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14. ABSTRACT
During the period of 01 August 2014 to 31 May 2015 the maximum entropy production (MEP) model, now formulated for all land-cover types including bare soil, canopy, water, snow and ice, was expanded to modeling global surface energy budget, fluxes and greenhouse gases (e.g. carbon dioxide and methane) fluxes, ocean freshwater fluxes, regional crop yield among others. An on-going study suggests that the global annual evapotranspiration (ET) over oceans may be significantly lower than previously thought. The MEP model

15. SUBJECT TERMS
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Report Title

Final Report: Using the Maximum Entropy Principle as a Unifying Theory for Characterization and Sampling of Multi-scaling Processes in Hydrometeorology

ABSTRACT

During the period of 01 August 2014 to 31 May 2015 the maximum entropy production (MEP) model, now formulated for all land-cover types including bare soil, canopy, water, snow and ice, was expanded to modeling global surface energy budget, fluxes and greenhouse gases (e.g. carbon dioxide and methane) fluxes, ocean freshwater fluxes, regional crop yield among others. An on-going study suggests that the global annual evapotranspiration (ET) over oceans may be significantly lower than previously thought. The MEP model parameterized turbulent transfer coefficients result in good estimates of surface fluxes of greenhouse gases, a finding pointing to a new method of modeling the global carbon budget using remotely sensed data. A new model of ocean freshwater fluxes derived from sea surface salinity provides independent estimates of ocean ET for cross-validation of the MEP modeled ET.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
07/06/2015	6.00	V. Nieves, J. Wang, J. K. Willis. A conceptual model of ocean freshwater flux derived from sea surface salinity, Geophysical Research Letters, (09 2014): 1. doi: 10.1002/2014GL061365
07/06/2015	8.00	Sanaz Moghim, Andrew Jay Bowen, Sepideh Sarachi, Jingfeng Wang. Retrieval of Hourly Records of Surface Hydrometeorological Variables Using Satellite Remote Sensing Data, Journal of Hydrometeorology, (02 2015): 147. doi: 10.1175/JHM-D-13-0127.1
07/06/2015	7.00	Husayn El Sharif, Jingfeng Wang, Aris P. Georgakakos. Modeling Regional Crop Yield and Irrigation Demand Using SMAP Type of Soil Moisture Data, Journal of Hydrometeorology, (04 2015): 904. doi: 10.1175/JHM-D-14-0034.1
07/07/2015	10.00	J. Wang, Rafael L. Bras. A model of surface heat fluxes based on the theory of maximum entropy production, Water Resources Research, (11 2009): 0. doi: 10.1029/2009WR007900
07/07/2015	16.00	J. Wang, R. L. Bras, V. Nieves. Statistics of multifractal processes using the maximum entropy method, Geophysical Research Letters, (09 2011): 0. doi: 10.1029/2011GL048716
07/07/2015	15.00	R. L. Bras, Jingfeng Wang. A model of evapotranspiration based on the theory of maximum entropy production, Water Resources Research, (03 2011): 0. doi: 10.1029/2010WR009392
07/07/2015	14.00	Jingfeng Wang, Rafael L. Bras, Veronica Nieves, Elizabeth Wood. Maximum Entropy Distributions of Scale-Invariant Processes, Physical Review Letters, (09 2010): 118701. doi: 10.1103/PhysRevLett.105.118701
07/07/2015	13.00	Jingfeng Wang, Rafael L. Bras. Reply, Journal of the Atmospheric Sciences, (06 2011): 1409. doi: 10.1175/2010JAS3735.1
07/07/2015	12.00	Jingfeng Wang, Rafael L. Bras. Reply to the Comments on “An Extremum Solution of Monin-Obukhov Similarity Equations”, Journal of the Atmospheric Sciences, (06 2011): 1409. doi: 10.1175/2010JAS3735.1
07/07/2015	11.00	Jingfeng Wang, Rafael L. Bras. An Extremum Solution of the Monin–Obukhov Similarity Equations, Journal of the Atmospheric Sciences, (02 2010): 485. doi: 10.1175/2009JAS3117.1
07/07/2015	9.00	R. L. Bras, G. Sivandran, R. G. Knox, J. Wang. A simple method for the estimation of thermal inertia, Geophysical Research Letters, (03 2010): 1. doi: 10.1029/2009GL041851
07/14/2014	5.00	Rafael L. Bras, Veronica Nieves, Jingfeng Wang, Yi Deng. A model of energy budgets over water, snow, and ice surfaces, Journal of Geophysical Research: Atmospheres, (06 2014): 0. doi: 10.1002/2013JD021150

TOTAL: 12

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received	Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

1. Huang, S.-Y., Y. Deng, and J. Wang, Re-Evaluation of the Earth's Surface Energy Balance Using a New Method of Heat Fluxes, American Geophysical Union Fall Meeting, San Francisco, CA, December, 2014.

2. Huang, S.-Y., and J. Wang, Force-Restore Model of surface temperature using a new parameterization of ground heat flux (H21C-1055), American Geophysical Union Fall Meeting, San Francisco, CA, December, 2013.

3. Sharif, H. E., J. Wang, A. Georgakakos, and R. L. Bras, Anticipating the value of high resolution, remotely-sensed soil moisture measurements in the modeling of regional agricultural yield and irrigation demand (H51I-1316), American Geophysical Union Fall Meeting, San Francisco, CA, December, 2013.

4. Shahnaz, S., and J. Wang, Carbon flux estimated from CO2 concentration using half order derivative method (B21A-0460), American Geophysical Union Fall Meeting, San Francisco, CA, December, 2013.

5. Wang, J, and R. L. Bras, A model of energy budget over water, snow and ice surfaces, American Geophysical Union Fall Meeting, San Francisco, CA, December 2012.

6. Wang, J, and R. L. Bras, An MEP model of surface heat fluxes, 8th Annual Meeting of Asia Oceania Geosciences Society, Taipei, Taiwan, 8-12 August 2011.

7. Bras, R. L., G. Bisht, J. Wang, Remote Sensing of Land Surface Energy Budget of Radiative and Turbulent Fluxes, ARO Terrestrial Science PI meeting, COE-WES, Vicksburg, MS, August 3-4, 2010

8. Bras, R. L., G. Bisht, J. Wang, Remote Sensing of Land Surface Energy Budget of Radiative and Turbulent Fluxes, 27th Army Science Conference, Orlando, Florida, Nov 29 – Dec 2, 2010

9. Bras, R. L., and J. Wang, An MEP model for remote sensing of evapotranspiration (invited talk), American Geophysical Union Fall Meeting, San Francisco, CA, December 2010.

