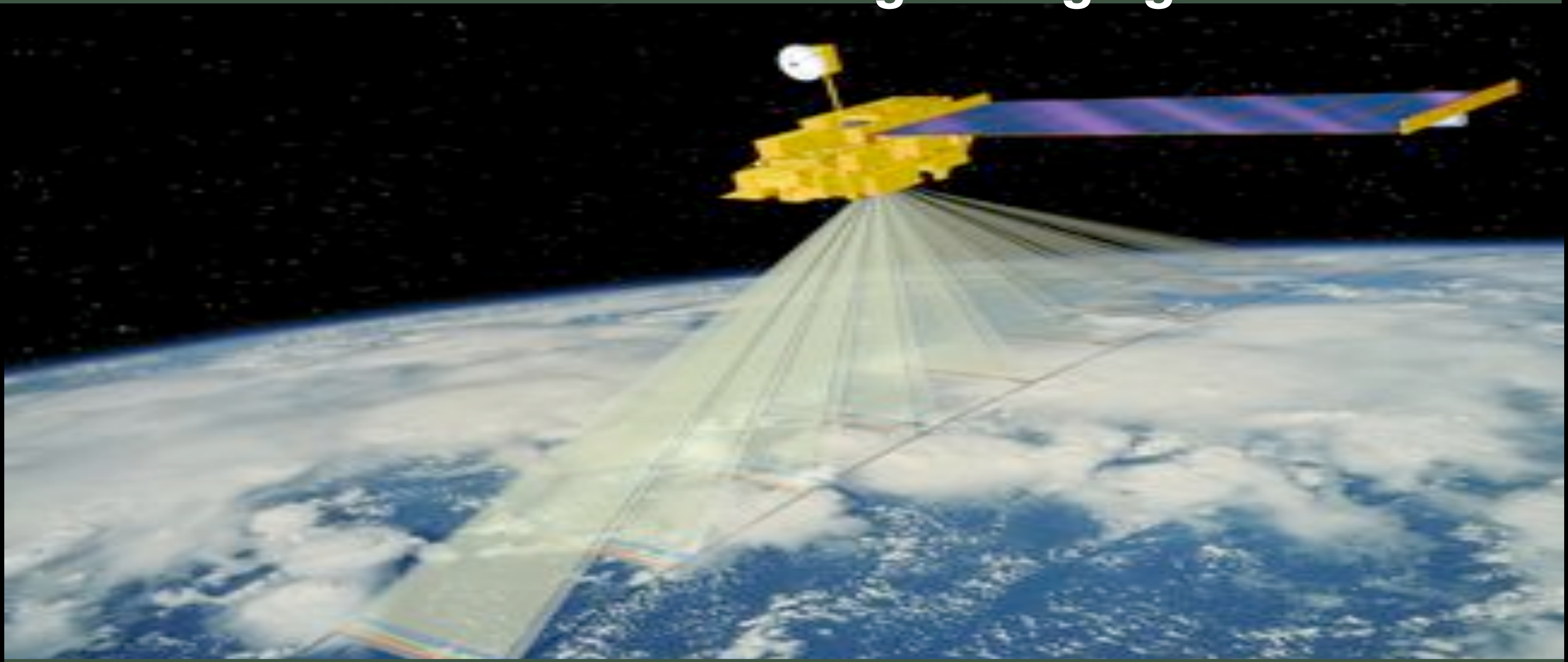
GO model inversion for mapping canopy height, cover, and aboveground woody biomass using NASA EOS Multiangle Imaging



Mark Chopping[1], Sawahiko Shimada[1,2], Michael Bull[3], Crystal Schaaf[4], Feng Zhao[4], Zhuosen Wang[4], John V. Martonchik[3], and others

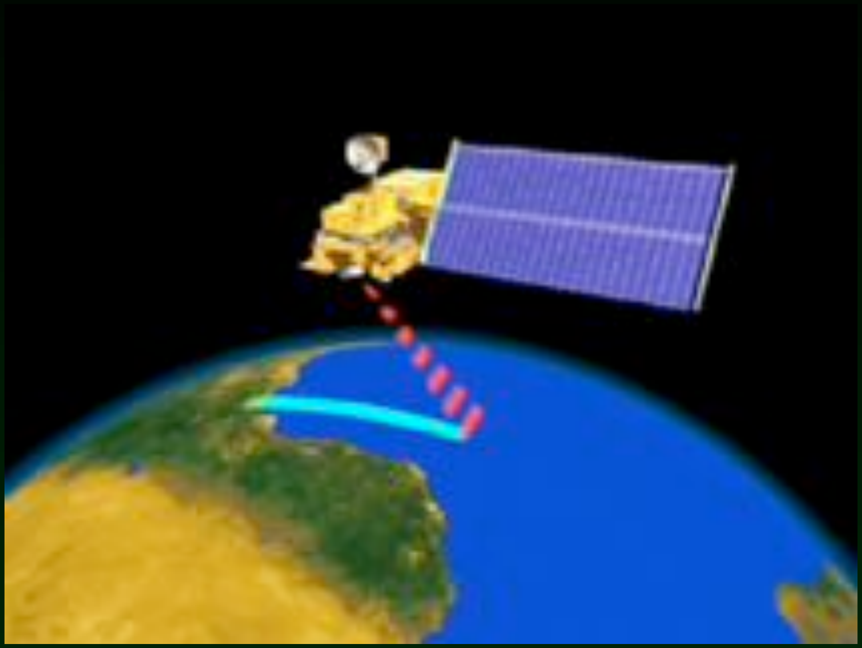
[1]Montclair State University [2]Tokyo University of Agriculture [3]NASA/JPL [4] Boston University

MODIS/VIIRS Science Team Meeting, Washington, DC January 26, 2010

Overview

1. Fundamentals
2. Eyes on the Prize
3. Methods & Quick Recap.
4. New Results and Work in Progress
5. Conclusions

MODIS is a multiangle instrument



(VIIRS will be too)

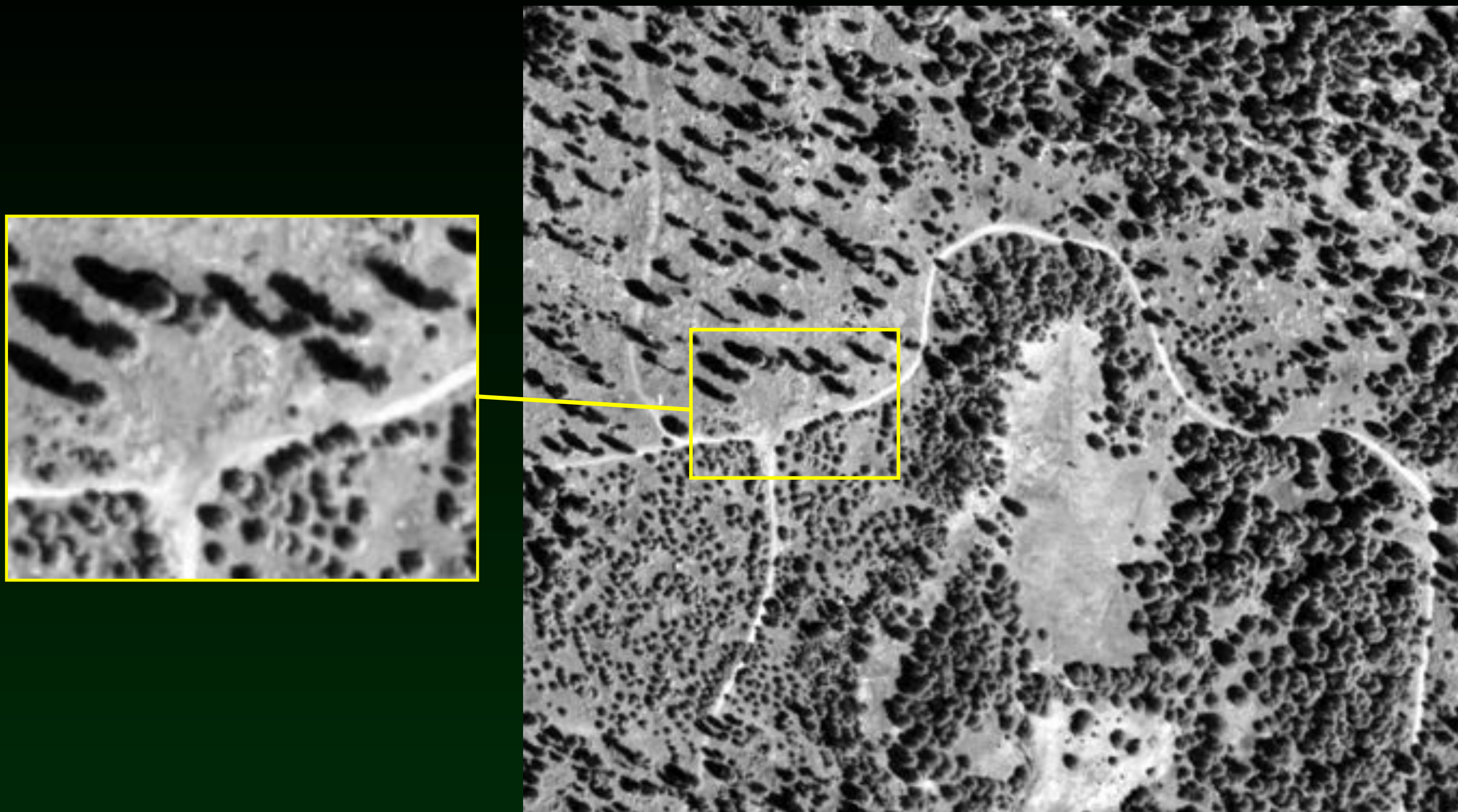
Fundamentals

The terrestrial surface is NOT FLAT

Protrusions cast shadows

Fundamentals

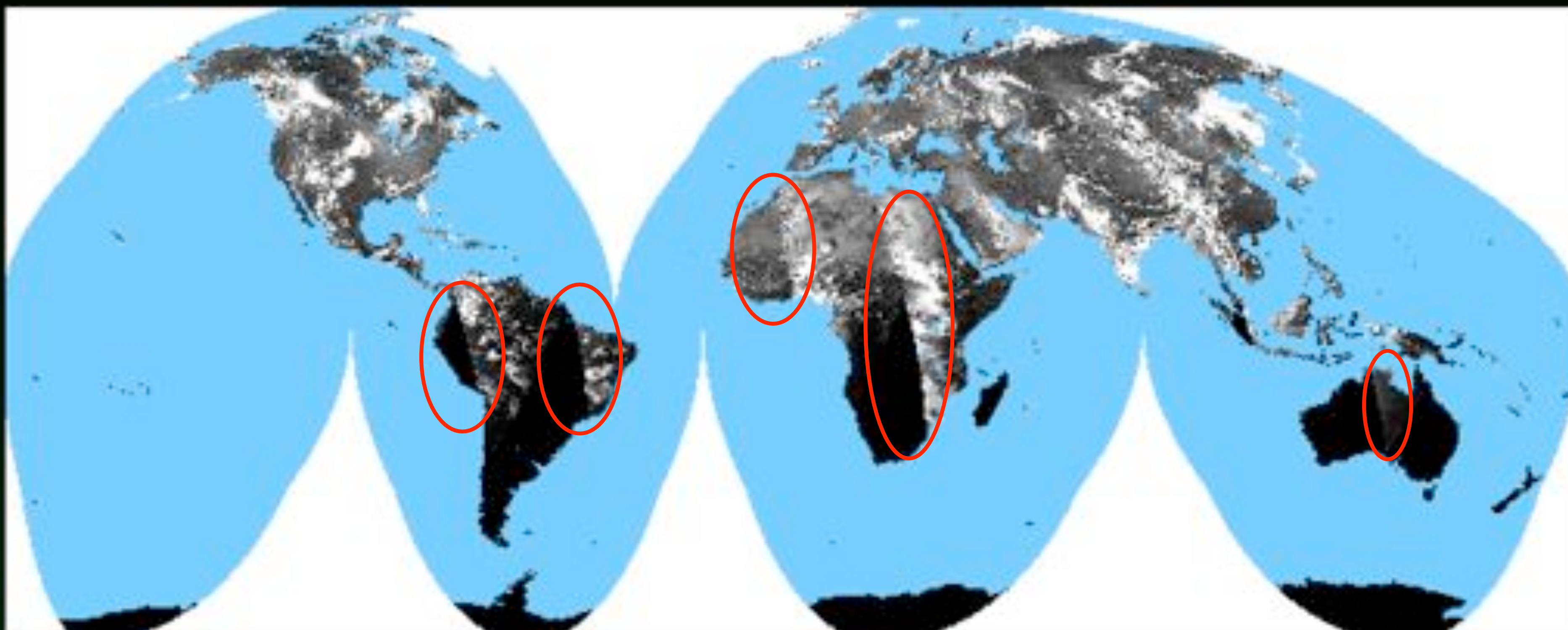
The terrestrial surface is NOT FLAT



Trees cast shadows; and scattering elements in the canopy & below introduce reflectance anisotropy

Fundamentals

Combined effects of lack of flatness and large off-nadir across-track viewing:



NOAA AVHRR-GAC NEAR-INFRARED GLOBAL IMAGE

Implications

Surface-leaving spectral radiances observed at a variety of sun-target-sensor angular configurations are intrinsically inconsistent so we must make BRDF corrections. This is best accomplished by adjusting a dedicated BRDF model -- and this approach also provides measures of albedo and kernel weights that can be used for other purposes.

Since the observed radiation field is dependent on the physical structure of the surface, there is also the opportunity to access structural information -- but this is not easy (approaches: ANIX, SSI, RT/GO canopy reflectance models, spectral invariants).

Models have the advantage that the behavior of parameters can be checked.

Eyes on the Prize

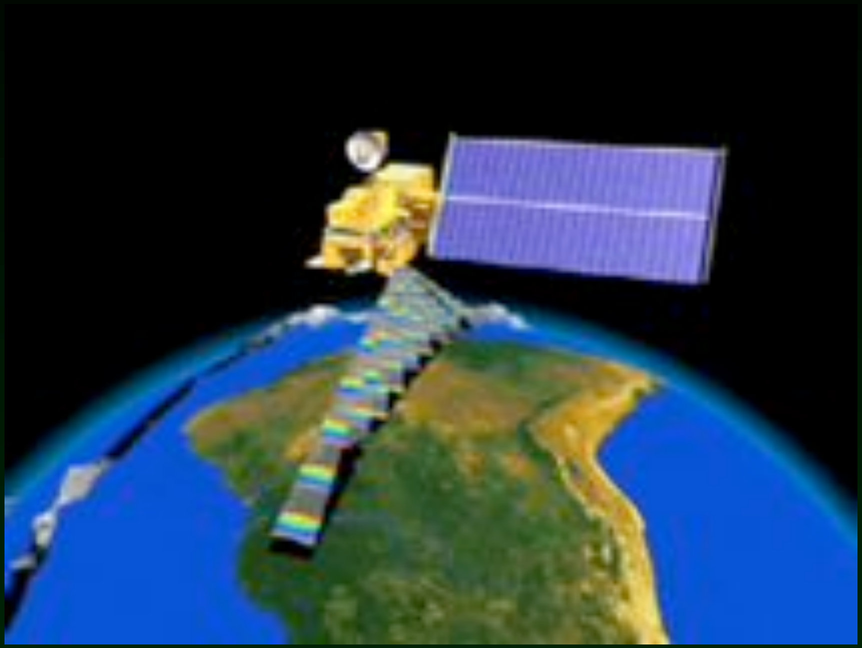
NASA Carbon Cycle and Ecosystems & Terrestrial Ecology Programs Science Question:

"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?"

To address these questions, we must be able to map the distribution of aboveground woody carbon stocks

New Mapping Work with MISR

MISR: EOS multiangle imager



- Nine cameras viewing in the along-track direction
- Advantage: almost instantaneous acquisition
- Disadvantage: thinner swath = lower coverage

New Mapping Work with MISR

Goal: Produce woody plant maps (fractional cover, mean height, aboveground biomass) for 2000 & 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 (235.8 million locations in maps)

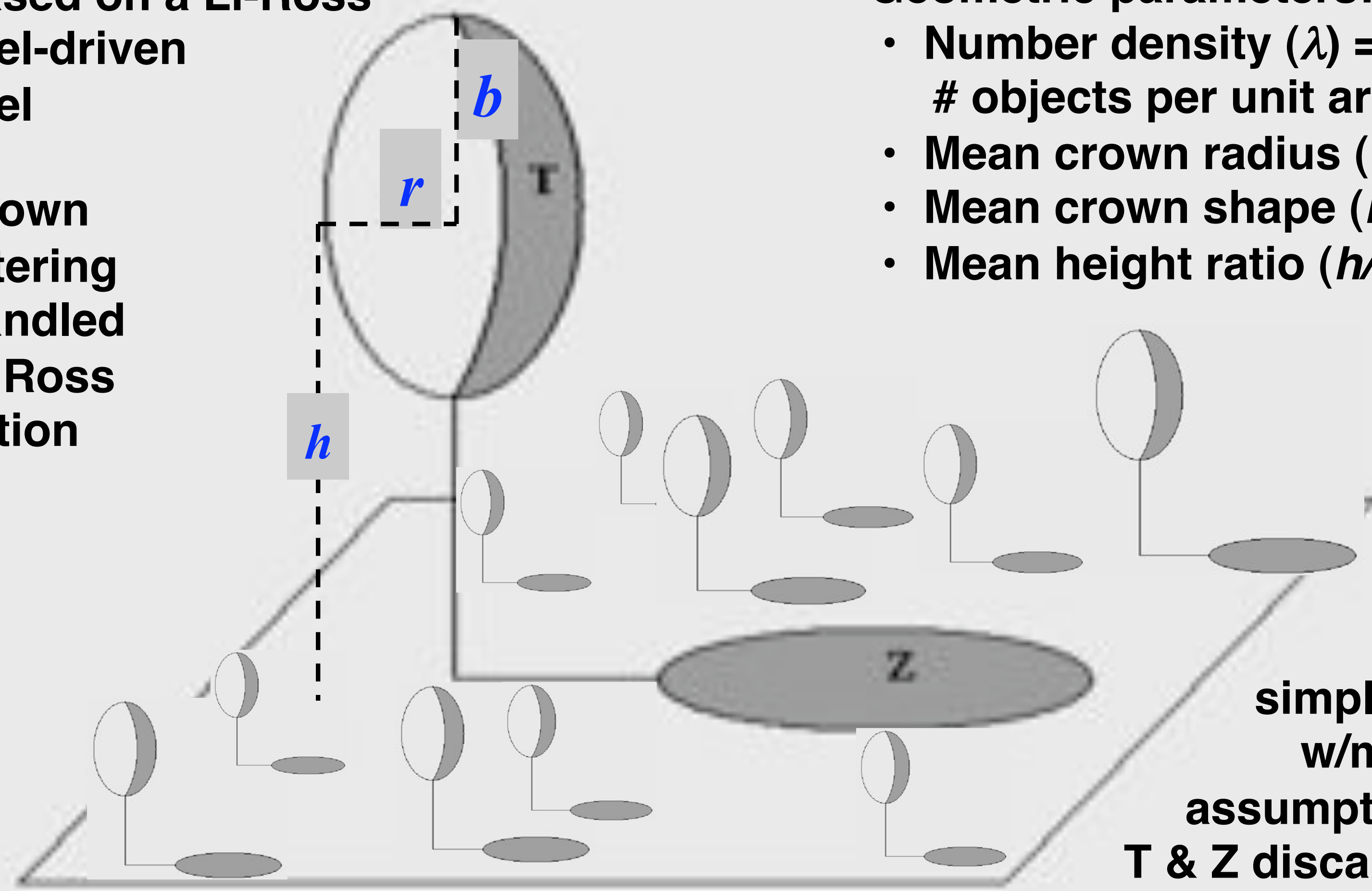
Approach: GO model inversion using injection of a dynamic (per-pixel) background, derived from BRDF model kernel weights. The GO model is simple - but that is part of the experiment.

Methods: Geometric-Optical Model (~Li-Strahler)

Adapted from: Wenge Ni-Meister

The GO model variant
Is based on a Li-Ross
kernel-driven
model

In-crown
scattering
is handled
by a Ross
function



Geometric parameters:

- Number density (λ) = # objects per unit area
- Mean crown radius (*r*)
- Mean crown shape (*b/r)*
- Mean height ratio (*h/b)*

Very simplified w/many assumptions
T & Z discarded

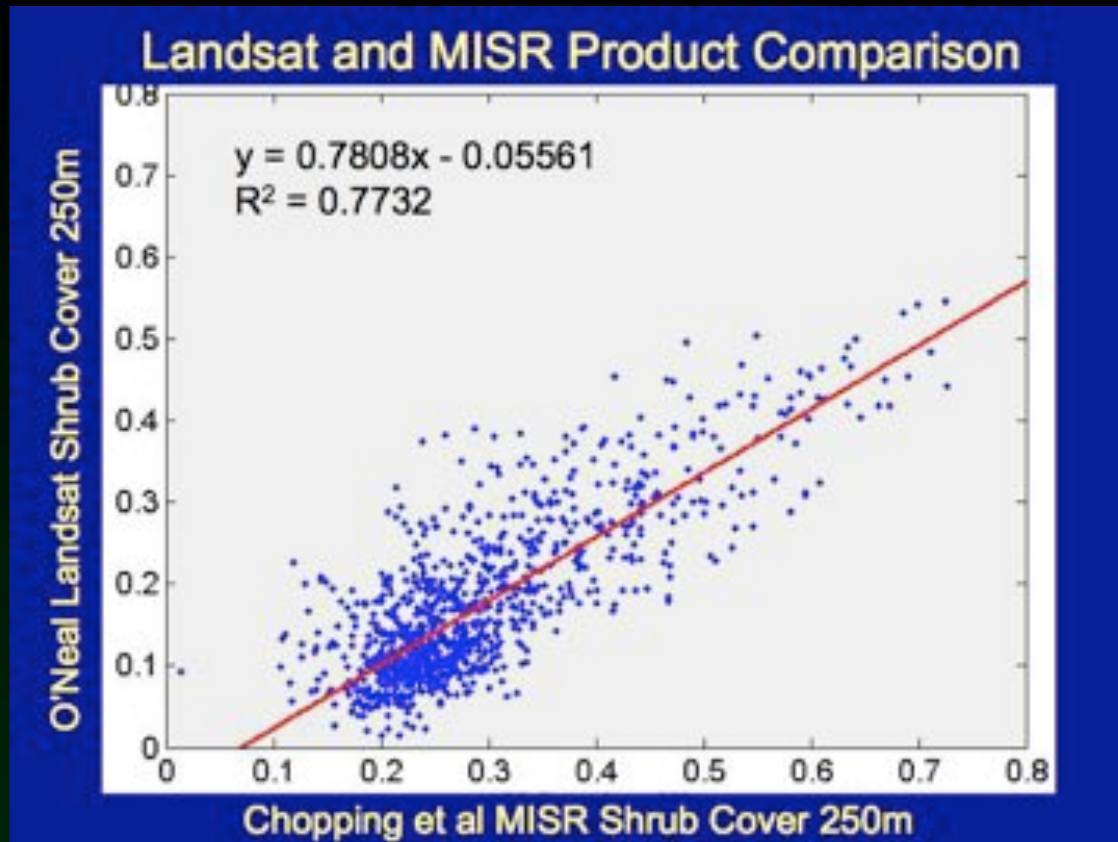
But before inversion we have to estimate the background contribution.
We can do this using the kernel weights of a Li-Ross BRDF model.

Forschung durch serendipity

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 $h = h/b \times b$; $b = b/r \times r$ 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 Mountains adjacent to the USDA, ARS Jornada Experimental Range.

MISR/GO vs Landsat Shrub Cover

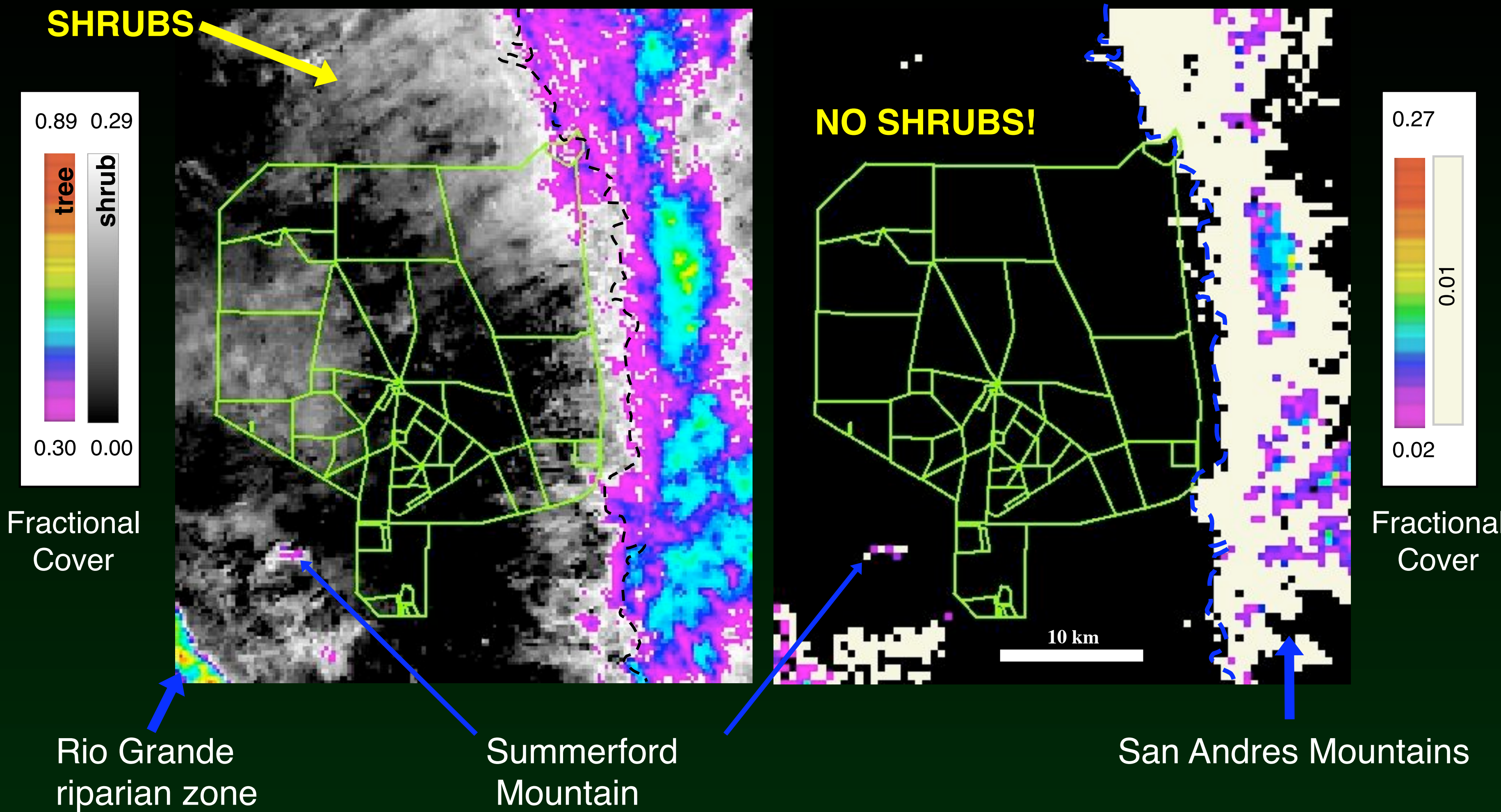
Shrub mapping by Kelley O'Neal (UMD) in Chihuahuan Desert grasslands in New Mexico using Landsat and spectral unmixing showed an R^2 of 0.77 vs our MISR/GO results (Landsat aggregated to MISR scale).



