Differences in Grass-Shrub Transition Zone Canopy Composition from CHRIS/Proba Multi-Angle Data

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***Abstract* - The surface spectral-directional reflectance of a grass-shrub transition zone at 631 nm was estimated from spectral radiance images in a narrow (~10 nm wide) band recorded by the Compact High Resolution Imaging Spectrometer (CHRIS) flown on the European Space Agency's Proba micro-satellite. An experimental satellite-borne sensor developed by Sira Electro-Optics Ltd. (UK), CHRIS is one of the few sources of multi-angular reflectance data on kilometer scales, providing up to five looks in different directions at a given target within the space of a few minutes. For a selected December 23, 2003 overpass, orbital ephemeris were used to obtain the viewing geometry for the set of four available images. The images were resampled to a consistent 25 m grid and used to invert a simple geometric bidirectional reflectance distribution (BRDF) model for plant number density, plant width, and plant height. The retrieved parameters were compared to subsets of high resolution aerial photographs. The inversions did not always result in the expected parameter behavior and further work is required to determine the underlying reasons, which may include decoupling model parameter response to brightness and anisotropy.**

Keywords; canopy; ecotone; multi-angle; BRDF model inversion.

I. INTRODUCTION

Grass-shrub transition zones in desert grassland environments where the flora continues to change from grass to shrub domination are of much interest to ecologists. The USDA, ARS Jornada Experimental Range near Las Cruces, New Mexico (USA) includes such a zone which this has been the subject of much research aimed at developing remote sensing methods which might enable monitoring of these transformations over large areas [1-3]. It is located in the northern part of the Chihuahuan Desert where perennial grass cover has dramatically decreased and shrub density dramatically increased since the 1880's. These trends are continuing [4] with important implications for desert albedo, hydrological and biogeochemical processes, and ecological function. In this zone, remotely-sensed brightness in the solar (visible and near infra-red) wavelengths is mainly controlled by the density of the understory of black grama grass (*Bouteloua eriopoda*) and broom snakeweed (*Gutierezzia sarothrae*), rather than by the larger plants, mostly honey mesquite (*Prosopis glandulosa*) but also Mormon tea (*Ephedra torreyana*), and soaptree yucca (*Yucca elata*). There are difficulties in interpreting multi-spectral remote sensing data here which are not trivial; for example, it is difficult to determine the proportions of bare soil, grama grass and snakeweed in the lower canopy using multi-spectral methods since reflectance patterns can be very similar (Fig. 1).

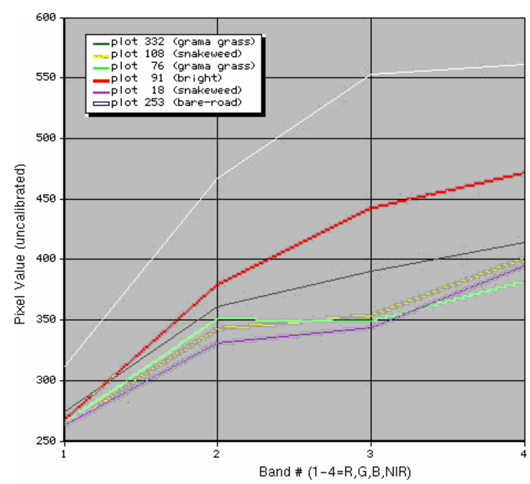

Fig. 1. IKONOS multi-spectral patterns for locations in the transition zone.

To address this, efforts are being made to exploit data from an experimental multi-angle sensor, CHRIS, developed by Sira Electro-Optics Ltd. (UK). CHRIS is one of the few sources of multi-angular reflectance data on kilometer scales, providing up to five looks at a given target within the space of a few minutes. This is achieved through tilting and nodding of the satellite, only possible because of the Proba satellite's ability to autonomously orient itself at different angles with respect to the surface while viewing the same target area on the ground. CHRIS acquires images in up to 62 spectral channels in the range 415 - 1050 nm with a spectral resolution of 5 - 12 nm and it is highly configurable in terms of swath, spectral channels and spatial resolution. The Jornada Experimental Range is one of the 22 sites worldwide selected in 2000 for the exploitation of data from the CHRIS instrument. For the CHRIS/Proba Jornada Experiment, Mode 3 (Land Channels) was chosen, providing a nominal ground sampling distance of 17 m and 18 spectral channels with a full swath. The imaged areas encompass a variety of plant communities and topoedaphic conditions, including black grama grassland, grass-shrub transition, mesquite-dominated shrubland, areas infested with broom snakeweed, areas of sand entrainment and deposition, experimental plots, and swales.

