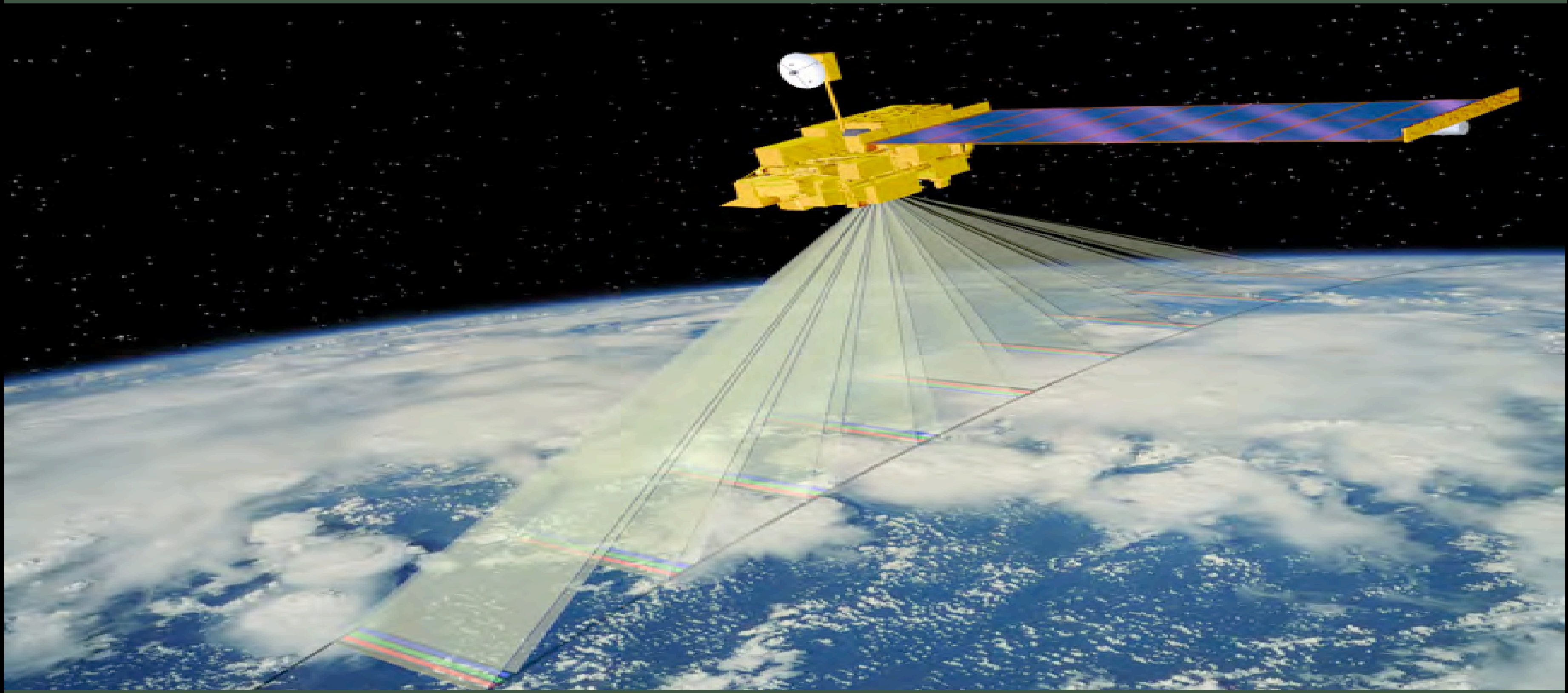
Mapping Vegetation with the NASA Earth Observing System
Multiangle Imaging SpectroRadiometer



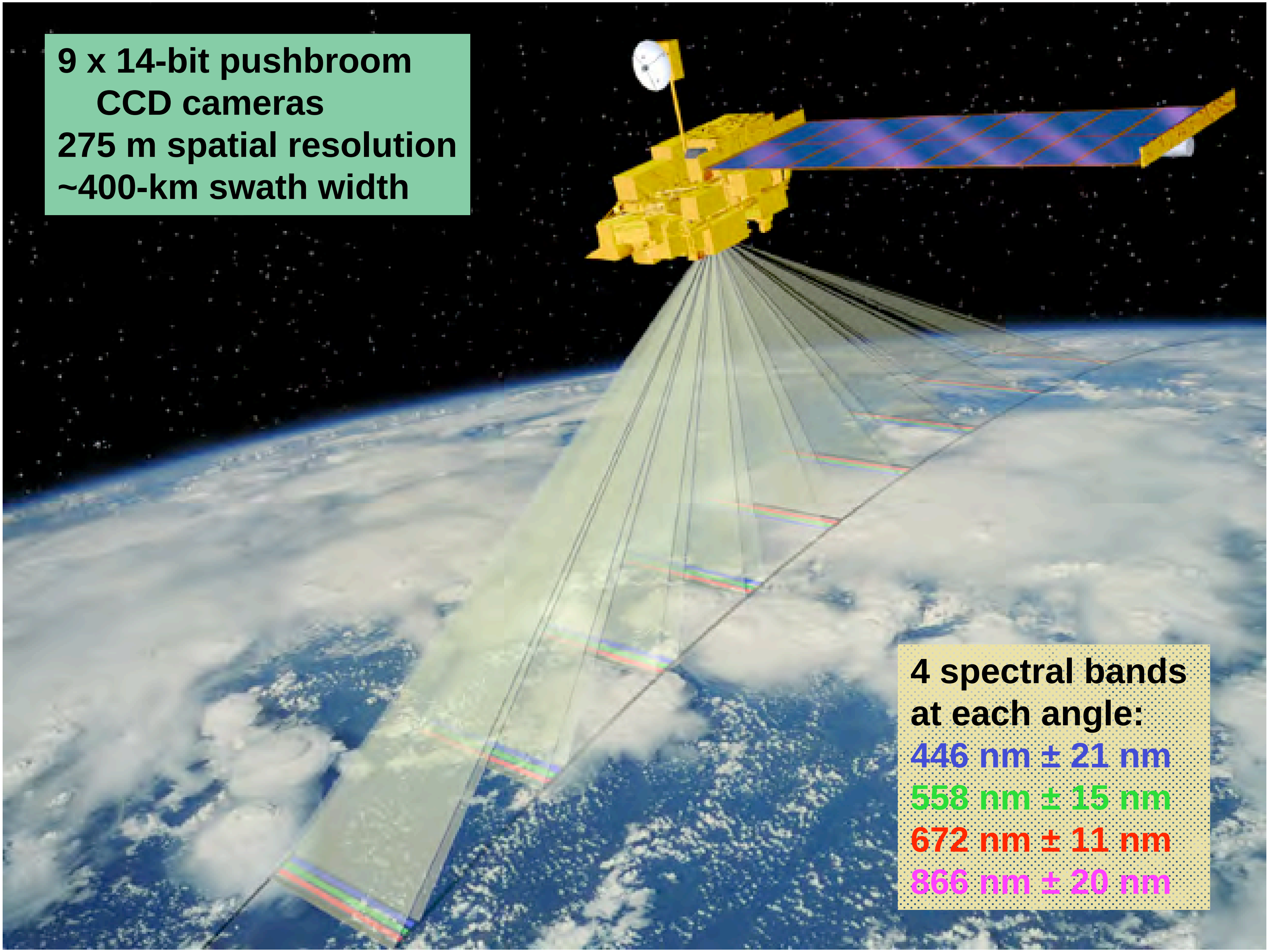
Mark Chopping

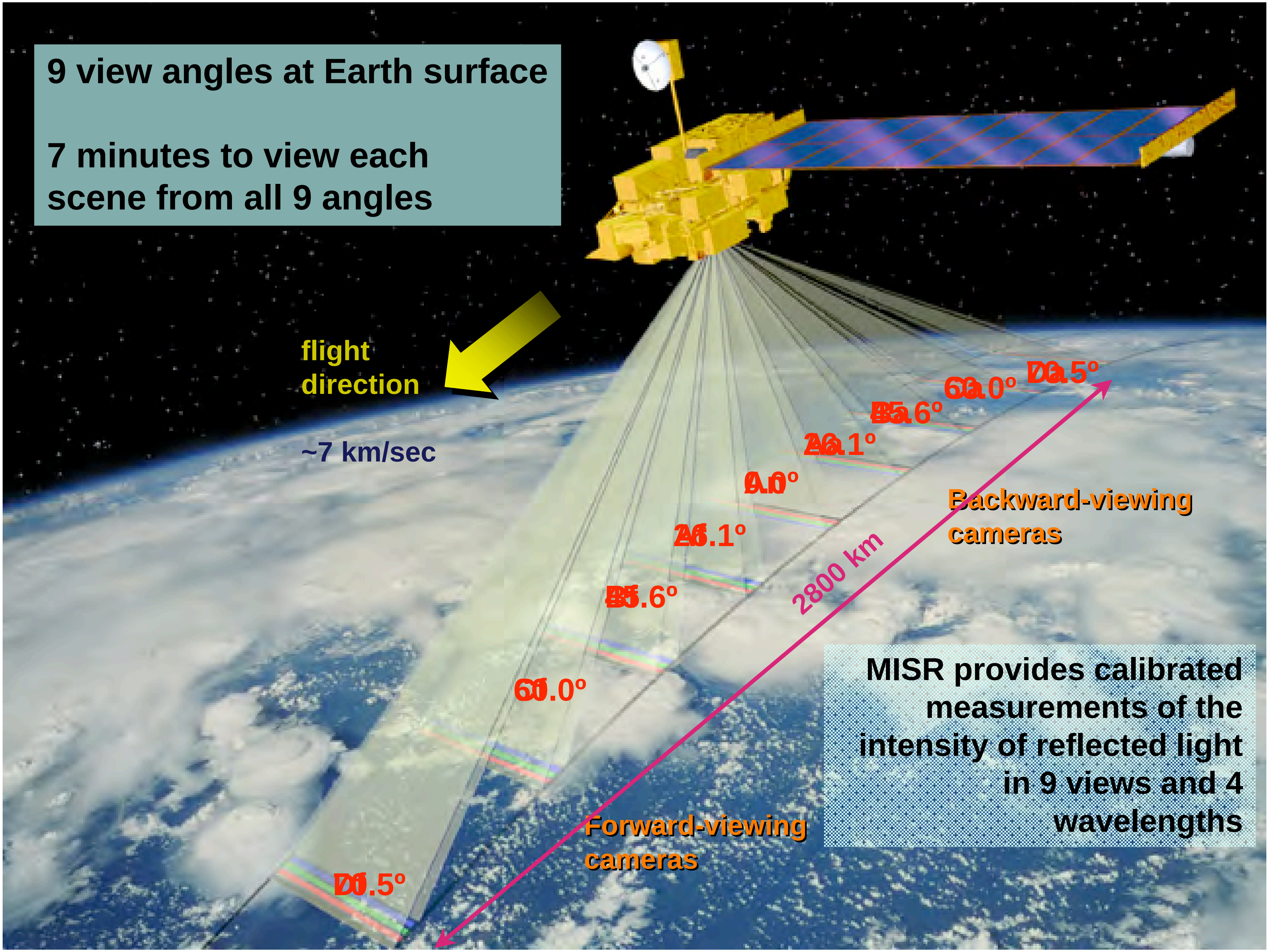
With contributions from David Diner, Amy Braverman, John V. Martonchik, Jing M. Chen, Lihong Su, Albert Rango, Debra P.C. Peters, Andrea Laliberté, Anne Nolin, J-L Widlowski, Bernard Pinty, Nadine Gobron, Michel Verstraete, Rob Braswell, and Julian Jenkins

Montclair State University

Overview

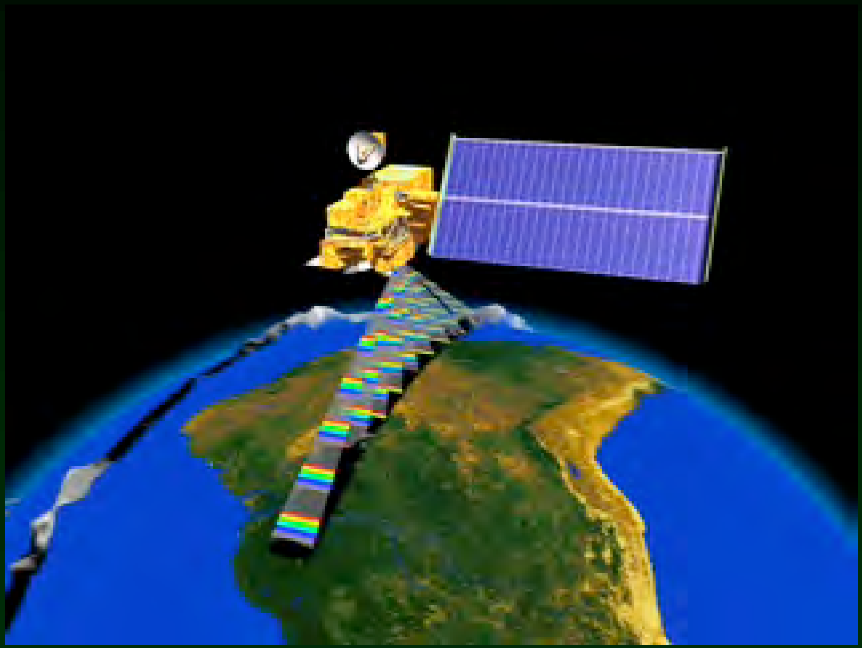
- **Brief Introduction: The MISR instrument on the Terra satellite**
- **Brief Overview of MISR data products**
- **MISR research relevant to remote sensing of canopy structure:**
  - **Focus on physical structure**
  - **Results from GO model inversion (focus)**
  - **Other approaches**


9 x 14-bit pushbroom
CCD cameras
275 m spatial resolution
~400-km swath width
4 spectral bands
at each angle:
446 nm ± 21 nm
558 nm ± 15 nm
672 nm ± 11 nm
866 nm ± 20 nm


9 view angles at Earth surface
7 minutes to view each scene from all 9 angles
flight direction
~7 km/sec
70.5°
60.0°
45.6°
26.1°
0.0°
26.1°
45.6°
60.0°
70.5°
Backward-viewing cameras
2800 km
Forward-viewing cameras
MISR provides calibrated measurements of the intensity of reflected light in 9 views and 4 wavelengths

MISR vs MODIS Acquisition

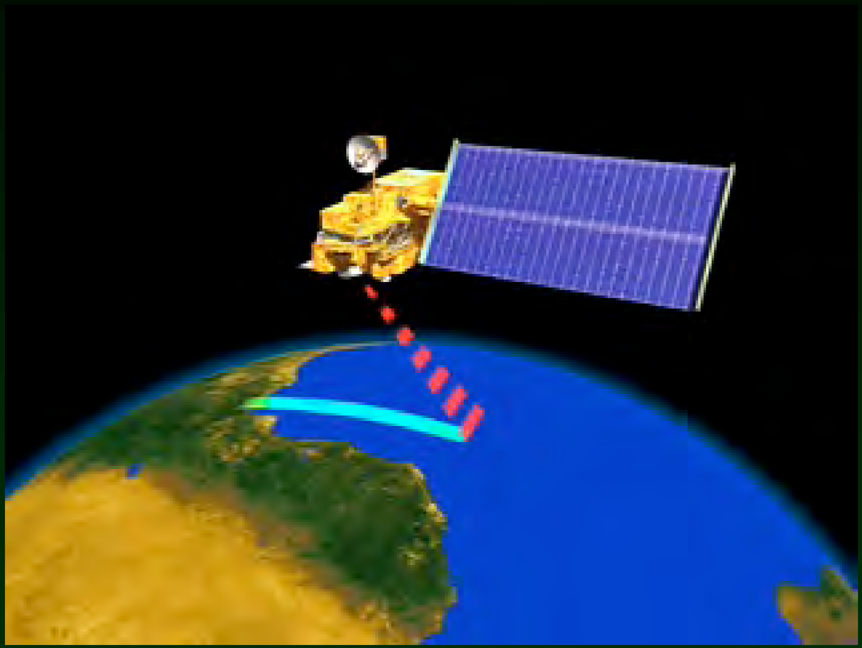
From a multi-angle perspective, MISR is more efficient
…but revisit time is longer



MISR

~simultaneous acquisition

(~7 minutes)

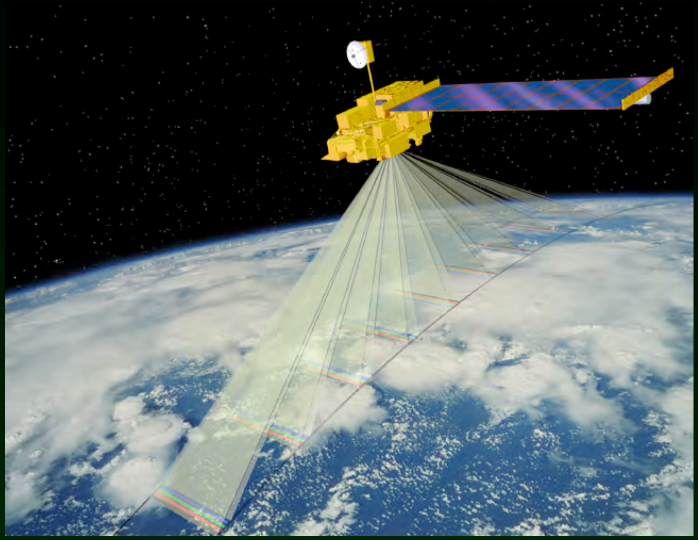


MODIS

accumulating / sequential

(several days)

Why multi-angle?



1. Change in brightness, color, and contrast with angle helps distinguish different types of surfaces, clouds, and airborne particles (aerosols)

2. Oblique slant paths through the atmosphere enhance sensitivity to aerosols and thin cirrus

3. Changing geometric perspective provides 3-D views of clouds

4. Time lapse from forward to backward views makes it possible to use clouds as tracers of winds aloft

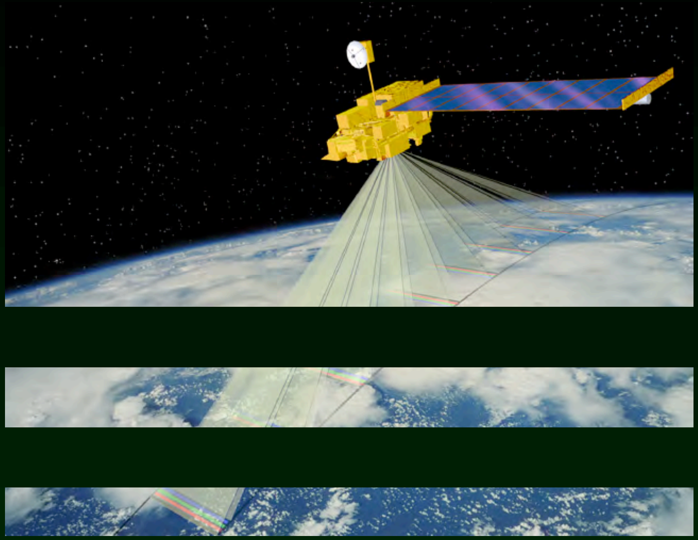
5. Different angles of view enable sunglint avoidance or accentuation

6. Integration over angle is required to estimate hemispherical reflectance (albedo) accurately

+7. Given MISR multi-angle reflectance factors, we should be able to retrieve information on the 3-D structure of the surface (i.e., canopy structure parameters such as canopy height, crown cover, crown shape,

measured using spectral techniques -- canopy structure cannot.

