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An integration of phenocam observations with machine learning helps monitor leaf phenology in tropical evergreen forests

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Abstract

In tropical evergreen forests, leaf phenology actively regulates biogeochemical cycles of carbon and water fluxes. However, an efficient and scalable approach for monitoring leaf phenology is still lacking. In this research, we aim to develop a rigorous method that integrates phenocam observations of image time-series with machine learning to enable accurate, automatic monitoring of leaf phenology. Furthermore, we want to use this monitoring method to find whether the El Nino phenomenon in 2015 has created some impacts on the responses of different kinds of trees. We hypothesis that different groups of trees will respond in different ways. To test this hypothesis, we will focus on the tropical forest site Amazon Tall Tower Observatory in Brazil. For this site, we will firstly identify the individual tree crowns, with which we will then converge them into matrix form. Further, we will design algorithms to extract the GCC index for each individual tree crown automatically. And finally, we will plot the GCC data against time and use machine learning to eliminate noise. Moreover, we will use the final images to test our hypothesis. The success of this project will not only provide algorithms for phenology monitoring but also accumulates essential datasets to advance the understanding of phenology patterns and mechanisms in tropical evergreen forests, especially the individual-level responses in extreme environmental conditions.

Introduction

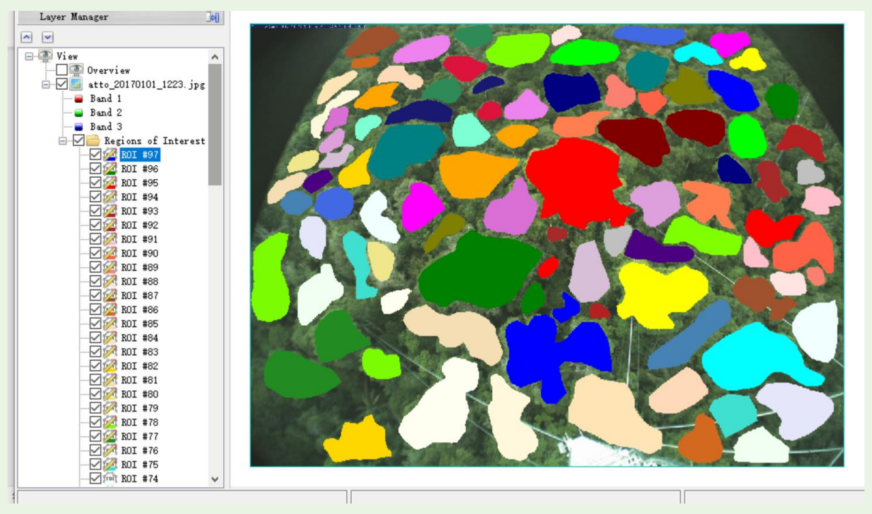
Tropical phenology largely regulates biogeochemical cycles of carbon and water fluxes (Restrepo-Coupe et al., 2017), with important vegetation mediated feedbacks to regional climates (Wright et al., 2017). However, tropical phenology remains complex and poorly understood (Albert et al., 2019). Much recent evidence from tower-phenocams shows the forest ecosystem appears evergreen all year round, but strong seasonal leaf phenology dynamics occur at the individual tree-crown level (Lopes et al., 2016). This unique phenology pattern further explains the large dry season increase in tropical forest photosynthesis (Wu et al., 2016) and satellite-detected greenness (Wu et al., 2018). Therefore, it is increasingly important for the field to move towards the study of leaf phenology at the individual tree-crown level.