Courtesy: Kelley O'Neal, U. Maryland

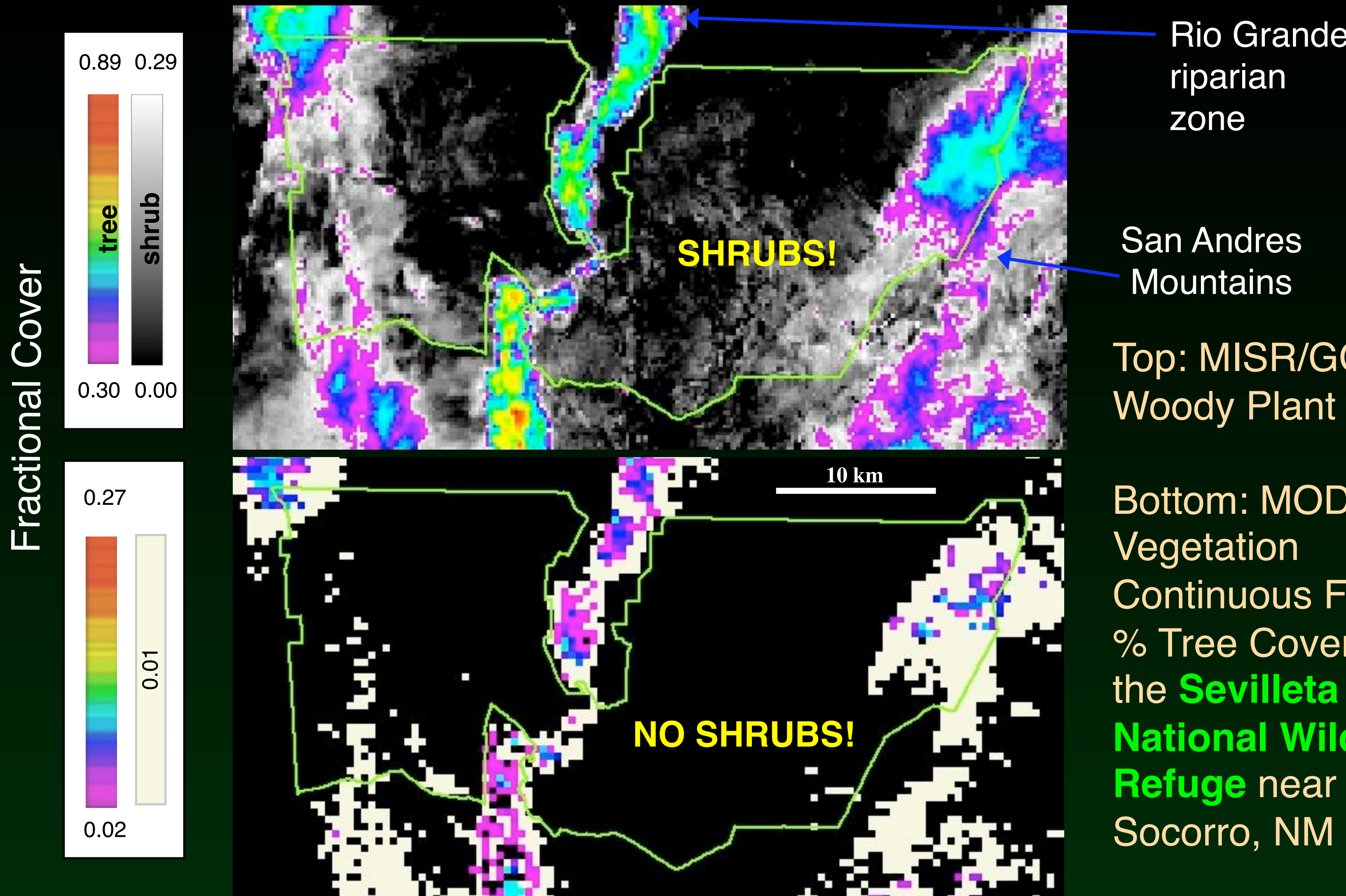
We also showed good results vs. maps derived from Ikonos high resolution panchromatic imagery.

MISR 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**

MISR Cover Retrievals with VCF % Tree Cover Map



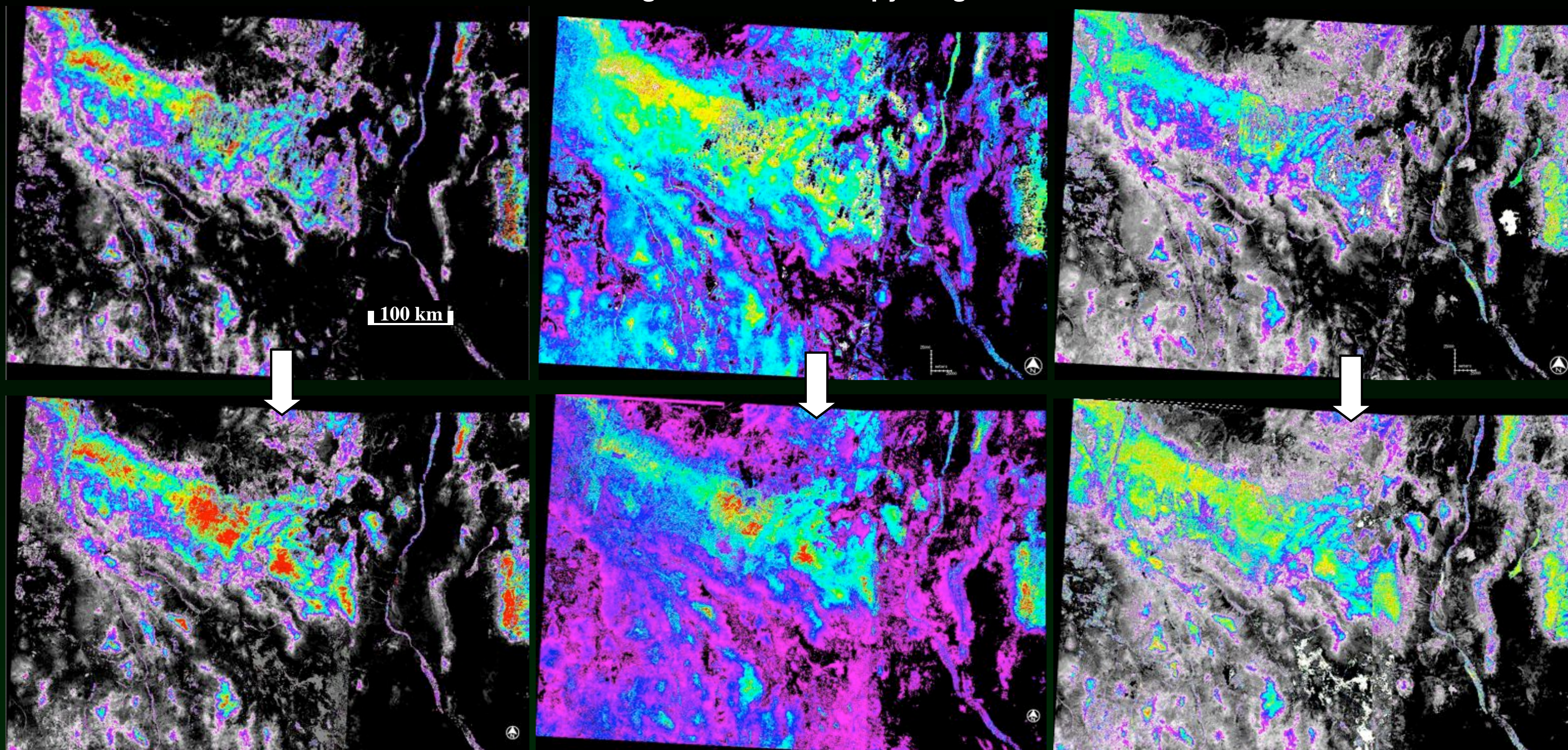
Top: MISR/GO Woody Plant Cover

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

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

Compositing on min(RMSE) for Large Area Mapping @ 250 m

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

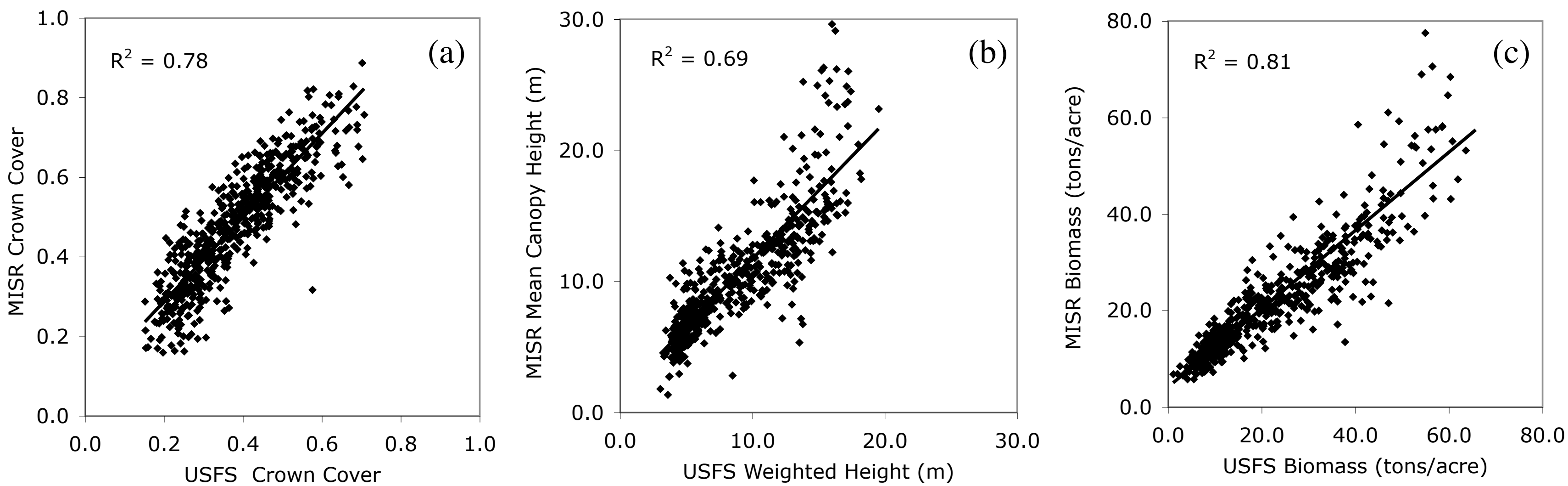


Aboveground Biomass
0.00 — 6.70 — >50.0
Tons/acre
0.00 — 15.0 — >110.0
Mg ha⁻¹ — 100 km

Mean Canopy Height
< 1.00
1.00 — >20.00
meters

Fractional Crown Cover
0.00 — 0.29
Shrubs
0.30 — 0.90
Forest

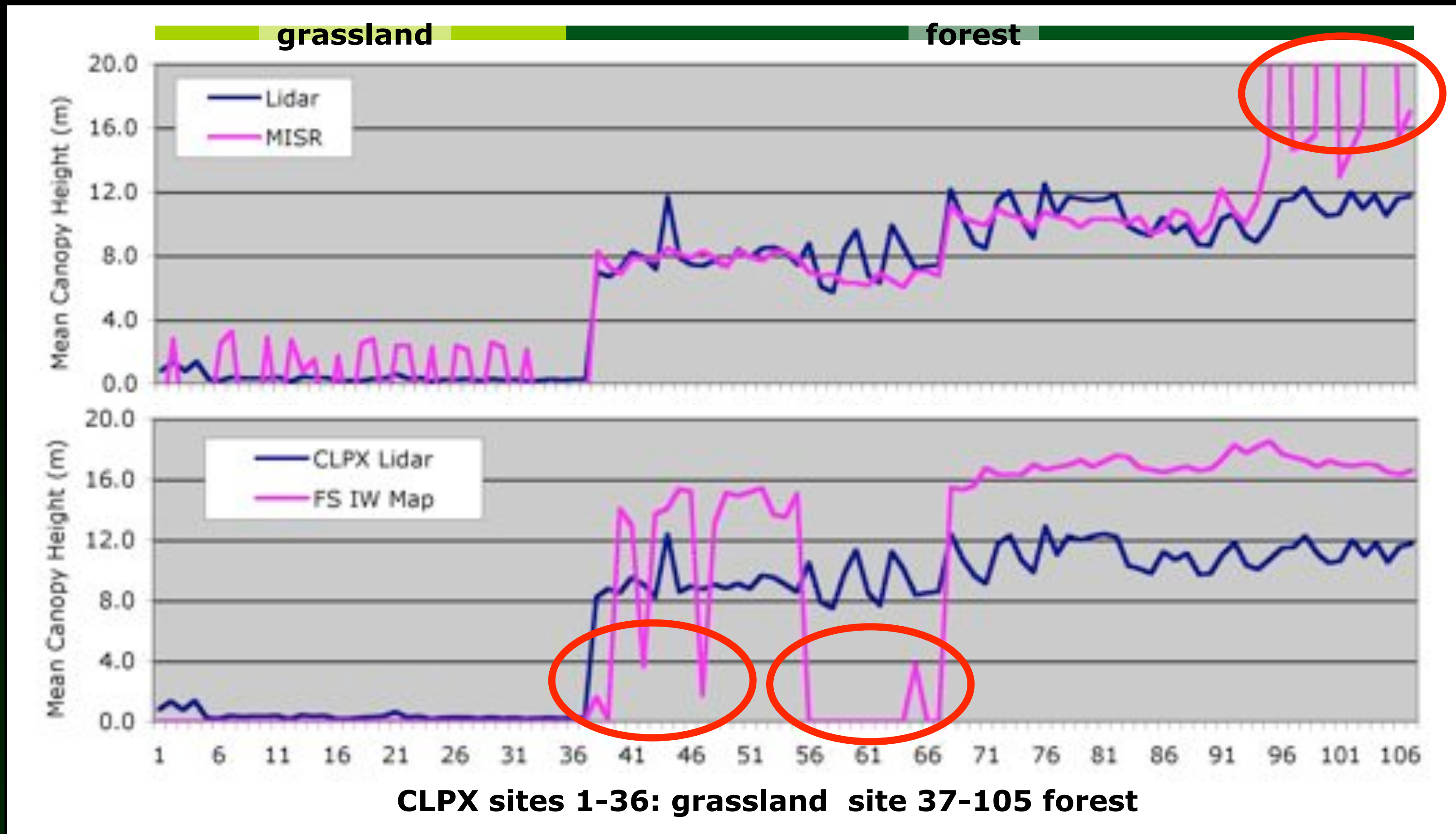
AZ & NM Canopy Cover, Height & Biomass Mapping Results



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%).

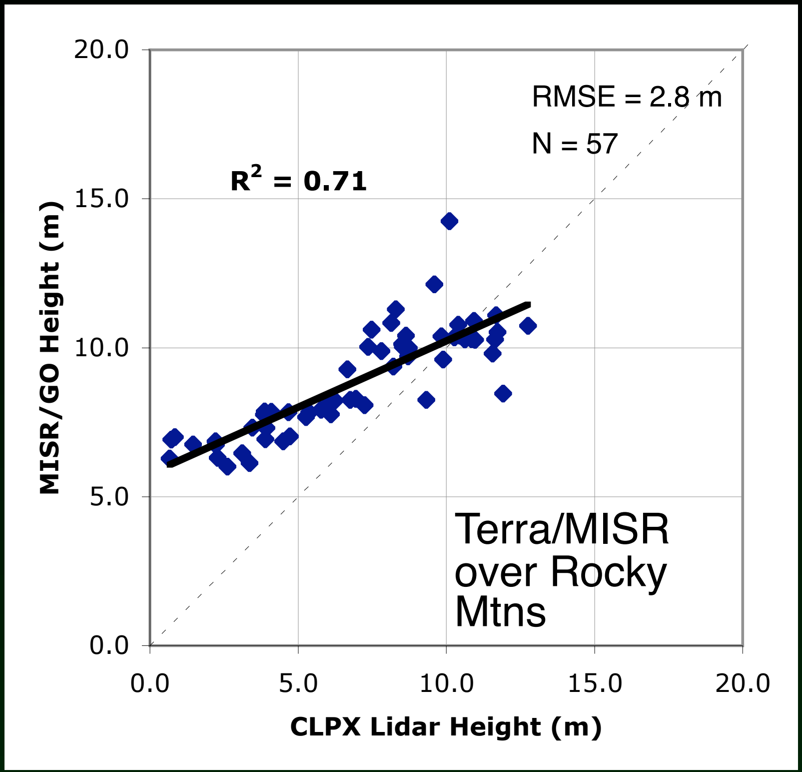
These results were highly compatible with the MODIS-based Forest Service 2005 Interior West maps. But how to validate properly? Lidar and high resolution data are needed (field inventory data are at the wrong scale for heterogeneous canopies). So: how well can we do vs discrete-return lidar?

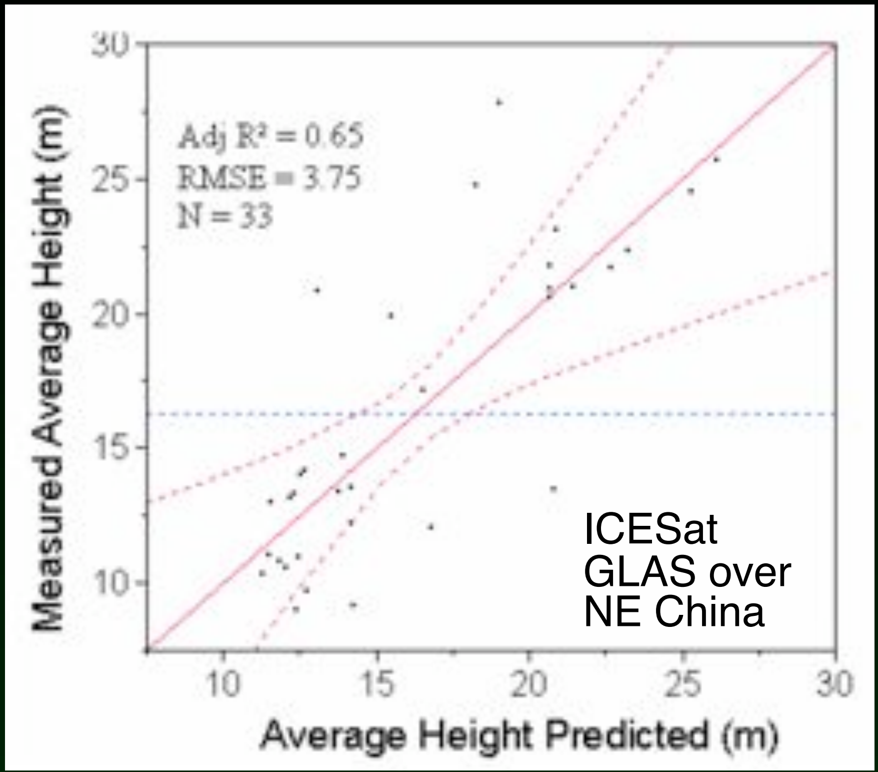
Colorado Rockies: MISR/GO Results vs CLPX lidar data



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 (f.cov goes to 1.0).

“Estimates from Active Instruments Not Perfect”

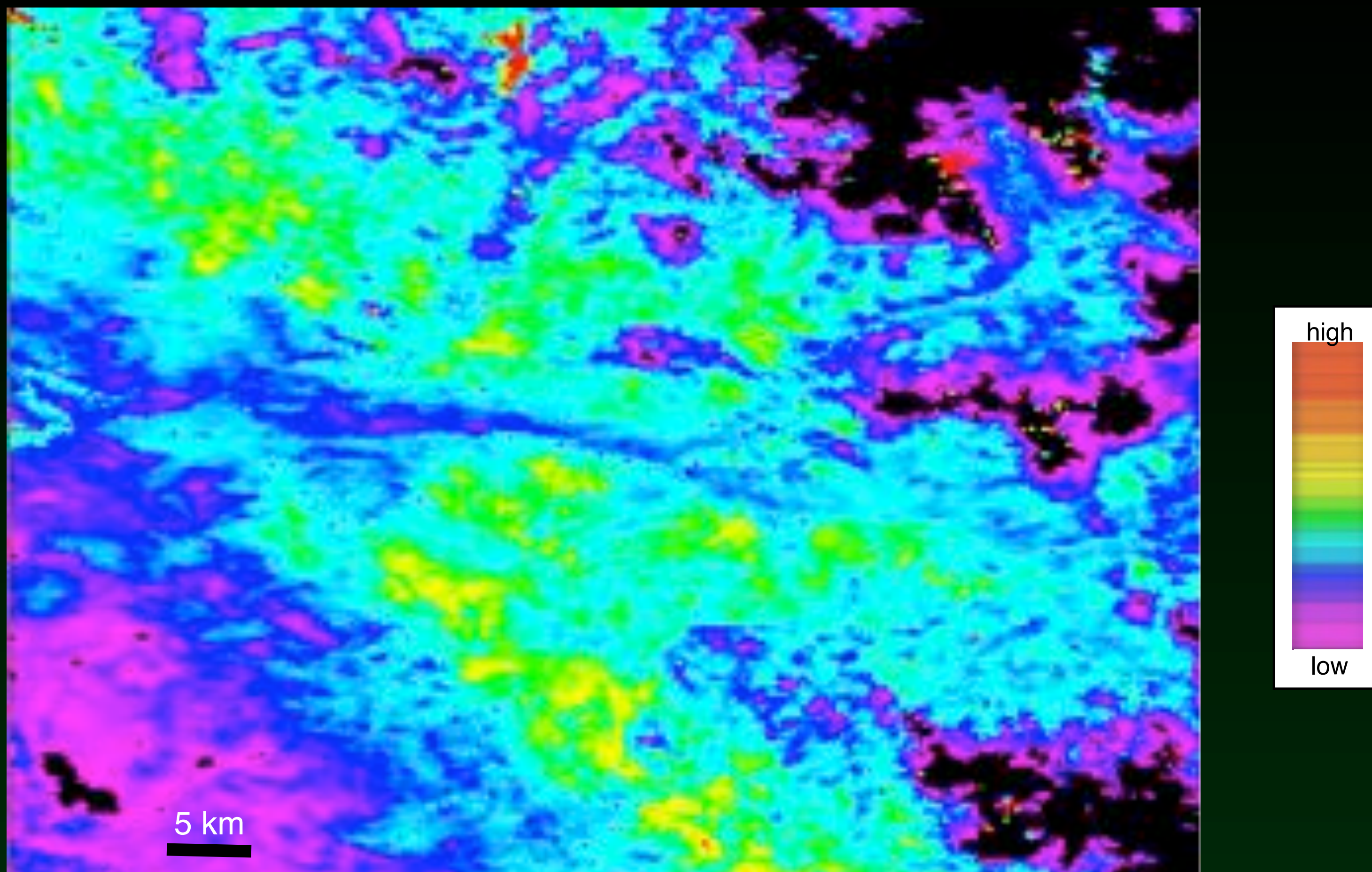




Not strictly comparable… but you get the idea

Notice the offset and bias in the MISR/GO-lidar relationship

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

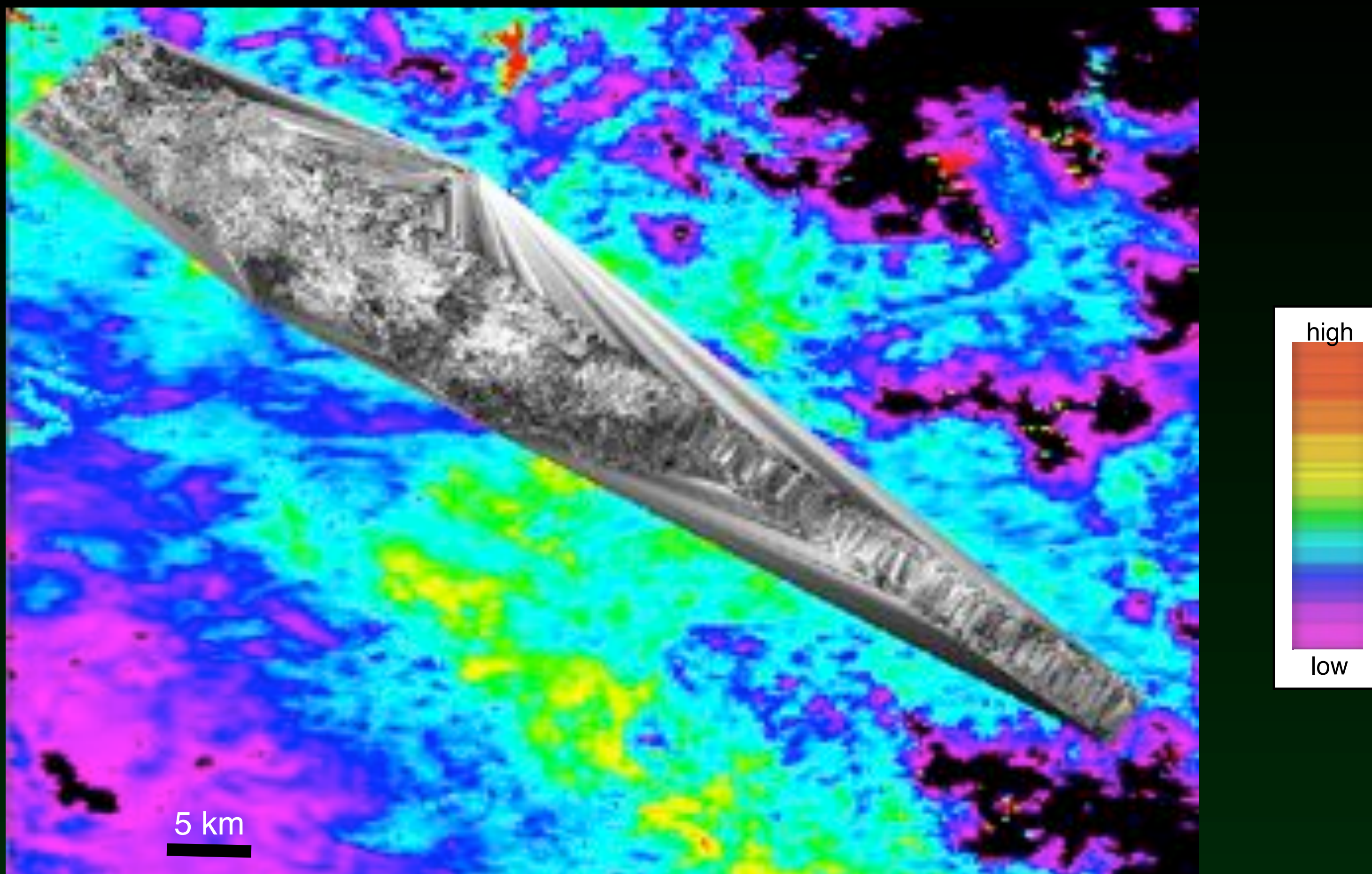


Greyscale: Interpolated LVIS RH100 canopy heights (September 2008)

