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Scaling up canopy leaf phenology in the Central Amazon – from tower mounted RGB cameras to Landsat 8

Nathan Borges Gonçalves [1]
Bruce Walker Nelson [1]
Aline Pontes Lopes [1]

[1] National Institute for Amazon Research - INPA
Av. André Araújo, 2.936 - Petrópolis - 69067-375 - Manaus - AM - Brazil
{nathanborges, bnelsonbr ,alineplopes}@gmail.com

Abstract. Tower mounted RGB cameras in Central Amazonia have detected three seasonal contrasts in visible bands for *terra firme* forest upper canopy in dry season when compared to wet season: (1) more bright green crowns with recently flushed new leaves, causing gradual landscape scale green-up over the dry season; (2) more crowns at the brief pre-flush leafless stage; and (3) higher inter-crown variance of greenness. Here we confirm all three patterns at the Landsat 8 scale, using 15m pan-sharpened green and red bands from a pair of 2015 dry and wet season images of the same scene. Solar elevation angles were very similar between the two images (< 0.7º difference) and view angles were restricted to < 0.6º off-nadir, thus controlling for BRDF effects. We controlled for atmospheric effects as a co-variable, using the coastal aerosol band. Greenness based on visible bands was strongly seasonal, but this was not the case for NDVI and EVI vegetation indices. At 30 m resolution, and using surface reflectance of pixels selected from a narrow range of TOA Coastal aerosol, NDVI was slightly higher in the dry season (0.895) than in the wet season (0.860). EVI was not different between the two seasons. On the other hand, variance for both NDVI and EVI was higher in dry season as expected from tower data.

Palavras-chave: dry season green-up, tropical forest

1. Introduction

Central Amazon seasonal leaf phenology has been described for samples of a few tens to a few hundreds of upper canopy tree crowns using tower mounted RGB cameras (Nelson et al. 2014; Lopes et al. 2016; Wu et al. 2016). The forests observed by these three cameras suggest that dry season leaf flush drives seasonal changes in greenness detected by the Moderate Resolution Imaging Spectro-radiometer (MODIS), because recently flushed tree crowns have a higher Enhanced Vegetation Index (EVI), than do crowns with older leaves (Lopes et al 2016). Each of the three study areas monitored with cameras is, however, smaller than a single MODIS pixel. Furthermore, broader scale patterns of seasonal leaf phenology based on MODIS images have been a subject of controversy (e.g., Galvão et al. 2011; Morton et al. 2014; Saleska et al. 2016). Solar elevation angle has a seasonal trend during the Central Amazon dry season, that causes a progressive decrease in MODIS sub-pixel shade content and consequent increase in NIR reflectance and increase in EVI, creating a false green-up trend. Recent BRDF corrections (Guan et al. 2015; Bi et al. 2015), however, show that dry season green-up remains after removing this bias.

The debate on remotely sensed Amazon green-up would benefit from analysis of data at the intermediate scale provided by Landsat 8, providing a bridge between tower-based and MODIS-based observations of Amazon forest seasonal leaf phenology. Here we examine several predictions at the Landsat 8 resolution that are expected from tower-mounted RGB camera results. We compare a mid-dry and a mid-wet season image of the same area. We first evaluate 15m resolution pan-sharped Red and Green reflectance and then examine NDVI and EVI seasonality at 30m resolution.

At 15m resolution (similar to upper canopy single crown diameter) and for visible bands only, our objective is to confirm and extend three seasonal patterns for the Central Amazon that were detected by the tower cameras (Lopes et al. 2016, Nelson et al. 2014). We expect (1) higher average landscape greenness in the dry season, (2) higher inter-crown variance of greenness in the dry season and (3) greater dry season abundance of trees at the pre-flush leafless stage. By confirming these three patterns, we also extend to a new and larger area the ecological consequences of these patterns – that dry season green-up does in fact occur across the Central Amazon and that dry season leaf flush drives this green-up (Lopes et al. 2016, Wu et al. 2016).

About 60-85% of all trees are known to flush a new set of leaves each year and to do so primarily in the five driest months of the year (Nelson et al. 2014, Lopes et al. 2016). At the crown scale, EVI vegetation index is high for several months after flushing, then drops slowly (Lopes et al. 2016). Because flushing is concentrated in the dry season (and causes higher visible greenness in the dry season), we also expect EVI to be higher in the dry season than in the wet season Landsat images. Our fourth objective, therefore, is to confirm this pattern with both EVI and NDVI at the 30m scale.