II. METHOD

A CHRIS spectral radiance image set from December 28, 2003 was selected on the basis of overlap extent, cloud cover, image quality and angular sampling. The angular sampling is close to the principal plane and a large overlap region with four or five looks is provided [5]. The five directional images were co-located and resampled to a 25 m grid using a 1 m IKONOS panchromatic image as reference, with absolute root mean square error at the control points < 3 m. Orbital ephemeris were used to obtain the angular sampling configurations. Surface spectral reflectance estimates were calculated using the 6S atmospheric correction code for all Mode 3 bands and assuming a desert aerosol type. Meteorological data indicated a visibility of 16.1 km for both dates from which an optical thickness at 550 nm of 0.3 was estimated. For this area the four available directional images were used to adjust the non-linear Simple Geometric Model (SGM) [5-7] which was inverted for mean plant number density, radius and height using an iterative direct search optimization code with min(RMSE) as the objective, as described in [5]. The parameter describing crown shape was set to 0.75 (oblate). The encapsulated Walthall soil-understory sub-model [8] was driven here by multi-angle observations from CHRIS. The Walthall model parameters were scaled according to reflectance in the CHRIS image viewing closest to nadir to allow for variations in the composition of the soil-understory complex. Constraints were imposed by raising RMSE if height > 4 m, LAI < 0, fractional cover > 0.9, plant density <= 0 or plant width <= 0. Inversions were restricted to using only the 631 nm band because in this region absorption by plant photosynthetic materials and pigments is maximal, contrast between soil and vegetation is at a maximum, and the single scattering approximation is more valid than in the near infra-red.

The SGM model was fitted to the entire overlap region of the CHRIS data set with four or five angular looks, i.e., for raster images of 264 rows by 477 columns corresponding to 125,928 inversion problems. The results for the area surrounding the transition site were extracted and compared to high resolution aerial photographs.

III. RESULTS AND DISCUSSION

The model fitting resulted in very low RSME values (mean, standard deviation and mode all < 0.01). When inverted with scaled Walthall model parameters the SGM produced a very small proportion of negative parameter values (0.01% of all 125,928 locations for density and width and 12% for height) occurring at bright, sparse locations. Only the retrieved height parameter had negative values within the transition site study area. Context for the comparisons between the retrieved parameter maps and aerial photograph subsets is provided by Fig. 2; this shows both the distribution of the Normalized Difference Vegetation Index (NDVI) – a measure in which fractional vegetation cover, foliage density and greenness are confounded – at 4 m resolution and panchromatic brightness values at 1 m resolution for the transition site area. The dark spots in the Fig. 2 (b) are large shrubs – mostly mesquite – and the mottled grey areas indicate a more dense understory.

