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MULTISCALE CLIMATE VARIABILITY OF THE REGIONAL WEATHER FORECAST ETA MODEL SHORT AND LONG RANGE RUNS

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Abstract: In this work a case study of a multi-scale analysis of the short and long range Eta model runs. Here we compared the output of this numerical weather model to a representative local station dataset during part of a summer season. In this context, we use the variance wavelet analysis, using the continuous wavelet transform to compute the wavelet spectrum or scalogram. The Eta Model used here is a grid point weather forecast model configured with 40 km resolution. One of the characteristics of the model is the eta vertical coordinate which reduces the pressure gradient force errors near mountain regions. The time scheme applied is the forward-backward scheme for the adjustment terms and first-forward-then-uncentered scheme for the horizontal advection. Lateral boundary conditions are prescribed along a single outer line without need for boundary relaxation. The prognostic variables are temperature, specific humidity, horizontal wind, surface pressure, the turbulent kinetic energy and cloud liquid water/ice. The model has complete physics package and the cumulus convection is parameterized by the Betts-Miller scheme. The objective of this analysis is to identify the differences between the atmospheric scales present in the short-range and long-range model runs. Here we found the identification of the timescales in which long-range integration scale exhibits larger difference from the short-range integrations. This can help to indicate the weather systems of low predictability in the model. Moreover, the analysis helps to identify the weather systems that are not represented by the model in the seasonal climate integrations.

Keywords: eta model, wavelet, climate analysis

Abstract

1. INTRODUCTION

The wavelet analysis is a mathematical technique which is very useful in many applied areas for understanding the multi-scaling signal aspects. Originally applied in geophysics to the analysis of seismic signals, the wavelet transforms were better and broadly formalized thanks to mathematicians, physicists, and engineers efforts [18]. Therefore, the use of wavelet techniques in data analysis has exponentially grown, since it represents a synthesis of old techniques associated with robust mathematic results and efficient computational algorithms under the interest of a broad community [10].

In atmospheric applications, the main characteristic of the wavelet technique is the introduction of the time- decomposition. A well known example of such a behavior can be found in the musical structure, where it has been interpreted as events localized in time. Although it belongs to a more complex structure, a piece of music can be understood as a set of musical notes characterized by four parameters: frequency, time of occurrence, duration and intensity [6, 7, 13].

In this work a multi-scale analysis of the short and long range Eta model runs are done and compared to a representative local station data sets during part of a summer season. In this context, the main direction has been followed for this signal analysis is the variance wavelet analysis, using the continuous wavelet transform or, in analogy with Fourier terminology, the wavelet spectrum or scalogram.

The objective of this analysis is to identify the differences between the atmospheric spectra present in the short-range and long-range model runs. The identification of the timescales in which long-range integration spectrum exhibits larger difference from the short-range integrations can help to indicate the weather systems of low predictability in the model. Moreover, the analysis should help to identify the weather systems that are not represented by the model in the seasonal climate integrations.

In the following sessions some basic concepts on wavelet analysis, scalogram and wavelet variance are present, data and methodology is discussed and after it some final remarks are done.

2. DATASET

The dataset comprises the observation taken from at site located and the Eta Model grid-box values from a 72-hour and a 4.5-month integrations. The measurements at Fazenda São Bento $(19^o33'48, 2''\text{S}, 57^o0053, 8\text{W}$ were taken from an experimental station located in the western part of Brazil in the Pantanal region, a flat terrain area covered mostly by homogeneous grassy vegetation. In Figure 1 a picture of the experimental station is presented. One can consider this place as a representative place of this region.

During the summer periods, deep convection and heavy rains can develop in few hours in the region and after it the main rivers carries a flood that usually cover the soil for three-four months a year, from March-June, in large subregions of Pantanal region.

However, the Pantanal region has the meteorological characteristics of a middle latitude region. As reference the mean climatology temperature and precipitation ranges can be found in the monthly from the National Institute of Meteorology (INMET).