Tower-mounted phenocams may be the most accurate way to quantify tropical leaf phenology from individuals to landscapes (Lopes et al., 2016; Wu et al., 2016). However, current approaches for phenology analysis still subject to several outstanding critics. First, most of the current analyses still focus on the exploration of phenology variations at the ecosystem scale without considering vast phenology variability at the individual tree-crown level (Alberton et al., 2017). Second, a few studies that focused on individual-level phenology extraction relied intensively on either visual assessments or semi-automatic assessments (Lopes et al., 2016; Wu et al., 2016), while an efficient and scalable approach for predicting leaf phenology is still lacking. The prime challenge that limits current automatic algorithm developments is because tropical phenology is so diverse, and most previous analyses that only relied on the color information of phenocam observations are insufficient to quantify such high phenological diversity. Third, although a recent study that relied on drone-based frequent image surveys demonstrates the feasibility of machine learning for improving quantification of leaf phenology in tropical evergreen forests (Park et al., 2019), a similar approach has not yet been tested in the phenocam image time series.

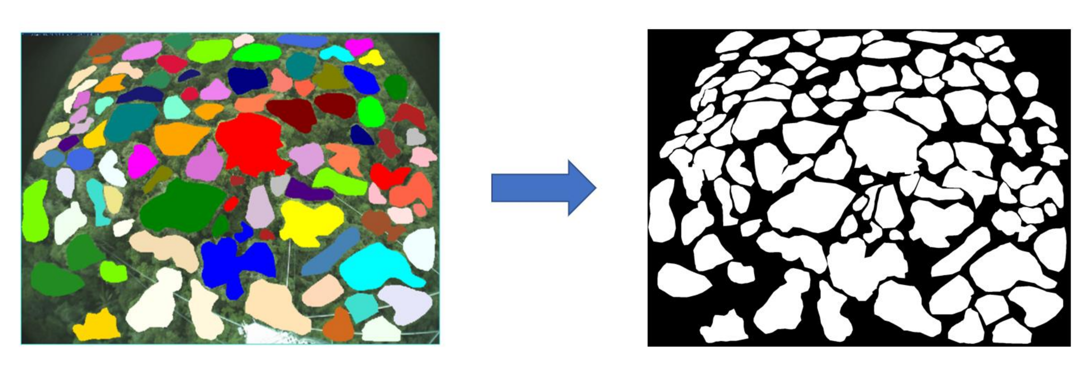
The goal of this research thus aims to develop a rigorous method that integrates phenocam image time-series with machine learning to enable accurate, automatic monitoring of leaf phenology. And using this monitoring method, we hypothesis that different groups of trees will respond to the El Nino phenomenon in 2015 in different ways. Therefore, to evaluate our hypothesis as well as the effectiveness of our method, we will focus on explore the individual level phenology pattern of one tropical evergreen forest site Amazon Tall Tower Observatory (ATTO; 2°8′N, 59°00′W; mean annual rainfall of 2352 mm/year) in Brazil. Upon the success of this project, we expect that it will provide not only improved algorithms for phenology monitoring but also accumulates valuable datasets to advance the understanding of phenology patterns and mechanisms in tropical evergreen forests, especially the individual-level responses in extreme environmental conditions.

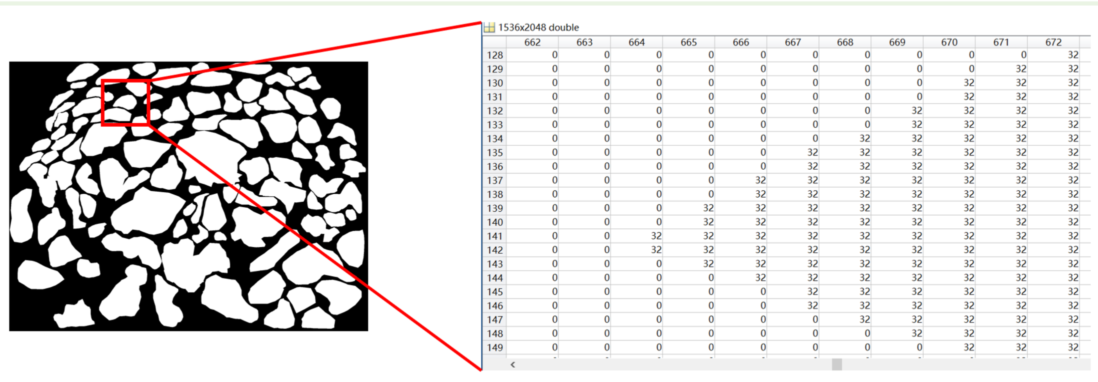
Methodology

For the Amazon Tall Tower Observatory data (referred as ATTO in the following), we shall firstly identify the individual tree crowns in the image and draw a region of interest (ROI) to cover the canopy of tree with distinct label number in the ENVI.