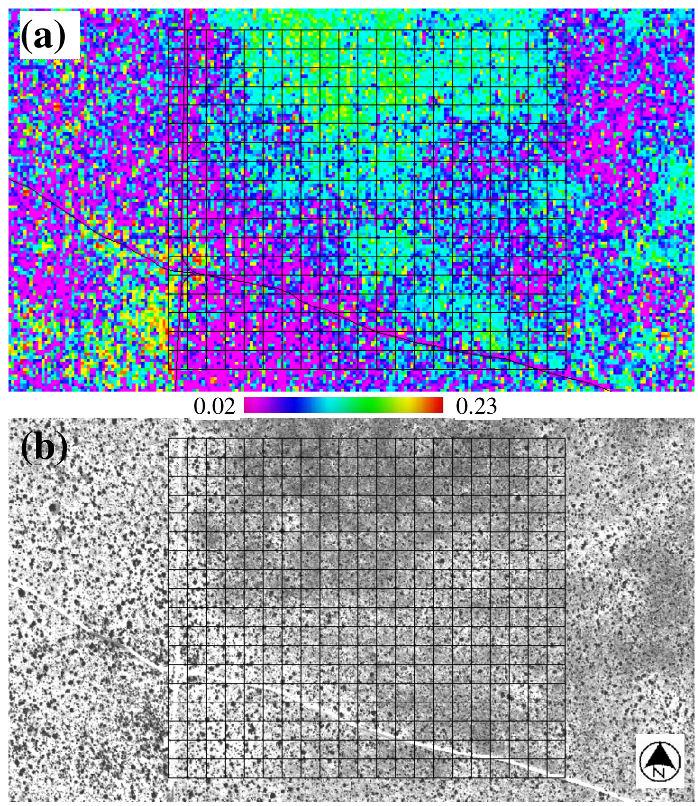

Fig. 2. (a) IKONOS 4 m Normalized Difference Vegetation Index (b) IKONOS 1m panchromatic image. The grid interval is 25 m; other lines are roads.

It can be seen that the NDVI image reflects the distribution of the understory of broom snakeweed and sparse grama grass lending weight to the assumption that the understory controls overall brightness. There is a much weaker correlation with large plant distributions with both very low values (where typically inter-shrub fractional vegetation cover is very low) and very high values (corresponding to acacia groves and very large mesquite where NDVI approaches its maximum of 0.23; i.e., yellow through red colors in the image).

The relationships between the parameters retrieved by inversion of the BRDF model and canopy characteristics can be seen by inspection of parameter maps (Fig. 3) and aerial photograph subsets (Fig. 4). The latter correspond to 3 rows x 5 columns of cells in the parameter maps, centered at the numbered locations in Fig. 3. Location #1 is near the intersection of sand roads leading into and out of the range with a mostly large shrubs: a low plant density was retrieved which is reasonable as there are fewer broom snakeweed and mean plant width and height are also low in spite of a few acacia just to the NE of the intersection. Location #2 is about 75 m SE of the intersection and has a high density, reflected in the retrieved value, with moderate mean width retrieved but failed inversions for height (negative values were obtained). Location #3 is E of the intersection and extremes of density were estimated with moderate width, although conditions appear similar to that of location #2 – however here too the inversion for height failed. Location #4 is about 175 m N of the intersection and rather high density was estimated with moderate-to-high width and some failures for height. There is a division in the density and width values which corresponds to the division of the area into the W part dominated by the road and large plants; and the E part which has far greater understory cover. Location #5 is the E-most selected and is intersected by the road. Low density and moderately high mean width and height values were retrieved; this may be owing to the greater abundance of grass here, confirmed through field observation (note darker photograph). Locations #6 and #8 are areas with less grass and a high snakeweed density but low density and high width and height were retrieved. Location #7 is N of location # 4 and is again divided longitudinally with the W part dominated by the road and large plants and the E part showing a dense understory with fewer large plants. Higher (lower) density was retrieved for the W (E) part indicating a response to large plants, while negative (low) height values were obtained for the W (E) parts, respectively.

Overall, the distributions of parameter values show gradients across the site, although it is not always clear that there is a direct or easy interpretation. This may not be surprising, since it is difficult to visually estimate or to quantify plant density or width because a large number of small (~20 cm diameter) broom snakeweed plants can importantly impact the mean value. Locations where inversions failed – typically providing negative and unphysical values for canopy height – invariably correspond to areas where the understory is very sparse, more soil is exposed and larger plants dominate.

IV. CONCLUSIONS

This paper has reported on work directed at exploiting the angular signature from CHRIS on Proba for determination of canopy structure and composition in grass-shrub transition zones. The model inversions resulted in low RMSE values and meaningful gradients in adjustable parameters but did not always result in the expected behavior: values were not always easy to interpret or physically reasonable. This may be because the canopy parameters are easily confounded in these discontinuous canopies. In a related study [5], decoupling the effects of brightness and anisotropy – by making the assumption that the soil-understory complex is a more important control on overall nadir brightness than large shrub density – appeared to be feasible. However it is possible that simultaneous inversions for plant number density and width are not feasible since these parameters both respond mainly to brightness (a function of fractional cover). Further work will pursue the questions surrounding model inversion and whether the relationships used to scale the soil-understory lower boundary with nadir brightness require refinement.