Canopy Structure?



We are starting to develop canopy structure products from MISR… This has taken time because it requires the development and operationalization of canopy reflectance models that take large-scale structure (canopy spatial heterogeneity, crown shape, foliage clumping) into account (RT codes treat the surface as a turbid medium).

MISR Vegetation Products

Partly validated MISR standard vegetation products include global LAI and fPAR, obtained via lookup tables based on RT

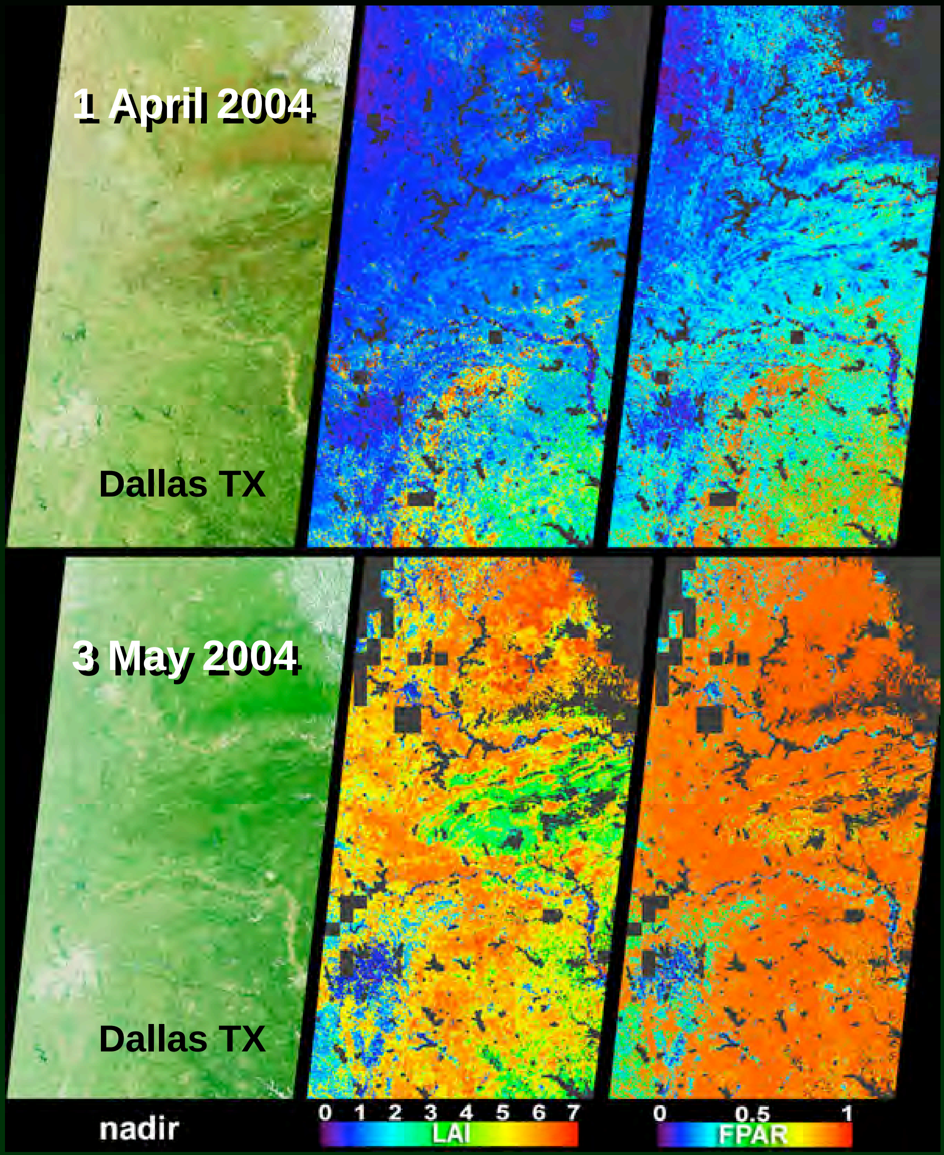
Related radiation products include albedo, DHR, BHR, BRDF…

Level 3 Products: 0.5° derived from averaging select Level 1 and Level 2 parameters over daily, monthly, seasonal and annual time periods

http://eosweb.larc.nasa.gov/PRODOCS/misr/level3/overview.html

L2 Aerosol/Surface Product (MIS05)

Surface parameters



CONTENTS AND ATTRIBUTES

- **Radiometric surface parameters (directional reflectances, albedos)**

  Derived from single overpass--no temporal compositing

  Atmospherically corrected

- **Vegetation-related quantities (albedo-based surface NDVI, LAI, FPAR)**

  LAI-FPAR retrievals are based on 3-D RT models

  Prescribed biome map is not required

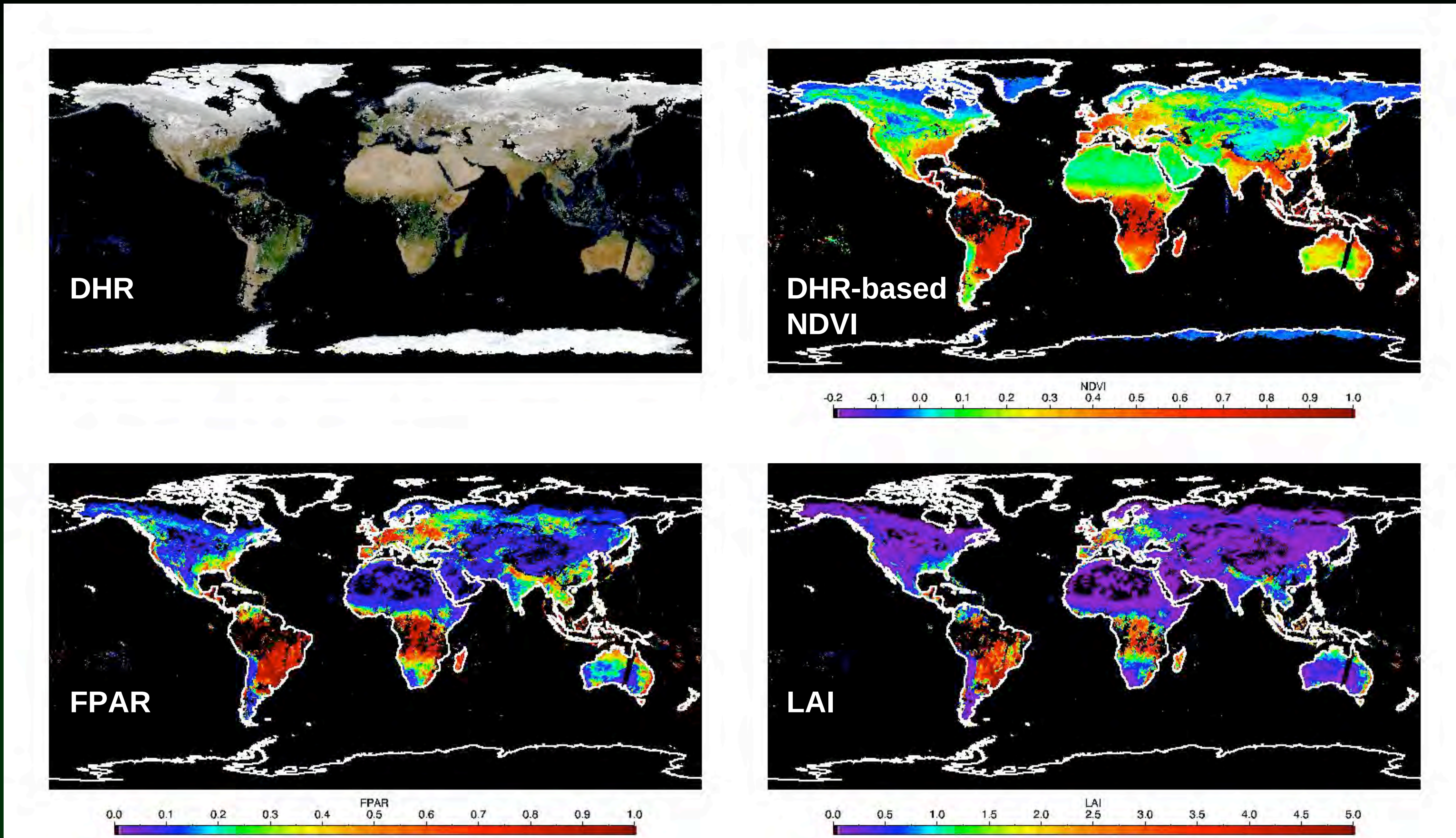
MISR LAI / fPAR Product

All necessary radiative transfer parameters are pre-computed and stored in a Canopy Architecture Radiative Transfer (CART) file.

The MISR LAI / fPAR retrieval algorithm does not depend on a particular canopy radiation model as the elements of the CART are components of various forms of the energy conservation law. The MISR leaf area index (LAI) product has been shown to be accurate to within 0.5 LAI in herbaceous vegetation and savannas and is an overestimate by about 1.0 in broadleaf forests (Diner *et al*. 2005).

L3 Gridded Surface (MIS09) at 0.5°

Radiative and biogeophysical parameters



Canopy Structure from MISR

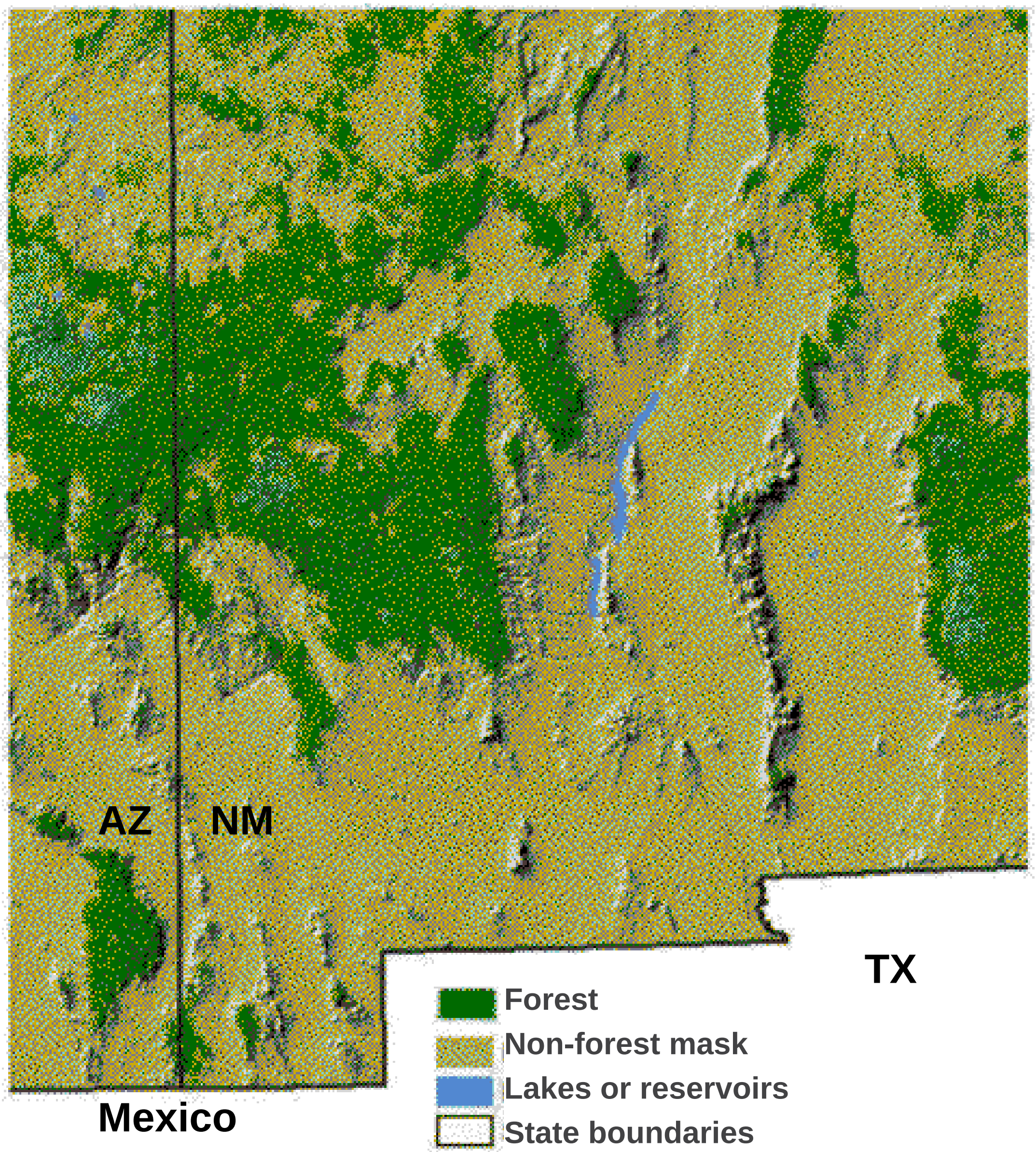
Canopy architecture and spatial heterogeneity are very important parameters in forests…

… but also affect carbon storage, vegetation dynamics, and productivity of grasslands undergoing woody encroachment (for example)

…sometimes we don't see the wood for the trees

We need maps of structural parameters for grasslands as well as savannas, woodlands and forests: shrubs now occupy 83% of current and former US grasslands (not to mention elsewhere)

We have a lot of real estate occupied by non-forest woody plants (nowadays)



Source: USDA, US Forest Service Forest Inventory Analysis, Forest Cover map for the Interior West

Structure: A Strength of Multiangle Remote Sensing

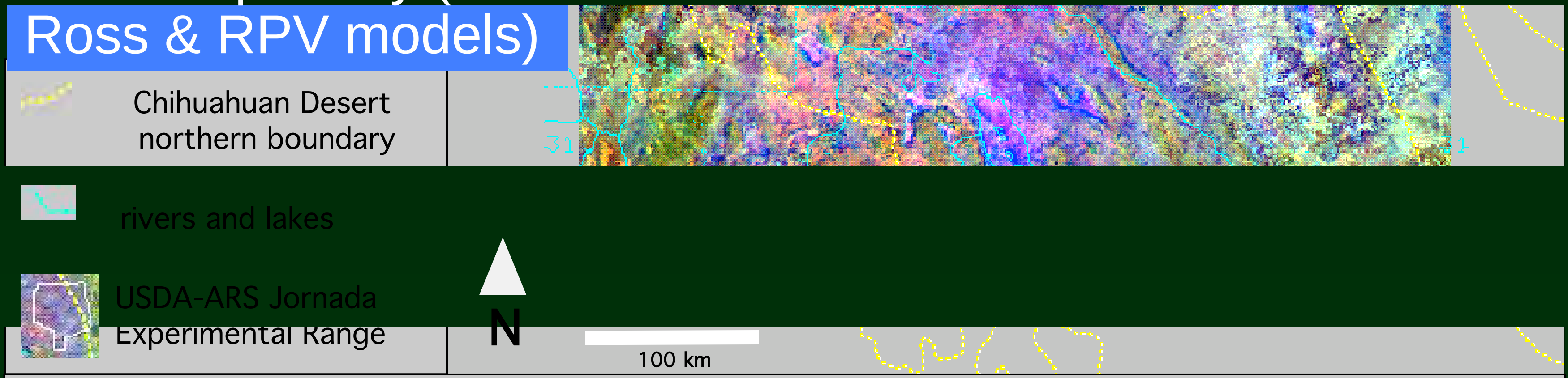
- **Multi-angle sampling provides sensitivity to vegetation canopy structure through the physical phenomena of shadow-hiding and volume scattering by leaves**

- **Multi-angle data are best interpreted through canopy reflectance models, which have greater explanatory power than empirical measures**

- **However, interpretation is difficult because the real world is complex and complex models can be difficult, impractical, or even impossible to invert: We have to decide on the appropriate level of complexity, or devise appropriate inversion protocols (e.g., injection of *a priori* knowledge)**

Multi-Angle Data are Sensitive to Canopy Structure

In the 1980s we recognized large directional effects in AVHRR VNIR data resulting from variations in canopy structure; in the 1990s we learned how to model these semi-empirically (Li-Ross & RPV models)



Multispectral image from AVHRR VIS, NIR, and Mid-IR channels ?

Canopy Structure from MISR Observations

Workers have sought to obtain measures of canopy structure using NASA multi-angle observations (white=MISR and/or MODIS, blue=mostly MODIS) by following a variety of approaches:

- ***A. Empirical / Data Mining / Synergistic***
- ***B. Radiative Transfer modeling/LUTs***
- ***C. Canopy Openness from MRPV-k parameter***
- ***D. Clumping Index***
- ***E. Structural Scattering Index (Li-Ross)***
- ***F. Geometric-Optical and Hybrid Models***

All these avenues have proved worthwhile

Focus on Canopy Structure from GO Modeling

Chopping *et al*. performed GO modeling studies using MISR in the SW US at the

Plot scale	**25 m^2**	**2003-4**
Landscape scale 1	**> 27 km^2**	**2005**
Landscape scale 2	**> 3,519 km^2**	**2005-6**
Regional scale	**~ 240,000 km^2**	**2006**
Continental/Global scale…		**20xx?**

Other workers engaged in GO modeling with MISR and/or MODIS: Jing Chen (University of Toronto), Jicheng Liu (Boston University)…

Chopping, M. (2006a), Progress in retrieving canopy structure parameters from NASA multi-angle remote sensing, Terra/Salomonson session, ***Proc. IGARSS'06***, Denver, CO, July 2006.

Chopping, M., (2006b) Multi-angle remote sensing and applications, in *Advances in Land Remote Sensing: System, Modeling, Inversion and Applications*, S. Liang (ed), in review 06/06.

Chopping, M., Su, L., Rango, A., Martonchik, J.V., Peters, D.P.C., and Laliberte, A. (2006a), Remote sensing of woody shrub cover in desert grasslands using MISR with a geometric-optical canopy reflectance model, ***Remote Sens. Environ.***, accepted, 07/06.

Chopping, M., Su, L., Laliberte, A., Rango, A., Peters, D.P.C., and Kollikkathara, N. (2006b), Mapping shrub abundance in desert grasslands using geometric-optical modeling and multiangle remote sensing with CHRIS/Proba. ***Remote Sens. Environ.***, in press.