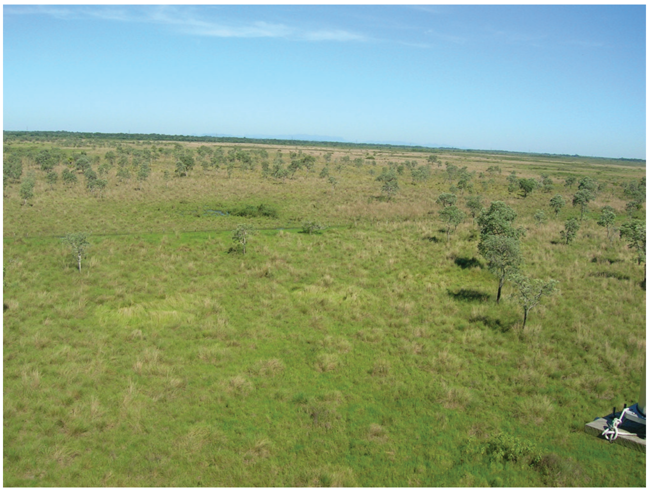

Figure 1 – Experimental station located in the western part of Brazil in the Pantanal region Fazenda São Bento $(19^o33'48, 2''$ **S,** $57^o0053, 8$**W).**

The Eta Model [2, 17] is a grid point model configured with 40km resolution. One of the characteristics of the model is the eta vertical coordinate [16] which reduces the pressure gradient force errors near mountain regions. The time scheme applied is the forward-backward scheme for the adjustment terms and first-forward-then-uncentered scheme for the horizontal advection. Lateral boundary conditions are prescribed along a single outer line without need for boundary relaxation [16]. The prognostic variables are temperature, specific humidity, horizontal wind, surface pressure, the turbulent kinetic energy and cloud liquid water/ice. The model has complete physics package [11]. The cumulus convection is parameterized by the Betts-Miller scheme [1] and modified by [11]. The atmospheric radiative transfer applies the Lacis and Hansen scheme [12] to treat the shortwaves and Fels-Schwarzkopf scheme [8] for the longwaves. The land surface scheme is based on the Chen scheme [4]. The atmospheric turbulence is treated by the Mellor-Yamada 2.5 level [14]. More details of the configuration can be found in [5]. The model initial conditions are taken from National Centers for Environmental Prediction analysis, whereas the lateral boundary conditions are taken from CPTEC/INPE global model [3].

This 3D weather model produces operationally forecasts for 24, 48 and 72-hours resulted from the integration of new observational data. These forecast cover at least all South America in grid-boxes. The model grid-box which contains the point of the station data was extracted to construct the time series. This point is located far from the lateral boundaries. Four 6-hourly model time series were constructed, one from a continuous 4.5-month integration, and three other from short integrations: 24, 48 and 72-hour time series. The 24-hour time series are constructed from the the 6, 12, 18 and 24-hour forecasts, the 48-hour time series are constructed from the 30, 36, 42 and 48-hour forecast, and finally the 72-hour time series are constructed from the 54, 60, 66 and 72h-hour forecasts.

3. BASIC CONCEPTS IN CONTINUOUS WAVELET TRANSFORM

The continuous wavelet transform (CWT) of a time series f is defined by the integral transform,

$$\mathbf{W}_f^{\psi}(a,b) = \int_{-\infty}^{\infty} f(u)\bar{\psi}_{a,b}(u)\,du \qquad a > 0,$$

where

$$\psi_{a,b}(u) = \frac{1}{\sqrt{a}}\,\psi\left(\frac{u-b}{a}\right)$$

represents a chosen wavelet function family, named mother–wavelet. The parameter a refers to a scale, b is a translation parameter or localization of the mother–wavelet function and $\bar{\psi}_{a,b}(u)$ is the conjugate complex of $\psi_{a,b}(u)$. The variation of a has a dilatation effect (when $a > 1$) and a contraction effect (when $a < 1$) of the mother–wavelet function. Therefore, it is possible to analyze the long and short period features of the signal or the low and high frequency aspects of the signal. As b varies, the function f is locally analyzed in the vicinities of this point. The continuous wavelet transform is linear and covariant under translation and dilatation transform. Then this transform can be used in the analysis of non-stationary signals to obtain information on the frequency or scale variations of those signals and to detect its structures localization in time and/or in space.