10. Wang, J., R. L. Bras and V. Nieves, Use of the entropy methods in modeling eco-hydro-geomorphological processes (invited talk), American Geophysical Union Fall Meeting, San Francisco, CA, December 2010.

11. Nieves, V., E. Wood, J. Wang, and R. L. Bras, Maximum entropy distributions of scale-invariant processes, American Geophysical Union Fall Meeting, San Francisco, CA, December 2010.

12. Moghim, S., S. Sarachi, J. Wang, and R.L. Bras, Retrieval of Hourly Records of Surface Hydro-meteorological Variables using Satellite Remote Sensing Data, American Geophysical Union Fall Meeting, San Francisco, CA, December 2010.

13. Wang, J., R. L. Bras, G. Sivandran, and R. Knox, "A Simple Method for Estimation of Thermal Inertia Using Remote Sensing Observations," American Geophysical Union Fall Meeting, San Francisco, CA, December 2009.

14. Wang, J., E. Wood, and R. L. Bras, Maximum Entropy Solution of Power-law Distribution of River Networks, American Geophysical Union Fall Meeting, San Francisco, December 2008.

15. Wang, J. and R. L. Bras, Application of the Principle of Maximum Entropy Production (MEP) in Modeling Land Surface Energy Balance, American Geophysical Union Fall Meeting, San Francisco, December 2008.

16. Wang, J, and R. L. Bras, On Ignorance Prior Distributions and the Principle of Indifference, Workshop on maximum Entropy Production in the Earth System, Workshop on maximum Entropy Production in the Earth System at Max-Planck Institute for Biogeochemistry, May 2008.

Number of Presentations: 16.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

08/20/2012 3.00 Jingfeng Wang, Rafael L. Bras. An application of the maximum entropy production principle in modeling heat fluxes over land surfaces,
BAYESIAN INFERENCE AND MAXIMUM ENTROPY METHODS IN SCIENCE AND ENGINEERING: 31st International Workshop on Bayesian Inference and Maximum Entropy Methods in Science and Engineering. 09-JUL-11, Waterloo, Ontario, Canada. : ,

08/20/2012 1.00 Jingfeng Wang, Rafael L. Bras, Veronica Nieves. A Bayesian analysis of scale-invariant processes,
BAYESIAN INFERENCE AND MAXIMUM ENTROPY METHODS IN SCIENCE AND ENGINEERING: 31st International Workshop on Bayesian Inference and Maximum Entropy Methods in Science and Engineering. 09-JUL-11, Waterloo, Ontario, Canada. : ,

08/20/2012 2.00 Jingfeng Wang, Rafael L. Bras. On ignorance priors and the principle of indifference,
BAYESIAN INFERENCE AND MAXIMUM ENTROPY METHODS IN SCIENCE AND ENGINEERING: 31st International Workshop on Bayesian Inference and Maximum Entropy Methods in Science and Engineering. 09-JUL-12, Waterloo, Ontario, Canada. : ,

TOTAL: **3**

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Book

08/11/2013 4.00 Jingfeng Wang, Veronica Nieves, Rafael L. Bras. MaxEnt and MaxEP in modeling fractal topography and atmospheric turbulence, Berlin: Springer Verlag, (09 2013)

TOTAL: **1**

Received Book Chapter

TOTAL:

Patents Submitted

Patents Awarded

Awards

1. Rafael L. Bras, Distinguished Member, ASCE, 2015
2. Rafael L. Bras, National Hispanic Scientist of the Year Award, Museum of Science and Industry, Tampa, Florida, 2014

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Husayn El Sharif	1.00	
Shih-Yu Huang	1.00	
Sabina Shahnaz	1.00	
Sanaz Moghim	0.00	
FTE Equivalent:	**3.00**	
Total Number:	**4**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
Veronica Nieves	1.00
FTE Equivalent:	**1.00**
Total Number:	**1**

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Rafael L. Bras	0.05	Yes
Jingfeng Wang	0.10	
FTE Equivalent:	**0.15**	
Total Number:	**2**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

Names of Personnel receiving masters degrees

NAME
Sabina Shahnaz (to be awarded)
Total Number: 1

Names of personnel receiving PHDs

NAME
Sanaz Moghim
Husayn El Sharif (to be awarded)
Shih-Yu Huang (to be awarded)
Total Number: 3

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

This project reveals that multi-scaling hydro-meteorological processes can be characterized by the maximum entropy principle from the perspective of both a physical principle and an inference algorithm. We have demonstrated that the statistical distributions of a multi-scaling process can be derived using the maximum entropy method characterized by parameters representing macroscopic observable properties of the physical process. This finding laid the foundation for a new observation network design concept. The information entropy-based network design is capable of predicting the optimal locations of the stations to be included in the network configuration measured by the information gain under physical and budgetary constraints without using arbitrarily selected objective or cost functions.

We further developed an innovative model of evapotranspiration (ET) and heat fluxes using the maximum entropy method and its derivative the maximum entropy production (MEP) principle. The newly formulated MEP model overcomes difficulties with existing approaches to the modeling and estimation of the exchange of water and energy over the Earth-atmosphere interface. The MEP model of ET is the first physically-based method for predicting ET without using water vapor pressure gradient data. It is also the first physically based model to predict the surface energy budget (or all turbulent and conductive heat fluxes in the surface energy balance equations) without using temperature and water vapor gradient data while closing the energy budget. Its applications to the study of climate and ecosystems are facilitated by its advantageous properties such as parameter parsimony. In contrast to existing models the MEP model does not rely on difficult to obtain wind speed and surface roughness parameters. We have shown that the development of the MEP model opens new opportunities for monitoring and modeling water-energy-carbon cycles at scales ranging from local to global.