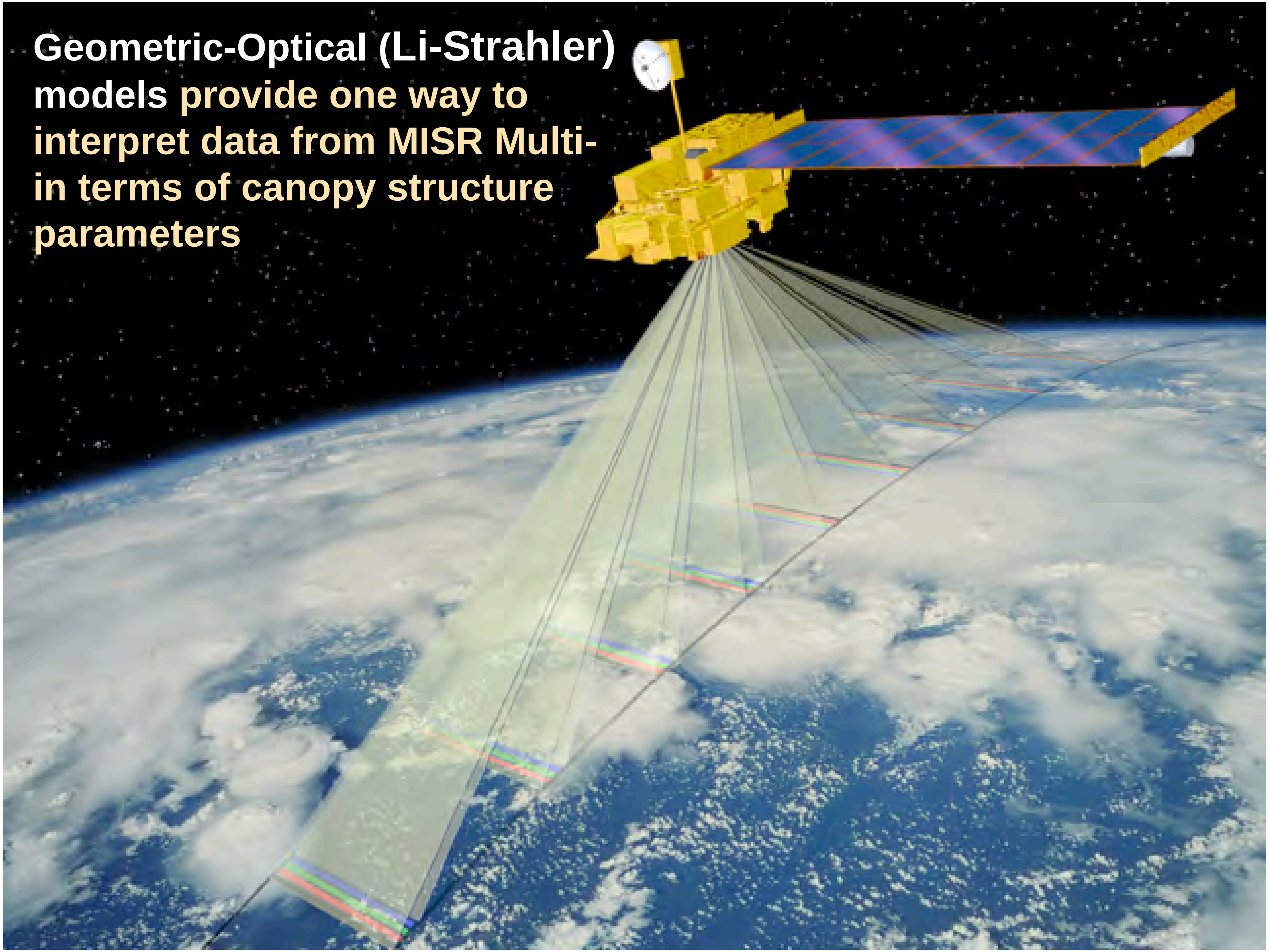
Chopping, M., Su, L., Laliberte, A., Rango, A., Peters, D.P.C., and Martonchik, J.V. (2006c) Mapping woody plant cover in desert grasslands using canopy reflectance modeling and MISR data, ***Geophsyical Research Letters***, July 2006, in press.

Chopping, M., J.V. Martonchik, *et al.* (2005), Geometric-optical modeling of desert grassland canopy structure with MISR, ***Proc. ISPMSRS 2005**,* I: 141-143

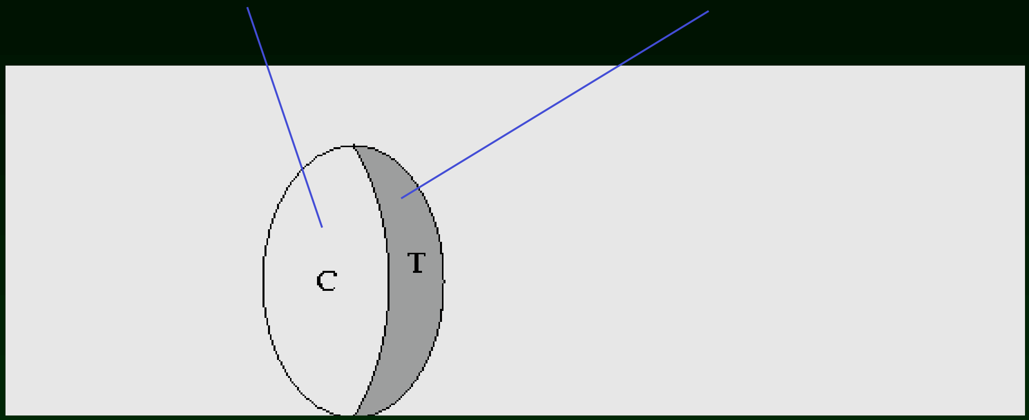
Chopping, M.J., Su, L., Rango, A., and Maxwell, C. (2004). Modelling the reflectance anisotropy of Chihuahuan Desert grass-shrub transition canopy-soil complexes, ***IJRS*** 25: 2725–2745.

Chopping, M., Laliberte, A., and Rango, A. (2004), Exploitation of multi-angle data from CHRIS on Proba: First results from the Jornada Experimental Range, European Space Research Institute (ESRIN), Frascati, Italy, **ESA Special Publication SP-578**,109-117.

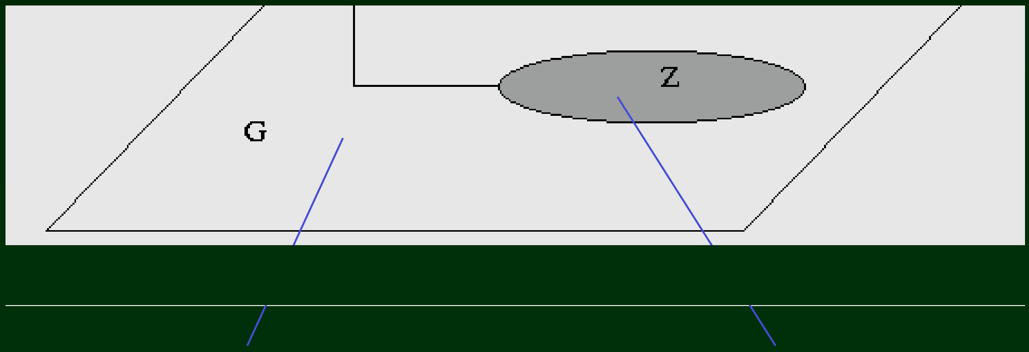
Chopping M.J., Rango, A., Havstad, K.M., Schiebe, F.R., Ritchie, J.C., Schmugge, T.J., French, A., Su, L., McKee, L., and Davis, R.M. (2003), Canopy attributes of Chihuahuan Desert grassland and transition communities derived from multi-angular airborne imagery, ***Remote Sens. Environ.*** 85(3): 339-354.


Geometric-Optical (Li-Strahler) models provide one way to interpret data from MISR Multi- in terms of canopy structure parameters

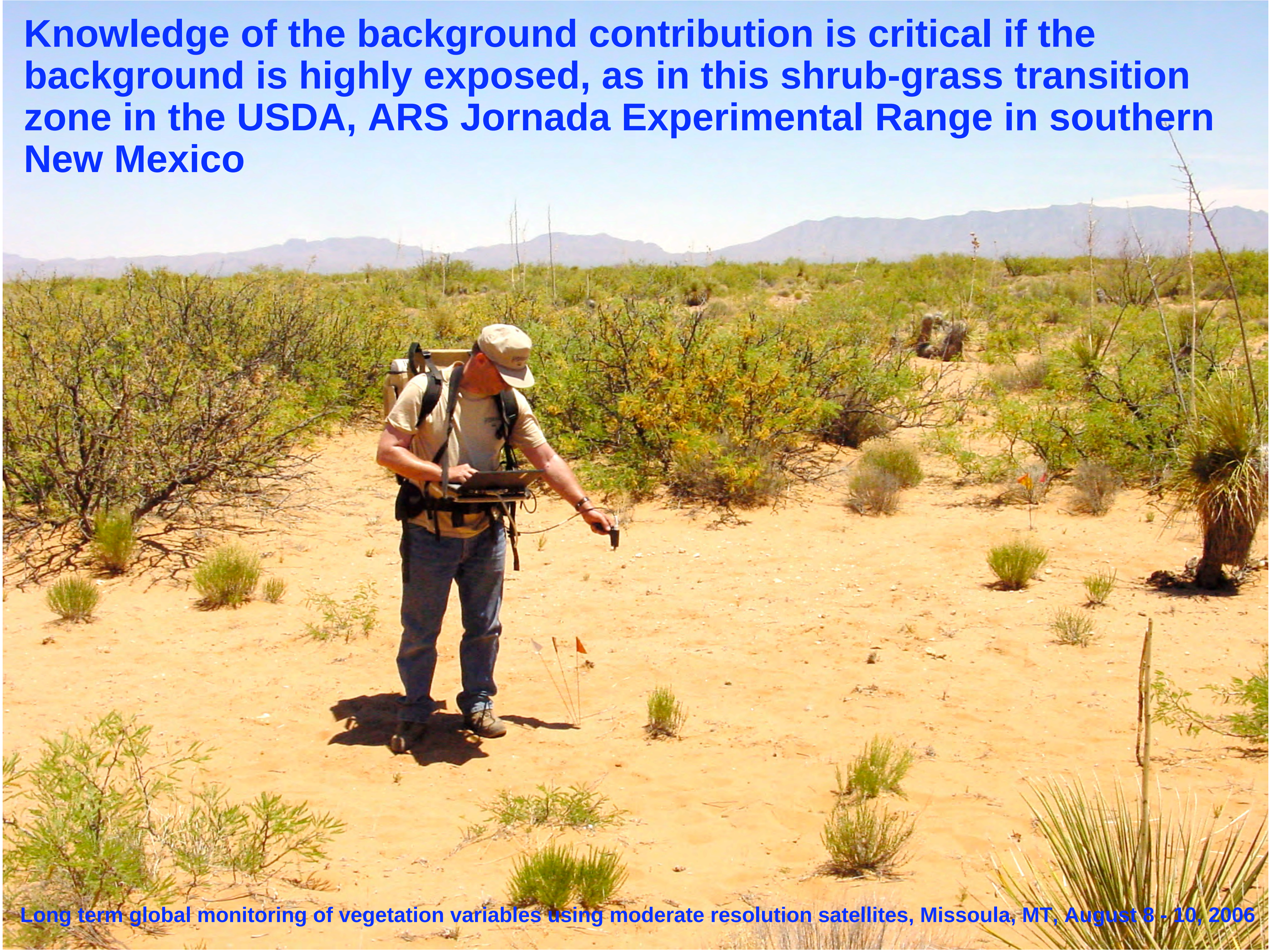
- mean crown radius
- plant number density
- mean canopy height
- background brightness and anisotropy (functions of understory density)



_G, C, T, Z_ can be assumed Lambertian or may have defined reflectance anisotropies

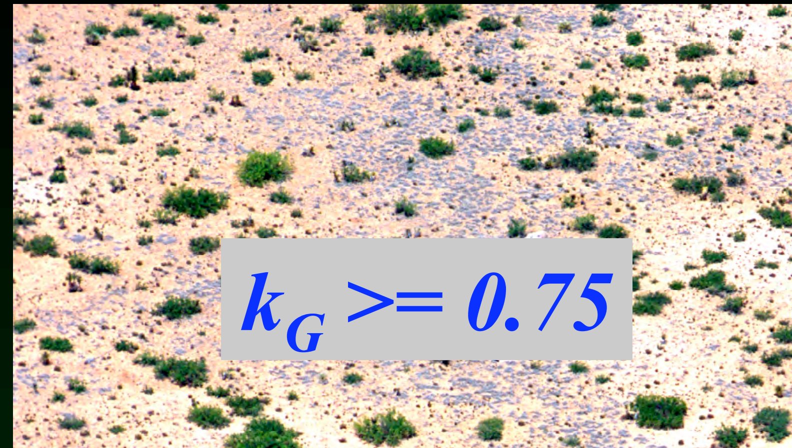


Knowledge of the background contribution is critical if the background is highly exposed, as in this shrub-grass transition zone in the USDA, ARS Jornada Experimental Range in southern New Mexico

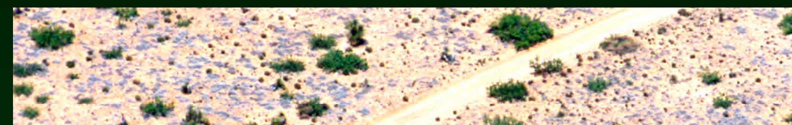


How to Obtain the Background Signal?

The ability to estimate the brightness and anisotropy of the background is a major prerequisite for the use of GO models in many places



i.e., G = ??



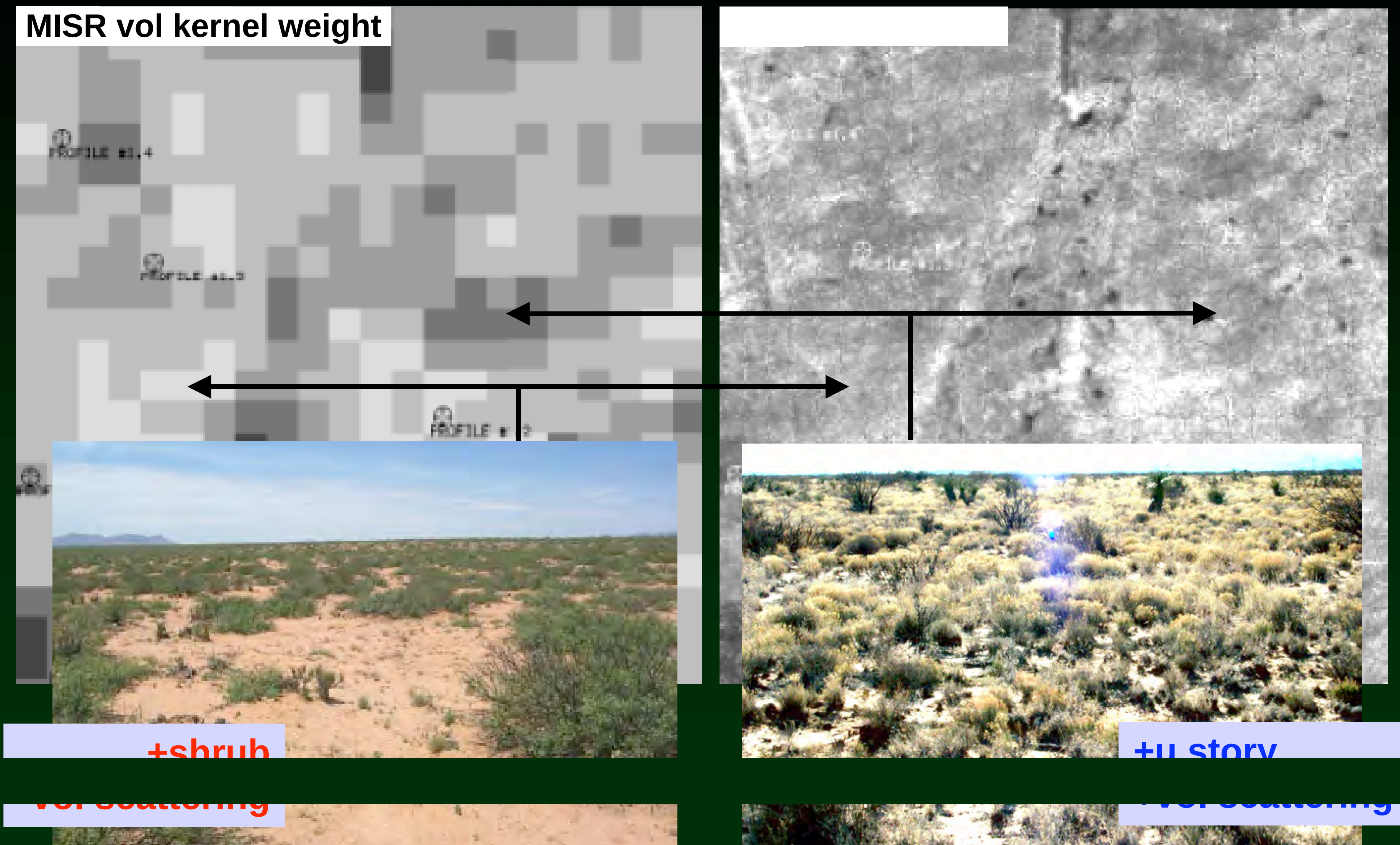
Can *G* be Lambertian?

NO

Can *G* have static anisotropy?

