Ecological Modelling 265 (2013) 136–139

Contents lists available at SciVerse ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Short communication

The effect of drought stress on self-organisation in a seasonal tropical rainforest

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ARTICLE INFO

Article history:
Received 16 February 2013
Received in revised form 2 June 2013
Accepted 3 June 2013
Available online 7 July 2013

Keywords:
Self-organisation
Exergy capture ability
Tropical rainforest
Drought stress

ABSTRACT

From late 2009 to 2010, southwestern China experienced a severe drought. We evaluated the self-organisation of a seasonal tropical rainforest in response to drought stress. The forest had the least self-organization in 2010, and during the dry season (March–April) of 2010, the forest was least able to capture exergy (Rn/DR). The rate of long wave radiation (I/DR) loss was highest in 2010. The thermal response number of canopy temperature (TRNc) and Rn/DR showed similar trends and decreased from the rainy season to the dry seasons in each of the three years.

1. Introduction

Relatively small changes in tropical rainforest dynamics have the potential to substantially affect canopy structure and gross ecosystem productivity and thus feedback to climate change. Forests respond to a variety of interannual environmental changes, particularly drought events. For instance, Amazon forests appear vulnerable to increasing moisture stress, with the potential for large carbon losses to exert feedback on climate change (Asner et al., 2004; Asner and Alencar, 2010; Malhi et al., 2008; Phillips et al., 2009; Anderson et al., 2010).

In recent years, many ecophysiological studies of drought tolerance or adaptation potential in climate change scenarios have been published (Asner et al., 2004; Meir et al., 2006; Misson et al., 2010). However, the majority of these studies focus on carbon, whereas comparative studies in mixed forests are rare. Furthermore, increased moisture stress is a dominant feature of some modelled climate scenarios for tropical rainforest (Cox et al., 2008; Salazar et al., 2007).

Over the long term, the incoming solar radiation (short-wave radiation) absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing long-wave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This exergy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by long-wave radiation that is absorbed by clouds and greenhouse gases (Wagendorp et al., 2001). The atmosphere in turn radiates long-wave exergy back to Earth as well as out to space. Albedo is one key variable controlling the radiation exergy budget of the land surface. The albedo determines how much solar radiation (short-wave radiation) is absorbed at the surface (and is thus available for biophysical processes) and how much is reflected back into the atmosphere. High temperature indicates high long-wave emission (Allen et al., 2001). Evaporation and metabolism act as negative feedbacks against the increase in ecosystem temperature heated by solar radiation by transferring radiation into latent heat and chemical exergy. From the physical aspect, according to the Stephan–Boltzmann law, exergy flux density, $ULR = \varepsilon\delta Tc^4$, where ε is emissivity, δ is the Stefan–Boltzman constant, and Tc, is canopy temperature. Higher canopy temperature indicates higher long-wave radiation loss (Schneider and Kay,

Abbreviations: Rn/DR, capture exergy; I/DR, the rate of long wave radiation; TRNc, the thermal response number of canopy temperature; *Tc*, canopy temperature; Ws, wind speed; VPD, vapour pressure deficit; LAI, leaf area index; ET, evapotranspiration.

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http://dx.doi.org/10.1016/j.ecolmodel.2013.06.010

1994). In a tropical rainforest with close canopy, the exergy balance could approximate: Net radiation (Rn) is nearly equal to latent heat flux (LE) plus sensible heat flux (Hs). Ecosystem is intrinsically distinguished from abiotic systems by its self-organization ability. Therefore, assessing the ecosystem self-organization ability is one of the key scientific issues to understand the process. The hypotheses of exergy transformation in self-organizing open systems, quite beyond classical energetics, involve concepts of self-development in exergy terms. During self-organization, system designs develop and prevail that maximise power intake, exergy transformation, and those uses that reinforce production and efficiency (Odum, 1988). Lin et al. (2009) developed thermodynamic indicators of exergy capture and dissipation to quantify the degree of a forest's self-organisation. These indicators of the ecosystem's operational self-organisation are particularly useful for studies of complex terrestrial ecosystems. Over three years (2004–2006), they found that the average self-organisation values were clearly separated by season. Reflection and long wave radiation are the two primary pathways for exergy loss. In the tropical seasonal rainforest they studied, long wave radiation contributed most to exergy loss and was negatively correlated with the ability to capture exergy (Rn/DR). From late 2009 through 2010, the Xishuangbanna region in southwestern China experienced the most severe drought on record since 1959, providing a unique opportunity to directly evaluate how these self-organisation indicators change with drought stress in a tropical rainforest. In this study, we will explore thermodynamic theory to assess the effect of drought stress on self-organisation in a seasonal tropical rainforest.

