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The Flooding Pampa Grasslands: a Radiative Transfer Model approach

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ABSTRACT

Some vegetation communities in Flooding Pampa grasslands remain flooded from short periods of days to months. We propose the use of Radiative Transfer Models as possible approach to estimate biophysical variables. Reflectance measurements of flooded canopies were performed for different leaf area index, water depth and geometrical configuration. Water strong absorption properties were present from near-infrared and especially at short-wave infrared wavelengths. There was no sensibility to vegetation spectral response when canopies were totally submerged. Strong directional effects were observed in the presence of water.

Keywords: flooded grasslands, remote sensing, reflectance model

RESUMEN

Algunas comunidades vegetales de los pastizales de la Pampa Deprimida permanecen inundadas desde días hasta meses. Por ello, proponemos el uso de modelos de transferencia radiativa (MTR) para estimar variables biofísicas en estos ambientes. Se realizaron mediciones de reflectancia en canopeos de área foliar variable con distintos niveles de agua y condiciones geométricas de medición. El agua mostró una fuerte absorción a partir del infrarrojo cercano y no permitió diferenciar la presencia de vegetación sumergida. Se encontró un considerable efecto de la reflexión especular en presencia de agua.

Palabras claves: pastizales inundados, sensores remotos, modelo de reflectancia

Introduction

The Flooding Pampa grasslands grow over a large plain where climate, flat topography and soil conditions determine periodic floods. More than 60% of soils of the Flooding Pampa have drainage limitations and some vegetation communities remain flooded from short periods of days to months (Burkart et al., 2005, Perelman, 2000).

Development of empirical or semiempirical methods to derive canopy biophysical characteristics such as leaf area index (LAI) from simple vegetation indices has been largely explored by the remote sensing community during the last two decades. However, in flooded environments for example, the presence of water could bring some problems in the interpretation of vegetation indices to infer biophysical variables (Beget and Di Bella, 2007). Recently, the understanding of the radiative transfer processes inside canopy through analytical reflectance models makes possible using more mechanistic approaches. Radiative transfer models simulate the interactions between sun-light and vegetation cover (leaves+soil). Their inversion allows esti-

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mating canopy variables from reflectance observations.

This study presents an experimental framework for the development and validation of a radiative transfer models for flooded canopies.

Materials and methods

Canopies background and water bodies

Plants of *Pittosporum tobira* sp were selected for canopy reflectance measurements. Shoots were collected outside on the trees and 'planted' in an artificial soil to simulate a canopy of 12 cm height. The advantage of *Pittosporum tobira* is to be rigid enough to keep the structure almost the same with or without water submersion. Five different canopy densities were generated covering a wide range of LAI (0.7-5.2). After completion of the spectral measurements vegetation was weighted and the leaf area of a subsample (35% of shoots) was measured with a Li-Cor© LI-3100 Area Meter. LAI vertical distribution was also measured every centimetre over a subsample of shoots. The artificial soil was a light brown painted tap with small holes to maintain vertically the shoots. The canopy was placed in the middle of a container large enough (90x36x15cm^3) to limit possible border effects. The container was also used to measure pure water reflectance at a range of depths over the artificial soil as well as over a white and a black panel.

For each density, reflectance measurements were taken over canopies without water, with an intermediate level of water (5 cm) and with the canopy totally submerged (13 cm of water).

Leaf optical properties

ASDFieldSpec© spectroradiometer coupled to an integrating sphere was used to measure *Pittosporum tobira* leaf hemispherical-directional leaf reflectance and transmittance. Eight leaves were sampled at two locations, avoiding the central vein. To get absolute hemispherical-directional reflectance and transmittance leaf values, reference Spectralon®, and Teflon plates were used respectively for reflectance (R_s) and transmittance (T_t), known signatures were measured before each leaf sample (S_r^b and S_t^b, respectively). Then, reflectance (S_{ri}) and transmittance (S_{ti}) of each sample were measured. More details on the methodology could be found in Ma et al. (2007).