NO

The Li-Ross *vol* kernel weight is sensitive to the understory



Simple Geometric-optical Model Inversion Protocol

The Walthall model (*W*) is used to represent the background and a Ross function allows for within-crown volume scattering; *G* is replaced with *W* and *C* with Ross, so that

$$R = \cancel{G}\, W.k_G + \cancel{C}\, Ross.k_C$$

***T* and *Z* are considered black**

invert the LiSparse-RossThin kernel-driven model against Red band MISR data in 9 views

obtain relationships between the kernel weights and the background BRDF in the MISR plane by fixing shrub statistics and adjusting the Walthall model parameters

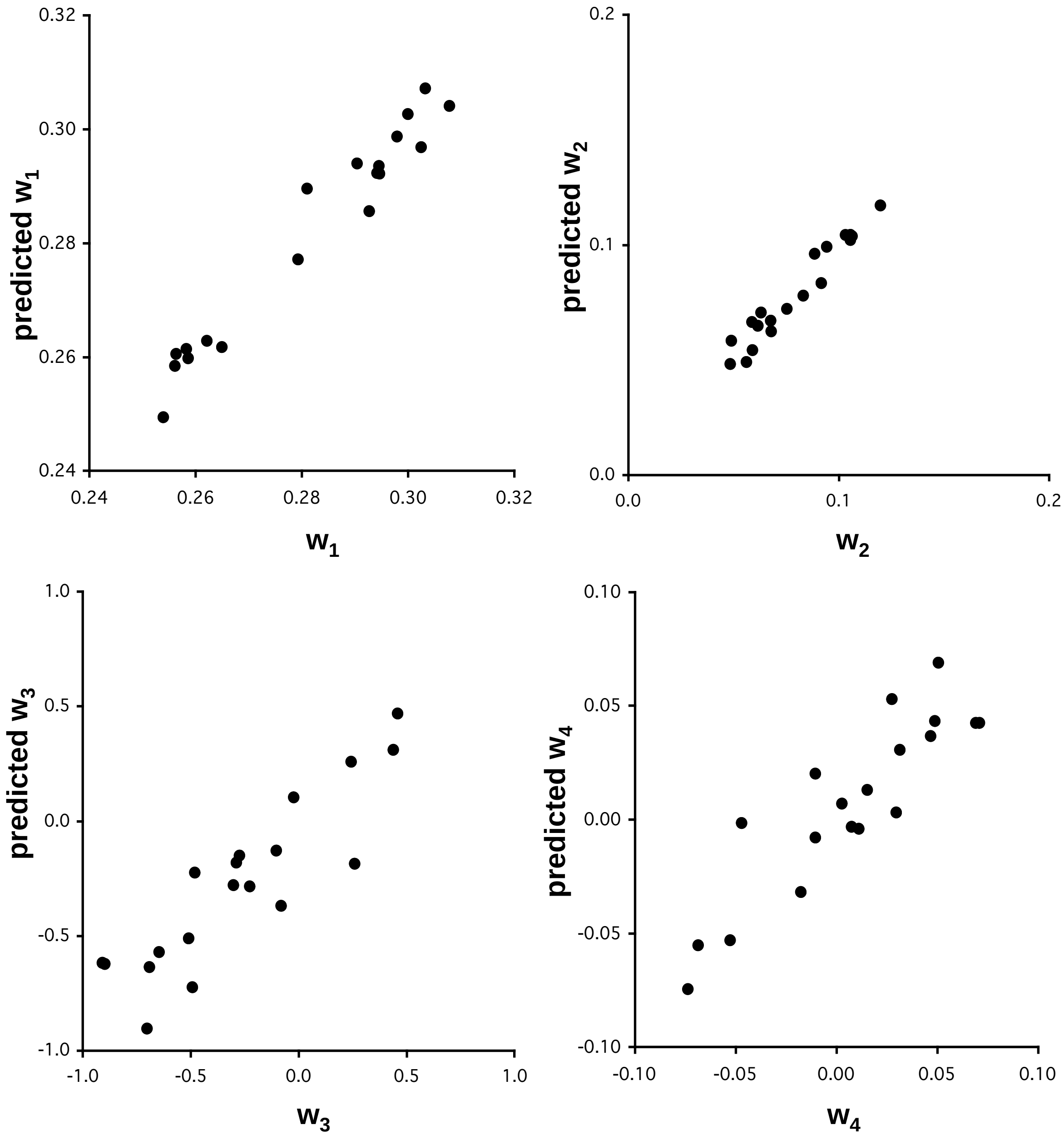
obtain estimates of woody shrub mean radiius and number density via thresholding 1 m IKONOS panchromatic imagery

MISR Red Band BRFs in Nine Cameras

invert the SGM model using the estimated background and fixing all parameters except mean shrub radius; adjust the model against MISR data

calculate fractional shrub cover from mean shrub density

How Useful is the Volume Scattering Kernel Weight?



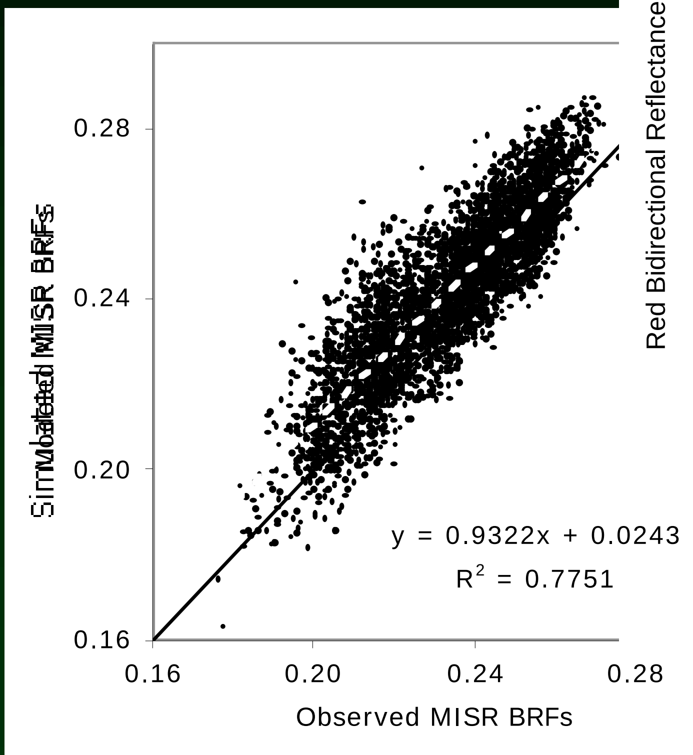
	p-value			
	w1	w2	w3	w4
Intercept	0.4	0.0	0.3	0.3
iso_misr	0.3	0.5	1.0	0.9
geo_misr	0.5	0.2	0.7	0.8
vol_misr	0.5	0.4	0.1	0.1
blue	0.5	0.6	0.6	0.5
green	0.2	0.3	0.9	0.9
NIR	0.2	0.4	0.9	1.0

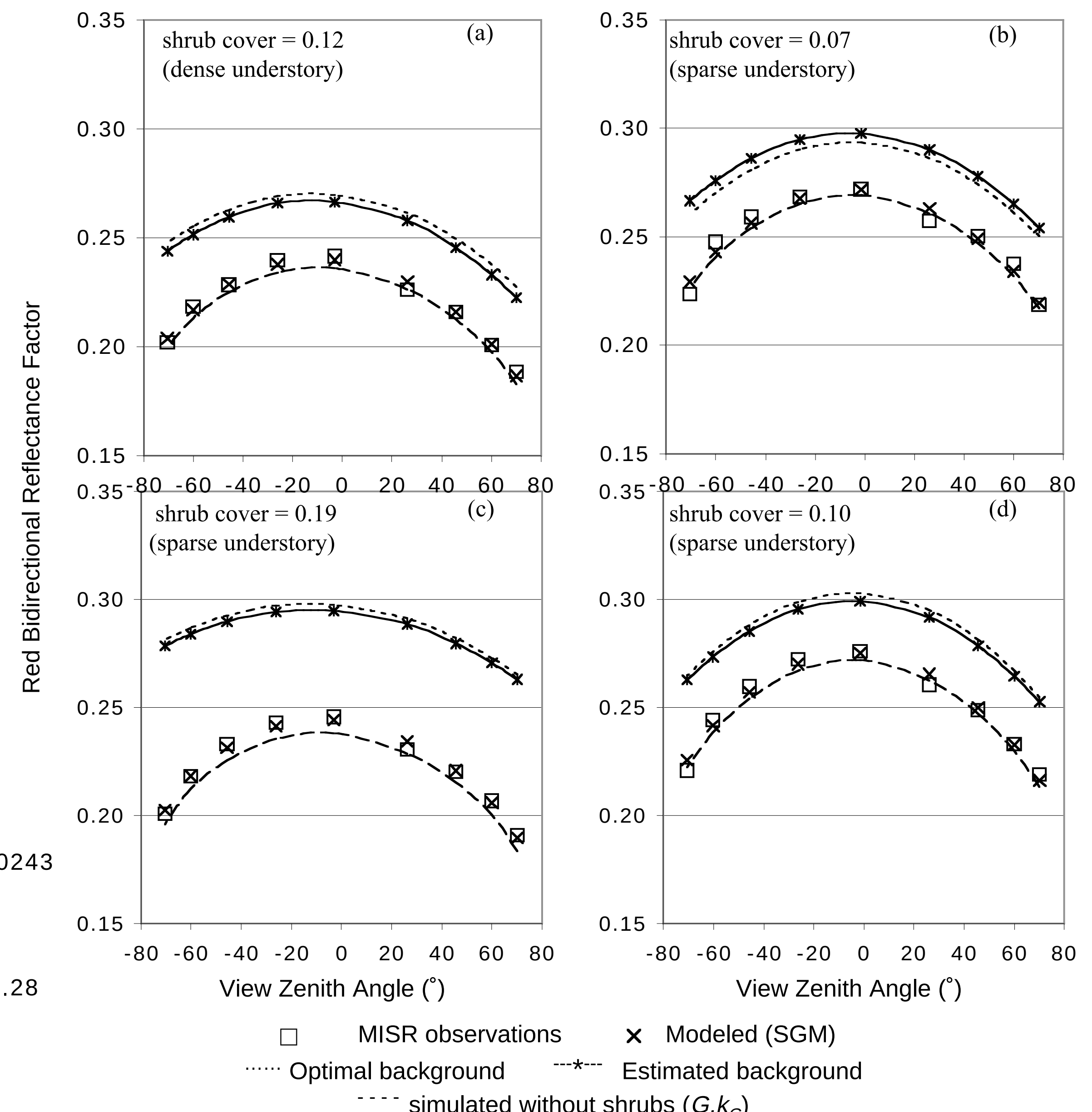
	coefficients			
	w1	w2	w3	w4
Intercept	0.07	0.28	-4.37	0.52
iso_misr	-1.31	1.06	-3.24	-0.55
geo_misr	0.50	1.26	12.56	-0.93
vol_misr	-0.49	-1.01	-67.40	6.85
blue	-1.40	1.43	56.28	-5.83
green	2.02	-2.31	-11.02	0.87
NIR	1.09	-0.92	5.58	-0.03

Bold =2 highest coefficients for each parameter
Red = match between coefficient magnitude & *p*.
The volume scattering weight is very important in estimating the background BRDF shape.

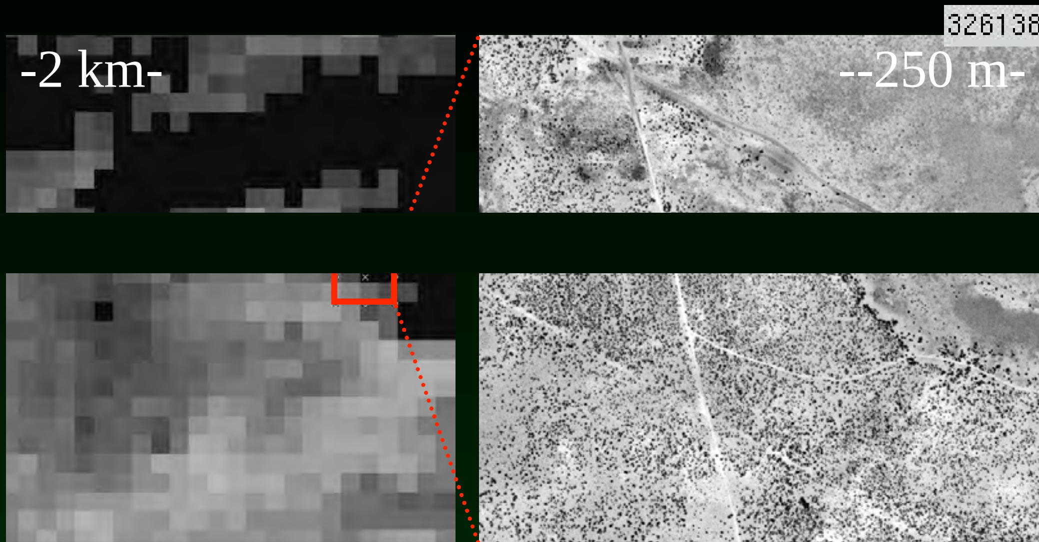
GO Model Simulations of MISR BRFs

Simple Geometric Model, red band, mapped @ 250 m in all nine cameras

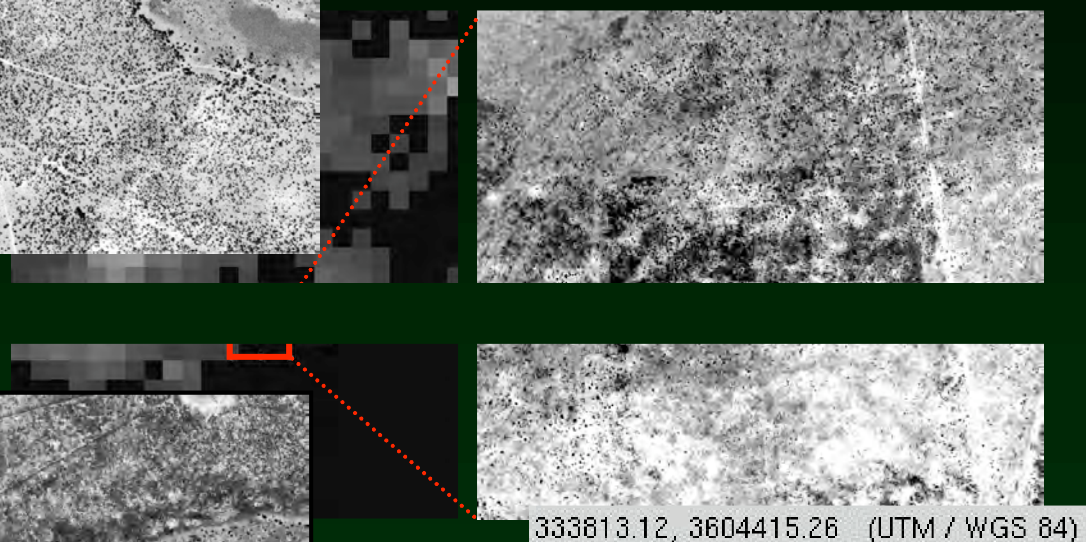




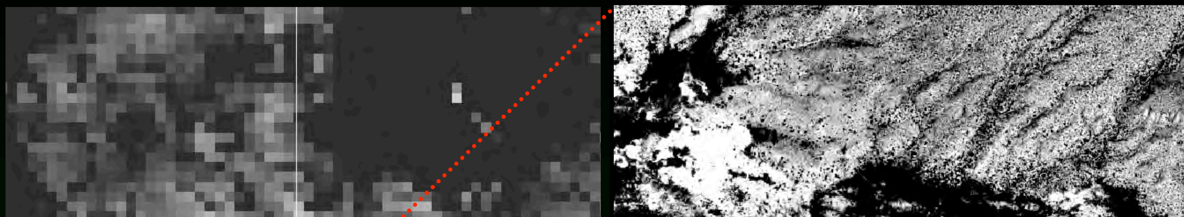
Comparisons of Retrievals with IKONOS 1 m pan Images



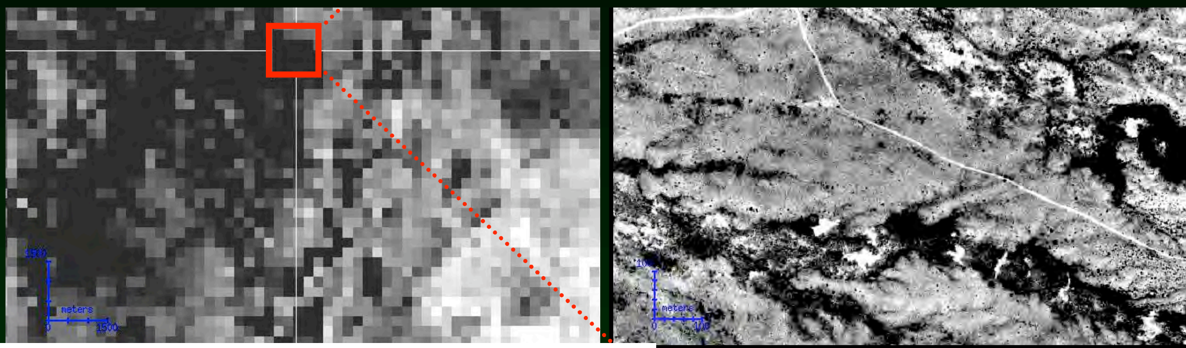
Examples from the USDA, ARS Jornada Experimental Range



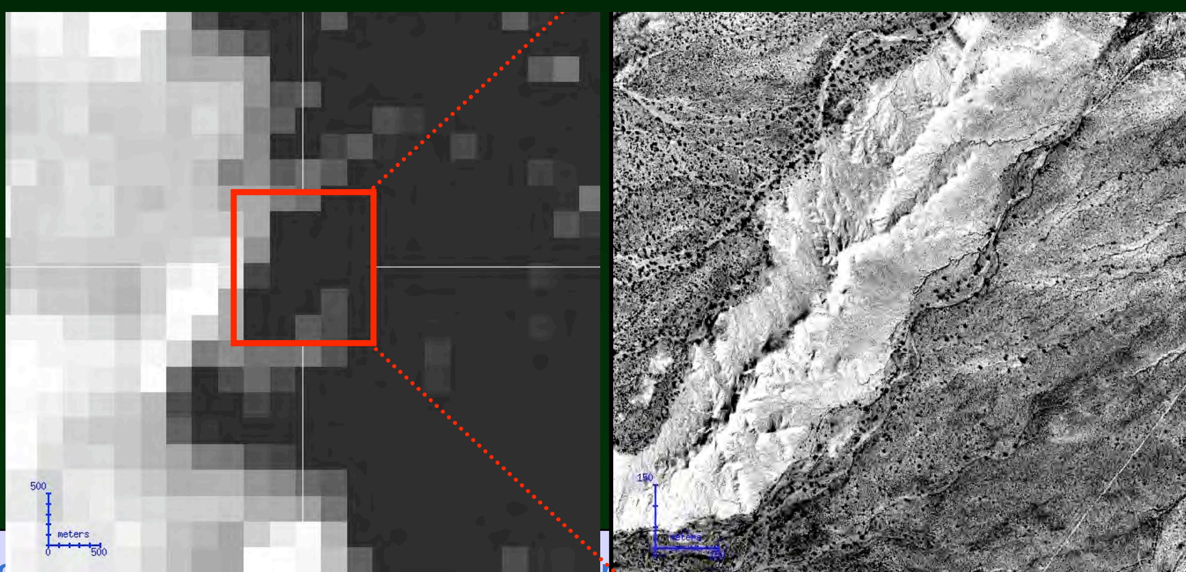
Comparisons of Retrievals with 1 m Orthophotography



Examples from the Sevilleta National Wildlife Refuge near Socorro New Mexico.

