MODIS and MISR Reflectance Anisotropy: Applications in Mapping Vegetation

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Talk Outline

1. **Why Anisotropy?**
2. **Results: SWUS, Arctic**
3. **Summary**

Why Anisotropy?

We want to take note of reflectance anisotropy in MODIS solar wavelength bidirectional reflectance factor data for three reasons:

1. **To correct for the effects of surface BRDF and Sun-target-sensor geometry***

2. **To obtain accurate land surface albedo estimates**

3. **To obtain additional information on the surface (physical, empirical, or thematic)**

***adjustment to a preferred geometry. This is where the anisotropy bus stops for many people.**

Why Anisotropy?

We are focusing on #3 and how this might address a core NASA Carbon Cycle and Ecosystems & Terrestrial Ecology Programs Science Question:

"How are the Earth's carbon cycle and ecosystems changing and what are the consequences for the Earth's carbon budget, ecosystem sustainability, and biodiversity?"

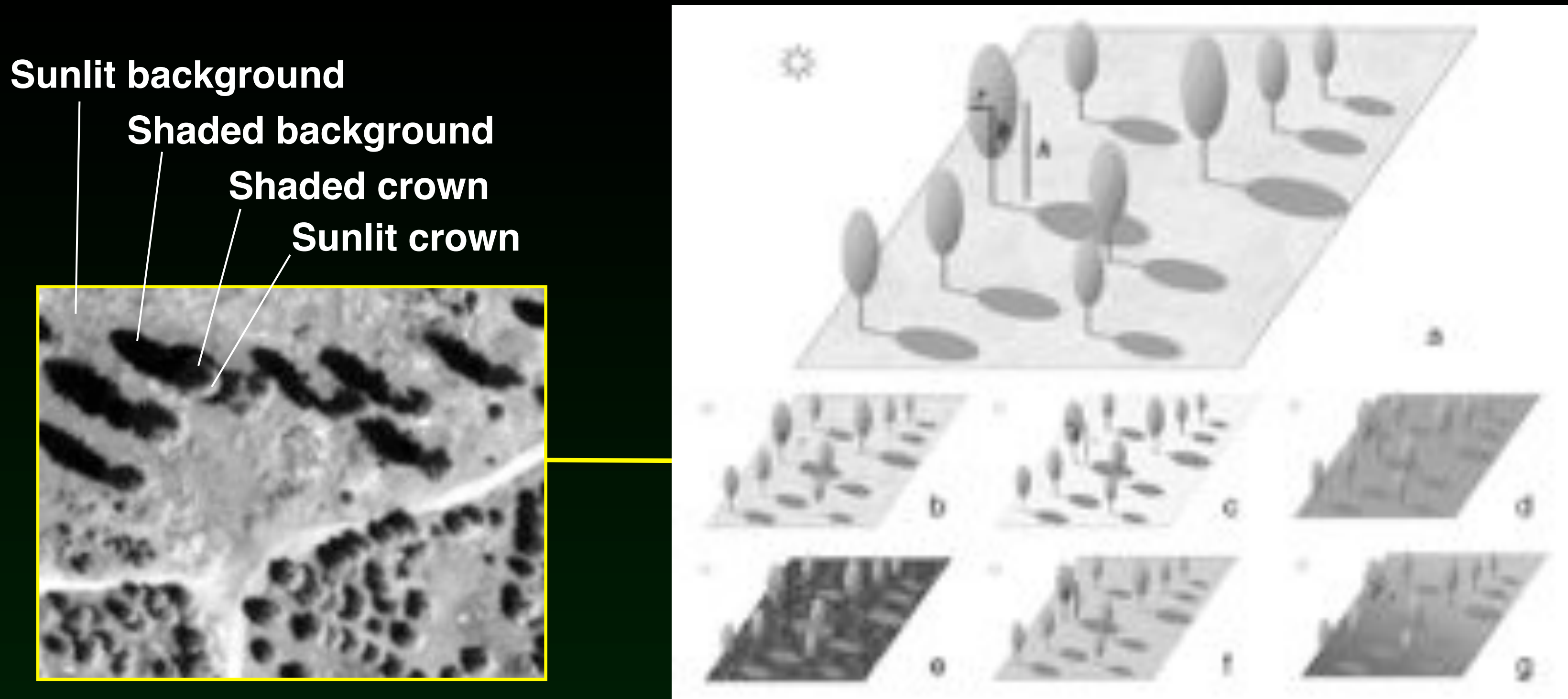
Specifically: can we map the distribution of aboveground woody carbon stocks, canopy structure (at least cover & height) and vegetation type by exploiting the structural signal available via reflectance anisotropy in MISR and MODIS BRFs?

Regions: southwestern US (forest and shrub-dominated grasslands) and Arctic tundra (shrub expansion).

Outline of Progress to Date (*reference data used*)

2006: **work exploiting MISR data for shrub mapping (*ref: high resolution imagery; MODIS VCF; Landsat*)**
2007: **first maps of regional canopy crown cover, canopy height, and aboveground woody biomass (*ref: USFS maps made using MODIS+other geospatial data layers and an empirical model*)**
2008: **Colorado Rockies study testing canopy height mapping capability using high resolution lidar (*ref: ALS40 scanning lidar with 1.5 m shot spacing; hi-res imagery*)**
2009: **produced maps of fractional woody plant cover, mean canopy height, and aboveground biomass) for 2000 and 2009 for the southwestern US (*ref: USFS MODIS-based biomass, airphoto pine beetle, and Landsat burn maps*)**
2010: **work examining MISR/GO mapping in the Sierra National Forest, CA (*ref: NASA LVIS waveform lidar, CANAPI-derived tree #density, cover, radius, and height*)**
2010-11: **preliminary mapping efforts in Arctic tundra with MODIS (*ref: vhr aerial imagery, QuickBird, field survey*).**

Info: Sunlit/Shaded Fractions Change with Sun/View Angles



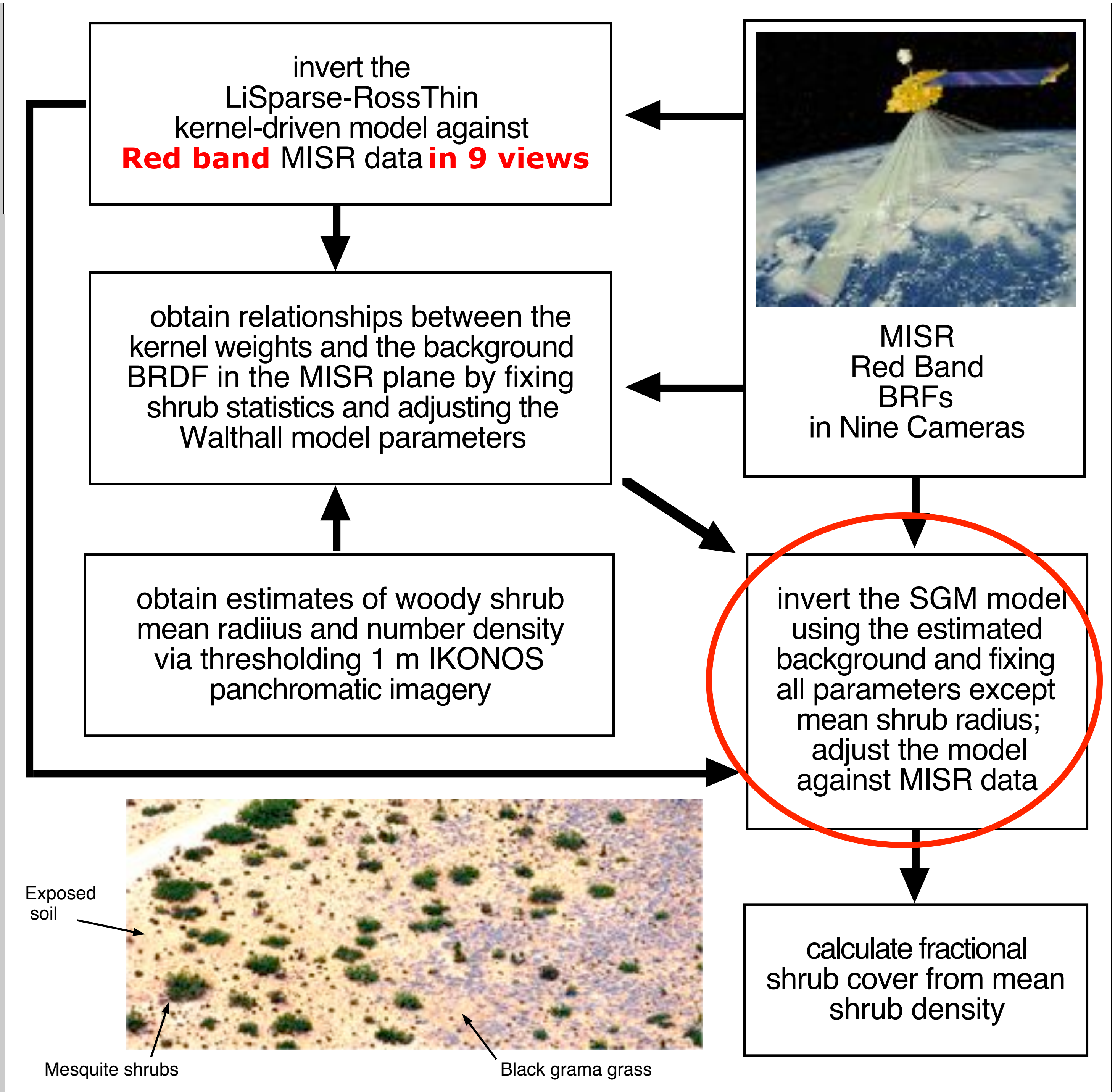
Shadowing and scattering from trees and shrubs modify reflectance anisotropy, providing the opportunity to access structural information via BRDF models, or via geometric-optical models. GO model inversion must deal with non-uniqueness of solutions (different combinations of parameters can result in similar BRF patterns). Which parameters to fix? Which assumptions are acceptable? Background BRDF? Inversion method robust?

GO Model Inversion Protocol

A BRDF model (*W*) is used to represent the background and a <u>Ross function</u> allows for within-crown volume scattering; *G* is replaced with *W* and *C* with Ross, so that

$$R = \not{G}\, W.k_G + \not{C}\, Ross.k_C$$

***T* and *Z* are considered black (zero contribution)**

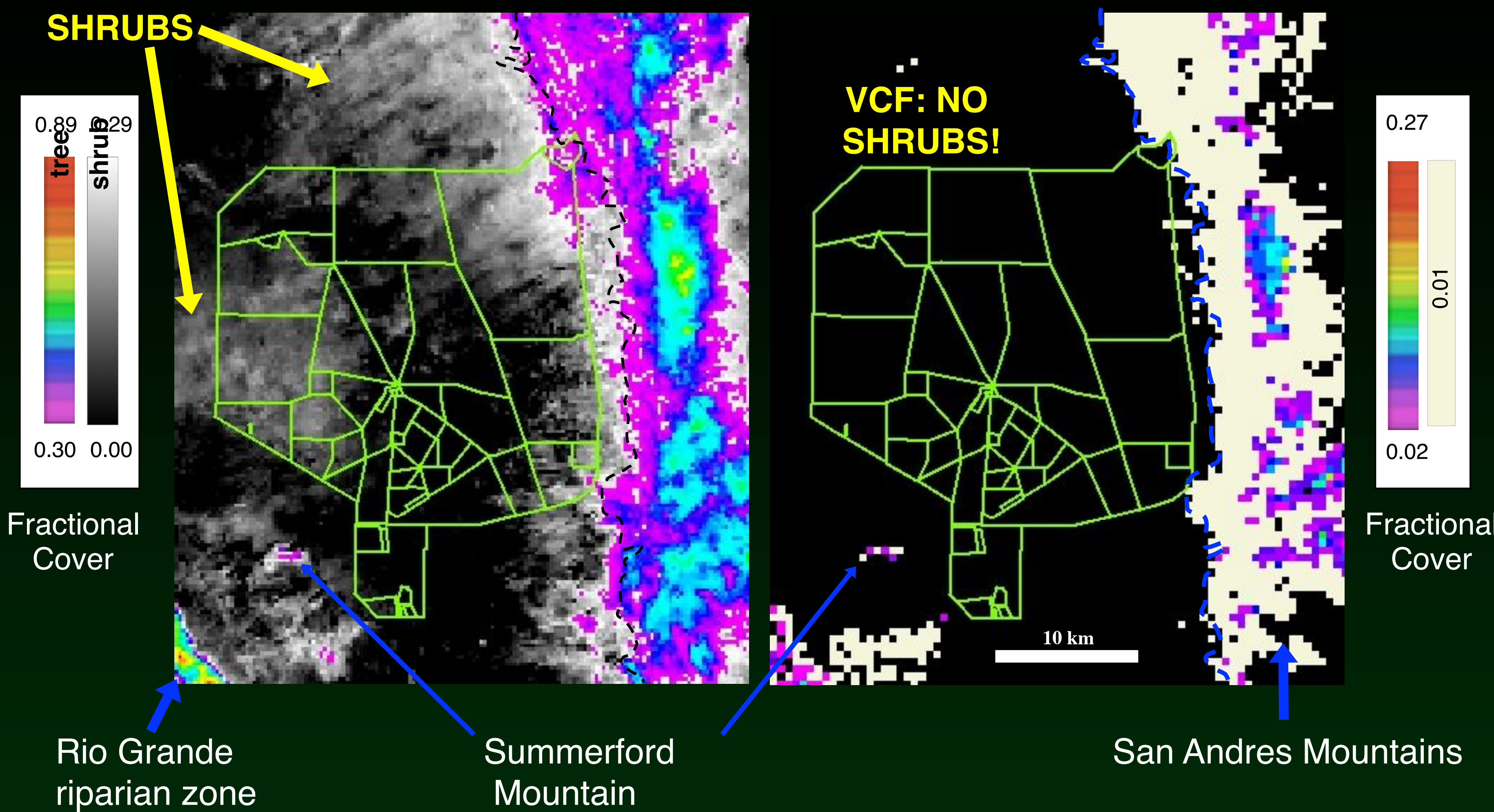


Reflectance Anisotropy & Canopy Structure

Initial work in New Mexico (2004-2007) was focused on shrub cover mapping -- but we realized that we could also obtain estimates of canopy height through fixing the GO model *h/b* and λ parameters and inverting for *r* and *b/r* ($h = h/b \times b$; $b = b/r \times r$).

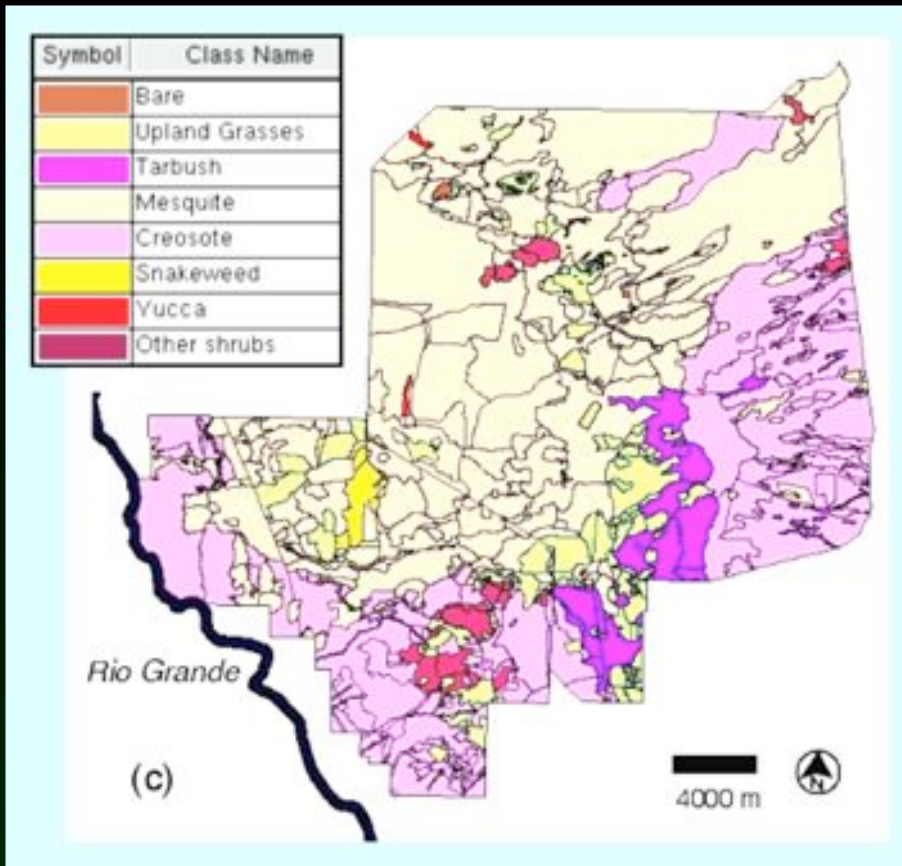
We only realized this by accident, after extending the mapping area to include the San Andres Mountains adjacent to the USDA, ARS Jornada Experimental Range.

