

Revista Brasileira de Geografia Física



Homepage: www.ufpe.br/rbgfe

ANALYSIS OF INFLUENCE OF EVAPOTRANSPIRATION ON RAINFALL IN AN ATLANTIC FOREST USING REMOTE SENSING DATA

Josiclêda Domiciano Galvíncio¹, Hewerton Alves da Silva², Sorin S. Popescu³

¹Professora of Universidade Federal de Pernambuco/Departamento de Ciencias Geograficas/Pos-graduacao em Desenvolvimento e Meio Ambiente- Bolsista de Pos-doutorado da Texas A&M University- Pesquisadora do CNPq. E-mail: josicleda@hotmail.com - corresponding author, telephone 558121267275 fax 558121268275

²Mestre da Universidade Federal de Pernambuco/Departamento de Ciencias Geograficas.

³Texas A & M University- Department of Ecosystem Science and Management- s-popescu@tamu.edu Artigo recebido em 10/02/2014 e aceite em 10/03/2014

ABSTRACT

Quantifying and monitoring evapotranspiration in large natural forests is vital for monitoring the climate, water resources and biodiversity of the ecosystem, especially in an area with high climatic variability, water and biodiversity, such as Northeast Brazil. The objective of this study is to evaluate evapotranspiration in areas of the Atlantic Forest using remote sensing data and to determine how evapotranspiration can affect rainfall changes on a local scale. We used the Surface Energy Balance Algorithm for Land (SEBAL) and Thornthwaite models to estimate evapotranspiration. The input models used Landsat images and observations from agro-meteorological stations. An estimate of the actual evapotranspiration by the Thornthwaite method was over a 10-day period, and SEBAL was used over 24 hours. The daily actual evapotranspiration was between 5 and 6 mm/day. We computed the cross correlation coefficient and standard error with lag seven (10-day) for maximum evapotranspiration with SEBAL (Evap_SEBAL_max) and rainfall decennial (R10). The evapotranspiration had a positive correlation with rainfall. The correlation is significant for the last ten days (lag -1), with r=0.389. While this value does not indicate a strong statistical correlation by itself, physically it designates a positive influence of the local evapotranspiration on local precipitation, given all the other environmental aspects that influence precipitation. The results suggest that local evapotranspiration can be influencing the local rainfall. Thus, knowing the amount of water being used by the forest and released to the atmosphere is important. These results can be used for improve climate prediction and climate change models at the local scale.

Keywords: SEBAL, energy balance, climatic variability, ecosystem.

Introduction

The evapotranspiration from vegetated surfaces transfers large amounts of water and energy (in the form of latent heat) to the atmosphere through the evaporation of water in soil and transpiration, in plants. Given the great concern over global water scarcity, it is increasingly necessary to quantify and monitor water availability at various spatial and temporal scales via soil-plant-atmosphere interactions. Quantifying and monitoring evapotranspiration in large natural forests is vital for monitoring the climate, water resources and biodiversity of the ecosystem, especially in an area with high climatic variability, abundant water and biodiversity, such as Northeast Brazil.

"More than half of the solar energy absorbed by land surfaces is currently used to evaporate water. Climate change is expected to intensify the hydrological cycle and to alter evapotranspiration, with implications for ecosystem services and feedback to regional global climate. Evapotranspiration changes may already be underway, but direct observational constraints are lacking at the global scale. Until such evidence is available, changes in the water cycle on land—a key diagnostic criterion of the effects of climate change and variability—remain uncertain" (Jung et al. 2010).

Jung et al. (2010) showed that global annual evapotranspiration increased on average by 7.161.0 millimeters per year per

decade from 1982 to 1997. "After that, coincident with the last major El Nino event 1998, the global evapotranspiration increase seems to have ceased until 2008. This change was driven primarily by moisture limitation in the Southern Hemisphere, particularly Africa and Australia. In these regions, microwave satellite observations indicate that soil moisture decreased from 1998 to 2008. Hence, increasing soil-moisture limitations on evapotranspiration largely explain the recent decline of the global landevapotranspiration trend. Whether changing behavior of evapotranspiration is representative of natural climate variability or reflects a more permanent reorganization of the land water cycle is a key question for earth system science".

The amount of water used by vegetation can be reliably estimated by analyzing evapotranspiration data. Studying the temporal and spatial variations of evapotranspiration in large forests can improve climate and hydrological forecasts and assist in the mitigation of natural disasters that are caused by severe drought or flooding. existing information The evapotranspiration in Brazilian forests rely on eddy covariance data systems that record continuous latent heat fluxes observed at meteorology stations. These observations are scarce and limited to singular locations; therefore, the data do not represent the spatial variations found in large forests. Remote sensing techniques can compensate for such limitations. Currently, remote sensing has provided accurate estimations evapotranspiration at various temporal and spatial scales using data from the thermal electromagnetic band (Silva et al. 2012A; Silva et al. and 2012B, Oliveira et al. 2011).

Evapotranspiration can be used to infer soil moisture, assess climate systems, assess drought and flood and even serve in several military applications. At broad spatial scales, the patterns of evapotranspiration are essential as input to mesoscale and general circulation models because they affect the water cycle and energy balance of the earth-atmosphere-ocean system (Anderson et al. 2012).

Climate change has emerged as another issue of great concern worldwide. The IPCC (2007) has forecasted diminishing water resources, particularly in arid and semiarid regions of the world. The estimation of evapotranspiration helps monitor water resources. Furthermore, evapotranspiration has a strong relationship with the amount of carbon that is sequestered by forests (Moura et al. 2012 and Galvíncio et al. 2012) and the amount of moisture in the atmosphere, which causes changes in rainfall.