Technology Transfer

Final Report of ARO W911NF-12-1-0095

Using the Maximum Entropy Principle as a Unifying Theory for Characterization and Sampling of Multi-scaling Processes in Hydrometeorology

Co-PIs: Rafael L. Bras and Jingfeng Wang
Georgia Institute of Technology, Atlanta, GA

20 August 2015

Table of Content

1. Statement of the Problem Studied

Accurate prediction of environmental conditions for army operations requires understanding, Monitoring and modeling complex systems associated with hydro-meteorological, geomorphological and ecological processes over a wide range of space and time scales. Variabilities in these processes are often characterized by certain invariant properties across a broad range of closely coupled scales referred to as scaling (or multi-scaling) behavior. Such scaling behavior is expected to have important influence on the output of hydrological systems such as runoff, surface heat and water fluxes, and biomass productivity among others. For example, circulation in the atmosphere is known to result from the interaction of energy expressed at multiple scales; soil moisture depends on precipitation, topography, soils and vegetation that themselves show richness and variability at scales that span many orders of magnitude; the organization of landscapes and the drainage networks again is the result of complex interactions at multiple scales and in fact exhibit organizational patterns with no dominant scales. Understanding the multi-scaling properties of the above examples is necessarily a first step in monitoring and modeling these processes. There are many ad hoc empirically and physically based theories and models to describe the multi-scaling behavior. Yet a universal principle for analyzing the multi-scaling processes is still elusive. The project is an attempt to explore the feasibility of such a unified framework for characterizing multi-scaling behavior and use the results in the effective design of hydrologic data collection networks.

One promising theory for a general and simple organizing principle is Maximum Entropy (MaxEnt). The objective of this proposal is to explore the MaxEnt and its derivative the Maximum Entropy Production (MEP) principle as unifying principles to characterize multi-scaling hydro-meteorological processes such as rainfall, soil moisture, and water /heat fluxes and to develop MaxEnt-based design of data collection networks for the sampling of multi-scaling processes and MEP-based model of surface fluxes. The MaxEnt, as an inference algorithm as well as a physical principle, is able to assign probability distributions to the microscopic states of a system based on its known macroscopic properties, and retrieve useful information from incomplete noisy data using entropy as a consistent quantitative measure of information.

The project has two main objectives: (1) to explore the Maximum Entropy (MaxEnt) as a unifying principle in characterizing multi-scaling hydro-meteorological parameters including rainfall, soil moisture and surface water and energy fluxes for designing data collection network of multi-scaling processes; and (2) to develop Maximum Entropy Production (MEP)-based models of surface heat and water fluxes using remote sensing only input.

2. Summary of the Most Important Results

MaxEnt Characterization of Multi-scaling Processes MaxEnt probability distributions of self-similar processes characterized by power-law distribution (e.g. drainage area of river network) and homogeneous/non-homogenous multi-scaling processes characterized by (multi-scaling) moments of the incremental processes (e.g. surface soil moisture and topography over some regions) have been derived and validated using field and remote sensing observations.

We have demonstrated that the MaxEnt theory allows the statistical behavior of the scale-invariant self-similar processes such as drainage area of river network (DARN), surface soil moisture (SSM), and digital elevation map (DEM) to be characterized by a small number of macroscopically observable quantities. Such scale-invariant behavior resulting from selforganization emerges as the most probable and macroscopically reproducible state. It turns out that the geometric mean provides essential information for shaping river networks. The geometric mean is identified as an important parameter, in addition to the moments, in characterizing multi-scaling incremental processes of soil moisture and topography. More importantly, our analysis indicates that the ME theory is a universal and unified framework to characterize those processes governed by scale-invariant laws. The cases studies are demonstrate in Figures 1 and 2 below

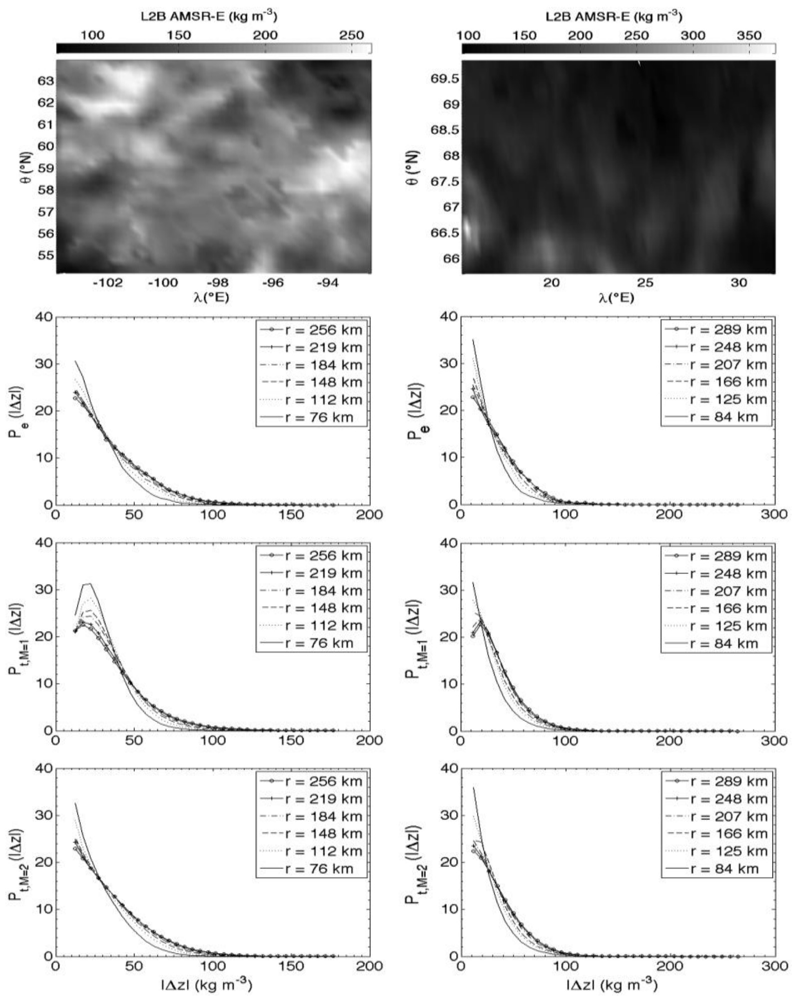

Figure 1. From top to bottom. Left panels: L2B AMSR-E soil moisture map for October 18, 2009 and region R1SSM, associated empirical (P_e) and the MaxEnt distributions for M=1,2 ($P_{t,M-1}$ and $P_{t,M-2}$ according to Eq. (12) of (Nieves et al., 2010). Right panels: same for region R2SSM. Maps are represented in longitude _ and latitude _ degrees. All probabilities are plotted versus the absolute value of the increments $\Delta z = \left| z(\vec{x}_1) - z(\vec{x}_2) \right|$ for different separation distances $r = \left| \vec{x}_1 - \vec{x}_2 \right|$.