Reflectance measurements

Reflectance measurements were performed indoor using a 2000 watts halogen projector plugged into a stabilized power source. The projector was placed at a sufficiently large distance to the target (10-15 m) to get better collimated light beam over the sampled area. Measurements were achieved during night to avoid contamination by natural illumination. An ASDFieldSpec© spectroradiometer equipped with a 8° FOV lens was measuring reflected radiation in the 350-2500 nm range with a 1 nm of spectral sampling interval and a spectral resolution around 3 nm for the shorter wavelengths up to about 10 nm for the longer wavelengths. Calibrations were made frequently using a Spectralon Labsphere® reference panel to get absolute reflectance values.

Measurements were made for three incidence angles (θ_s= [8° 30° 60°]) for 9 viewing zenith angles ($_o$=[-60° -45° -30° -15° 0° 15° 30° 45° 60°]) in the principal plane (relative azimuth angle, φ_s- φ_o =0°). Measurements were replicated 30 times from which the average was computed. These 3×9 = 27 series of directional measurements were achieved over the 5 canopies with different LAI with 3 depths of water ([0 5 13cm]) resulting in 15 canopy cases. Pure water was measured in the container with several depths ([0 0.15 1 2 4 8 12 cm]) over the three backgrounds, resulting in 21 cases. Additional tests were achieved to check that the possible interactions with the sides of the container were neglectable both for pure water and canopies.

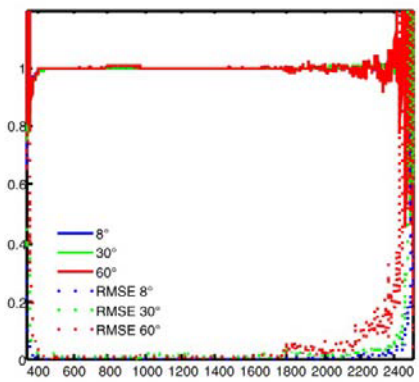

Fig. 1: Reference panel mean reflectance and root mean squared error (RMSE) for illumination angles ($n_{8°}$=8, $n_{30°}$=11, $n_{60°}$=10).

Measurements accuracy was evaluated by replication of the measurements over the reference panel (Fig. 1). Values of RMSE for the θs=8º were lower than 0.002 in the 350-1800 nm range. For 30º and 60º RMSE was lower than 0.015 for the same range of wavelengths. Between 1800 and 2200 nm uncertainties were higher by a factor of 2 for s=[8º 30º] and by a factor of 3 for the s=60º case. Above 2200 nm instrumental noise was very high and dominating.

Results and discussion

Leaf optical properties

Average values of the 16 replicates of reflectance and transmittance achieved over the *Pittosporum tobira* leaves showed typical spectral features with strong absorption in visible wavelengths, high reflectance and transmittance values in the near-infrared and absorption peaks near 1450 and 1950 nm associated to water leaf content (Fig. 2). Differences between lower and upper faces were stronger in the visible and short wave infrared domains, where lower face reflects more while transmitting about the same, leading to a weaker absorption. Conversely, in the near-infrared, upper faces reflect more and transmit less. Note that most of the single scattering contribution will come from the upper faces, which will allow approximating leaf optical properties by those of the upper face.

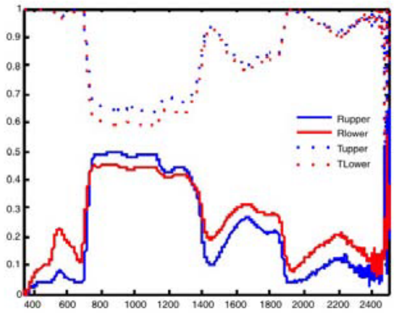

Fig. 2: Mean leaf spectral reflectance and transmittance of upper and lower faces.

Effect of water depth on background reflectance

Reflectance dependency to geometrical configuration was first analyzed for two contrasted wavebands at 600 and 1100 nm (Fig. 3 and 4) over the three backgrounds and the 7 water depths. Measurements show a relatively Lambertian behaviour of the background without water (depth = 0), with however a broad specular feature observed at inclined illumination angles ($_s$ = 60°). This specular feature increases rapidly as a function of water depth and illumination zenith angle ($_s$). It is much stronger at 600 nm than at 1100 nm.

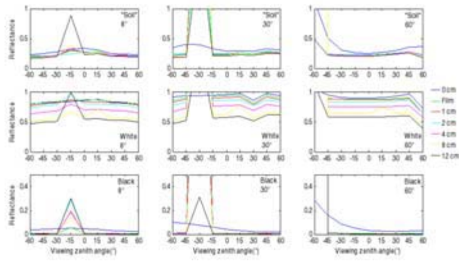

Fig. 3: Backgrounds reflectance at 600 nm as a function of viewing angles for different water depths. s is indicated in each box.

