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Ecosystem Resilience to Drought and Temperature Anomalies in the Mekong River Basin

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Abstract. Climate change is leading to an increasing in the frequency and intensity of extreme weather events, which significantly affect ecosystems stability. In this study, ecological stability metrics in response to wet/dry events and warm/cold events on vegetation greenness were assessed using an auto-regressive model of NDVI in the Mekong River basin (around 759,000 km^2) where large ecological and climatic gradients exist. Gridded temperature, and the Global Standard Precipitation Evaporation Index (SPEI) and antecedent NDVI were used as model predictors. The forest in north Laos was more resilient to the temperate and wet/dry anomalies events than other regions in the basin. Drought reduced green biomass in north Laos, northeast Thailand and Myanmar, but in these tropical climate regions' the vegetation biomass was also more responsive by higher temperatures. Vegetation in northeast Thailand, Cambodia and the Mekong delta were less sensitive to the temperature anomalies effect compared to other part of Mekong River basin. The map of resistance and resilience metrics can help to determine the most vulnerable regions to extreme events for policy makers.

1. Introduction

Climate change is considered as one of the major factors putting pressure on ecosystems worldwide. Climate models have found a connection between global warming and the occurrence of climatic extreme events, such as wet and dry anomalies (floods and droughts), in frequency, intensity and duration, which expected to significantly affect ecosystem [1]-[3], e.g. vegetation shift [4] and tree mortality [5]. Within this content, assessment of ecosystem stability to extreme events is crucial to qualify the sensitivity of ecosystems to environmental disturbance, but also to improve the understanding of the mechanism that govern vegetation response. The effect of extreme events on ecosystems after an event has been vanished has been referred to as "memory effect" [6]. Memory effects can be evaluated assessing the ecosystem response to climate-induced disturbance [7]. For this purpose, resilience and resistance metrics of ecosystem stability have been developed by analyzing

anomalies of an ecosystem property relative to their annual cycle. In this study we refer to ecosystem resilience as its the ability to recover after a disturbance, while its resistance expresses the response or sensitivity of ecosystem to an extreme events [8], [9].

To assess ecosystem resilience and resistance, it is possible to use different methods, such as lagged cross correlation analysis, canonical correspondence analysis or the persistence of NDVI trend [10]-[12]. Several studies have focused on the assessment of ecosystem stability, but there are not studies yet on the impacts of climatic anomalies on ecosystem in the Mekong River Basin (MRB). However, understanding the potential impacts of rainfall and temperature anomalies on vegetation is crucial in this region, home of approximately 70 million people and a highly biodiverse region.

The research aims to: (1) investigate both ecological resilience and resistance of ecosystems in the MRB to wet/dry anomalies and temperature anomalies using an ecological model based on remote sensing and climate data [7], [13] and (2) improve the understanding of ecosystem stability in the MRB. Analysis of vegetation responses to extreme events is important for ecological and environmental management programs, early warning and forecasting future climate-induced vegetation change in the MRB. Moreover, this research will help to identifying those regions in the MRB that are more sensitive to climate anomalies providing vulnerability maps, which can provide a guide for ecological and environmental management decisions in the MRB.

2. Study area

The MRB, which is shown in Figure 1, is originated in the Tibetan plateau in China. The basin covers six countries, is equivalent to 795,000 km^2, where the outlet run into the South China Sea (Figure 1a). The MRB climatic system is governed by the northeast and southwest monsoon [13]. The temperature and precipitation in the MRB are topographically uncertain place to place. The entire basin average temperature is around 24 ^{O}C and the range of precipitation ranges to 600 mm/year in the Tibetan plateau to more than 3,000 mm/year in Laos. The vegetation in the basin (Figure 1b) is unevenly distributed and associated with elevation, especially in the upper MRB, temperature, and precipitation system, especially in the lower MRB [14,15].
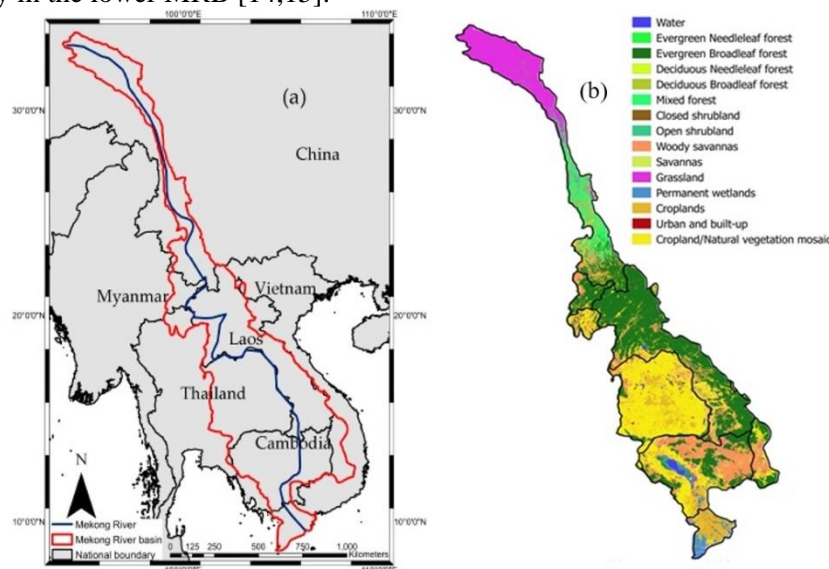
Figure 1. (a) The location, and (b) land cover, which retrieved from MODIS land cover type product (MCD12Q1) [16].