(Nieves et al., 2010)

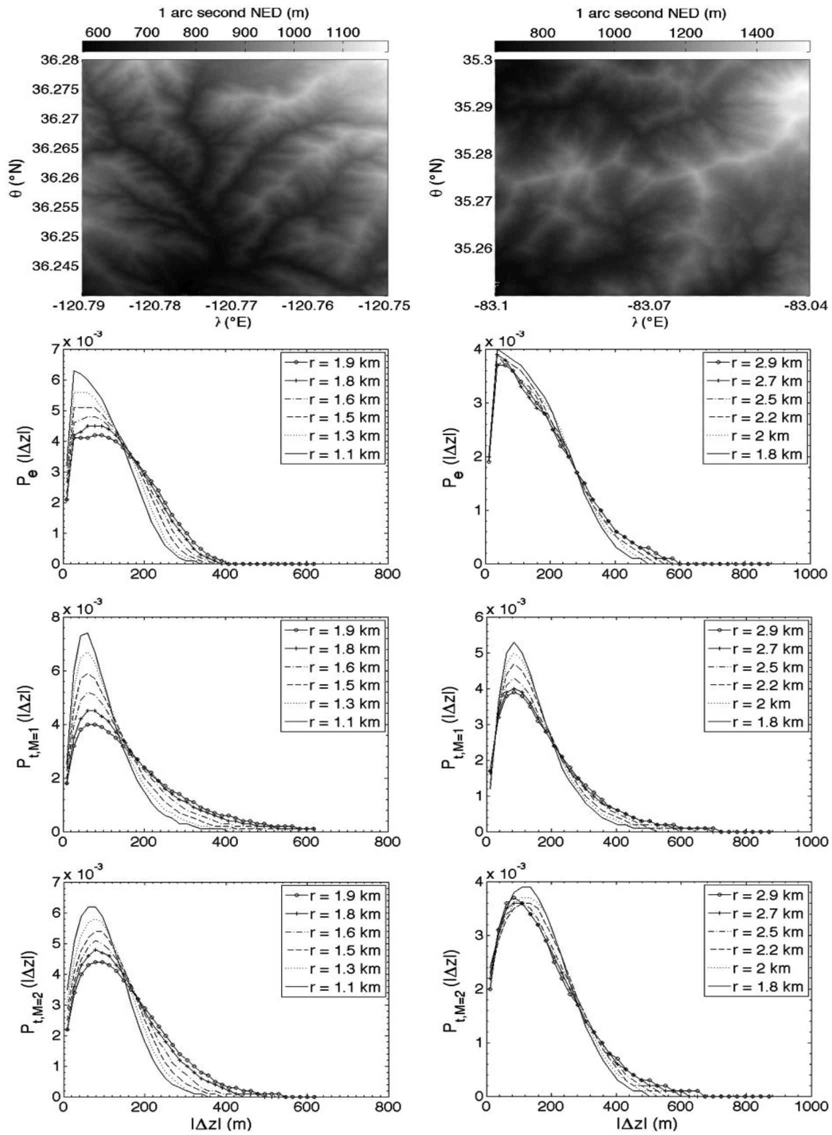

Figure 2. Same as in Figure 1 for regions R1DEM and R2DEM corresponding to the 1 arc second USGS National Elevation Dataset (NED). (Nieves et al., 2010)

We further show that the MaxEnt principle offers a unifying and general framework for inferring statistics of multifractal processes at different scales when combined with the wavelet representation of the cascade model. Three quantities, namely the multifractal condition, the multi-scaling moments, and the geometric means, are most important in characterizing the multifractal processes. The MaxEnt formalism leads to the probability distribution of the multi-scaling parameter of a multifractal process and those of the increments of topography at different scales, preserving the cascade properties without computing histograms. More importantly, the MaxEnt theory opens new possibilities of gathering information of multifractal processes beyond the scales of observation. Our findings might be of interest to those who deal with the complexity and limitations of observational data and helpful to improve the understanding of broad geophysical processes governed by scaling laws. Figure 3 illustrates a case study.

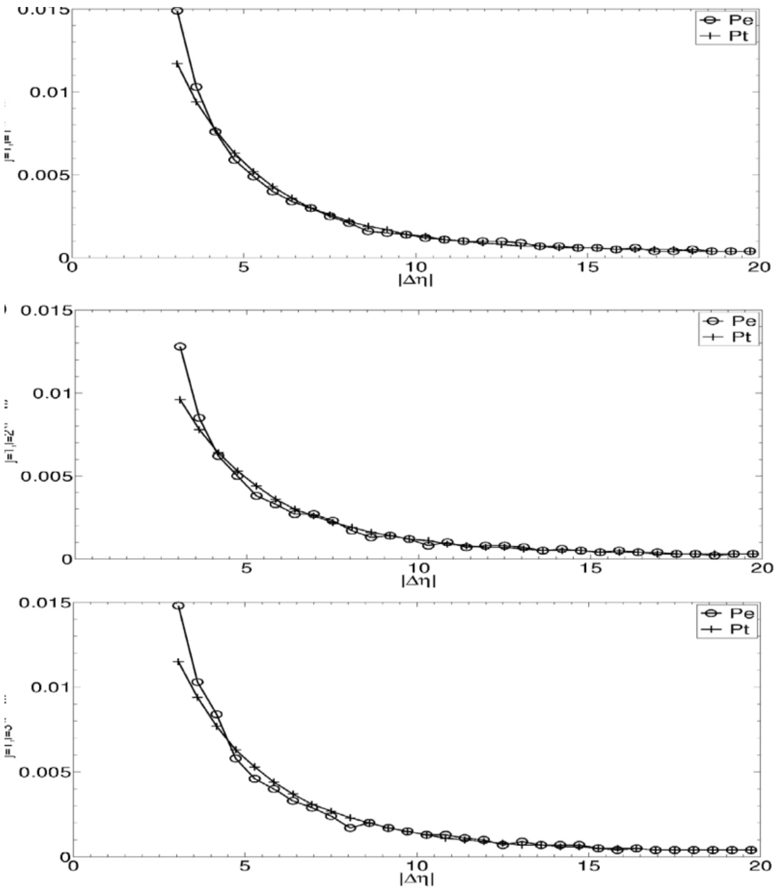

Figure 3. Empirical (P_e) and predicted MaxEnt distributions for N = 2 (P_t or equation (3) in the wavelet domain as in [Nieves et al, 2011]) of the random variable $\eta_{j,l,\vec{k}}$ (i.e., $A_{r/r'}$) which characterizes the scaling properties of a multi-fractal process. According to the wavelet decomposition, l = (a) 1, (b) 2 and (c) 3, respectively, from the scale of observation j = 1 to the j = 2 one (downscale cascade). Results correspond to order 3 Battle-Lemarié basis. Correlation coefficients are of around 0.99. (Nieves et al., 2011)