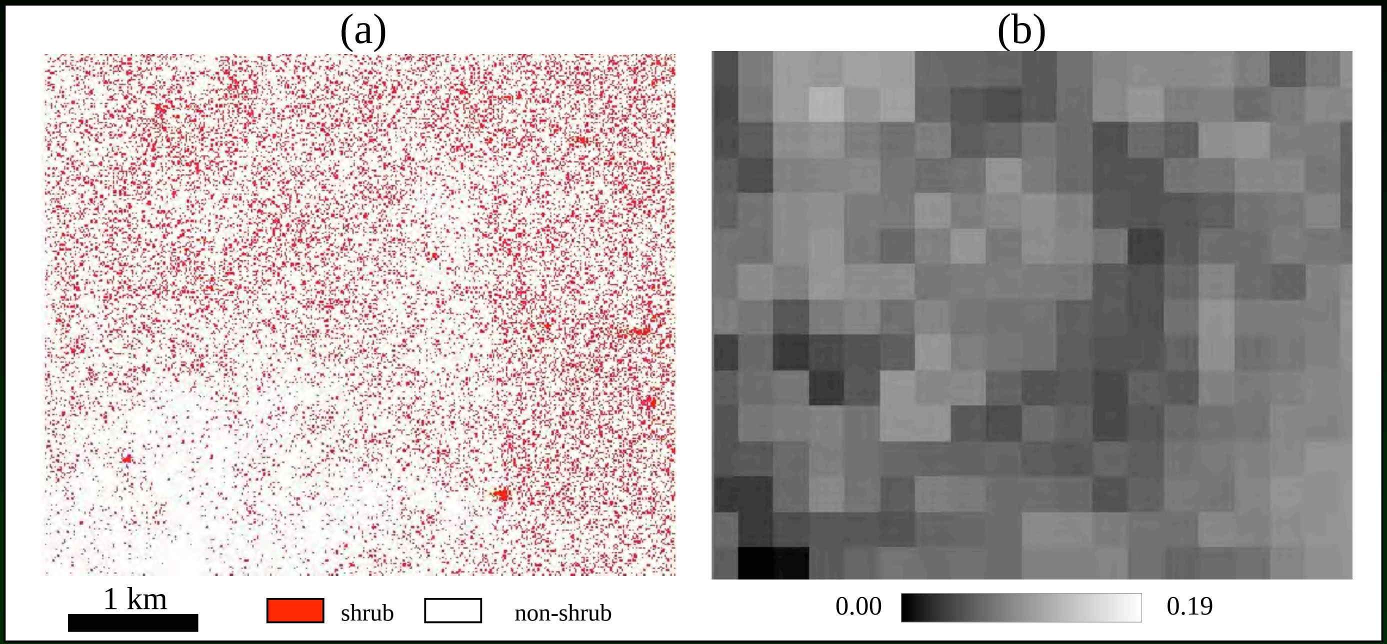


346233.64, 3789149.21 (UTM / WGS 84)



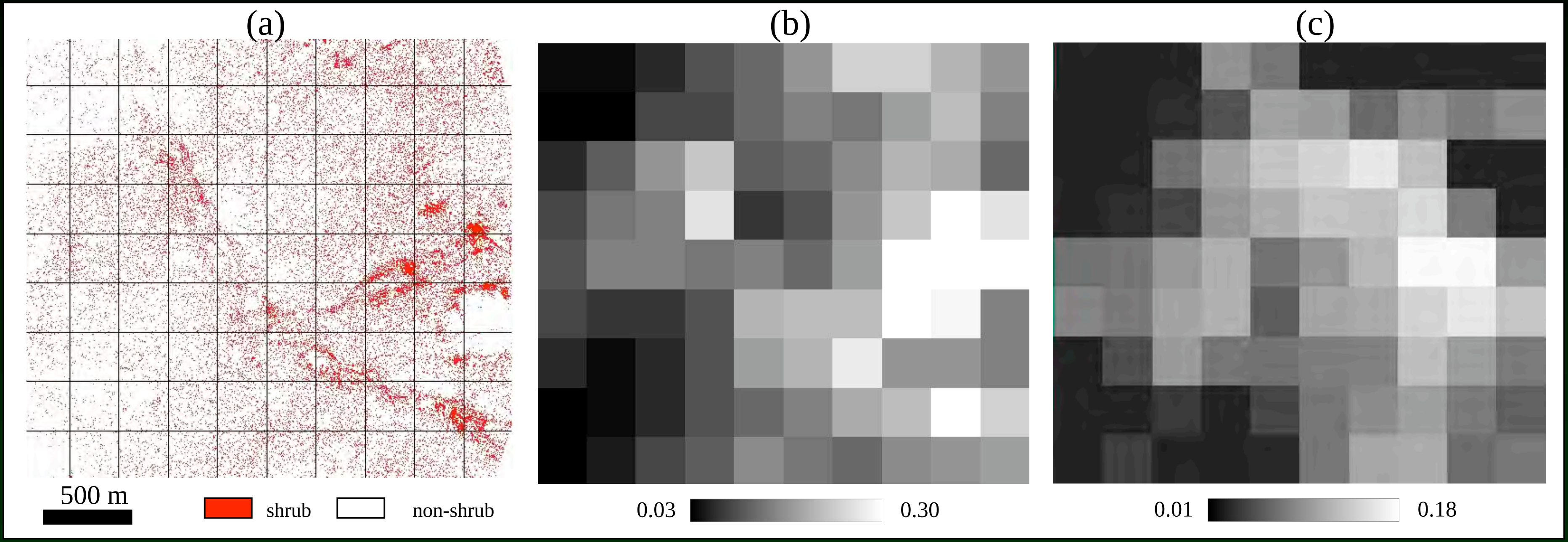
316601.99, 3794665.52 (UTM / WGS 84)

Evaluation of Retrievals vs QuickBird imagery: Pastures 8/9



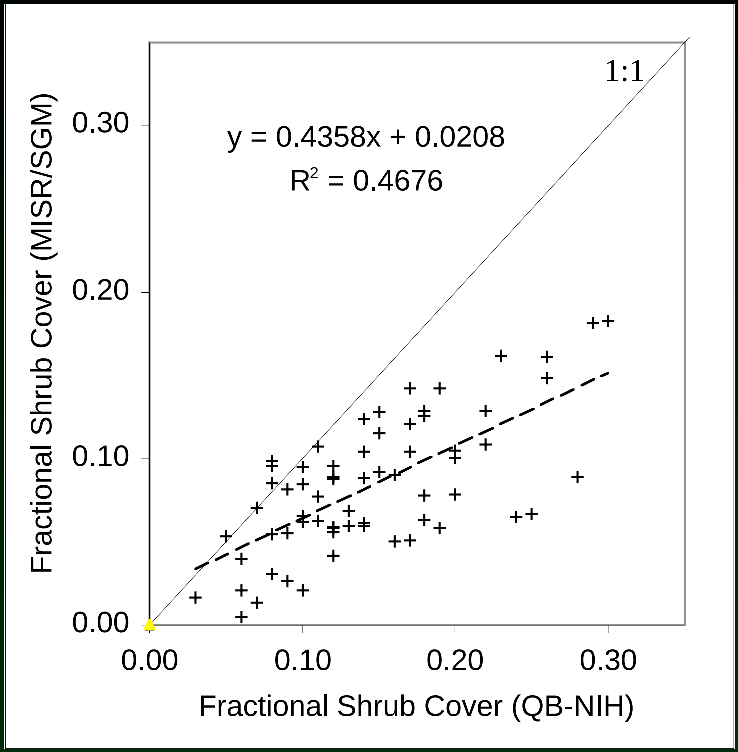
(a) QuickBird shrub map obtained using image segmentation techniques
(b) Fractional shrub cover retrieved using MISR via inversion of the GO model.

Evaluation of Retrievals vs QuickBird imagery: Pasture 12



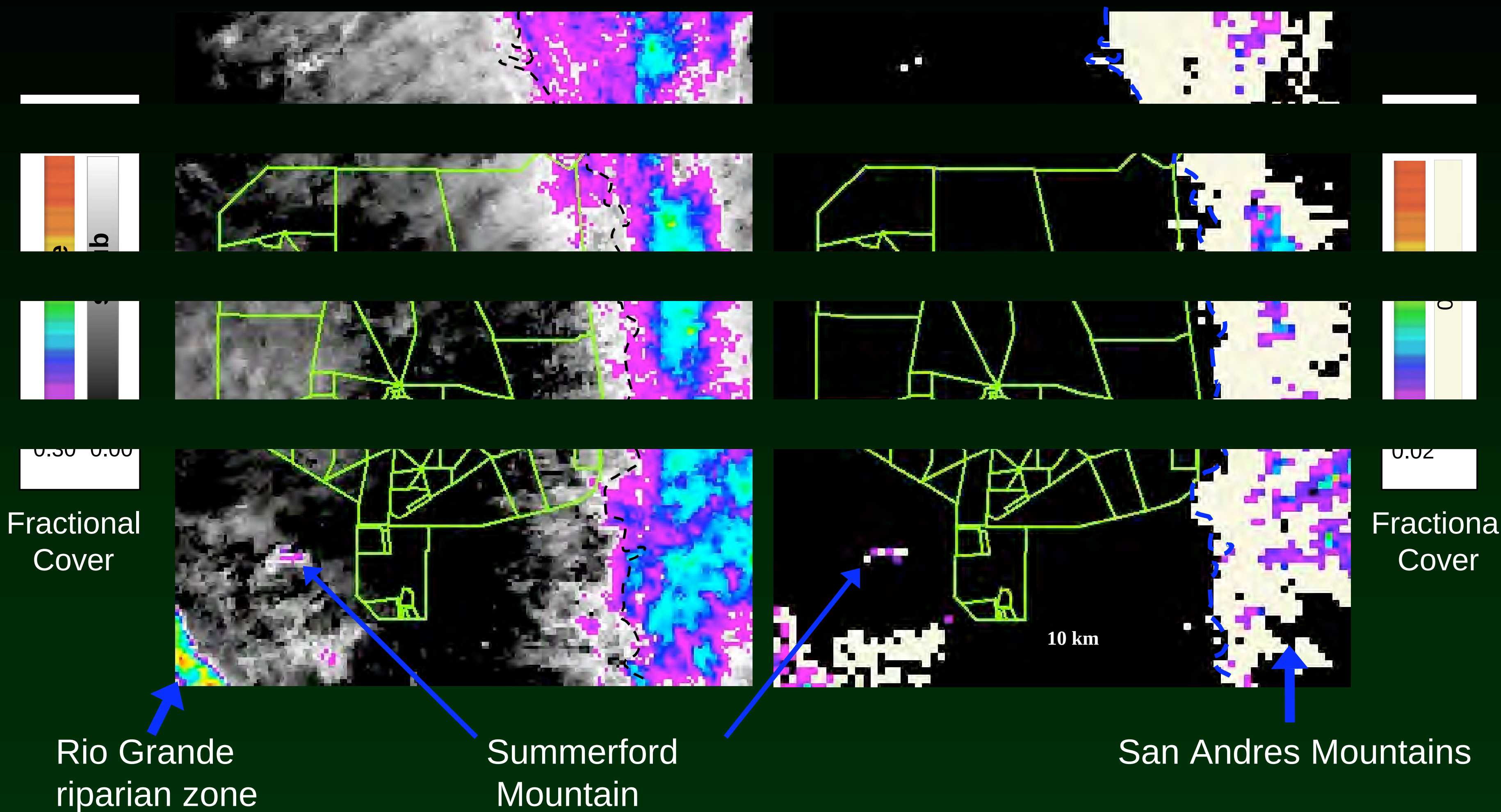
(a) QuickBird shrub map obtained using image segmentation techniques
(b) Fractional shrub cover at 250 m^2 derived from the QuickBird map.
(c) Fractional shrub cover retrieved using MISR via inversion of the GO model.

Evaluation of Retrievals vs QuickBird imagery:



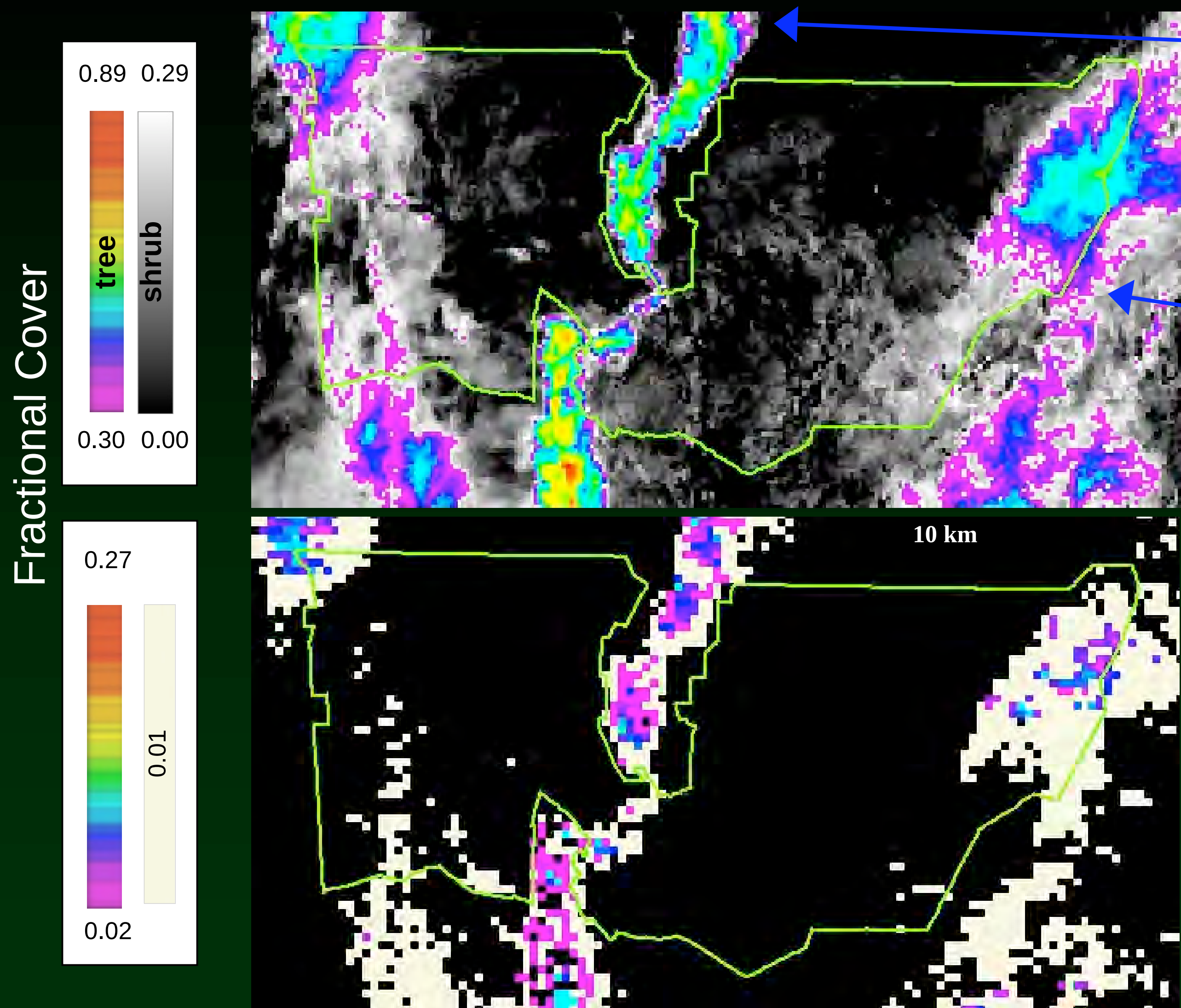
A reliable if biased relation was found between MISR/GO retrieved fractional woody plant cover and that obtained from QuickBird imagery for areas ~10 km from the calibration sites (Chopping, Su, Laliberte, Rango, Peters, and Martonchik, Mapping woody plant cover in desert grasslands using canopy reflectance modeling and MISR data, *Geophysical Research Letters*, in press).

Comparisons of Retrievals with VCF % Tree Cover Map



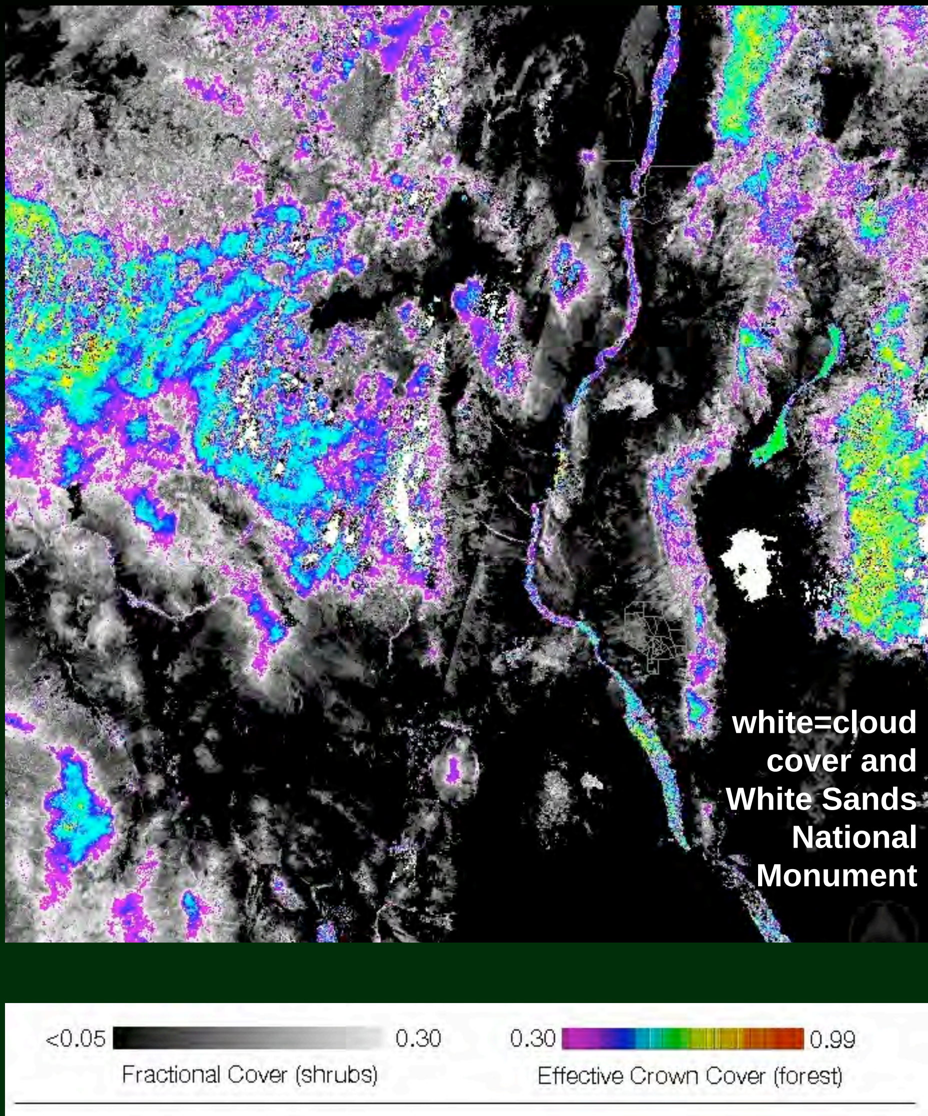
Left: MISR/GO Woody Plant Cover Right: MODIS Vegetation Continuous Fields % Tree Cover for the **USDA, ARS Jornada Experimental Range**