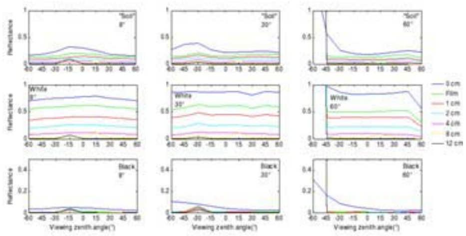

Fig. 4: Backgrounds reflectance at 1100 nm as a function of viewing angles for different water depths. $_s$ is indicated in each box.

When focusing on nadir observations ($_o$=0°) and near vertical illumination ($_s$=8°), where specular effect should be minimum, reflectance shows obviously a very strong spectral effect as a function of water depth, modulated by the background optical properties (Fig. 5). For the white background, gradual effects are observed in the visible and near-infrared with a decrease of reflectance when water depth increases. However, in the shortwave-infrared domain where water absorption is dominant, even the presence of a thin film of water on top of the background decreases reflectance down to almost zero. The black background shows very little effects as soon as water is added, with reflectance values around 0.01. The synthetic soil shows intermediate sensitivity to water depth.

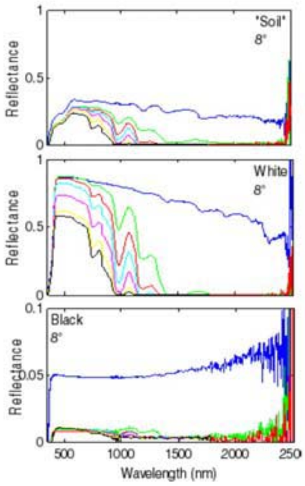

Fig. 5: Backgrounds spectral reflectance for water depths. s=8°and o=0°.

The decrease of reflectance as a function of water depth is well illustrated by Fig. 6, particularly for the white background: it shows a very classical exponential decrease of reflectance when the optical depth of the absorbing material increases. Saturation is observed already for 4 cm water at 970 nm corresponding to a small water absorption band, and for 10 cm at 1100 nm where water absorption is weaker. For the lower wavelengths, saturation is not yet reached at 12 cm water depth, reflectance showing still some sensitivity to water depth variation. For artificial soil and black backgrounds, the trends are similar to that of the white background, with however a large difference in the magnitude of the variation: the black background shows an extremely reduced variation and that of the artificial soil an intermediate magnitude (Fig 6).

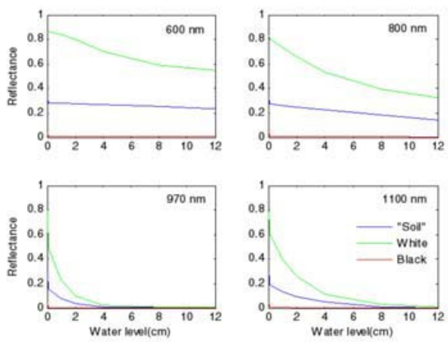

Fig. 6: Reflectance of backgrounds at 600, 800, 970 and 1100 nm as a function of water depth (cm). $_o$=0° and $_s$=8°.

Effect of water depth on canopy reflectance

Canopies show the typical spectral response of green tissues: strong absorption in visible wavelengths, high reflectance values in the near-infrared and strong absorption in short-wave infrared region (Fig. 7). Variability associated with LAI is less considerable in the near-infrared region. When 5 cm of water are added reflectance values in near-infrared decrease proportionally more in canopies of low LAI, because higher fraction of water cover is observed. When canopies are totally submerged reflectance in near-infrared decrease and showed a peak at 800 nm and at 1070 nm. Strong water absorption properties are observed from 1150 nm. There are no strong differences between canopies for the totally submerged situation.

