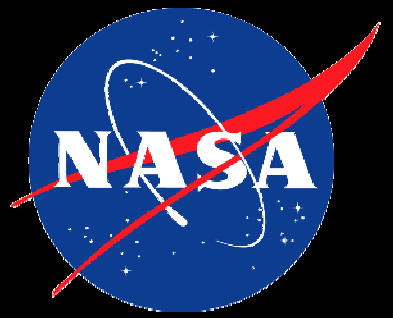
NASA Goddard Space Flight Center
Hydrospheric and Biospheric Sciences Laboratory
Terrestrial Information Systems Branch (Code 614.5)



Use of In-Situ and Airborne Data to Assess Satellite-Based Estimates of Directional Reflectance and Albedo

Miguel O. Román, Ph.D.
Miguel.O.Roman@nasa.gov

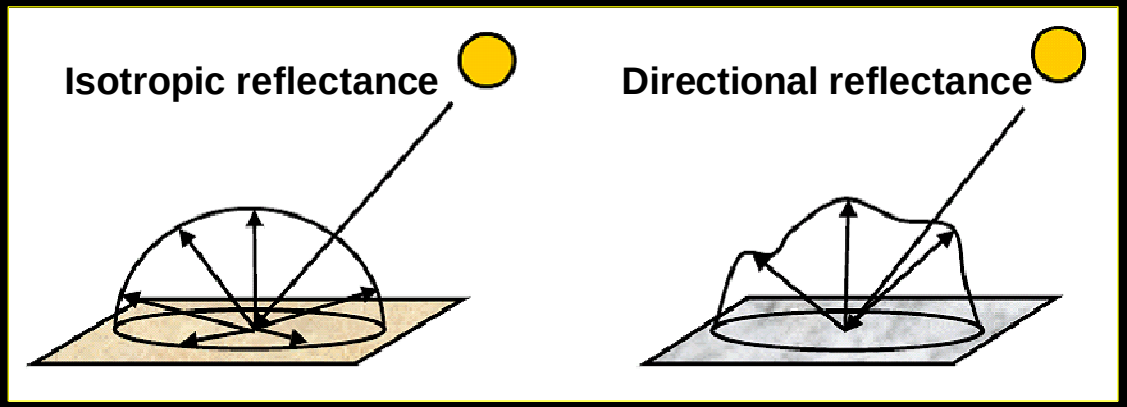
STAR Seminar – Tuesday, Nov. 3, 2009
9:30 a.m. – 10:30 a.m.
Room 707, World Weather Building

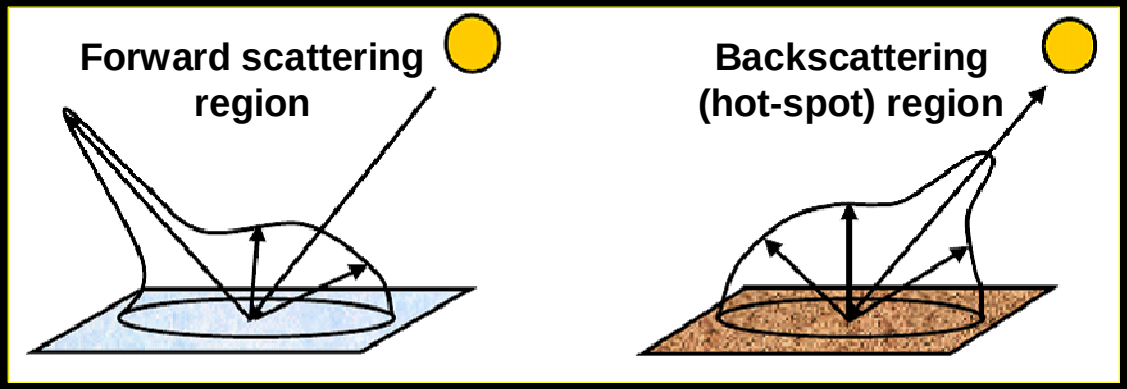
Outline

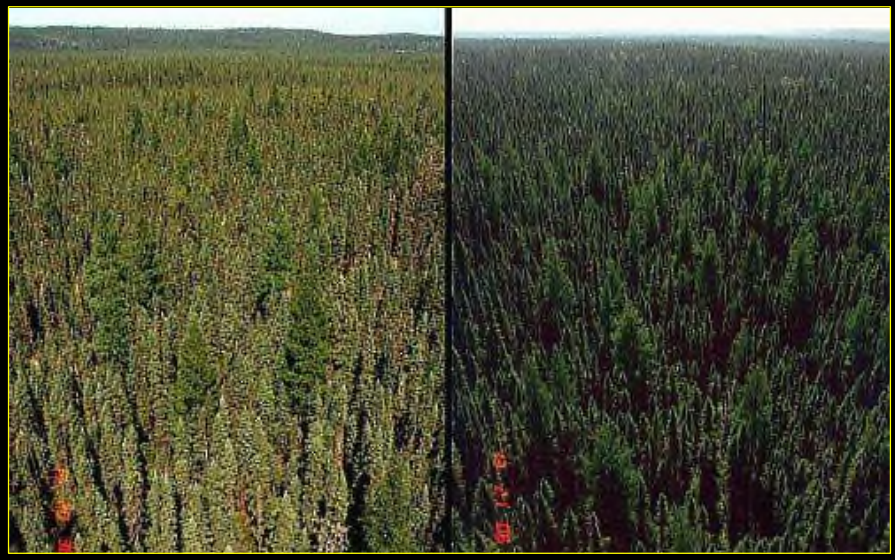
- ***BRDF/Albedo*:**
  - Overview & Dataset Applications
  - *Validation Efforts*: Assessment of Spatial Representativeness
- ***Cloud Absorption Radiometer (CAR)*:**
  - *CAR BRDF/Albedo Product:* Algorithm Theoretical Basis
  - *Case Study*: 2007 CLaSIC-IOP (US Southern Great Plains)
- **Future Work…**