"Increases in greenhouse gases increase the radiative forcing and thus not only increase surface temperatures but also enhance the hydrological cycle as much of the heating at the surface goes into evaporating surface moisture" Thenbert (1998). Global temperature increases signify that the water holding capacity of the atmosphere increases and, together with enhanced evaporation, the actual atmospheric moisture increases, as is observed to be happening in many places (Hense et al. 1988; Gaffen et al. 1991.1992; Gutzler, 1992, Ross and Elliot, 1996). Of course, enhanced evaporation depends upon the availability of sufficient surface moisture and over land; this depends on the existing factor climate. This is one complication in terms of the expected response and a likely to be model dependent. However, it follows that naturally-occurring droughts are likely to be exacerbated by enhanced potential evapotranspiration, both in nature and models Gregory et al. (1997). Thenbert (1998) raises several questions, such as, "what are the processes by which rainfall is changed? Globally there must be a balance between evaporation and rainfall, but what is the relationship locally?"

According to Jung et al. (2010), the land evapotranspiration (ET) is a central process in the climate system and a nexus of the water, energy and carbon cycles. Global land ET returns about 60% of annual land rainfall to the atmosphere. Terrestrial ET can affect rainfall, and the associated latent heat flux helps to control surface temperatures, with important implications for regional climate characteristics such as the intensity and duration of heat waves.

(1998)Thenbert analyzed the implications for rainfall rates and climate change due to atmospheric moisture residence times and cycling. The main questions of this study were: "what is the relationship among changes in evaporation, changes in moisture content of the atmosphere, and changes in rainfall? What are the factors that should be taken into account to explain the changes?" The IPCC 1995 report (IPCC, 1996) states that several models indicate an increase in rainfall intensity, suggesting a possibility for more extreme rainfall events. It is further argued that one reason why we should expect spotty increases in rainfall is because of mismatches in the rates of the rainfall versus evaporation.

Previous studies conducted worldwide were performed on large scales (or global scales); studies on small scales or local scales do not exist, especially in Brazil. Of course, evapotranspiration depends on the availability of water and the climate on the local scale. However, many areas are dry due to high evaporation and scarce water availability (lack of rainfall) over the years, for example, the semiarid area of NE Brazil.

Even with all of these global problems, Brazil has advanced strategies for monitoring and conserving natural resources, especially water resources. Additionally, the United States has a strategic plan that monitors and protects water resources and uses satellite imagery to monitor evapotranspiration, as in (Anderson et al. 2012).

In Brazil, several studies have been conducted that use remote sensing to estimate evapotranspiration in irrigated agricultural areas (Gusmão et al. 2012; Bezerra et al. 2012, Santos et al. 2010; Santos el at. 2009; Teixeira et al. 2008A) and in natural forest areas (Machado et al. 2012; Machado et al. 2010 and Teixeira et al. 2008B). These authors have obtained excellent estimates when compared to data observed at micrometeorological stations.

It is possible to estimate evapotranspiration with high accuracy using

satellite images; furthermore. evapotranspiration is related to local rainfall. The increase in moisture content in the atmosphere promotes heavy rain events and flood risk, as observed in various areas of the world (Karl et al. 1996). Some models used by the IPCC (2007) suggest decreased rainfall in northeastern Brazil: however, the models still uncertain. Therefore. evapotranspiration at the local level may be useful for climate models of regional circulation. These uncertainties in rainfall scenarios stem from the partial quantification of moisture in the atmosphere and the amount of moisture at specific locations that directly affects the rates of rainfall on the local scale.

Trenberth and Guilemont (1996) show that the temporal variability of evaporation is much less than that of rainfall and, so the latter dominates both the spatial and temporal variability of the fresh water flux evaporation-rainfall.

In climate studies, we seek to knowledge synthesize of complex environmental interactions through models that can quantify, qualify and manage water resources available for precipitation. The importance of forecasts and climate simulations increases when these predictions are often used to save lives, especially in humid and semi-arid regions of the world exposed to floods and high rates of evaporation or affected by severe drought, with low space-time rainfall rates, high evaporation and uneven distribution of these factors. In these regions the water is a key element in the socio -economic framework of region, creating the need for the rationalization of its use. Therefore. monitoring and predicting climate becomes fundamentally important in such areas, for establishing guidelines to follow to provide better fit and decision making when climatic extremes occur.

Using a model synthesizes past, present and future conditions, however, there are differences between the events observed and their model estimation. These differences represent the uncertainties of the models, and a way to minimize them is to select the model

based on physical criteria of the system. These criteria can be represented by mathematical, statistical, or stochastic-mathematical expressions. For example, one method used for such purposes is cross correlations analysis.

In an attempt to find relations between different spatial and temporal climatic variables, many scientists around the world have used statistical analysis of the different environmental climatic and conditions, (Runge et al. 2014; Long et al. 2014; Galvincio et al. 2013; Galvincio et al. 2013A; Vassolera and Zebende 2012; Sang et al. 2012; Zhang et al. 2011; Galvincio et al. 2010; Silva and Galvincio, 2009; Pinto et al. 2006; Hidalgo 2005; Galvincio and Sousa, 2002; Galvincio et al. 2002; Sukharev et al. Galvincio 2001: Sousa and 2000: Padmanabhan and Rao 1990 and Katz, 1988). Finding connections or correlations among data is one of the central themes of many scientific studies. A good example is climate research and forecasting, which has far ranging applications to agriculture, fisheries, ecosystems, water resources, infrastructure, and disaster planning. Given the many complex interactions among the Earth's oceans, atmosphere, land, ice and biogeochemistry, and the sheer size of observational and climate model data sets, it is often difficult to identify which processes matter most for a particular climate phenomenon. A useful approach has been to correlations among different examine variables to identify relationships, (Sukharev at al. 2001).

