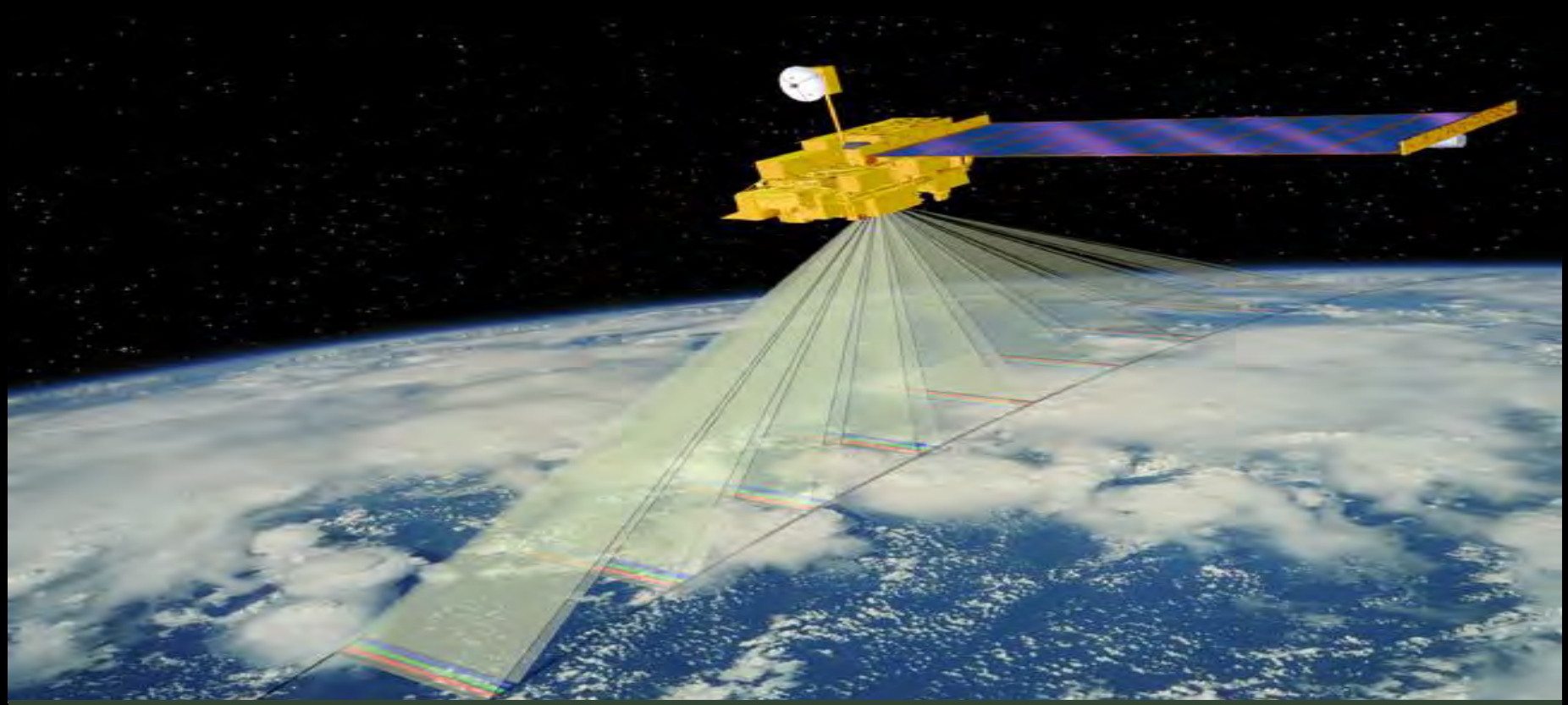
Canopy Height, Crown Cover, and Aboveground Biomass Mapping for the SW United States from MISR, 2000 & 2009



Mark Chopping[1], Sawahiko Shimada[1,2], Michael Bull[3], John V. Martonchik[3]

[1]Montclair State University [2]Tokyo University of Agriculture [3]NASA/JPL

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

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North American Carbon Program

MISR Data Users' Symposium 2008, Pasadena, CA, December 11-12, 2008

Overview

1. Eyes on the Prize
2. Methods and a Quick Recap.
3. The Big(ger) Picture: SWUS
4. Conclusions / Future work

Eyes on the Prize

Context: NASA Carbon Cycle and Ecosystems & Terrestrial Ecology Programs

"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?"

To address these questions, *we must know*:

- **The distribution of aboveground woody carbon stocks**
- **How much, where, & why woody C stocks are changing**
- **How much of the annual net flux from land is the result of disturbance and recovery?**

Eyes on the Prize

- The goal is to make wall-to-wall maps of forest and shrub canopy parameters over large areas and at annual intervals, on < 300 m grid.
- The focus is on structure, not function: woody crown cover, canopy height, & biomass (plus background brightness and BRDF, crown shape).
- Gaps unacceptable to the land community
- The 10-year record from 2000 is important.

Future Solutions: DESDynI

Full Waveform Lidar/InSAR Mission

March 2007: Selected by the Decadal Survey for Solid Earth and Canopy Structure/Biomass.

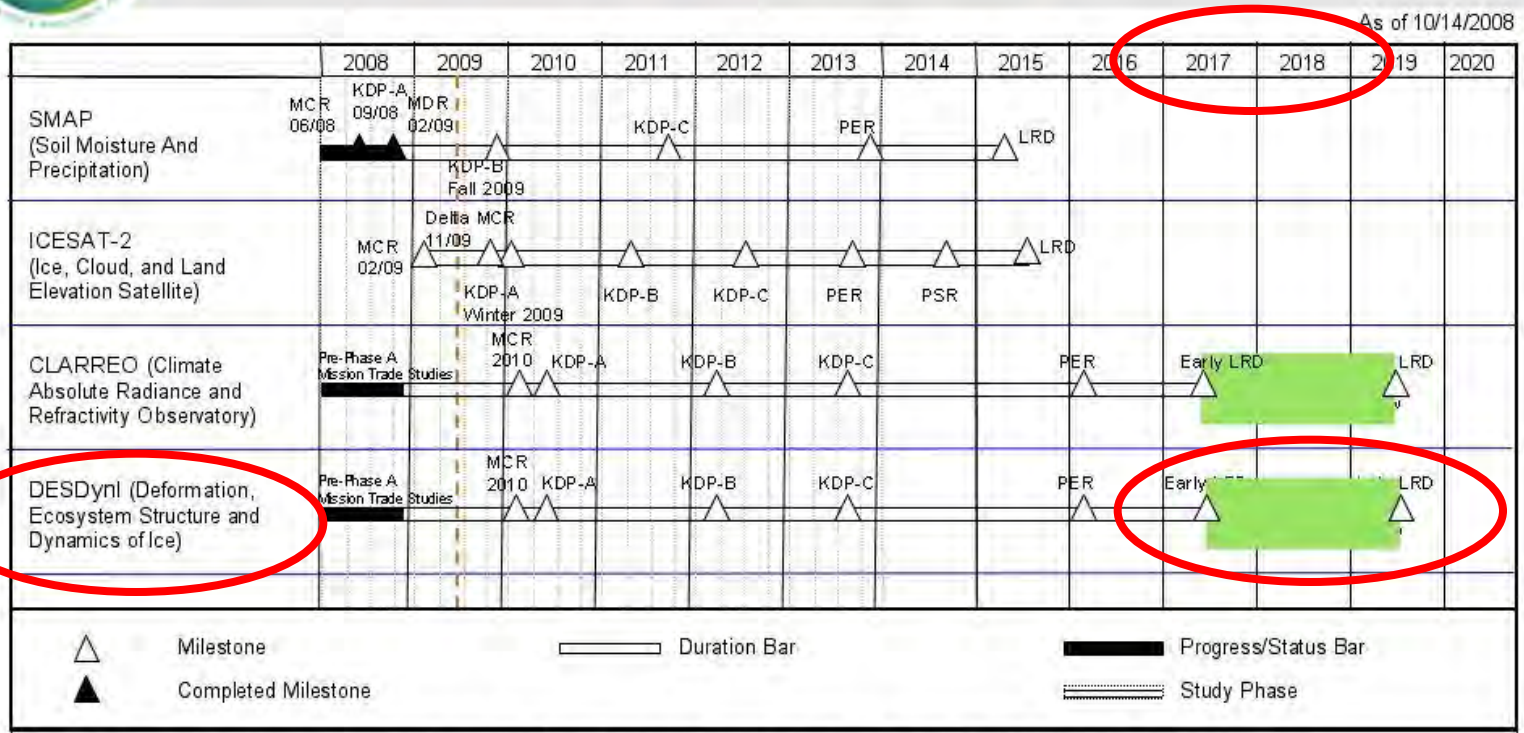
April/May 2008: expected launch timeframe about 2013-15 (NASA CCE workshop, Adelphi, MD).

August 2009: expected launch timeframe is now 2017-18 (NASA VURSAL workshop, Fairbanks, AK).

October 2009: Confirmation of 2017-18 launch.

DESDynI Delayed

Tier 1 Mission Readiness



These schedules are driven by technical readiness and by available resources
*Readiness Window depends on resources **and** total mission cost.*

System Design Decisions will be made within the next year (for SMAP & ICESat-2) or the next 2-3 years (CLARREO & DESDynI)

DESDynI Delayed

- There will be no time machine on the DESDynI satellite(s). Once the record is lost, the record is lost forever.
- Biomass is dynamic (disturbance, regrowth).
- Can we do science and provide context for this 5-yr mission using existing NASA Earth Observing assets?

