Multi-Angle Data from CHRIS/Proba for Determination of Canopy Structure in Desert Rangelands

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Abstract - **Multi-angle spectral radiance images from the Compact High Resolution Imaging Spectrometer (CHRIS) on the European Space Agency's Proba satellite were acquired over desert grasslands in the USDA, ARS Jornada Experimental Range near Las Cruces, New Mexico, USA. The data were used to obtain multi-angle ratio images and to effect spatial bidirectional reflectance distribution function (BRDF) model inversions. The results show that there is canopy 3-D structure information observable in ratio images but physical interpretation is difficult. Inversion of a simple non-linear model for three canopy parameters resulted in low root-mean-square error values. The difficulty of decomposing the effects of brightness and reflectance anisotropy (BRDF shape) in complex desert shrub landscapes with varying soil-understory characteristics was overcome by allowing linear scaling of the parameters of the soil-understory sub-model as a function of near-nadir 631 nm reflectance. The retrieved parameter maps show a high spatial correlation between width and height but a different distribution for density. Examination of high resolution panchromatic and multi-spectral imagery shows that there are strong relationships between the retrieved parameters and canopy characteristics although further validation is required.**

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

INTRODUCTION

The USDA, ARS, Jornada Experimental Range, 37 km north of Las Cruces, New Mexico, is one of the 22 sites worldwide selected in 2000 for the exploitation of data from the CHRIS instrument. 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 [1- 2] with implications for desert albedo, hydrological and biogeochemical processes, and ecological function. Honey mesquite (*Prosopis glandulosa*) is the most important invading plant and is now a major dominant on sandy soils. CHRIS is an experimental sensor developed by Sira Electro-Optics Ltd. (UK) and 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.

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. 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.
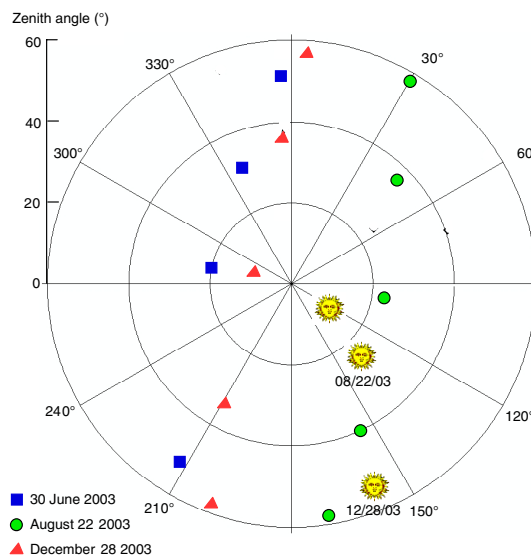

Fig. 1. CHRIS angular sampling.

METHOD

CHRIS spectral radiance image sets from 2003 were examined for overlap extent, cloud cover, image quality and angular sampling and acquisitions on August 22 and December 28 were selected. The 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 for each of the image sets (Fig. 1). 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. The August data were used to calculate forward- : back-scattering reflectance ratio images. The December data set was used in BRDF model inversion since the angular sampling is closer to the principal plane and it provides a larger overlap region with five looks. The anisotropy of reflectance spectra in indicated by Fig. 2.
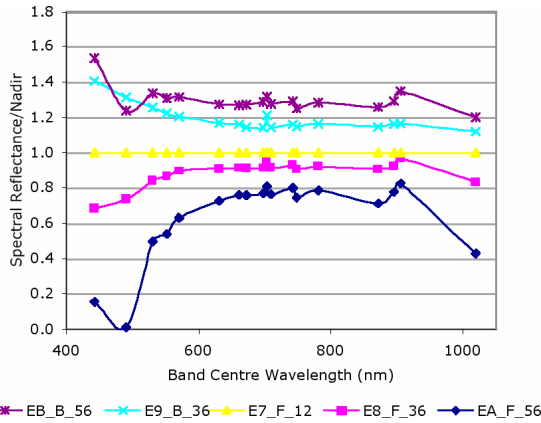

Fig. 2. CHRIS spectra for a bright target in the Jornada Experimental Range as a ratio of values viewing closest to nadir. Legend: scene code, (F)orward or (B)ack-scattering and view zenith angle (°).

