac{Q(T_2 - T_1)}{RT_2T_1} \quad (4)$$

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We obtain

$$\log P_2 - \frac{Q(T_2 - T_1)}{RT_2T_1 * 2.303} = \log P_1 \qquad (5)$$

Where Q, is the latent heat of evaporation = 43 kJ mol^{-1}, and Γ (ELR) = -dT/dz

$$\frac{-dT}{dz} = \Gamma_{H_2O} = \frac{T}{H} \qquad (6)$$

And

$$T = T_s \exp\left\{-\frac{z}{H}\right\} \qquad (7)$$

With equations [6] [7] and the conditions considered of the atmosphere being T_{H2O} = 5301 K M_v = 18.02 g mol^{-1}, g = 9.8 m s^{-2}, R = 8.3 J K^{-1}, the following result may be obtained:

$$h_{vs} \equiv {RT_s}/{gM_v} = 13.5\ km \qquad (8)$$

The length scale for humid air is compared to dry air, where h_{ds} = 8.4 km. Meanwhile, in the troposphere it is only composed of water vapor, then through basic principles of physics it is established that:

$$H = \frac{RT_{H_2O}}{gM_v} = 250\ km \qquad (9)$$

Which would give it an ELR, Γ, of 288/250 = 1.2 K / km, in comparison to 6.5 K/km or 9.8 K/km (humid to dry air). This difference is explained in physical terms because the water vapor is obligated to condense with altitude in the low part of the middle troposphere and, as such, it is a factor in helping the earth to retain water. From the ELR, we can discern that:

$$h_{H_2} = \frac{T^2}{\left\{\frac{-dT}{dz}\right\} T_{H_2O}} = 2.41\ km \qquad (10)$$

When T is 288 and Γ is 6.5 K/km, given that

$$T_{H_2O} \equiv \frac{Q_{H_2O}}{R} \cong 5301\ K \qquad (11)$$

Meanwhile the evaporation-condensation force is derived from the upward acceleration of the portion of air due to the loss of condensation water vapor minus the pull-down traction of the water vapor in any z on the column caused by gravity. In fact, as can be noted from empirical calculations, the ratio of the upward force to the pull-down traction is 5:1 in favor of f_E – the evaporation / condensation force. It is calculated as:

$$f_E = P_{H_2O}\left(\frac{1}{h_{H_2O}} - \frac{1}{h_v}\right) \qquad (12)$$

Figure 1 summarizes the methodology used to perform the calculations presented by the biotic pump theory.

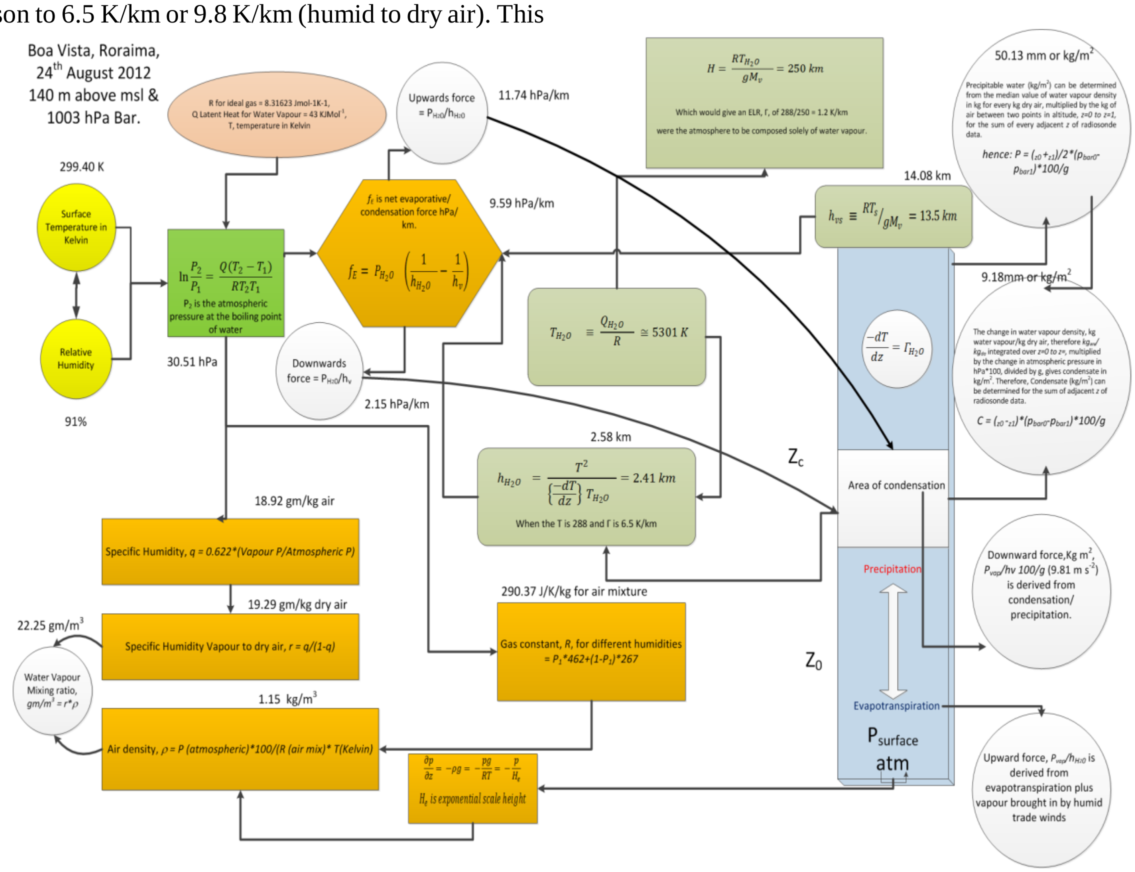

Figure 1. Scheme of the methodology used, from the physics of the biotic pump theory [11]