MaxEnt-Based Hydrologic Observation Network Design A design of MaxEnt-based observation network has been formulated and tested. A key and innovative component of the design is the concept of "information gain", defined as the difference between the information entropy of the posterior and prior distributions, expressed in terms of information entropy of the processes to be sampled. The design criterion is to optimize the information gain under the physical and financial constraints such as topography, existing network infrastructure, budget among others. Based on the statistical distributions of the variables to be samples, the MaxEnt network design specifies the new sampling locations by maximizing the information gain. A major advantage of the MaxEnt network design is that the resulting optimal network is independent of to-be-sampled variables. Mutual information of the variables sampled from all stations is automatically taken into account through the probability distributions of the variables, e.g. the MaxEnt distributions of the multi-scaling processes characterized by macroscopic parameters. The MaxEnt-based design method avoids the arbitrariness of cost functions in other optimization methods. The effectiveness of the MaxEnt method has been evaluated by comparing the information gain of another entropy-based design method called "net information transfer" (NIT). A case study is illustrated in Figure 4.

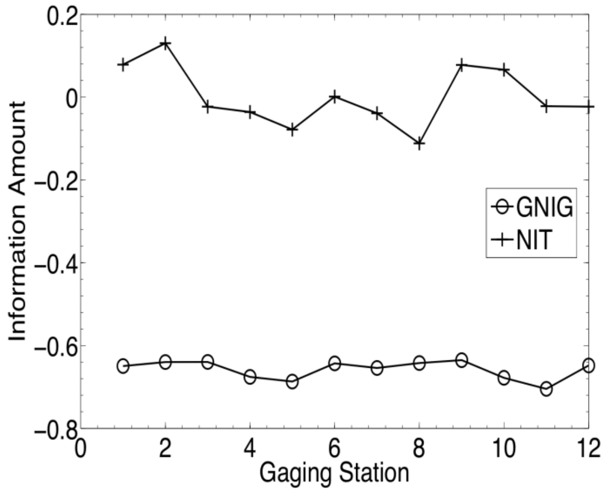

Figure 4. Information amount defined as the information entropy based on "global net information gain" (GNIG) and net information transformation (NIT) indexes at the gaging stations within a watershed in southern Illinois (Markus et al., 2003). GNIG values are rescaled by a factor of 100 for the purpose of illustration.
Markus, M., H. V. Knapp, and G. D. Tasker, Entropy and generalized least square methods in assessment of the regional value of streamgages, *J. Hydrol*., 283, 2003.

Maximum Entropy Production (MEP) Model of Surface Heat Fluxes An innovative model of surface heat fluxes has been formulated tested by applying the maximum entropy production principle to non-equilibrium thermodynamic land-ocean-atmosphere systems. The MEP formalism leads to analytical expressions of evapotranspiration (latent heat), sensible and land-ocean-snow surface heat fluxes as functions of surface radiation fluxes, temperature, and/or surface humidity. Compared to the existing models, the MEP Model has major advantages including automatically balancing the surface energy budgets by partitioning the radiation energy input, not using near-surface temperature and humidity gradients, wind speed and roughness data, covering the entire range of soil wetness from dryness to saturation among others. The MEP model has been validated using field observations over all types of land covers (bare soil, canopy, water, snow, and ice). The MEP model offers a potential solution to the problem of ‘‘no single (existing) land surface model is capable of capturing all features of the surface energy balance under all conditions’’. Its application to remote sensing of global surface energy budgets yields promising results. Some test results are illustrated in the figures below.

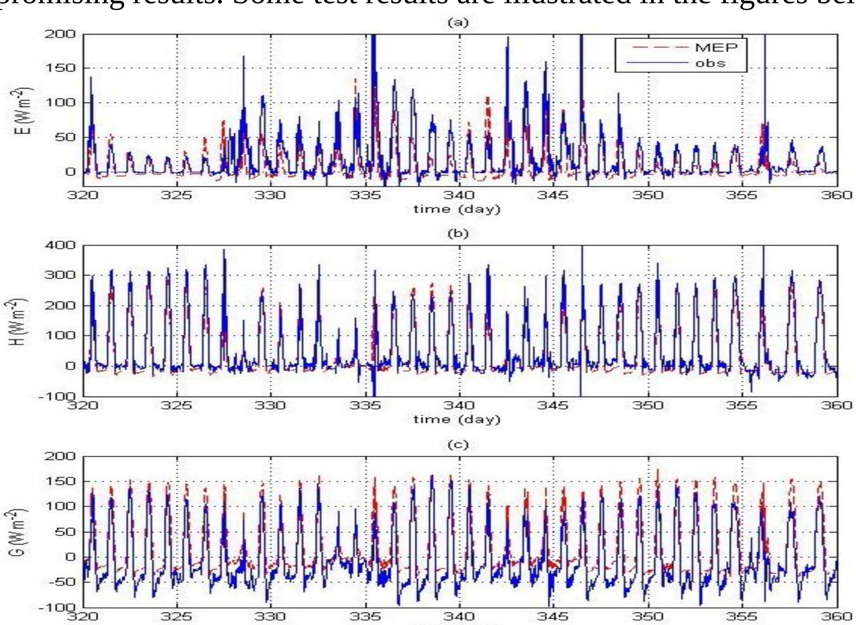

Figure 5 The MEP model predicted evaporation E, sensible heat flux H, and ground heat flux G (broken red) vs. the observed fluxes (solid blue) from SGP97 experiment at the site of CF01ARM during 31 May–30 June 1997 for the case of bare soil.
(Wang and Bras, 2011)