Eyes on the Prize: New Mapping Work

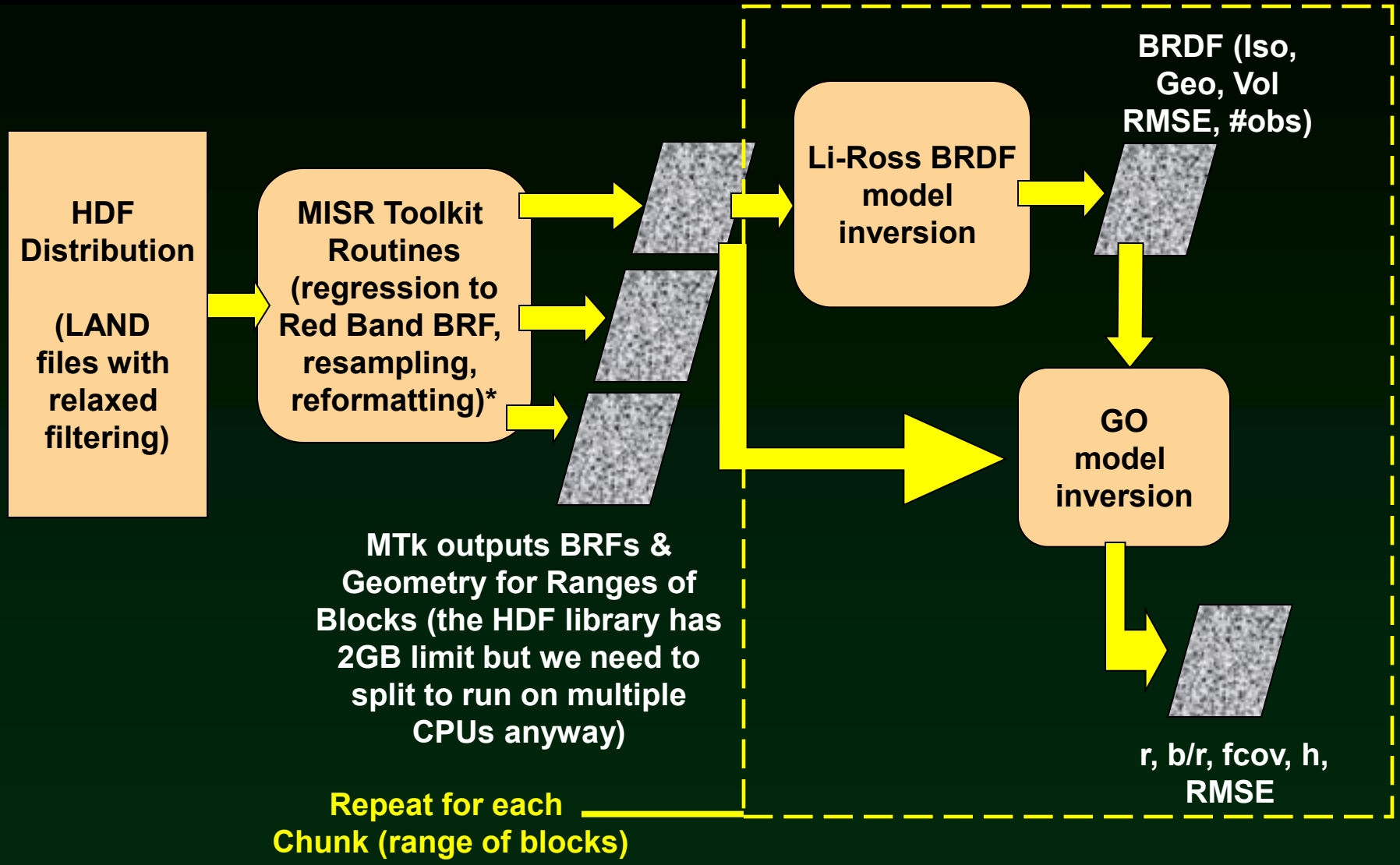
Since it's the Terra/MISR 10th birthday we thought we would go for maps for 2000 and 2009 -- a decade -- for the southwestern United States.

Using the 275 m red band radiances in all cameras = ~400 million model inversions (235.8 million locations in maps). That's a lot!

Approaches:

- **MISR/GO (physical-empirical)**
- **MISR/Li-Ross BRDF model (semi-empirical)**

Mapping Work: Processing Chain



*easier to write C code to write the scripts rather than edit 150+ scripts by hand

Methods & Recap: Geometric-Optical Models (Li-Strahler)

The Skinny:

It's a discrete object model with *a priori* dynamic background and Ross in-crown volume scattering

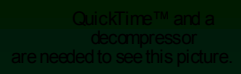
Very simple (but less simple than NDVI).

Too simple?

Methods & Recap: MISR Shrubs vs Landsat

The GO model is simple and makes assumptions… but works

Shrub mapping by Kelley O'Neal (UMD) in Chihuahuan Desert grasslands in New Mexico using Landsat and spectral unmixing showed an R^2 of 0.77 vs our MISR/GO results (Landsat aggregated to MISR scale) -- from AGU 12/08.



We also showed good results vs. maps derived from Ikonos high resolution panchromatic imagery. Note: we don't have a "MISR Product".

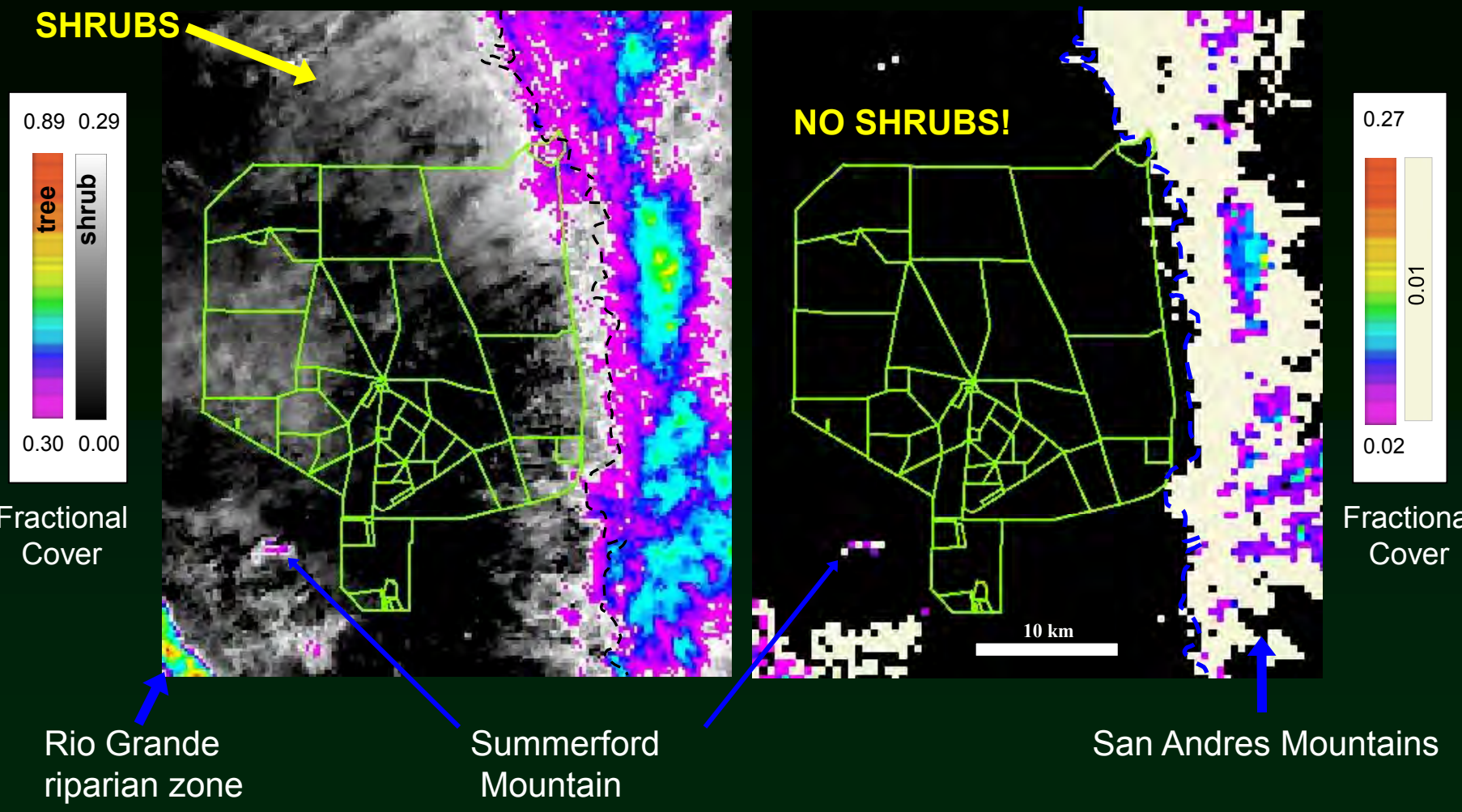
Forschung durch serendipity

The initial funded work on New Mexico (2004-2007) was focused on shrub cover mapping using BRDF and GO model inversion (MISR red band @250m)

We realized that we could also obtain estimates of canopy height through $h = h/b \times b$; $b = b/r \times r$ …by fixing the h/b (crown center height/vertical radius) parameter and λ (plant number density) and inverting for r and b/r.

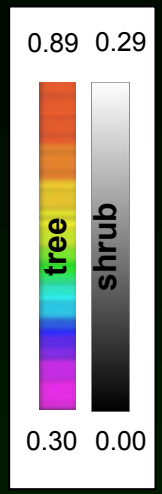
We only realized this by accident, after extending the mapping area to include the San Andres Mtns.

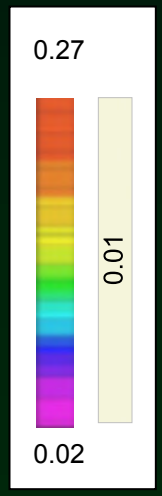
Comparison of Cover Retrievals with VCF % Tree Cover Map



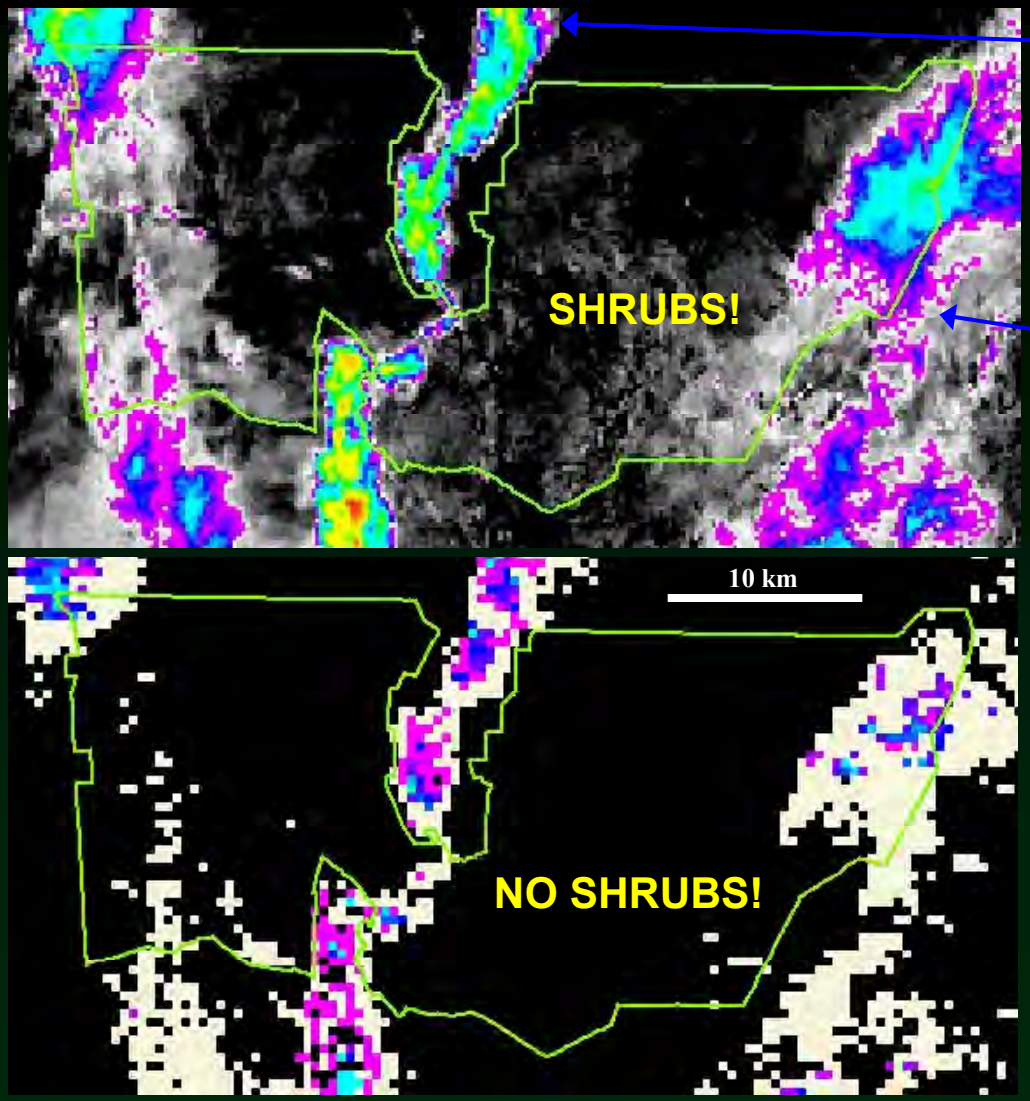
Left: MISR/GO Woody Plant Cover Right: MODIS Vegetation Continuous Fields % Tree Cover for the **USDA, ARS Jornada Experimental Range & environs**