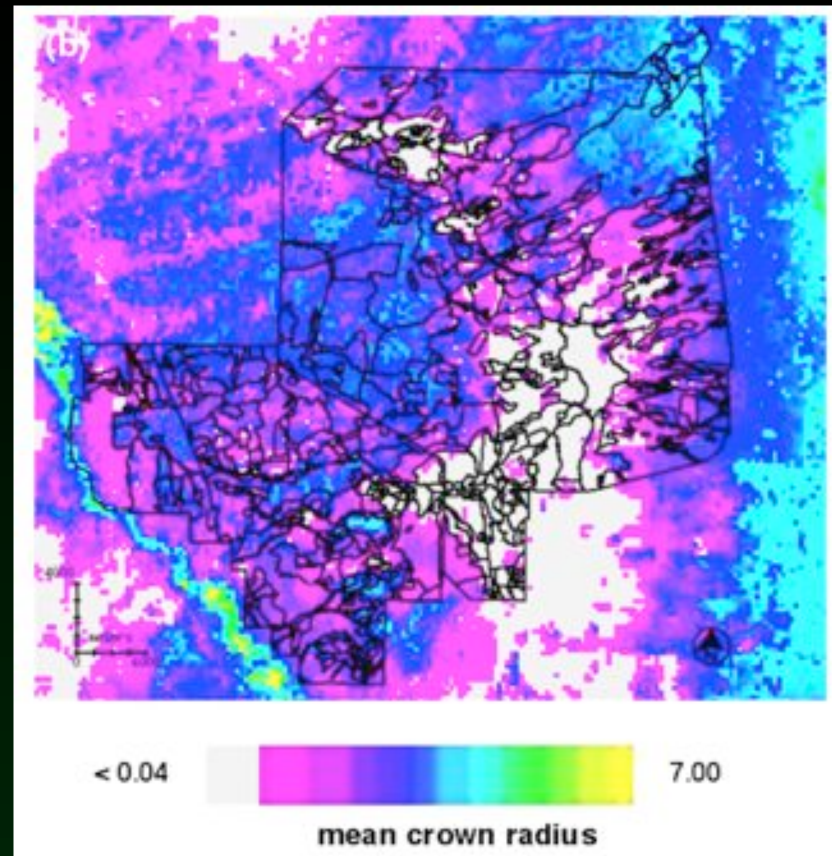
MISR Cover Retrievals vs VCF % Tree Cover Map



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

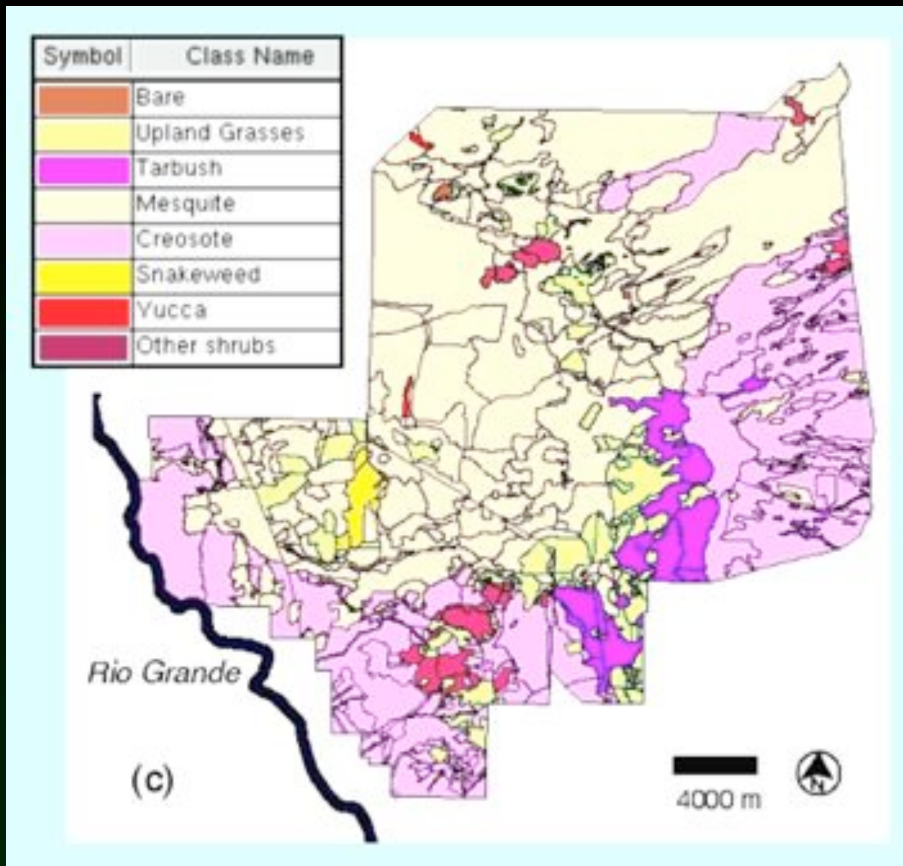
Shrub Crown Radius & Shape in Desert Grasslands

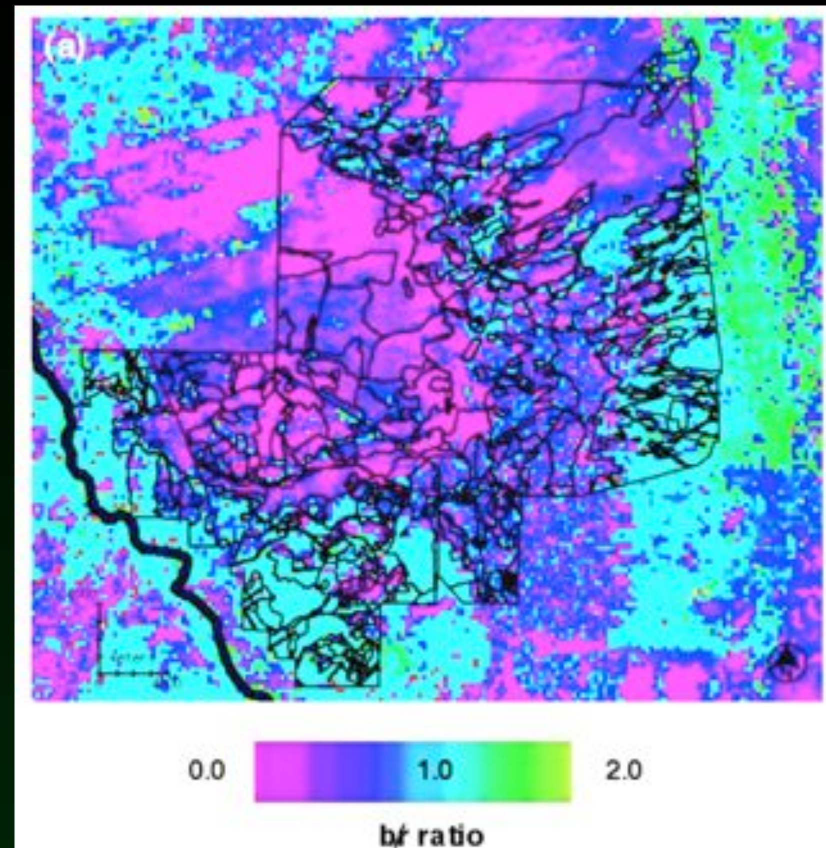




Mean Crown Radius (*r*) and Crown shape (*b*/*r* ratio) from MISR/GO are Effective Parameters -- but their distributions make sense.

Shrub Crown Radius & Shape in Desert Grasslands

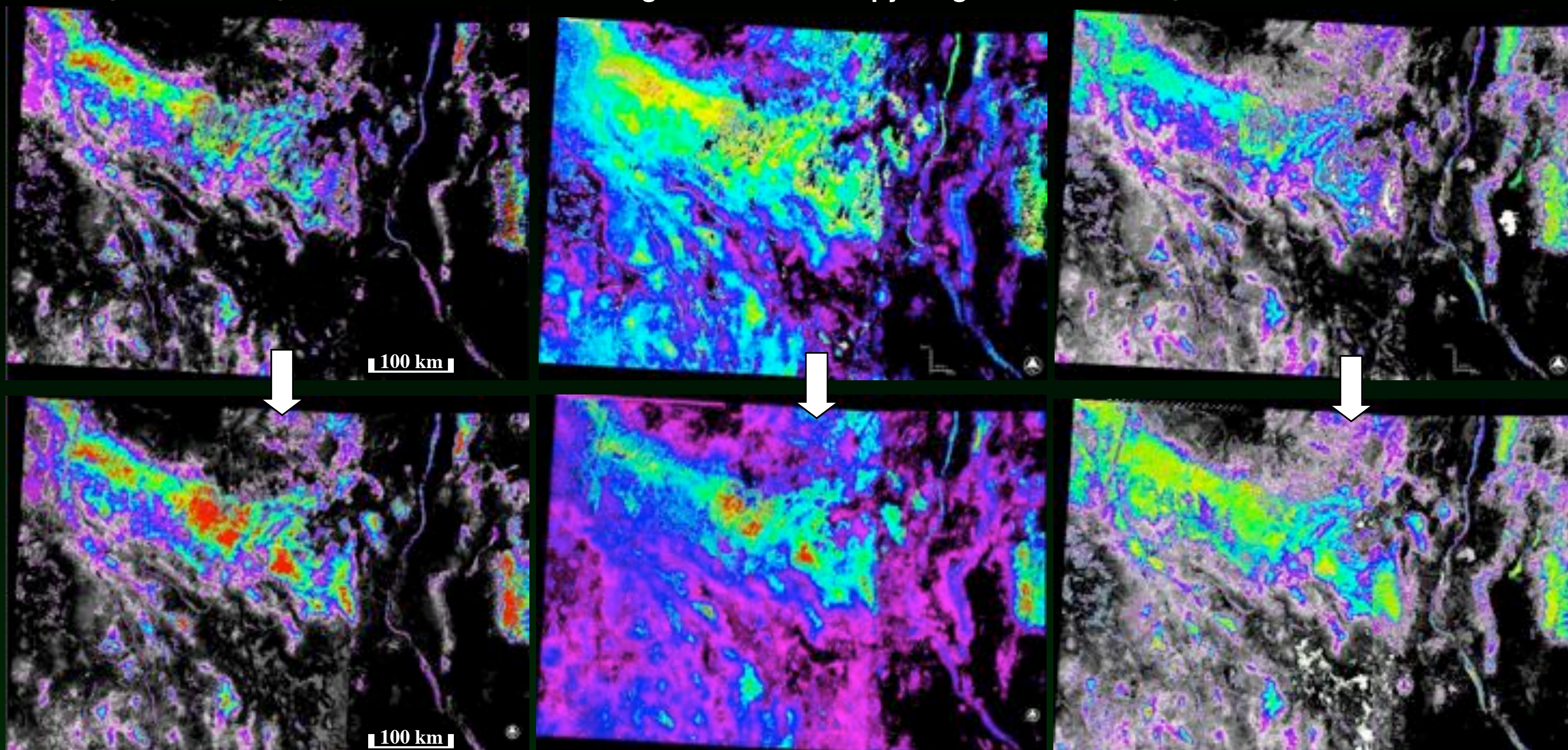




Mean Crown Radius (*r*) and Crown shape (*b/r* ratio) from MISR/GO are Effective Parameters -- but their distributions make sense.

MISR/GO 250 m maps for June 2002, composited on min(RMSE)

Regional Aboveground Biomass | Regional Mean Canopy Height | Regional Forest Crown Cover



Aboveground Biomass

0.00 – 6.70 | >50.0
Tons/acre
0.00 – 15.0 | >110.0
Mg ha^{-1}

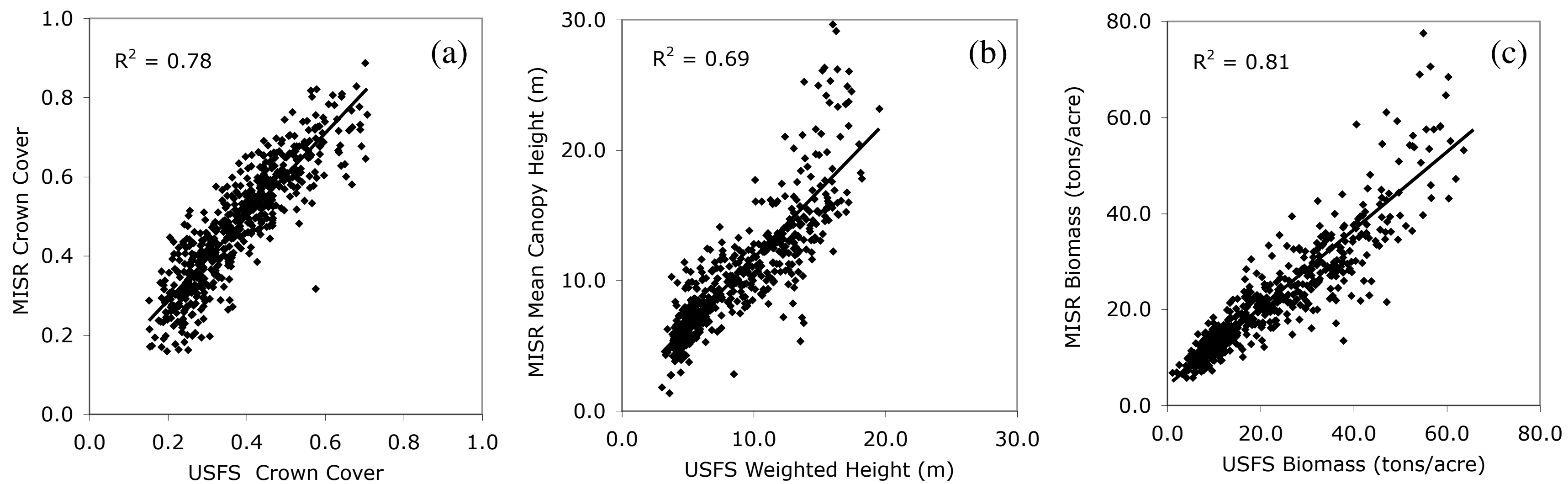
Mean Canopy Height

< 1.00
1.00 | >20.00
meters

Fractional Crown Cover

0.00 | 0.29
Shrubs
0.30 | 0.90
Forest

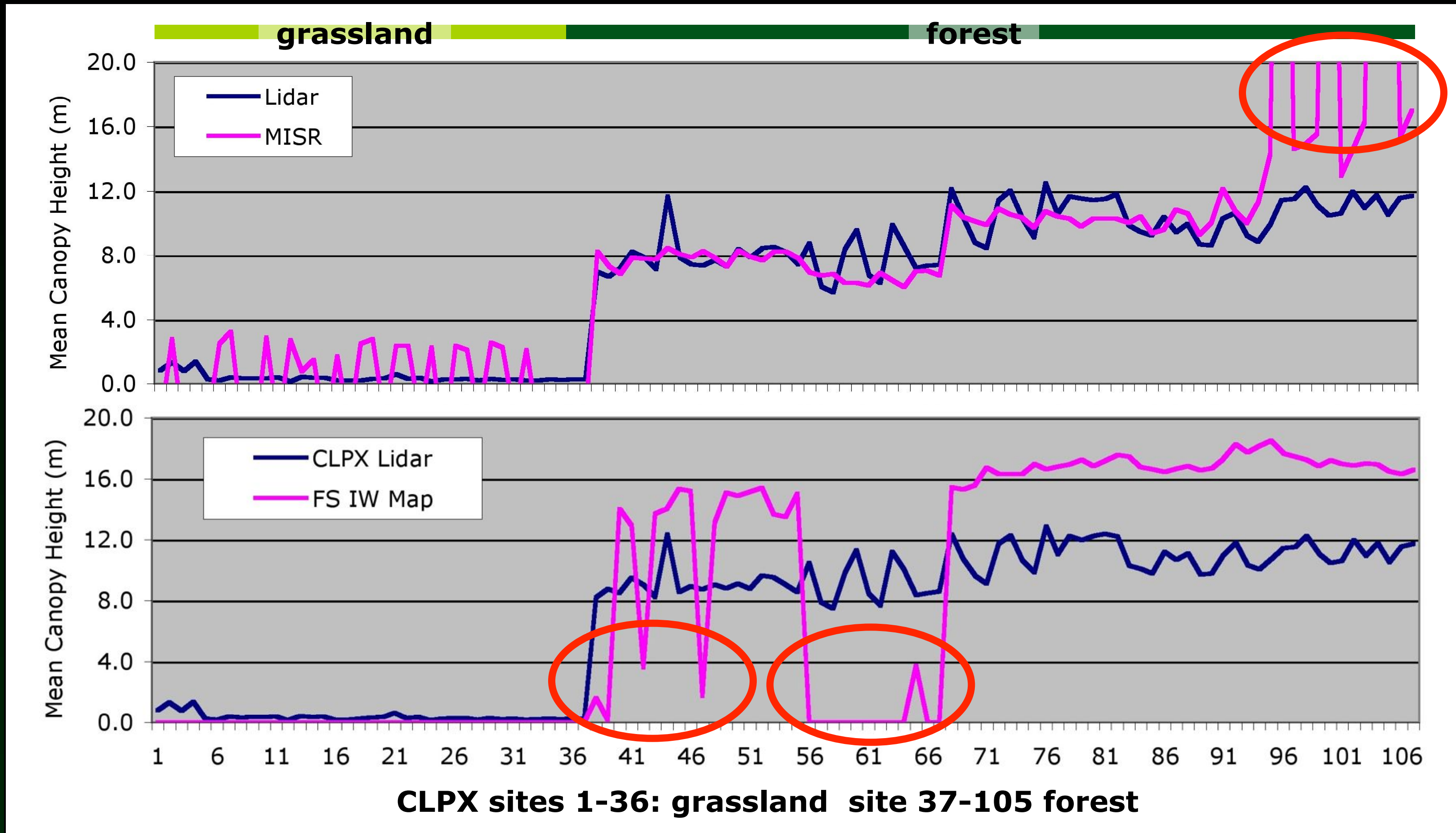
AZ & NM Canopy Cover, Height & Biomass Evaluations



Results: (a) Crown cover, (b) canopy height, and (c) woody biomass Retrievals with screening for topographic effects using a Digital Elevation Model from the Shuttle Radar Topography Mission. Points with RMSE >= 0.01 and a few outliers ±2 st. devs. from the mean of crown cover were discarded, retaining 576 points (54%).

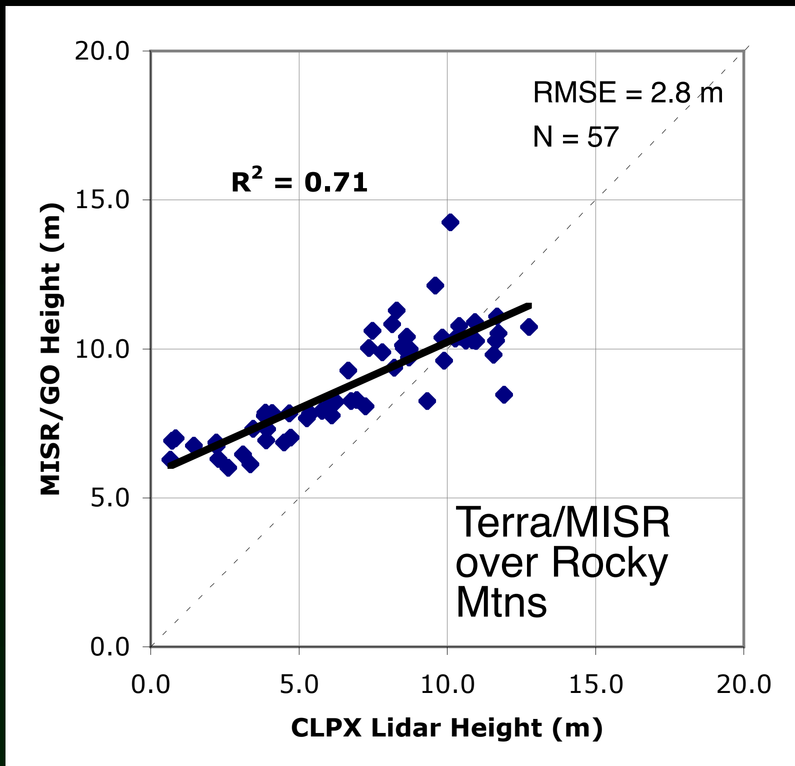
These results were *highly compatible* with the MODIS-based Forest Service 2005 Interior West Forest Maps for 2001-3. . . but this is not really validation: <u>How accurate are the USFS MODIS-based maps?</u> Lidar and high resolution imagery are needed.