Wet and dry season Landsat 8 images of the same scene were selected for dates have nearly identical solar elevation angles and we restricted our analysis to an area within half a degree of off-nadir view angle, thus eliminating any artifacts that might arise from different view and solar elevation angles between the two seasons.

For our objectives above we predict that:

(1) Average Green Chromatic Coordinate (GC) across the landscape will be higher in the dry season;
(2) GC variance in local neighborhoods (5x5 pixel kernel) will be higher in the dry season;
(3) Red reflectance variance in local neighborhoods will be higher in the dry season;
(4) EVI and NDVI will be higher in the dry season image;
(5) EVI and NDVI variance will be higher in the dry season.

Predictions (1) and (4) are based on the tower camera observation that many Central Amazon tree crowns flushed a cohort of dense new leaves in the 2-3 months prior to August, but by February the landscape was dominated by dark green crowns. Newly flushed crowns had higher GC (and higher EVI) than did crowns with dark green leaves, which are older. Predictions (2) and (5) are based on the tower camera observation that in the dry season the forest is a heterogeneous mix of crowns with recently flushed leaves (high GC and EVI), crowns with older dark green leaves that have not yet flushed (intermediate GC and EVI) and leafless crowns (low GC and EVI). The latter stage is a brief pre-flush state lasting about one month (Nelson et al 2014). Prediction (3) is expected if there are more of these bare pre-flush crowns present in the landscape in the dry season than in the wet season. At the ATTO site, the camera shows this brief pre-flush stage is present in 5-10% of all crowns at its peak frequency in July or August in the dry season, but is present in only 0-1% of crowns at any one time from January to March (Lopes et al. 2016).

2. Methods

We obtained two images of scene 230/63, centered at 59.31^{o}W, 4.34^{o}S. One image was from the mid wet season (08 Feb 2015) when tower mounted cameras near Manaus and at ATTO tower show very little leaf flushing or pre-flush leaf abscission and a predominance of dark green leafy crowns across the landscape. The other image was from the dry season (19 Aug 2015), when recently flushed crowns and pre-flush leafless crowns are expected to be abundant. At the Manaus and ATTO towers, the dry season (precipitation <100 mm mo^{-1}) typically lasts two months and begins in July or August. The Landsat 8 image region selected for this study has an average dry season length of 2.9 months (from TRMM 3b43 v7), typically in July, August and September, so climate is very similar to the ATTO and Manaus tower sites. In the El Nino drought year of 2015, July and August were the first two months of a longer dry season and the dry season image was obtained in mid-August prior to strong drought effects.

To avoid the pitfalls of BRDF artifacts (Galvão et al. 2011), solar elevation angles for the wet and dry season images were 57.61º and 56.93º respectively, so differed by only 0.7º. Both images were cloudy but a small region of interest (ROI) of 9 x 11 km with no clouds or very thin clouds was useable near the scene center. Off-nadir view angles of our ROI were very small, reaching a maximum of 0.46º off-nadir in the back-scatter direction and 0.54º in the forward-scatter direction. By restricting view angles to near-nadir, we avoid BRDF artifacts related to the difference between view and solar azimuth angles. This is important as the two solar azimuth angles were very different between the August and February images.

Full atmospheric correction to obtain surface reflectance did not successfully remove all thin clouds from the green band within our ROI. We instead used TOA reflectance of Green, Red and pan bands. We then controlled for the spatial and seasonal variation of aerosols, thin clouds and atmospheric scattering by using the TOA reflectance of the Landsat 8 Coastal Aerosol band (B1) as a co-variable. To reduce underlying target effects on B1 TOA reflectance, we used the local minimum of B1 (from a 5x5 pixel, moving window) as a proxy for atmospheric additive reflectance at each pixel. This was satisfactory as we had only tall plateau forest in our final ROI.

We restricted our analysis to flat areas of *terra firme* forest on undisturbed plateaus. We used smoothed 30m SRTM digital elevation data to mask slopes greater than 4º and to separate plateaus from lower areas. Water bodies, deforestation, bright clouds and cloud shadows were masked manually. We also masked any pixels whose 5x5 pixel neighborhood included any masked pixels by these other criteria.