The non-linear Simple Geometric Model (SGM) [3-4] was inverted for mean plant number density, radius and height using an iterative direct search optimization code as described in [4] with min(RMSE) as the objective. The parameter describing crown shape was set to 0.75 (oblate). The SGM assumes potential contributions from geometric-optical and volume scattering phenomena (1):

$$R = G_{Walthall}(\vartheta_i,\ \vartheta_v,\ \varphi)\ .\ k_G(\vartheta_i,\ \vartheta_v,\ \varphi) \qquad (1)$$
$$+\ C_{Ross}(\vartheta_i,\ \vartheta_v,\ \varphi)\ .\ k_C(\vartheta_i,\ \vartheta_v,\ \varphi)$$

where ϑ_i, ϑ_v and φ are the view zenith, solar zenith and relative azimuth angles, respectively; k_G and k_C are the calculated proportions of sunlit and viewed background and crown, respectively; $G_{Walthall}$ is the calibrated Walthall model [5]; and C_{Ross} is the simplified Ross turbid medium approximation for optically-thin or thick plane parallel canopies. The encapsulated Walthall soil-understory sub-model was driven here by multi-angle observations from CHRIS with parameters scaled as a function of nadir reflectance. Constraints were imposed by

raising RMSE if height > 4 m, LAI < 0, fractional cover > 0.9, plant density <= 0 or plant width <= 0. In addition inversions were restricted to using only the 631 nm band images because in these wavelengths absorption by plant photosynthetic materials and pigments is maximal and the single scattering approximation is more valid.

RESULTS AND DISCUSSION

High values in the ratio image correspond to sparse large plants on very bright and sparse understory backgrounds. More densely-populated areas (e.g., high snakeweed and grama grass density; swales) have lower values. However, this relation is difficult to quantify and may not be general.
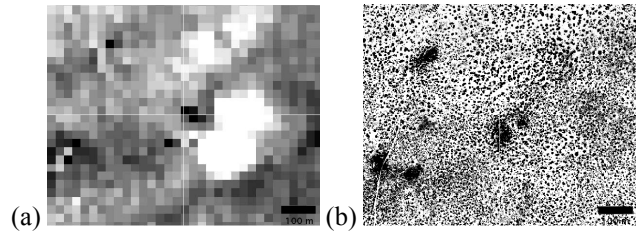

Fig. 3. (a) CHRIS 631 nm forward- : back-scattering ratio image chip, August 22, 2003 (b) corresponding IKONOS 1m panchromatic image from 05/23/01.

SGM model fits to data provided low RSME values (mean, standard deviation and mode < 0.01). Inversion with fixed Walthall model parameters resulted in a relatively large proportion of negative parameter values, 18% for plant number density. The areas where inversions failed correspond to locations with bright soil and sparse understories (Fig. 4) as a result of the model's inability to cope with situations where vegetation is extremely sparse.
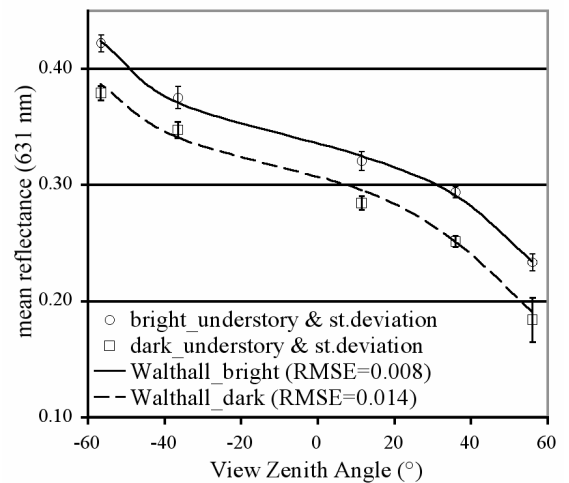