3. Materials and methods

The Normalized Difference Vegetation Index (NDVI) time series from January 1982 to December 2013 were downloaded from the Global Inventory Modeling and Mapping Studies (GIMMS) [17] for qualifying the response of ecosystem. The raw bimonthly NDVI image were filtered using Savitzky-Golay method and were resampled to monthly scale using the average of bimonthly NDVI image, then all images were reprojected as GCS-WGS1984. Monthly temperature data were downloaded from the

Climate Research Unit Time Series Version 3.23 (CRU-TS 3.23) [18] in the same time frame as NDVI dataset. Monthly standardize NDVI anomalies and monthly standardized temperature anomalies were derived by removing the seasonal variation of the NDVI and temperature time series. The drought effect was evaluated using the Standardized Precipitation – Evapotranspiration index (SPEI), is calculated from the average water balance, [19], [20] with the same temporal frame as NDVI time series data. In this study, 3-month SEPI was used to quantify extreme events effect to the ecosystem. Positive value represents wetter condition than average, while negative value shows dryer condition than average. The monthly temperature anomalies and 3-month SPEI data were resampling to GIMMS's resolution using a bilinear interpolation and were reprojected as GCS-WGS1984.

4.   Model to assess ecosystem resilience and resistance

In this study, an auto-regressive model based on De Keersmaecker et al. [7] was applied to predict NDVI anomalies in each pixel based on climatic variables and antecedent NDVI to account for memory effects at every time step. The model parameters reflect the different sensitivity of vegetation to climatic and vegetation and thus allow to estimate ecosystem resilience and resistance to drought and temperature anomalies for each pixel. The model, shown as Equation 1, was applied every month in every pixel [7].

$$NANO_t = \beta\ NANO_{t-1} + \alpha\ SPEI_t + \varphi\ TANO_t + \varepsilon_t \qquad (1)$$

Where $NANO_t$ and $NANO_{t-1}$ are standardized NDVI anomalies at time t and $t-1$, respectively. $SPEI_t$ and $TANO_t$ are 3- month SPEI and standardized temperature anomalies at time t. ε_t represents the residual term of time t.β, α and φ are model parameters, which are related to ecosystem resilience and resistance metrics. Each model parameter can be related to a different ecosystem stability metric. φ represents vegetation response to instantaneous temperature change, e.g. a temperature resistance metric. Similarly, α is indicated a drought resistance metric. β is an indicator for the dependence of anomalies on the previous values, hence, it represents the ecosystem resilience metric. Where β is large (small), the vegetation has a strong (less) influence from the previous time step and the ecosystem recovers slowly (quickly) from perturbations. Based on De Keersmaecker et al. [7], this optimal model was selected based on the root mean square error (RMSE) of observed and modeled standardized NDVI anomalies. Only those pixels with RMSE < 0.9 were considered as a good fit and the model retained.