Comparison of Cover Retrievals with VCF % Tree Cover Map





Fractional Cover



Rio Grande riparian zone

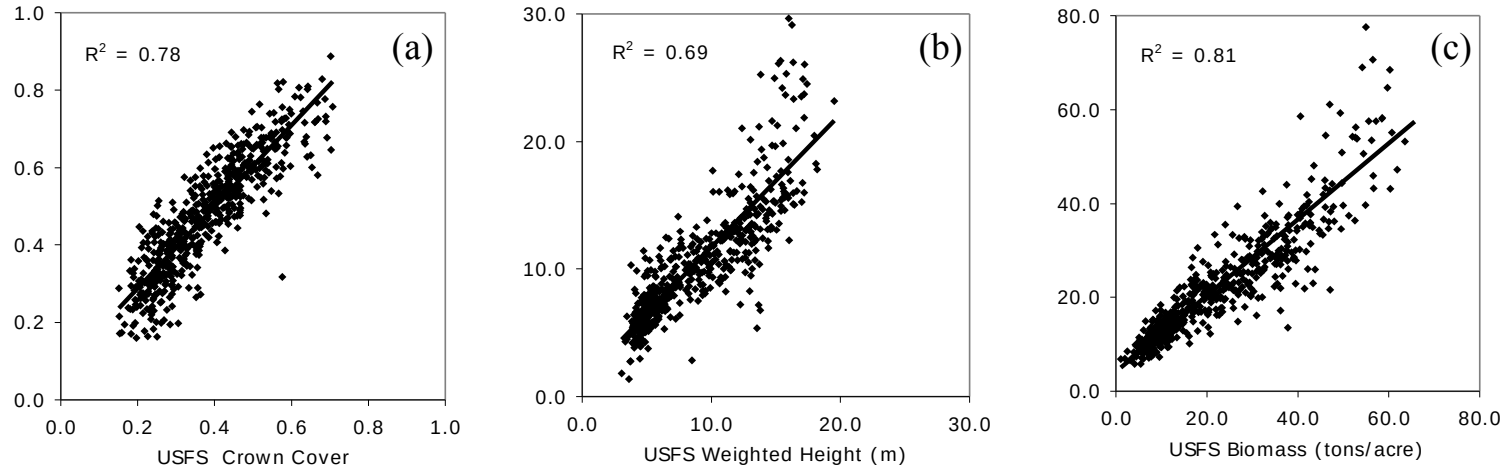
San Andres Mountains

Top: MISR/GO Woody Plant Cover

Bottom: MODIS Vegetation Continuous Fields % Tree Cover for the **Sevilleta National Wildlife Refuge** near Socorro, NM

Cover is too high b/c the effects of height not accounted for: what happens if *h*/*b* or *b*/*r* are free?

AZ/NM Canopy Structure/Biomass Mapping Results



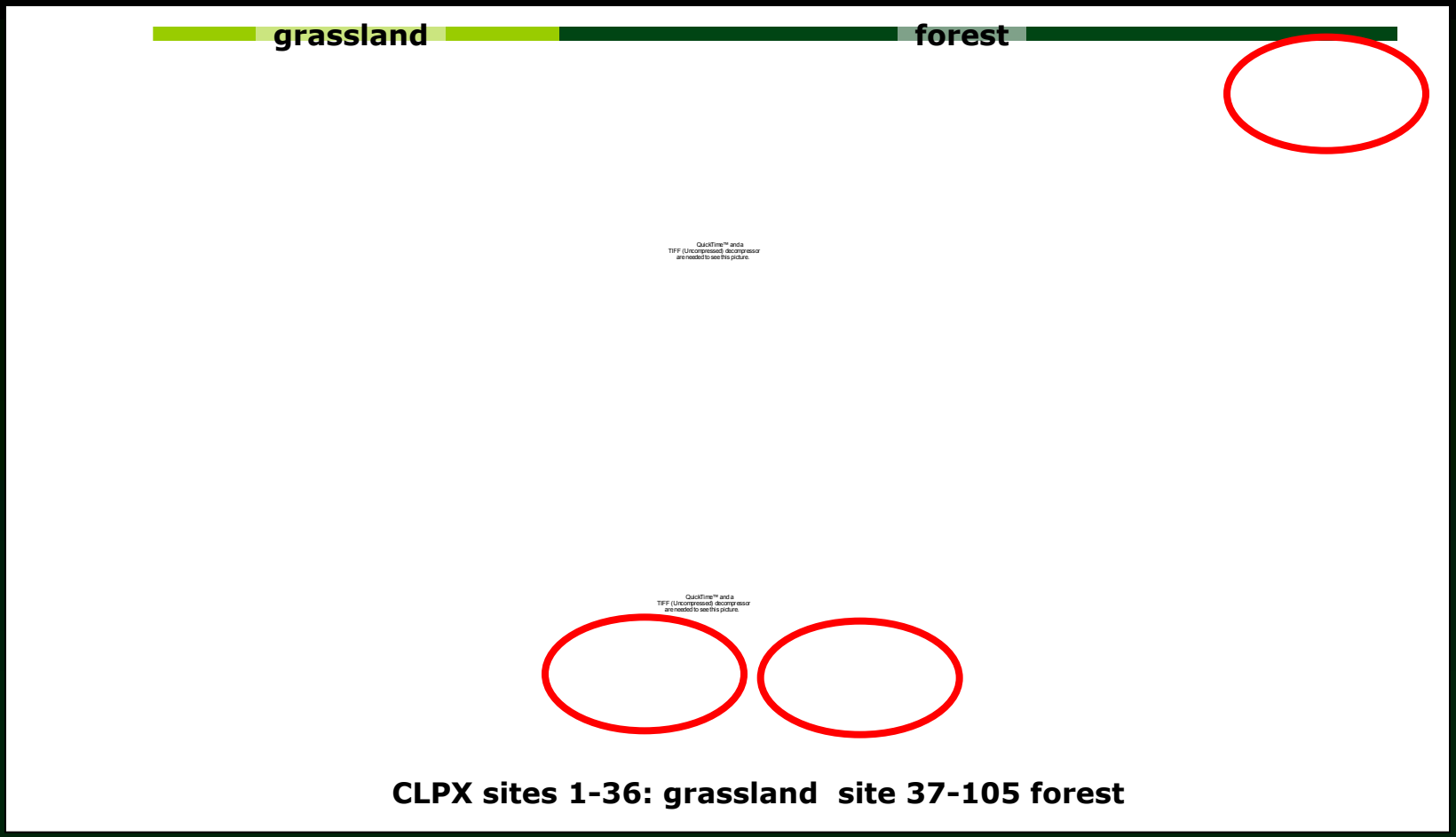
Results: (a) Crown cover, (b) canopy height, and (c) woody biomass Retrievals with screening for topographic effects using a Digital Elevation Model from the Shuttle Radar Topography Mission. Points with RMSE >= 0.01 and a few outliers ±2 st. devs. from the mean of crown cover were discarded, retaining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

..vs Forest Service 2005 Interior West maps

~ not vs field inventory or lidar ~

How well can we do vs discrete-return lidar at 250 m?

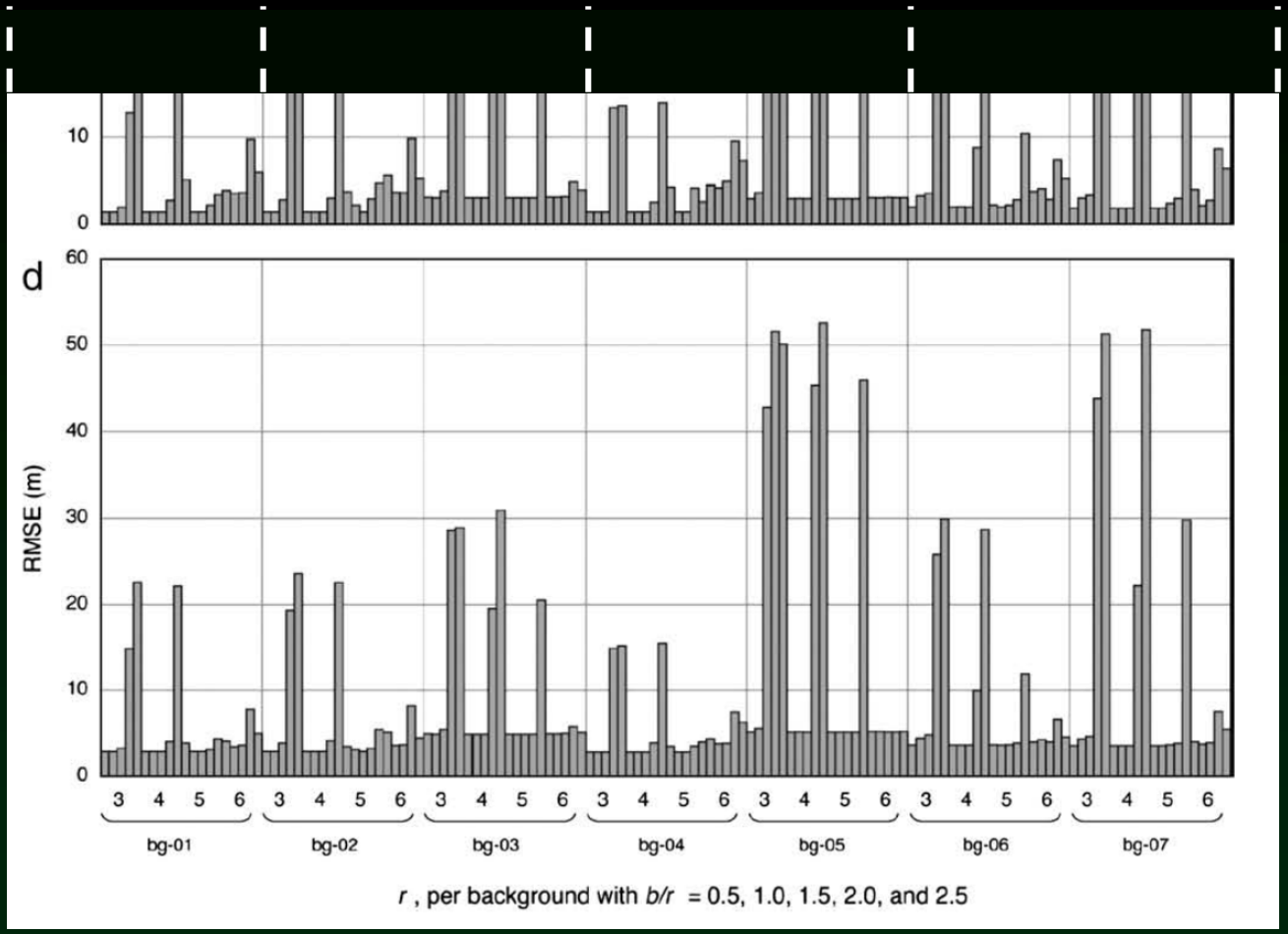
Colorado: MISR/GO Results vs CLPX lidar data