2. Methods

2.1. Study site

The study was conducted at a tropical seasonal rainforest site (21°57′ N, 101°12′, 750 m asl) in the town of Menglun, Xishuangbanna Prefecture, southwestern China. The permanent ecological research plot is in the centre of the Nature Reserve; it shows no sign of recent anthropogenic disturbance other than hunting trails. The annual mean temperature is 21.8 °C, and the average minimum annual temperature is 7.5 °C. The mean annual wind speed is 0.5 m s^{-1}. Annual precipitation averages 1557 mm, of which 85% occurs during the May–October rainy season. The November–April dry season comprises both a cool dry season from November to February and a hot dry season from March to April. The cool dry season is characterised by relatively low temperatures and heavy fog during the night and throughout the morning. The hot dry season is dry and hot during the afternoon, with fog occurring in the morning only. This site is located on a small flat area between two hills extending from east to west and is a permanent plot (dominated by *Paulownia Pometia tomentosa and Terminalia myriocarpa*) dedicated to long-term ecological research and managed by the Tropical Rainforest Ecosystem Station, the Chinese Academy of Sciences. The plot is also part of the ChinaFLUX long-term ecological monitoring project. This type of forest is primarily formed in wet valleys and lowlands and on low hills where heavy radiation fog frequently occurs (Cao et al., 1996).

2.2. Instruments and measurements

All measurements were made on a 72 m meteorological tower. Air temperature and humidity (HMP45, Vaisala, Finland), rainfall (52203, Young, USA), and global and infrared incident and reflected radiations (CNR1, Kipp and Zonen, USA) were measured above the canopy. All meteorological data were collected at 1 min intervals and compiled as 30 min averages or sums with a CR1000 datalogger (Campbell Scientific Inc., USA). The vapour pressure deficit (VPD) was calculated based on air temperature and humidity.

Canopy temperature (*Tc*) was measured with an infrared thermometer (Apogee, USA) mounted 52 m above the ground.

The leaf area index was measured with a LAI-2000 (LI-COR Inc., USA) every month.

2.3. Data analysis

Mathematic analysis of the thermodynamic parameters describing exergy capture ability and exergy dissipation ability of ecosystem was carried out in terms of exergy balance, thermodynamics, physiology and ecology. It is suggested that Rn/DR (net radiation/downward short-wave radiation) (Schneider and Kay, 1994) can be used to describe exergy capture ability, and TRN (thermal response number) can be used for the measurement of exergy dissipation ability in this research.

Luvall and Holbo (1989) proposed the thermal response number (TRNc) to quantify the buffer capacity of a system against incoming exergy.

TRNc can be simply interpreted as the amount of radiation required to change one unit temperature as a logical metric for comparison of thermal properties across ecosystems.

TRNc was calculated as $\sum_{t1}^{t2}\mathrm{Rn}(\Delta t)/\Delta T$, where $\sum_{t1}^{t2}\mathrm{Rn}(\Delta t)$ is the net radiation, Rn, over the time interval Δt, and ΔT is temperature variation over Δt, chosen here to be 1 day.

In summary, self-organization is measured through exergy capture ability by Rn/DR and exergy dissipation ability by the TRNc.

VPD was calculated from hourly measurements of air temperature and relative humidity.

3. Results

3.1. Climate factors patterns

The meteorological measurements showed seasonality in rainfall, air temperature (Ta), wind speed (Ws), vapour pressure deficit (VPD) and leaf area index (LAI). In this study site, the drought lasted from the beginning of August 2009 until October 2010. The average rainy season (May–August) rainfall was only 57.4 mm in 2010, which is much lower than the average value for the past 50 years of 213.7 mm (Fig. 1). LAI was lower in 2010 than in 2008 and 2009 (Fig. 2d). LAI slowly decreased from the beginning of the dry season and in March 2010 was only 3.3 (SE = 0.39).

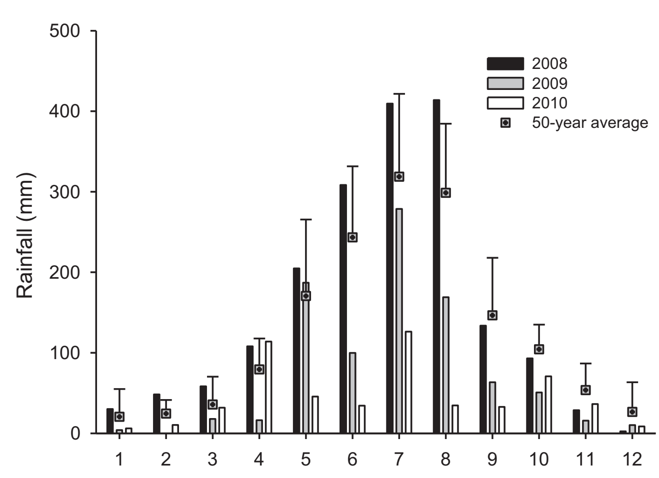

Fig. 1. Average monthly rainfall in the years 2008, 2009 and 2010, and for the past 50 years (+1 SE).