Comparisons of Retrievals with VCF % Tree Cover Map

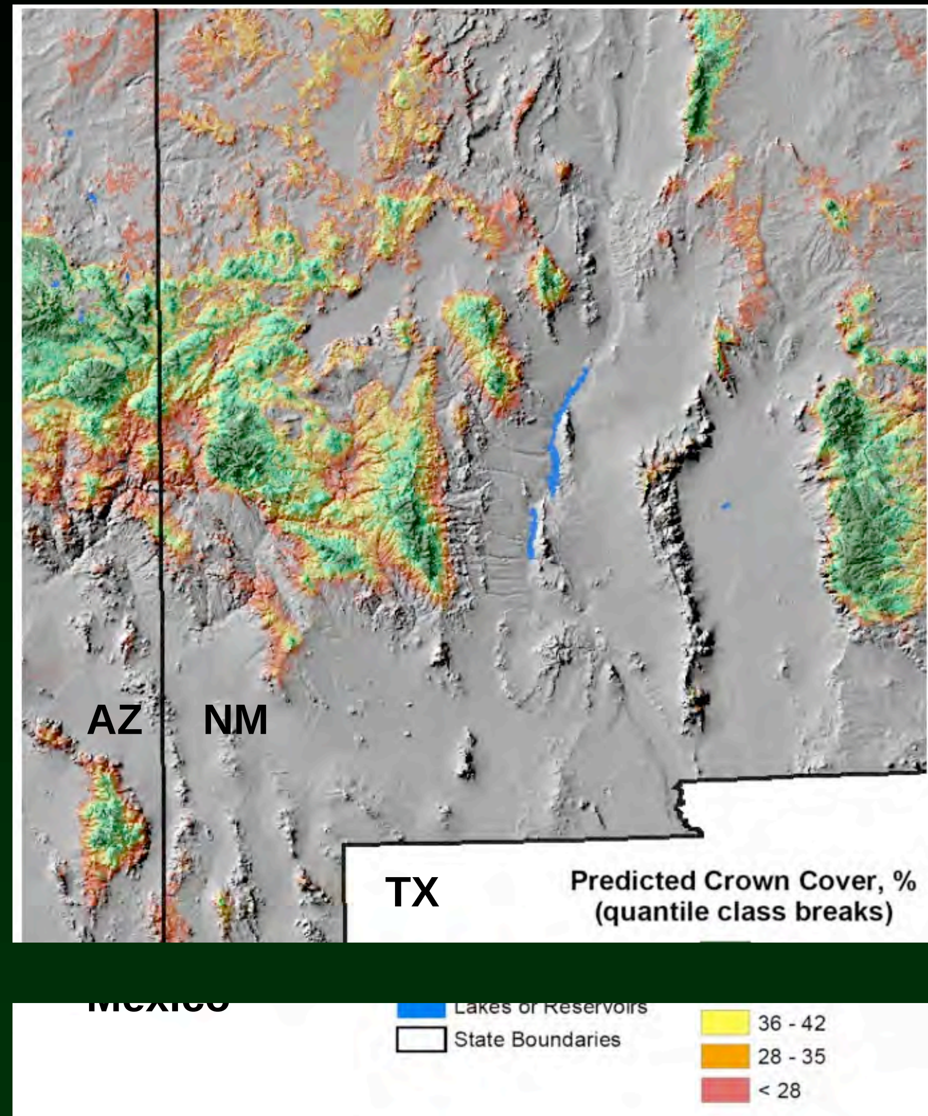


Top: MISR/GO Woody Plant Cover
Bottom: MODIS Vegetation Continuous Fields % Tree Cover for the **Sevilleta National Wildlife Refuge** near Socorro, NM

