PERSISTENT EFFECT OF 2015 EL NIÑO DROUGHT ON NIR REFLECTANCE OF CENTRAL AMAZON UPLAND FORESTS?

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ABSTRACT

A Landsat 8 surface reflectance (SR) image of the Manaus region acquired 27 July 2016, seven months after the El Niño drought of 2015 ended, was compared to a pre-drought SR image (10 August 2015) and a recent SR image (28 July 2022), the latter two representing normal climate conditions. All three have similar DOY, similar solar elevation angles and fixed view angle for the area of interest – part of a large military reserve 35 km northeast of Manaus. The seven-month post-drought image shows lowered NIR reflectance of the forest canopy in all forest types, with greatest effect on well-drained oxisol plateaus with deep water table, suggesting persistent physiological damage to leaves or decreased upper canopy LAI. These patterns must still be corroborated using other Central Amazon scenes and sensors.

Key words — Amazon forest, drought effect, NIR reflectance

1. INTRODUCTION

The high radiometric resolution of Landsat 8 OLI sensor provides an opportunity for monitoring seasonal and interannual change in tropical forest spectral patterns since 2013. Visual inspection of an L8 image of the Manaus area acquired on 27 July 2016, seven months after the end of a severe El Nino drought, appears to show low near infra-red (NIR) reflectance of plateau forests compared to surrounding mid- and lower-slope forests, which are closer to the water table.

However, NIR reflectance will decrease as sub-pixel shade fraction increases [1]. Plateau forests on well drained oxisols near Manaus have a more irregular canopy with larger gaps and more emergent crowns than do mid and low slope forests [2], possibly favoring increased shade fraction on plateaus.

Here we compare the L8 image acquired at seven months post-drought to two control images each of which did not have strong droughts in the preceding five years. We ask (1) if the post-drought image shows lowered NIR across all forest types when compared to the two control images; (2) if some topographic forest types show greater NIR decrease than others; and (3) if the topographic differences are reinforced by differences in canopy roughness effect on sub-pixel shade fraction.

2. MATERIAL AND METHODS

The three images of the Manaus region (orbit 231, row 062) are Landsat 8 surface reflectance Collection 2, Level 2, Tier 1, obtained from USGS Earth Explorer. Images were scaled to SR as a fraction, using Collection 2 gain and offset coefficients [3].

The study area (centered at -59.78 longitude, -2.79 latitude) is part of a large military reserve near Manaus (Amazonas, Brazil) and is well protected from disturbances such as fire and logging. A drought affected the region in 2015. The Global Precipitation Measurement dataset [4] estimates that three months (Aug-Oct/2015) had less than 100 $mm.mo^{-1}$ of rainfall and six consecutive months (Jul-Dec/2015) had less than 122 $mm.mo^{-1}$.

False-color RGB (SWIR1-NIR-RED) images were prepared, first using the same fixed reflectance values for the min and max stretch of each band across all three dates (Figure 1); then using image-specific and window-specific 1% and 99% cumulative frequency cuts per band (Figure 2).

Difference image histograms were prepared for three bands (Figure 3) and a difference image is shown for NIR reflectance (Figure 4). Differences images were normal climate reflectance (2022) minus reflectance in post-drought conditions (2016). Reflectance was expressed as a percentage prior to subtraction. The 2022 image followed a long period of non-drought conditions and was preferred over the 2015 pre-drought acquisition for making all difference images, because it has almost identical view and illumination geometry as the post-drought 2016 image (Table 1).

Date	DOY	Sun AZ	Sun ELEV
2015-08-10	222	56.2	56.1
2016-07-27	208	51.2	54.1
2022-07-28	209	51.4	54.2

Table 1. Day-of-year, solar azimuth, and solar elevation angles for the three Landsat images of scene 231/062

For question 3, we visually examined spatial patterns of reflectance in each of the six main optical bands of the 2016 post-drought image, to see if plateau forests had consistently lower reflectance than slope forests in all bands. This would be consistent with greater canopy roughness causing higher sub-pixel shade fraction, but also consistent with shade increase from post-drought leaf loss or leaf wilting. Our study area is at the eastern edge of a Landsat scene, where view and illumination angles comprise a forward scattering arrangement that should increase sensitivity of all bands to sub-pixel shade caused by texture or by leaf loss differences between plateau and slope forests [5].

3. RESULTS

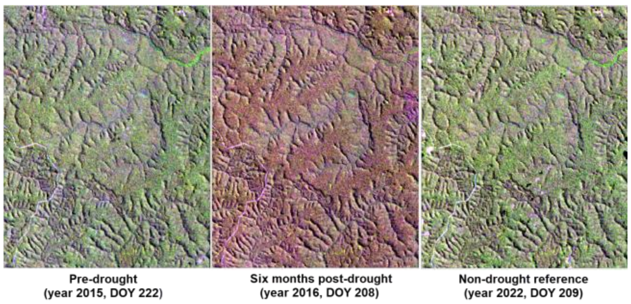

Figure 1. False-color RGB (SWIR1-NIR-RED) surface reflectance images of the 2015 pre-drought, 2016 seven-month post drought and the 2022 reference image. All three images use the same set of min and max reflectance value cutoffs per band when stretching. Each image is 9.5 km wide.