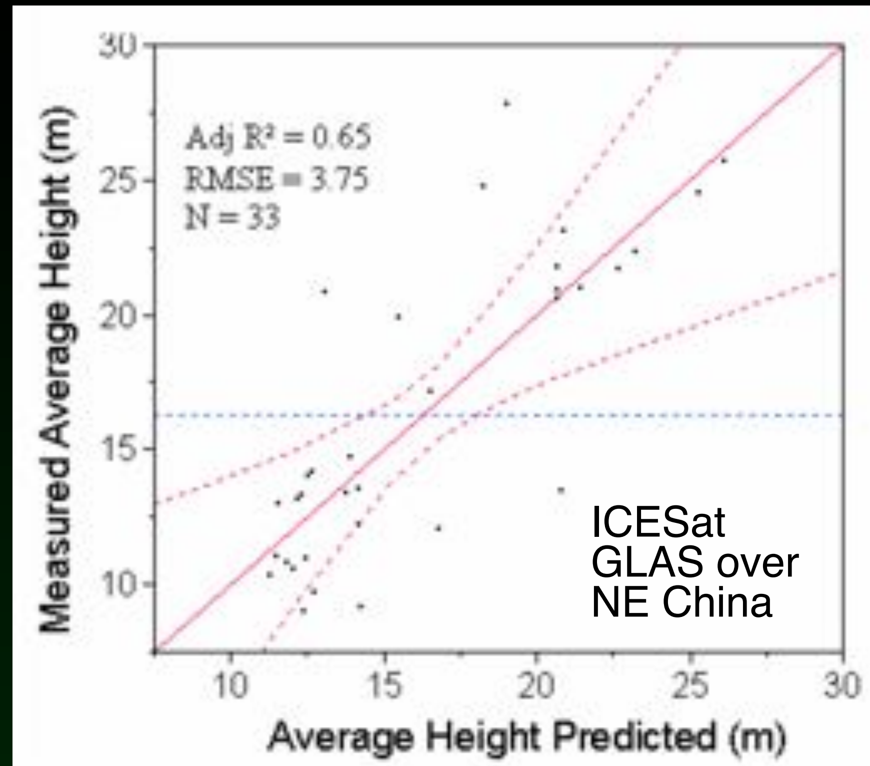
MISR/GO vs Discrete Return Lidar (Colorado Rockies)



CLPX lidar = very high resolution discrete-return lidar (Leica ASL40). U.S. Forest Service Interior West (IW) empirical height estimates seem to be worse vs CLPX lidar heights than MISR/GO. There are retrieval faliures @ the Fool Creek site (#97-#107; these were clearcut in the 1950s). Anomalies are easily screened out b/c inversions fail spectacularly (cover goes to 1.0).

MISR/GO (CO Rockies) and IceSAT GLAS (NE China)





- The GO model <u>mean</u> canopy height vs. heights from waveform lidar based on cumulative energy return: apples and oranges?
- Lidar heights are likely to be more robust because of the nature of the measurement but are sensitive to slope, footprint size, and crown shape. *Lidar overestimates tree heights on slopes.*

Southwestern US: MISR/GO Maps for 2000 & 2009

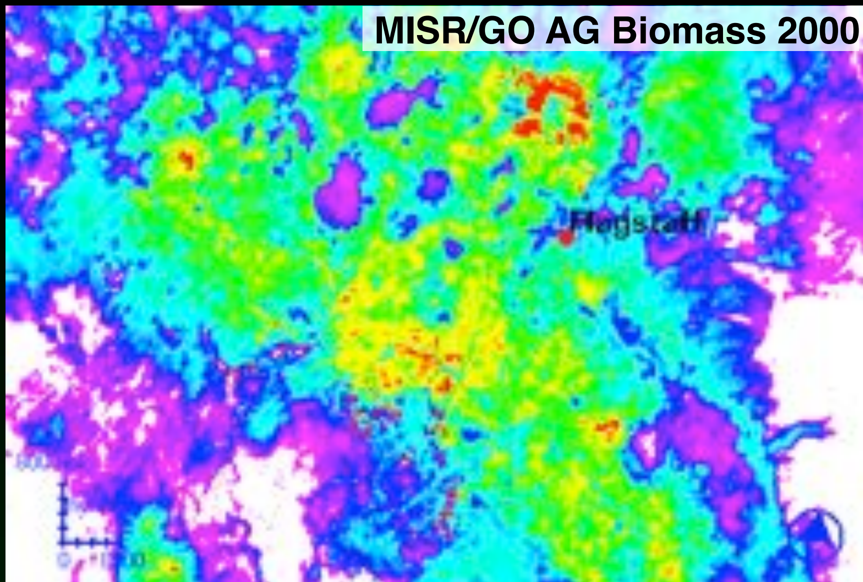
Goal: Produce maps of fractional woody plant cover, mean canopy height, and aboveground biomass) for 2000 and 2009 for the southwestern United States.

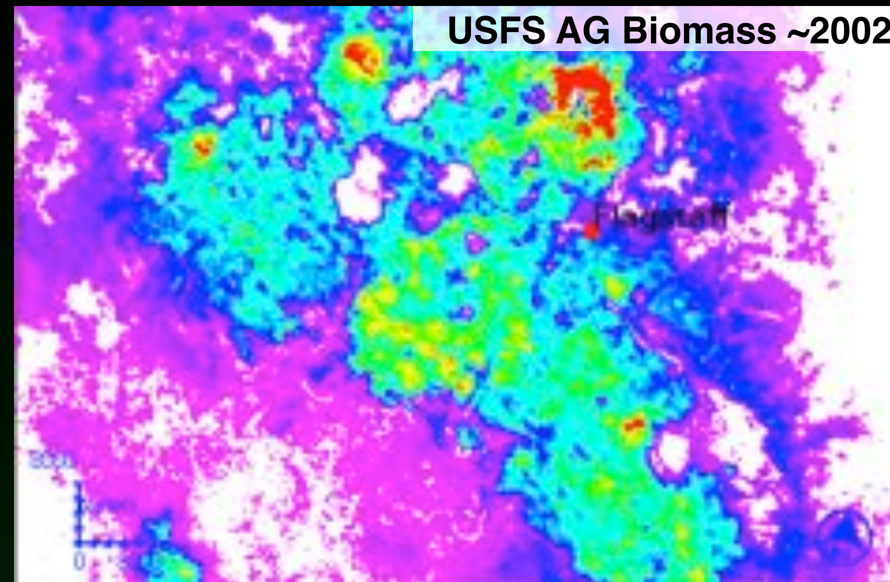
Data: MISR 275 m red band radiances in all nine cameras, mapped to a 250 m grid: ~400 million inversions for each year (235.8 million locations).

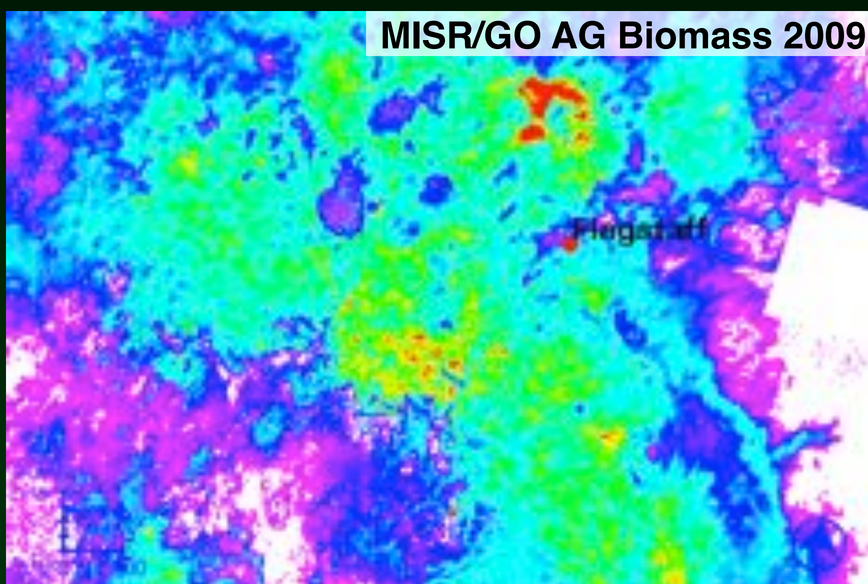
Approach: Geometric-optical (GO) model inversion *using injection of a dynamic background estimated via BRDF model kernel weights*.

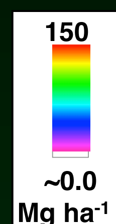
Results: appears promising but requires further evaluation with better reference data and refinements to the inversion protocol.

Southwestern US: MISR/GO Maps for 2000 & 2009







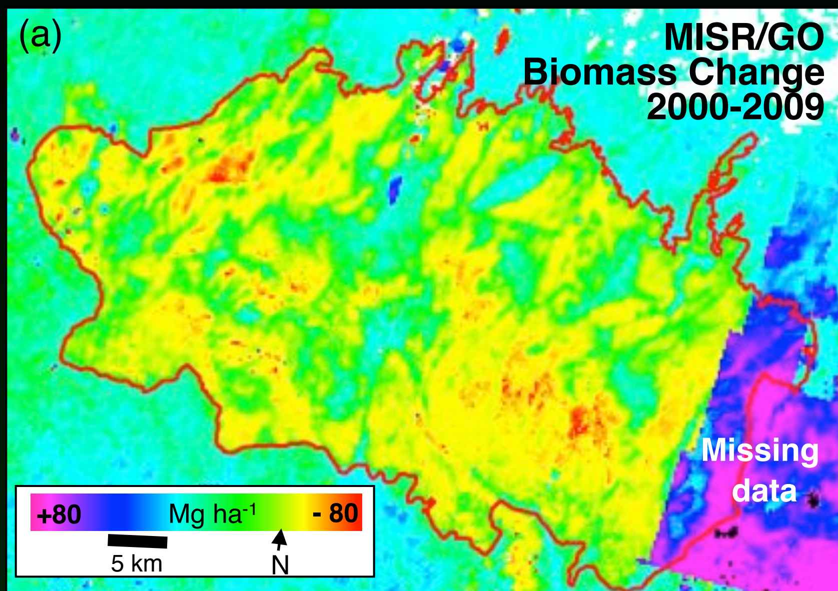


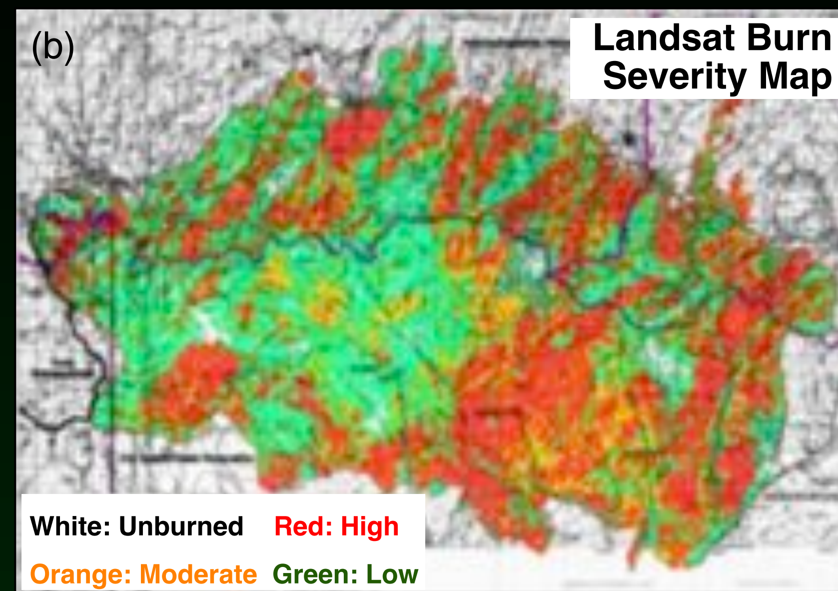
The USFS Aboveground Live Biomass Map, 2002 is based on Forest Inventory Analysis, MODIS, and other geospatial data.

The MISR/GO Aboveground Biomass Maps, 2000 and 2009 are from GO model inversion against red band BRFs.

Rodeo-Chediski Fire, Arizona, 2002

Change in Aboveground Live Biomass from MISR

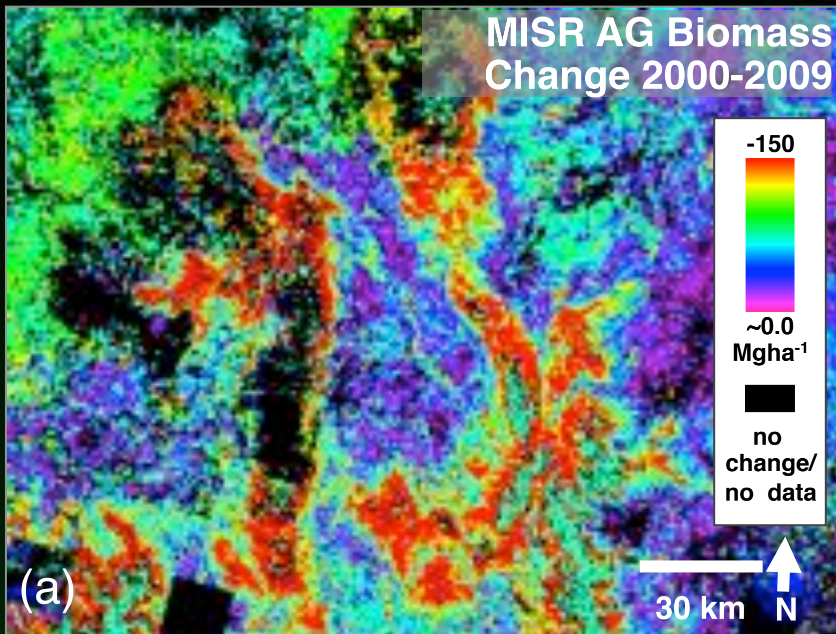


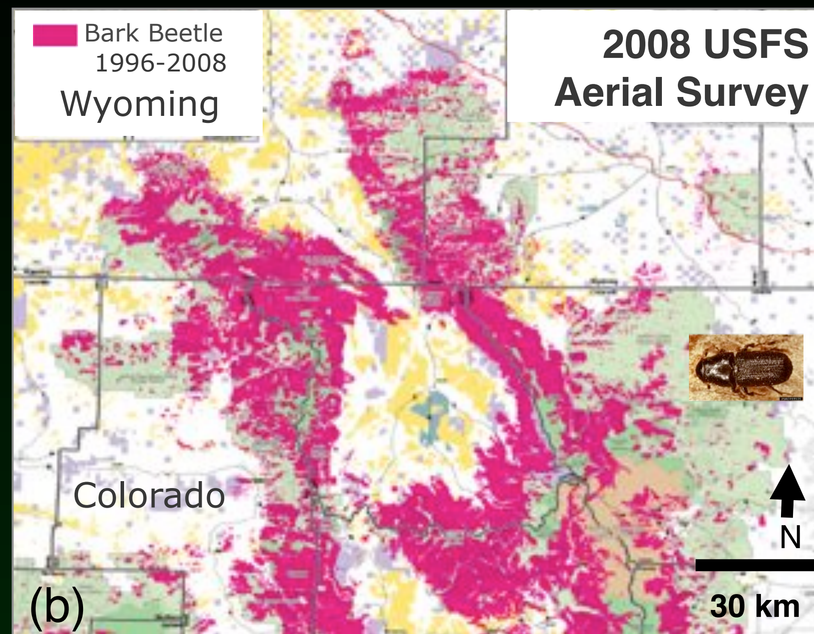


MISR/GO biomass change map also matches Landsat-based Monitoring Trends in Burn Severity (MTBS) fire perimeters by burn severity.

CO/WY Forest Biomass Loss from Pine Beetle

Change in Aboveground Live Biomass from MISR



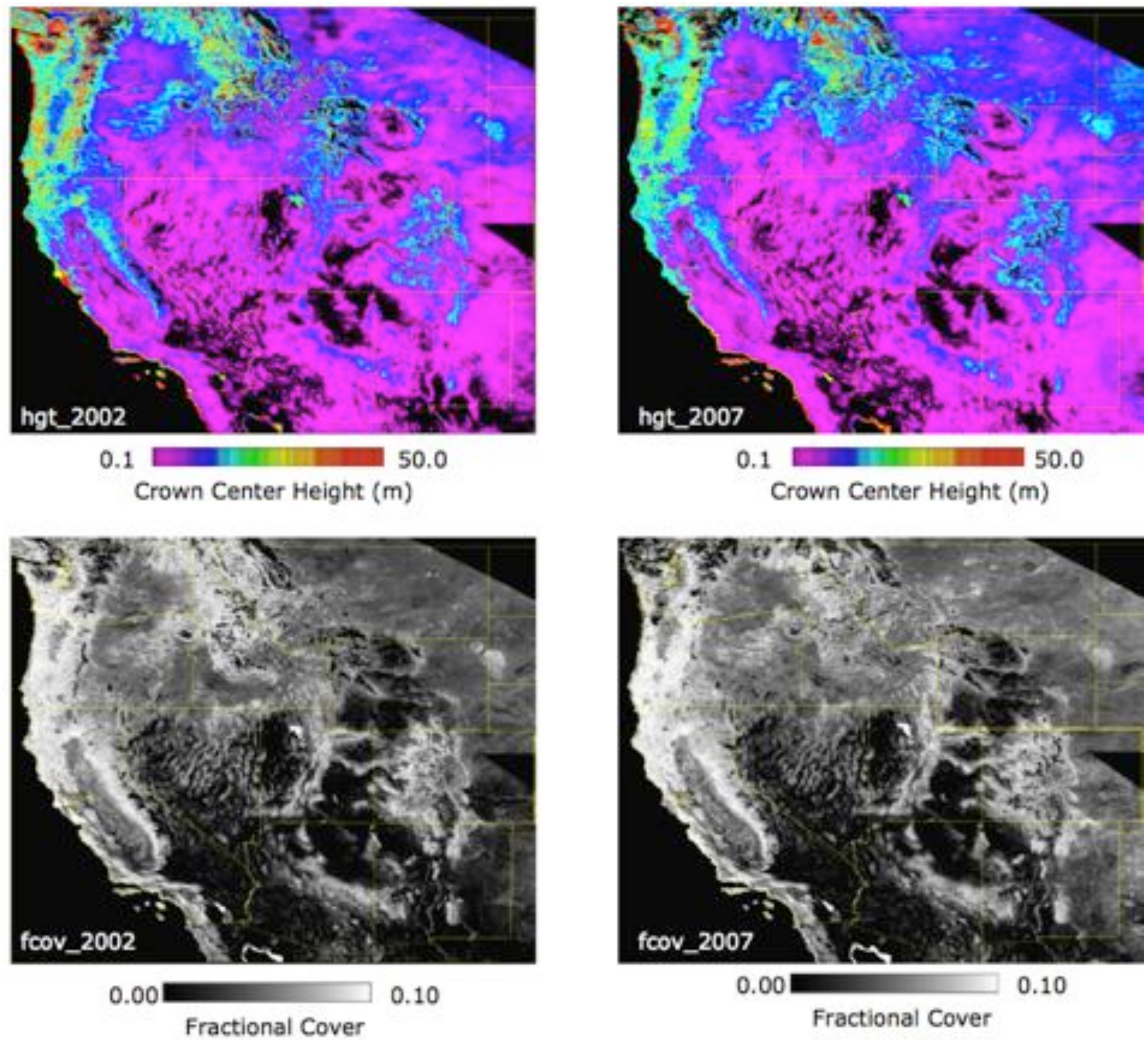


Biomass estimates are more robust than cover or height

MODIS/GO Retrievals, SWUS

GO model inverted with MODIS 250 m red band BRFs.