3. Results

The graphics from Figures 2 and 3 correspond to the behavior presented by changes in wind speed and evaporative force averaged every five minutes, for 30 days during each of the study months, applying the methodology shown in Figure 1.
Meteorological data were consulted in: http://www.ots.ac.cr/meteoro/default.php?pestacion=2, where information from La Selva station is available for the scientific community.

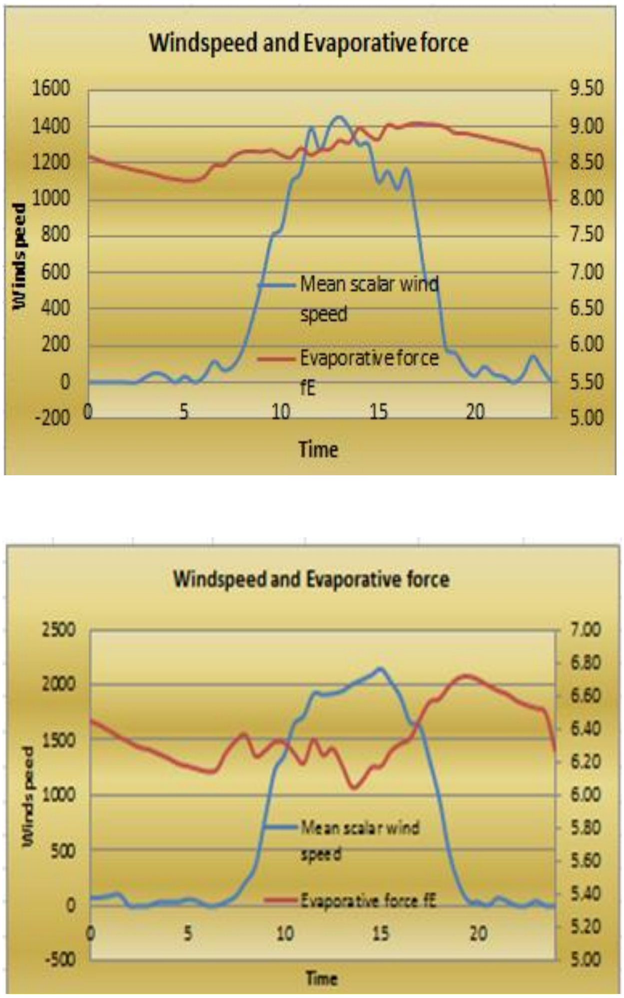

Figure 2. Results of evaporative force and wind speed for May and June 2013

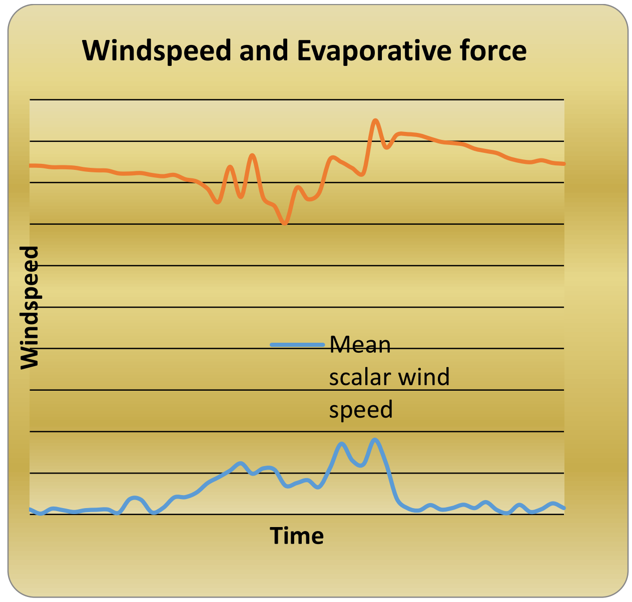

Figure 3. Wind speed and evaporative force for September 2013

4. Conclusions

The evidence shown suggests a good correlation between the evaporative force (f_E) and the wind when measured during 24 hours. Thereby, it seems the air flow from the trade winds is influenced by changes in the evaporative force, that is, by diurnal changes in absolute humidity (specific): the latter follows precisely the changes in f_E.

Hence, preliminary calculations on the meteorology of the La Selva biological station in Costa Rica contribute to conjecture in the direction suggested by the theory by Makarieva and Gorshkov.

The implications are critical to better understand the consequences of deforestation, thus, questioning the results of climatic models that indicate with deforestation a reduction of 15 to 20% of precipitation in the western part of the Amazon basin. The biotic pump theory indicates a reduction of over 90% in precipitation as a consequence of deforestation and, therefore, desertification of the central part or west of the Amazon basin.

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