Time series analysis deals with the estimation of the characteristic properties and times of stochastic processes. This can be achieved either in the time domain by studying the autocovariance function, or in the frequency domain by studying the spectrum.

According to Runge et al. (2014), lagged correlation analysis is a simple and very common method in many fields of science, popularized in climate research already by the seminal works of Walker (1923, 1924). This method is the first step to gain insights into the possible interaction mechanisms between different processes.

Specifically, the cross-correlation lag function is used to assess the time delay and to quantify the strength of the link mediated by a certain mechanism. To name just a few examples, Lanzante (1996) computed lag correlations of sea surface temperatures between different tropical regions to assess their mutual interaction. Klein et al. (1999) studied the mechanism by which the El Nino–Southern Oscillation (ENSO) influences the Atlantic and Indian Oceans and southern China.

The Atlantic Forest, one of the most important forests of Brazil, is the major tropical forest of South America. The forest contained major wealth that was exploited by the colonizers. The original forests are nearly completely gone and continue to experience devastation and fragmentation. The forest is threatened to become extinguished.

The original area of the Atlantic Forest in Brazil was 1,315.460 km2, whereas today the forest only totals 8.5% of the original (SOS Mata Atlantic, 1998). CEPF (2001) indicates that the deforestation indices are major in Northeast Brazil. Despite the massive deforestation and fragmentation of the Atlantic Forest, the forest is extremely rich in biodiversity. It harbors a high proportion of Brazilian species and has high levels of endemism. Even with the high rate of deforestation in the Atlantic Forest, it still represents 16% of the total area of the Amazon Rainforest.

The Atlantic Forest contributes to the water balance and climate via 8 mm/day/m² of evapotranspiration. This is equivalent to 8 liters/day/m². The total area of the Atlantic Forest is 111,000 km². This is equivalent to 324,000,000,000 liters/day of evapotranspiration. Much of the energy is used to transform liquid water into vapor form. Furthermore, the forest is important to the energy balance.

Forests are of great importance for the maintenance of the current climate. Restoring forests can mitigate or even reverse atmosphere climatic changes, such as global warming. Continued deforestation will affect rainfall. To understand the importance of forests in the climate system, especially to

rainfall and temperature, scientists must study phenomena at local scales, with local specificity, rather than extrapolating phenomenon occurring at distant and large extents. The variations of hydrological cycles on a local scale must be understood, especially evapotranspiration.

The purpose of this study is to evaluate the evapotranspiration estimate in areas of the Atlantic Forest using remote sensing data and infer how the evapotranspiration affects rainfall changes on a local scale, using cross correlation.

Materials and Methods

Study area

Fig. 1 displays the location of the study area. The area belongs to the Brazilian Atlantic Coastal Forest in northeastern Brazil, which is in Pernambuco state. The area is covered with dense and humid forests and has little variation in temperature. The area does not have a dry season. The wettest months are July and August, whereas less rainfall occurs in October and November (Fig. 2). The coldest month is August, and the warmest month is February. The Atlantic Forest is an ecosystem that is greatly important to Brazil; however, much of the area has been deforested and replaced by sugar plantations.

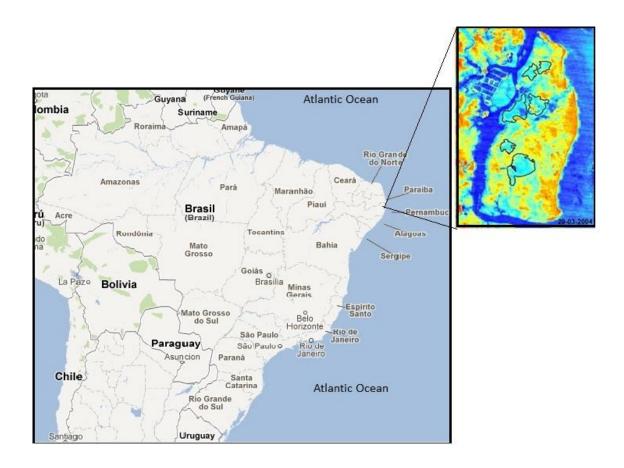


Figure 1 – Location of the Atlantic Forest in the study.

The Google maps adapted. The imagery at the top right is Landsat 5 of Mar/29/2004.

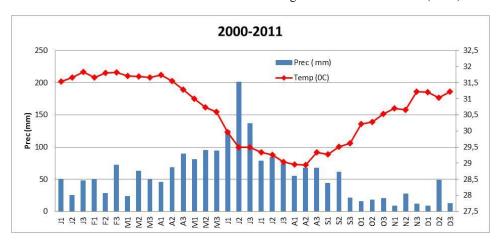


Figure 2 – Climatology of the study area.

Data

In this study, we used Landsat images that correspond to nine dates: Feb/15/2006, Mar/29/2004, Apr/01/2005, Jun/02/2010, Aug/18/2003, Aug/26//2006, Sept/08/2005, Sept/26/2000 and Oct/08/2010. These images were obtained from the INPE-National Institute for Space Research and initially downloaded as georeferenced images through the GLOVIS portal of the United States Geological Survey (USGS). The spatial resolution of Landsat 5 is 30 meters in the visible and near infrared and 120 meters in the thermal range. The satellite revisit time is 16 days. The area of this study is covered by the path and row of 214/65. We selected images that were cloud-free over the study area.