To test our first three predictions, we used 15 m pixels, because they are about the same size as individual tree crowns. (Seasonal patterns at landscape scale using tower-mounted cameras were derived from timelines of each crown.) We pan-sharpened to 15m by the simple mean method, using the Landsat 8 pan band and a true color RGB band stack, that preserved the values of each of the input bands. The L8 pan band spans only the green and red range, so the outputs are:

$$R_{ps} = 0.75 * R + 0.25 * G \quad (1)$$
$$G\_ps = 0.75 * G + 0.25 * R \quad (2)$$
$$B\_ps = 0.5 * B + 0.25 * G + 0.25 * R \quad (3)$$

Where the suffix "_ps" indicates the output pan-sharpened band and R, G and B represent the inputs. All inputs were 30m TOA reflectance (x 10000, as 16 bit integer), and all outputs were in the same units, at 15m resolution. We made no further use of the blue pan-sharpened band as it is highly contaminated by red and green inputs.

We then obtained the Green Chromatic Coordinate (GC), which Lopes et al. (2006) used to demonstrate seasonality in crown greenness, seasonality of inter-crown variance in greenness, and derived crown leaf ages since their last flush:

$$Green\_Coordinate = G\_ps / (G\_ps + R\_ps) \quad (4)$$
$$Red\_Coordinate = R\_ps / (G\_ps + R\_ps) \quad (5)$$

3. Results and Discussion

We confirmed our first and second predictions. The Green Coordinate derived from TOA reflectance was higher (Figure 1) and had higher local variance (Figure 2) for the dry season image compared to the wet season image. We controlled for the spatial and temporal effects of aerosols and atmosphere as a covariable along the X axis of each figure. These results at Landsat 15m scale are consistent with the crown-scale seasonal patterns from a tower-mounted RGB camera at the ATTO site in the Central Amazon.

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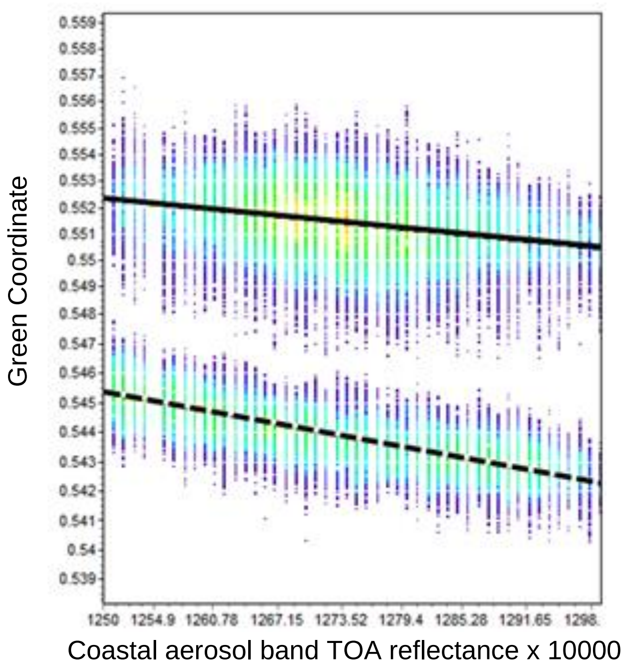

Figure 1. Mean of Landsat 8 Green Coordinate in 5x5 pixel moving window, versus proxy for additive atmospheric effects in the same 5x5 pixel moving window. Solid line is dry season, broken line is wet season.