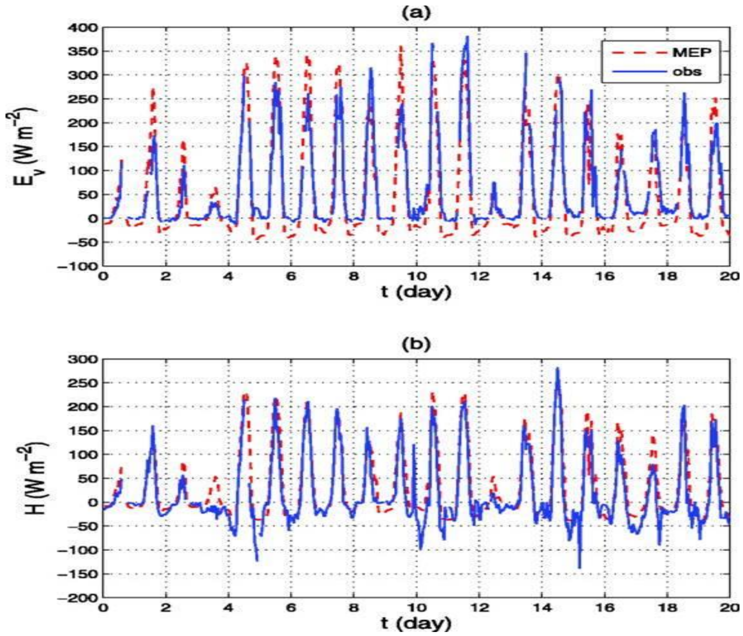

Figure 6 The MEP model predicted transpiration Ev and sensible heat flux H (broken red) vs. the observed fluxes (solid blue) from the Harvard Forest experiment during 19 August – 8 September 1994 for the case of canopy.
(Wang and Bras, 2011)

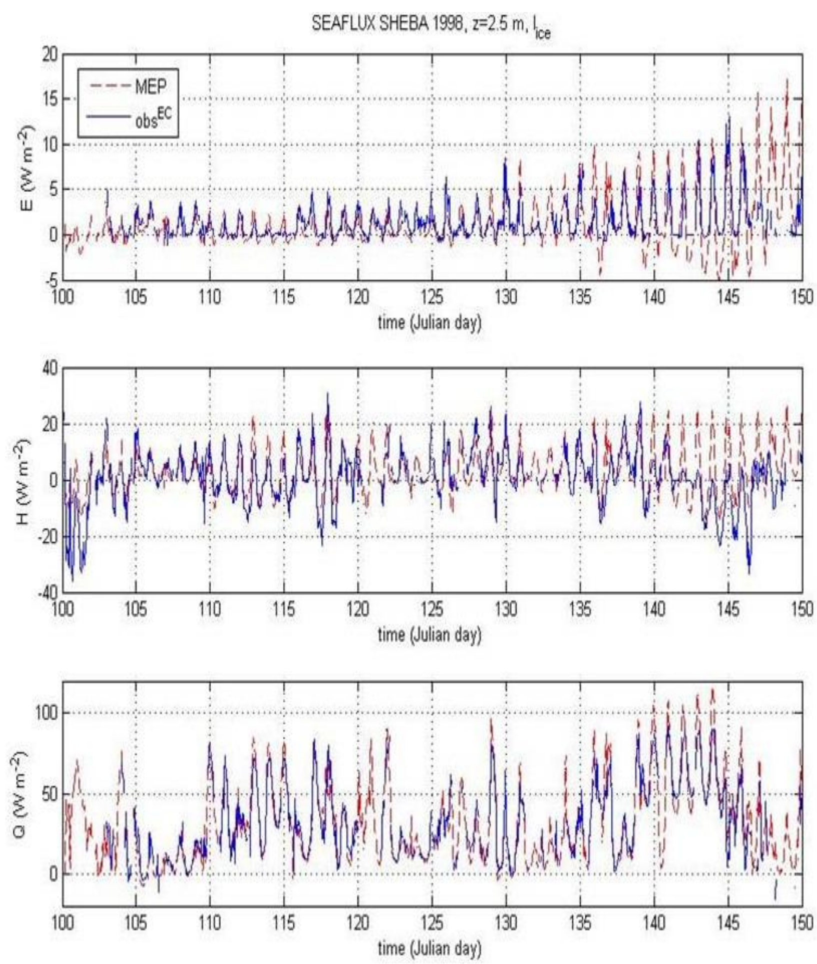

Figure 7 MEP model predicted latent heat flux *E* (top panel), sensible heat flux *H* (middle panel), and ice surface heat flux *Q* (bottom panel) vs. observed eddy covariance fluxes from the SHEBA experiment over the Arctic Ocean during 10 April to 30 May 1998 for the case of ice surface.
(Wang et al., 2014)