ACKNOWLEDGMENTS

We would like to thank Mike Cutter (Sira Electro-Optics Ltd.), Kris Havstad, Amy Gonzalez, and Enrique Gomez-Landesa (Jornada Experimental Range/NMSU).

REFERENCES

[1] Rango, A., Ritchie, J.C., Kustas, W.P., Schmugge, T.J., Brubaker, K.L., Havstad, K.M., Prueger, J.H., and Humes, K.S., "JORNEX: A remote sensing campaign to quantify rangeland vegetation change and plant community-atmosphere interactions". *Proc. 2nd International Conference on GEWEX*, Washington, DC, 445-446, 1996.

[2] Privette, P., G.P. Asner, J. Conel, K.F. Huemmrich, R. Olson, A. Rango, A.F. Rahman, K. Thome, and E.A. Walter-Shea., "The EOS Prototype Validation Exercise (PROVE) at Jornada: overview and lessons learned", *Remote Sens. Environ*. 74:1–12, 2000.

[3] Qin, W., and Gerstl, S. A. W., "3-D scene modeling of Jornada semi-desert vegetation cover and its radiation regime". *Remote Sens. Environ*. 74: 145–162. 2000.

[4] Gibbens, R.P., Beck, R.F., McNeely, R.P. and Herbel, C.H., "Recent rates of mesquite establishment in the northern Chihuahuan Desert", *Journal of Range Management* Vol. 45, 585–588, 1992.

[5] Chopping, M.J., Laliberte, A., and Rango, A., "Multi-angle data from CHRIS/Proba for determination of canopy structure in desert rangelands", Proceedings of IGARSS'04 (these proceedings), 2004.

[6] Chopping, M.J., Su, L., Rango, A., and Maxwell, C., "Modeling the reflectance anisotropy of Chihuahuan Desert grass-shrub transition canopy-soil complexes", in press, *International Journal of Remote Sensing*, 2004.

[7] Chopping M.J., A. Rango, K.M. Havstad, F.R. Schiebe, J.C. Ritchie, T.J. Schmugge, A. French, L. McKee, and R.M. Davis, "Canopy attributes of Chihuahuan Desert grassland and transition communities derived from multi-angular 0.65μm airborne imagery", *Remote Sens. Environ.* Vol. 85, No. 3, 339-354, 2003.

[8] Walthall, C.L., J.M. Norman, J.M. Welles, G. Campbell, and B.L. Blad, "Simple equation to approximate the bidirectional reflectance from vegetative canopies and bare surfaces", *Applied Optics* Vol. 24(3): 383-387, 1985.

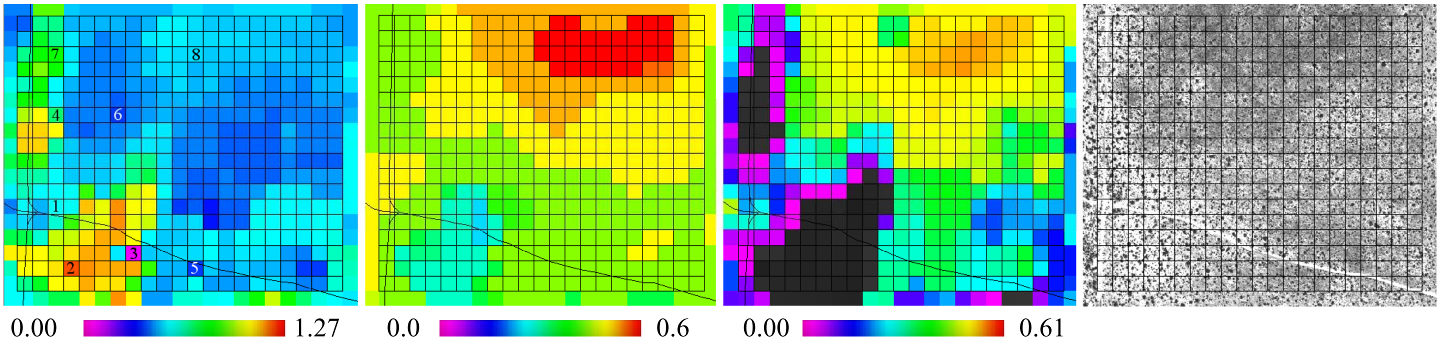

Fig. 3 Left to right: plant number density / m^2; plant width (m); plant height (m; black indicates negative values); 1 m IKONOS panchromatic image. The grid interval is 25 m. Other lines are roads.