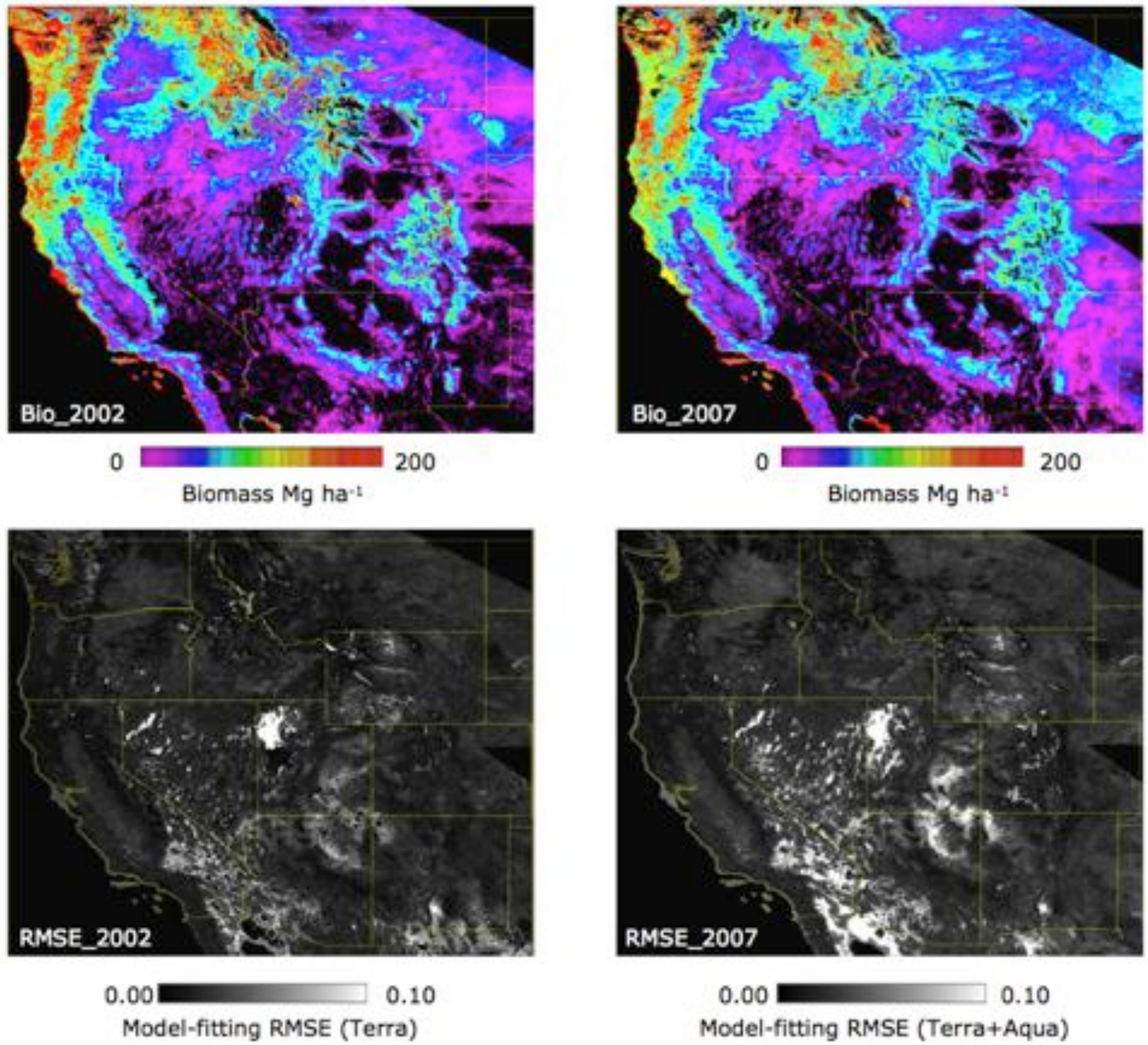
The accuracy and precision of the retrievals is limited by the ability to predict the background BRDF at each location.



MODIS/GO Retrievals, SWUS

GO model inverted with MODIS 250 m red band BRFs.

Biomass was obtained via regression of USFS Interior West biomass values on *f*.cov and mean height



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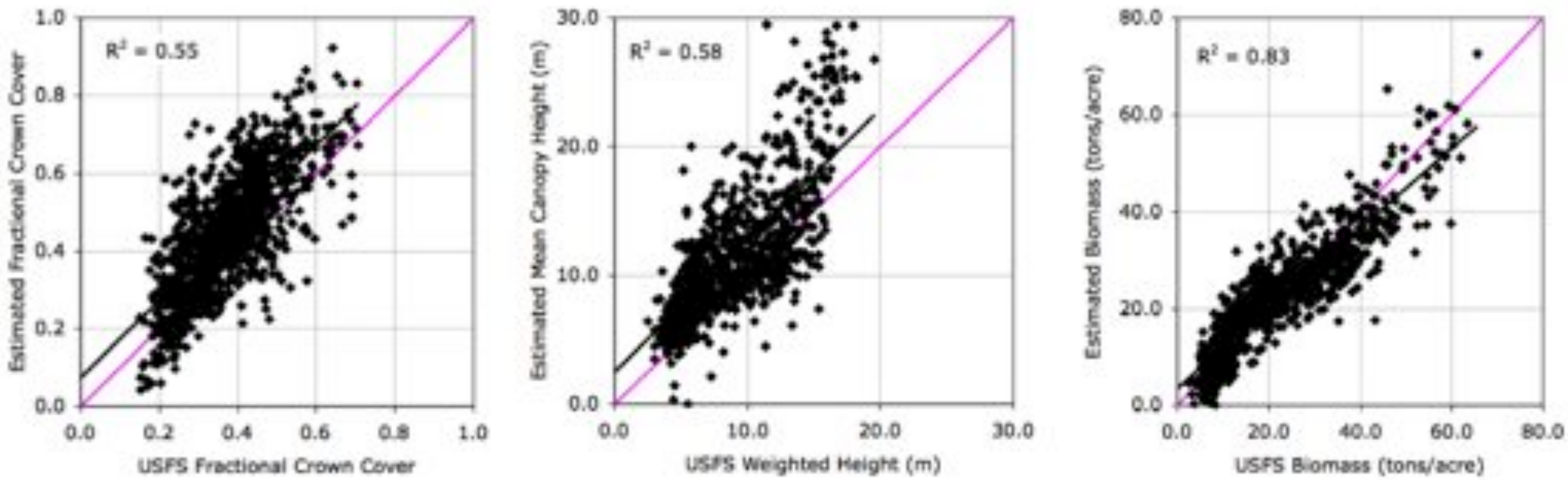


Error Table	frac. cov	mean_hgt	AG Biomass	
	dim.less	meters	tons/acre	Mg ha^{-1}
MRE (%)	27.88	41.52	26.35	26.35
MAE	0.10	3.18	4.12	9.23
2 ST.DEV.	0.31	6.65	23.19	51.99
MEANS	0.45	7.33	3.46	7.75
R^2	0.55	0.59	0.83	0.83
RMSE	0.13	4.16	5.28	11.84

Results for the GO model inverted with MODIS 250 m red band BRFs vs USFS MODIS-based Maps for the Interior West (empirically-derived).

How good (or bad) are these results?

The MODIS/GO inversion results are slightly less accurate than the corresponding MISR/GO results but both seem reasonable with respect to USFS maps and known disturbance events (wildfire, pine beetle damage extent) . . . but how good are these maps, really?

We noticed that in the MISR-based maps the magnitudes of the cover and height values were reversed in some places. For example, in forest in the Sierra National Forest in California, we obtained cover > 0.5 and mean heights < 15 m, where they are actually closer to < 0.2 and > 30 m, respectively: *the retrievals are clearly incorrect* (non-uniqueness of solutions).

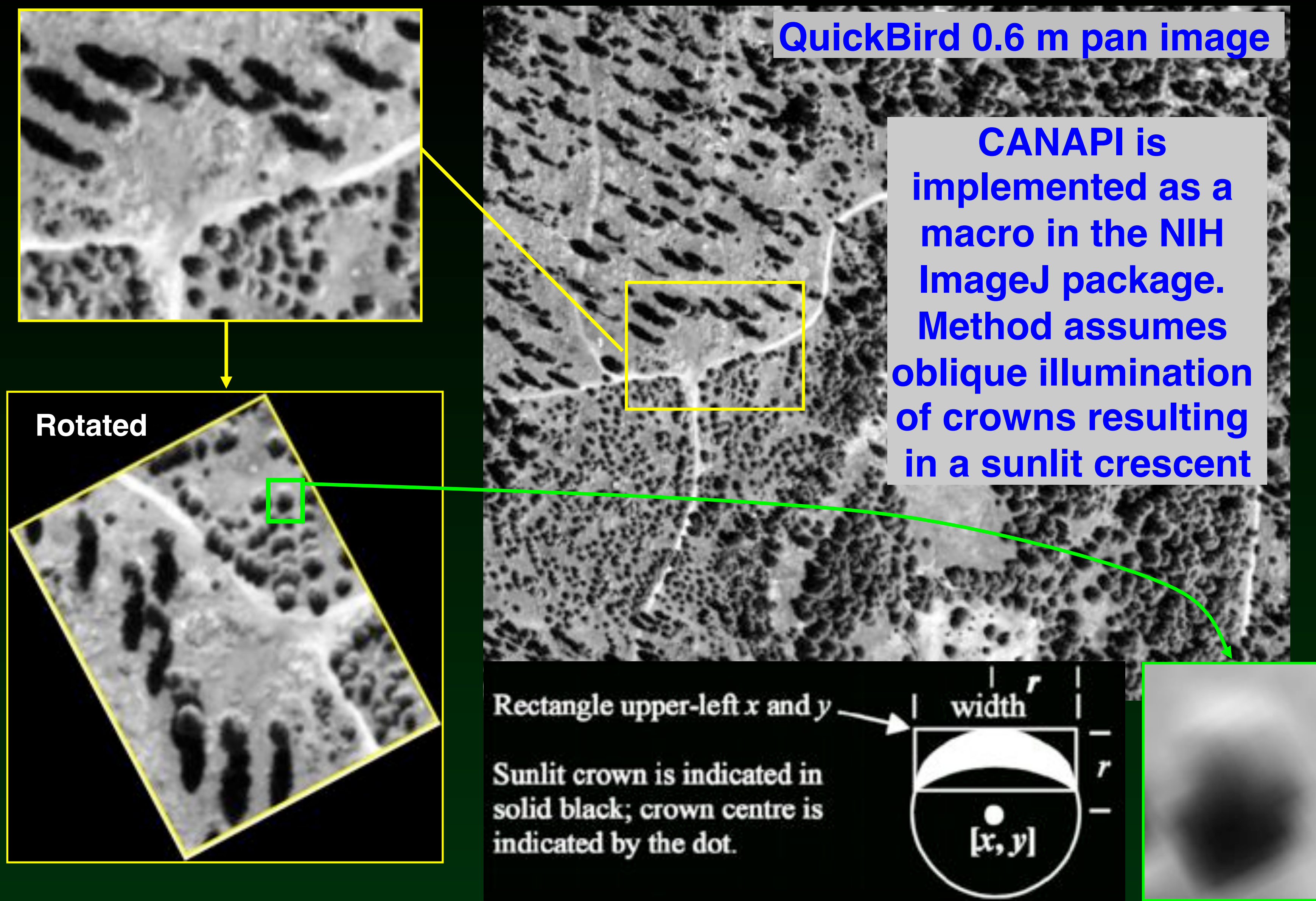
Upshot: we needed to check / test / improve retrieval approach using high quality reference data.

How can we evaluate the retrievals?

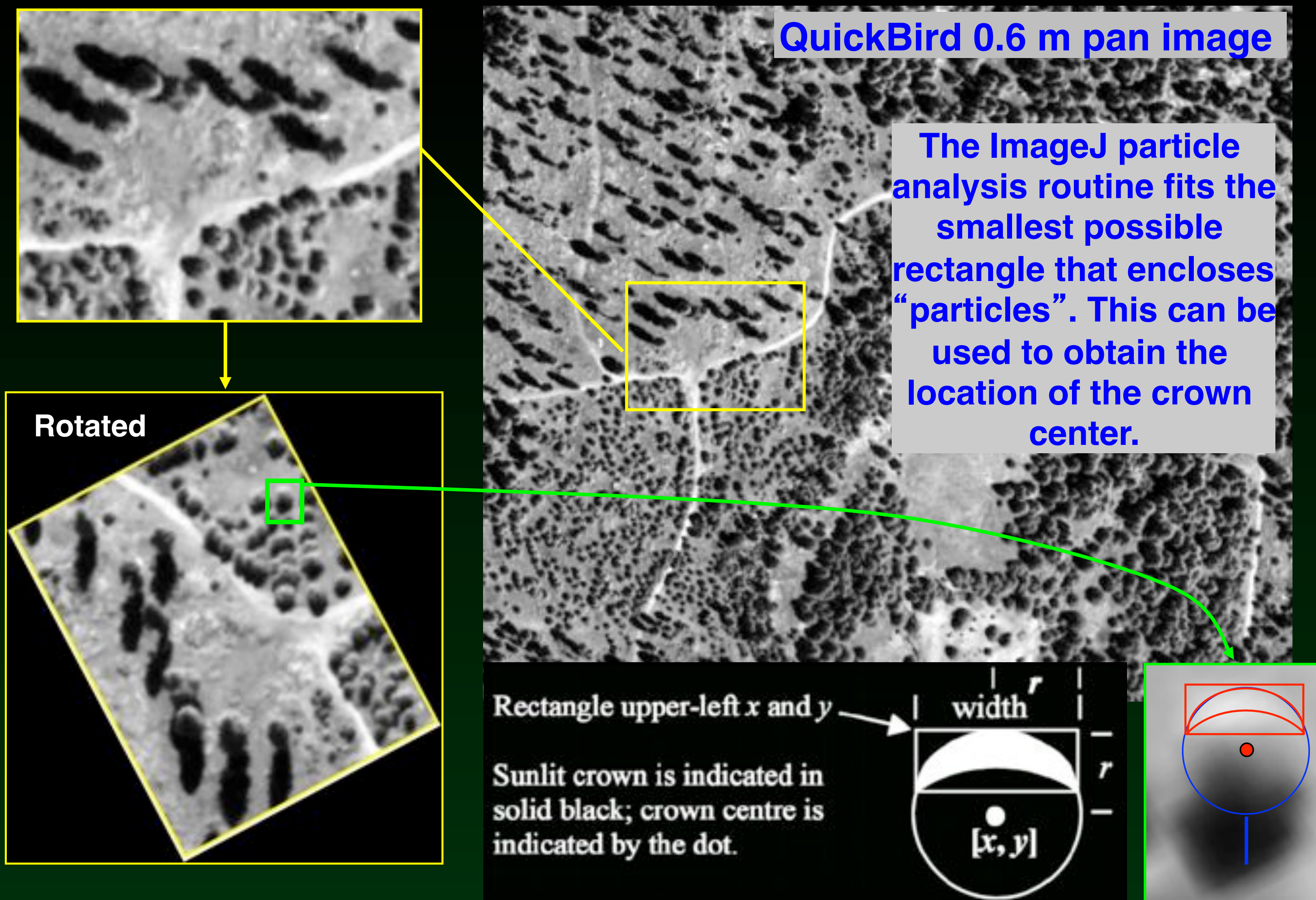
Possibilities:

- **field inventory, e.g., USFS Forest Inventory Analysis -- but at the wrong scale for assessing moderate resolution products where canopies are heterogeneous**
- **Other MODIS-based maps, e.g., USFS ~2002, VCF.**
- **High resolution SAR-based biomass maps, e.g., NBCD 2000**
- **height metrics from lidar e.g., Laser Vegetation/Ice Sensor (LVIS, a waveform lidar).** ***Lidar overestimates heights on slopes*****.**
- **maps of canopy parameters (tree number density, mean radius, fractional crown cover) from high resolution panchromatic imagery**

CANAPI: Reference Data from High Resolution Imagery



CANAPI: Reference Data from High Resolution Imagery



Validation Data from High Resolution Panchromatic Imagery

Crown Detection And Tree Height Estimates from High Resolution Panchromatic Imagery

QuickBird scene 5 June, 2003

Sierra Nevada, CA

CANAPI can process very large volumes of imagery rapidly. http://csam.montclair.edu/~chopping/CANAPI

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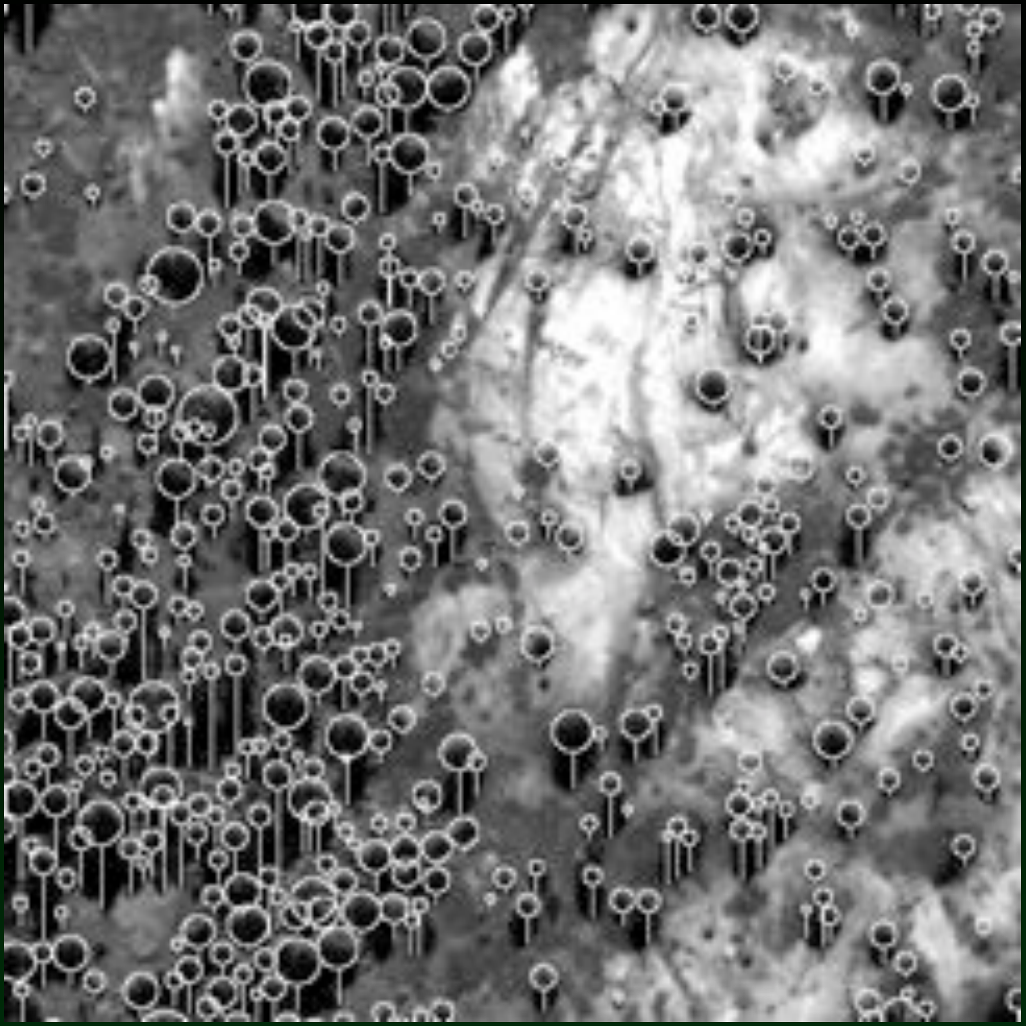