Such a transform is called the continuous wavelet transform (CWT), because the scale and localization parameters assume continuous values. The CWT of an one dimension time series is a two dimension representation in a the so called scalogram, that can be real or complex depending the wavelet one is using. It is also possible to get the inverse function of this transform, namely:

$$\mathbf{IW}_f^{\psi}(u) = \frac{1}{C_\psi} \int_{-\infty}^{\infty} \int_0^{\infty} \frac{1}{a^2} \mathbf{W}_f^{\psi}(a,b)\, \bar{\psi}_{a,b}(u)\, da\, db,$$

where C_ψ is a constant that depends on the chosen wavelet function.

A wavelet function must satisfy the following conditions.

1) The integral of the wavelet function, usually denoted by ψ, must be zero.This assures that the wavelet function has a wave shape and it is known as the admissibility condition.

2) The wavelet function must have unitary energy.This assures that the wavelet function has compact support or has a fast amplitude decay (in a physical vocabulary *e-folding time*), warranting a physical domain localization.

The wavelet function used in this work is the so called Morlet wavelet . This function is formed by a plane wave modulated by a Gaussian function and it is given by

$$\psi(x) = \pi^{-\frac{1}{4}} \left(e^{i\xi x} - e^{-\frac{\xi^2}{2}} \right) e^{-\dfrac{x^2}{2}},$$

where ξ is a non dimensional value. Ordinarily ξ is assumed to be equal to 5 to make the highest and lowest values of ψ be approximately equal to $1/2$, thus the admissibility condition is satisfied [6].This wavelet is a complex function it is possible to analyze the phase and the modulus of the decomposed signal. In this work only the modulus aspect is explored.

The wavelet transform is a transform that preserves the energy. In analogy with the terminology adopted in Fourier analysis, the squared modulus of the wavelet coefficients of the CWT is called scalogram and the product of two CWT of distinct functions is called cross-scalogram [9]. The scalogram informs if the analyzed signal has multi-scale characteristics and which scales participate in the processes depicted by the signal. Focusing on the measurement and characterization of the local kinetic energy in each scale in turbulence flow, the variance wavelet analysis or the wavelet spectrum has been originally defined by [15] as

$$S(a) = \int_{-\infty}^{\infty} \mathbf{W}_f^{\psi}(a,t) dt.$$

These are the main aspects used in this work. On the scalogram analysis will be focus on the results inside the boundary influence cone. This cone was constructed to avoid the non-periodic borders effects on the signal analysis in the worse case of a discontinuity on the signal on the boundaries. On the scalograms presented here the scale a is convert to pseudo frequency k to compare the scalogram an the Fourier transform of the datasets.

4. RESULTS AND DISCUSSIONS

In Figures 2, 3 and 4 are presented the scalograms, and wavelet global and Fourier spectrum for the observational relative humidity dataset and Eta Model relative relative humidity dataset for short and long runs, respectively. The main aspect observed in those wavelet global and Fourier spectra are the spike on the diurnal frequency. Most of the energy is concentrate on these variations for all cases. On the other hand, how these energy is distributed during the time marching changes significantly. The observational data presented energy oscillations from one day to the other while the long term runs presented a almost constant pattern of energy, this support the idea that there is a strong contribution of the diurnal cycle in these long runs. On the short runs, the $48h$ case has the closest behavior of the observational data. This fact agrees with the experience of weather forecasters.