Color scale: MISR/GO *h+b* (Terra orbit 46009, August 11, 2008)

BG based on a few cover estimates; recalibration is needed

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



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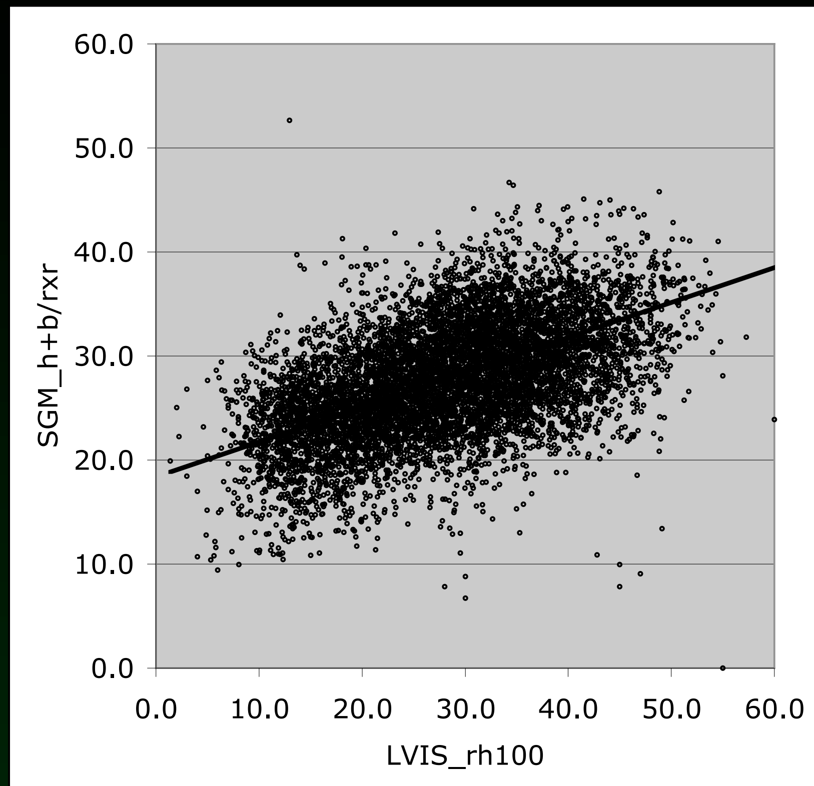
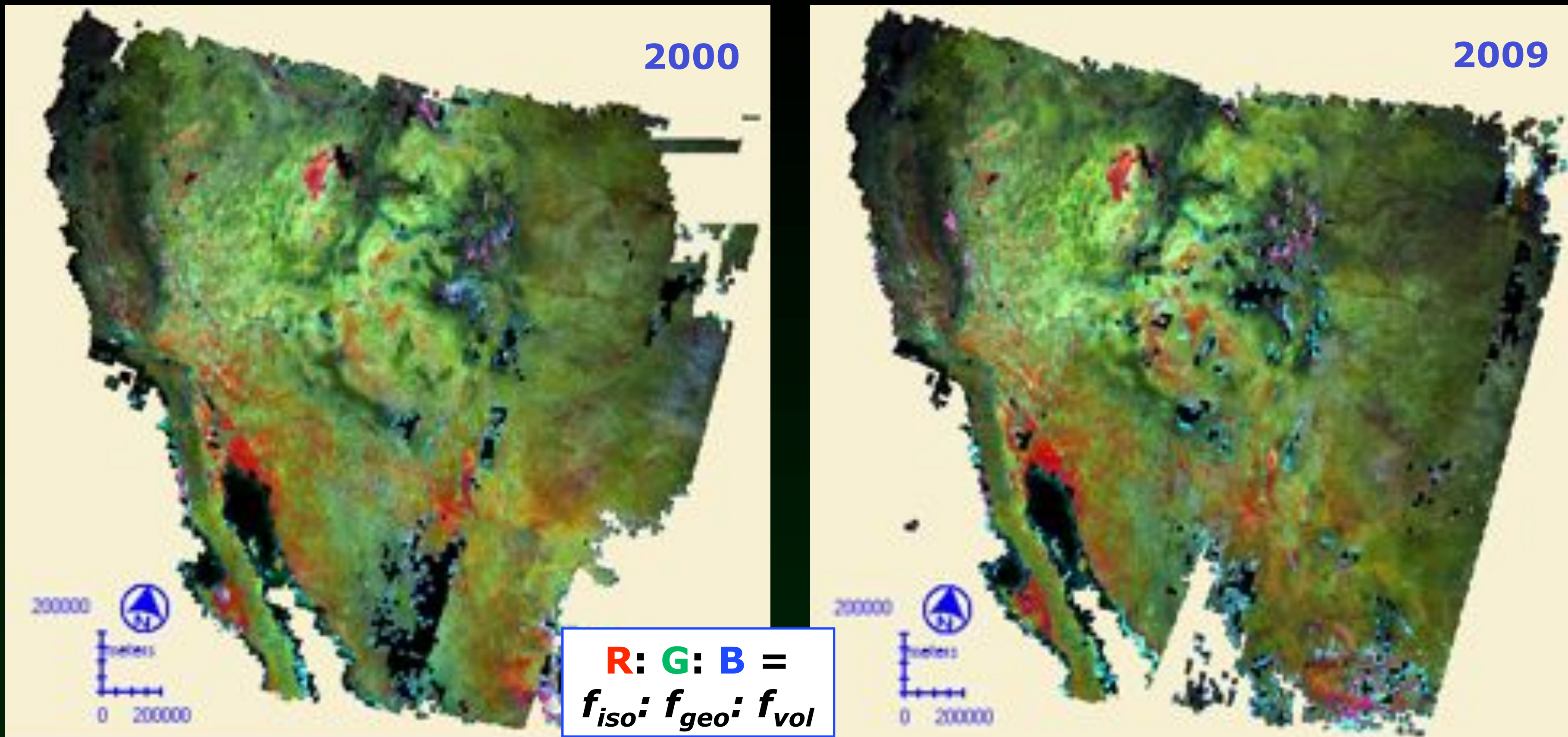
Canopy height: Initial MISR/GO vs LVIS (Sierra Nevada)



Retrieval offset/bias -- but this is at least partly because the dynamic background used was based on a few cover estimates extracted from Google Earth. Recalibration is clearly needed: we will be able to do this using canopy statistics from high resolution imagery (see later slides).

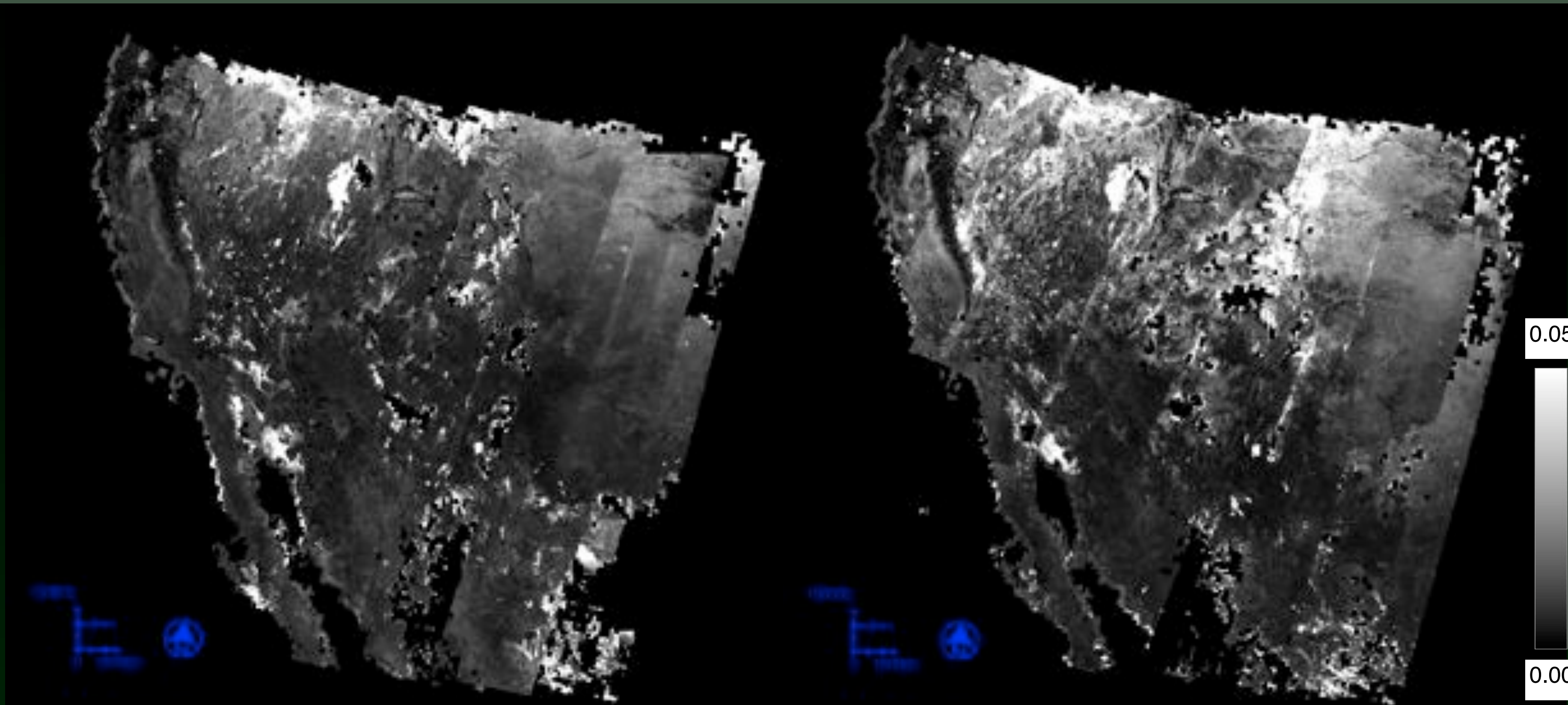
The Southwestern United States: L-RModel Kernel Weights



Li-Ross BRDF Model Kernel weight composite. The weights are needed for calculation of albedo and prediction of the background contribution -- and can be used empirically e.g., in classification.

from selected May 15 - June 15 MISR paths only

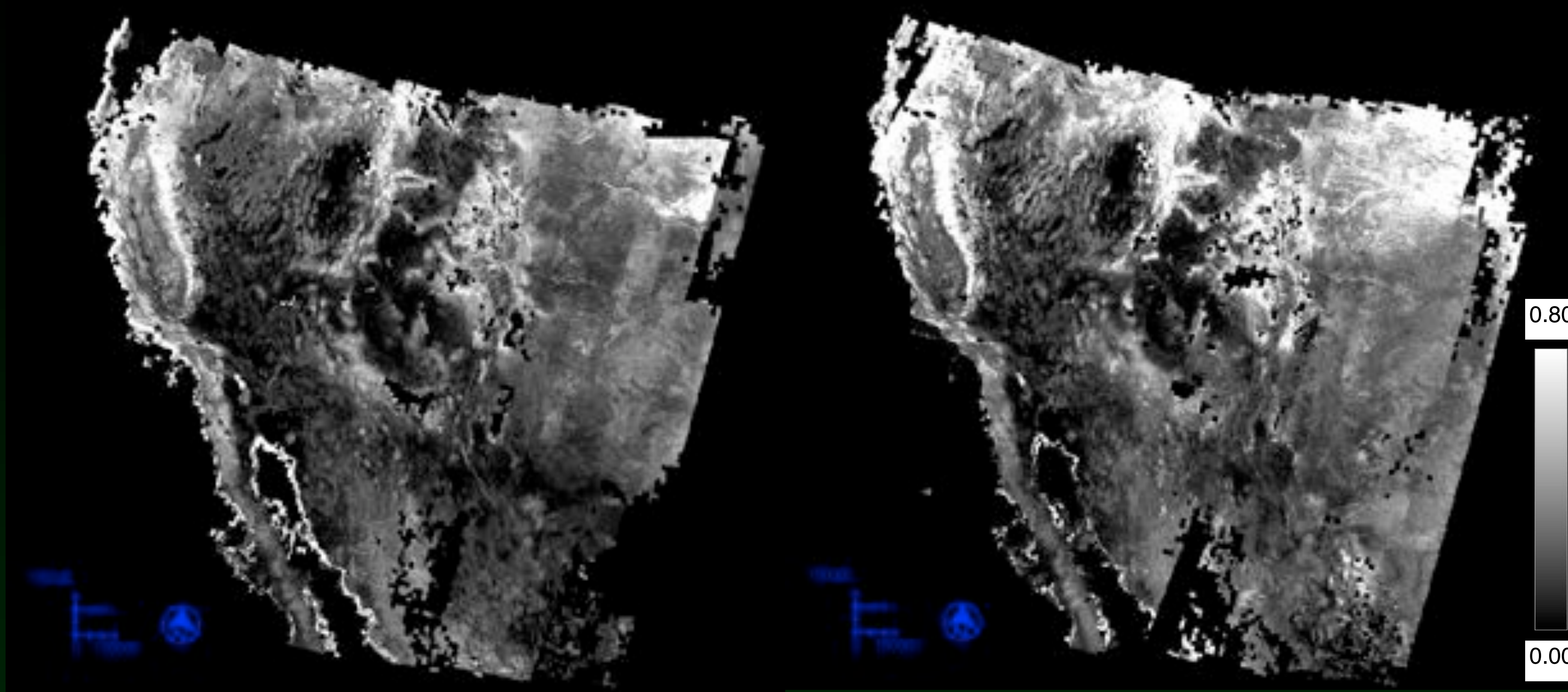
The Southwestern United States: Model-Fitting Error



RMSE (GO model fitting error), 2000 and 2009

…from selected May 15 - June 15 MISR paths

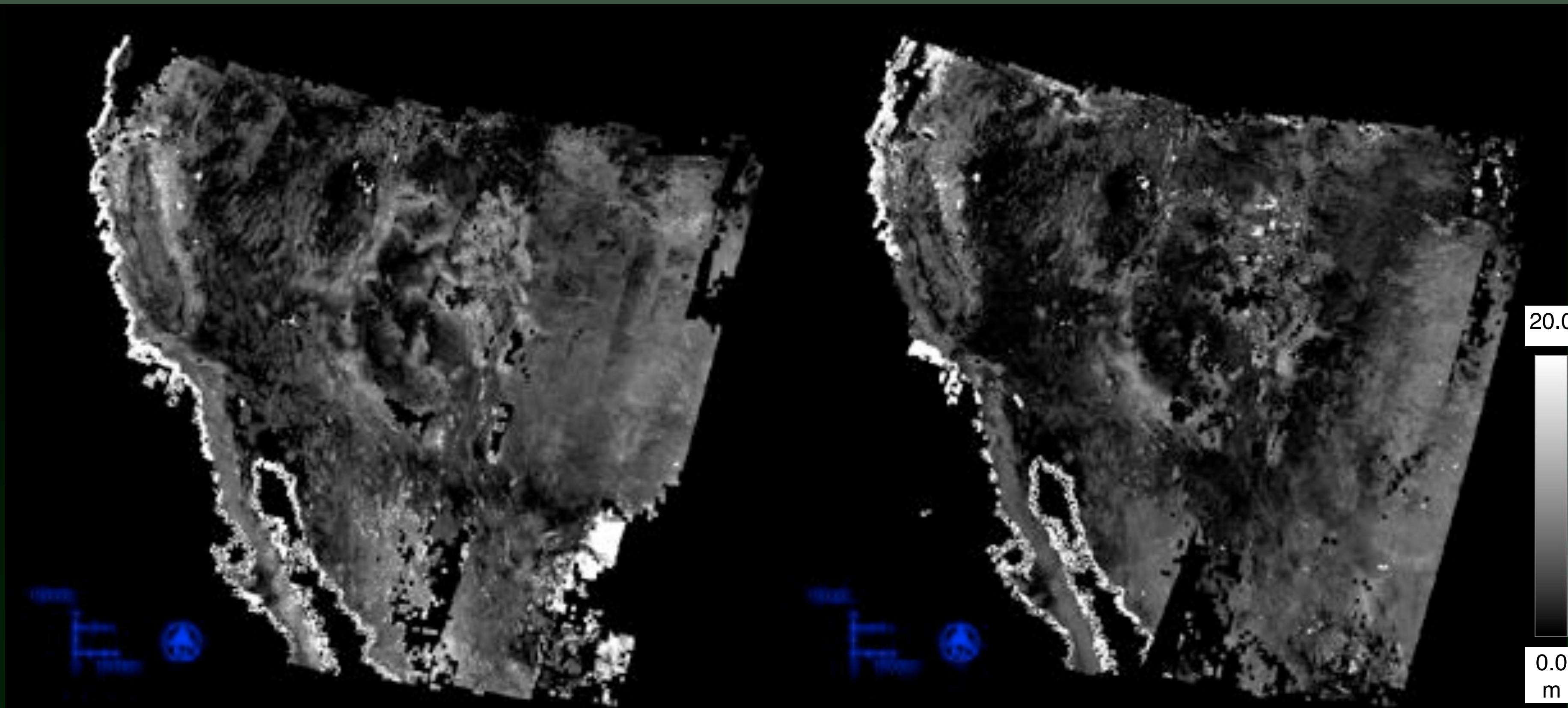
The Southwestern United States: Crown Cover



Fractional Crown Cover 2000 and 2009

…from selected May 15 - June 15 MISR paths

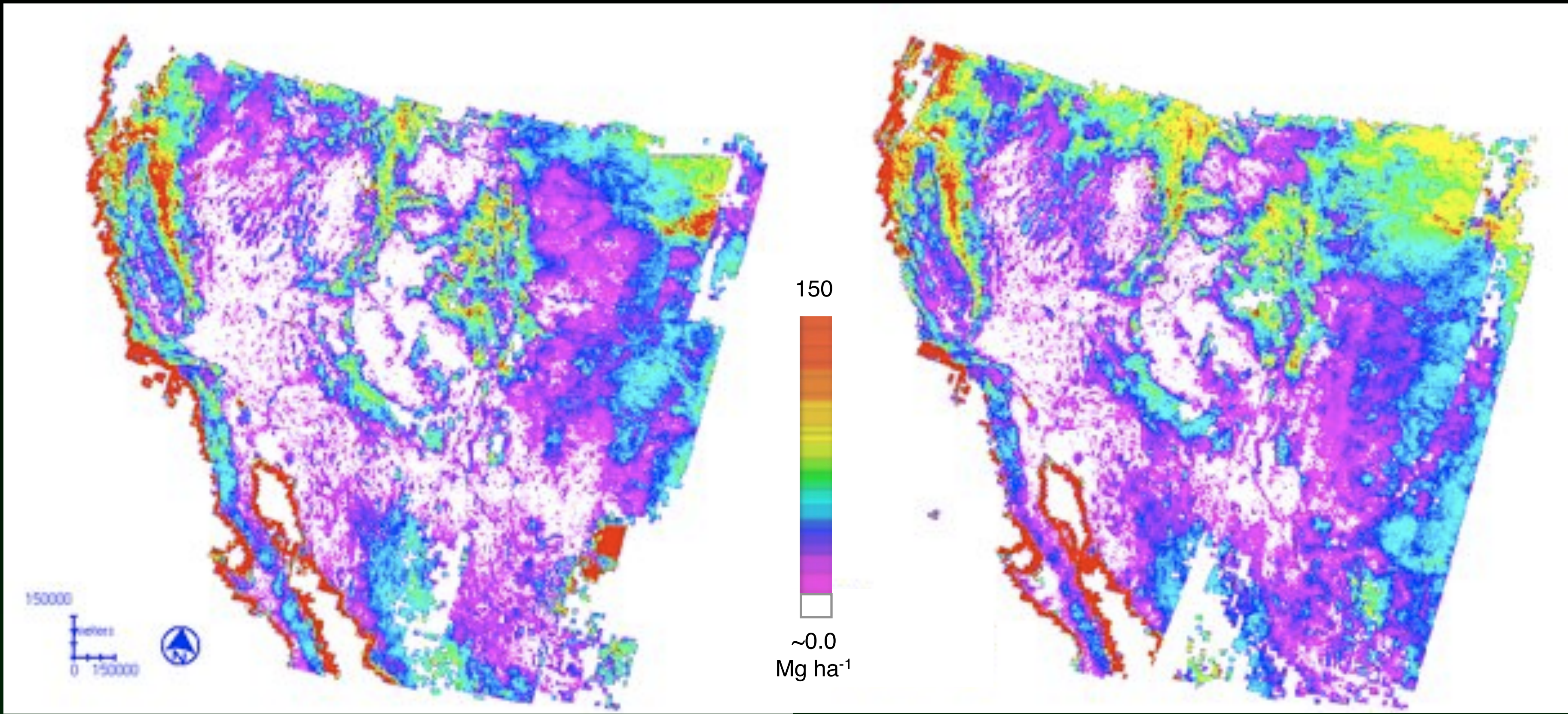
The Southwestern United States: Crown Height



Mean crown center height (m) 2000 and 2009

…from selected May 15 - June 15 MISR paths

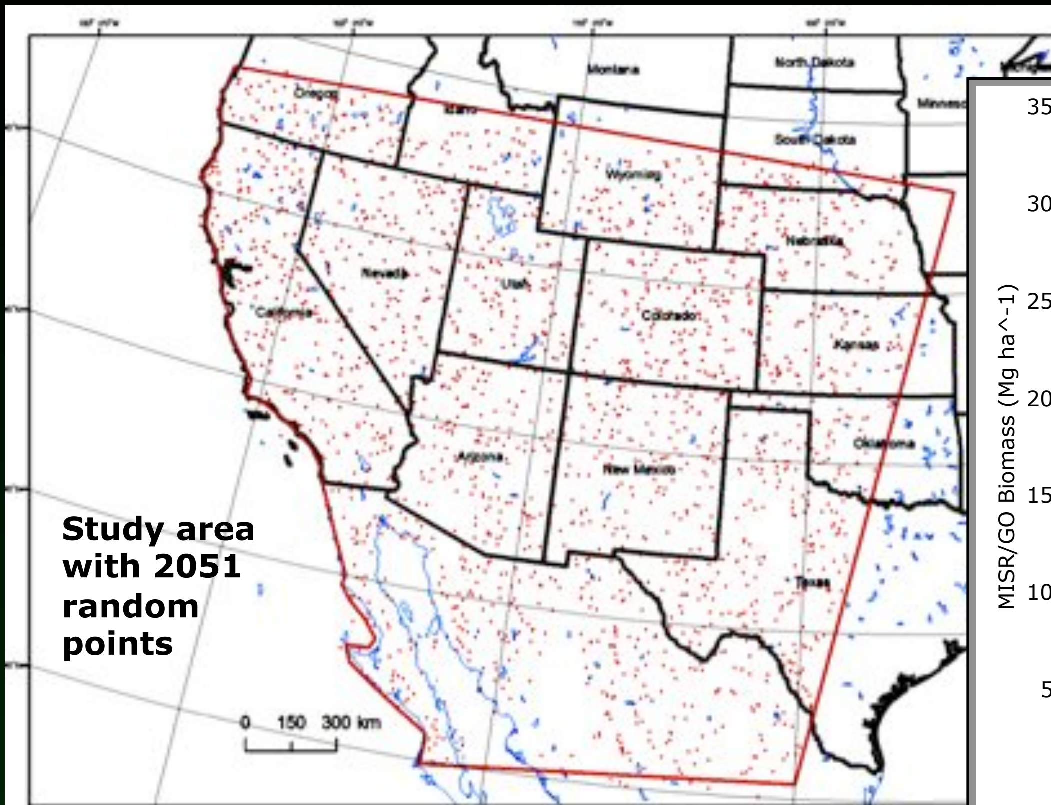
The Southwestern United States: AGL Biomass