Then, we converge the ROI image into binary matrix form and each region shall be filled with the corresponding tree ID number (show in figure below).





Next, we extract the Green Chromatic Coordinate (GCC) index from each tree canopy region automatically by programming.

$$GCC = \frac{Green}{Red + Green + Blue}$$

Finally, we plot the GCC data against time and use machine learning method to fit the discrete data and eliminate noise of the time-series images with Gaussian method. And we also make prediction according to the average data in normal years.

Results

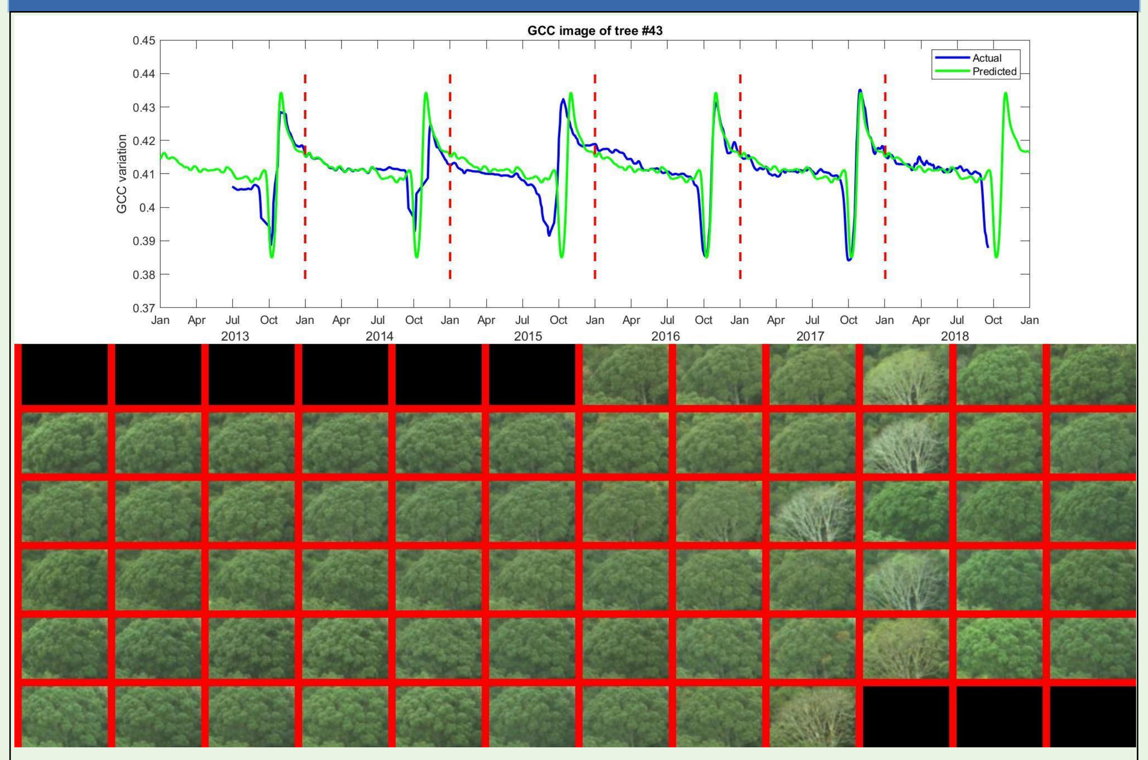


Figure 1. An example of deciduous tree time series image with significant advance shift in 2015 according to our prediction. The physical image series are for verification.