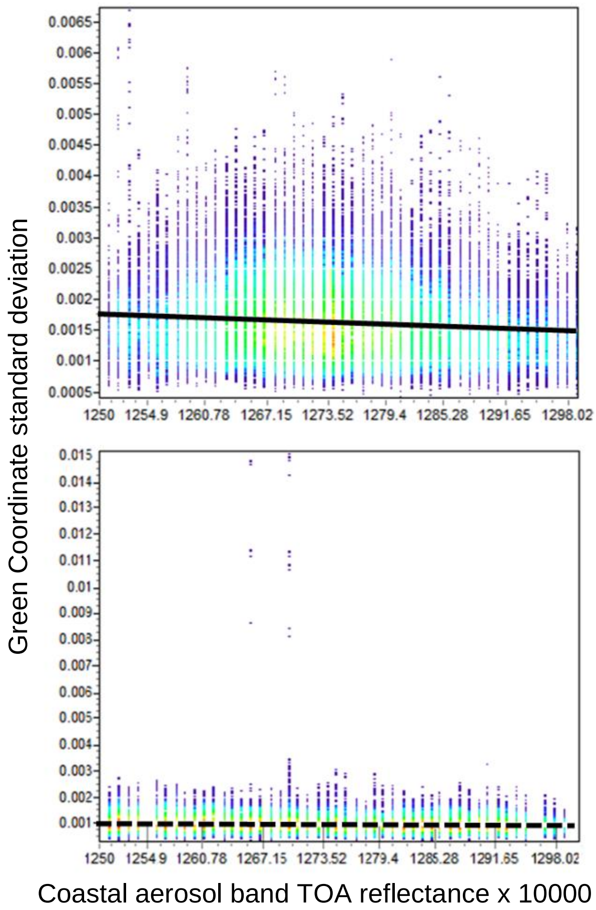

Figure 2. Local variance of Landsat 8 Green Coordinate in 5x5 pixel moving window, versus proxy for additive atmospheric effects in the same 5x5 pixel moving window. Solid line is dry season, broken line is wet season.

The Red Coordinate was lower in the dry season (not shown). This is mathematical certainty, as the two coordinates are complementary fractions that sum to 1.0 at each pixel. It is also a mathematical certainty that the local variance of the RC will be higher in the dry season if the GC local variance is higher in the dry season.

Part of the dry season local variance in the GC may be due to more leafless crowns in the dry season. Another part of the high dry season local variance in GC is due to the presence of recently flushed trees. We can infer that recently flushed crowns (high GC) are far more abundant than crowns at pre-flush leafless stage (low GC), because the average GC across the landscape was higher in the dry season. We conclude that higher dry season greenness is due to the large number of trees which flushed out bright green leaves in June, July and August, i.e. in the 2-3 months prior to the date of the dry season Landsat image. Therefore, a seasonal pattern of many crowns concentrating their flush events in the early dry season of the Central Amazon (as seen in tower mounted cameras), is also consistent with the differences we see at Landsat 15 m scale between dry and wet season images.

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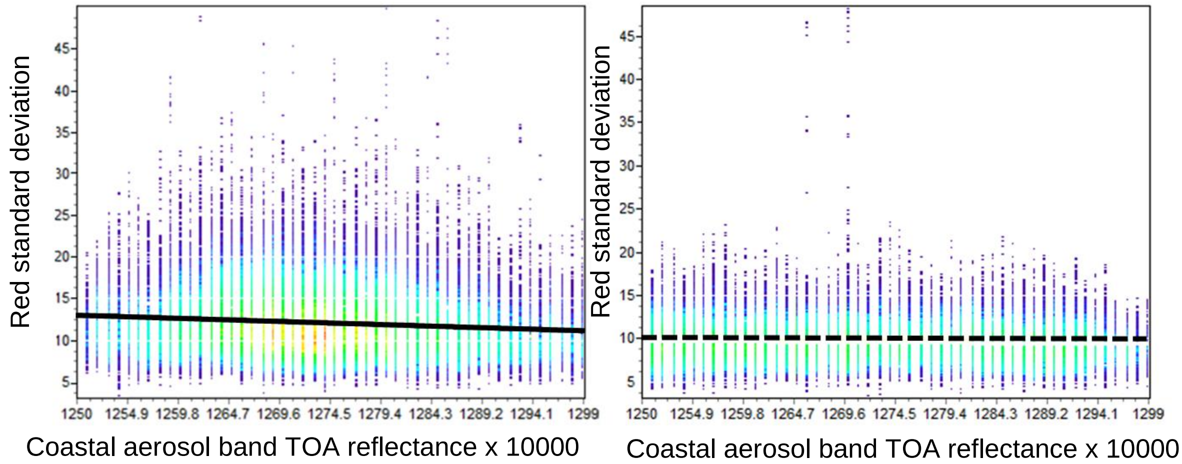

Figure 3. Local variance of Landsat 8 red band TOA reflectance in 15m pixels is higher in the dry season, indicating a higher number of scattered tree crowns at pre-flush leafless stage. Solid line is dry season, broken line is wet season.

Despite the forest being generally greener in the dry season, we expect a greater abundance of scattered leafless crowns in the dry season. This led to our third prediction, that red reflectance variance within local neighborhoods will be higher in the dry season. This prediction was also confirmed (Figure 3). Scattered leafless crowns cause a salt-and-pepper pattern of very high local variance within a matrix of lower variance. This pattern is stronger in the dry season local variance image (Figure 4).