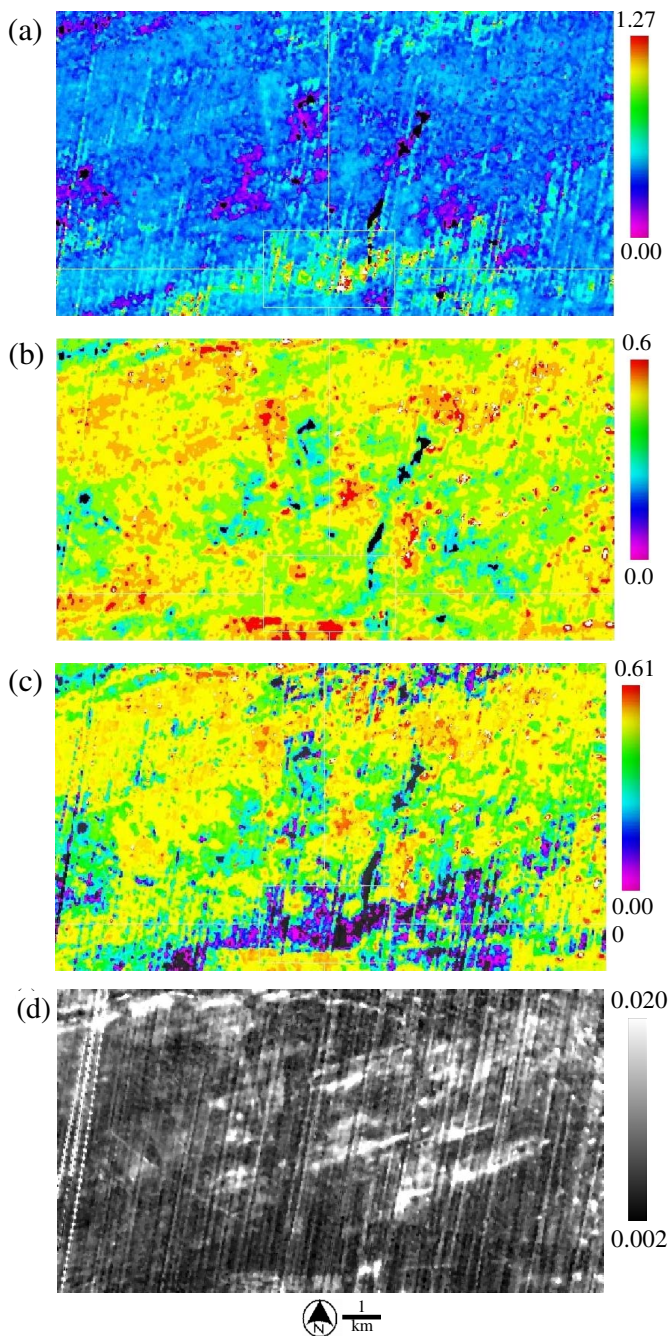Fig. 4. CHRIS reflectance and Walthall model fit to data.

(a)

1.27

0.00

(b)

0.6

0.0

(c)

0.61

0.00
0

(d)

0.020

0.002

⊕ N 1/km

Fig. 5. Parameter maps from SGM model inversion with Walthall model parameters estimated from nadir 631 nm brightness): (a) plant number density, (b) mean plant width (m), (c) mean plant height (m), (a) – (c): median filtered, black indicates negative values, white values > red, (d) absolute RMSE.

The SGM with scaled Walthall model parameters produced far fewer instances of negative parameters (0.01% of locations for density and width and 12% for height), with these again occurring at bright, sparse locations. The spatial distributions of

retrieved parameters do not precisely match that seen in an IKONOS 4 m NDVI and false color images (Figs. 5-7) except for broad differences in fractional cover e.g., between grass- and shrub-dominated and exposed soil areas. Density and width distributions correspond well to what is observed in high resolution panchromatic IKONOS panchromatic images (Fig. 8). Lower density and width are associated with brighter soil areas, while higher density and width are associated with denser areas. Retrieved width is higher for the grama grass areas in the south-central part of the maps; vegetation is more homogeneous here.
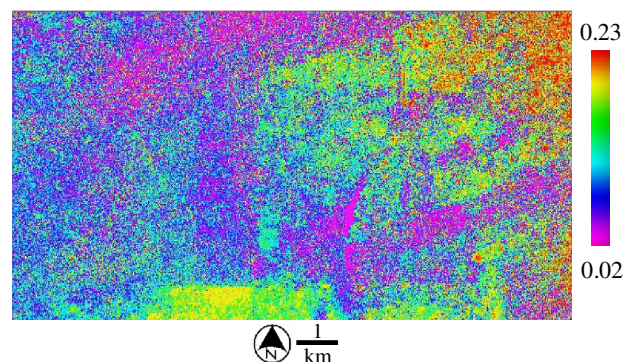

0.23

0.02

⊕ N 1/km

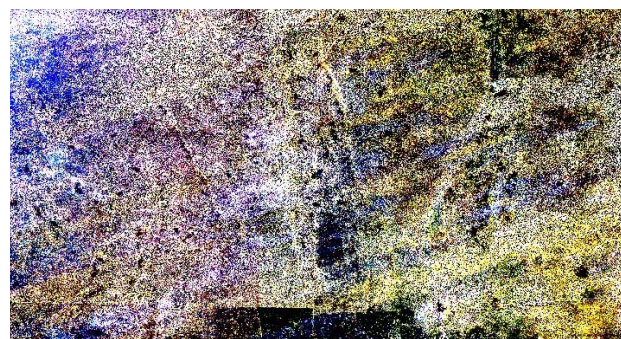Fig. 6. NDVI from 07/20/00 IKONOS 4 m scene.

Fig. 7. IKONOS 421 (near-infrared, green, red) false color composite, almost covering the area shown in Fig. 5.