5.   Results and discussion

The ecosystem resilience and resistance metrics from the model parameters are shown as Figure 2. Regarding the errors, the model showed good performance in the forest ecosystems, especially in the south China, Laos, and Cambodia; it was only poor fitted in the grassland ecosystem in the Tibetan plateau in China, and cropland in the northeast of Thailand and the Mekong delta in Vietnam. This was probably due to (1) low range of climate and vegetation variables variability, (2) poor quality of time series input data, or (3) vegetation response from the other disturbances, such as ecological management and irrigation [7].   (4) vegetation memory effects not accounted for.
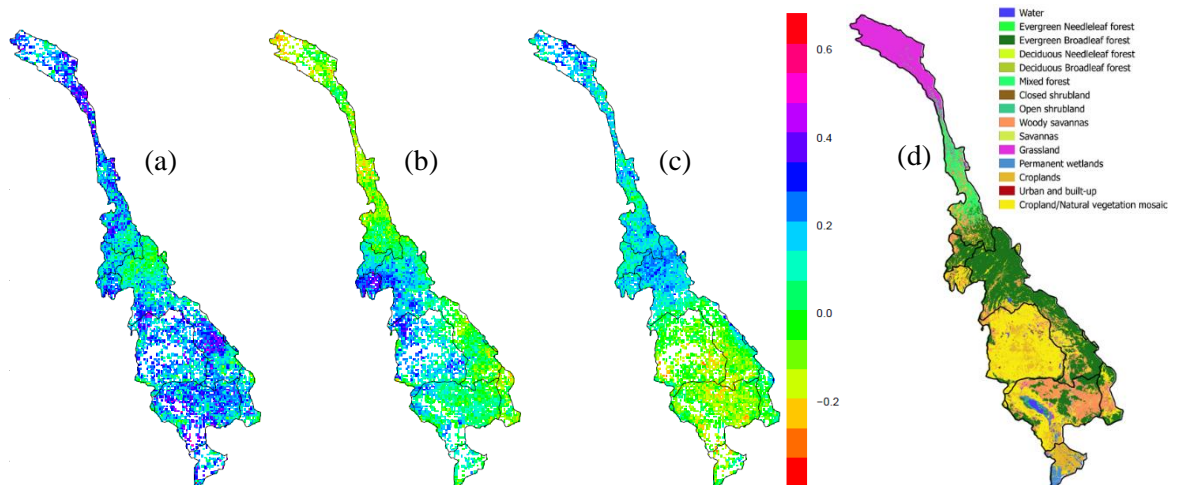
Figure 2. Model parameters which reflect (a) *β*, vegetation resilience, (b) *α*, indicated a drought resistance metric and (c) *φ*, temperature resistance metric. Pixels with RMSE > 0.9 are excluded. The colored bar represents the standardized coefficient scale. (d) Land cover in the Mekong River basin.

The vegetation resilience metric *β* (Figure 2a) is positive and large in the North Yunnan Province, China, in the south of Laos and Cambodia. It indicate that the ecosystem in those regions has low resilience or low recovery rates after climatic disturbances, needing more time to return to the equilibrium state. On the contrary, the evergreen forest in northern Laos showed high resilience, is indicated by values close to zero, with low recovery rates after disturbance more quickly return to the equilibrium state compared to the evergreen forest ecosystem in the south of Laos (Figure 2d).

From the vegetation drought resistance metric (*α*) (Figure 2b) it can be seen that vegetation in the upper part of basin has a negative response to drought events. Wetter (dryer) climate conditions decrease (increase) vegetation greenness, especially mixed forest biome, which widely spread in Yunnan province, evergreen forest biome in south Laos and Savanna in south Vietnam; however, the evergreen forest in north Laos, Myanmar and north Thailand shows positive value of vegetation drought resistance metric, e.g. low resistance to extreme climatic events, e.g., drought, and leading to decreasing biomass and vegetation greenness. The metric of vegetation resistance of temperature anomalies (Figure 2c) shows that vegetation in the north basin (cold climate) mostly shows a positive response with higher temperature anomalies, which increase vegetation greenness. Yet south Laos and northeastern Thailand and Cambodia shown a very large negative *φ* value that means the vegetation in these regions has low resistance (in the negative response) to temperature anomalies.

This modeling analysis is recommended to use when the ecosystem resilience and resistance will be monitored because the input data are used based on lag 1-month (or lag several month) of vegetation greenness data and several climate variables are represented updated climatic events, and could be taken into account which is useful to monitoring for preventing the ecosystem changing to un-equilibrium state. Other indicators, e.g. resistance and resilience metrics from cross-correlation analysis [10], can capture the time that when the vegetation will show the highest response to the climatic extreme event and this information could be incorporated to improve the modeling scheme.