We also used data (wind speed and direction, air and soil temperature, pressure,

solar radiation, humidity and rainfall) from the weather station at Carpina, Pernambuco state, located at longitude -35.24° and latitude -7.85°

Methods

This study used the **SEBAL** methodology (Energy Balance Algorithm for Land) to estimate the daily evapotranspiration Thornthwaite (1955)to and evapotranspiration over ten days. Figure 3 was adapted from the article of Sander et al. (2010)indicate the schematic to of representation SEBAL. Detailed procedures of the SEBAL algorithm can be found in (Machado et al. 2012; Bezerra et al. 2008; Teixeira et al. 2008; Zwart and Bastiaanssen 2007; Bastiaanssen et al. 2005; Bastiaanssen and Ali 2003; and Bastiaanssen et al. 1998).

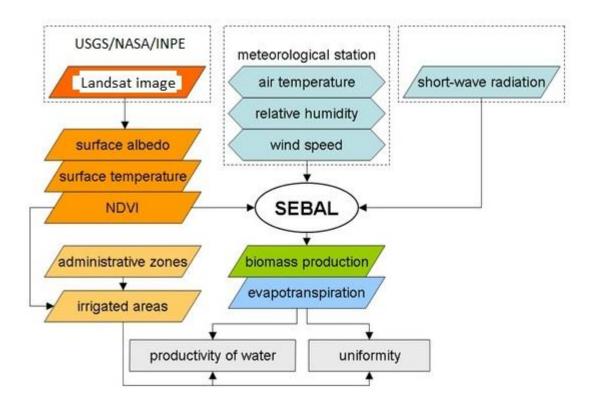


Figure 3 - Visual representation of the SEBAL inputs that are required to calculate biomass production and actual evapotranspiration from Landsat images, including the performance indicators. Adapted from Sander et al. (2010).

All of the images were processed in ERDAS Imagine 9.3, which is licensed by the Department of Geographical Sciences of Federal University Pernambuco state.

Criteria for methods evaluation

SEBAL method has evaluated and validated in several studies, such as Silva et al. (2012), Gusmão et al. (2012), Machado et al. (2012), Santos et al. (2011), Mendonca et al. (2009), Bezerra et al., (2008), Teixeira et al. (2008A), Teixeira et al. (2008B), Meireles et al. (2007), Zwart and Bastiaanssen (2007), Bastiaanssen et al. (2005), and Bastiaanssen and Ali (2003). Bastiaanssen et al. (1998) provided accurate estimates. To verify the accuracy of the estimates in this study, we consider the previously published estimates in SEBAL evaluation studies as the reference data.

To evaluate the role of surface evapotranspiration in influencing rainfall, we investigated the cross correlation coefficients for seven lag times.

The data were analyzed using Cross Correlation Coefficients.

Cross Correlation Functions (CCF) and Lagged Regressions (R)

When analyzing the relationship between two time series $(y_t \text{ and } x_t)$, the series y_t may be related to past lags of the x-series. The sample cross correlation function (CCF) is helpful for identifying lags of the x-variable that might be useful predictors of y_t .

In R, the *sample CCF* is defined as the set of sample correlations between x_{t+h} and y_t for $h = 0, \pm 1, \pm 2, \pm 3$, and so on. A negative value for h is a correlation between the xvariable at a time before t and the y-variable at time t. For instance, consider h = -2. The CCF value would give the correlation between x_{t-2} and y_t .

Lagged regression models

Consider a lagged regression model of the form

1

$$Y_{t=\sum_{-\infty}^{\infty}\beta_h X_{t-h}+V_t}$$

Where X_t is an observed input time series, y_t is the observed output time series, and V_t is a stationary noise process.

This model is useful for identifying the (best linear) relationship between two time series and forecasting one time series from the other.

Cross-Correlation Function - CCF

The cross-correlation function of jointly stationary X_t and Y_t (Storch and Zwiers, 1999) is

$$\rho_{xy}(h) = \frac{y_{xy}(h)}{\sqrt{y_x(0)y_y(0)}}$$

Where $\rho_{xy}(h) = \rho_{yx}(-h)$ but $\rho_{xy}(h) \# \rho_{xy}(-h)$. In this study we used Standard Error (Std. Error) to investigate cross-correlation.

Results and discussion

Fig. 4 depicts the actual evapotranspiration average and maximum estimates with SEBAL. Note that the Landsat image for February 15, 2006 generated the largest values of the actual evapotranspiration, followed by April. This is expected because the summer in Brazil is December to April. The solar radiation is very high and causes high

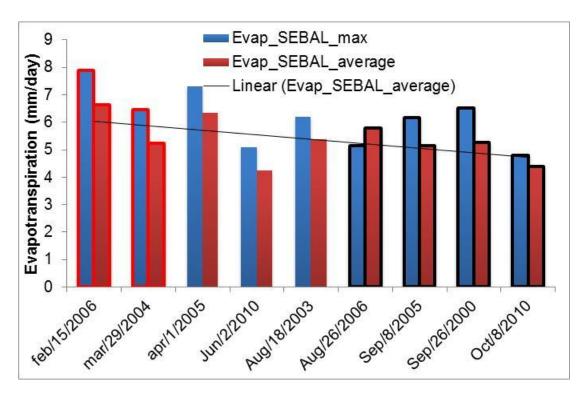


Figure 4 – Actual evapotranspiration over 12 days and 9 months during 2000 to 2011. Contour red is summer and contour black is winter.