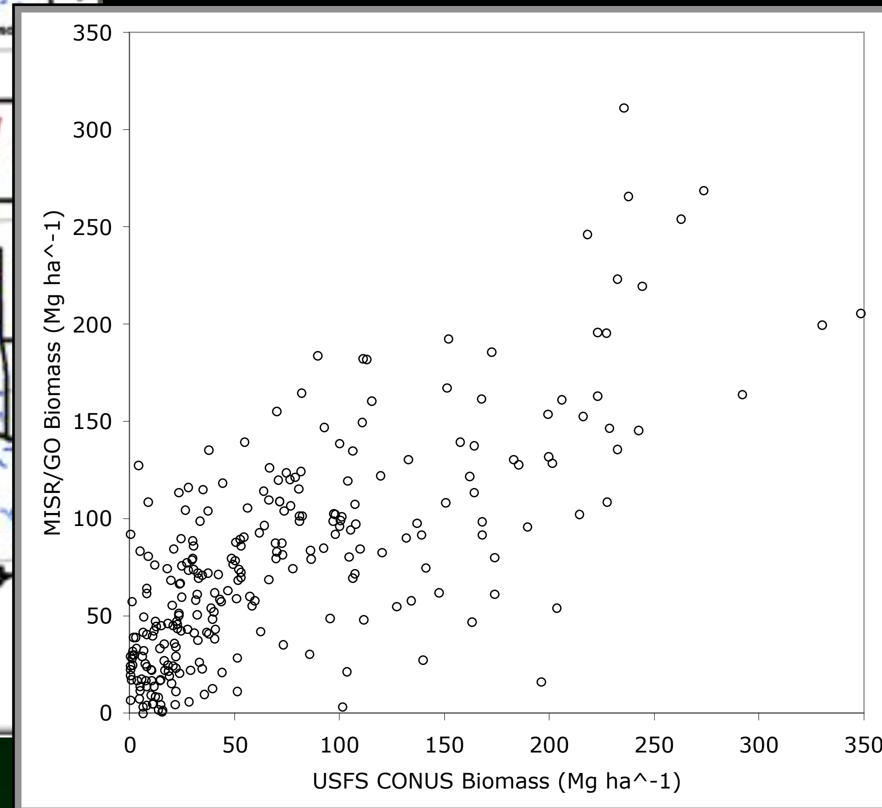


Aboveground Live Biomass (Mg ha^{-1}) 2000 and 2009
White = zero and missing retrievals
Regressed on USFS estimates (Blackard *et al*. 2008, RSE)

…from selected May 15 - June 15 MISR paths

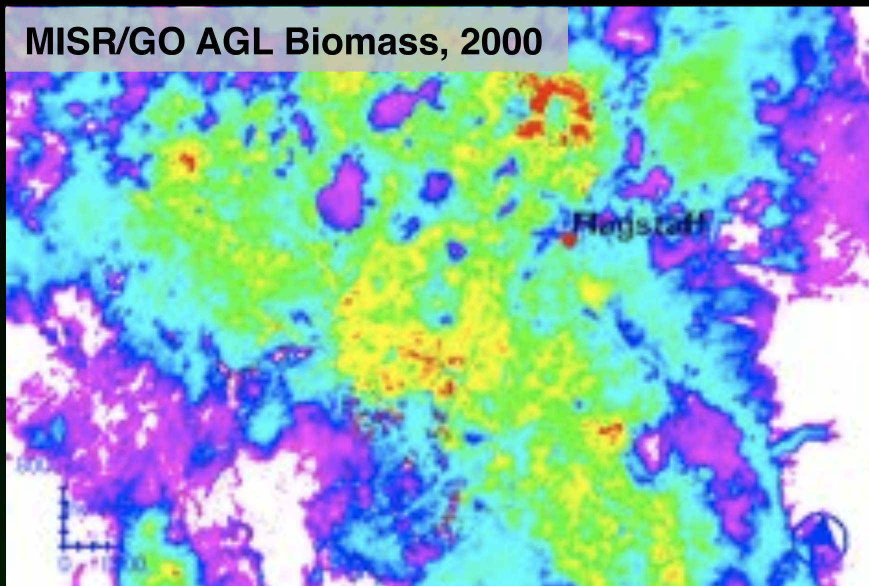
The Southwestern United States: MISR/GO vs USFS Biomass



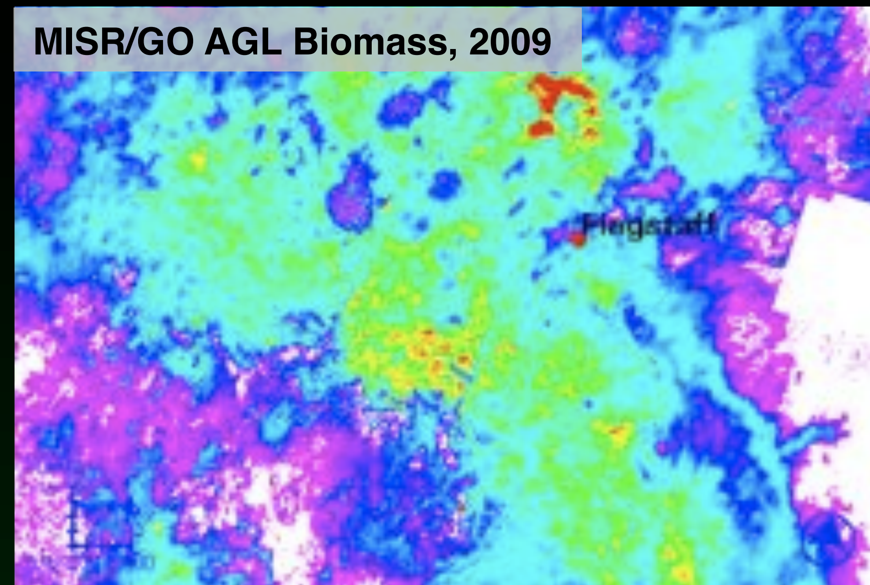


MISR/GO Aboveground Live Biomass (Mg ha^{-1}) for 2000 vs USFS AGL Biomass for 2002 (Blackard *et al*. 2008), random points, filtered by RMSE. How good are the USFS estimates?

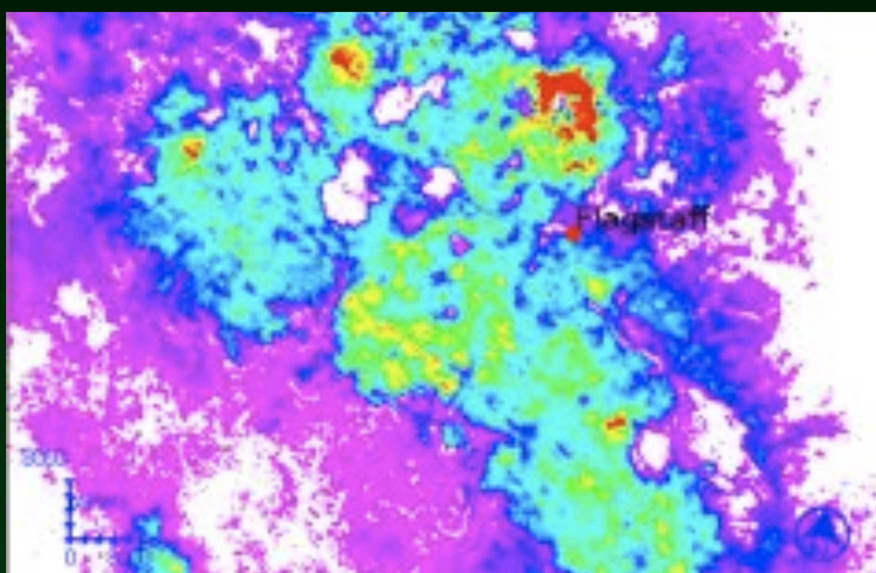
The Southwestern United States: MISR/GO vs USFS Biomass



MISR/GO AGL Biomass, 2000

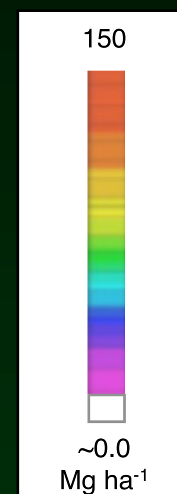


MISR/GO AGL Biomass, 2009



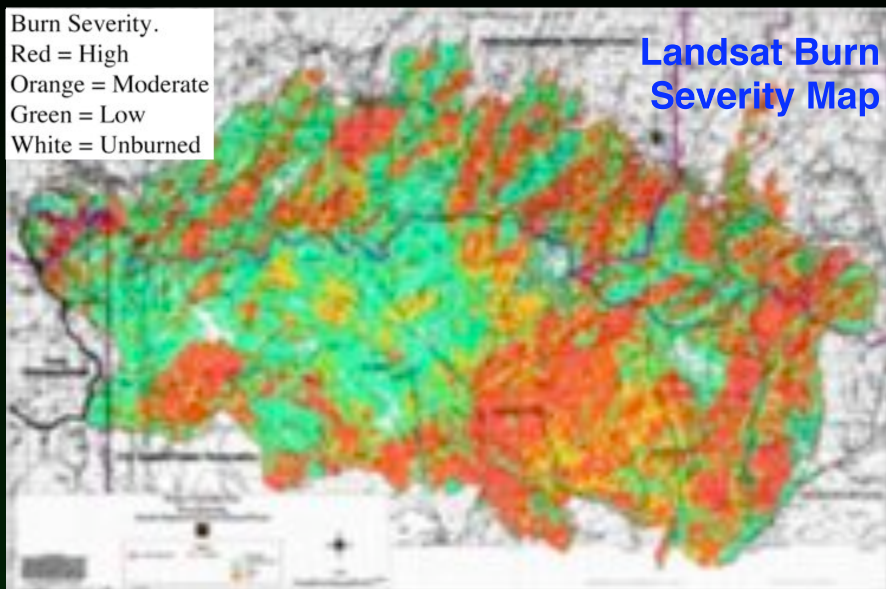
← **USFS Aboveground Live Biomass, 2002**

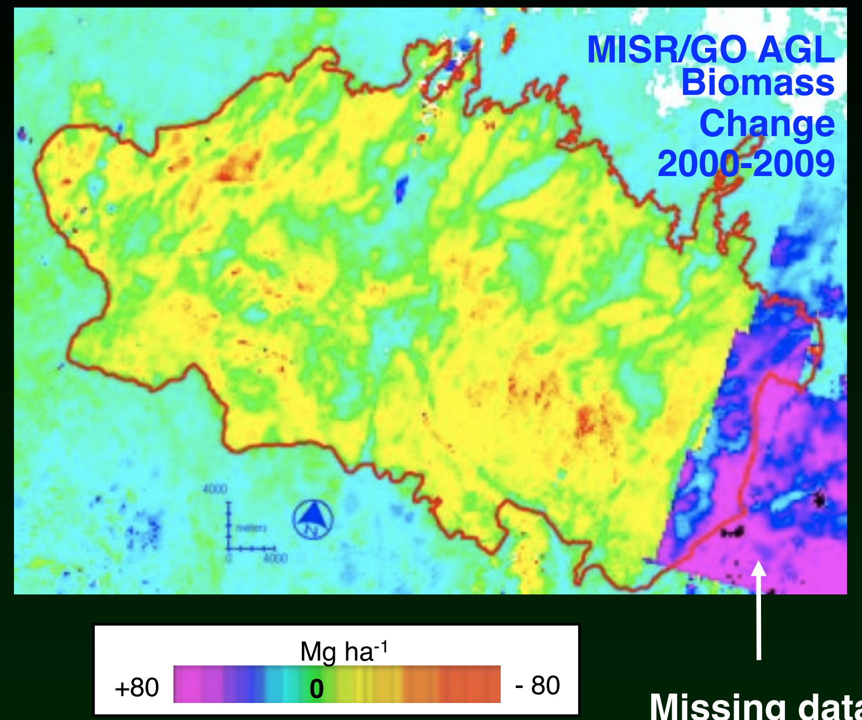
Based on Forest Inventory Analysis, MODIS, and other geospatial data.



2002 Rodeo-Chediski Fire, Arizona

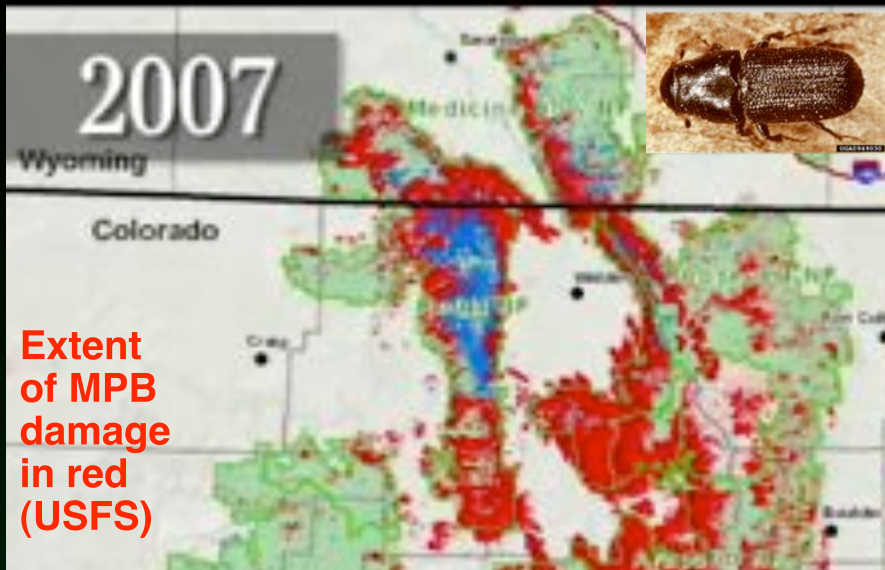
Change in Aboveground Live Biomass from MISR

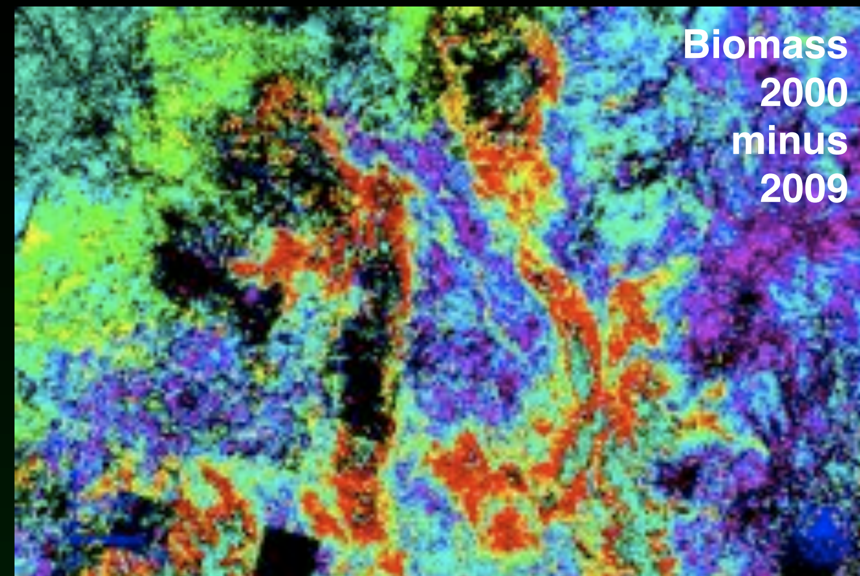


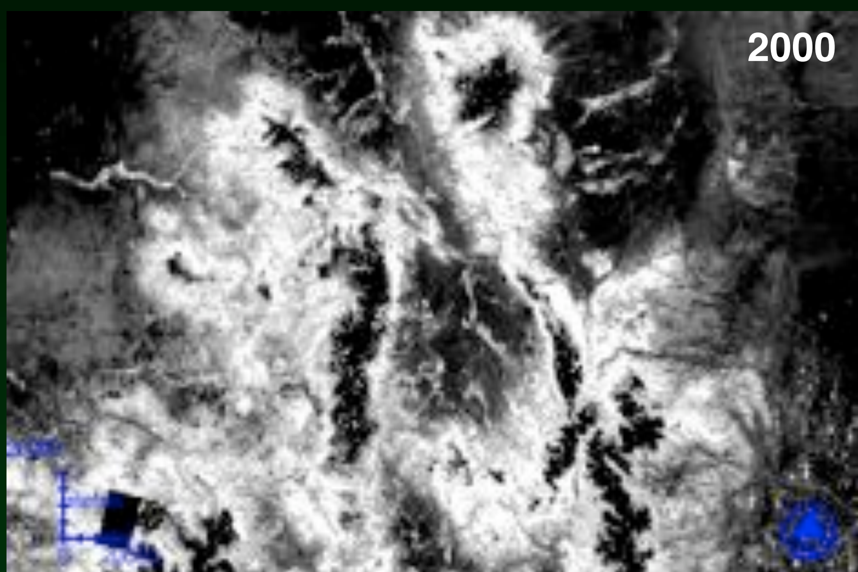


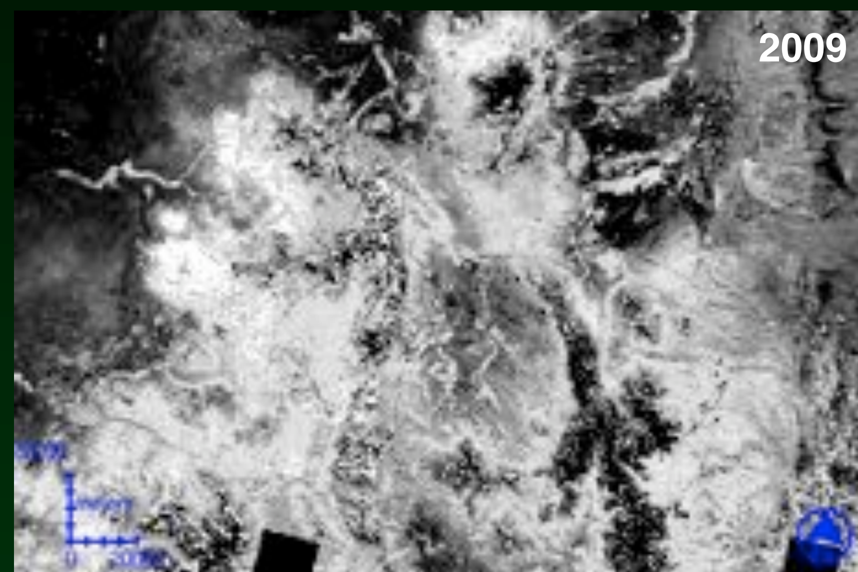
Biomass estimates more robust than cover or height