Forest Service Interior West (IW) empirical height estimates seem to be much worse vs CLPX lidar heights than MISR/GO. We see anomalies @Fool Creek #s97-107 - but these are easily screened out b/c the inversion fails spectacularly (cover goes to 1.0).

Colorado: MISR/GO Results vs CLPX lidar data

Inversion runs for 140 combinations of backgrounds and starting points. Y axis: RMSE of MISR/GO vs lidar mean canopy heights. Starting values for *r* and *b/r* indicated on the X axis, with *b/r* in the order 0.5,1.0,1.5, 2.0, and 2.5.



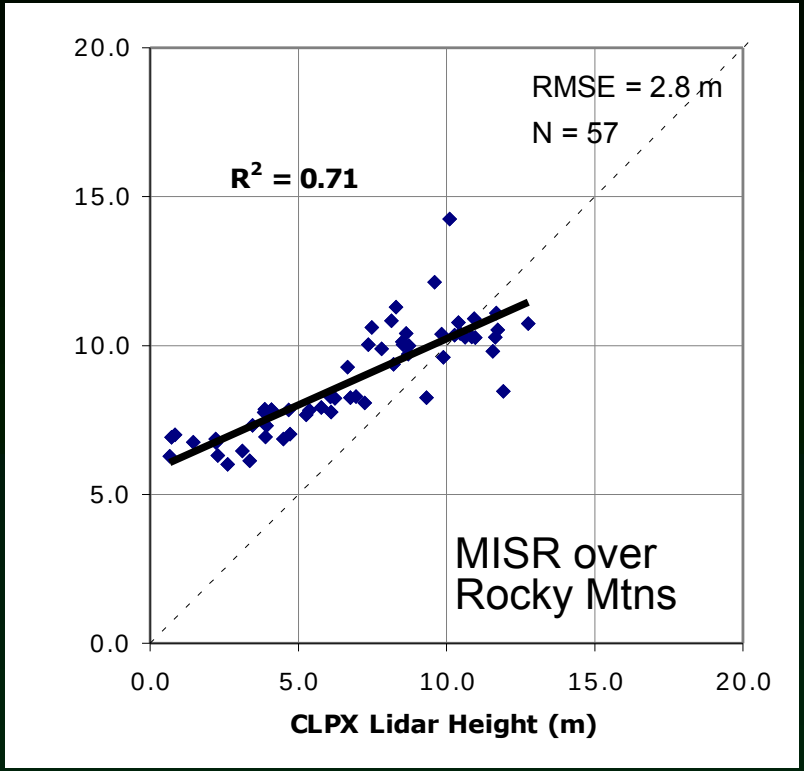
April (snow) or September (no snow) with/without calculation of height as abs(*h*+*b*). Two backgrounds were intentionally poor in order to demonstrate the importance of good BG predictions.

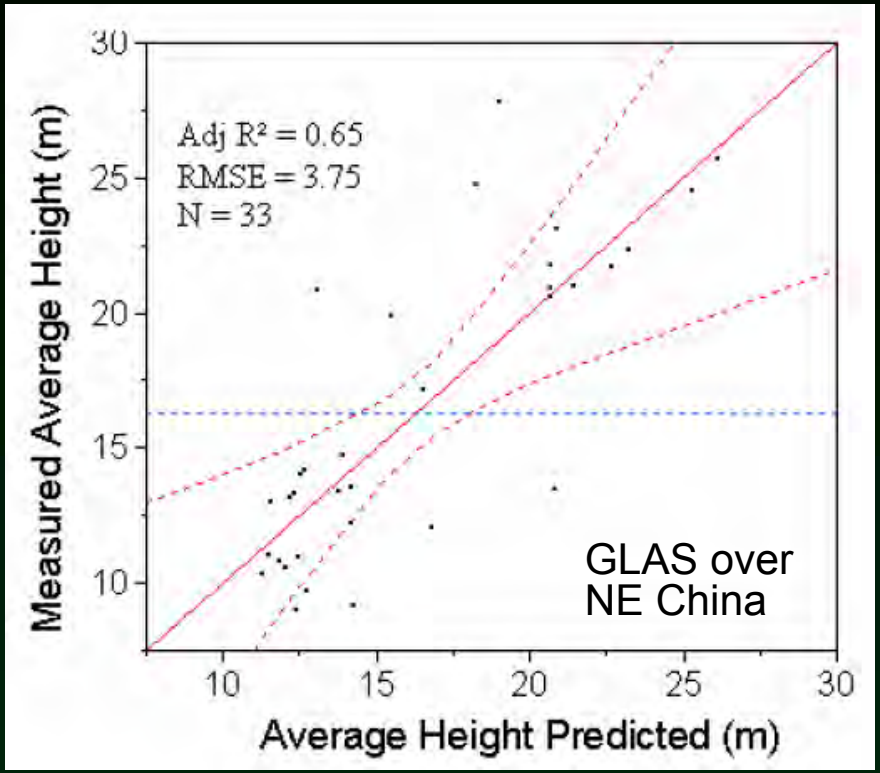
Reasonable backgrounds using red band iso, geo, vol only

Predicted background red band brightness in the vicinity of the North Park and Rabbit Ears CLPX sites: (a) Walthall isotropic parameter (b) 45° VZA in the backscattering direction, solar principal plane, with overhead sun (c) 45° VZA in the forward-scattering direction, solar principal plane, with overhead sun.

These predictions are quite reasonable (if unverifiable).

“Estimates from Active Instruments Not Perfect”