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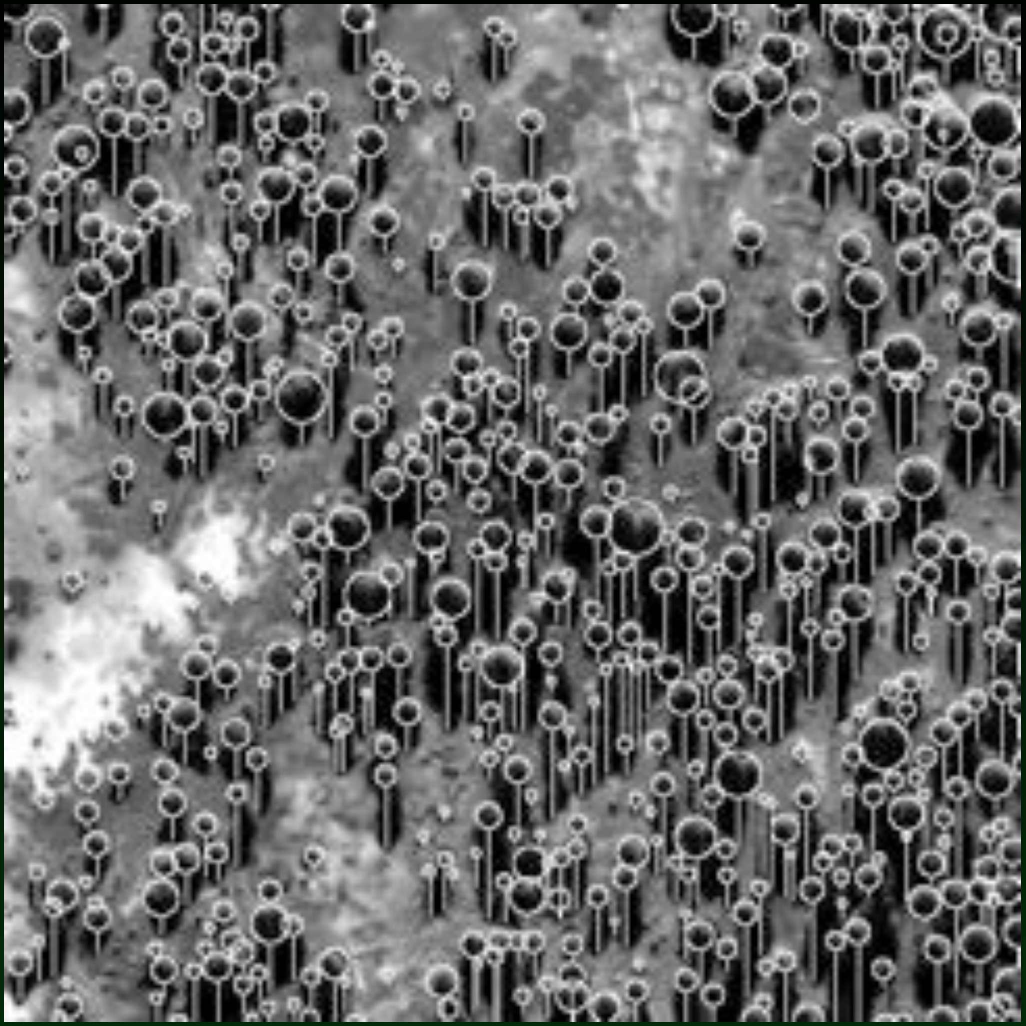

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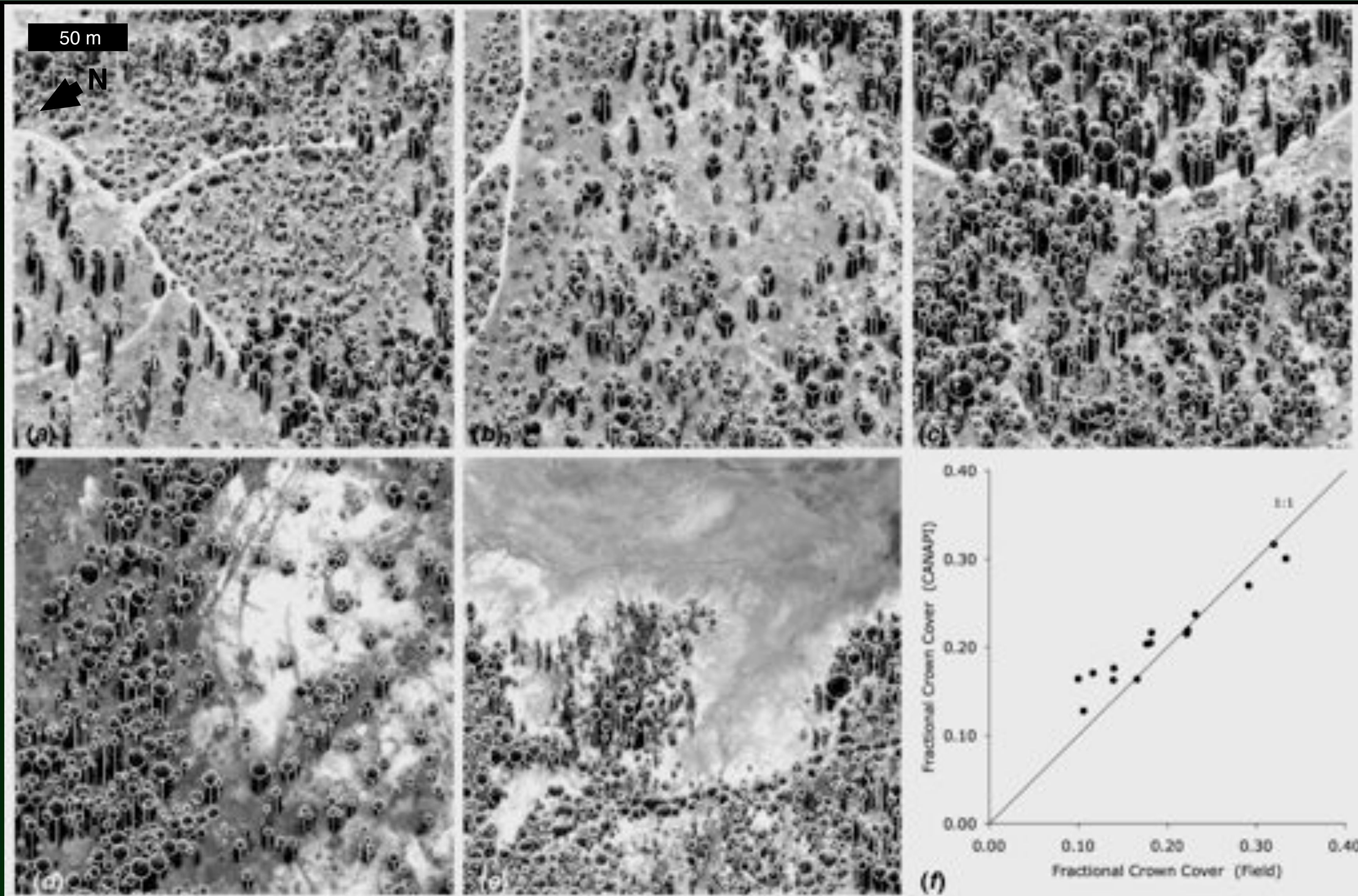


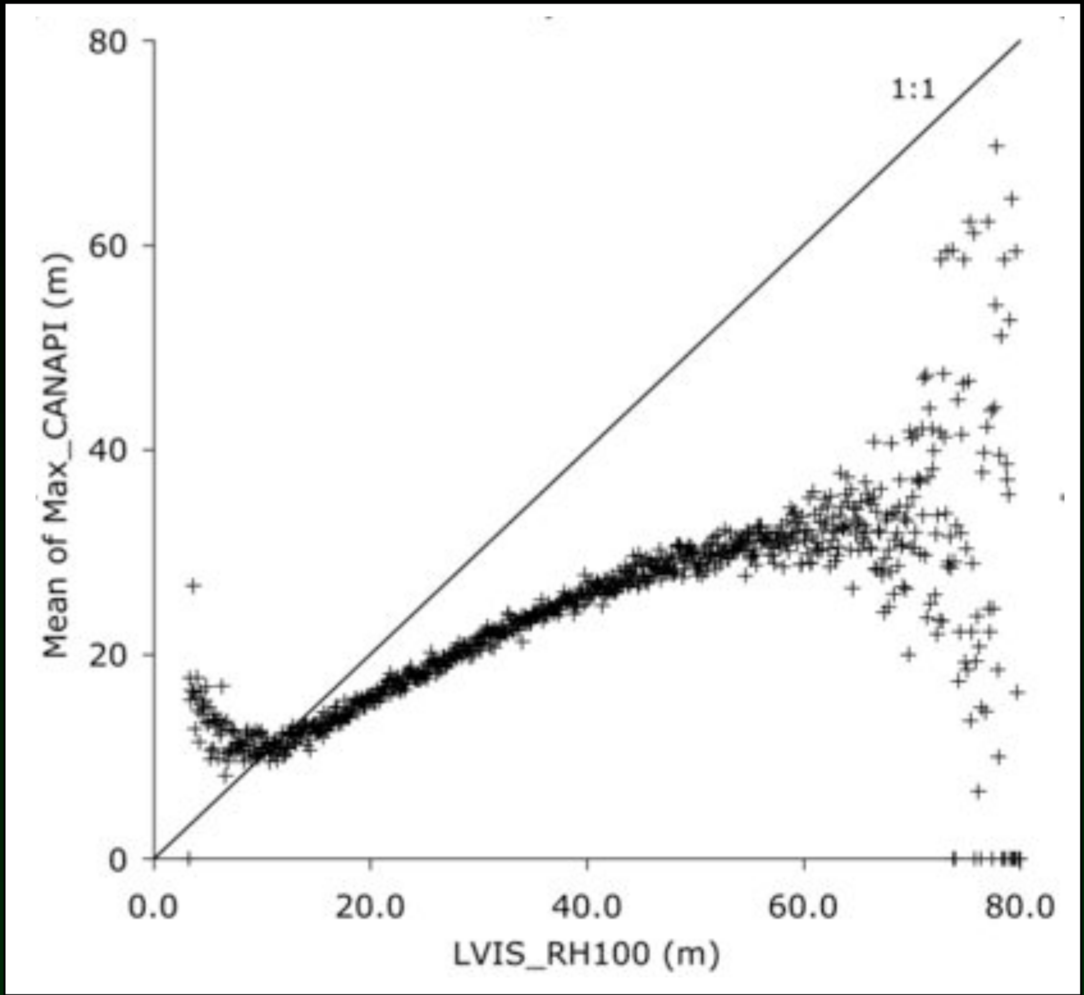
Scatter plot: CANAPI cover estimates vs Teakettle Experiment field estimates

Validation Data from High Resolution Panchromatic Imagery

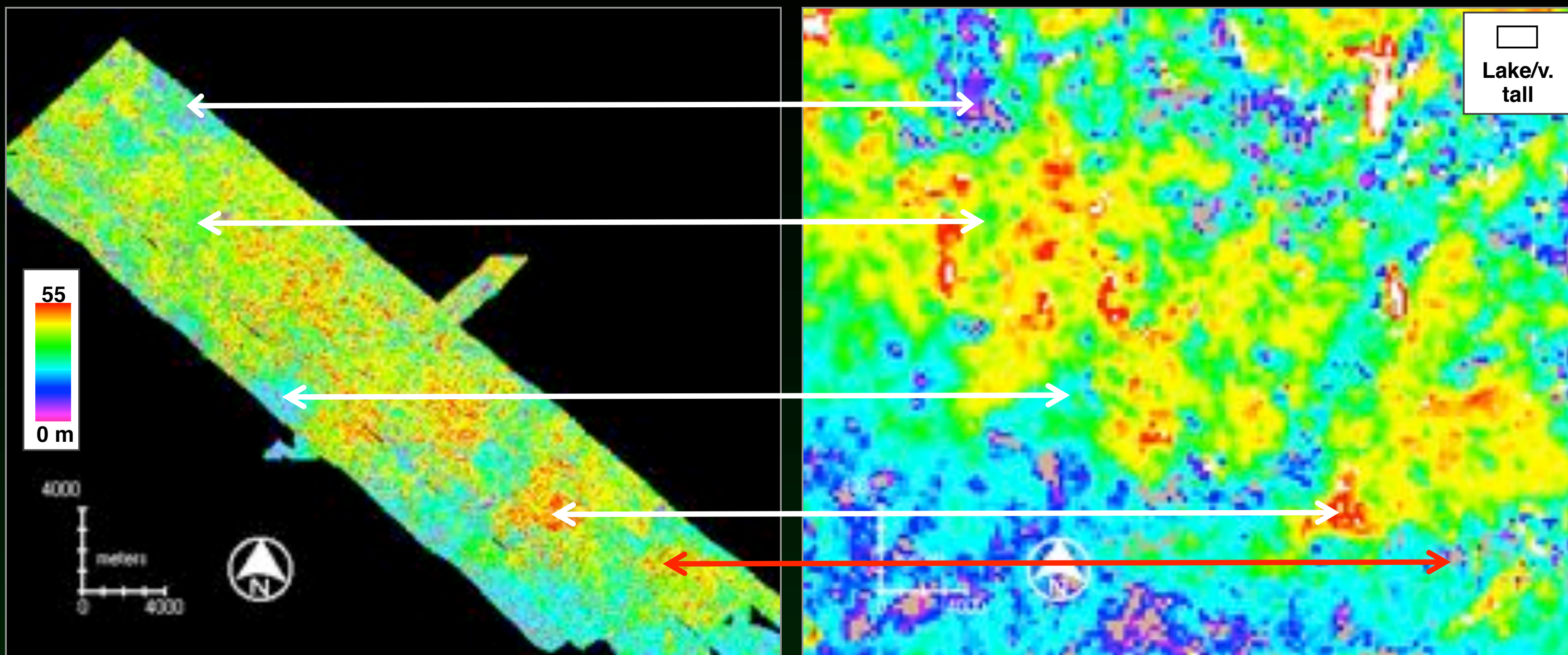
Relationship of CANAPI maximum values to LVIS RH100 values, excluding RH100 values < 3.0 m. The CANAPI heights are the means for each RH100 value (10 cm binning).

If the range is restricted to 3 < RH100 < 60 m (61% of the observations) then the R^2 is 0.94, significant at the 99% level, with a relative RMSE of 0.25 m.

Bias may be owing to lidar height overestimation on slopes.



Sierra Nevada: MISR/GO Canopy Height & LVIS RH100

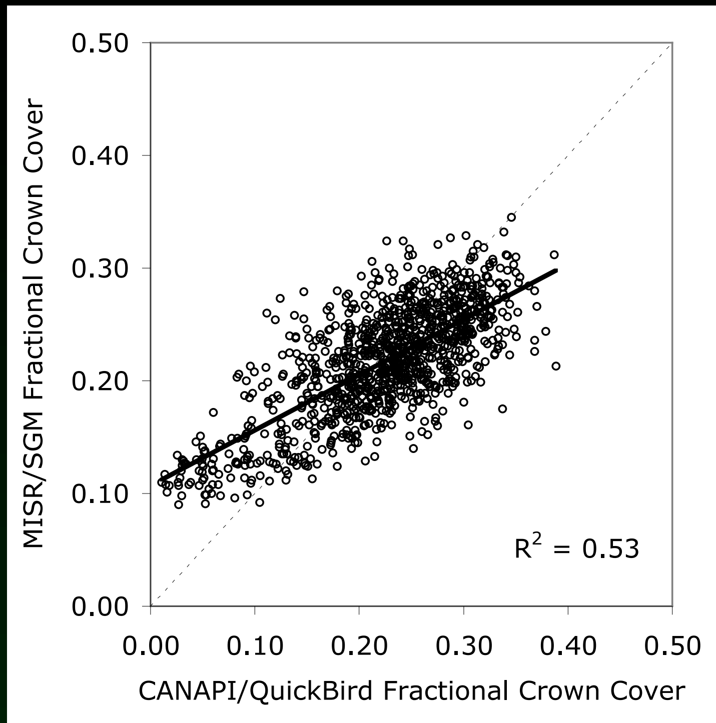


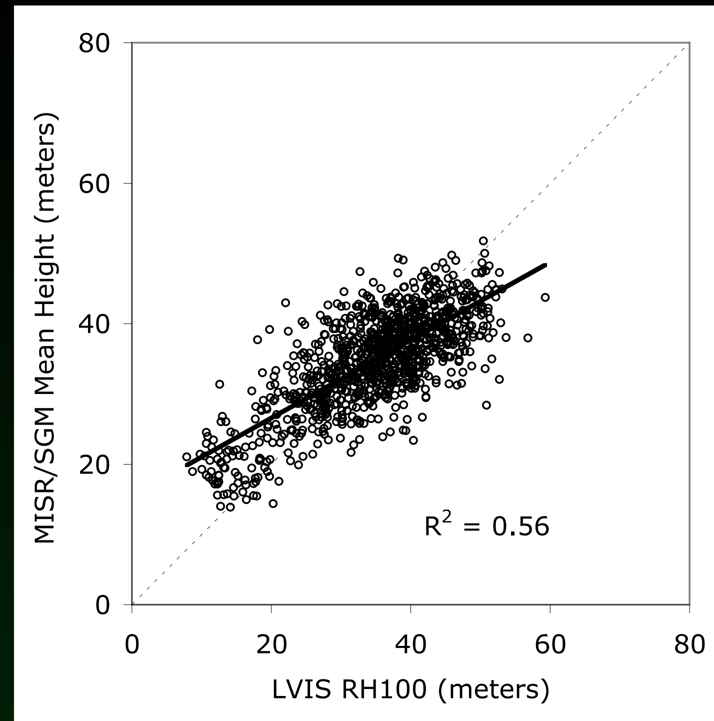
LVIS RH100 **MISR/GO Mean Canopy Height**

concurrence divergence

MISR data from Terra orbit 46009, August 11, 2008; dynamic background based on CANAPI/QuickBird cover estimates and *b/r* from LVIS RH50.