Data Analyssis when N=9

We analyzed the relationship between actual evapotranspiration using SEBAL and rainfall over ten days, at a local scale. We computed the cross correlation coefficient and standard error with a lag of seven days for the maximum evapotranspiration using SEBAL (Evap_SEBAL_max) and rainfall decennial (R10) (Table 1). Prior to rainfall, the evapotranspiration had a positive correlation with rainfall, lag 0. For lags 1 and 2 the cross correlation was negative. For lags -1, -2, -3, -4, -5, -6 and -7 the cross correlations were positive. This means that evapotranspiration

had a positive influence on rainfall. That is, the increased evapotranspiration produced rainfall increases. While this value does not indicate a strong statistical correlation by itself, physically it designates a positive influence of the local evapotranspiration on local precipitation, given all the other environmental aspects that influence precipitation. It is noteworthy that the interest in this correlation value in our study is from a physical interpretation and not statistical. This value is considered significant for climate since the climate data are very heterogeneous, with high spatial and temporal variation. The evapotranspiration is not the only variable influencing the rainfall; other environmental variables too determine the amount of rainfall. Galvincio and Sousa (2002) analyzed the relation between rainfall and El Nino events in Sao Francisco basin and obtained similar correlation values to this study. In Galvincio and Sousa (2002) 85% of values have no statistical significance, but the interest in correlation values of was physical and not statistical.

igure 5 shows CCF of lags. Note that results are similar with the no resample data. For lag -1, N=9, r=0.38 and for N=50, r=0.31.

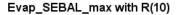
This study shows a positive relation between evapotranspiration and rainfall. With climate change, we could probably expect an increase in evapotranspiration, which can lead to an increase in local rainfall. Jung et al (2010) show that evapotranspiration in the area of this study will increase. "It is hard to evaluate whether this is part of the natural climate oscillation, or a climate-change signal in which land evapotranspiration becomes more and more supply limited in the long term. The latter would imply that there is a limit to energy- and temperature-driven acceleration of the terrestrial hydrological cycle and that it may have been reached. The consequences would be a decreasing productivity terrestrial and a reduced terrestrial carbon sink. preferential partitioning of energy fluxes at the land surface into sensible, rather than latent, heat flux and thus accelerated a land-surface warming, and intensified regional landatmosphere feedback" (Jung et al 2010).

Table 1- Cross correlation results. Series pair: Evap_SEBAL_max with R(10)

Lag	Cross Correlation	Std. Error ^a
-7	.092	.707
-6	.085	.577
-5	.010	.500
-4	.277	.447
-3	.332	.408
-2	.293	.378
-1	.389	.354
0	.226	.333
1	196	.354
2	010	.378
3	.346	.408

4	.157	.447
5	.165	.500
6	142	.577
7	432	.707

a. Based on the assumption that the series are not cross correlated and that one of the series is white noise.



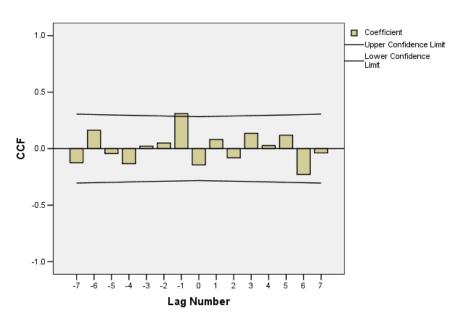


Figure 5 – Cross correlation with series pair: Evap_SEBAL_max with R(10), data resamples, N=50.

The above analyses show a moderate correlation relationship between precipitation rates and evapotranspiration.

If local evapotranspiration have influence about local rainfall is possible that the local rainfall frequency and intensity be impacted. This situation can be worrying because Trenberth (1998) declared that is important to consider the frequency of precipitation events. According to Trenberth (1998) if rain rates increase faster than rain amounts, then the frequency of rain occurrence could decrease. Similar results had been published for studies near the city of Recife. Souza and Azevedo (2012) analyzed

the climate change effects derived from maximum rainfall and and minimum temperatures in Recife, using the RClimdex software. They used daily data of rainfall and temperatures (maximum and minimum) in the period 1961 to 2008 in Recife, assigned by INMET. The results derived from the precipitation did not show significant trends of reduction. On the other hand, they noted an increased frequency of extreme rainfall events from 1980, with daily rainfall exceeding 100 Compared to the temperatures mm. characteristics for this area, all temperature observations indicate positive trends, indicating an increase of the maximum and minimum temperatures around

throughout the 47 years analyzed, with increased frequency of hot days and nights, as noted by the increase in heat waves in the region. Recife city is situated in the area of the Atlantic forest.

In a study by Haylock et al. (2005) on trends in total and extreme rain to South America, it was observed that there were large regions with spatial coherence in the signals of the trends as well as overall agreement between the indices. All proposed climatic indices, related to rainfall, except CDD (Consecutive Dry Days), showed a tendency to increase with moisture conditions. The total annual precipitation (PRCPTOT) showed general features that are also present in other indices, such as increased of moisture in the southernmost part of Brazil and Paraguay, northeastern Argentina and Ecuador and northwestern Peru, increased tendency to drought in the southernmost part of Chile and Peru and southwestern Argentina. The rain gauges in the north and northeast of Brazil showed no sign of a consistent trend. Previously, Hastenrath and Greischar (1993) and Marengo et al. (1998) found positive trends in precipitation in northeastern Brazil. In the Northeast region, some researchers, such as Souza and Azevedo (2009), Santos and Brito (2009 and 2007), Silva and Azevedo (2008), have used the RClimdex to monitor trends climatic in some states of the region.