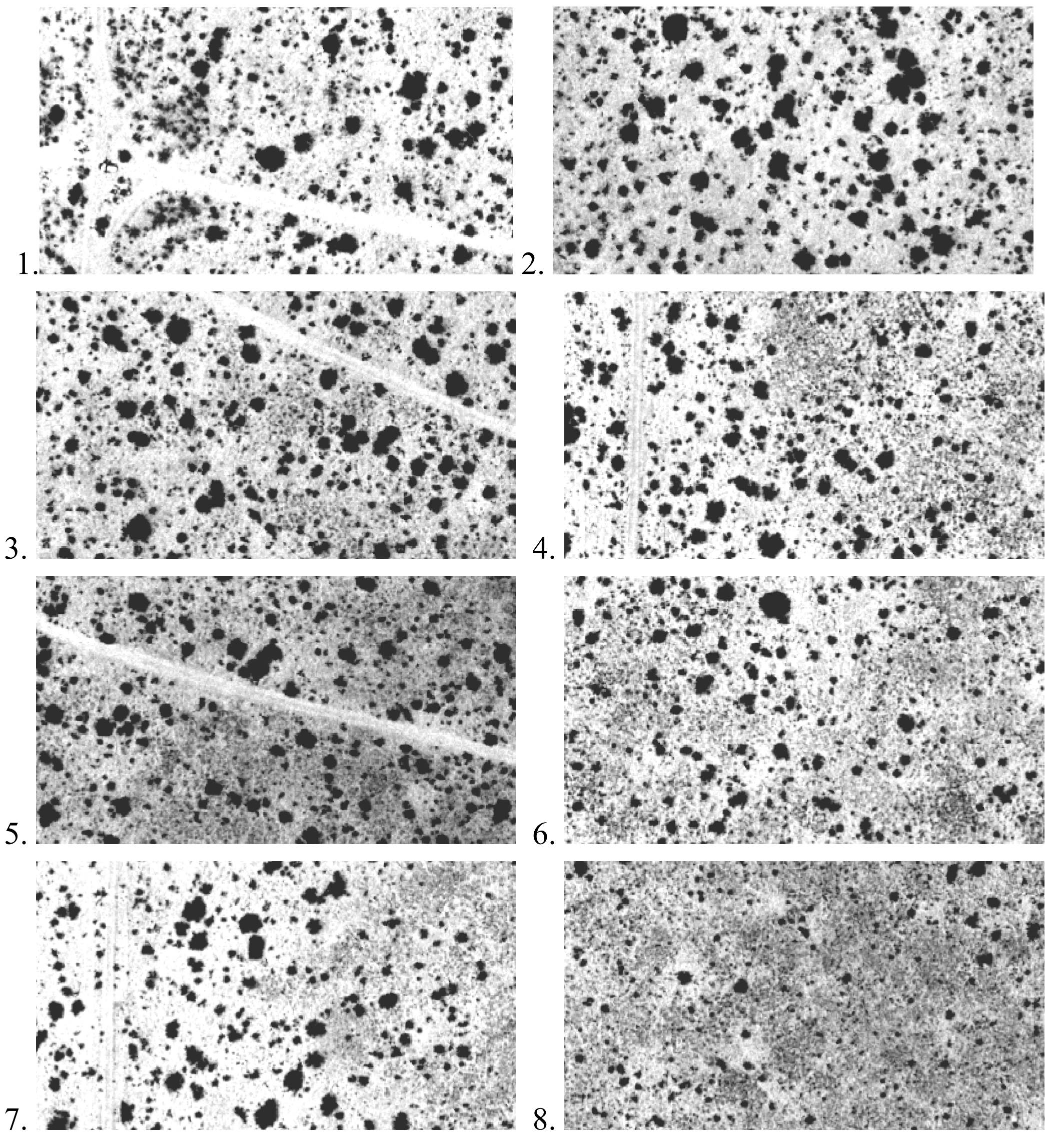

Fig. 4 Aerial photograph subsets of 3 rows by 5 columns of 25 m^2 cells centered on the corresponding numbered labels in Fig. 3.