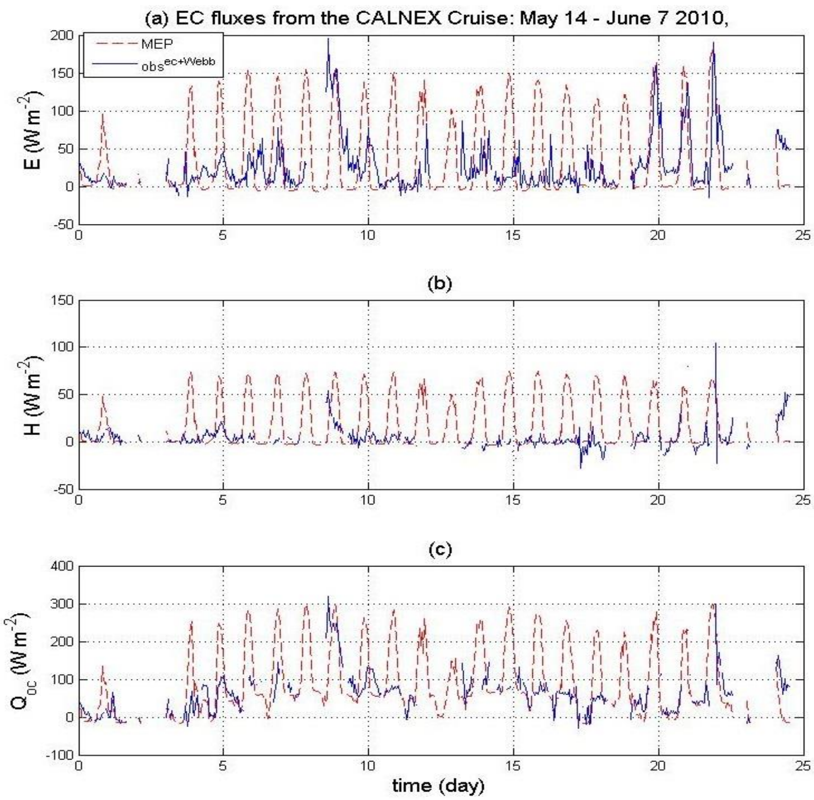

Figure 8 MEP model predicted (broken red) (a) latent heat flux *E* and (b) sensible heat flux *H*, water surface heat flux Q_{OC} computed from the energy balance equation $Q_{OC} = R_n^L - E - H$ where *E*, *H*, and net long-wave radiation R_n^L are the measured fluxes from the CALNEX cruise during 14 May to 7 June 2010.
(Wang et al., 2014)

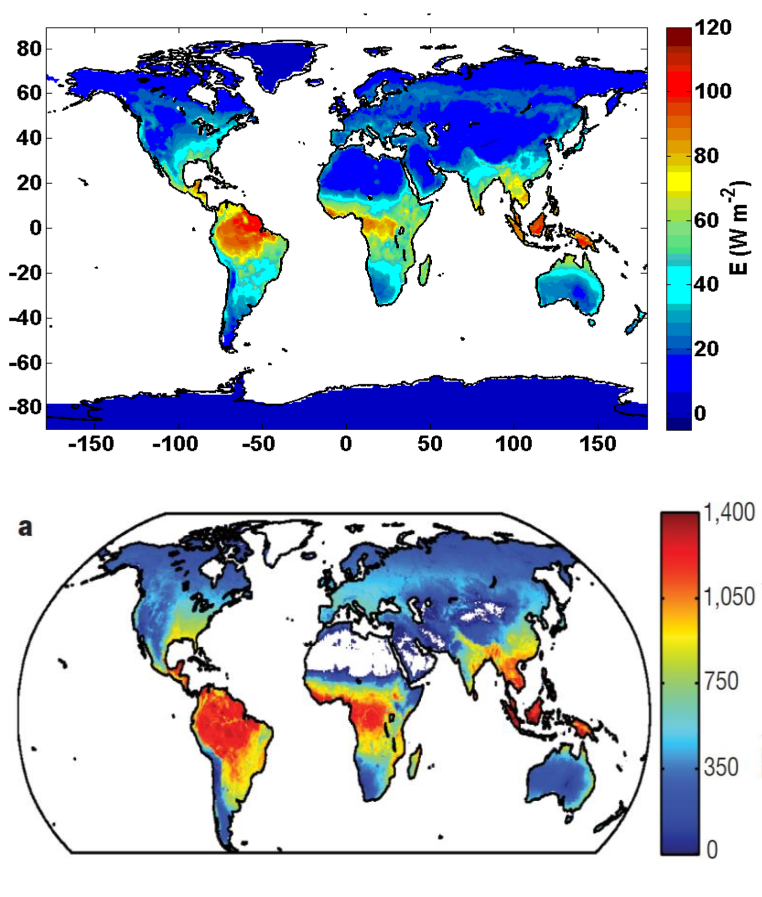

Figure 9 Application of the MEP model to remote sensing of global surface energy budget. (top panel): MEP modeled annual mean evapotranspiration (ET) *E* (2001-2010) using NASA CERES surface radiation and temperature data supplemented by the NASA MERRA reanalysis surface humidity data. (bottom panel): annual mean *E*T (1982–2008) based on FLUXNET, satellite remote sensing and surface meteorological data (Jung et. al., 2010). 1000 mm yr^{-1} is equivalent to ~ 80 W m^{-2}. (Huang et al., 2015)

Ocean Freshwater Flux-Sea Surface Salinity Model The project provided an opportunity of pursuing several innovative ideas that has led to the development of new methods for monitoring and modeling water-energy-carbon cycles of the Earth system. A new conceptual model has been developed to express freshwater flux (evaporation minus precipitation) as a function of sea surface salinity (SSS) (and vice versa). The model is formulated using an idealized one-dimensional diffusion equation for the ocean surface layer. The surface freshwater flux is expressed in terms of time-history of the sea surface salinity. This is the first physically-based freshwater flux model independent of SSS gradient. The surface freshwater flux estimated using the new model is in good agreement with existing estimates of freshwater fluxes. This model has the potential to enhance our capability of monitoring and modeling global freshwater fluxes and salinity as a data retrieval algorithm for remote sensing. The model may improve physical parameterization in coupled ocean-atmosphere models to study the global water cycle. A case study of the model is shown below in Figure 10.