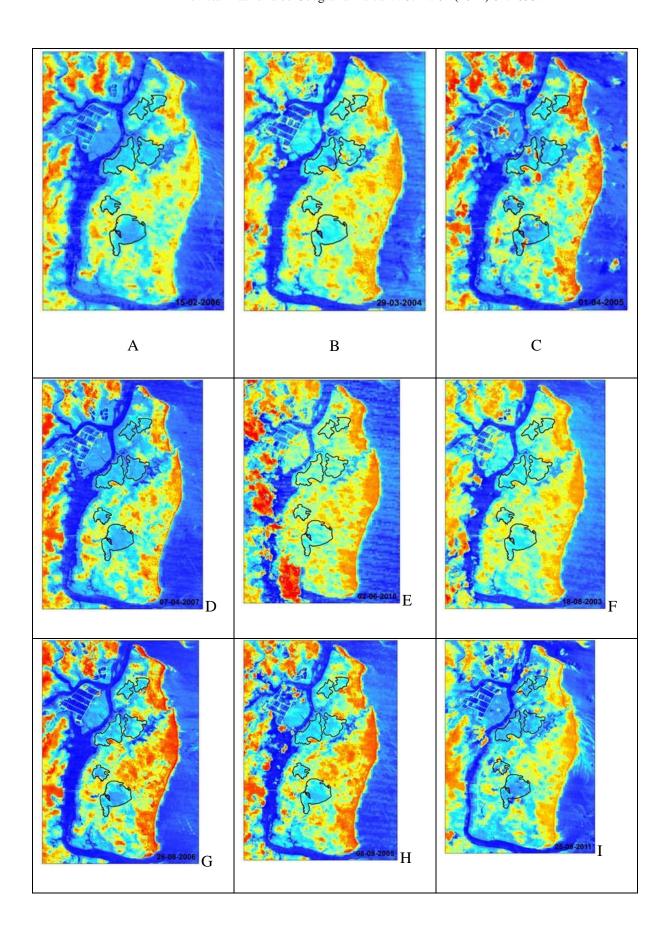
The scientific community has given great emphasis to climate change as a result of global warming, particularly since the publication of the 4th Report of the IPCC (IPCC, 2007). This report mentions that in Brazil the natural disasters of atmospheric origin are likely to continue increasing, especially storms and intense rainfall events over the south and southeast regions of Brazil and the worsening drought in the northeast and advancement on the northern and central regions.

In this study, we showed that the evapotranspiration has positive influence on rainfall, at local scale. It's important to study the spatial and temporal variable of evapotranspiration because the spatial variability of evapotranspiration can be influencing the local rainfall. However,

knowledge of spatial variability of rainfall evapotranspiration and is precarious in Brazil. The spatial distribution of climate stations is not sufficient to determine the spatial characterization of rainfall and evapotranspiration at local scale, in Brazil. The precariousness of climate data with spatial distribution at local scale was in part resolved with remote sensing data. Other studies have showed that estimating the evapotranspiration with remote sensing methods is possible, with good results (Machado et al. 2012; Silva et al. 2012A; Silva et al. and 2012B, Gusmão et al. 2012; Bezerra et al. 2012, Oliveira et al. 2011, Santos et al. 2010; Machado et al. 2010, Santos el at. 2009; Teixeira et al. 2008A and Teixeira et al. 2008B).

In Figure 6, we show the spatial and temporal variation of evapotranspiration estimated with remote sensing in the study area. The actual evapotranspiration appears more homogeneous between 2006 and 2011 than during 2000. As shown previously, the evapotranspiration increases from December to April in Brazil (i.e., summer). The solar radiation is very high and causes high evapotranspiration. In this study, the months of April (Figures 6 C and D) and September-October (Figures 6 G and H), have high evapotranspiration. In general, evapotranspiration in Atlantic forest was 5 to 7 mm/day. In built areas (coastline) the evapotranspiration was less than 1mm/day (red area), although these areas used to belong to Atlantic Forest areas prior to urbanization. This situation contributes to the change in local climate, temperature increase and alterations in rainfall distribution (intensity and frequency) at local scale.

The increase in evapotranspiration during September-October may be due to the end of the wet period. The wet period occurs between May and August (Fig. 1). Precipitation also has a strong influence on the evapotranspiration. Therefore, it is recommended that this process is studied further. These results will improve climate prediction and climate change models at the local scale.



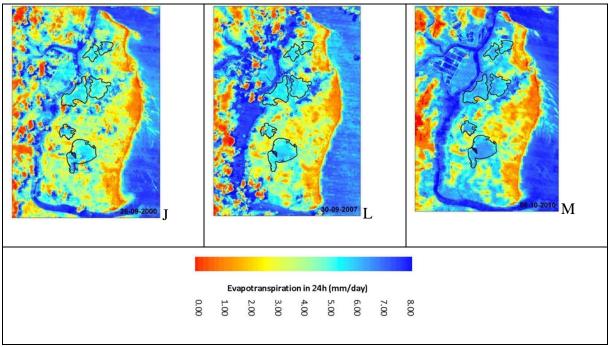


Figure 6–Daily actual evapotranspiration in A- 09-06-2000; B - 08-18-2003; C-03-29-2004; D-.04-01-2005; E-09-08-2005; F- 02-15-2006; G - 08-26-2006; H-04-07-2007; I - 09-30-2007; J - 06-02-2010; L - 10-06-2010 and M - 08-25-2011.

It is important to mention that in this study area we do not have climate stations with vapor flux monitoring (evapotranspiration) and therefore, it is only possible to estimate evapotranspiration at local scale with remote sensing data. We recommend the implementation of similar studies in other areas with similar climate conditions to validation this statement, especially in areas with large forests in urban areas and cities with coastline.

Conclusion

Cross-correlation lag functions are commonly used to identify interaction mechanisms between climatological processes, in particular to assess possible time delays of a mechanism and as a measure to quantify the strength of the link mediated by the mechanism. In this article, we investigated how evapotranspiration interferes in local rainfall based on mean correlations that typically occur in time series analysis of evapotranspiration and rainfall for Atlantic forests. This mean correlation of a simple cross-correlation lag function's maximum value and lag has potential to give a physical

explanation of the effect of evapotranspiration in rainfall and come to the conclusion that cross-correlation can be used for such analyses.