Sierra Nevada: MISR/GO Canopy Height & LVIS RH100

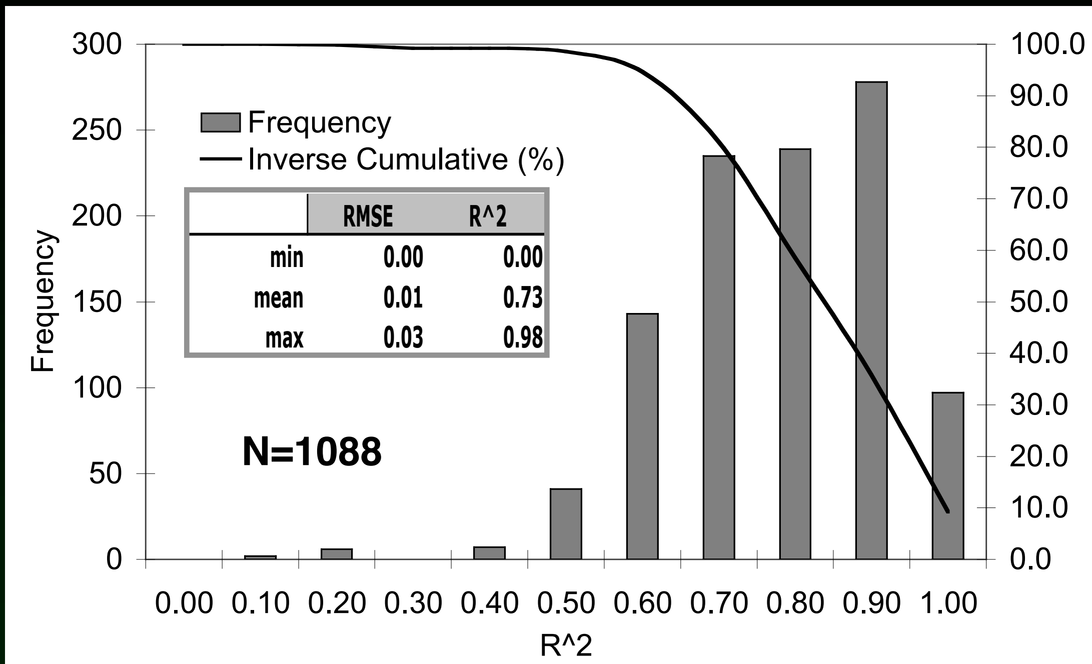




RH100 = -20.68 + (*r* x 11.06) + (*b*/*r* x 0.42)

Note that this is an area of considerable topographic variation (LAND product required relaxation of flags; no other corrections applied). The MISR/GO heights were retrieved using a background calibrated using canopy statistics from high resolution (0.6 m) panchromatic imagery, obtained using CANAPI.

Sierra Nevada Forest Site: MISR/GO Forward-Modeling



GO model driven with:

1. tree number density and mean crown radius from CANAPI
2. mean *b/r* from LVIS RH50 height metric
3. a background BRDF based on red band Li-Ross BRDF model kernel weights

. . . to produce sets of BRFs at the Sun-target-MISR angles. This was accomplished for all 1088 250 x 250 m areas within one-sixth of a QuickBird scene and N = 1048 (LVIS data were missing for 40 cases). Results: 99% have R^2 > 0.5 and 81% have R^2 > 0.7. This seems ok: the problem must lie in the inversion protocol -- or perhaps this is simply as good as it gets with this level of topographic variation.

Mapping Shrubs in Arctic Tundra

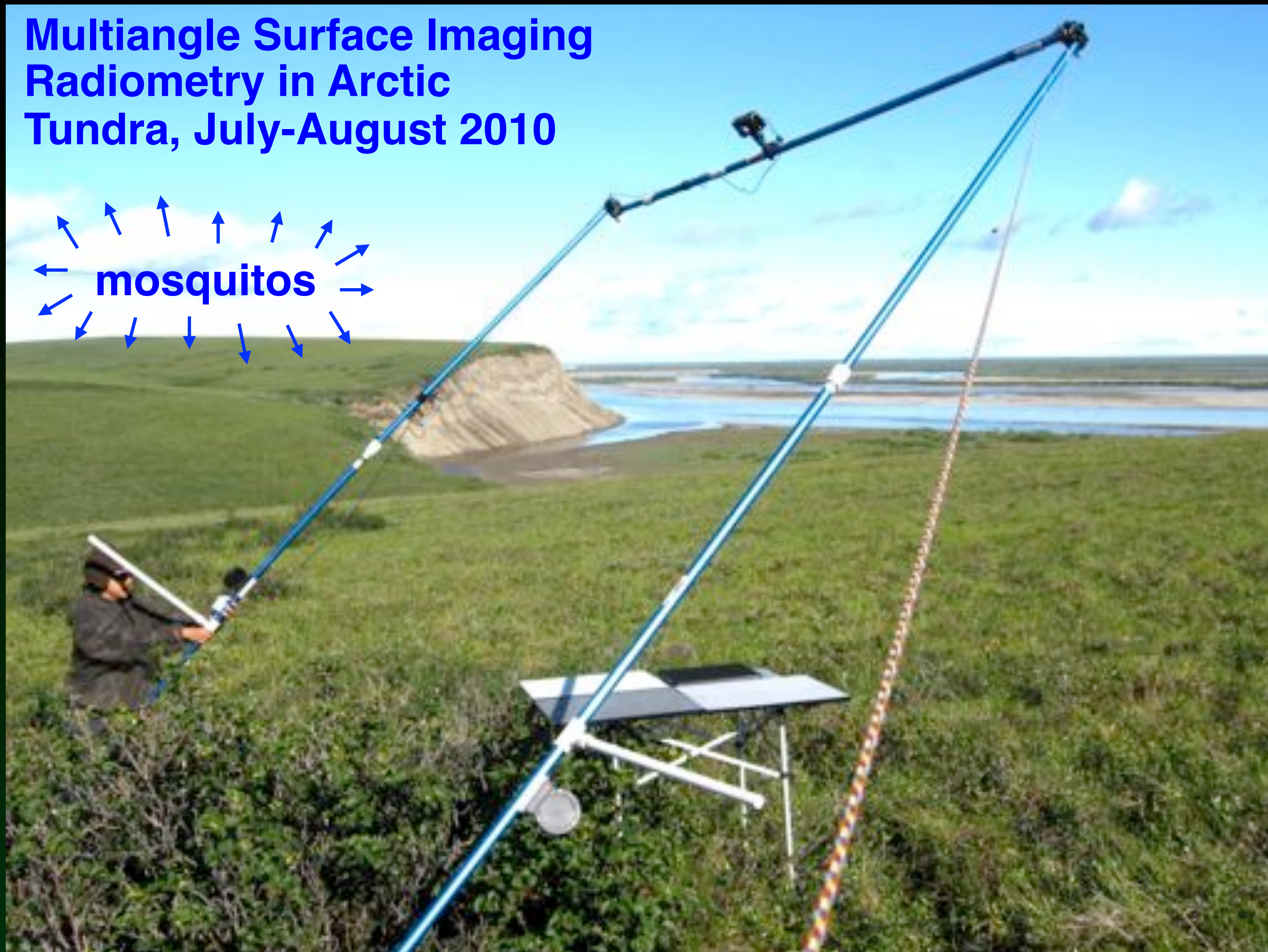
Increasing shrub abundance has been observed in Arctic tundra over the last 60 years. Shrubs are important because 1. expansion would decrease albedo, with feedbacks to climate; and 2. unlike trees shrubs are already present over a very large area and able to expand rapidly.

Vegetation mapping at high latitudes using MODIS presents challenges. Montesano *et al*. (2009) found that MODIS VCF tree cover may not be sufficiently precise to allow monitoring of 500 m pixel-level tree cover in the taiga–tundra transition zone, particularly for pixels with less than 20% tree cover.

In Arctic tundra, shrub cover is **rarely >10%**. This - together with **dark, heterogeneous tundra surfaces** (red band BRF rarely >0.06 except where bright lichens are abundant), **high solar zenith angles** (>50°, resulting large diffuse:direct irradiance ratio), and high cloud cover - makes the detection and measurement of shrubs from space **extremely challenging**.

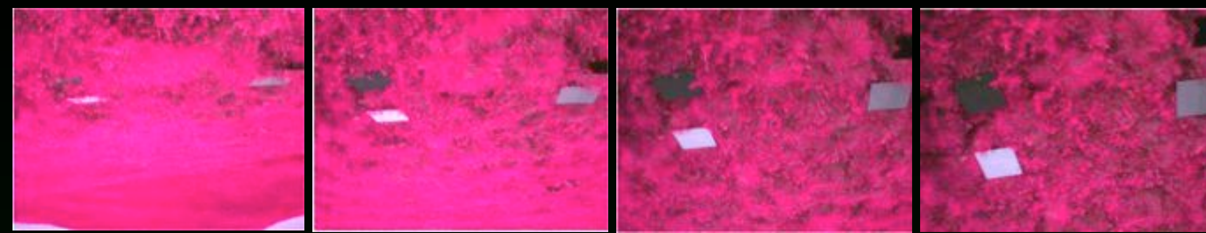
Mapping Shrubs in Arctic Tundra

Mapping Shrubs in Arctic Tundra

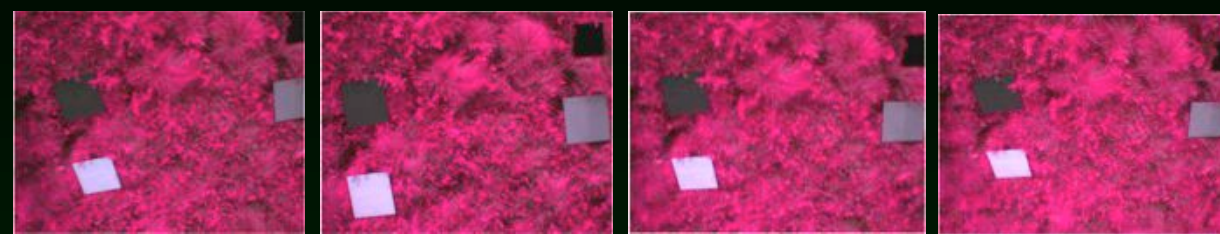


Mapping Shrubs in Arctic Tundra

Multiangle Surface Imaging Radiometry: Calibration of CMOS-based camera was achieved using four Spectralon Panels (2% 10% 25%, and 50%)

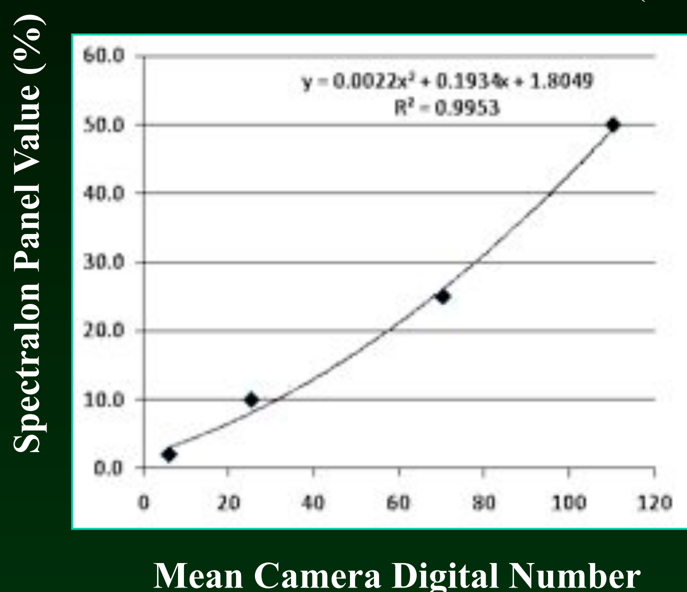


a. VZA (-70°) b. VZA (-60°) c. VZA (-45°) d. VZA (-30°)

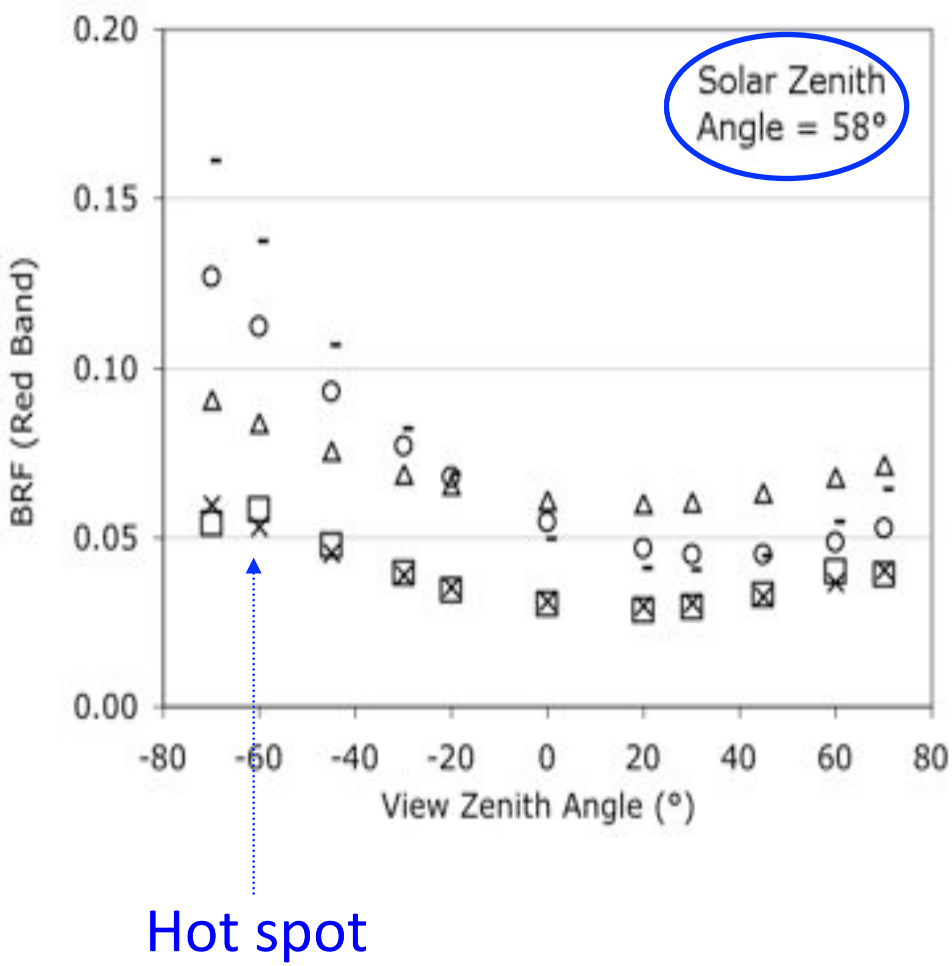


e. VZA (-20°) f. VZA (0°) g. VZA (20°) h. VZA (30°)

i. VZA (45°) j. VZA (60°) k. VZA (70°)



Mapping Shrubs in Arctic Tundra



Principal plane field and MISR BRFs (MISR adjusted to PP using the Walthall BRDF model)

□ Alder shrub (Field Imaging Radiometry)
× Model Fit (RMSE: 0.003)
△ Modeled Background (RMSE: 0.003)
○ Modeled MISR: 15% shrub (RMSE: 0.004)
- Modeled MISR: no shrub (RMSE: 0.003)

We need to determine what is causing this:

-Scale disparity (probable)?
-Model extrapolation?
-Mosquito aerosol?
-Other?

Mapping Shrubs in Arctic Tundra

Panchromatic Imagery | **Aerial photograph** | **Ground photographs**

Site 1936-20

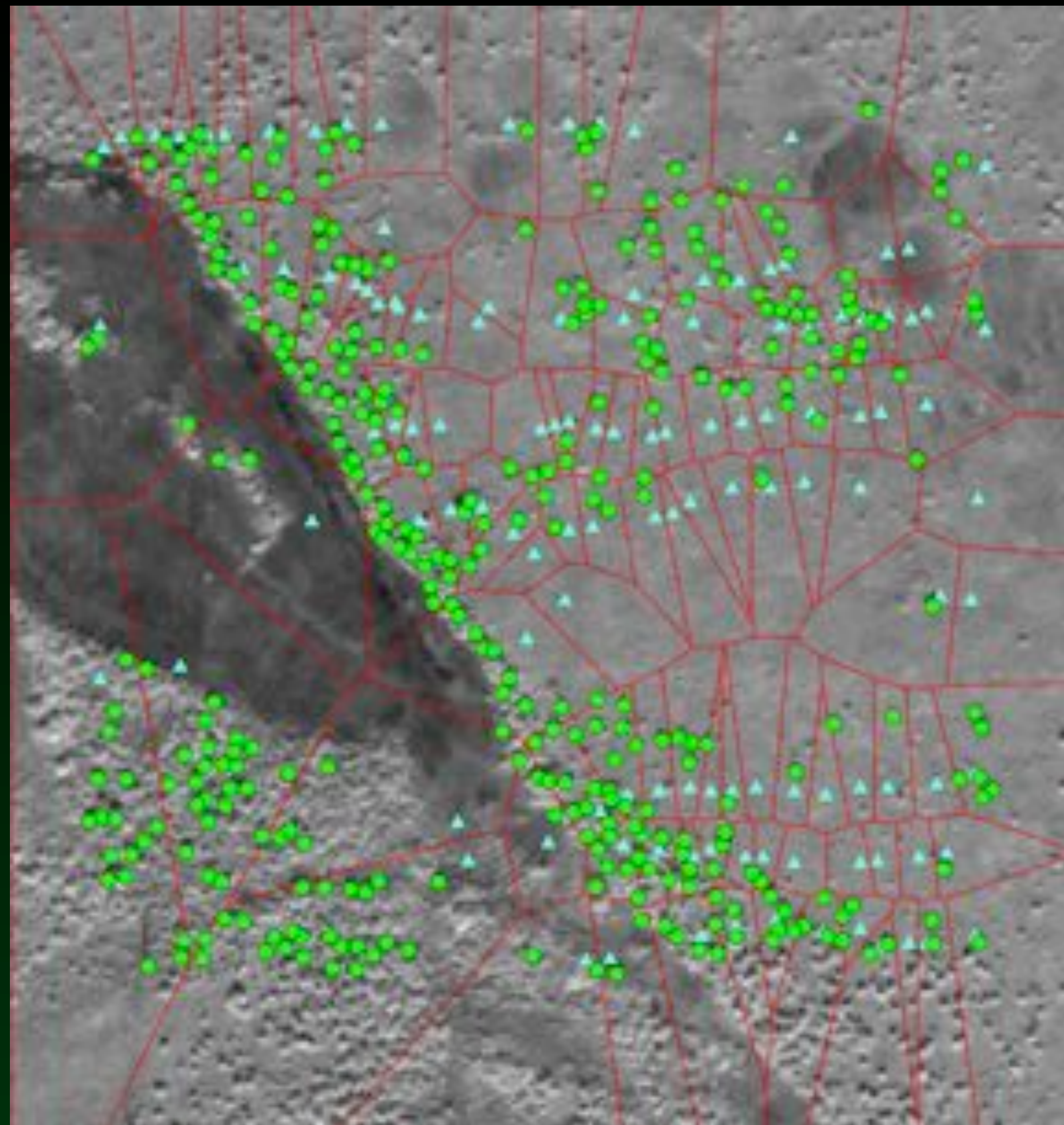
Site 1945-90

Site 1893-93

Shrubs in Arctic Tundra from MODIS

Using a combination of field data and air and satellite imagery three data sources, every individual shrub > 0.5 m within each 250 m x 250 m area was identified and was assigned the height of the nearest shrub height measured in the field.

Theissen polygons were drawn around each ground-measured shrub, and those polygons included the height and species information for each particular shrub.