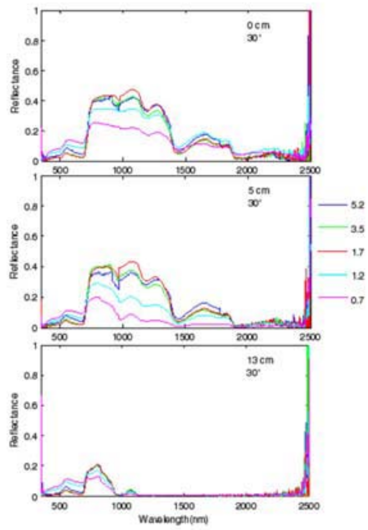

Fig. 7: Canopy spectral reflectance for different LAI and water depth. $_s$=30° and $_o$=0°.

To consider variations accounting for viewing angles over canopies measurements we analyzed three wavebands at 600, 800 and 1100 nm. As observed for backgrounds reflectance, directional effects are strongly present (Fig. 8, 9 and 10). Measurements show approximately a

Lambertian behaviour for canopies without water. As water is added (depth=5 and 13 cm), specular feature is increasingly evident for illumination angles ($_{s}$=8°, 30° and 60°). This broad directional effect is observed for the three wavebands (600, 800 and 1100 nm).

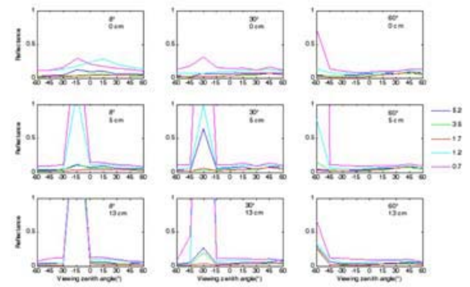

Fig. 8: Canopy reflectance at 600 nm as a function of viewing angles for different LAI and water depths. $_{s}$ is indicated in each box.

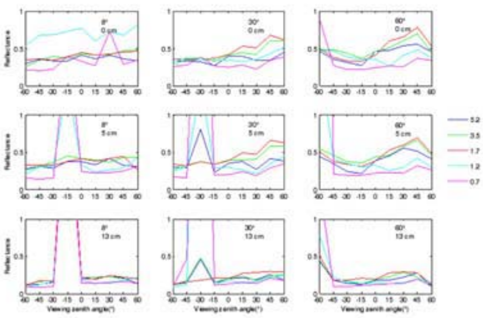

Fig. 9: Canopy reflectance at 800 nm as a function of viewing angles for different LAI and water depths. $_{s}$ is indicated in each box.

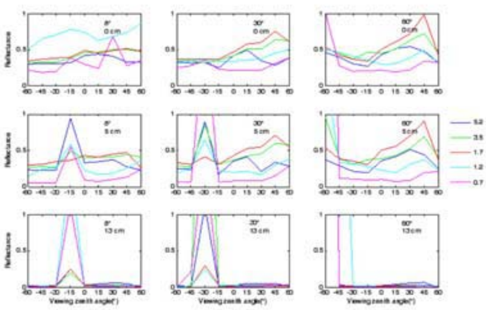

Fig. 10: Canopy reflectance at 1100 nm as a function of viewing angles for different LAI and water depths. $_{s}$ is indicated in each box.

Conclusions

Reflectance measurements of flooded canopies were experimentally performed for different leaf area index, water depth and geometrical configuration. Water strong absorption properties were present from near-infrared and especially at short-wave infrared wavelengths. We clearly observed that when water was present, specular reflexion was influencing measurements, meaning that an observation close to specular direction would end in difficult interpretation.

There was no sensibility to vegetation spectral response when canopies were totally submerged. It could be probably interesting to arrive at such conclusions, knowing if vegetation is totally or partially submerged. In case of partial submersion, it would be even more interesting to evaluate the possibility of estimating the leaf area index remaining above water. This task will be evaluated in the future over actual data.

Results presented above will be the empirical basis for the development of the flooded canopy reflectance model. Ratiative transfer models inversion will allow to improve the retrieval of canopy biophysical variables like emerged LAI and water thickness applicable to flooded grasslands and to extend it to other situation such as flooded rice crop.

A one-dimensional four-flux approximation model is proposed to simulate reflectance of vegetation submerged in shallow water based on the SAIL model (Scattering by Arbitrarily Inclined Leaves, Verhoef, 1984, 1985) coupled with a water reflectance model developed by Suits (1984). SAIL model is widely used in the remote sensing community for the estimation of vegetation biophysical variables. It computes light transfer inside the canopy taking account of canopy structure, leaf and soil optical properties and variables associated with measurements conditions.

Acknowledgements

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