CO / WY Forest Biomass Loss: Pine Beetle Devastation

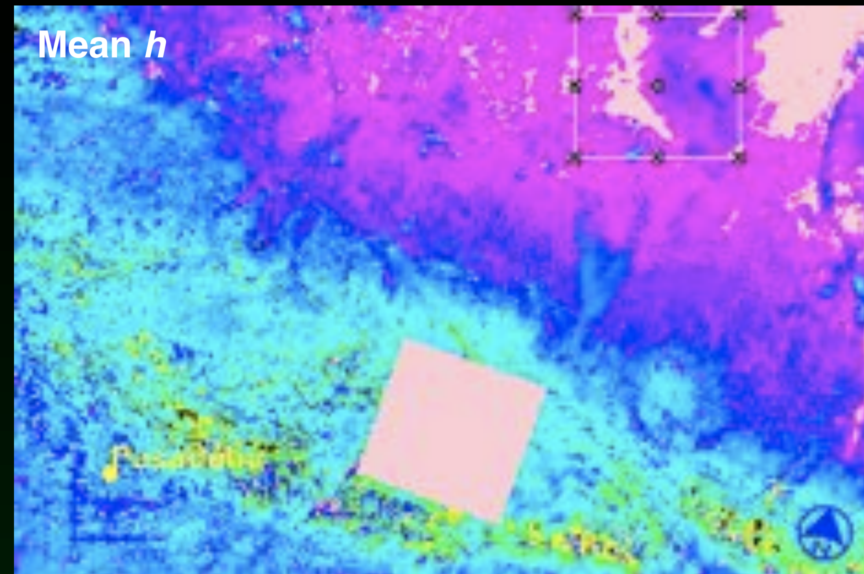


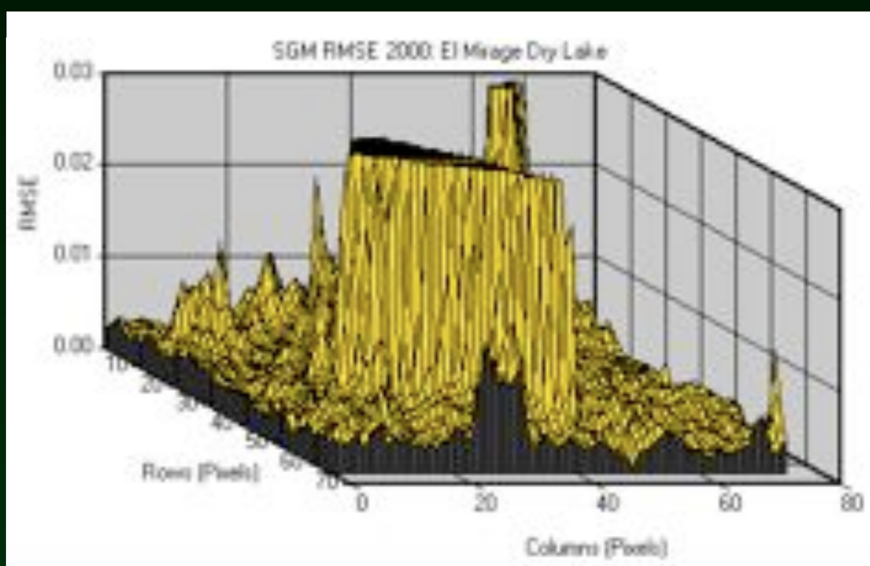


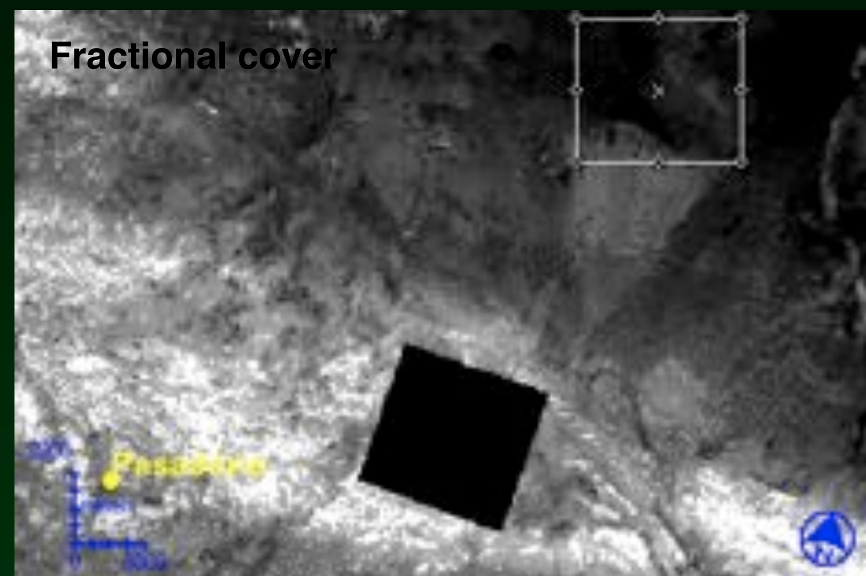




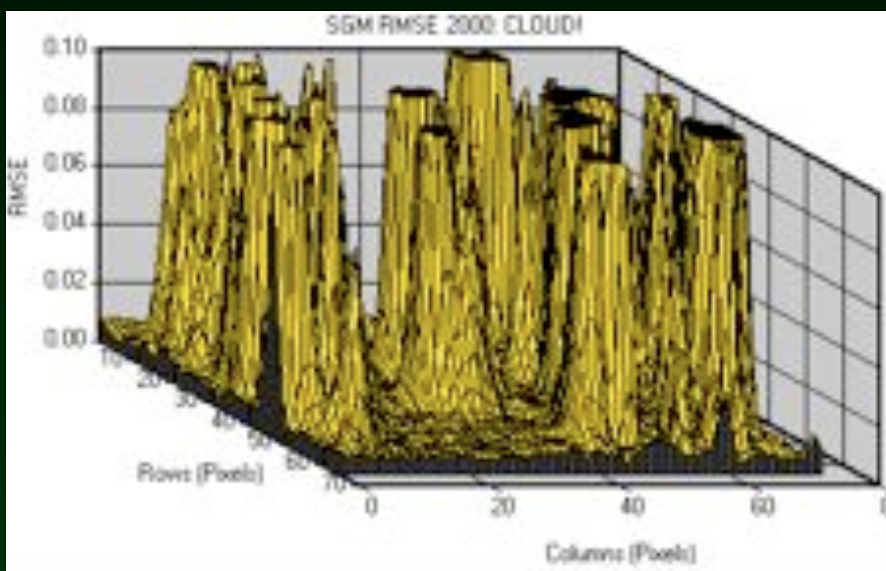
RMSE Example: El Mirage Dry Lake, CA

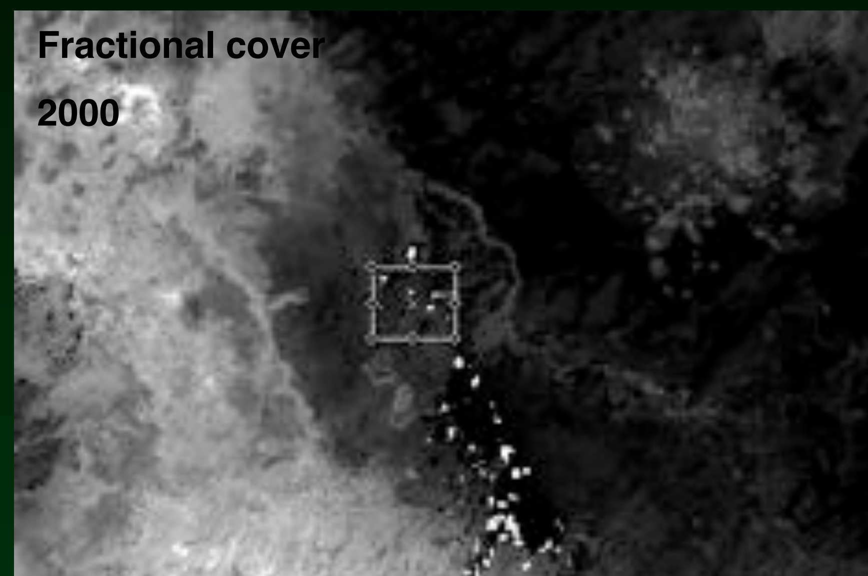




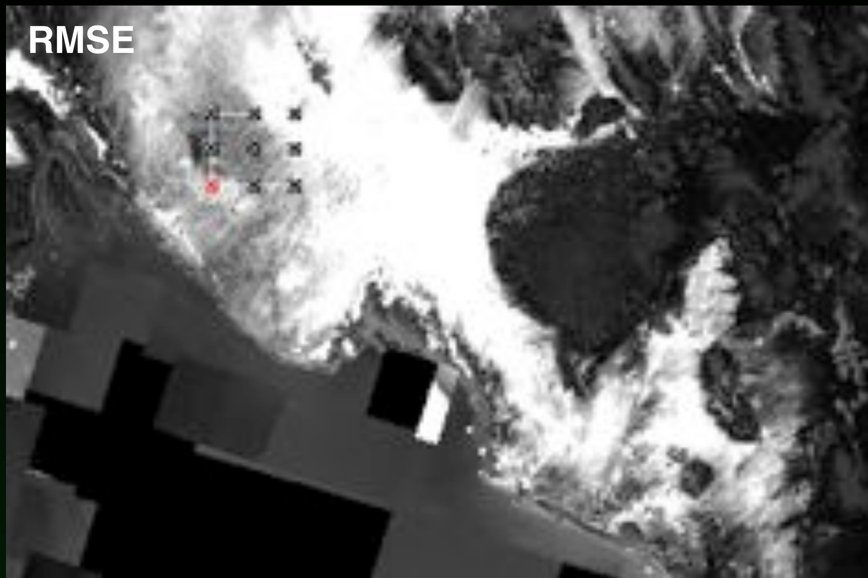


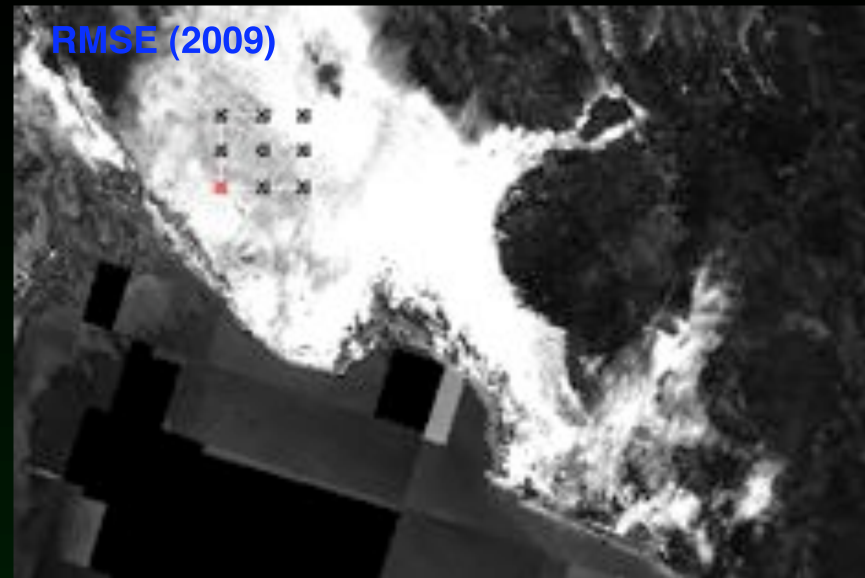
RMSE Example: Clouds

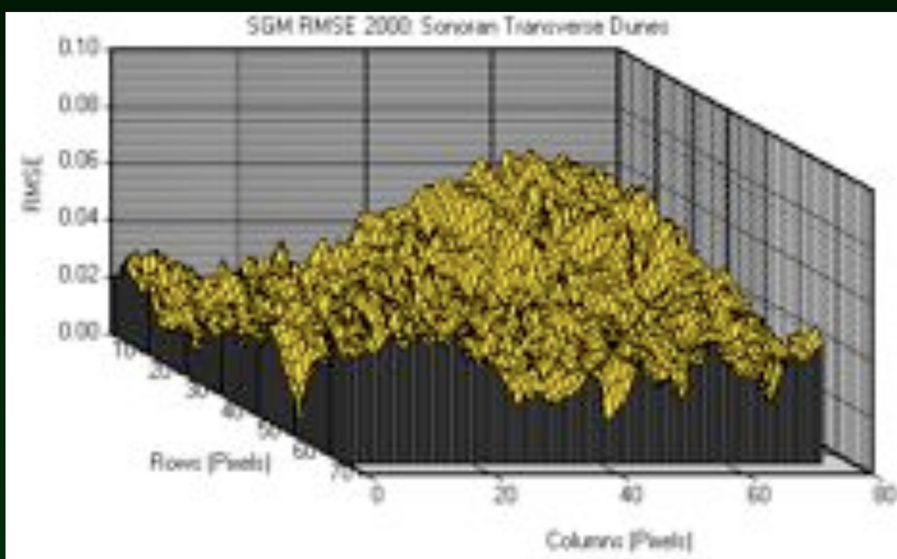


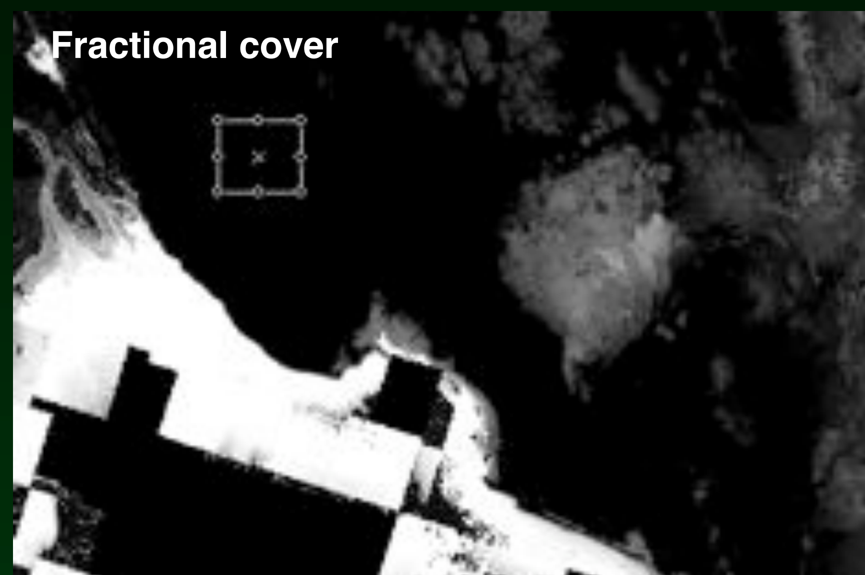


RMSE Example: Sonoron Desert Transverse Dunes

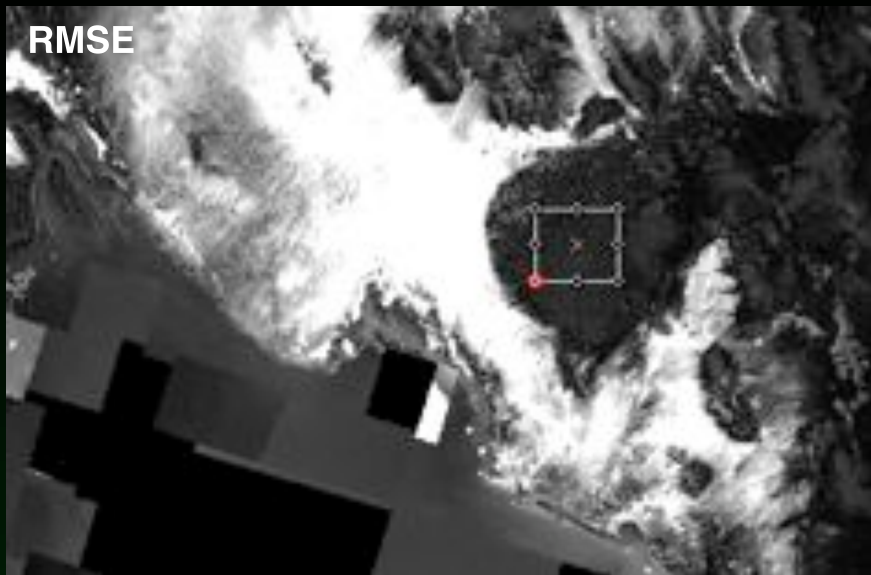


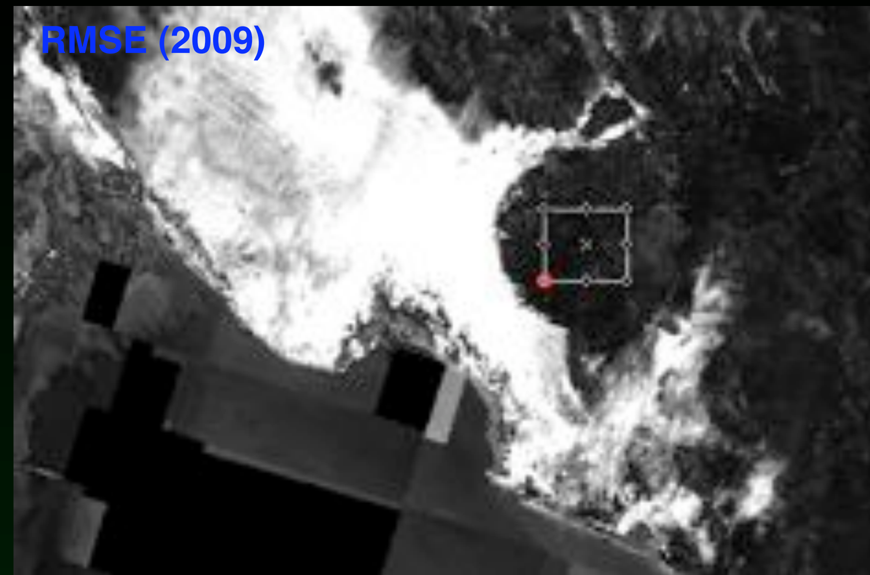


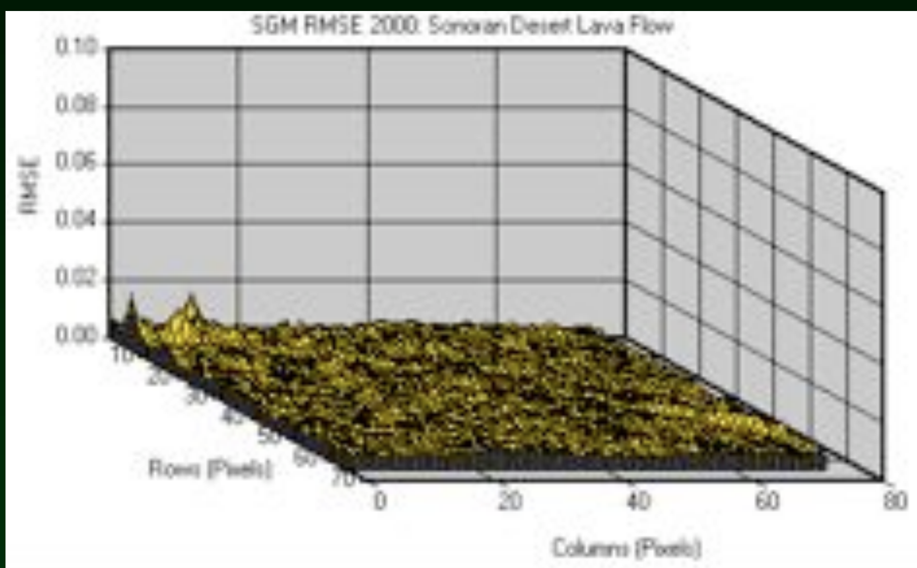


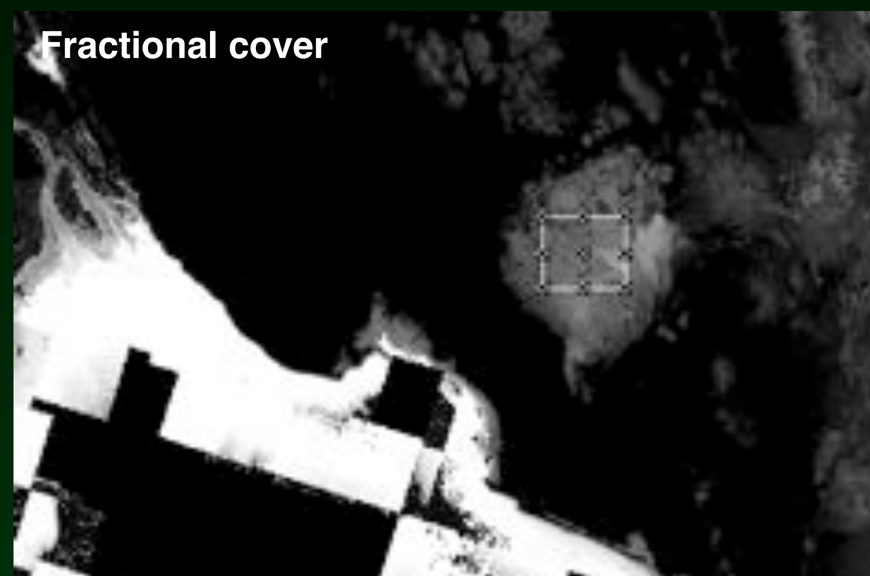


RMSE Example: Sonoron Desert Lava Flow

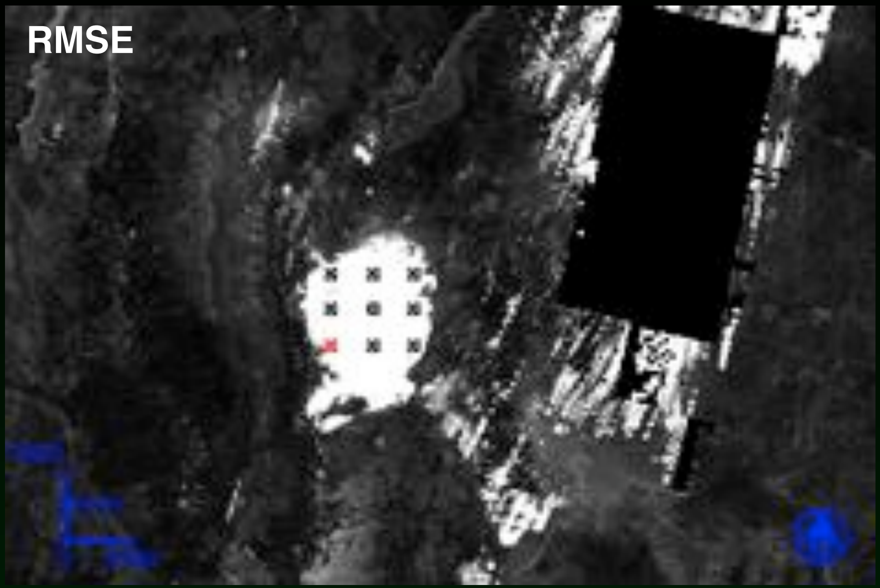


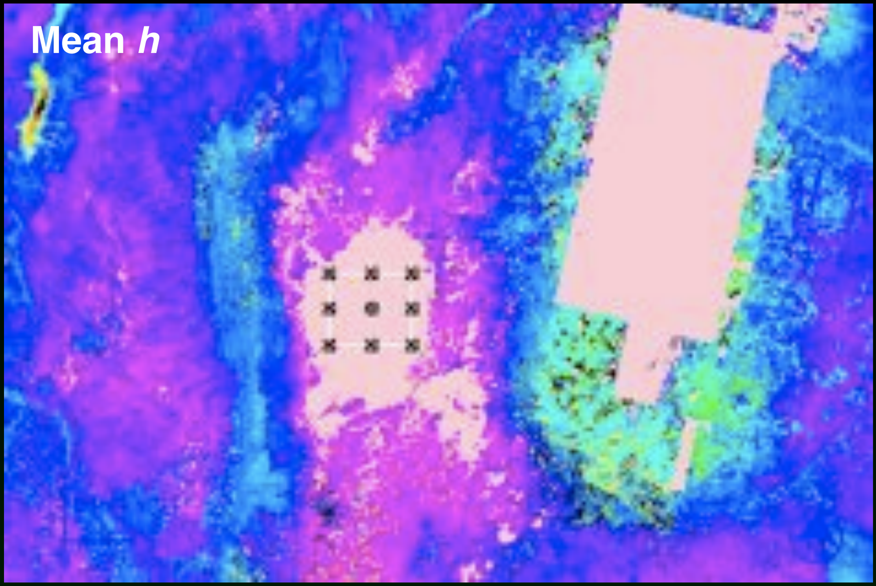


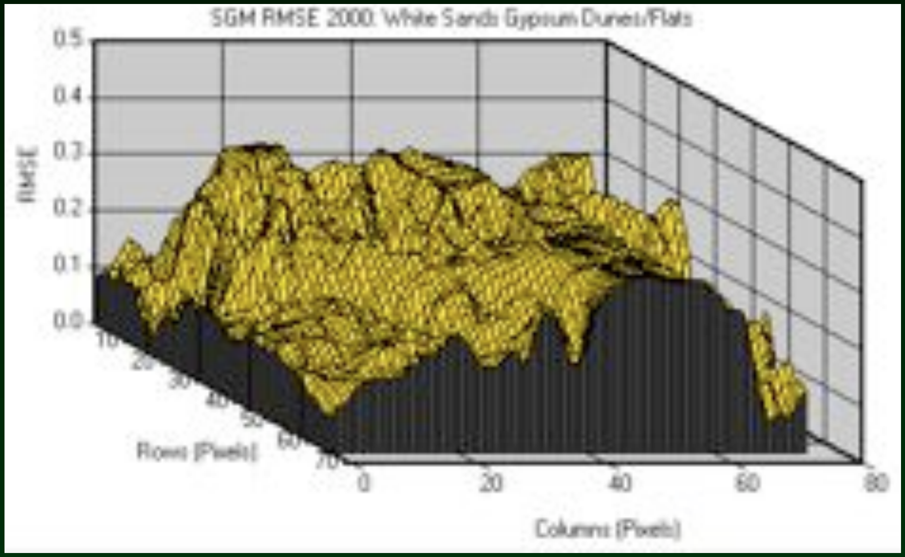


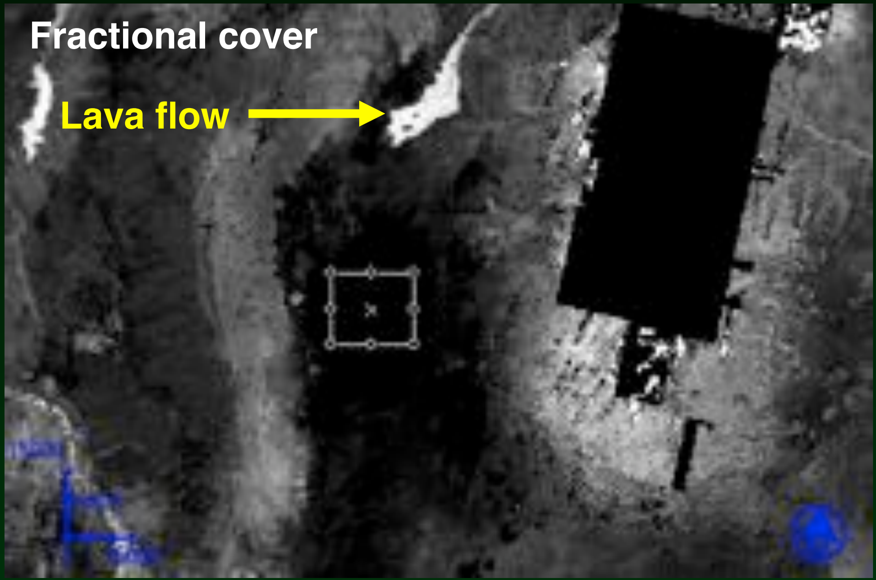


RMSE Example: White Sands Gypsum, NM

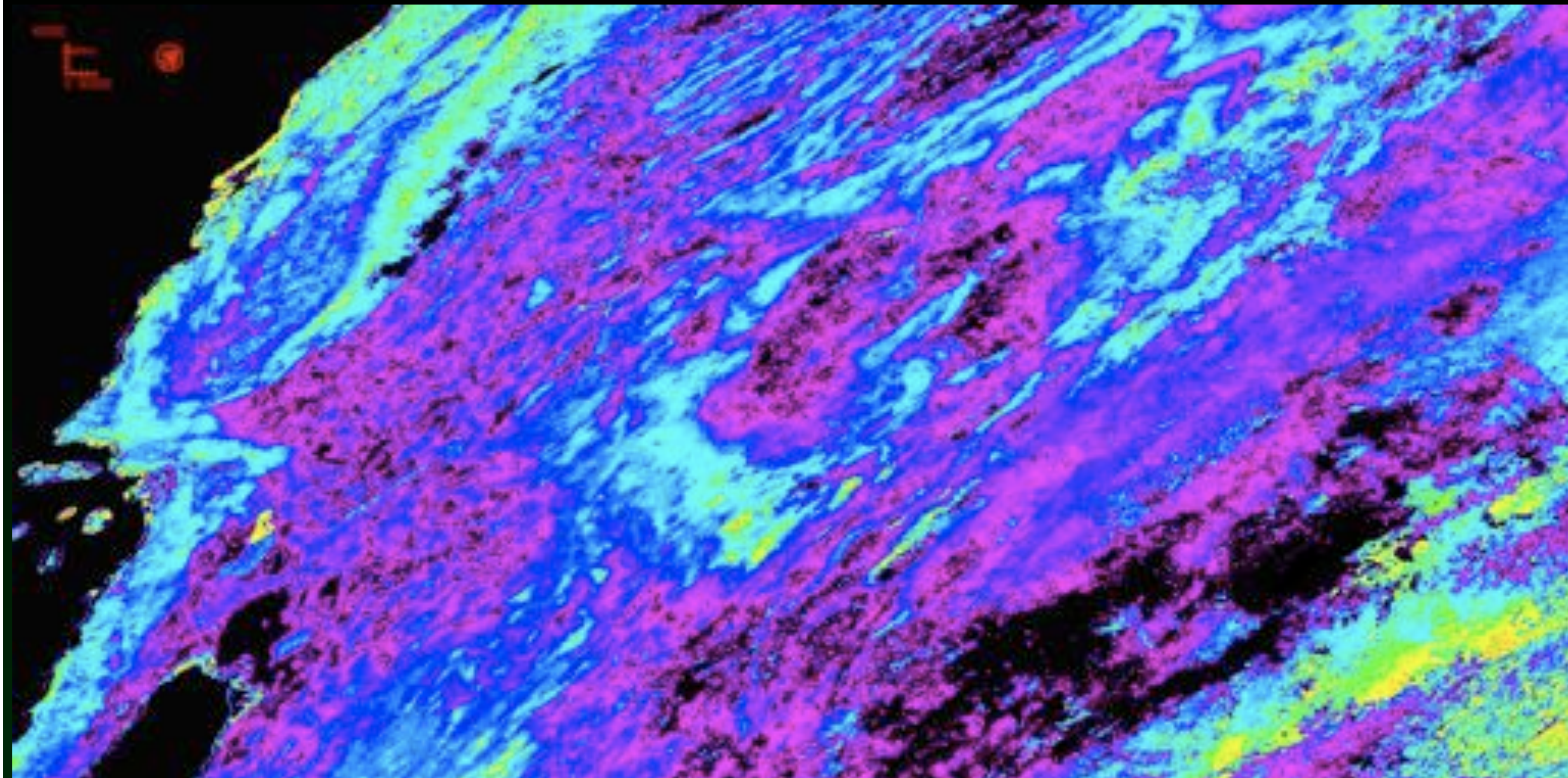






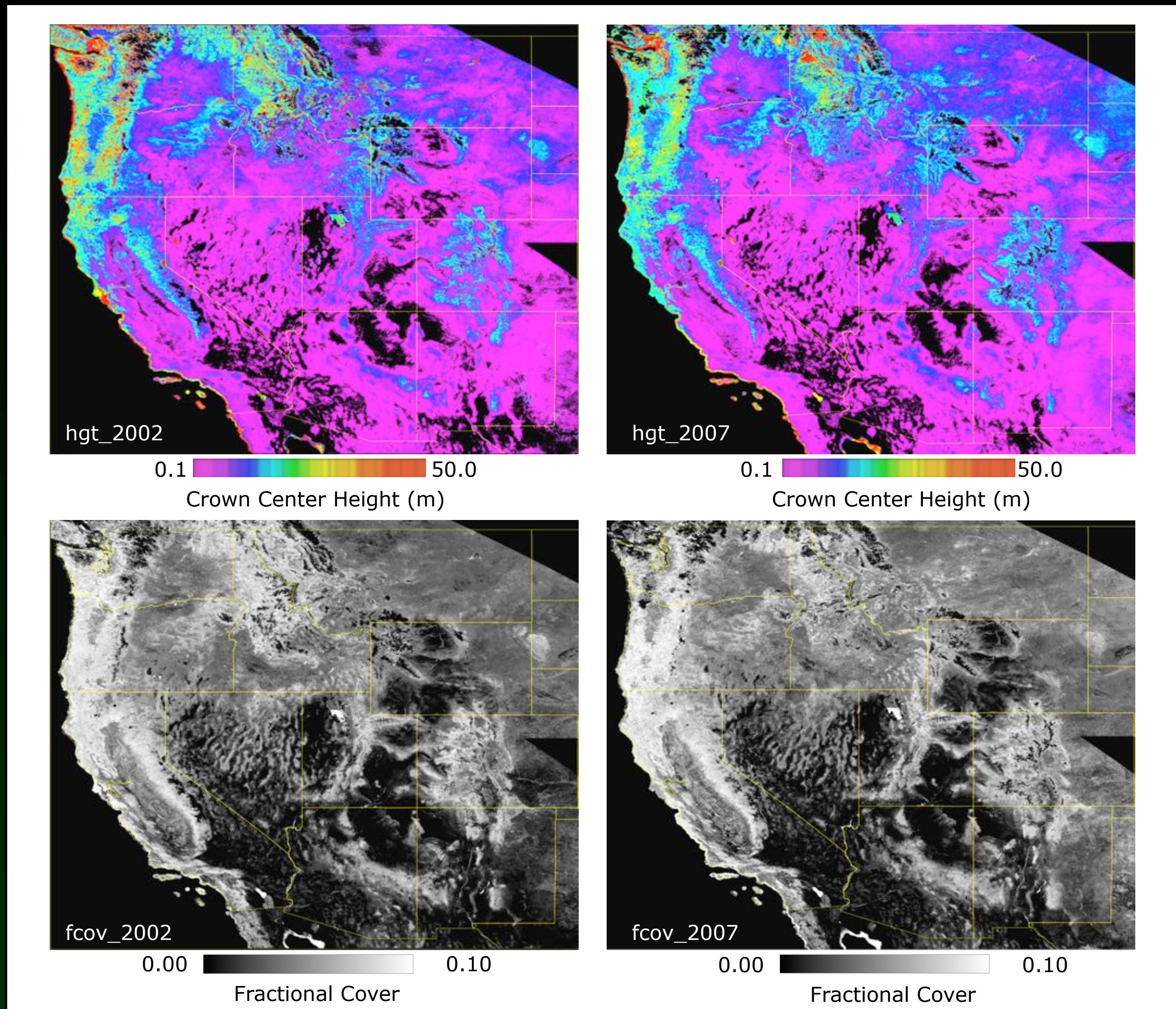


Can MODIS be used in a GO approach?