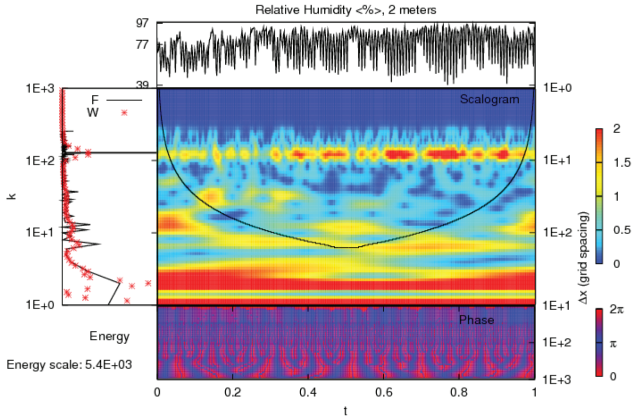

Figure 2 – Scalograms (central), phase (bottom), wavelet global spectrum and Fourier spectrum (left) for the observational dataset relative humidity dataset obtatined in Pantanal region.

These patterns also appeared on other variables such as pressure and air temperature. On Figures 5 and 6 a 2D plot of the scalogram energy is presented for the data, the short and the long runs for the variables of pressure and temperature for the comparations of the energy oscillation arround the diurnal frequency.

5. FINAL REMARKS

Here we found the identification of the timescales in which long-range integration scale exhibits larger difference from the short-range integrations. The verified that long-range runs are dominate to diurnal cycles. Moreover, this analysis helps to identify the weather systems that are not represented by the model in the seasonal climate integrations.

The similar behavior of the short range 48 h runs with the observational data interesting could be associate to the fact that the numerical model has an inertial to activate the so called "model physics" that governs the thermo and dynamics of the simulated troposphere.

The scalogram of the numerical runs and the observational dataset in association with phenomenology studies can help to indicate the weather systems of low predictability in the model. In this way the numerical forecast time series, especially humidity, somewhat contain the daily cycle of the particular time range forecast.