6.   Conclusion
This study applied a predictive model of NDVI anomalies based on multiple linear regression and auto-regression to assess the ecological stability due to wet/dry anomalies and temperature anomalies over the Mekong River Basin. The results showed good model fit for most of the pixels in all the basin (66 % of the basin) except the colder grasslands ecosystem in China and irrigated croplands in the northeast of Thailand and the Mekong delta in Vietnam. The ecosystem resilience and resistance metrics showed a clear pattern associated with the different land cover types in the MRB. The forest vegetation in the north Laos showed higher resilience to drought and temperature anomalies than other

regions. Areas with low resilience and resistance, where drought affects the vegetation greenness included north Laos, the northeast Thailand and Myanmar. In this regions vegetation growth was linked to higher temperatures. Yet the vegetation in the northeast Thailand, Cambodia and the Delta showed less sensitive to the temperature anomalies effect. The provided maps showing more vulnerable regions to climatic extremes can guide management decisions in the MRB.

7. References

[1]   International Development Research Centre 2015 *ScienceDaily* Available https://www.sciencedaily.com/releases/2015/10/151021104907.htm Accessed 2015 October 23.

[2]   Intergovernmental panel on climate change 2012 *Summary for Policymakers. In Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. ed C B Field V Barros, T F Stocker, D Qin, D J Dokken, K L Ebi, M D Mastrandrea, K J Mach, G -K Plattner, S K Allen, M Tignor, and P M Midgley (Cambridge, UK and New York, NY, USA: Cambridge University Press)

[3]   Walter F J 2012 Beyond productivity: Effects of extreme weather events on ecosystem processes and biotic interactions (Ph.D. Dissertation, University of Bayreuth, Germany). Available https://epub.uni-bayreuth.de/203/1/WalterDiss.pdf

[4]   Lloret F , Escudero A, Iriondo J M, Martinez-Vilalta J and Valladares F 2012 *Glob. Change. Biol*. **18** . 797–805

[5]   Lewis S L, Brando P M, Phillips O L, van der Heijden, G and Napstad, D 2010 *Science*. **331**. 554

[6]   Wiegand T, Snyman H A, Kellner K and Paruelo J M 2004 *Ecosystems*. **8**. 243 – 258

[7]   De Keersmaecker W, Lhermitte S, Tits L, Honnay O, Somers B and Coppin P 2015 *Global. Ecol. and Biogeogr*. **24**. 539–548

[8]   Kang B, Lee S J, Kang D H and Kim Y O 2007 *J. Hydro-Environ. Res*. **1**. 118–125

[9]   Harrison G W 1979 *Am Nat*. **113**. 659–669

[10]   García M, Litago J, Palacios-Orueta A, P ńzon J E and Ustin S L 2010 *Appl. Veg. Sci*. **13**. 146–162

[11]   Mitchell R J, Auld M H D, Le Duc M G, Robert M H 2000 *Perspect. Plant Ecol. Syst*. **3**. 142–160

[12]   Harris A, Carr A S and Dash J 2014 *Int. J. Appl. Earth Obs. Geoinf*. **28**. 131-139

[13]   Mekong River Commission 2005 Available: http://www.mrcmekong.org/topics/agriculture-and-irrigation/ Accessed 2015 July 3.

[14]   Rundell P W 2009 *The Mekong: Biophysical Environment of an International River Basin* ed Campbell I C. (Amsterdam: Academic Press) chapter 7 pp 143–160

[15]   Zhang B, Zhang L, Guo H, Leinenkugel P, Zhou Y, Li L and Shen Q 2014 *Int. J. Remote Sens*. **35**. 2835–2856

[16]   Friedl M A, Sulla-Menashe D, Tan B, Schneider A, Ramankutty N, Sibley A and Huang X 2010 *Remote Sens. Environ*. **114**. 168–182

[17]   Tucker C J, Pinzon J E, Brown M E, Slayback D A, Pak E W, Mahoney R, Vermote E F and El Saleous N 2005 *Int. J. Remote Sens*. **26**. 4485–4498

[18]   Harris I, Jones T, Osborn T and Lister D H 2013 *Int. J. Climatol*. **34**. 623–642.

[19]   Vicente-Serrano S M, Beguer ń S, López-Moreno J I, Angulo M and El Kenawy A 2010 *J. Hydrometeorol*. **11**. 1033–1043

[20]   Beguer ń S, Vicente-Serrano S M, Reig F and Latorre B 2014 *Int J Climatol*. **34**.