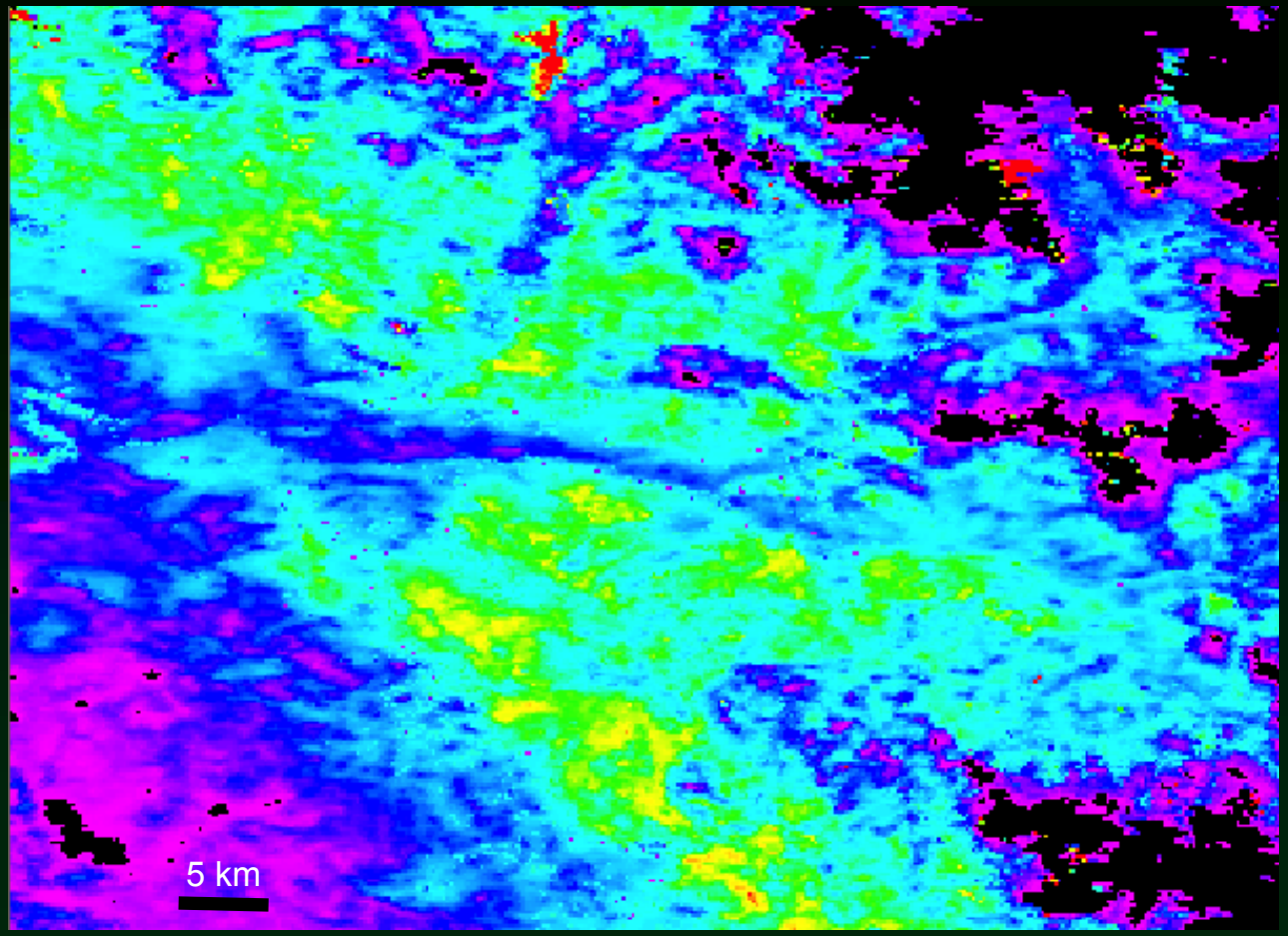




Not strictly comparable… but you get the idea

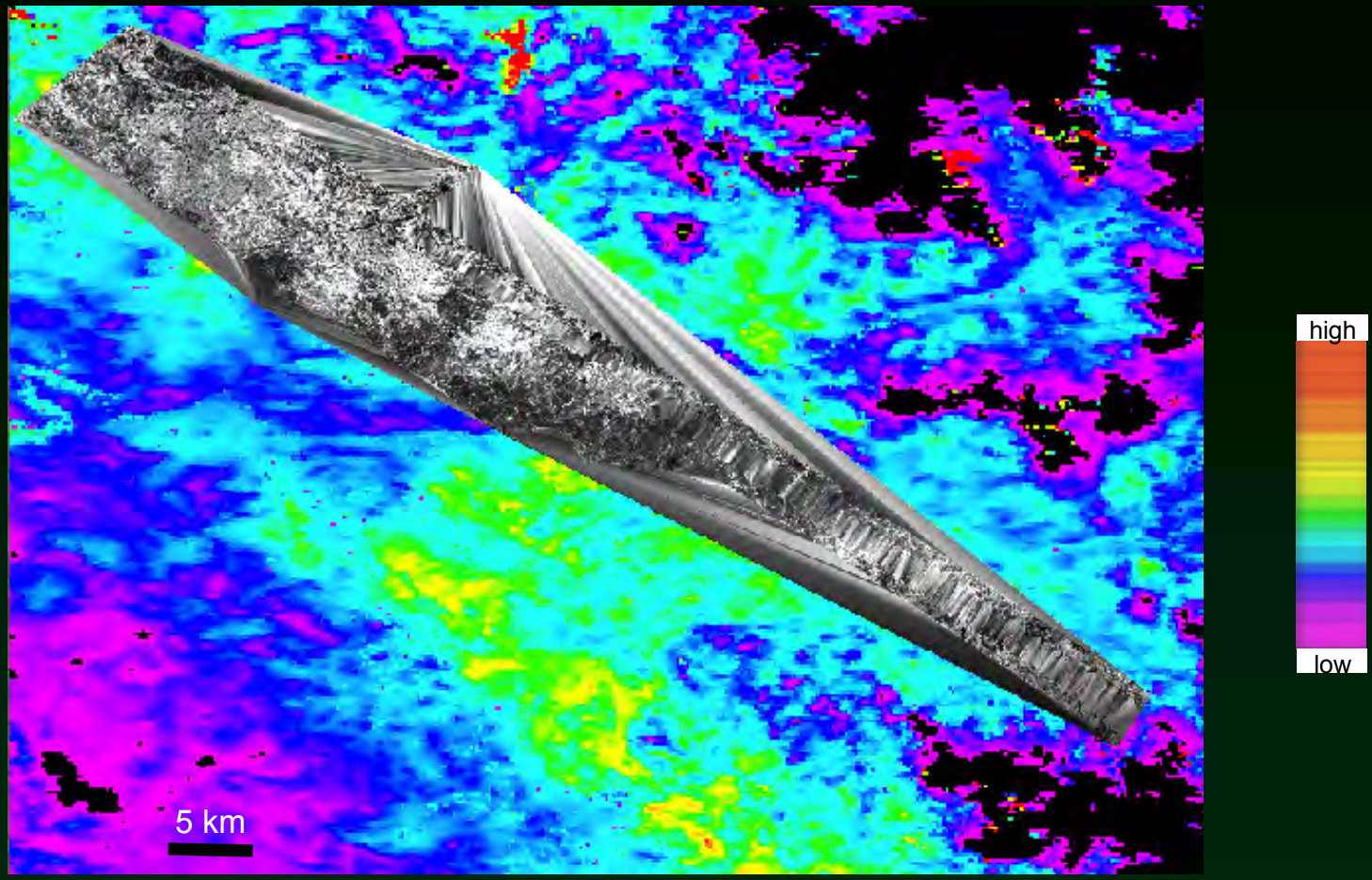
No corrections for topography….yet

Canopy height results: MISR/GO vs LVIS (Sierra Nevada)



Greyscale: Interpolated LVIS RH100 canopy heights
Color scale: MISR/GO *h*+*b* (scaled)

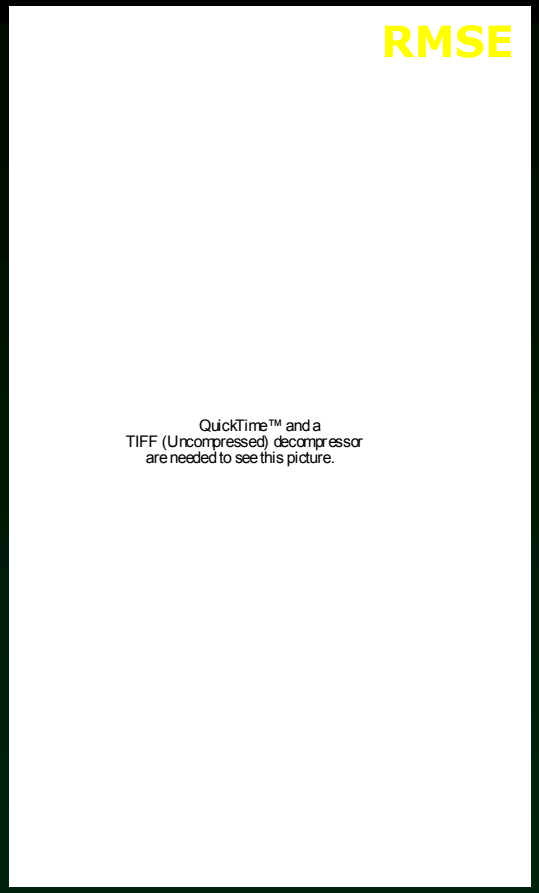
Canopy height results: MISR/GO vs LVIS (Sierra Nevada)



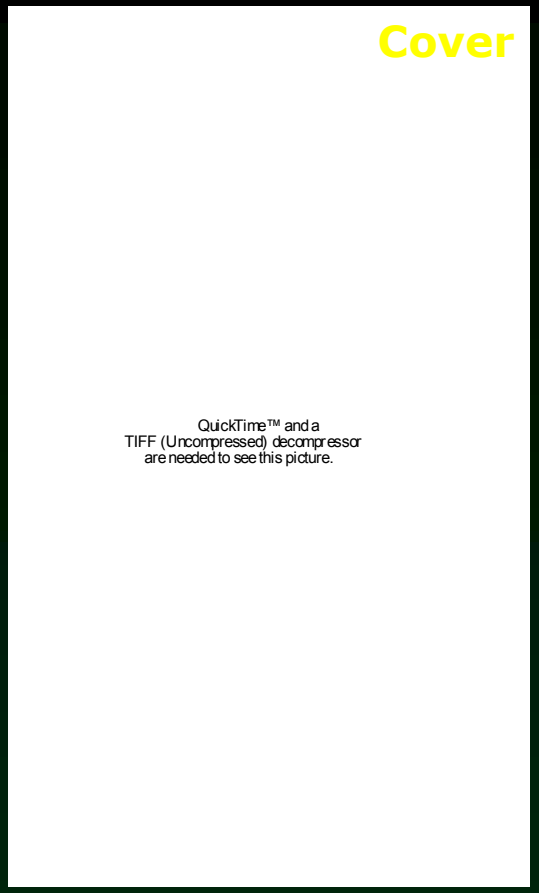
Greyscale: Interpolated LVIS RH100 canopy heights
Color scale: MISR/GO *h*+*b* (scaled)