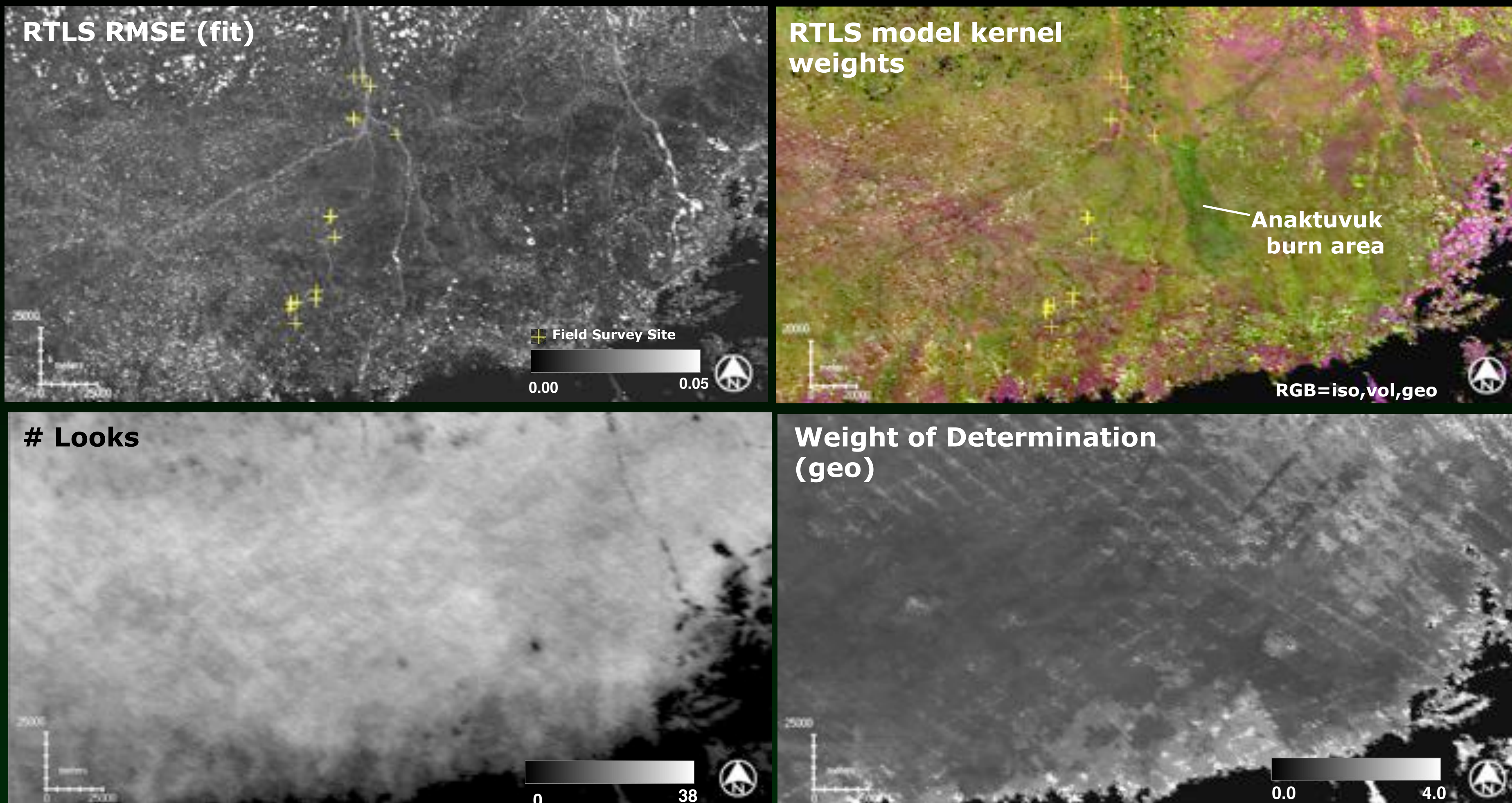


Shrubs in Arctic Tundra from MODIS

Site	Lat (dd)	Long (dd)	Dominant	% Dom	Total # Shrubs	Max Height (m)	Mean Height (m)	% Tall Shrubs (>=0.5 m tall)	Max Crown radius (m)	Mean Crown radius (m)	Crown Cover (%)
1936_20	69.639	-151.400	alder	86	760	2.7	1.6	2.1	5.1	1.2	5.1
1808_83	68.751	-152.307	alder	82	280	1.3	0.8	0.3	1.5	0.7	0.8
1865_28	68.813	-152.002	alder	85	480	2.7	1.0	0.6	3.0	0.7	1.2
1880_16	69.024	-151.787	alder	67	540	1.7	1.0	0.1	2.3	0.8	1.7
1819_02	68.771	-152.287	alder	82	405	2.9	1.6	3.2	2.4	1.2	3.0
1819_53	68.766	-152.294	alder	47	405	4.4	2.0	3.2	3.7	1.6	5.2
1830_26	68.787	-152.090	alder	91	460	5.0	1.6	1.8	7.3	1.1	2.9
1893_93	69.109	-151.847	alder	100	795	2.6	1.6	2.1	3.1	1.0	4.2
1901_45	69.113	-151.823	alder	100	990	3.1	1.9	1.4	2.4	1.0	5.5
1913_41	69.493	-151.536	willow	82	810	3.7	1.5	2.9	5.7	1.5	9.3
1845_90	68.782	-152.017	alder	93	840	3.3	1.7	1.9	4.0	1.4	8.3
1920_61	69.505	-151.535	alder	65	365	2.6	1.2	0.8	2.7	1.1	2.2
1884_13	69.033	-151.780	alder	100	500	3.5	1.3	1.2	2.8	1.0	2.7
1925_67	69.666	-151.505	alder	100	18	1.5	1.2	0.1	2.3	1.1	0.1

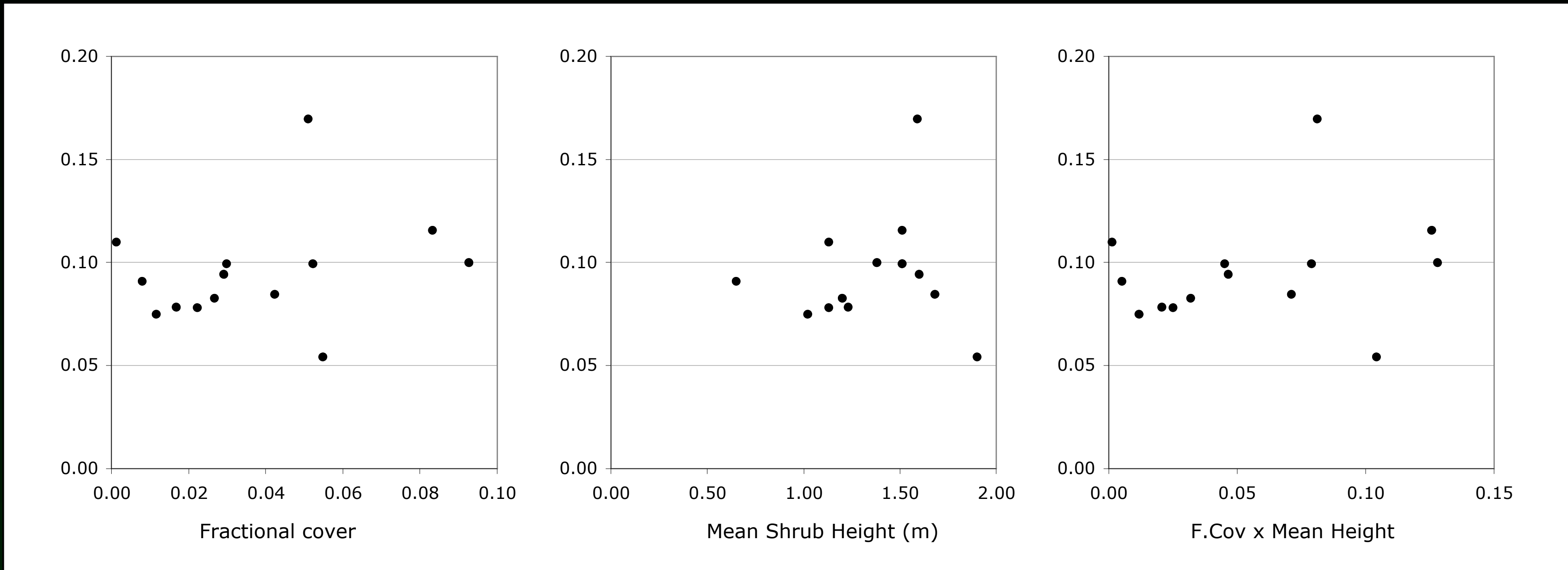
Inventory from Field Survey & Interpretation of High Resolution Imagery (aerial photography and QuickBird panchromatic imagery)

Shrubs in Arctic Tundra from MODIS



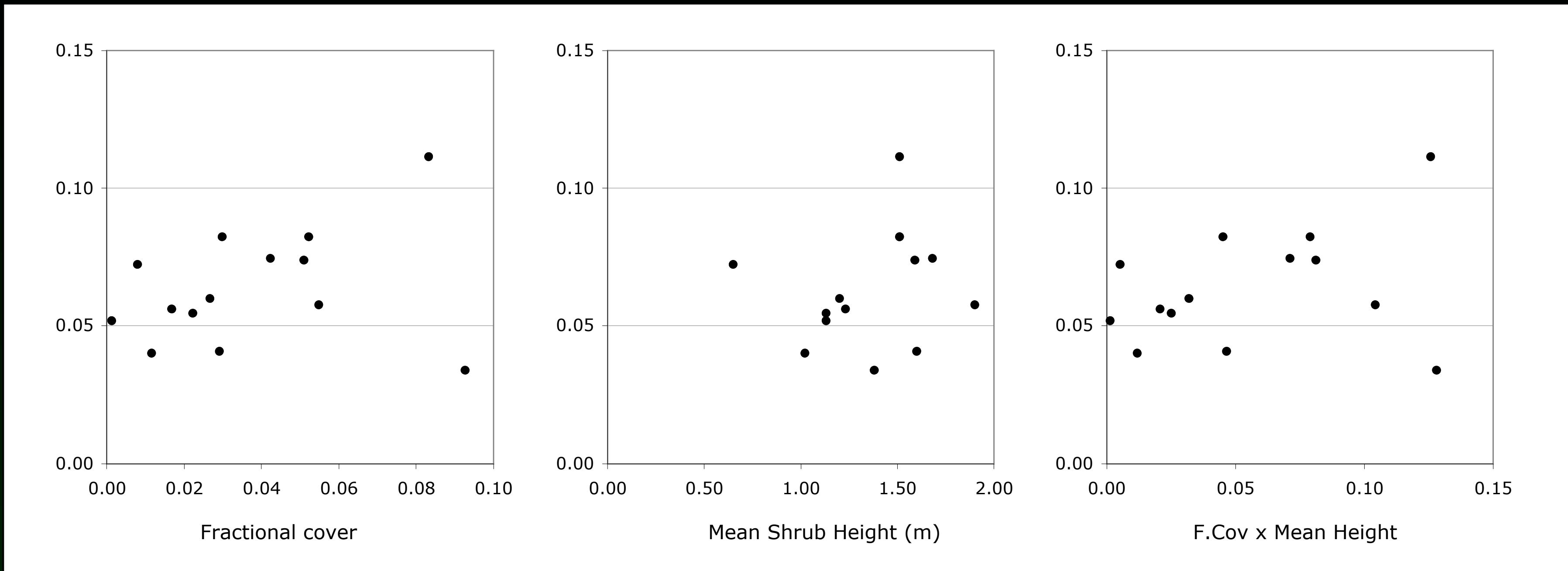
RossThick-LiSparseMODIS BRDF Model Inversion Results, North Slope of Alaska
The weight of determination for the geo kernel weight is often > 1.0

Shrubs in Arctic Tundra from MODIS



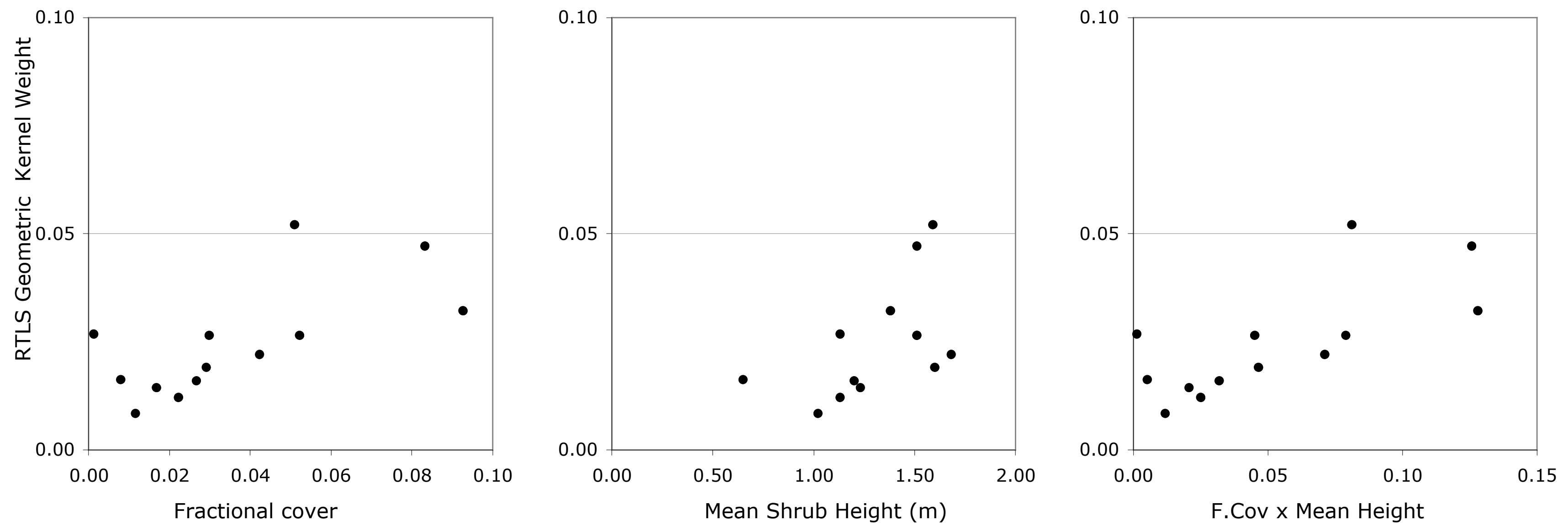
Isotropic kernel weight for the field sites
***vs*. fractional cover, mean shrub height, and their product**

Shrubs in Arctic Tundra from MODIS



Volume scattering kernel weight for the field sites
***vs*. fractional cover, mean shrub height, and their product**

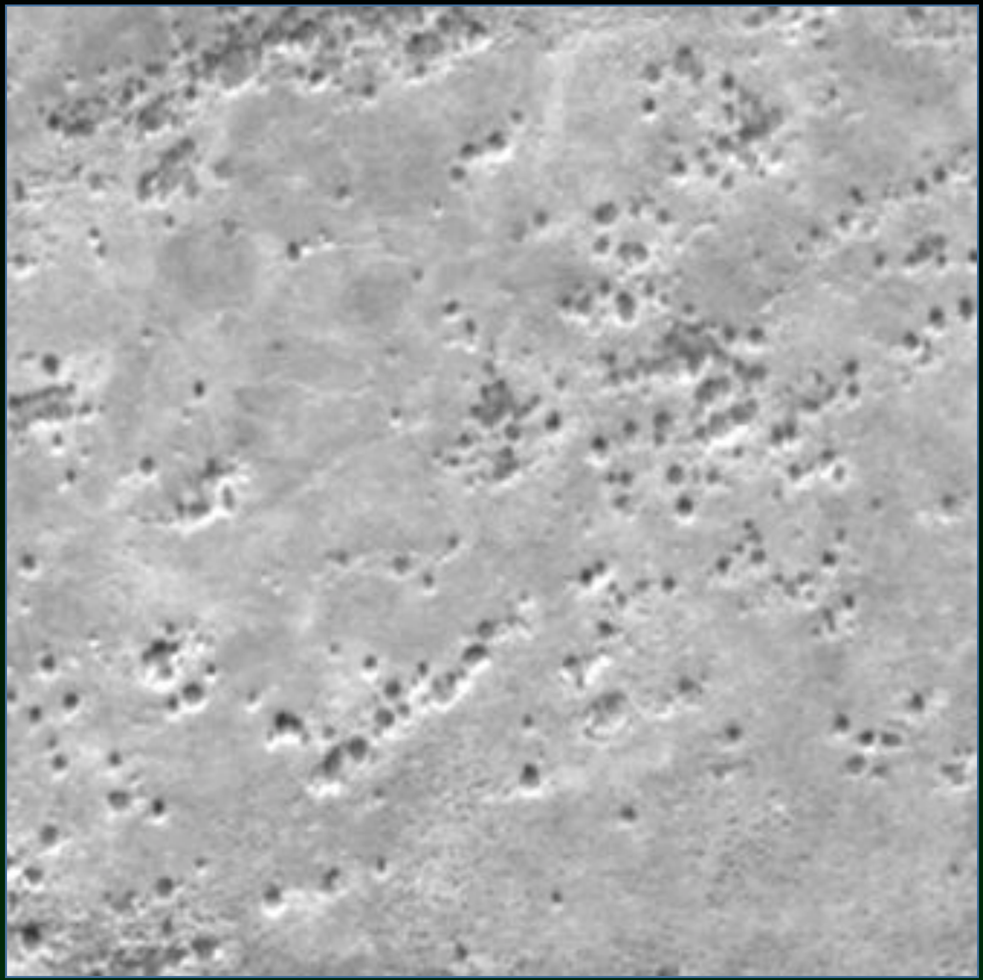
Shrubs in Arctic Tundra from MODIS



Geometric scattering kernel weight for the field sites *vs*. fractional cover, mean shrub height, and their product

Shrubs in Arctic Tundra from MODIS

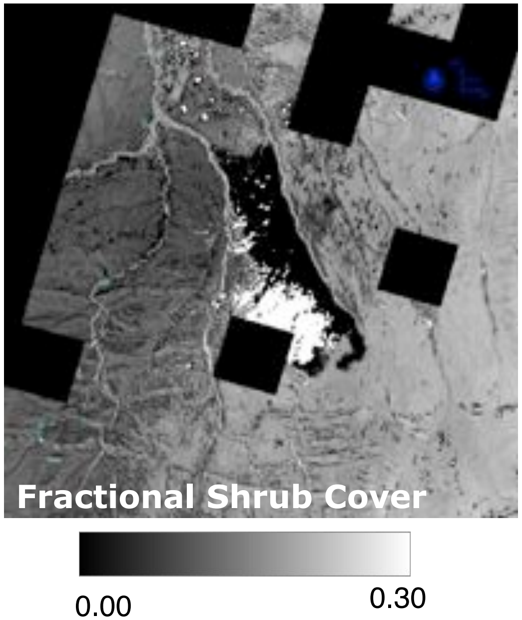
Why does the Geometric kernel weight reflect shrub abundance?