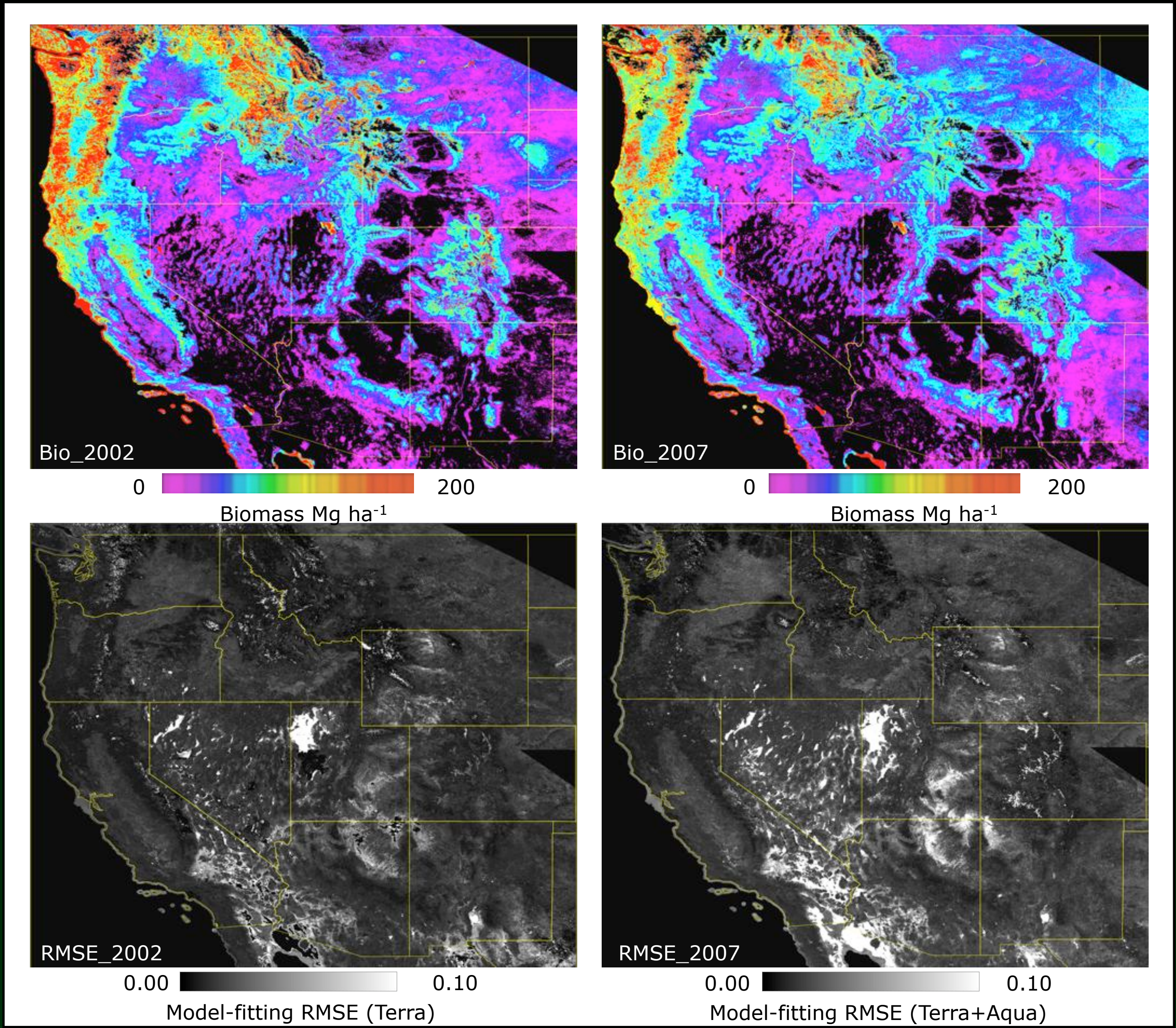


MODIS/GO mean canopy height map for the SWUS, Sinusoidal projection. MODIS views closer to the PP, so data should contain a lot of structural information. The map seems reasonable at this scale but how good is it?

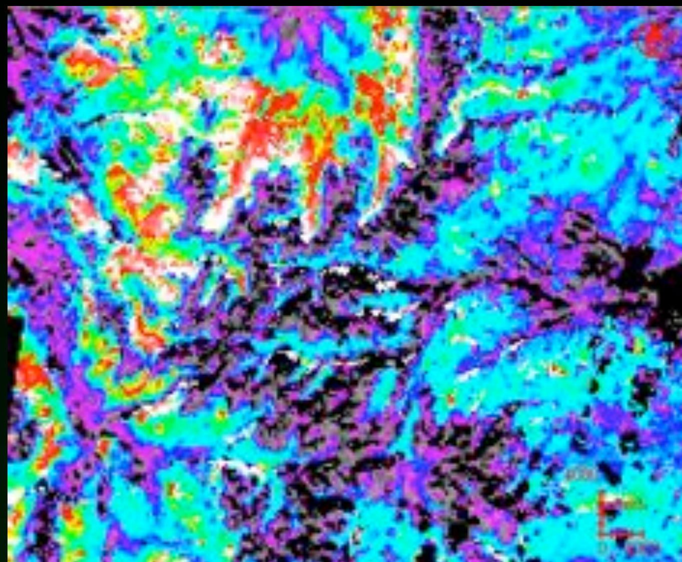
MODIS/GO Maps 2000 & 2007



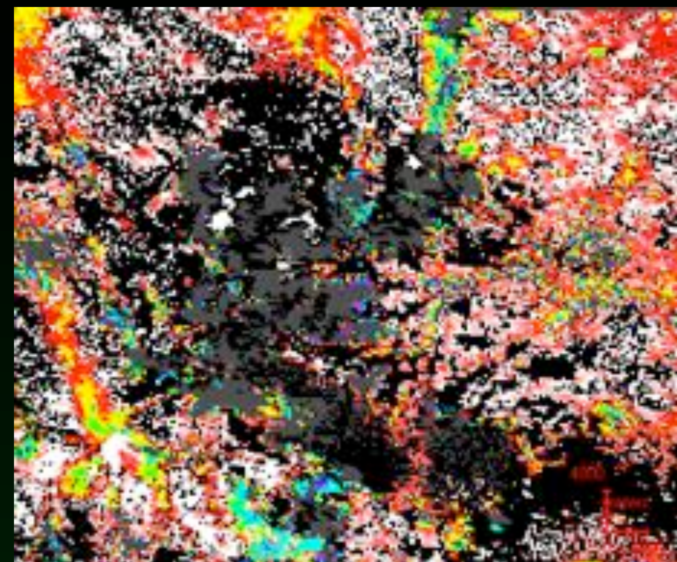
MODIS/GO Maps 2000 & 2007



. . . But thus far precision is far lower than MISR



MISR h (cleaner)

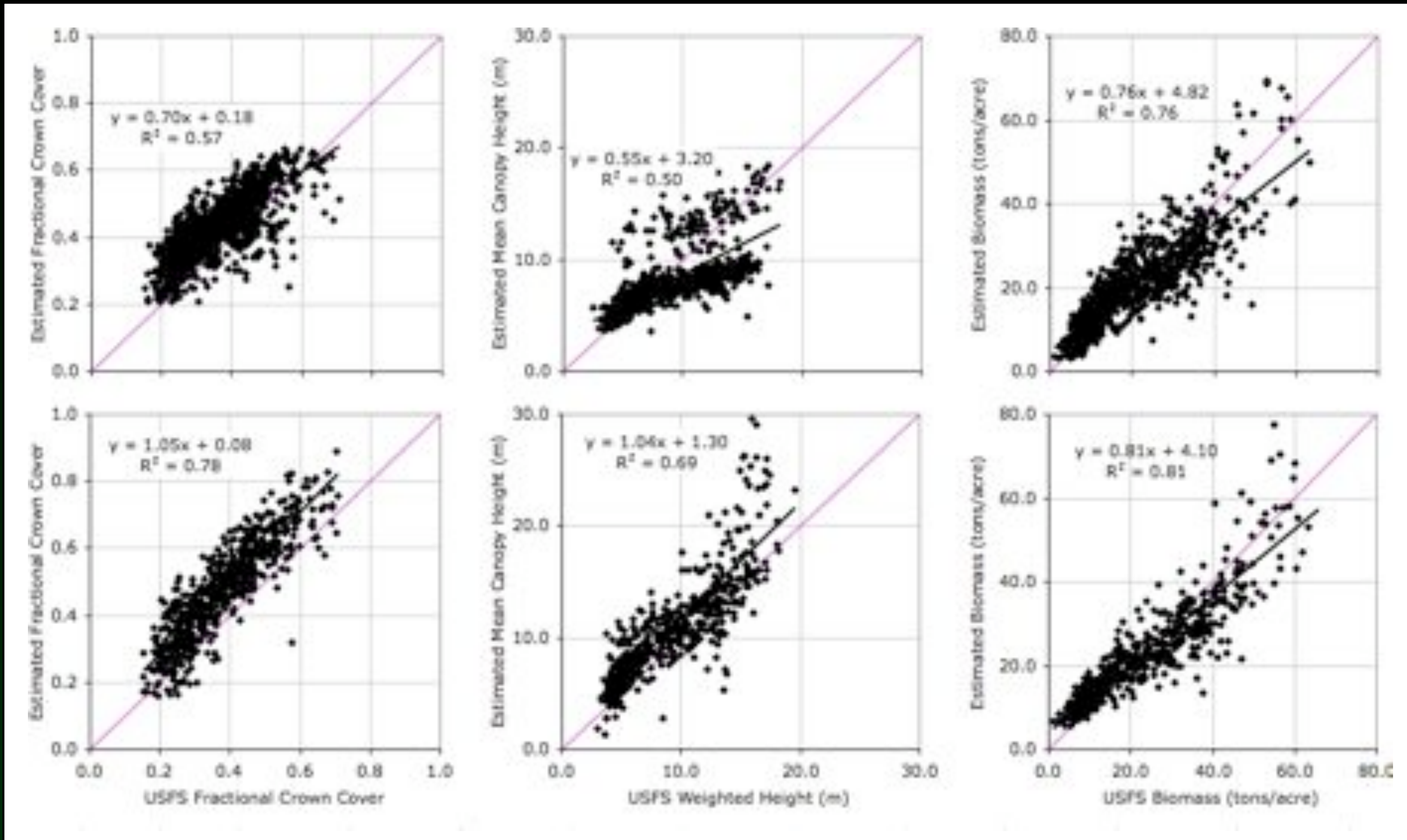


MODIS h (noisy/biased)

This is owing to the difficulty of obtaining a dynamic background: in spite of considerable effort, it has not yet been possible to find a dynamic background w/MODIS that performs better than a static one (this finding corroborated by research at U. Toronto).

MODIS/GO vs MISR/GO vs USFS Interior West Maps

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



Work In Progress

We need better specification of the canopy for a wide range of configurations to obtain better dynamic backgrounds and improve the GO model (and for validation).

We can use lidar (LVIS or discrete return when/where available) but we also need estimates of fractional cover @ 250 m.

We have recently developed a way to obtain cover and height data using high resolution panchromatic imagery (QuickBird, Ikonos, aerial photography). A demonstration and examples follow.

Work In Progress

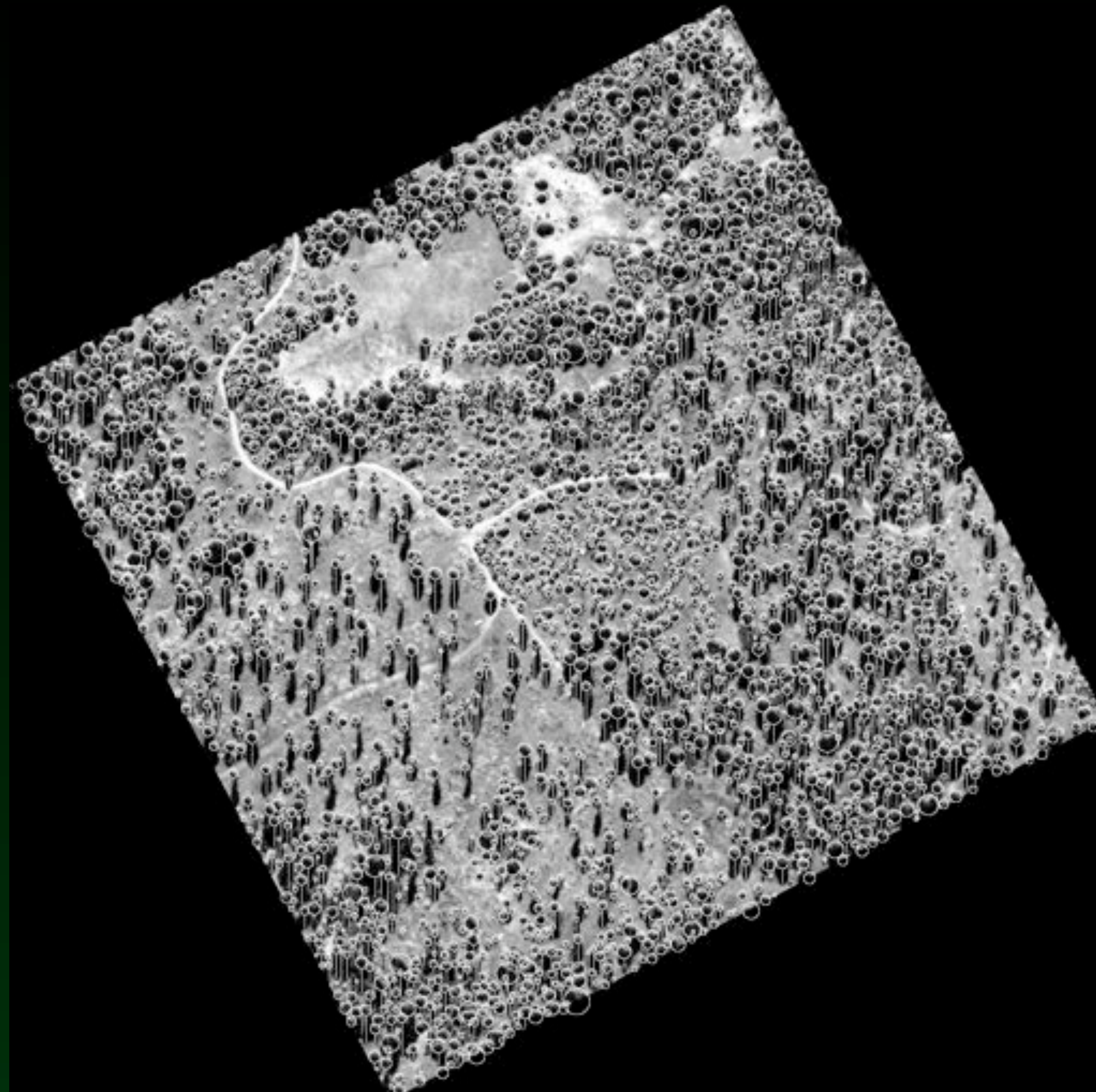
CROWN & HEIGHT ESTIMATION
with HIGH-RESOLUTION IMAGERY

Work In Progress

Crown Delineation And Tree Height Estimates from High Resolution Panchromatic Imagery

QuickBird scene 5 June, 2003

Sierra Nevada, CA

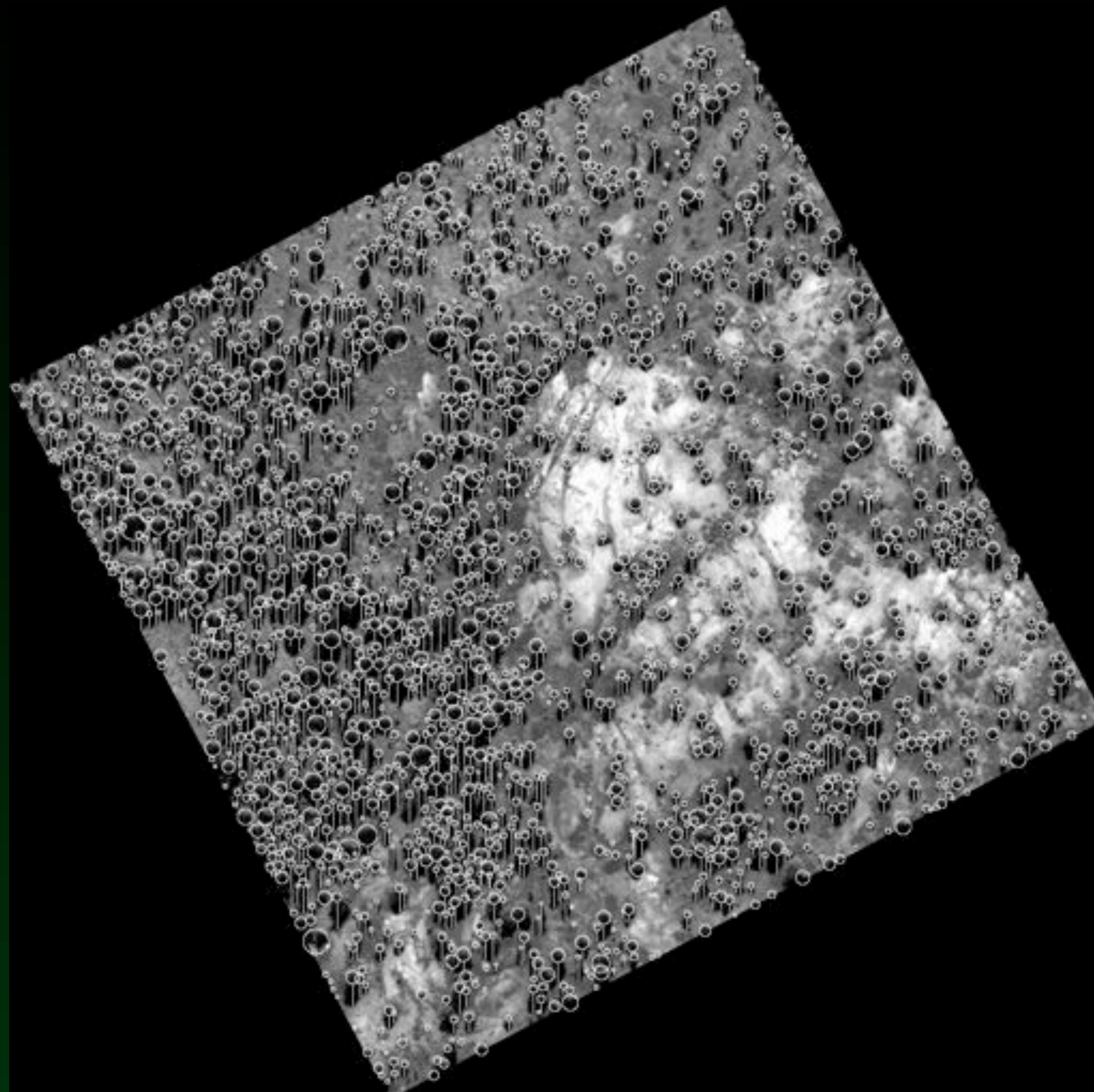


Work In Progress

Crown Delineation And Tree Height Estimates from High Resolution Panchromatic Imagery

QuickBird scene 5 June, 2003

Sierra Nevada, CA

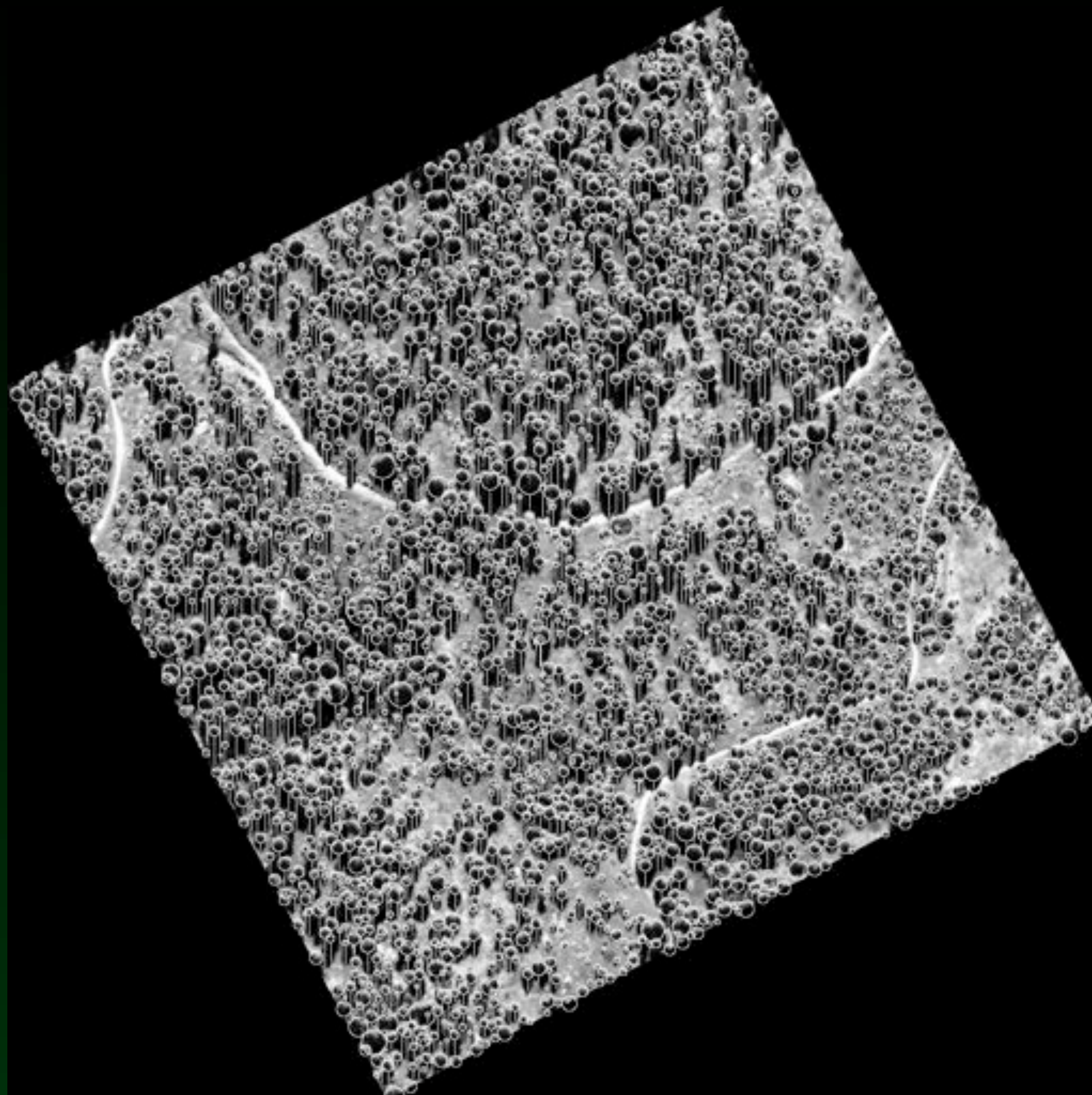


Work In Progress

Crown Delineation And Tree Height Estimates from High Resolution Panchromatic Imagery

QuickBird scene
5 June, 2003

Sierra Nevada, CA



Work In Progress

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QuickBird scene
5 June, 2003

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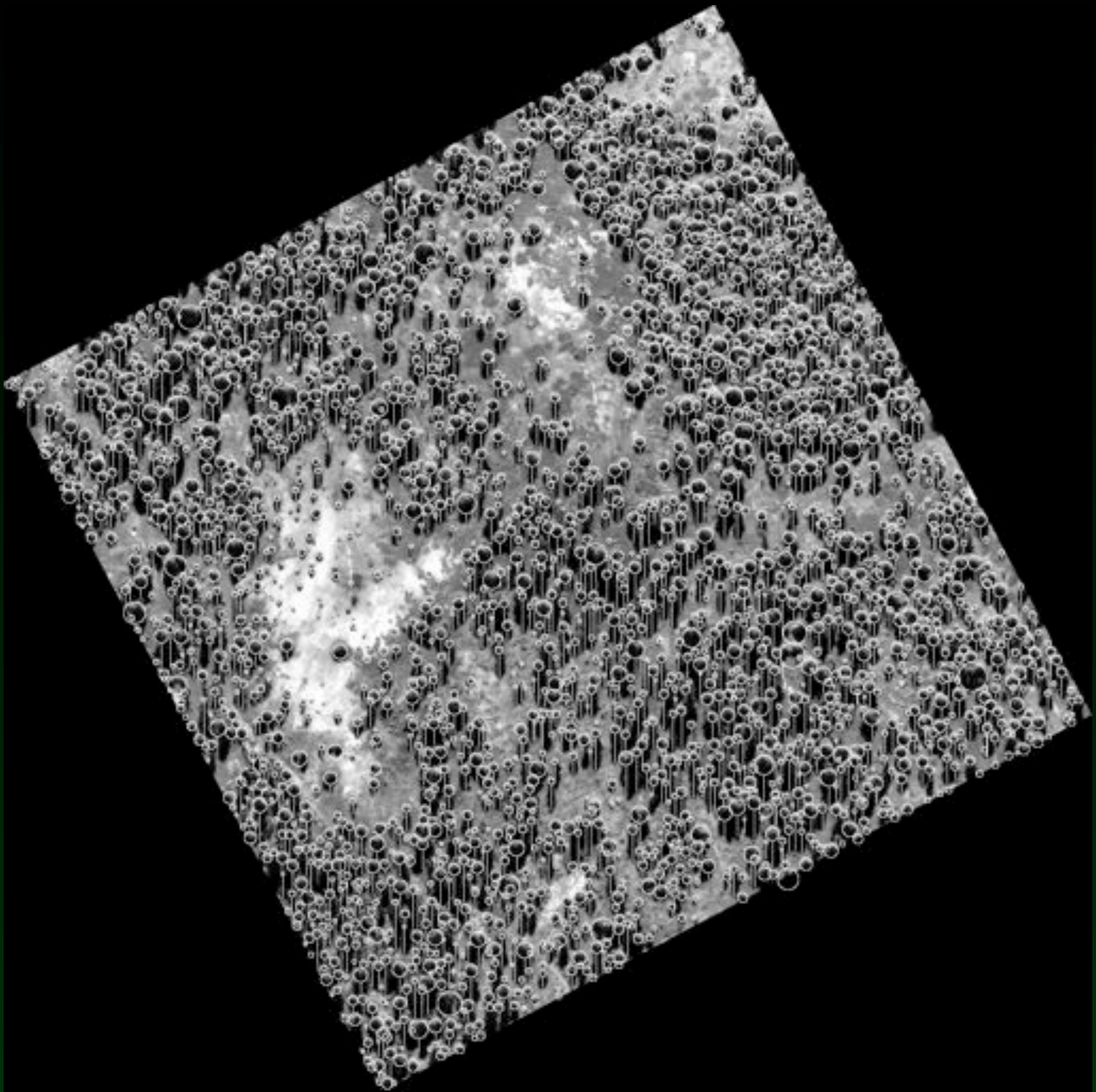