The “RMSE Cloud Trick”: Clouds pop out in GO model fitting RMSE

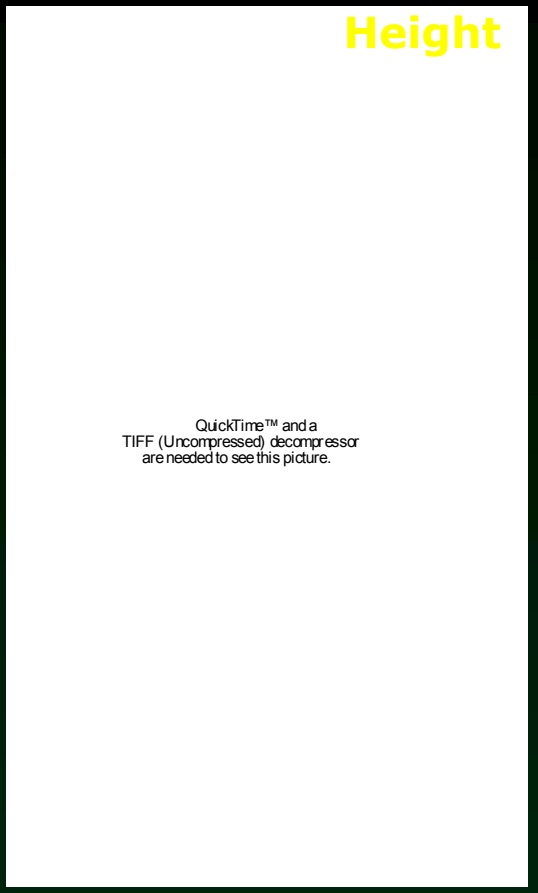
RMSE



Cover

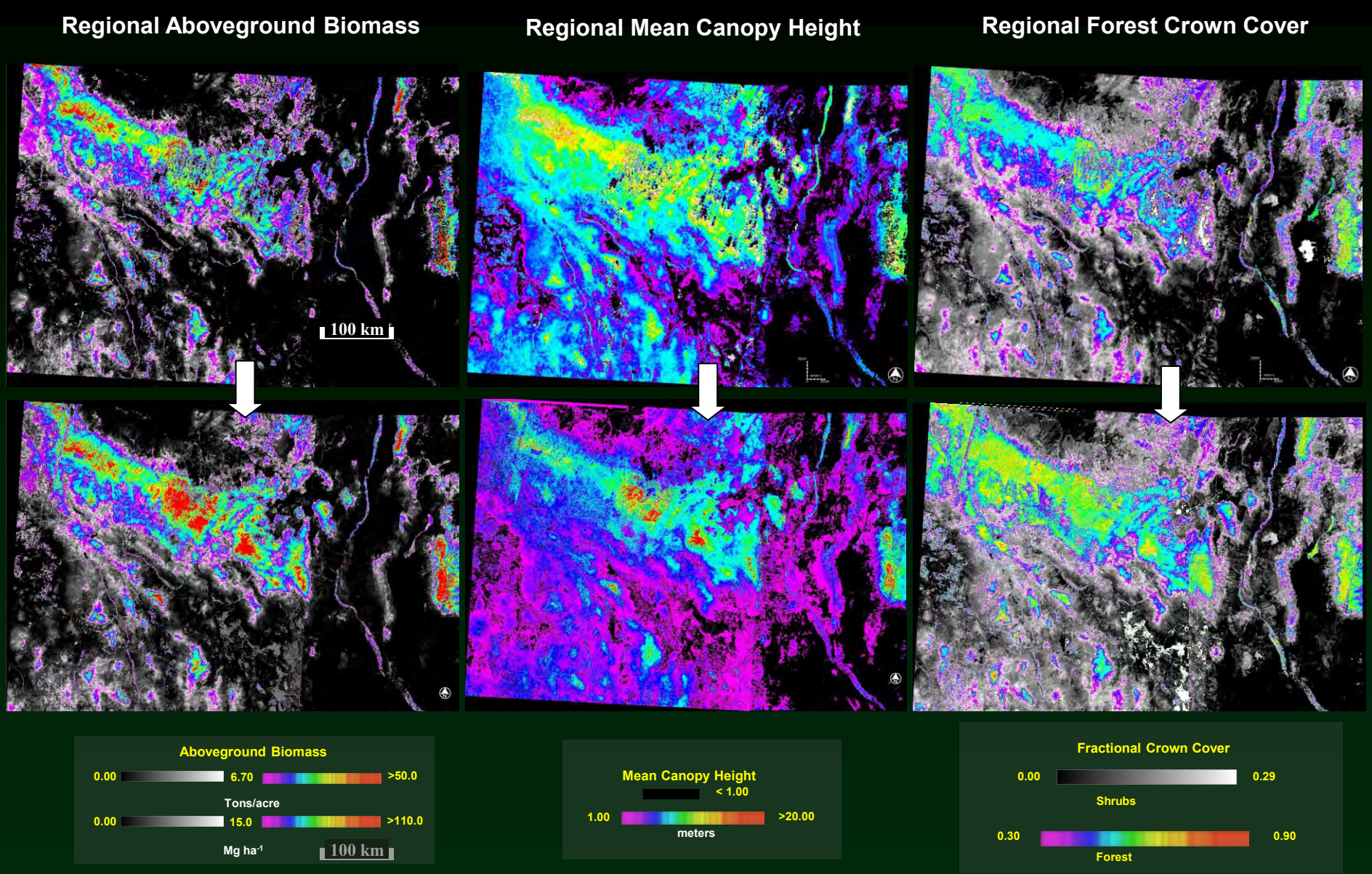


Height

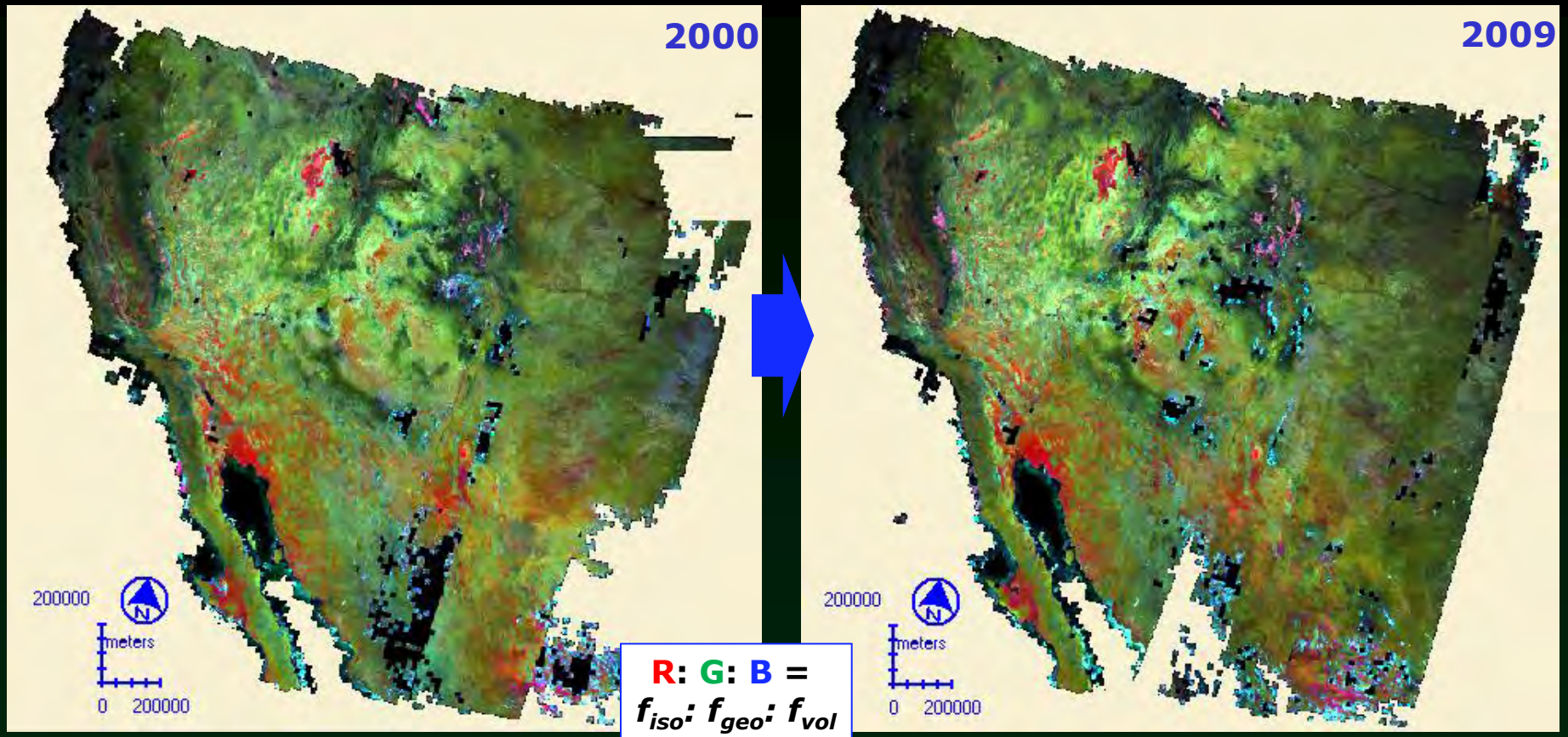


CLPX study 2008/9: MISR/GO model-fitting RMSE and effects on fractional crown cover & canopy height. Note correlation between model-fitting error and surface retrieval failures that are clearly owing to the presence of clouds. Other criteria? Relative azimuth?

…Allows Compositing on min(RMSE) for Large Area Mapping



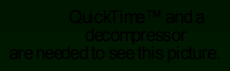
Li-Ross BRDF Model Kernel Weights: SWUS & N. Mexico

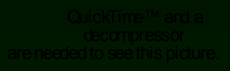


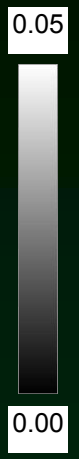
LiSparse-RossThin BRDF model kernel weight composite image. The weights can be used empirically and are also needed for prediction of the background contribution

...from selected May 15 - June 15 MISR observations only

Big Picture: the American Southwest



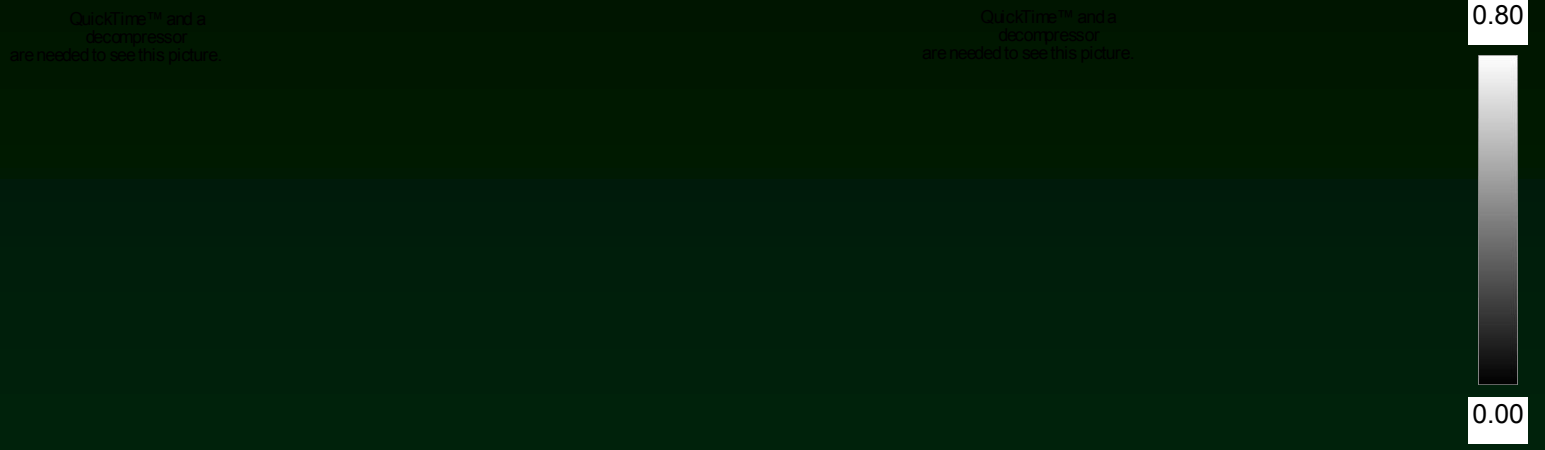




RMSE (model fit), 2000 and 2009

…from selected May 15 - June 15 MISR observations only

Big Picture: the American Southwest



Fractional Crown Cover 2000 and 2009

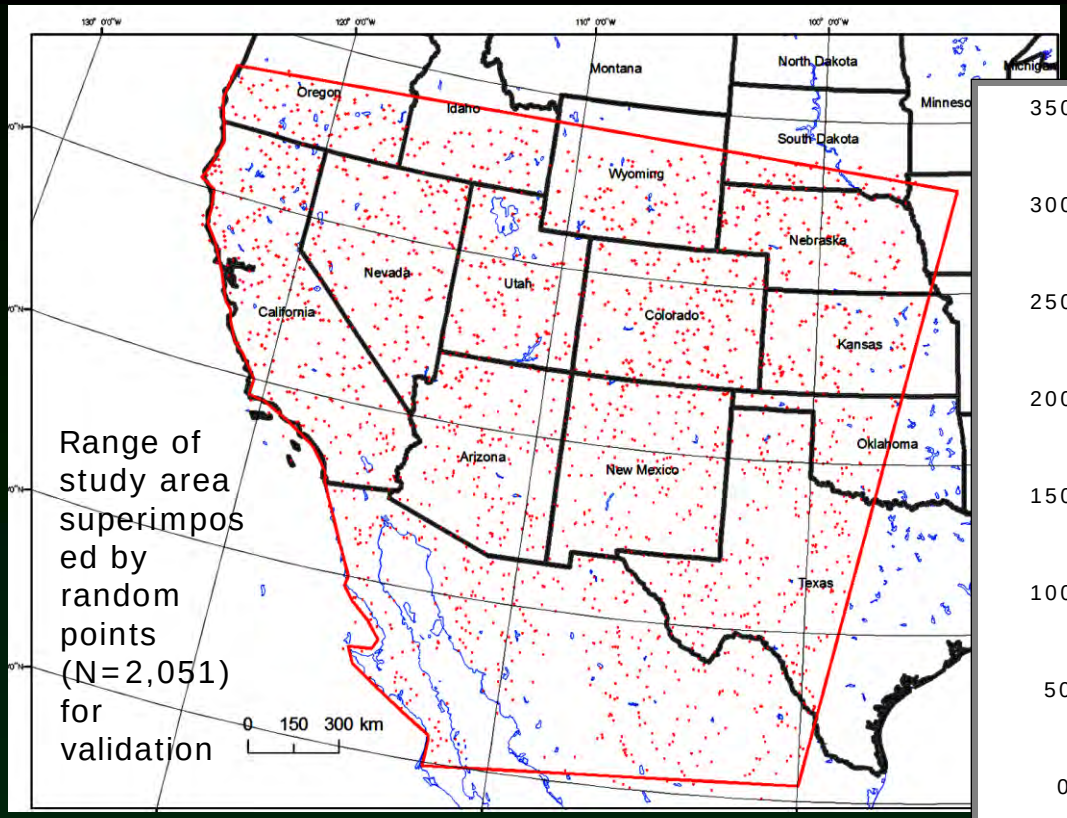
…from selected May 15 - June 15 MISR observations only