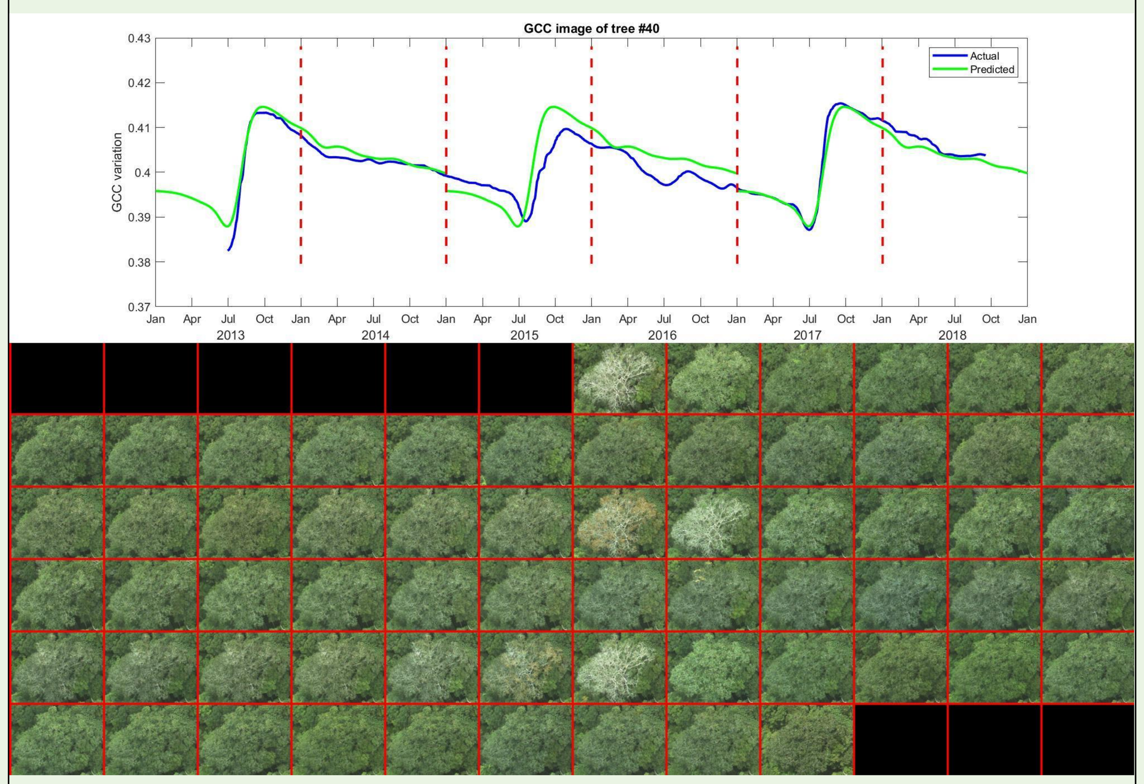


Figure 2. An example of deciduous tree time series image with backwards shift and change in pea values in 2015 according to our prediction.

- Statistical Result for ATTO site

	Advanced	Backwards
Evergreen Trees	29	39
Deciduous Trees	9	3

$$K^2 = \frac{80 \times (29 \times 3 - 39 \times 9)^2}{68 \times 12 \times 38 \times 42} \approx 4.281$$

From 80 samples, we count the number for each category. And according to the Chi-square independence test table, the K^2 is 4.281, which indicated that we have significance level alpha > 0.95 to conclude that the different kinds of trees show different responses to the El Nino phenomenon.

Conclusion

To conclude, in this research we have developed a complete procedure to process the phenocam images and converge the image data into visible time series images, which is important for further study. This will also help us understanding individual level phenology pattern in the tropical evergreen forest in a clearer way.
we also test our hypothesis that the responses to the El Nino Phenomenon vary from different category of trees in ATTO site. This will help us understanding how different individual trees respond to extreme environmental conditions. And the reasons for these various responses still need further study.

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