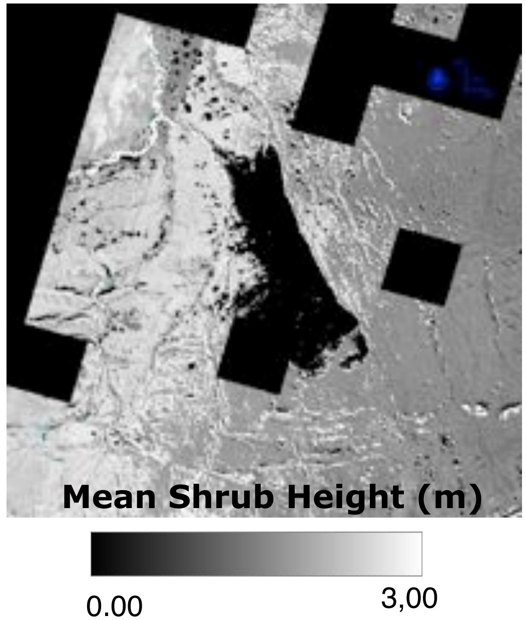


Shrub shadows create a large geometric signal (*c.f.* surface roughness)

Speculation: the iso/vol kernel weights don't reflect shrub abundance b/c the background already has low/high brightness/volume scattering

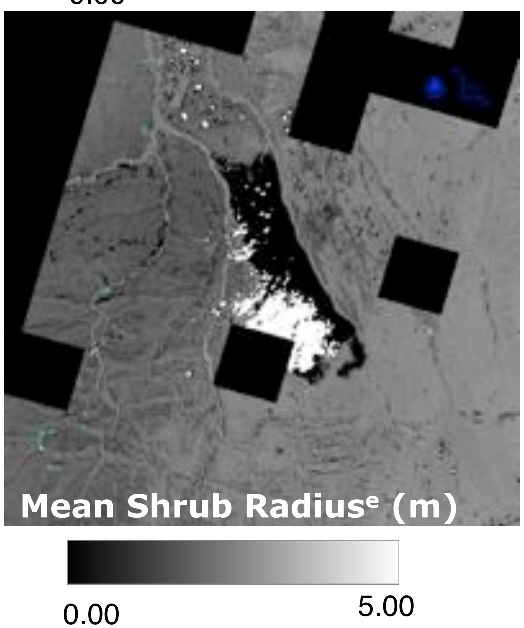
Mapping Shrubs in Arctic Tundra

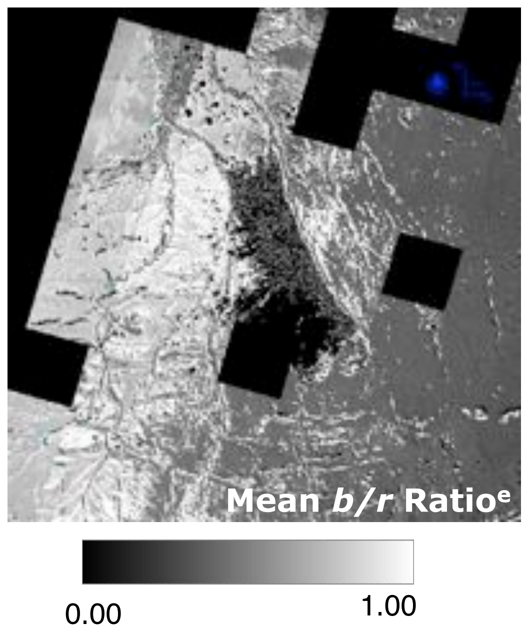


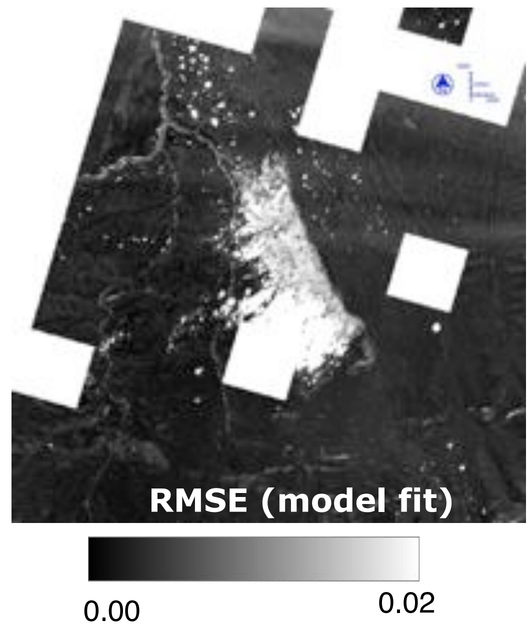


Initial GO model inversions with MISR red band BRFs:

- no shrubs in Anaktuvik burn area (center); shows more shrubs along rivers and on S-facing slopes
- Not evaluated yet
- New model variant that includes a Z component (dark & diffuse irradiance!)







MISR/GO Canopy Mapping at the Taiga-Tundra Interface: Kola Peninsula

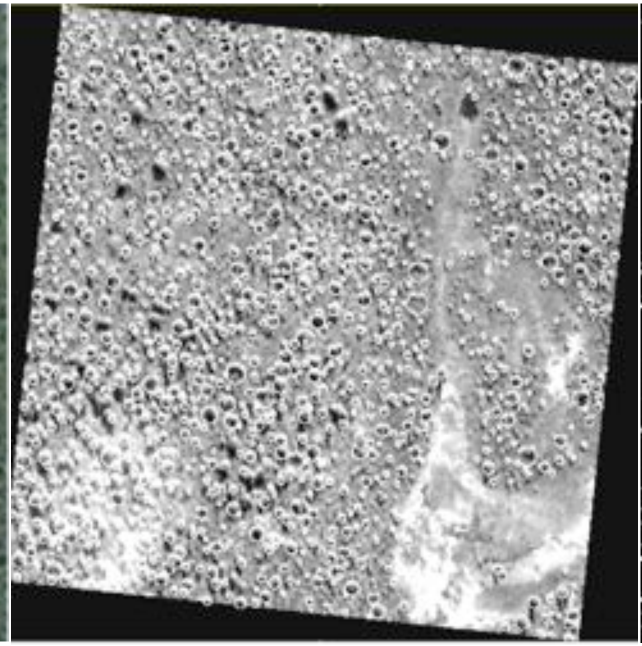
Collaboration with Arctic PPS Project (Gareth Rees, Annika Hofgaard):
Study area on the Kola Peninsula

Above: Grid delineating MISR pixels for study area on the Kola Peninsula over Google Earth imagery. Right: Study area, spanning dense boreal forest to open tundra, including shrubby areas.

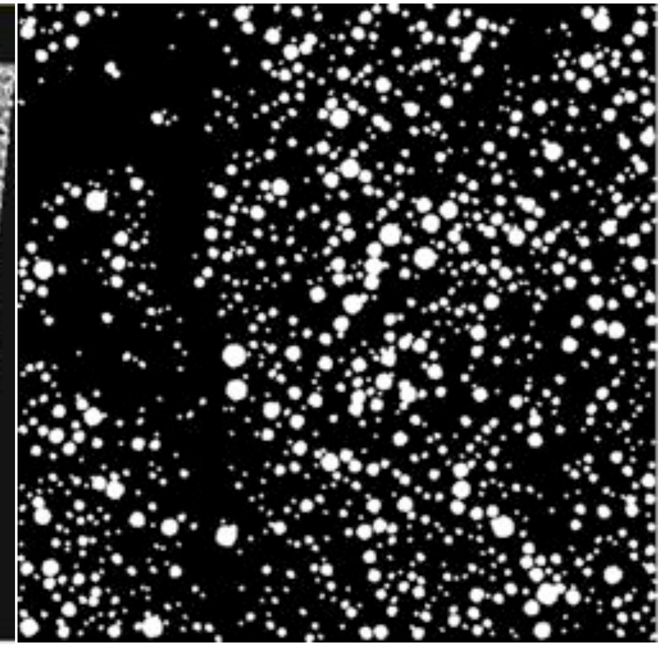
MISR/GO Canopy Mapping at the Taiga-Tundra Interface: Kola Peninsula

CANAPI Adapted for Arctic Trees and Shrubs

Original Google Earth imagery (north is "up")



Rotated image showing CANAPI estimates of crown locations and sizes (solar direction is up)

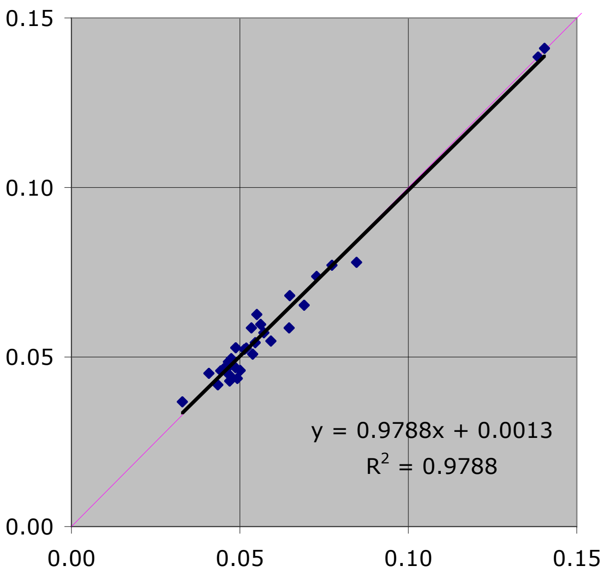


Crown map rotated to the original orientation

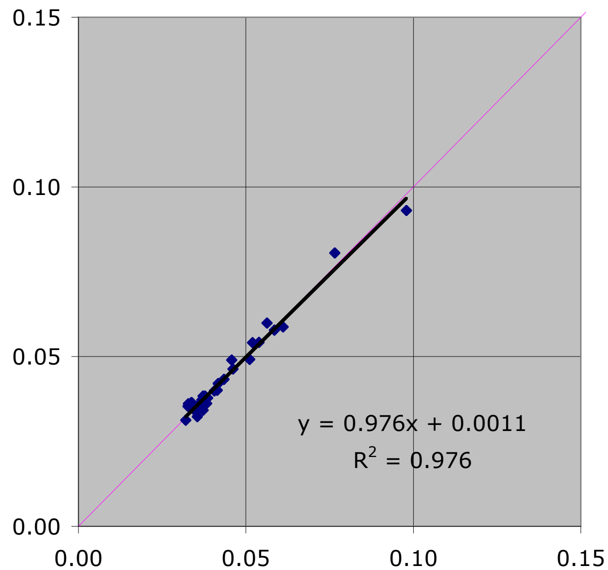
MISR/GO Canopy Mapping at the Taiga-Tundra Interface: Kola Peninsula

Prediction of RTLS model kernel weights for the background with RTLS estimates for all components (via AMBRALS):

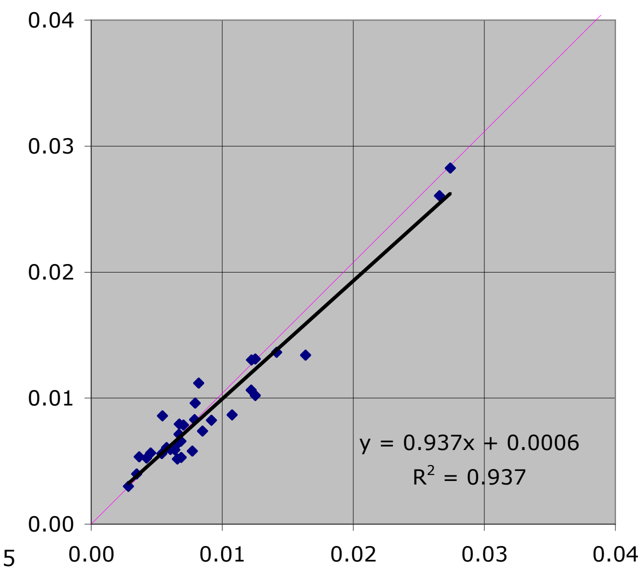
Isotropic Scattering



Volume Scattering

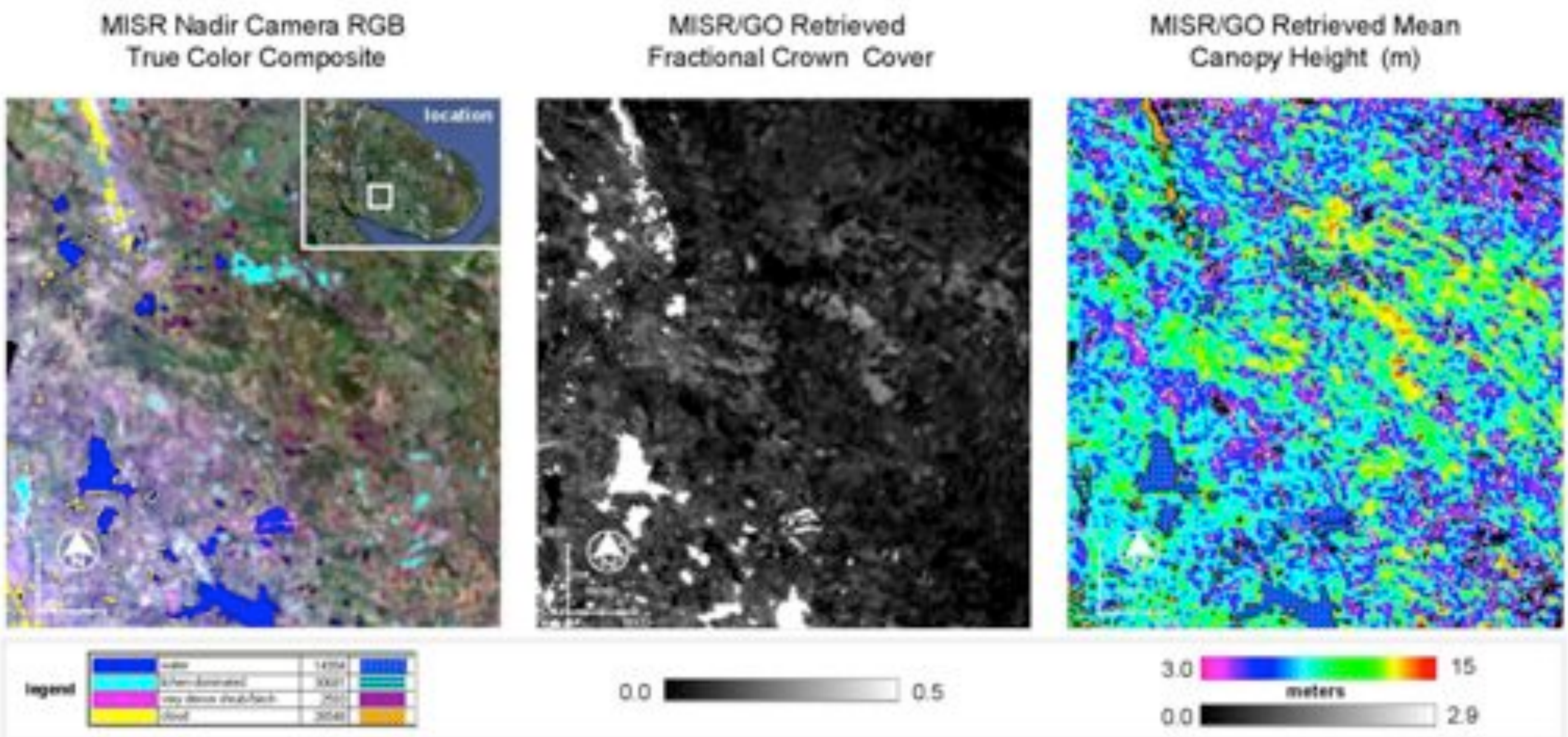


Geometric Scattering



MISR/GO Canopy Mapping at the Taiga-Tundra Interface: Kola Peninsula

First Attempts at GO model inversion



New GO model variant includes a Z component (dark surface, diffuse irradiance!) Masks for water, lichen-dominated areas, clouds, and dense shrubs derived from model fitting RMSE and An camera BRFs. Assessments to follow.

Summary 1/3

MISR/GO model inversions: We found good height matches with CLPX lidar and our Sierra Nevada National Forest work shows good modeled matches with MISR BRFs and LVIS heights but the inversion protocol requires further refinement. We have an improved method for providing dynamic backgrounds; this is important in both arid and Arctic biomes as in both the woody canopy cover can be sparse (and so most of the signal is from the background).

We have made important efforts to obtain better reference data from field surveys, high resolution imagery and lidar: high quality reference data are essential for validation and modeling work. We have a new method to develop data sets for extensive areas using CANAPI (this can also exploit Google Earth imagery). Demonstration and production codes are freely available via our web site.

Summary 2/3

Southwestern United States: MISR can provide estimates of first-order canopy structural metrics (crown cover, mean height) that are important for estimating aboveground biomass (and in other applications such as disturbance mapping) and are difficult to obtain in other ways. The potential to provide canopy structural information and thus context that is useful for future canopy structure missions that exploit active instruments is high, although we still face some challenges.

Arctic Tundra: We have acquired comprehensive field survey data and high resolution imagery for our Alaskan tundra sites and are using these to evaluate the potential for shrub mapping with parameters based on MISR and MODIS reflectance anisotropy. The most promising metric is the RossThick-LiSparse BRDF model's geometric scattering kernel weight.

Summary 3/3

Other approaches that exploit the directional signal in MODIS BRFs to provide first-order canopy structure parameters are also being pursued . . .

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Retrieval of canopy height using moderate-resolution imaging spectroradiometer (MODIS) data

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ABSTRACT

In this study we use the 500 m Moderate Resolution Imaging Spectroradiometer (MODIS) Bidirectional Reflectance Distribution Function (BRDF) product to develop multivariate linear regression models that estimate canopy heights over study sites at Howland Forest, Maine, Harvard Forest, Massachusetts and La Selva Forest, Costa Rica using (1) directional escape probabilities that are spectrally independent and (2) the directional spectral reflectances used to derive the directional escape probabilities. These measures of canopy architecture are compared with canopy height information retrieved from the airborne Laser Vegetation Imaging Sensor (LVIS). Both the escape probability and the directional reflectance approaches achieve good results, with correlation coefficients in the range 0.54–0.82, although escape probability results are usually slightly better. This suggests that MODIS 500 m BRDF data can be used to extrapolate canopy heights observed by widely-spaced satellite LIDAR swaths to larger areas, thus providing wide-area coverage of canopy height.

Recent Papers

Wang, Z., Schaaf. C.B., Lewis, P., Knyazikhin, Y, Schull, M.A., Strahler, A.H., Yao, T., Myneni, R.B., Chopping, M.J,, Blair, J. B. (2011), Retrieval of canopy height using moderate-resolution imaging spectroradiometer (MODIS) data, *Remote Sensing of Environment*, 115: 1595-1601.

Chopping, M. Schaaf, C.B., Zhao, F. Wang, Z., Nolin, A.W., Moisen, G.G., Martonchik, J.V., and Bull, M. (2011), Forest structure and aboveground biomass in the southwestern United States from MODIS and MISR, accepted for publication in *Remote Sensing of Environment*, doi:10.1016/j.rse.2010.08.031

Chopping, M., (2010), CANAPI: Canopy Analysis with Panchromatic Imagery, *Remote Sensing Letters* 2: 21-29.

Chopping, M., Nolin, A., Moisen, G.G., Martonchik, J.V.. Bull, M. (2009), Forest canopy height from Multiangle Imaging SpectroRadiometer (MISR) assessed with high resolution discrete return lidar, *Remote Sens. Environ* 113: 2172-2185

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Special Thanks: Xiaohong Chopping (neé Qi), David Diner (NASA/JPL), Bryan Blair (GSFC), Michelle Hofton (UMD), Michael Palace (UNH), NASA Vegetation Structure Working Group.


Thanks!
http://csam.montclair.edu/~chopping/wood
http://csam.montclair.edu/~chopping/tundra