The cross correlation coefficient between maximum evapotranspiration and rainfall decennial had positive values for all negative lags, which indicates a positive influence of evapotranspiration on rainfall. The correlation r =0.389 was the largest relation for the last ten days (lag -1). The correlation is near 0.3 to the last 40 days. Thus, local evapotranspiration may influence the local rainfall.

The monitoring of instantaneous, hourly and daily evapotranspiration in forests is possible using Landsat imagery. Thus, understanding the amount of water used by the forest and released to the atmosphere makes it possible to improve climate models and infer rainfall changes at local scale. In this study, we observed that the estimation of evapotranspiration using satellite images can help in the forecasting of local rainfall.

Acknowledgments

We thank CNPq for financial support through the network of PELD-Program Ecological Long Duration research, site 22, process number 558074/2009-0. We also thank the CAPES scholarship for providing Josicleda Domiciano Galvincio post-doctoral support.

References

- Anderson, Martha C. Richard G. Allenb,
 Anthony Morse, William P. Kustas, 2012.
 Use of Landsat thermal imagery in
 monitoring evapotranspiration and
 managingwater resources. Remote Sensing
 of Environment,
 http://www.kimberly.uidaho.edu/water/papers/remote/Anderson_Allen_Morse_Kustas_RSE_2012.pdf
- Bezerra, Bergson G.; da Silva, Bernardo B.; Bezerra, José R.C.; Sofiatti, Valdinei; dos Santos, Carlos A.C. 2012. Evapotranspiration and crop coefficient for sprinkler-irrigated cotton crop in Apodi Plateau semiarid lands of Brazil. Agricultural Water Management (Print), v. 2, p. 221-2241.
- Galvíncio, D. J.; Moura, B. M. S.; Silva, T. G. F. da; Silva, B. B.; Naue, C. R. 2013. LAI Improved to Dry Forest in Semiarid of the Brazil. International Journal of Remote Sensing Application, v. 3, p. 193-202.
- Galvincio, J. D.; Moura, M. S. B.; Silva, T. G.
 F.; Silva, B. B.; Naue, C. R. 201).
 Relationship Between Canopy and Leaf Spectral Response In Savanna. Revista Brasileira de Geografia Física, v. 6, p. 341-355.
- Galvíncio, J. D.; Moura, M. S. B.; Silva. B. B.; Machado, C. C. C.; Silva; Oliveira, 2012. T. H. Relationship Between Vegetation **Indices** and Canopy Chlorophyll in GPP Estimation. In: ASABE, 2012, Dallas. 2012 ASABE Annual International Meeting. Dallas: ASABE, v. 1. p. 53-xxx.
- Galvíncio, J. D.; Pimentel; R. M. M. Fernandes, J. G. 2010. Relationship of air and soil temperature with the amount of chlorophyll a and b in Jurema preta (Willd.) Poiret) in semi-arid northeastern

- Brazil. Revista Brasileira de Geografia Física, v. 3, p. 41-46,
- Galvíncio, J. D.; Sousa, F.de A. S. de . 2002. Relação Entre O Fenômeno El Niño E Os Totais Mensais Precipitados Na Bacia Hidrográfica Do Rio São Francisco. Revista Brasileira de Recursos Hídricos, v. 07, n.04, p. 113-119.
- Galvíncio, J. D. Sousa, F. de A. S.; Sousa, I. F. De. (2002). Uso De Modelos Auto-Regressvo E Médias-Móveis Para Geração De Vazões Médias Mensais Na Bacia Hidrográfica Do Alto São Francisco. XII Congresso Brasileiro de Meteorologia, Foz de Iguaçu-PR.
- Gusmao, Ana C. V. L.; Silva, Bernardo B. Da; Montenegro, Suzana M. G. L. And Galvincio, Josiclêda D.. Determinação do saldo radiativo na Ilha do Bananal, TO, com imagens orbitais. *Rev. bras. eng. agríc. ambient.* [online]. 2012, vol.16, n.10, pp. 1107-1114. ISSN 1415-4366. http://dx.doi.org/10.1590/S1415-436620120010000011
- Hastenrath, S.; Greischar, L. 199). Further Work on the Prediction of Northeast Brazil Rainfall Anomalies. Journal of Climate, 6, 743-758.
- Haylock, M. R.; Peterson, T. C.; Alves, L. M.;
 Ambrizzi, T.; Anunciacao, Y. M. T.; Baez,
 J.; Barros, V. R.; Berlato, M. A.; Bidegain,
 M.; Coronel, G.; Garcia, V. J.; Grimm, A.
 M.; Karoly, D.; Marengo, J. A.; Marino,
 M. B.; Moncunill, D. F.; Nechet, D.;
 Quintana, J.; Rebello, E.; Rusticucci, M.;
 Santos, J. L.; Trebejo, I.; Vincent, L. A.
 2006. Trends in total and extreme South
 American rainfall 1960-2000 and links
 with sea surface temperature. Journal of
 Climate, v. 19, p. 1490-1512.
- Haylock, M. R.; Peterson, T. C.; Alves, L. M.;
 Ambrizzi, T.; Anunciacao, Y. M. T.; Baez,
 J.; Barros, V. R.; Berlato, M. A.; Bidegain,
 M.; Coronel, G.; Garcia, V. J.; Grimm, A.
 M.; Karoly, D.; Marengo, J. A.; Marino,
 M. B.; Moncunill, D. F.; Nechet, D.;
 Quintana, J.; Rebello, E.; Rusticucci, M.;
 Santos, J. L.; Trebejo, I.; Vincent, L. A.
 2005. Trends in total and extreme South
 American rainfall 1960-2000 and links
 with sea surface temperature. Journal of
 Climate.