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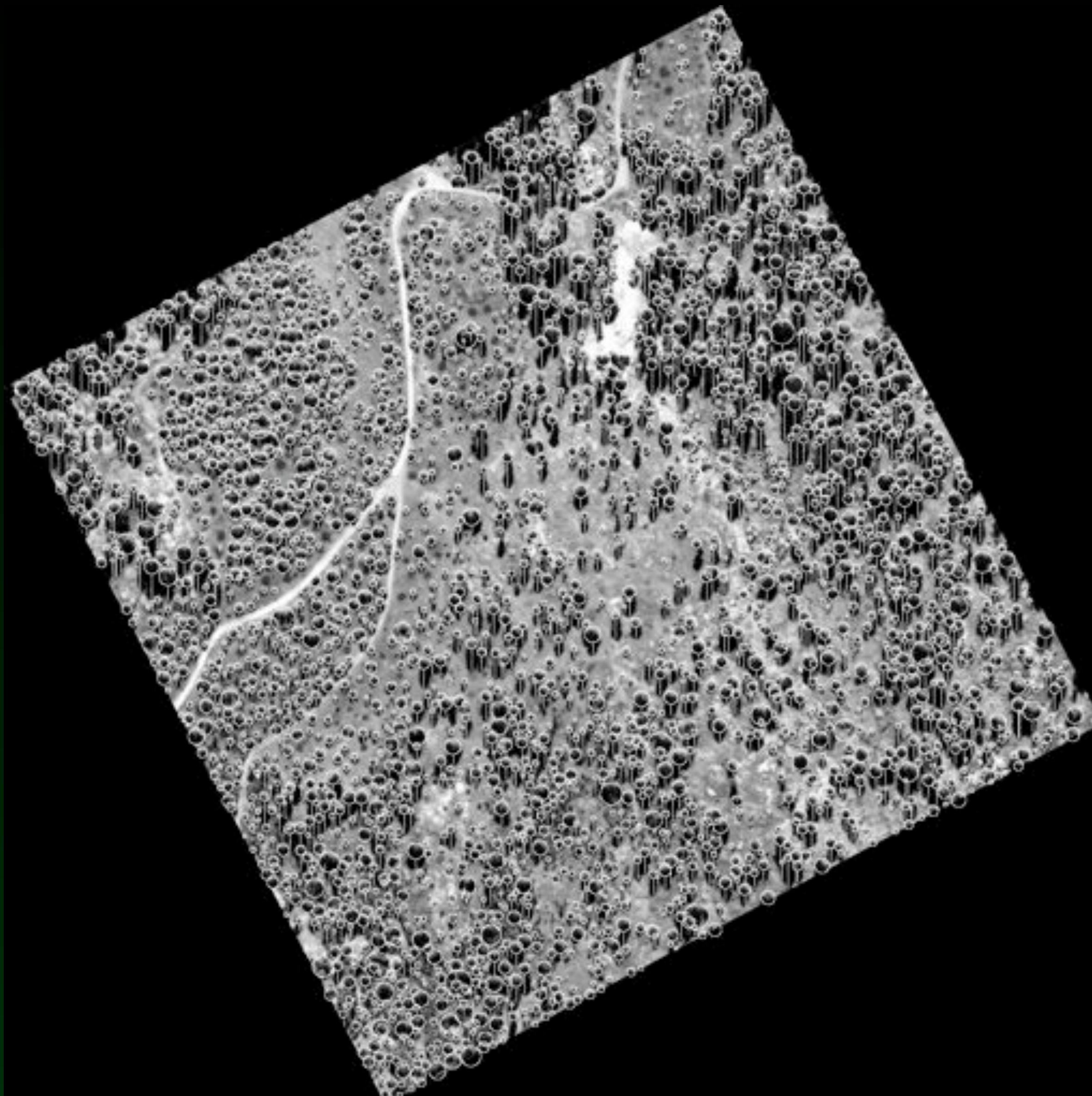

Work In Progress

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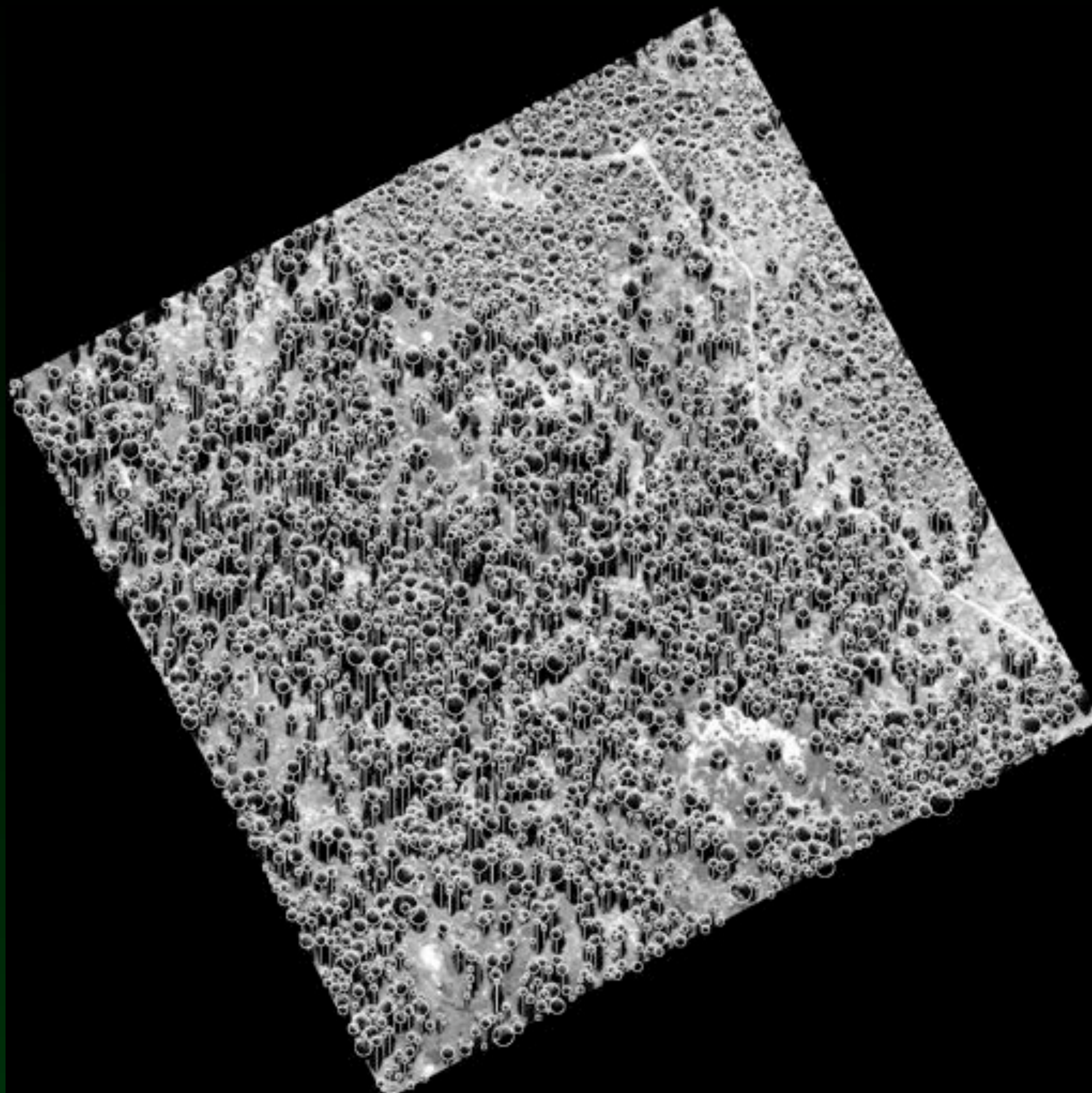
5 June, 2003

Sierra Nevada, CA



Work In Progress

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QuickBird scene 5 June, 2003

Sierra Nevada, CA

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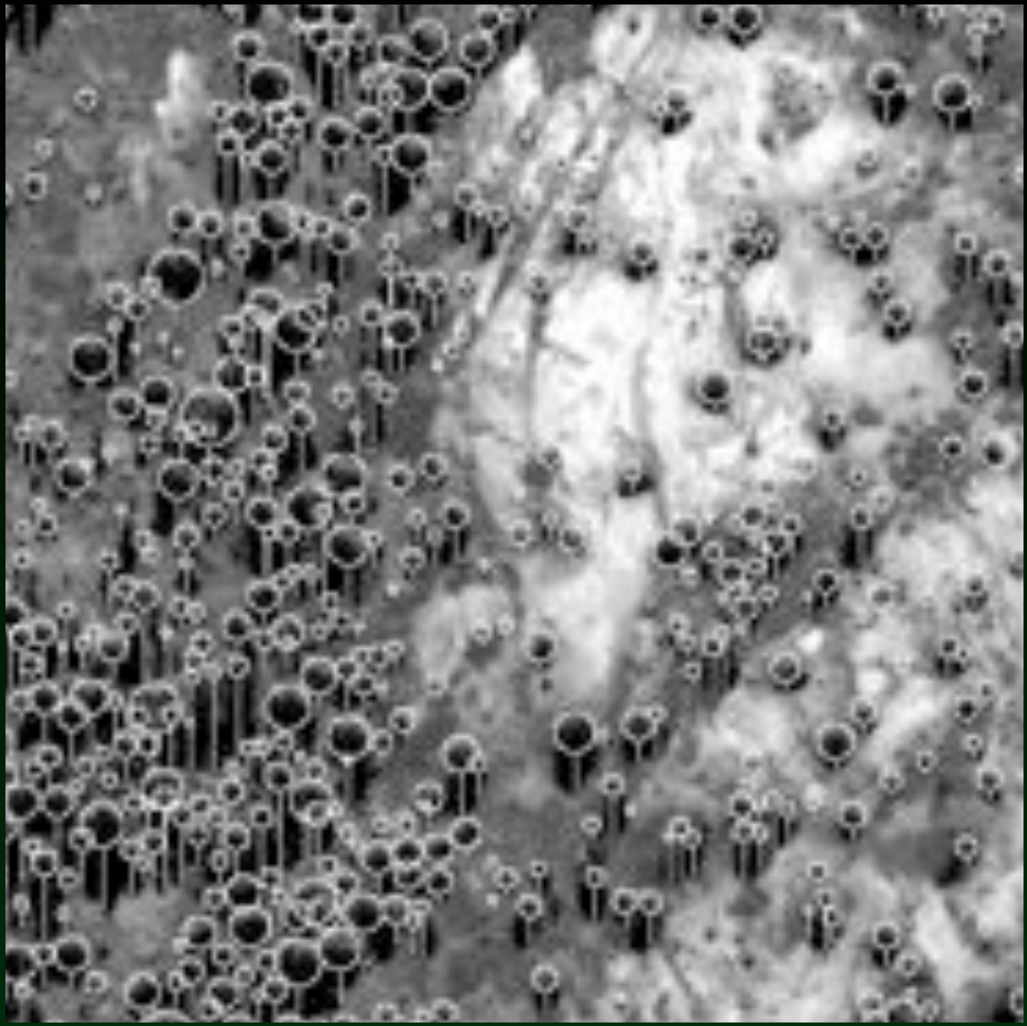
Sierra Nevada, CA



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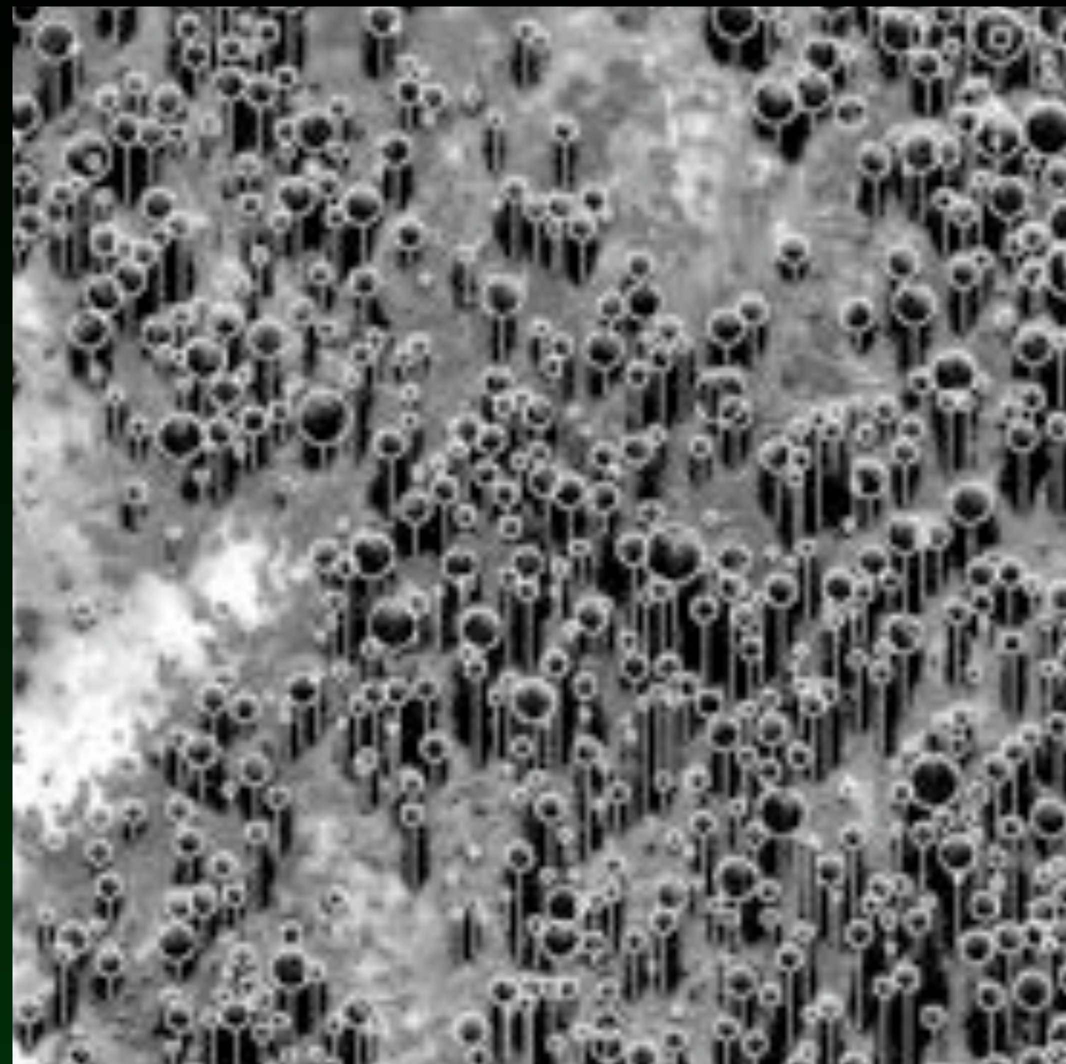

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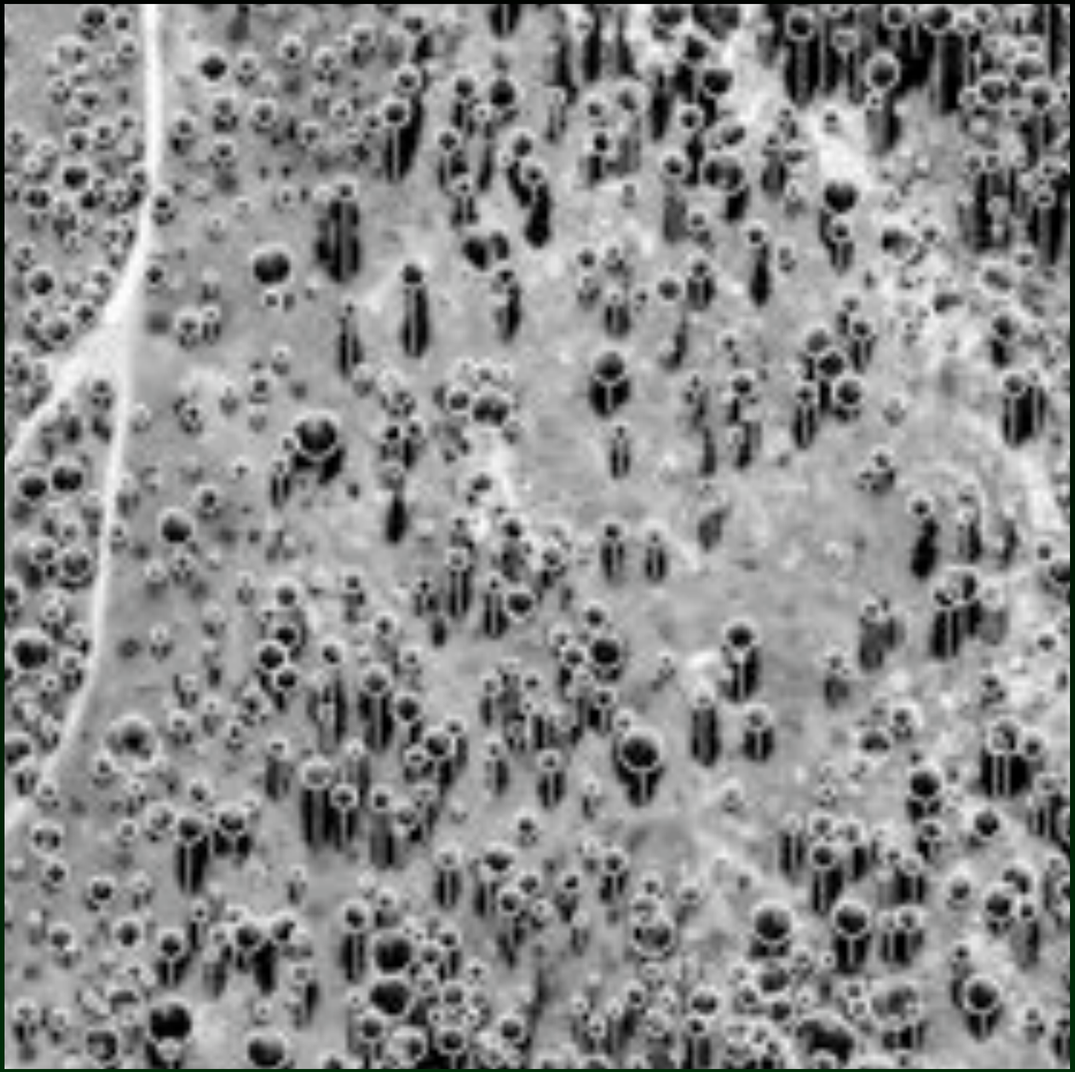

Work In Progress

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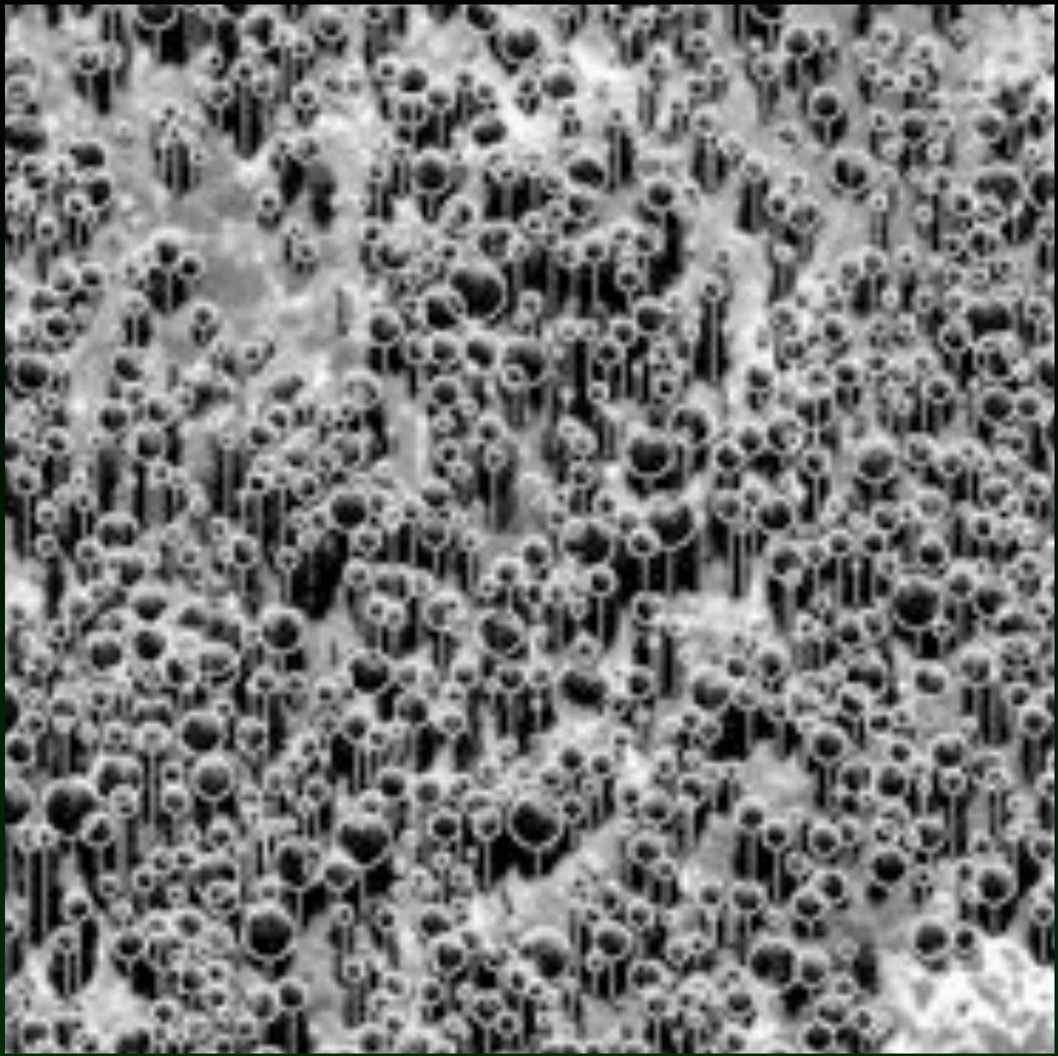
QuickBird scene
5 June, 2003

Sierra Nevada, CA

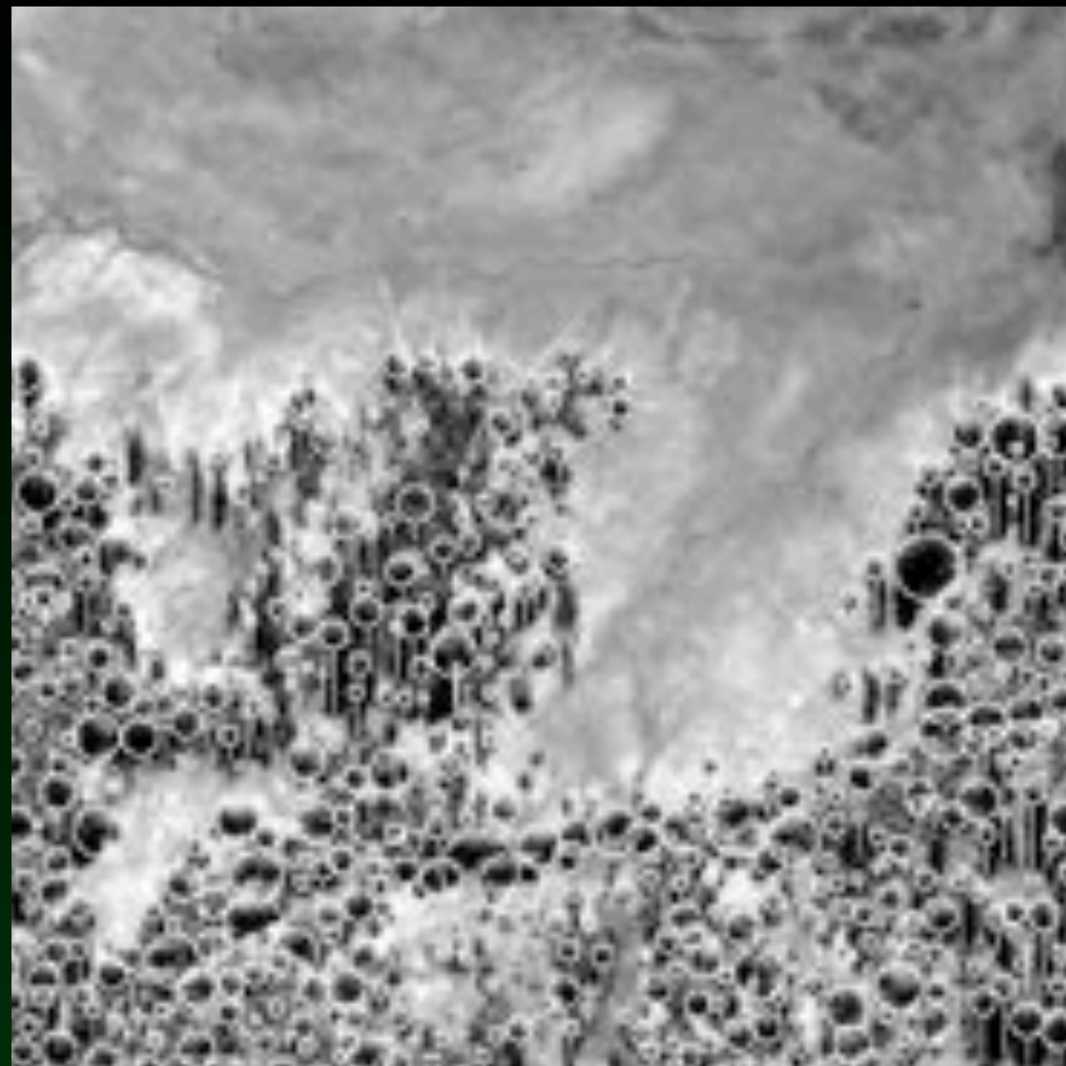


Work In Progress

Crown Delineation And Tree Height Estimates from High Resolution Panchromatic Imagery