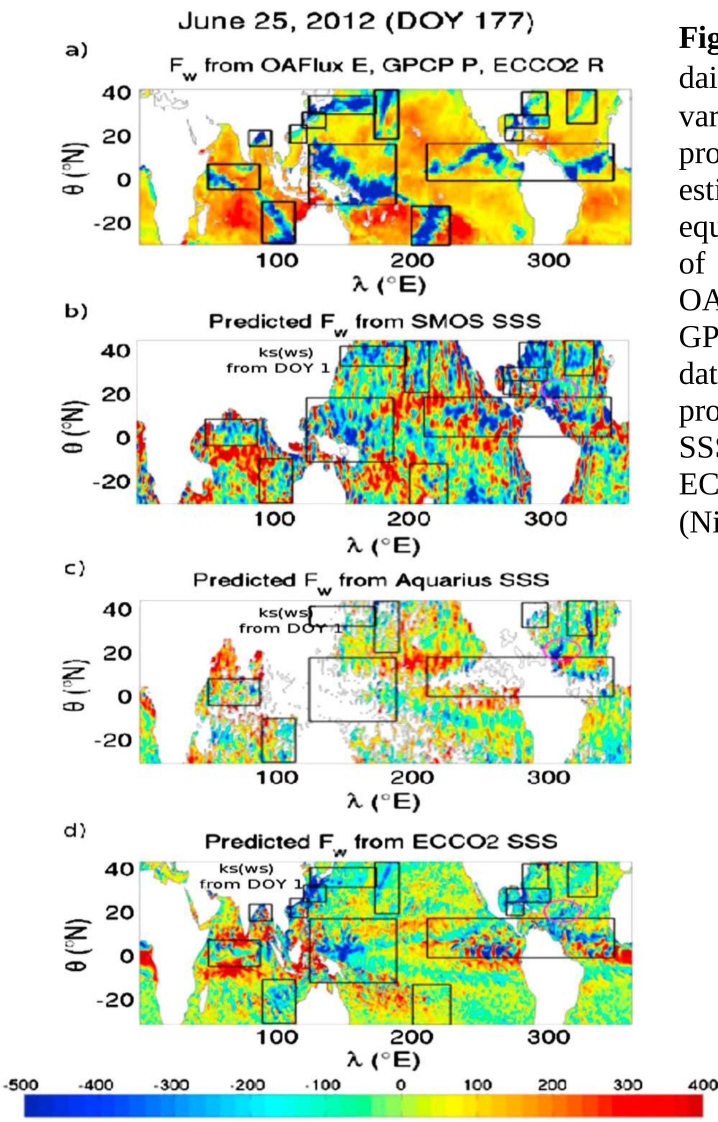

Figure 10 The new model predicted global daily net freshwater flux F_w (cm yr^{-1}) using various sea surface salinity (SSS) data product compared with the "direct" estimate according to the water balance equation. (a) water balance based estimate of F_w using evaporation E data from OAFlux product, precipitation P data from GPCP product, and ECCO2 global runoff R data ; (b) modeled F_w using SMOS SSS product, (c) modeled F_w using Aquarius SSS product, and (d) modeled F_w using ECCO2 SSS product.
(Nieves et al., 2014)

Surface Carbon Flux-Carbon Dioxide Concentration Model An innovative model of carbon fluxes has been formulated to relate surface CO_2 flux to the surface CO_2 concentration time-series. This is the first physically-based model of carbon flux independent of vertical gradient of CO_2 concentration. The model is built on the relationship between CO_2 flux and the time history of surface CO_2 concentration, known as half-order derivative, when the transport of CO_2 in the atmospheric boundary layer is described by a diffusion equation. The eddy-diffusivity is parameterized using the MEP model of surface heat fluxes. Test of the new model using in-situ data of CO_2 concentration and fluxes at several locations with diverse vegetation cover, geographic and climatic conditions confirms its usefulness and potential for monitoring and modeling greenhouse gases. The MEP-based parameterization of eddy-diffusivity allows the retrieval of global surface CO_2 fluxes using remote sensing observations. A case study is shown in Figure 11 below.

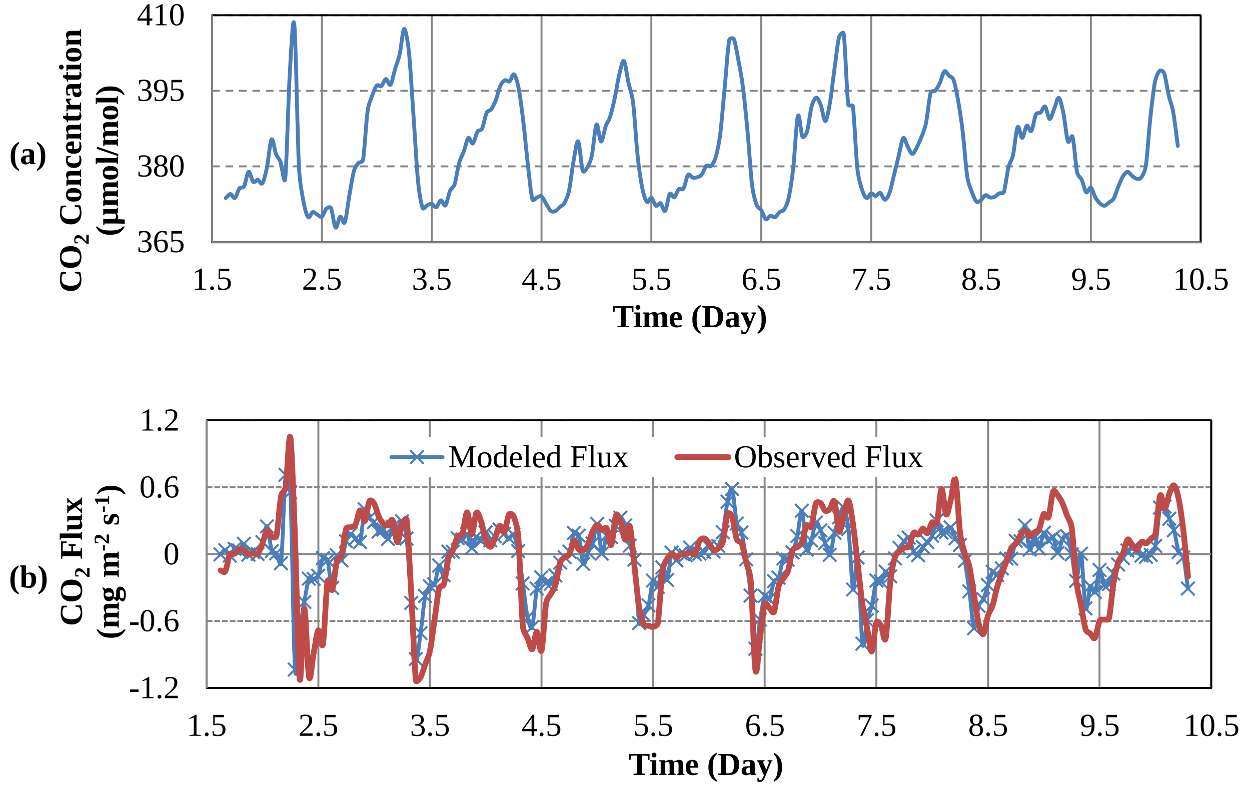

Figure 11: (a) Surface CO_2 concentration time-series measured at Santarem-Km67-Primary Forest, Brazil; **(b)** new model predicted CO_2 flux vs. observed CO_2 flux at Santarem-Km67-Primary Forest, Brazil 2003. Negative flux indicates day-time photosynthesis process. (Shahnaz et al., 2015)

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4. Shahnaz, S., and J. Wang, Carbon flux estimated from CO2 concentration using half order derivative method (B21A-0460), American Geophysical Union Fall Meeting, San Francisco, CA, December, 2013.

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