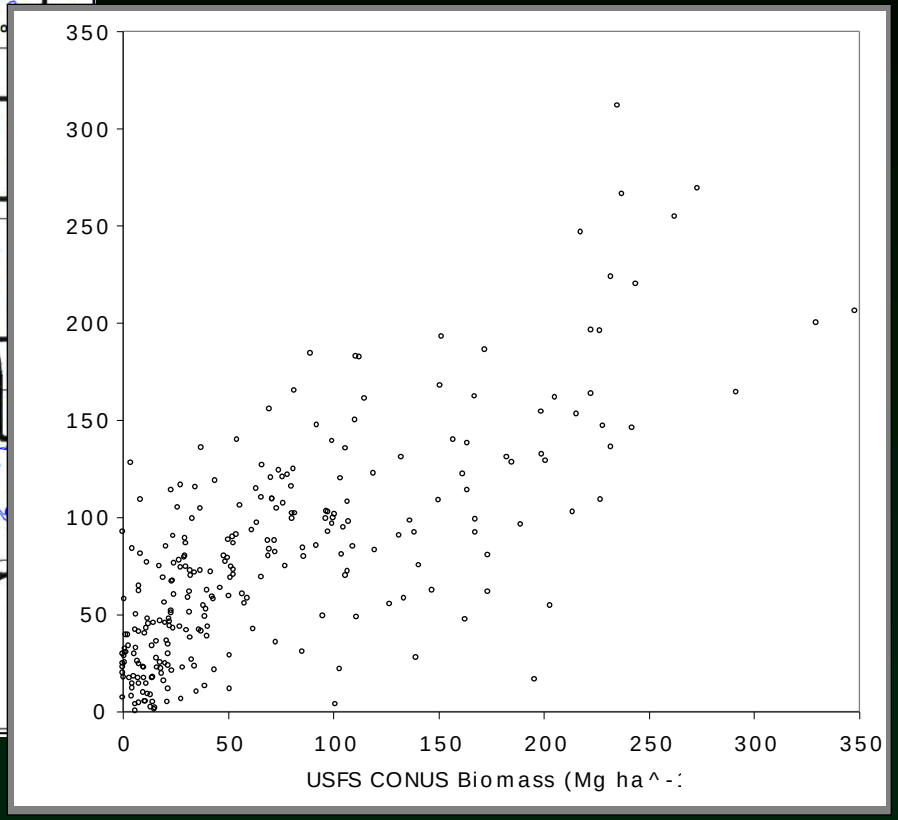
Big Picture: the American Southwest

Mean crown center height (m) 2000 and 2009

…from selected May 15 - June 15 MISR observations only

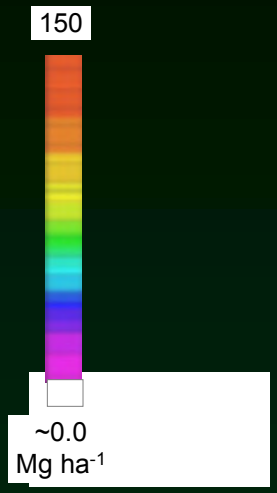
Big Picture: the American Southwest





MISR/GO Aboveground Live Biomass (Mg ha^{-1}) for 2000 vs USFS AGL Biomass for 2002 (Blackard *et al*. 2008) w/2051 random points. <u>But how good are the USFS estimates?</u>

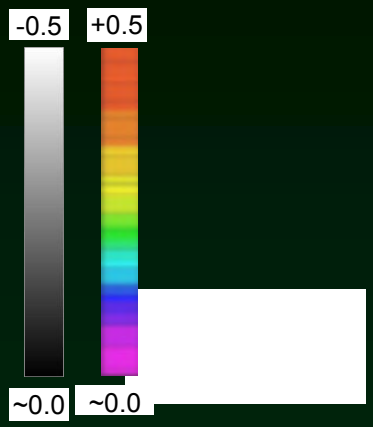
Big Picture: the American Southwest

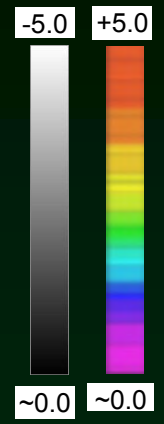


Aboveground Live Biomass (Mg ha^{-1}) 2000 and 2009

…from selected May 15 - June 15 MISR observations only

Big Picture: the American Southwest





Change in fractional cover and mean crown center height, 2000 minus 2009

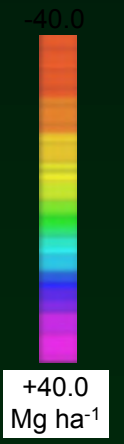
...from selected May 15 - June 15 MISR observations only

Big Picture: the American Southwest

Δ aboveground live woody biomass, 2000 minus 2009

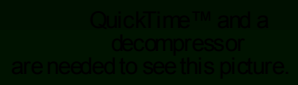
Missing & invalid values NOT flagged (it's really too early to attempt a map like this)

QuickTime™ and a decompressor are needed to see this picture.

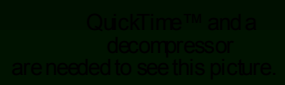


Quick Check: Rodeo-Chediski Fire, AZ

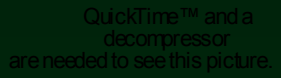
Landsat Severity Map



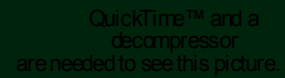
Δ *fcov* 2000-2009



USFS Biomass Map, 2002

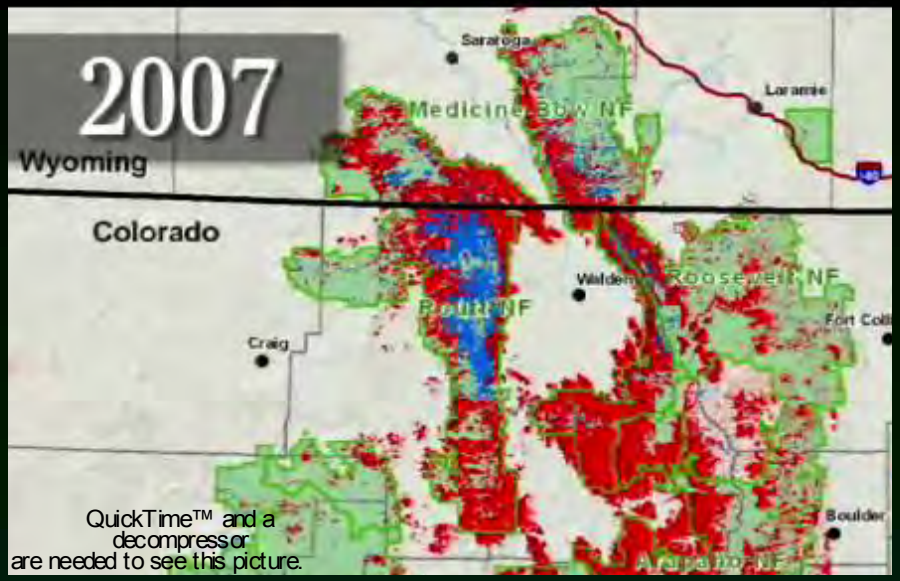


Δ *h* 2000-2009



Blackard *et al.*, 2008, RSE

Forest Biomass Loss: Pine Beetle Devastation



QuickTime™ and a decompressor are needed to see this picture.

2000

2000 minus 2009

QuickTime™ and a decompressor are needed to see this picture.

2009

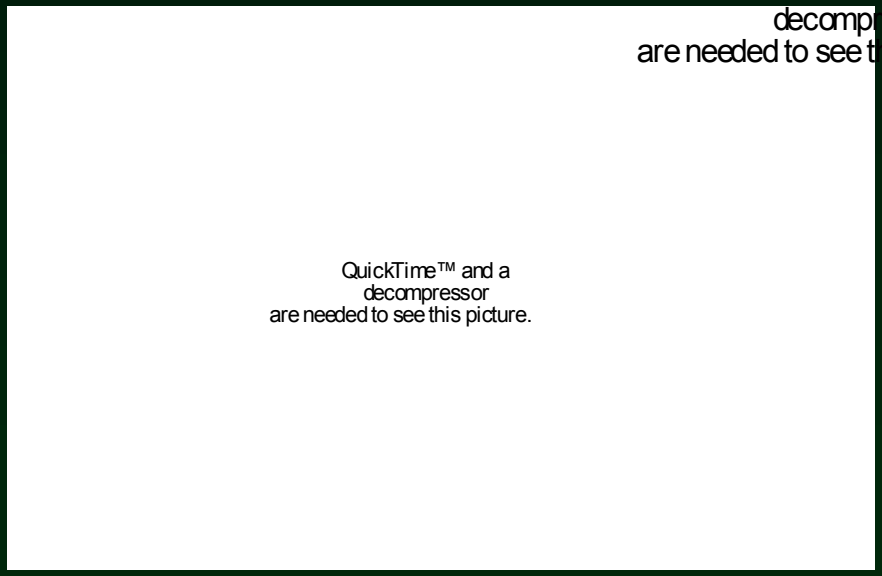
QuickTime™ and a decompressor are needed to see this picture.

QuickTime™ and a decompressor are needed to see this picture.