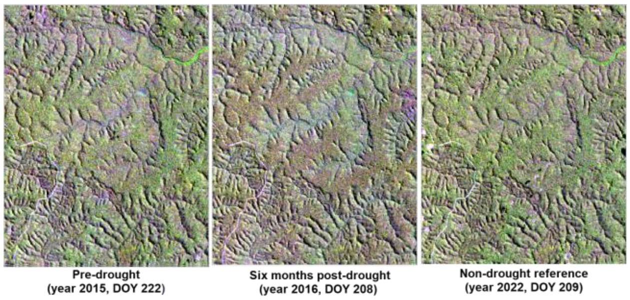

Figure 2. False color RGB images, same as in Figure 1 but using image specific and window specific 1% and 99% cumulative frequencies as min and max cutoffs for each band´s stretch. The post-drought 2016 image (center panel) differs from the two “normal climate” images in having lower greenness (lower NIR) on plateaus compared to gradual slopes.

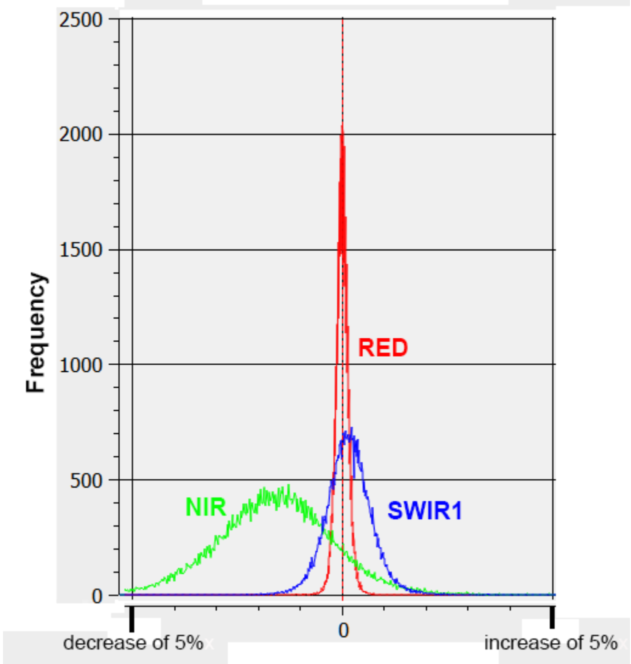

Figure 3. Difference image histograms by band in the more cloud-free north-central portion of the study area in Figure 1, showing: general decrease in NIR after drought, slight increase in SWIR1, no change in RED. Negative values indicate decrease when going from reference image to post-drought image.

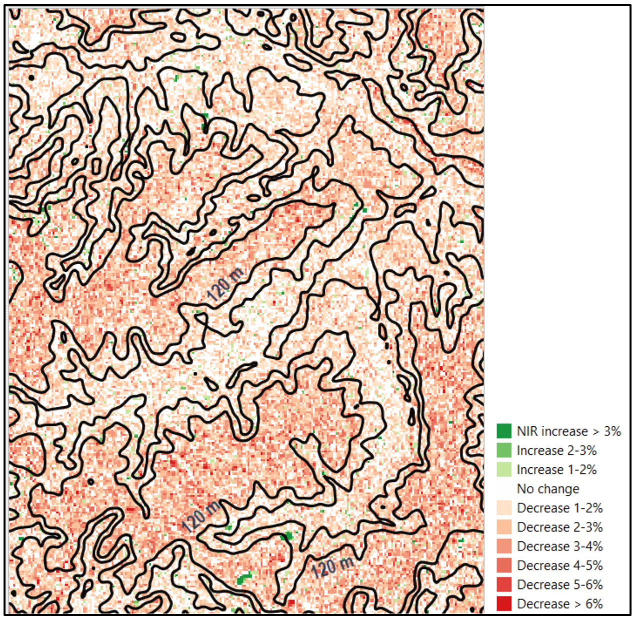

Figure 4. Difference image for NIR reflectance for same area as Figure 3, showing greater drought-associated decrease in NIR on plateaus. Contour intervals are 20 meters, with contour 120m following the shoulders of plateaus. Image is 6.4 km wide. Multipixel patches with extreme values are small clouds and their shadows.

Forests on plateaus and on slopes show NIR decrease in the post-drought image (Figures 1 and 3), but plateaus show greater post-drought decrease in NIR compared to slopes (Figures 2 and 4).

Regarding question 3, the post-drought green band showed a similar spatial pattern as the NIR band, with lower reflectance on plateaus compared to slopes. Blue and red bands showed a weak association with topography in the post-drought image. The shortwave infra-red bands, SWIR1 and SWIR2, showed no difference between slope and plateau in the post-drought image.

4. DISCUSSION

We speculate that the greater depth to water table on plateaus during drought led to persistent physiological damage to leaves and decreased upper canopy LAI, which could reduce upper canopy NIR reflectance of plateaus. NIR decreased on lower slope forests to a lesser degree, consistent with better access to water table during drought [6].

While shade fraction associated with canopy roughness seems not to be implicated in the differences between plateau and slope sites – because shade effects should occur in all bands and the SWIR1 and SWIR2 bands show no separation of smoother slope canopies and more textured plateau canopies in the post-drought image – there is an alternative explanation. Lowered SWIR from increased shade on post-drought plateaus, associated with fewer leaves in the drought-affected upper canopy, could be balanced out by increased SWIR from more bare branch exposure. Indeed, the ROI showed a very slight increase in SWIR1 in the post-drought image (Figure 3). Spectral unmixing could help tease apart this spatial and temporal interplay.

5. CONCLUSIONS

Seven months after the end of the strong El Niño drought of 2015, both plateau and slope forests near Manaus show decreased NIR in Landsat 8 images, with stronger effect on plateaus. This post-drought drop in upland forest NIR must be corroborated using other Central Amazon Landsat scenes and other sensors.

6. REFERENCES

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