MISR/GO Regional Woody Plant Canopy Cover

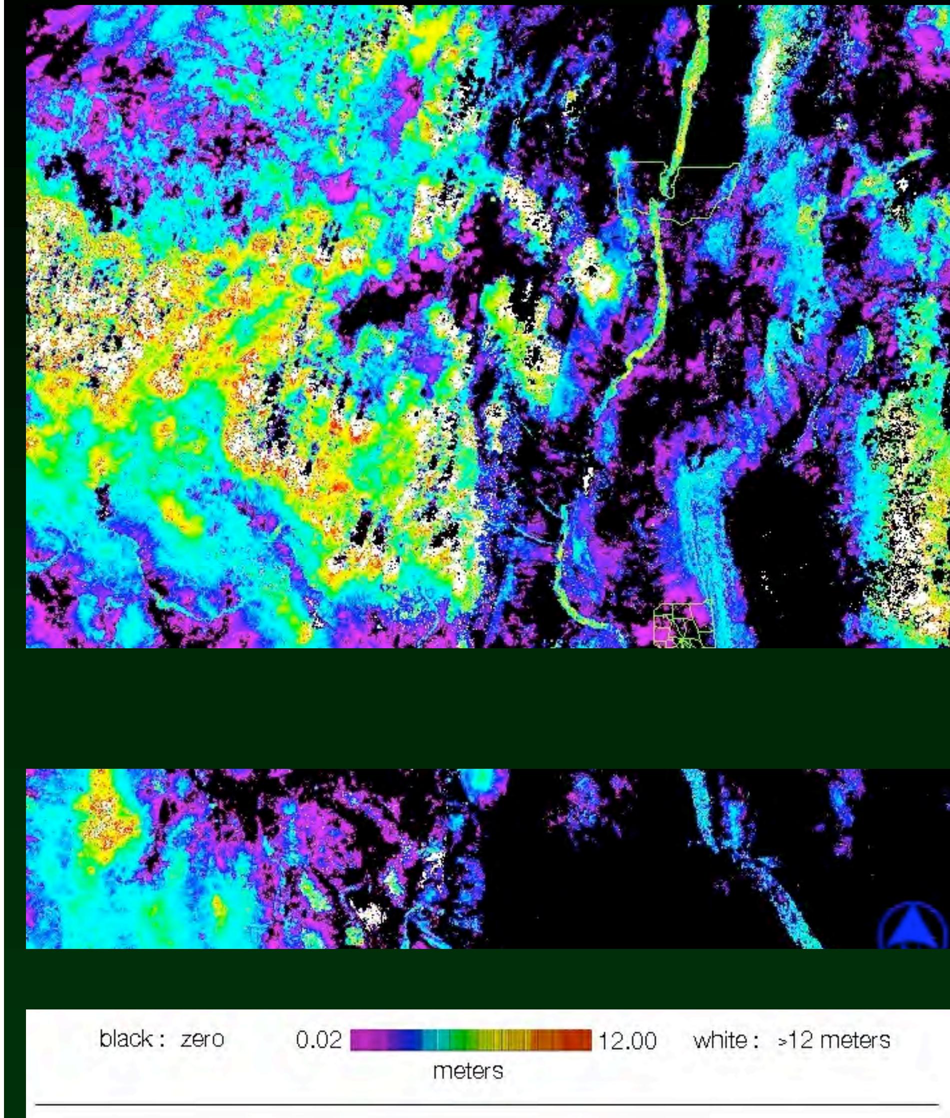


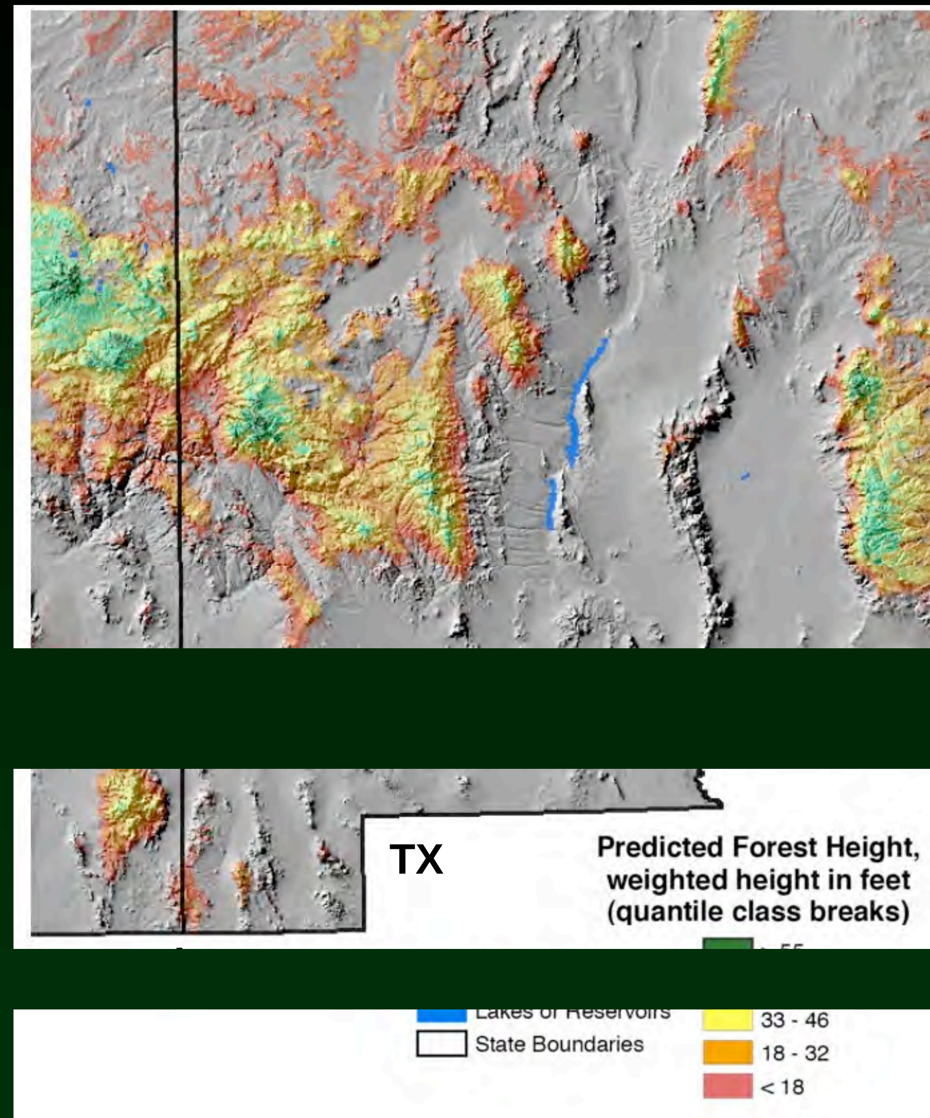
MISR/GO Canopy Cover



Forest Inventory Analysis Canopy Cover

MISR/GO Regional Woody Plant Canopy Height

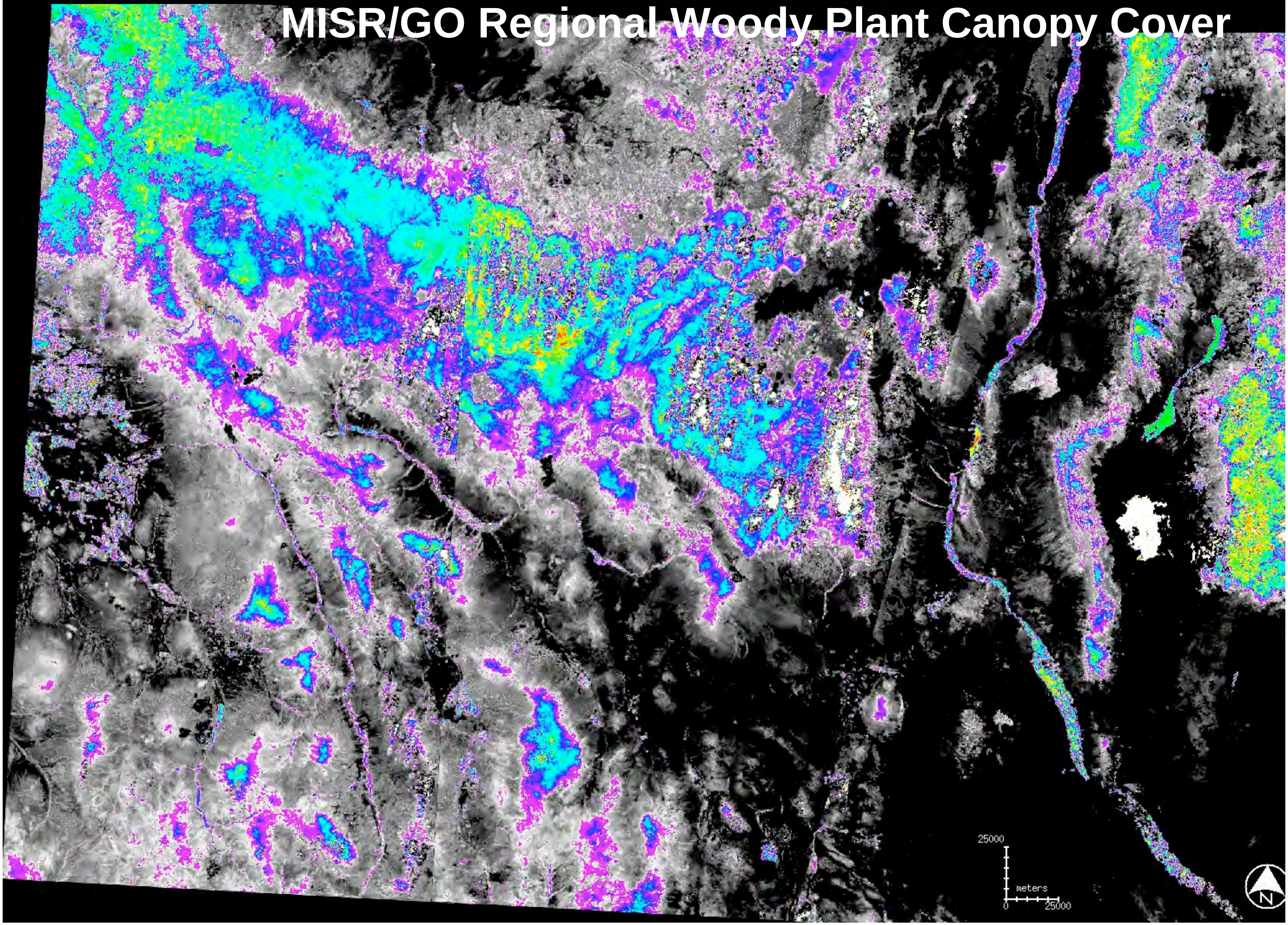




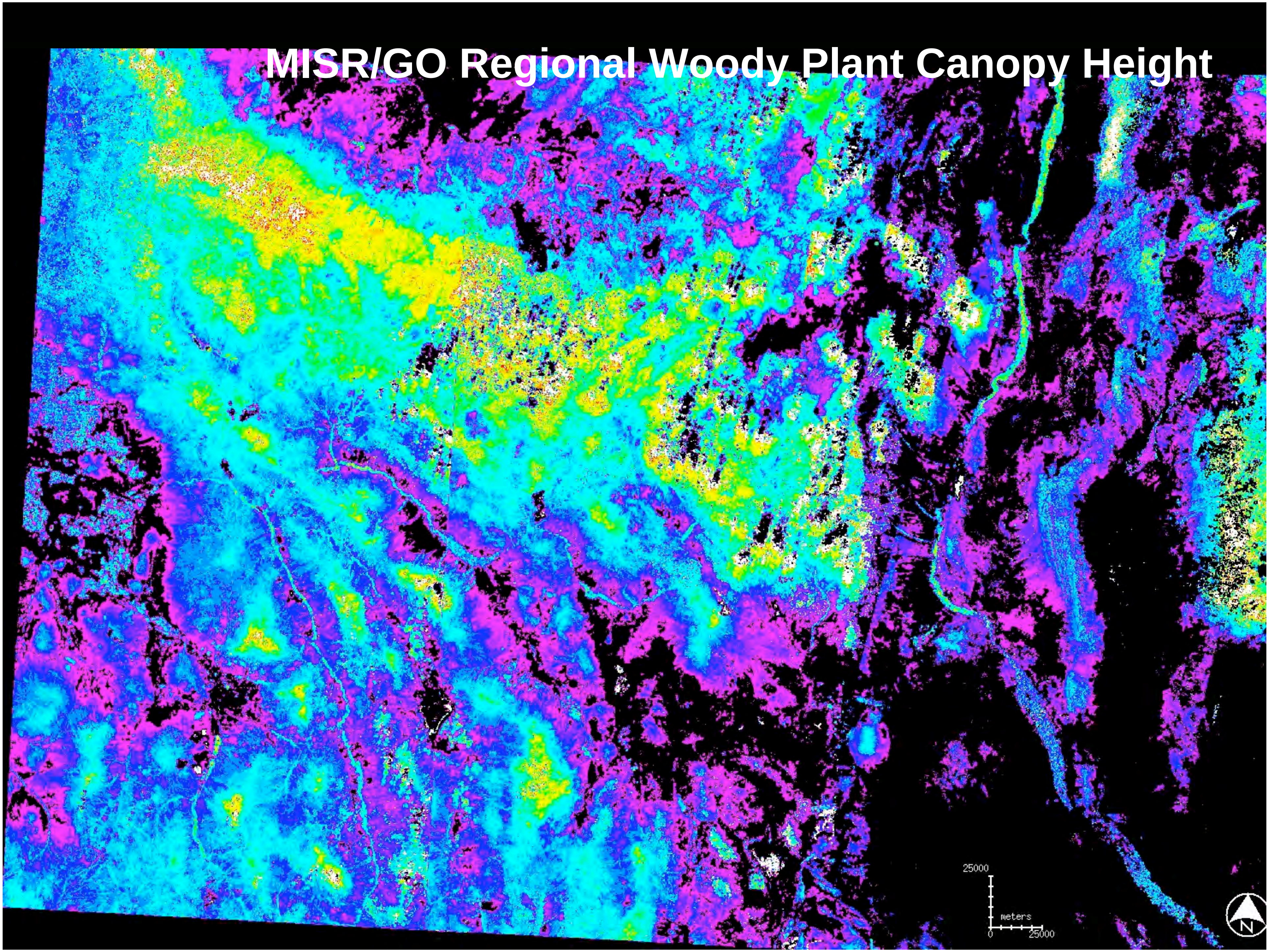
MISR/GO Mean Canopy Height

Forest Inventory Analysis Canopy Height

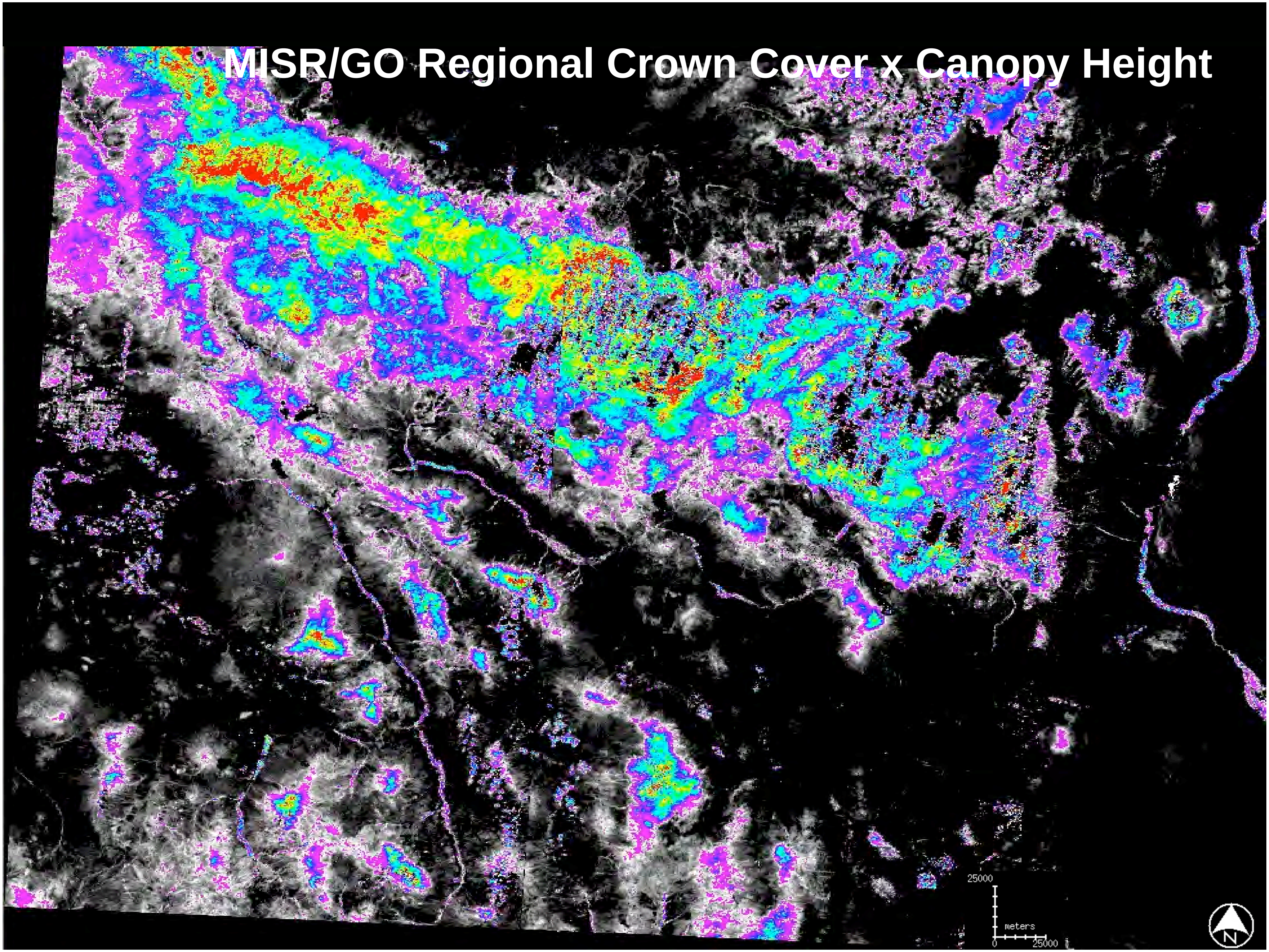
MISR/GO Regional Woody Plant Canopy Cover



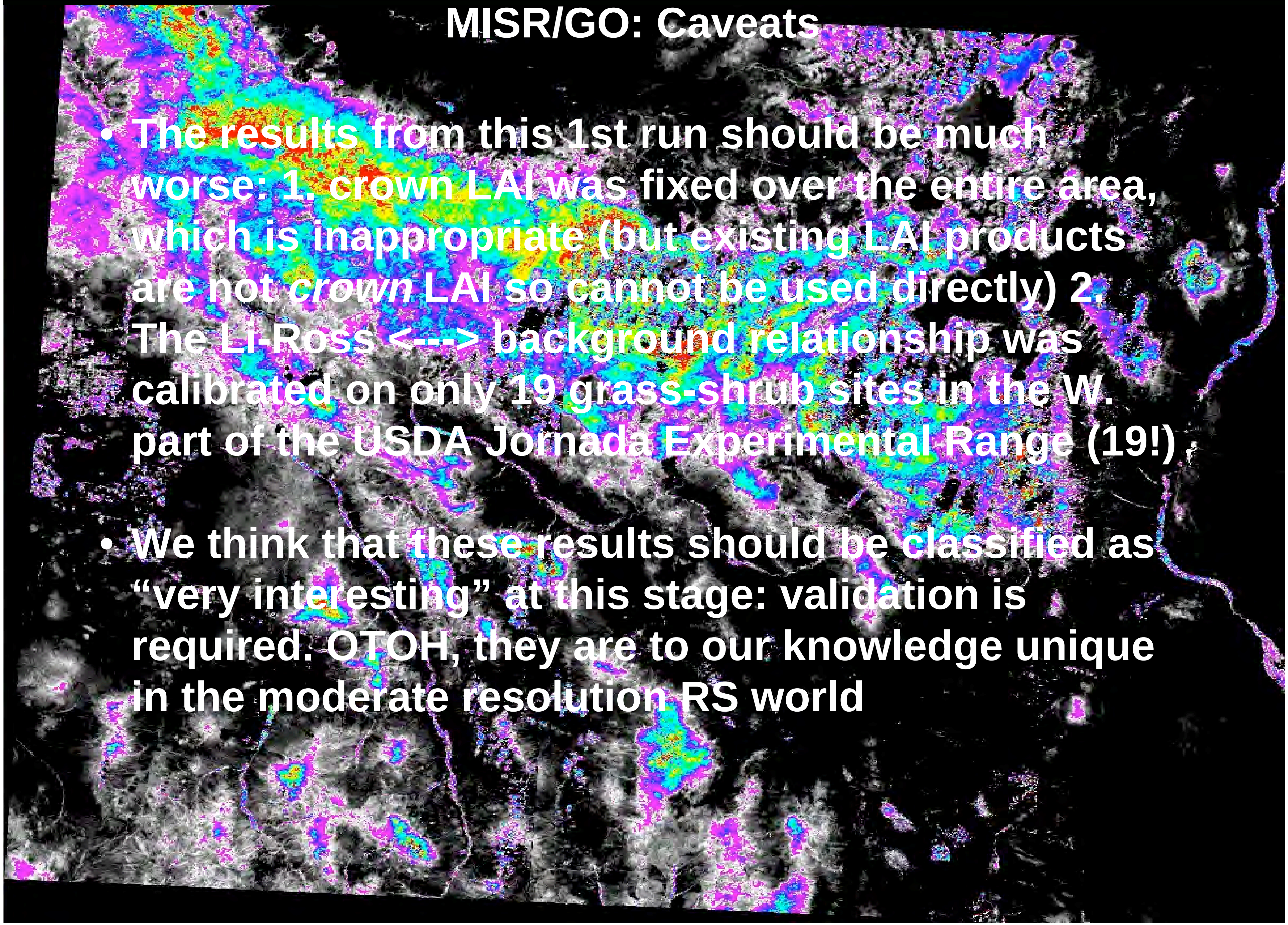
MISR/GO Regional Woody Plant Canopy Height



MISR/GO Regional Crown Cover x Canopy Height



MISR/GO: Caveats



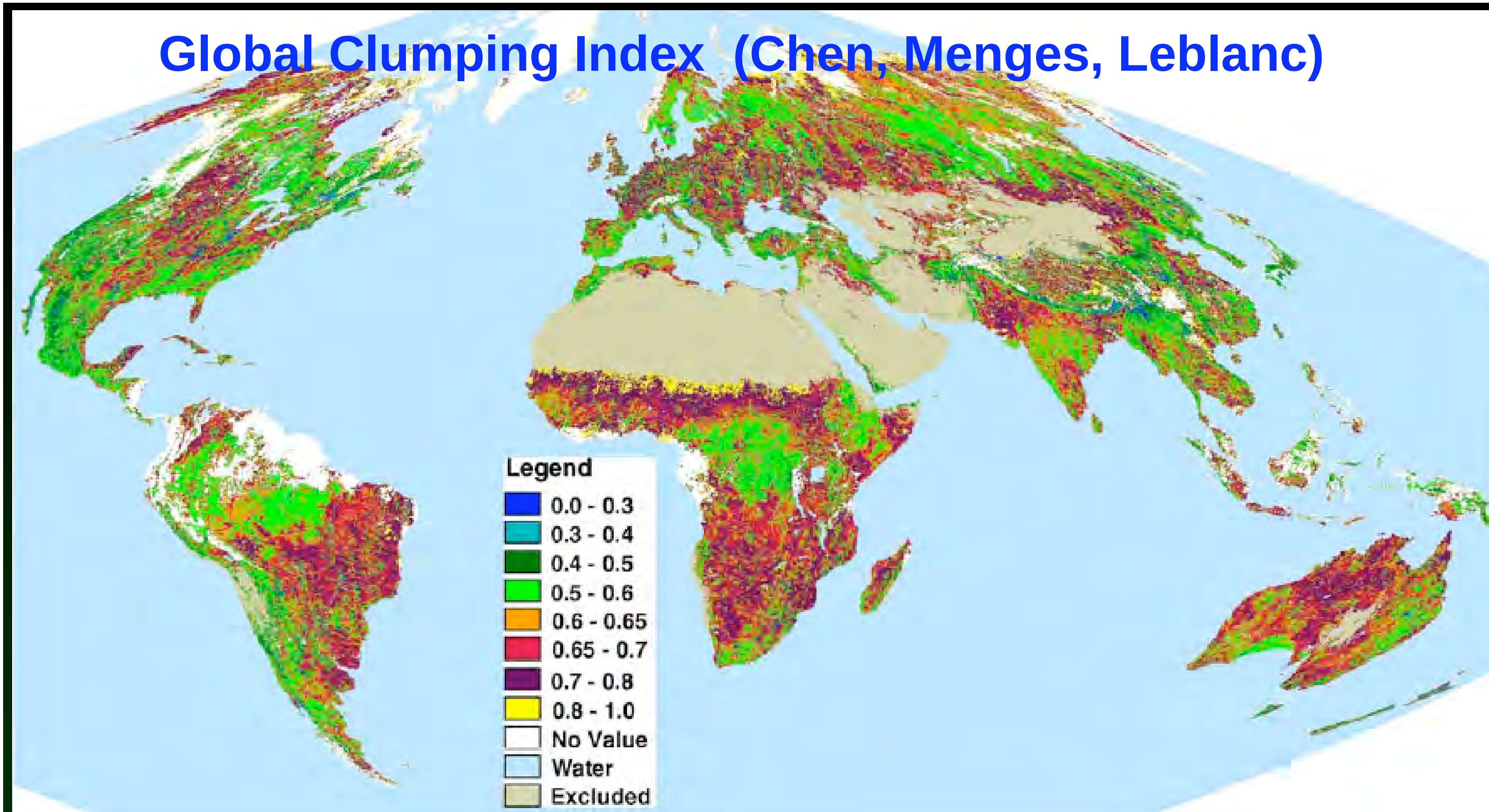
- The results from this 1st run should be much worse: 1. crown LAI was fixed over the entire area, which is inappropriate (but existing LAI products are not *crown* LAI so cannot be used directly) 2. The Li-Ross <---> background relationship was calibrated on only 19 grass-shrub sites in the W. part of the USDA Jornada Experimental Range (19!)

- We think that these results should be classified as “very interesting” at this stage: validation is required. OTOH, they are to our knowledge unique in the moderate resolution RS world

Other Approaches Used with MISR:

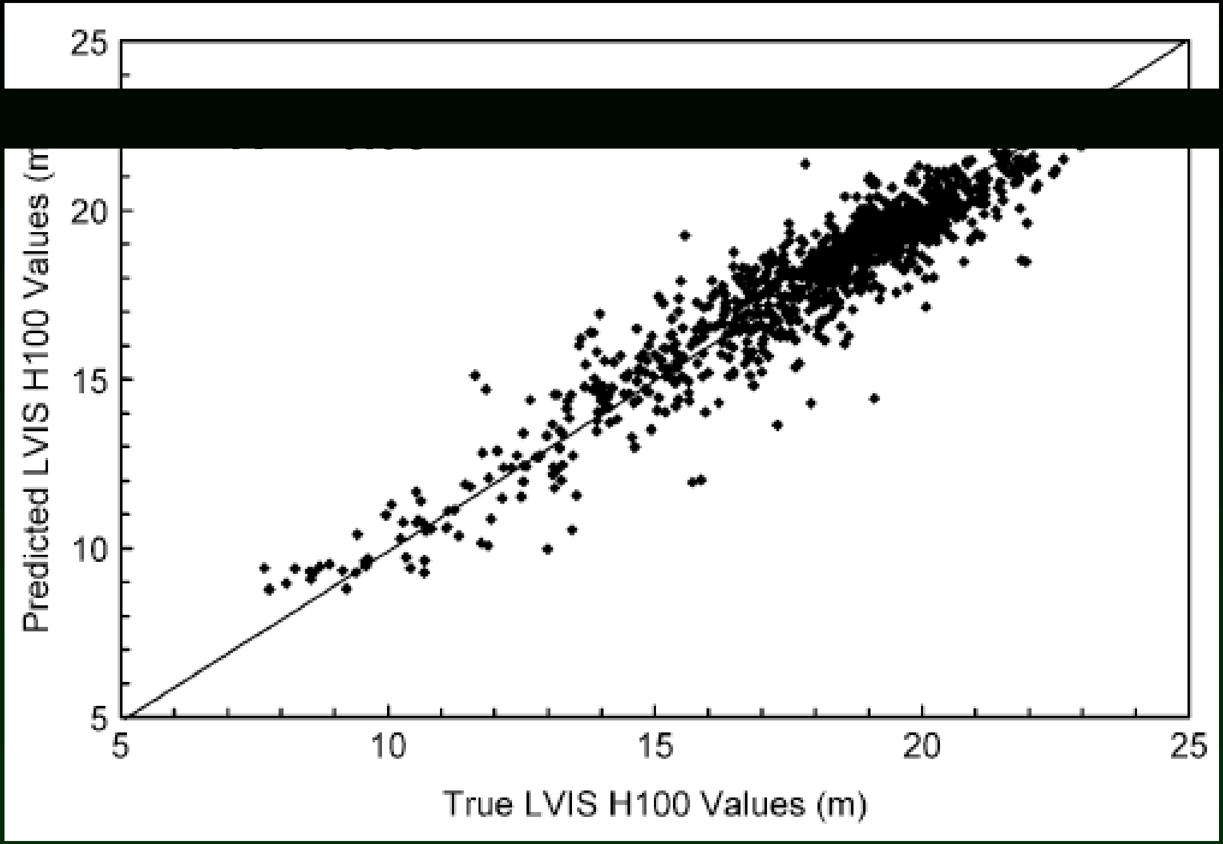
- ***Empirical / Data Mining / Synergistic***
- ***Canopy Openness from MRPV-k parameter***
- ***Clumping Index***

Global Clumping Index (Chen, Menges, Leblanc)



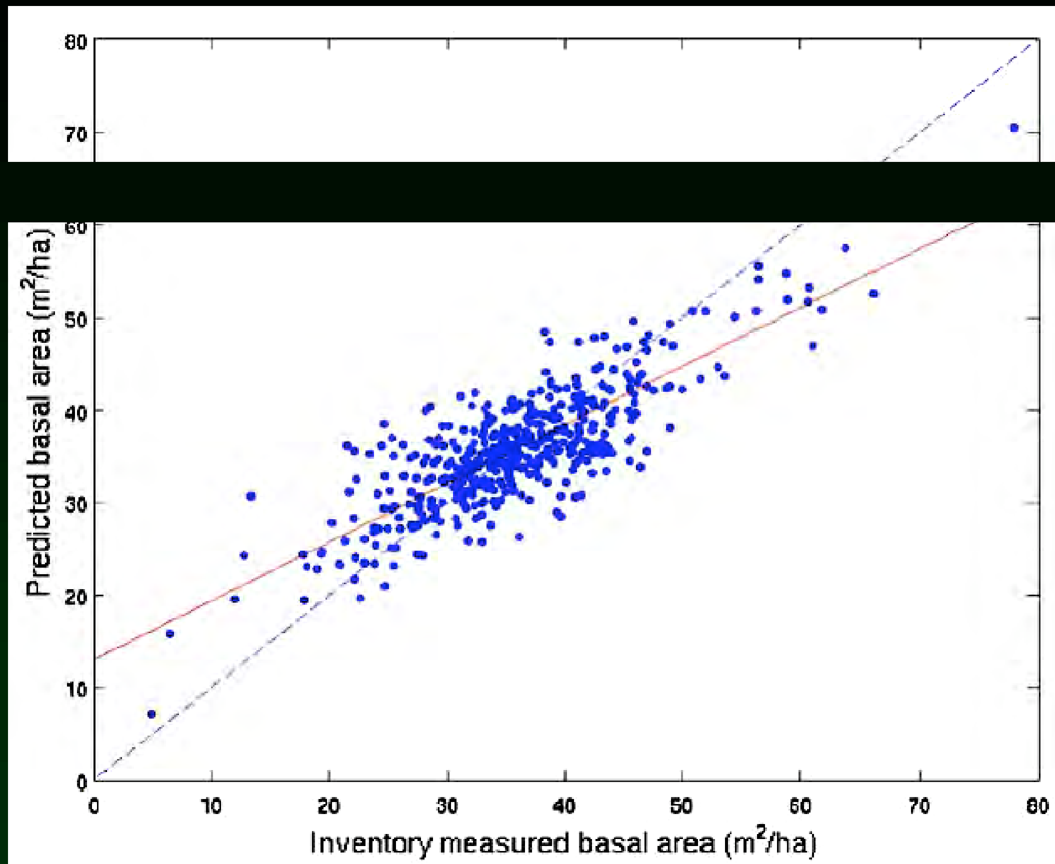
Chen et al. "Global mapping of foliage clumping index using multi-angular satellite data", *Remote Sens. Environ.* 97: 447 – 457, 2005. POLDER, not MISR -- but lessons learned with one instrument are often transferable to other instruments (Chen's group is also working with MISR).

Empirical/Synergistic: AirMISR Trained using Lidar (1)



Sparse lidar samples used with multivariate regression and ANN mappings to estimate measures of forest vertical structure from AirMISR data. Maximum canopy height was estimated with RMSE=0.92 m, R^2=0.89 vs LVIS lidar data. Kimes, D.S., K.J. Ranson, G. Sun, and J.B. Blair, "Predicting lidar measured forest vertical structure from multi-angle spectral data", *Remote Sens. Environ* 100: 503-511, 2006.