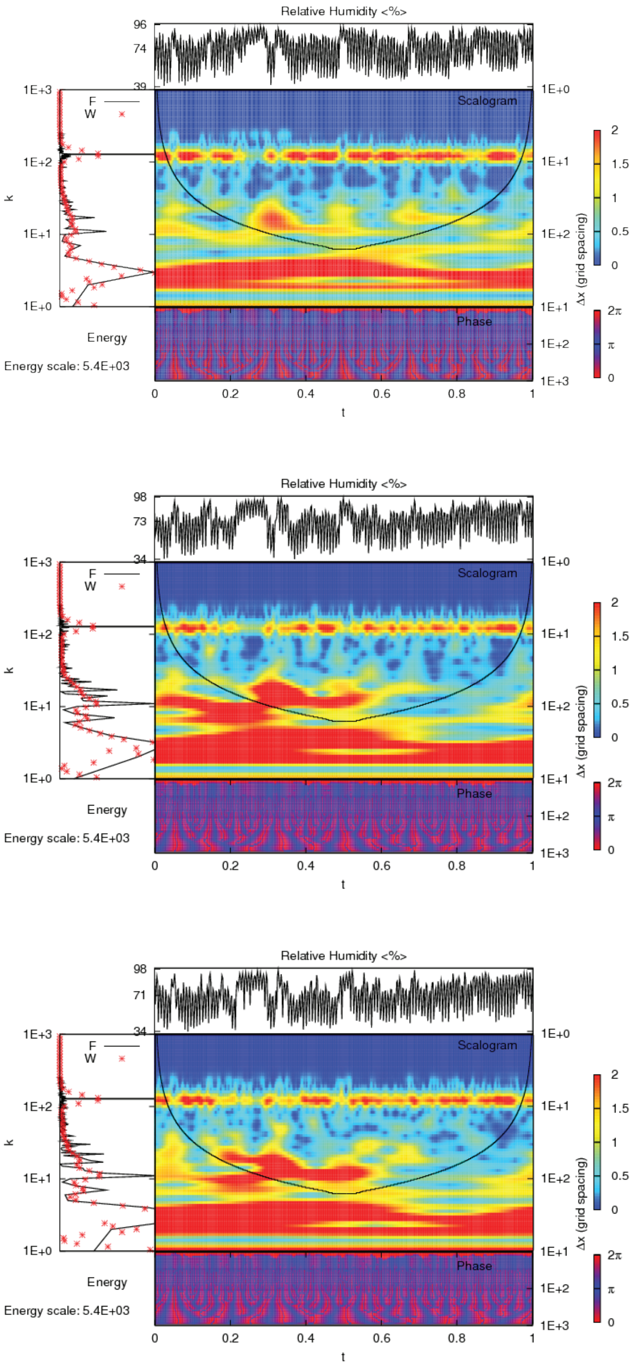

Figure 3 – Scalograms (central), phase (bottom), wavelet global spectrum and Fourier spectrum (left) for the Eta Model relative humidity datasets obtatined from the short runs : 24 **h,** 48 **h and** 72 **h.**

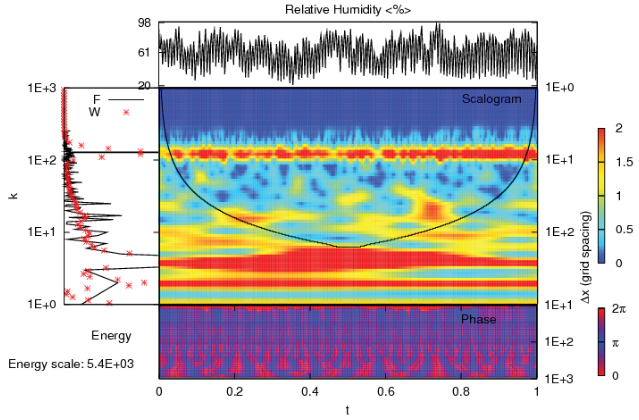

Figure 4 – Scalograms(central), phase (bottom), wavelet global spectrum and Fourier spectrum (left) for the Eta Model relative humidity dataset obtatined from the long run.

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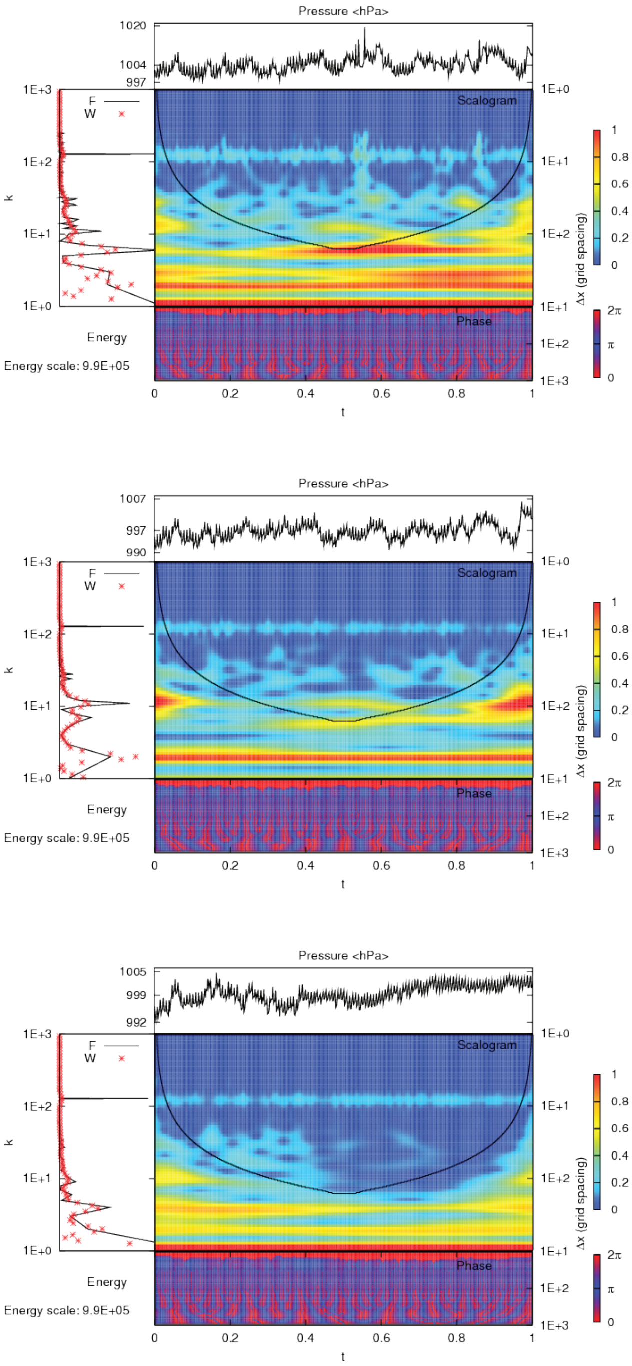