At 30 m resolution, and using surface reflectance of pixels selected from a narrow range of TOA Coastal aerosol, average NDVI of our ROI was higher in the dry season (0.895) than in the wet season (0.860). But the data clouds for NDVI from the two seasons overlap much more than they do for the Green Coordinate. EVI was not different between the two seasons. These results do not support our fourth prediction. However, both EVI and NDVI had higher variance in dry season (not shown), following the GC and Red reflectance variance pattern and confirming Prediction 5.

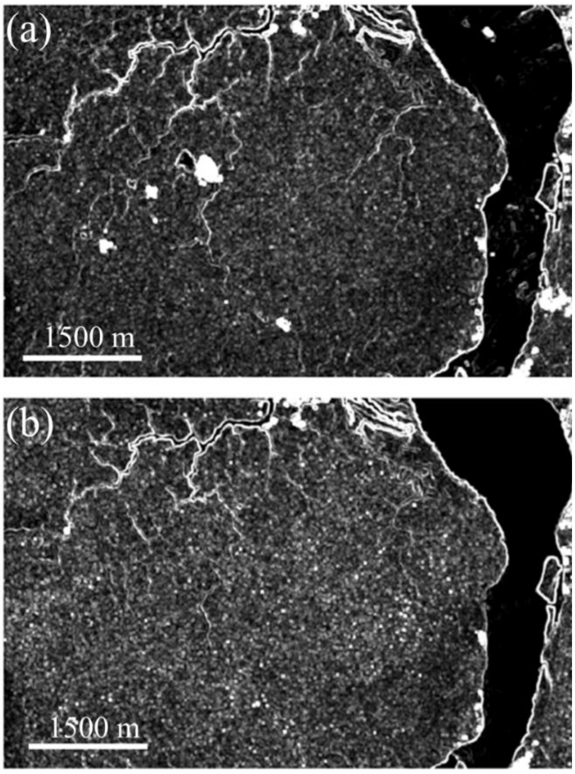

Figure 4. Local variance image of Landsat 8 red band TOA reflectance. Bright spots inferred to be isolated pixels occupied by a leafless crown, surrounded by leafy crowns in neighboring pixels. Upper image is wet season, lower is dry season. Identical linear stretches.

4. Conclusions

We found that 15m pan-sharpened green and red bands from Landsat 8 showed the same seasonal differences in canopy greenness detected by tower-mounted cameras at the individual crown scale.

5. Literature cited

Bi, J.; Knyazikhin, Y.; Choi, S.; Park, T.; Barichivich, J.; Ciais, P.et al. Sunlight mediated seasonality in canopy structure and photosynthetic activity of Amazonian rainforests. **Environmental Research Letters**, v.10, n.6, 2015

Galvão, L.S.; dos Santos, J.R.; Roberts, D.A.; Breunig, F.M.; Toomey, M. de Moura, Y.M. On intra-annual EVI variability in the dry season of tropical forest: A case study with MODIS and hyperspectral data. **Remote Sensing of Environment**, v.115, p.2350-2359, 2011

Guan, K. et al. Photosynthetic seasonality of global tropical forests constrained by hydroclimate. **Nature Geoscience**, v.8, n.4, p.284-289, 2015

Lopes, A. P.; Nelson, B. W.; Wu, J.; Graça, P. M. L.; Tavares, J. V.; Prohaska, N.; et al. Leaf flush drives dry season green-up of the Central Amazon. **Remote Sensing of Environment**, v.182, p.90-98, 2016

Morton, D. C.; Nagol, J.; Carabajal, C. C.; Rosette, J.; Palace, M.; Cook, B.D.; et al. Amazon forests maintain consistent canopy structure and greenness during the dry season. **Nature**, v.506, p.221-224, 2014

Nelson, B. W., Tavares, J. V., Wu, J., et al. 2014. **Seasonality of Central Amazon Forest Leaf Flush Using Tower-Mounted RGB Camera**. Available at: <https://agu.confex.com/agu/fm14/meetingapp.cgi#Paper/7861>. Accessed 20/07/2016.

Saleska, S. R.; Wu, J.; Guan, K.;Araujo, A. C.; Huete, A.; Nobre, A. D.; Restrepo-Coupe, N. Dry-season greening of Amazon forests. **Nature**, v.531, n.7594, p.E4-E5, 2016

Wu, J.; Albert, L. P.; Lopes, A. P.; Restrepo-Coupe, N.; Hayek, M.; Wiedemann, K. T. Leaf development and demography explain photosynthetic seasonality in Amazon evergreen forests. **Science**, v.351, n.6276, p.972-976,2016