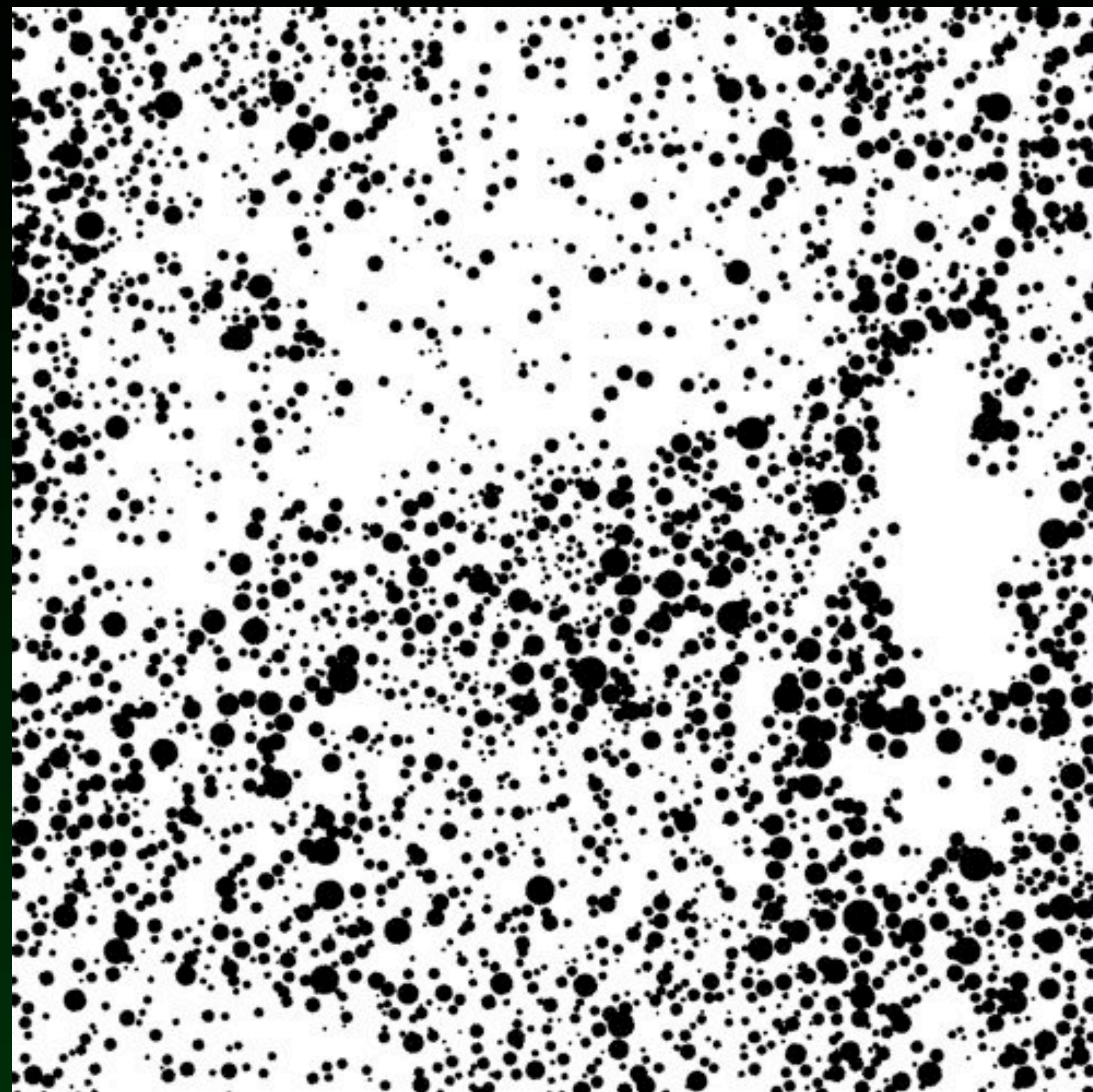
QuickBird scene 5 June, 2003

Sierra Nevada, CA



Work In Progress

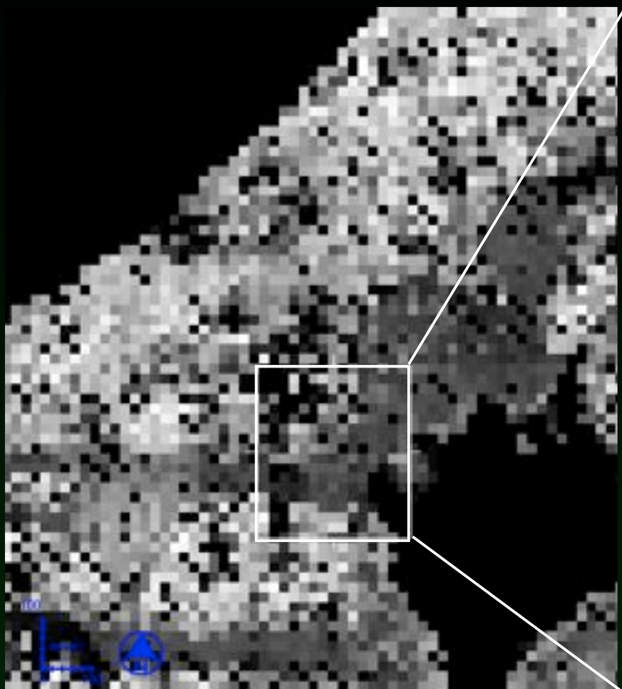
Binary crown maps will be used for calculation of fractional cover



QuickBird scene
5 June, 2003

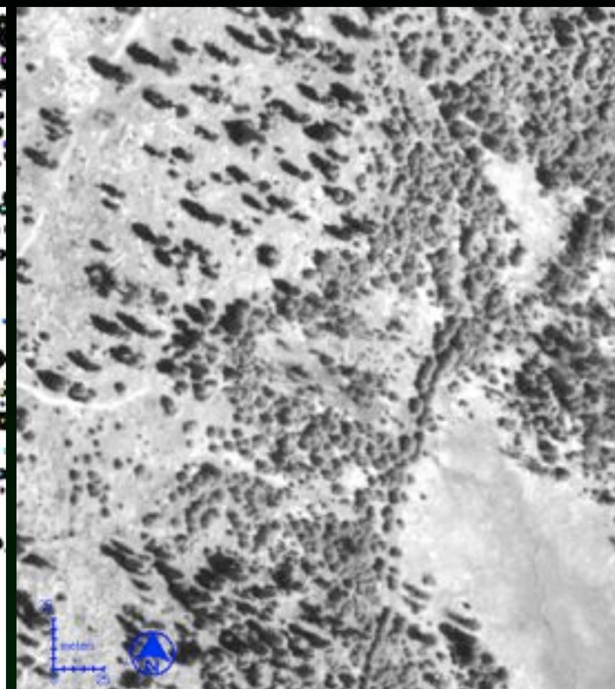
Sierra Nevada, CA

Work In Progress



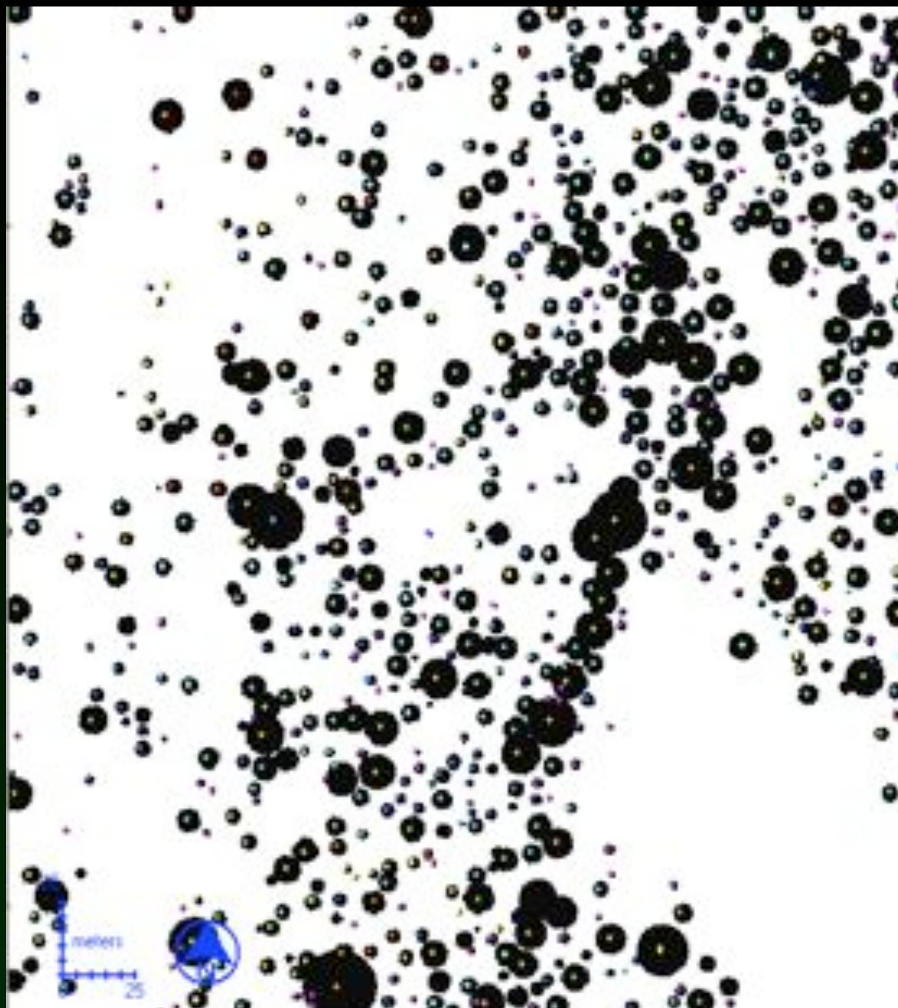
LVIS 20 m RH100 values (interpolated) September, 2008

Crown extent map with points indicating height at crown ctrs (red=high, purple=low)

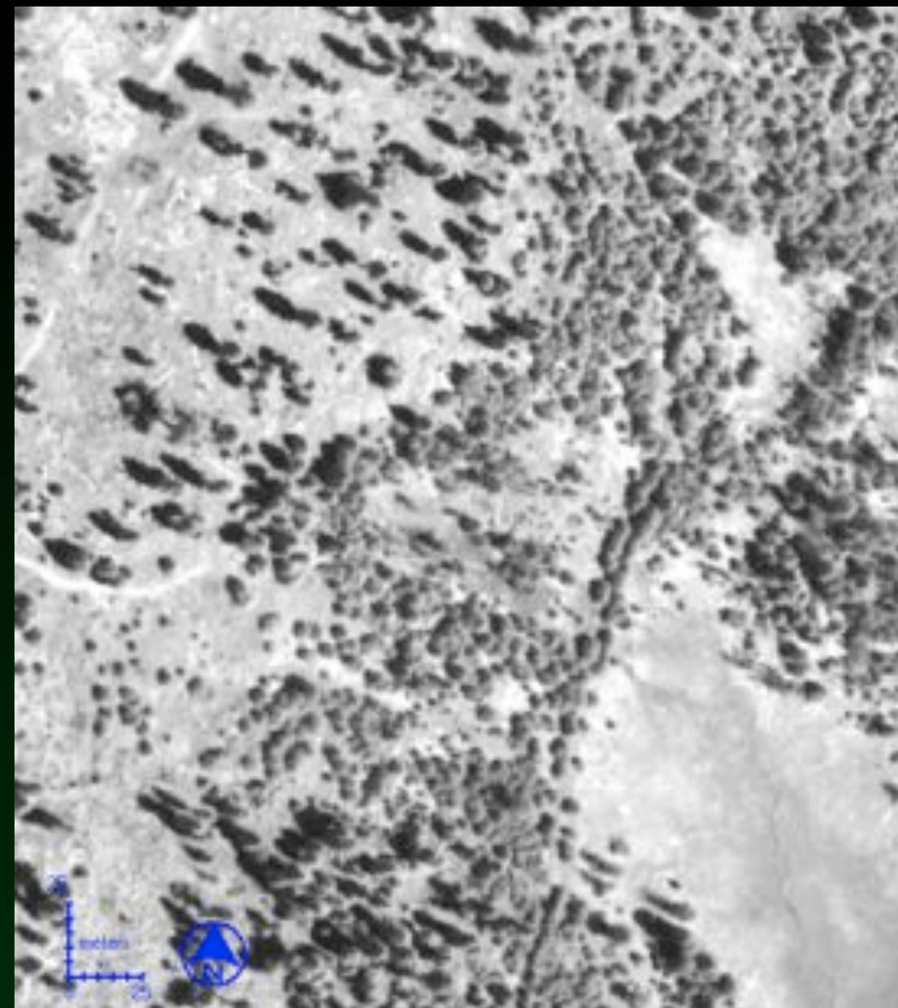


QuickBird 0.6 m pan image, 5 June, 2003

Work In Progress

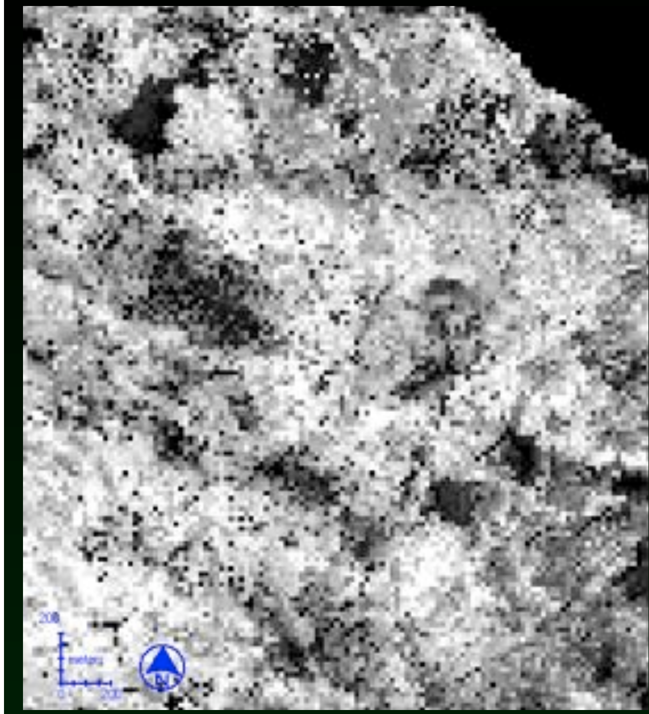


Crown extent map with points indicating height at crown ctrs (red=high, purple=low, white=0)

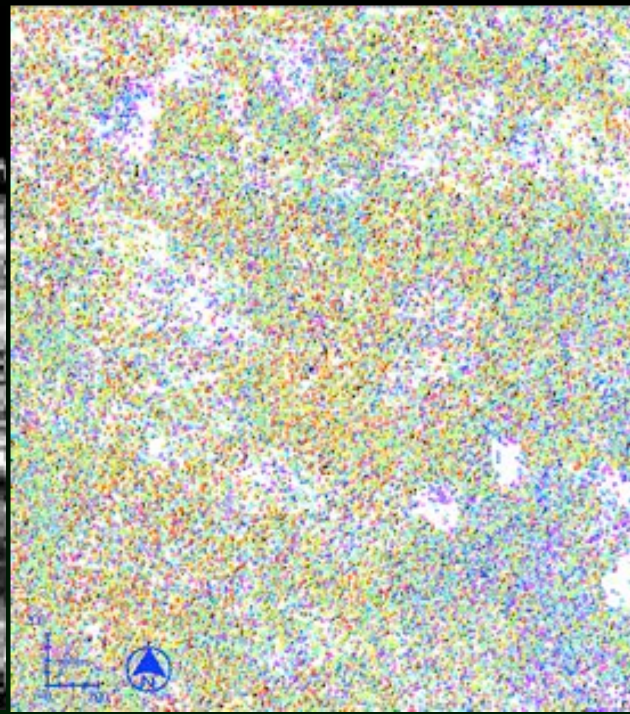


QuickBird 0.6 m pan image, 5 June, 2003

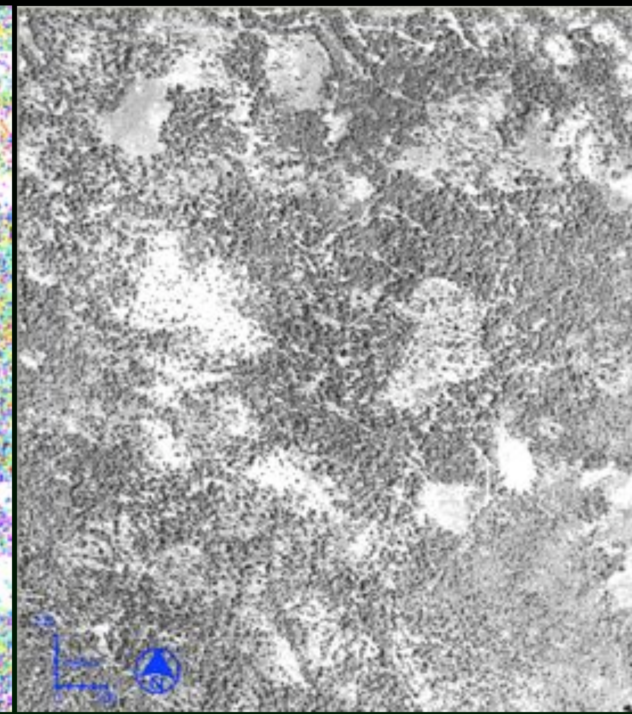
Work In Progress



LVIS 20 m mean RH100 (interpolated) September, 2008



Tree heights indicated by points at crown ctrs (red=high, purple=low, white=0)



QuickBird 0.6 m pan image, 5 June, 2003

We have only just obtained these results, so have not had the opportunity to assess LVIS vs QB relationship quantitatively (next week's job)

Conclusions

Crown cover and mean canopy height are retrieved with from the GO model, not through fitting or training, while AGL biomass is from regression on these. The output maps include shrubs.

The dynamic background is critical. We are not yet able to get a dynamic background using MODIS. We need the background contribution across the domain of sun-target-MODIS angular configurations -- but using a MISR-derived BRDF might incur large extrapolation error.

This approach is limited to biomes with sparse-to-moderate density stands -- however it will be very useful for applications in savannas, woodlands, arid forests, and desert grasslands worldwide.

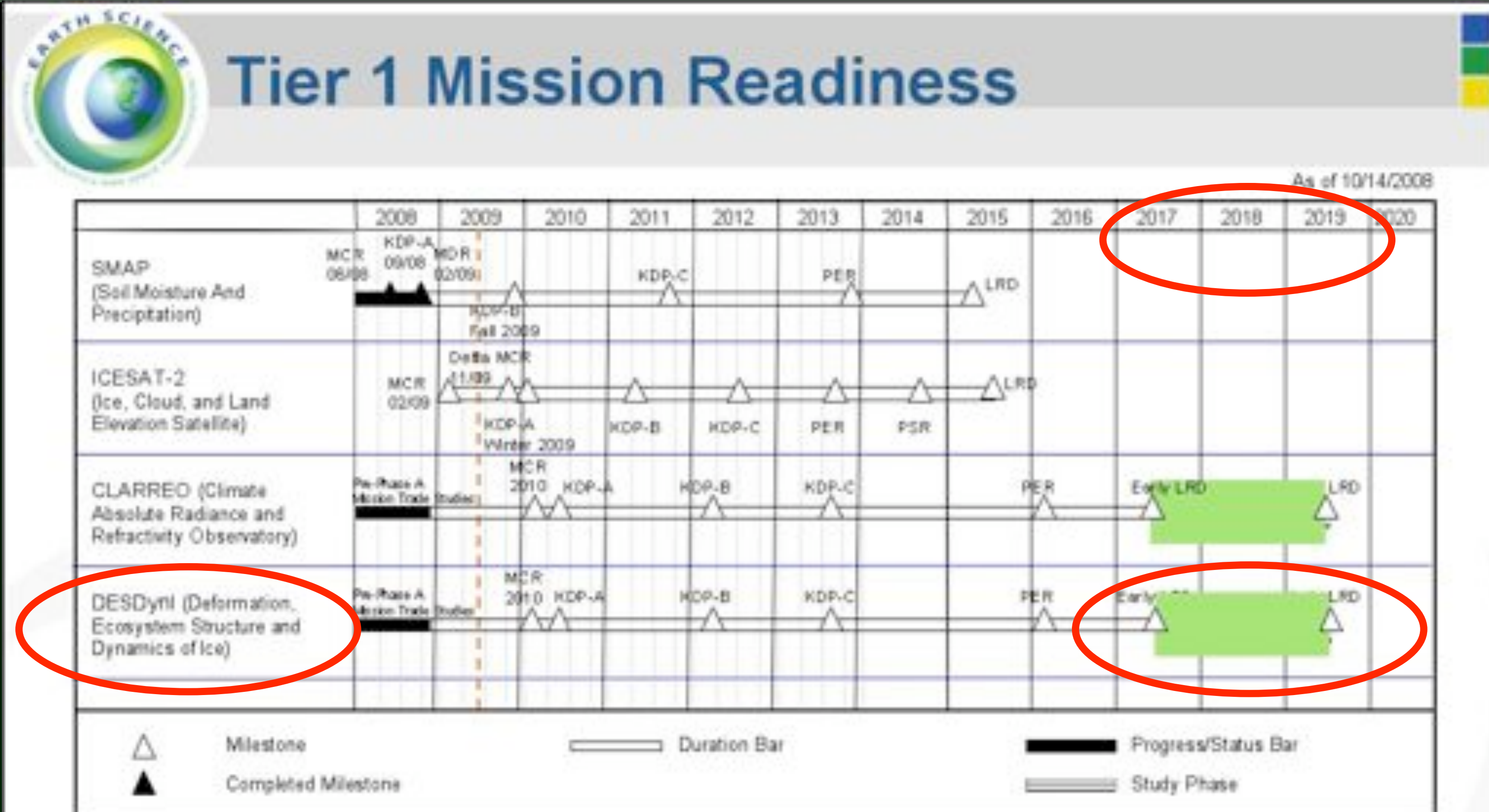
Conclusions

Validation against: 1. Lidar canopy heights (proceeding well but we are still seeing some anomalies); 2. high resolution imagery (in-house for sites and Google Earth for large areas: students are constructing a database); 3. assessment of trajectories through time.

The new method for obtaining crown maps/crown cover and height statistics from high resolution imagery will be useful in mid-latitudes and above (but not in the tropics!).

This work is also relevant to future structure/biomass mapping missions . . .

DESDynI Delayed



- **Waveform Lidar/InSAR Mission**
- **Mar 2007: Decadal Survey Selection**
- **Aug 2009: LRD pushed back to ~2017-2019**

Martha Maiden, Program Executive Earth Science Data Systems, NASA HQ, Oct. 20, 2009

DESDynI Delayed

- There will be no time machine on the DESDynI satellite(s): once the record has been lost, it's lost forever.
- Biomass is dynamic (disturbance, regrowth).
- We may be able to provide historical context for DESDyNI - for arid and semi-arid regions - using existing NASA Earth Observing System assets but we need to improve precision of retrievals.
- The model is "not magic". More complex models & other approaches may be useful (e.g., spectral invariants -- but the background is always required)

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.

Acknowledgments

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Data: MISR data from NASA Langley Research Center Atmospheric Science Data Center, with additional processing by Michael Bull (NASA/JPL). 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).

Special Thanks: Xiaohong Chopping (neé Qi), Michael Palace, NASA Vegetation Structure Working Group


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

That E-mail

“How about we stop trying to get BRDF from a VI and do it properly via an appropriate BRDF model, as with the MODIS MCD43 product? If we didn't learn anything in the wide swath moderate resolution RS community from ~15 years of research and publications on how to do this well with AVHRR and MODIS, heaven help us all. On the spectrum from pure convenience to physical perfection, the Li-Ross approach is by far the optimal one.

We can have a perfectly engineered instrument and excellent surface retrievals still end up with an inconsistent long-term record if we do not treat this with the attention it deserves. BRDF should be right up there with atmospheric correction as a priority action item on the VIIRS agenda but as of IGARSS'07 in Barcelona it was at the bottom of the to-do list for reprocessing AVHRR; and it has been suggested recently that surface BRDF can be handled without using a model explicitly developed to handle reflectance anistropy.

There is absolutely no good reason for this, or excuse for ignoring the accomplishments of the MODIS BRDF/Albedo team and their colleagues here and abroad. To fail to recognize these achievements and to suggest only slightly less demanding but less rigorous methods is like suggesting that dark object subtraction is the way to go for atmospheric correction of radiances from VIIRS. Does anyone think that that would be acceptable?”

Some History

Mid 80s AVHRR first used for land applications, with the importance of atmospheric corrections accepted (famous IJRS paper by Holben on max. val. compositing with NDVI; surface BRDF gets one short paragraph). Albedo is “isotropic”.

Early 90s Community largely recognized the need to take reflectance anisotropy of the terrestrial surface into account (e.g., Roujean et al. ’92, ’94, many others).

Mid 90s Debate on which model to use for BRDF/Albedo retrieval from MODIS (but no debate on the need to use a model, although some attempts to use a VI were also pursued e.g.,Wu et al. 1995). Many papers published.

Late 90s MODIS BRDF/Albedo ATBD: Li-Ross kernel-driven BRDF model type shown to be optimal for the albedo product and for production of consistent Nadir-equivalent BRDF-corrected Reflectance. More papers published. One (Hu et al. 1999) shows that coupled AC-BRDF model inversion provides superior results; another shows that combined MODIS-MISR inversions are better -- both were ignored (or at least, there were insufficient funds to implement).

2000s MODIS BRDF/Albedo algorithm now in production mode. Calls to reprocess AVHRR w/Li-Ross. GSFC to implement reprocessing (approach to BRDF correction?). Other uses of the BRDF model kernel weights demonstrated (e.g., classification, SSI, canopy/background separation).

Some History

2007 BRDF at the bottom of the GSFC AVHRR to-do list (IGARSS'97 Barcelona).

2009/10 BRDF from NDVI (c.f. Wu et al. 1995) --?

Albedo but no BRDF or NBAR products envisaged from VIIRS --?

Apparently many people still think that MODIS is a nadir-viewing instrument (or at least want to treat it that way). I have heard experienced RS scientists make this assumption.

My take: We should be building on the models, algorithms, and understanding developed in the AVHRR-MODIS era (. . . or is history doomed to repeat itself?)

A few of the people who worked on the MODIS BRDF/Albedo product and with Li-Ross models: Jean-Louis Roujean, Wolfgang Lucht, Charlie Walthall, the late great Mike Barnsley, Crystal Schaaf, Alan Strahler, Li Xiaowen, Hu, Philip Lewis, Baoxin Hu, Mat Disney, myself, others in the MODIS MOD43 team, various PhD students and p-d's.