CONCLUSIONS

This paper has reported on first efforts to exploit the angular signature from CHRIS on Proba for the Jornada Experimental Range Core Site specifically for determination of canopy structure in desert rangelands. Images of ratios of forward- to back-scattering spectral reflectance were shown to bear an important relation to mean plant size but more work is required to determine whether the relation is general enough for operational application. It seems likely that canopy parameters – plant number density, foliage density, plant width, shape and height, soil color, and understory composition – will be

confounded in the ratio metric. The SGM inversions resulted in low RMSE values and parameter values appeared reasonable when the soil-understory lower boundary was scaled with nadir brightness. Decoupling the effects of brightness and reflectance anisotropy – by making the assumption that the soil-understory complex is a more important control on overall nadir brightness than large shrub density – appears to be feasible. The spatial distributions of retrieved plant density, width and height parameters correspond well with observed canopy characteristics although further validation is required.

ACKNOWLEDGMENTS

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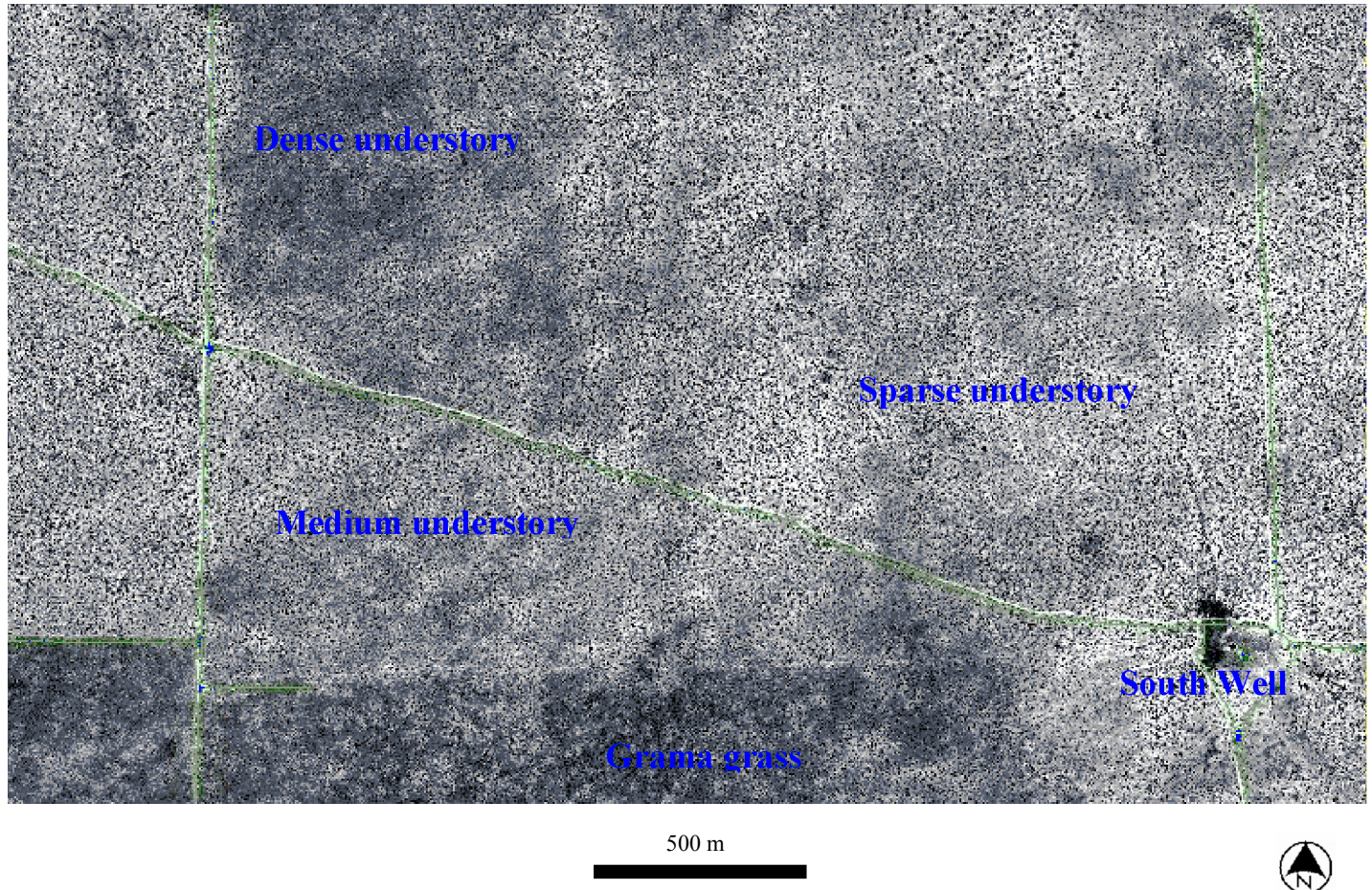
Fig. 8 IKONOS 1 m panchromatic image (10/27/00) corresponding to the white box in Fig. 3. The green lines are roads and fences.