Empirical/Synergistic: AirMISR Trained using Lidar (2)



Correlation between optical multi-angle reflectance signature measured with AirMISR and field observations in Bartlett Experimental Forest, New Hampshire. An ANN with 5 nodes was used to map basal stand area over an area of 19.1 km^2. J. Jenkins, S. Ollinger, R. Braswell *et al.*, Detecting patterns of canopy structure and carbon uptake with multi-angle remote sensing, 2004, unpublished results.

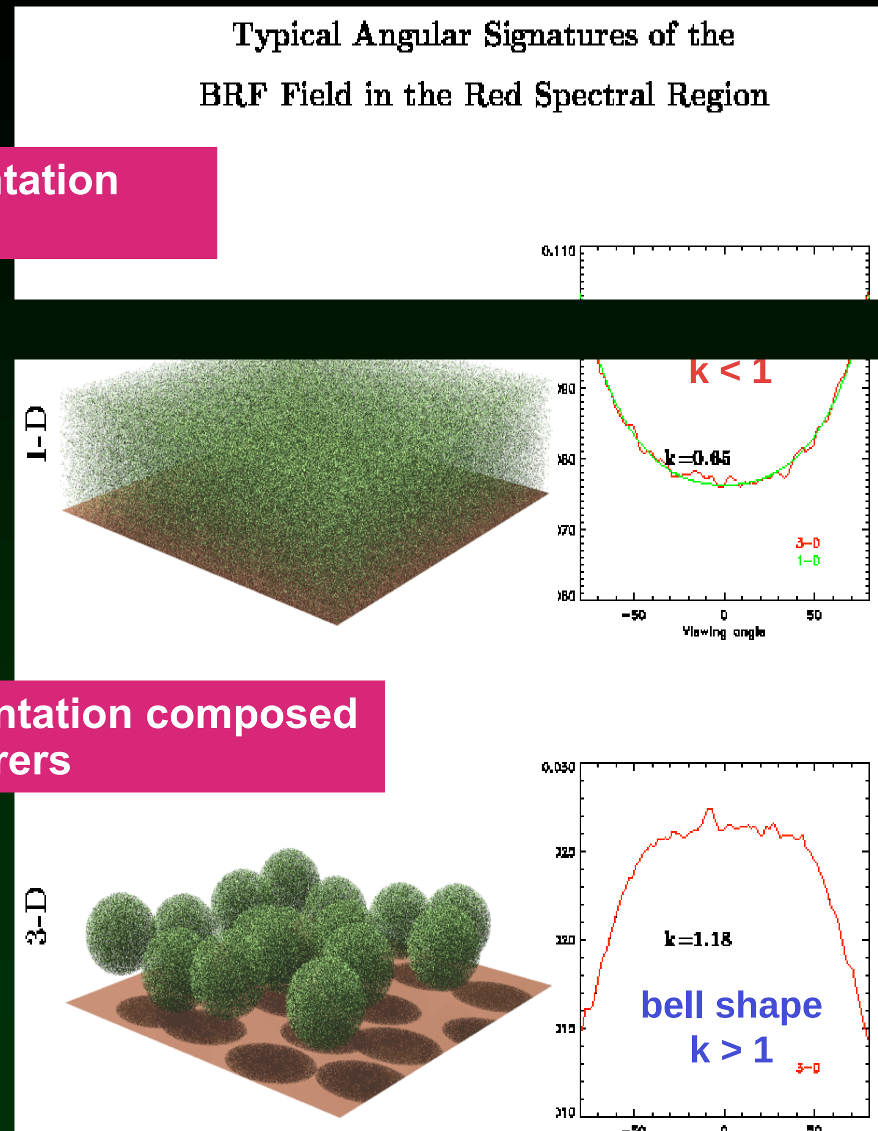
Canopy Openness from MRPV *k* parameter

Structurally homogeneous canopy representation composed of finite-sized scatterers

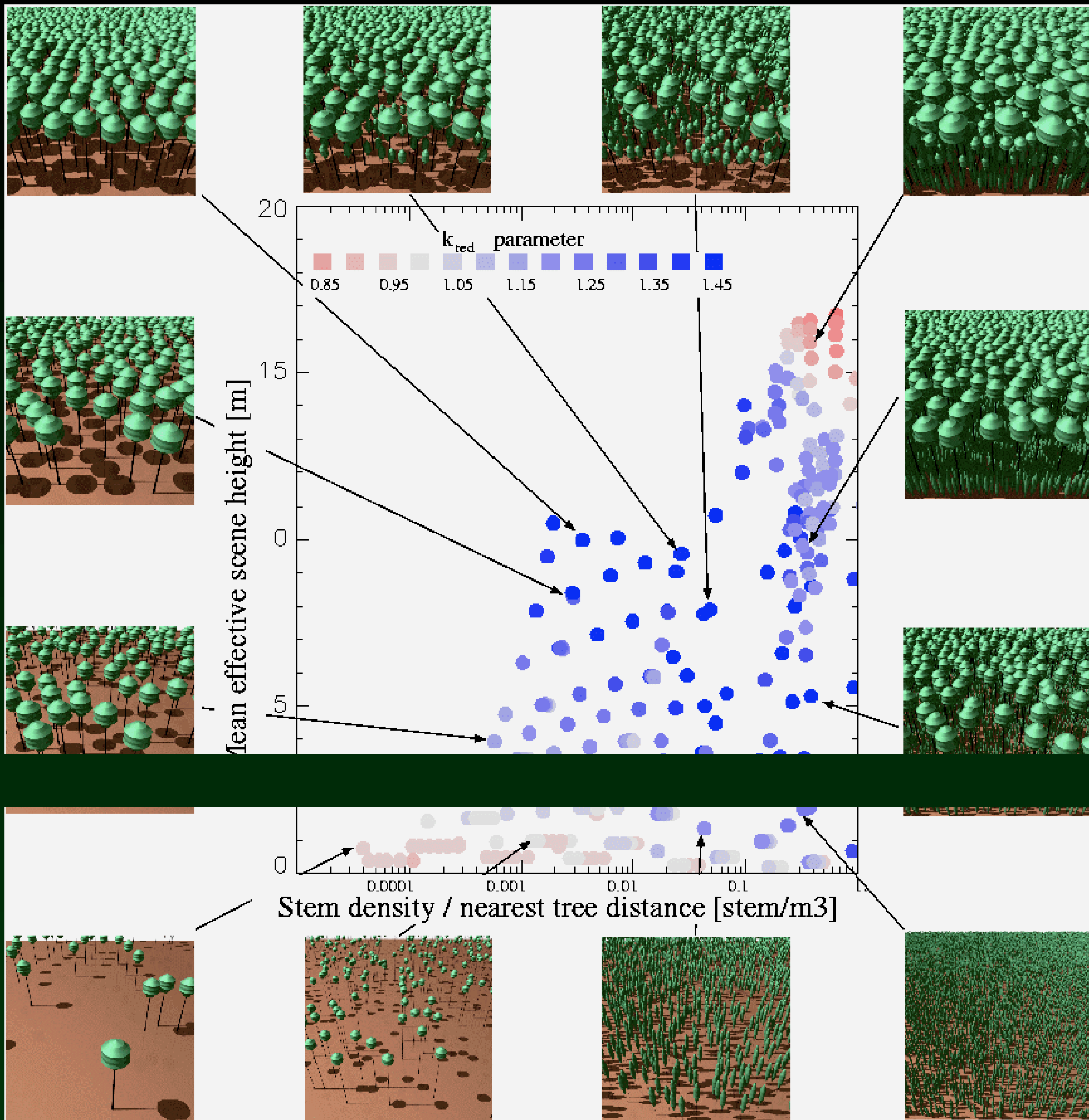
Parametric models
(e.g., Rahman-Pinty-Verstraete function)
BRF = BRF_0 * Shape term * Asymmetry term
Shape term = $[\mu\mu_0(\mu+\mu_0)]^{k-1}$

Structurally heterogeneous canopy representation composed of clumped ensembles of finite-sized scatterers

Exponent *k* establishes whether BRF angular signature gets darker off-nadir (bell-shaped, *k* > 1) or brighter off-nadir (bowl-shaped, *k* < 1)



B. Pinty, N. Gobron, J-L. Widlowski, M. Verstraete



Bowl-shaped and bell-shaped BRFs can be related to measures of canopy structure

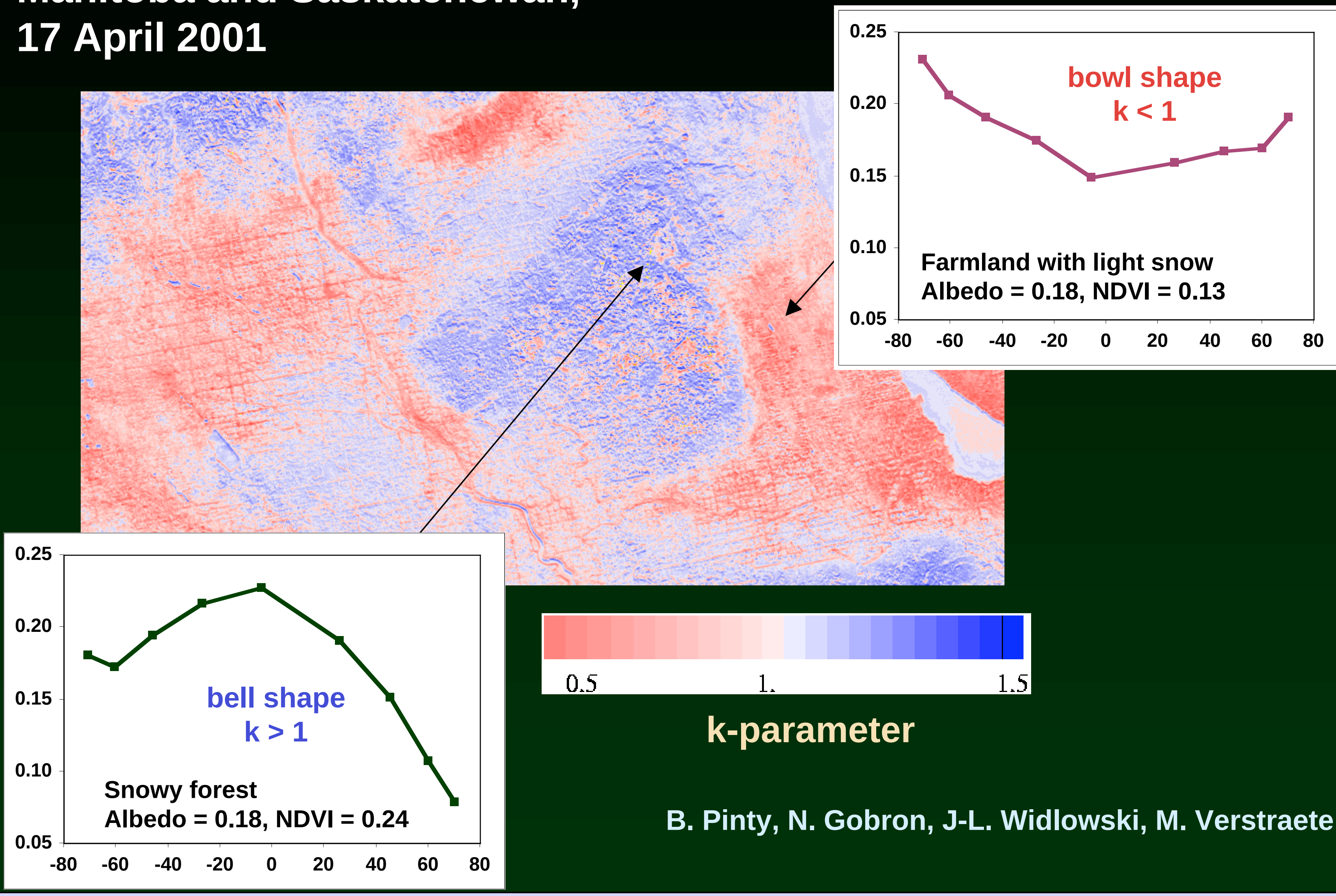
Bell-shaped BRF: Tree crowns of medium-high density against bright background

Sparse vegetation and dense, closed canopies

J-L. Widlowski et al. (2004), Clim. Change

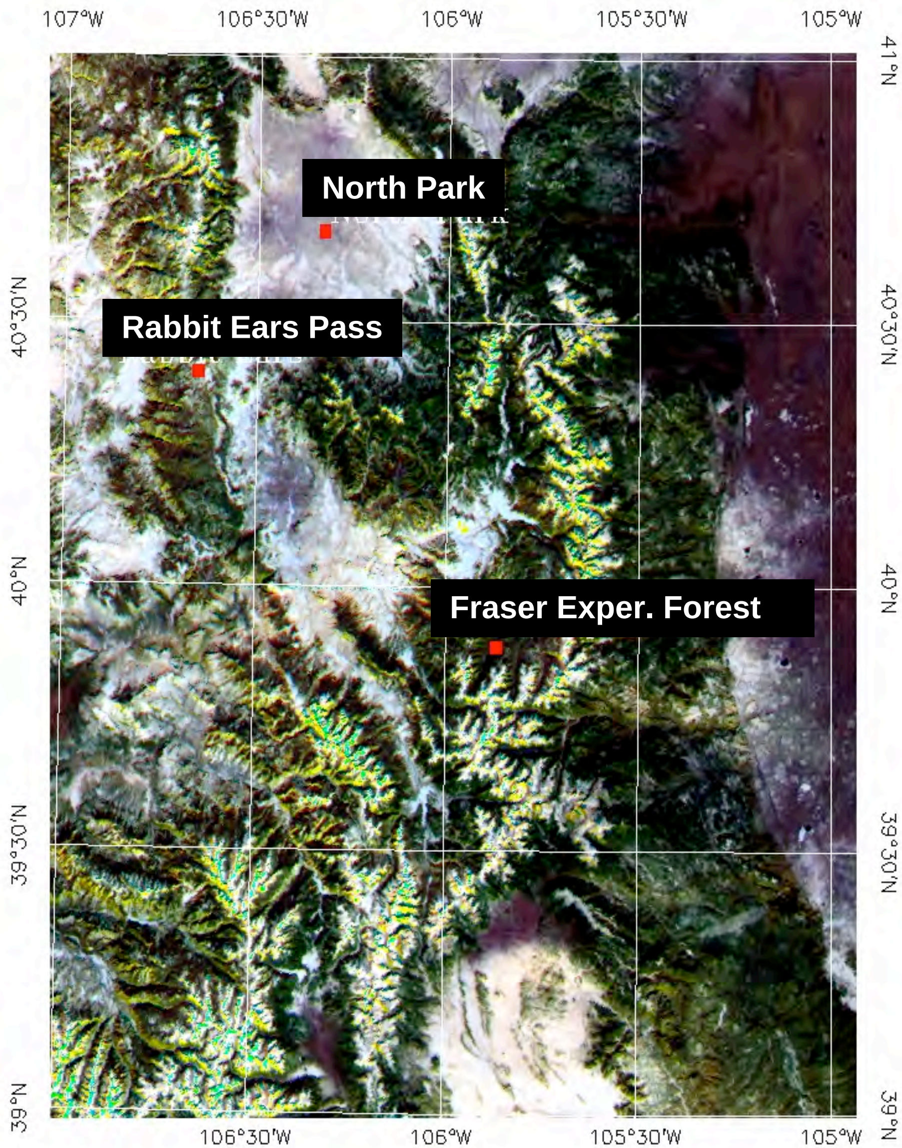
MRPV's *k* can be used to differentiate surface types

Manitoba and Saskatchewan, 17 April 2001



k-parameter

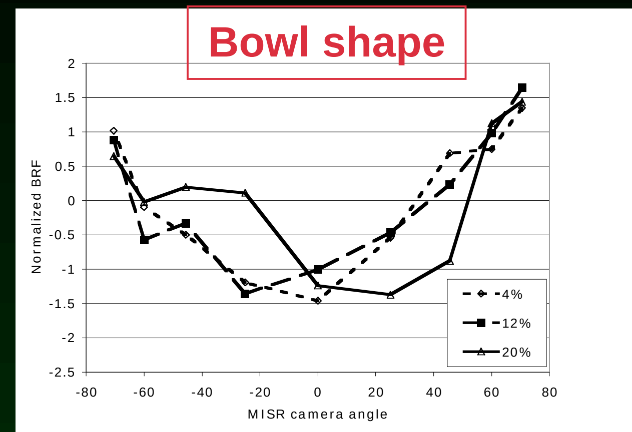
B. Pinty, N. Gobron, J-L. Widlowski, M. Verstraete



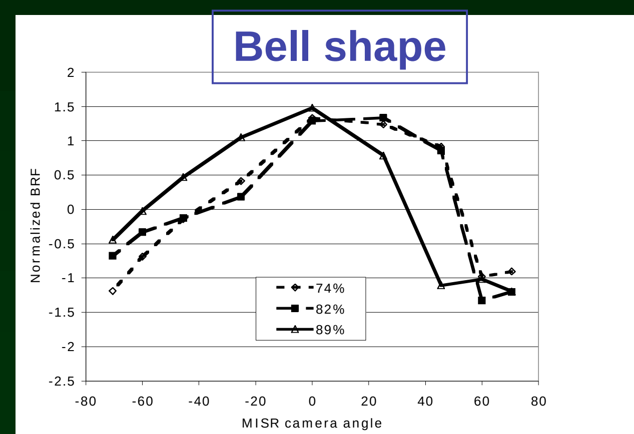
MISR multiangle composite

A. Nolin (2004), Hydrol. Proc.

MRPV *k* has been used to map forest density over snow



non-forested, low density



lodgepole pine, medium/high density

Conclusions

- MISR is an unique instrument with important applications in many disciplines (including vegetation mapping)
- We have made significant progress towards exploiting the structural information content of MISR data (empirical methods currently give the best results; models are gaining…)
- Multi-angle data provide a way to separate the background and upper canopy contributions, enabling the inversion of GO models for crown cover and mean canopy height over large areas (validation should be pursued)
- Retrieval of canopy structure measures is more challenging over shrubs than over trees (no surprise)
- Synergies between lidar and MISR-like multi-angle instruments should be pursued aggressively (continuity is not enough)

Acknowledgments

This research was supported by NASA Earth Observing System grant NNG04GK91G.

The MISR data used were obtained from the NASA Langley Research Center Atmospheric Science Data Center.

Forest Inventory Service data were provided by Gretchen Moisen, US Forest Service. Rocky Mountain Research Station, Ogden, UT.

Thanks to Matt Smith and the Global Land Cover Facility, University of Maryland, College Park, MD, for providing the VCF and SDB data.

The Jornada Experimental Range is administered by the USDA Agricultural Research Service and is a Long Term Ecological Research site supported by the National Science Foundation.

THANK YOU!

http://csam.montclair.edu/~chopping/woody
http://www-misr.jpl.nasa.gov/