American Southwest: El Mirage Dry Lake

RMSE

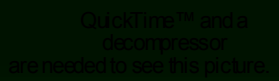
Mean *h*



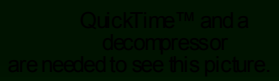
Fractional cover

American Southwest: Clouds

RMSE

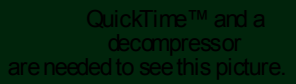


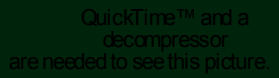
RMSE (2009)



Fractional cover

2000





American Southwest: San Bernadino NF

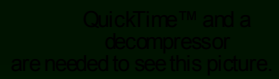
RMSE

Mean *h*

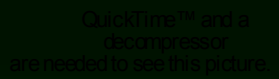
Fractional cover

American Southwest: Transverse Dunes

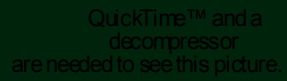
RMSE

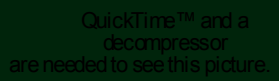


RMSE (2009)



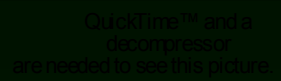
Fractional cover



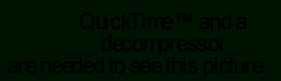


American Southwest: Lava Flow

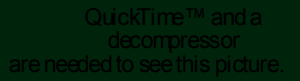
RMSE

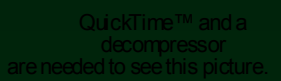


RMSE (2009)



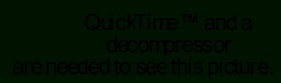
Fractional cover



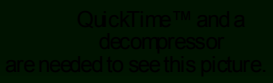


American Southwest: White Sands Gypsum, NM

RMSE

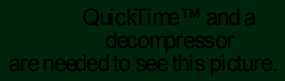


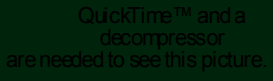
Mean *h*



Fractional cover

Lava flow →





American Southwest: MISR/GO vs UFSF Biomass

MISR/GO AGL Biomass 2000

QuickTime™ and a
decompressor
are needed to see this picture.

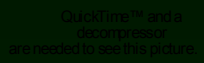
MISR/GO AGL Biomass 2009

QuickTime™ and a
decompressor
are needed to see this picture.

QuickTime™ and a
decompressor
are needed to see this picture.

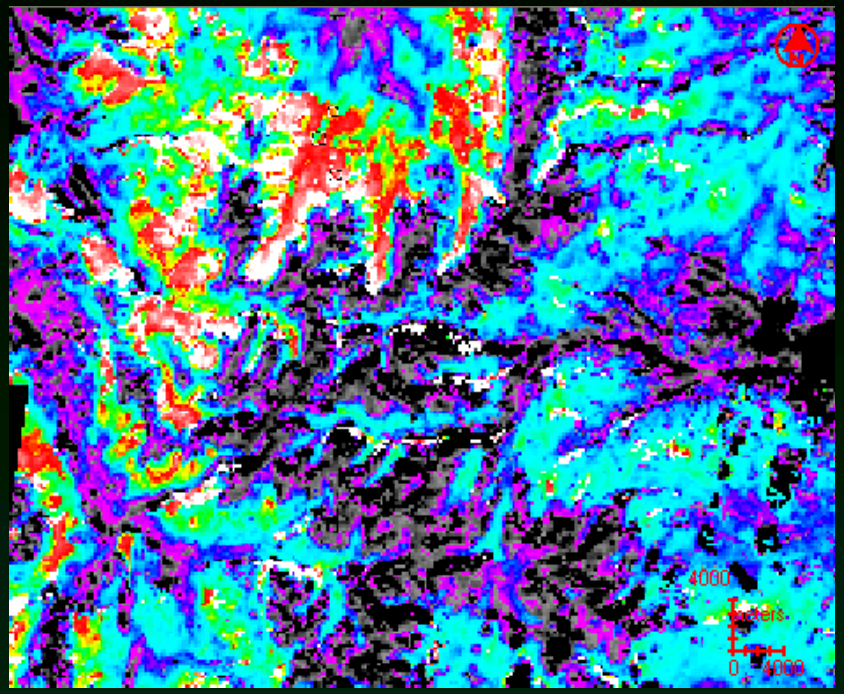
USFS AGL Biomass 2002

MISR + MODIS? We also worked on MODIS/GO mapping

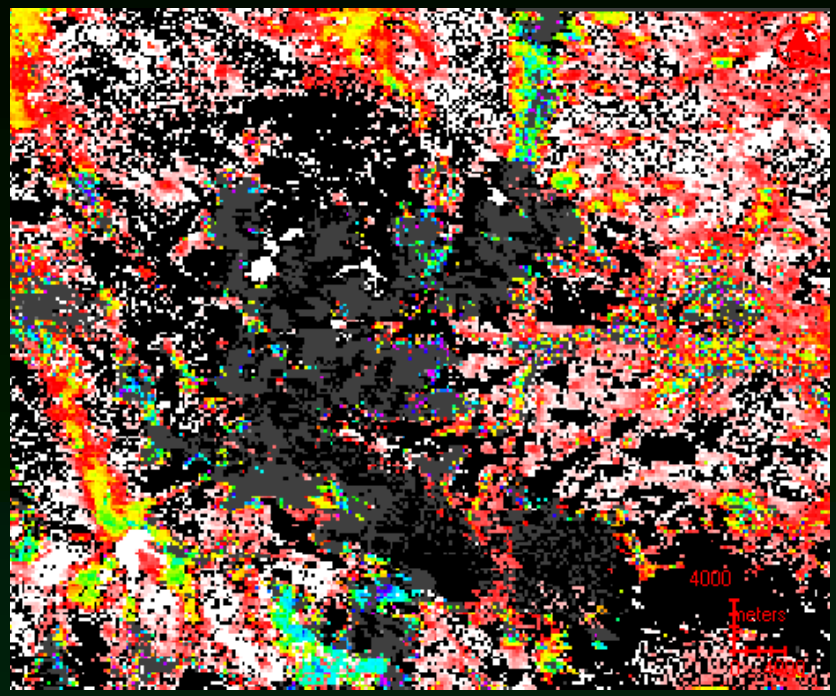


MODIS/GO mean canopy height map for the SWUS, Sinusoidal projection

…but noise is far higher than MISR/GO:



MISR h (clean)



MODIS h (noisy)

We subsequently found that in spite of considerable effort, it was not possible to find a dynamic background for MODIS that would perform better than a static one (partly a result of relative azimuths being closer to the solar PP)

MODIS/GO vs MISR/GO (vs USFS FIA-IW)

MODIS/SGM results (top row) and MISR/SGM results (bottom row).

QuickTime™ and a
decompressor
are needed to see this picture.

Meanwhile, outside the Southwestern United States…

MISR/GO vs 5 m Lidar (Fort Greely, Alaska)

Left:
Frac. Cover (0.0-1.0) for 2 snow backgrounds

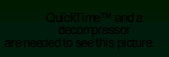
Center:
Canopy Height (0-10 m) for 2 snow backgrounds

Right:
lidar mean height (0 - 30 m)

MISR/GO vs 5 m Lidar (Fort Greely, Alaska)

The regression is not spurious; intercept and coefficients are all significant at the 0.01 level.

This is probably the best we can hope to do for dense boreal forest with dark backgrounds using GO models (will spectral invariants be better -- penetration into canopy lacking?)



MISR for Forest & Shrub Mapping: Conclusions/Future

- **Crown cover and mean canopy height are retrieved with a MISR/GO approach with no scaling not through fitting or training. Accuracy is: 1. "good" 2. a monotonic function of model fitting error, with implications for compositing.**
- **The 70° (D) camera data are often required to obtain canopy height (*c.f.* MSPI).**
- **The dynamic background is critical: using a static background BRDF gives noisy results and poor precision. Better w/o An camera: confirmed.**
- **Validation vs lidar heights is proceeding better than expected (further validation ongoing, e.g., vs Sierra Nevada LVIS RH100 estimates; Jornada desert site).**

MISR/GO for Forest Structure Mapping: Conclusions/Future

- Will this work in Alaskan forest? **No: stands are too dense & bg's too dark and heterogeneous -- apart from the high SZA.** …over the lower 48? **Not tested but highly unlikely.** However, it's very useful in savannas, woodlands, arid forests, desert grasslands worldwide. We will extend to other semi-arid/arid areas (Asia, Africa, S. America) when time allows.
- **Investigate alternative compositing criteria to fill holes in maps while avoiding RAA anomalies at the edges of paths.**
- MISR+MODIS/GO? Unfortunately MODIS is unable to provide reliable background predictions, a finding supported by research at U. Toronto by Jan Pisek.

MISR/GO for Forest Structure Mapping: Conclusions/Future

- **We are constantly striving to improve precision and reduce noise. We'd like to make bg calibration more robust; corrections for topography still pending.**
- **Validation vs lidar. Colorado Rockies: √ Sierra Nevada: in progress. Desert grasslands: field data+UAV+ Ikonos/QB+LVIS+MISR available (PhD st.#1 to assess).**
- **Generalizability of the GO approach: limited to biomes with sparse-to-moderate density stands.**
- **Proposal to map shrubs in Arctic tundra with MISR and MODIS selected (PhD st.#2 in Jan, *deo volante*).**

Recently Published Papers

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

Chopping, M., Moisen, G. Su, L., Laliberte, A., Rango, A., Martonchik, J.V., and Peters, D.P.C. (2008), Large area mapping of southwestern forest crown cover, canopy height, and biomass using MISR, *Remote Sens. Environ.* 112: 2051-2063.

Chopping, M., Su, L., Rango, A., Martonchik, J.V., Peters, D.P.C., and Laliberte, A. (2008), Remote sensing of woody shrub cover in desert grasslands using MISR with a geometric-optical canopy reflectance model, *Remote Sens. Environ.* 112: 19-34

Chopping, M. (2008), Terrestrial Applications of Multiangle Remote Sensing, in: *Advances in Land Remote Sensing: System, Modeling, Inversion and Applications*, S. Liang, ed., Springer- Verlag, 2008.

Upcoming Papers

- MODIS/GO manuscript submitted for Veg3D/Biomass Special Issue in early 2009 shows that a dynamic background cannot be obtained from MODIS, corroborated by work by Jan Pisek.

- Several manuscripts are planned/upcoming from the WIP just described (we've been lining up our ducks)

- Since there is a palpable danger that MISR/multi-angle results are ignored by the land community, we want to present watertight results, w/o being too picky.

Acknowledgments

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Data: MISR data from NASA Langley Research Center Atmospheric Science Data Center and Michael Bull. CLPX data: National Snow and Ice Data Center/CLPX (Miller, S.L. 2003. *CLPX-Airborne: Infrared Orthophotography and LIDAR Topographic Mapping)* Boulder, CO. USFS Biomass map and US-FIA maps for the Interior West: US Forest Service, Rocky Mountain Research Station, Ogden, UT (thanks to Gretchen Moisen, Jock Blackard and Ron Tymcio).

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- **Xiaohong Chopping (neé Qi)**
- **NASA Vegetation Structure Working Group.**


http://csam.montclair.edu/~chopping/wood