Figure 5 – Scalograms (central), phase (bottom), wavelet global spectrum and Fourier spectrum (left) for the experimental and Eta Model pressure datasets obtatined from from São Bento and the short runs of 48 h and long runs.

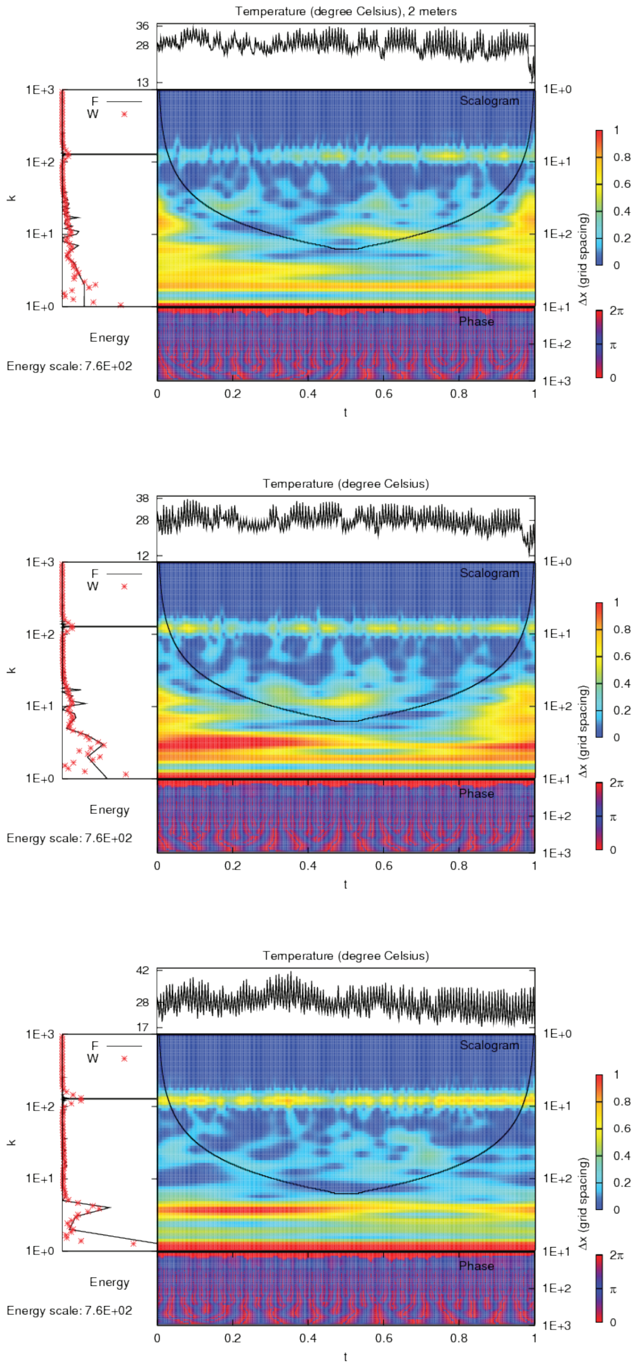

Figure 6 – Scalograms (central), phase (bottom), wavelet global spectrum and Fourier spectrum (left) for the experimental and Eta Model temperature datasets obtatined from São Bento and the short runs of 48 h and long runs.

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