- IPCC Intergovernmental Panel in Climate Change. 2001. Climate Change 2001: Impacts, Adaptation and Vulnerability. Genebra, Suica.
- Kevin E. Trenberth. Atmospheric moisture Residence Times And Cycling: Implications For Rainfall Rates And Climate Change. 199). Climatic Change 39: 667–694, 1998. Kluwer Academic Publishers. Printed in the Netherlands.
- http://echorock.cgd.ucar.edu/cas/Trenberth/trenberth.papers/ClilmChg39_667-694.pdf
- Machado, C. C. C. ;Galvíncio, J. D. ; Oliveira, T. H . 201). Estimativa dos valores de saldo da radiação e fluxo de calor no solo no município de São José do Sabugí - PB (Brasil), utilizando o algoritmo SEBAL, Coimbra. VI Seminário Latino Americano e II SeminárioIbero Americano de GeografiaFísica.Coimbra, v. 1. p. 49-62.
- Marengo, J.; Tomasella, J.; Uvo, C. 1998. Long-term stream flow and rainfall fluctuations in tropical South America: Amazonia, eastern Brazil and northwest Peru. Journal of Geophysical Research, n. 103, p. 1775-1783.
- Moura, M. S. B.; Galvíncio, J. D.; Silva. B. B.; Machado, C. C. C.; Oliveira, T. H.; Silva. (2012). Gross Primary production using related vegetation indices. In: ASABE, 2012, Dallas. 2012 ASABE Annual International Meeting. Dallas: ASABE, 2012. v. 1. p. 53.
- Pinto, E. J. de A.; Naghettini, M.; Abreu, M. L. De. (2006). Utilização de Indicadores Climáticos na Previsão Probabilística de Precipitações e Vazões na Bacia do Alto São Francisco. RBRH Revista Brasileira de Recursos Hídricos, Volume 11 n.4 Out/Dez, 137-151.
- Rocha, E. P. 2001. Balanco de Umidade e Influencia de Condicoes de Contorno Superficiais sobre a Precipitacao da Amazonia. Tese de Doutorado, Programa de Pos-Graduacao em Meteorologia, INPE, Sao Jose dos Campos, SP, Brasil.
- Santos, C. A. C.; Brito, Jose Ivaldo Barbosa
 De; Ramana Rao, T. V.; Menezes, H. E.
 A. 2009. Tendencias dos indices de precipitacao no Estado do Ceara. Revista
 Brasileira de Meteorologia, v. 24, p. 39-47.

- Santos, C. A. C.; Brito, J. I. B. 2007. Analise dos Indices de Extremos dara o SemiArido do Brasil e suas relacoes com TSM e IVDN. Revista Brasileira de Meteorologia, v.22, n.3, 303-312.
- Santos, Carlos Antonio Costa dos; Bezerra, Bergson Guedes; Silva, Bernardo B. Da; Rao, Tantravhi Venkata Ramana .2010a. Assessment of daily actual evapotranspiration with SEBAL and S-SEBI algorithms in cotton crop.Revista Brasileira de Meteorologia (Impresso), v. 25, p. 383-392.
- Santos, Carlos Antonio Costa Dos; Silva, Bernardo B. Da; Rao, Tatravahi Venkata Ramana. 2010. Analysis of evapotranspiration fraction using eddy covariance and remote sensing techniques. Revista Brasileira de Meteorologia (Impresso), v. 25, p. 427-436.
- Santos, Carlos Antonio Costa Dos; Silva, Bernardo B. Da; Rao, T. V. R.; Neale, Christopher Michael Usher. 2009. Energy balance measurements over a banana orchard in the semiarid region in the Northeast of Brazil. Pesquisa Agropecuária Brasileira (1977. Impressa), v. 44, p. 1365-1376.
- Silva, G.B.; Azevedo, P.V. 2008. Indices de tendencias de mudancas climaticas no Estado da Bahia. Engenharia Ambiental: Pesquisa e Tecnologia, Vol. 5, No 3.
- Souza, W.M.; Azevedo, P. V. 200). Avaliacao de tendencias das temperaturas em Recife-PE: mudancas climaticas ou variabilidade?. Engenharia Ambiental: Pesquisa e Tecnologia., v.6, p.462 472.
- Silva, C. A. V.; Galvíncio, J. D. 2009. Relationship Between The Climate And Runoff In The Pirapama-Pe River Basin. Revista Brasileira De Geografia Física, V. 2, P. 57-69.Storch, H. v.; Zwiers. F. W. 1999. Statistical Analysis in Climate Research. Cambridge University Press.[18].
- Sukharev 2001. http://www.gfdl.noaa.gov/bibliography/rel ated files/js0901.pdf
- Teixeira, A; Bastiaanssen, W; Moura, M; Soares, J; Ahmad, M; Bos, M. 2008. Energy and water balance measurements for water productivity analysis in irrigated

- mango trees, Northeast Brazil. Agricultural and Forest Meteorology, p. 1524.
- Teixeira, A; Bastiaanssen, W; Ahmad, M; Moura, M; Bos, M. 2008B. Analysis of energy fluxes and vegetation-atmosphere parameters in irrigated and natural ecosystems of semi-arid Brazil. Journal of Hydrology (Amsterdam), v. 362, p. 110-127.
- Thornthwaite, C.W.; Mather, J.R. 1955. The water balance.Publications in Climatology. New Jersey: Drexel Institute of Technology, 104p.