The Bidirectional Reflectance Distribution Function:

The BRDF describes the directional way solar radiation reflects from the surface.







Backscattering vs. Forward Scattering

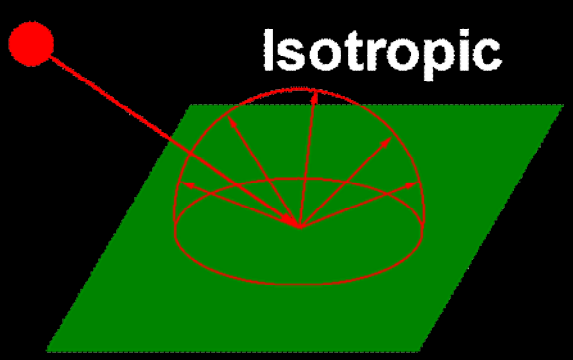
Photographs by Don Deering.

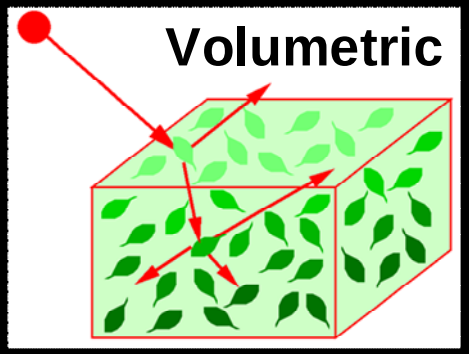
- Surface albedo can be accurately estimated from the BRDF.
- The '*shape*' of the BRDF contains information on the three-dimensional geometric structure of the surface.

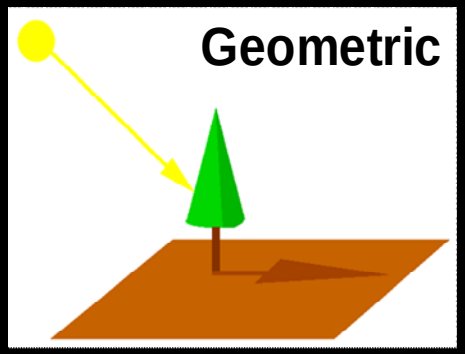
MODIS BRDF/Albedo Algorithm: Standard Products

MCD43A1 (Surface Reflectance Anisotropy)—
Supplies the three weighting parameters associated with the RossThickLiSparse Reciprocal (RTLSR) BRDF model that best describes the differences in radiation due to the scattering of each satellite pixel.

$$BRDF(\theta_s, \theta_v, \Delta\phi, \lambda) \cong R(\theta_s, \theta_v, \Delta\phi, \Lambda)$$
$$= f_{iso}(\Lambda) + f_{vol}(\Lambda)K_{vol} + f_{geo}(\Lambda)K_{geo}$$







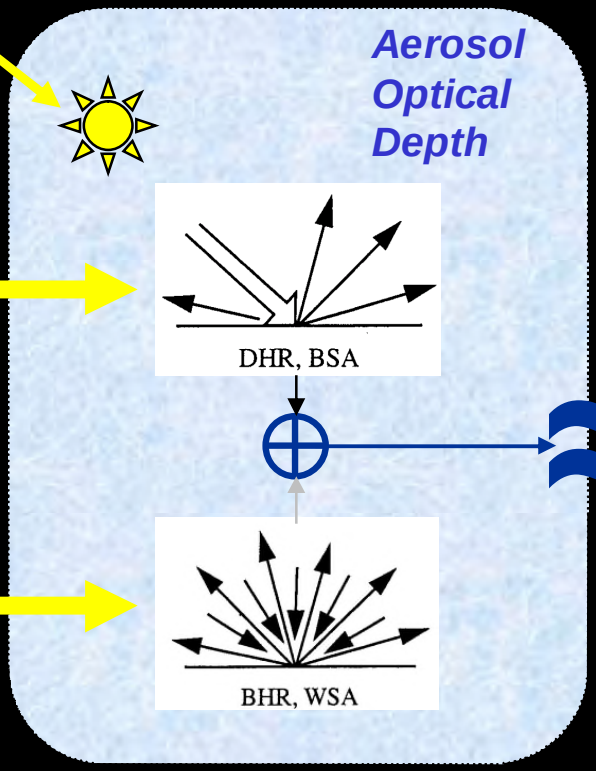
-Kernels, K, are functions of viewing and illumination geometry.

-Weights, f, are functions of biophysical properties.

MODIS BRDF/Albedo Algorithm: Standard Products

Solar Zenith Angle

Aerosol Optical Depth



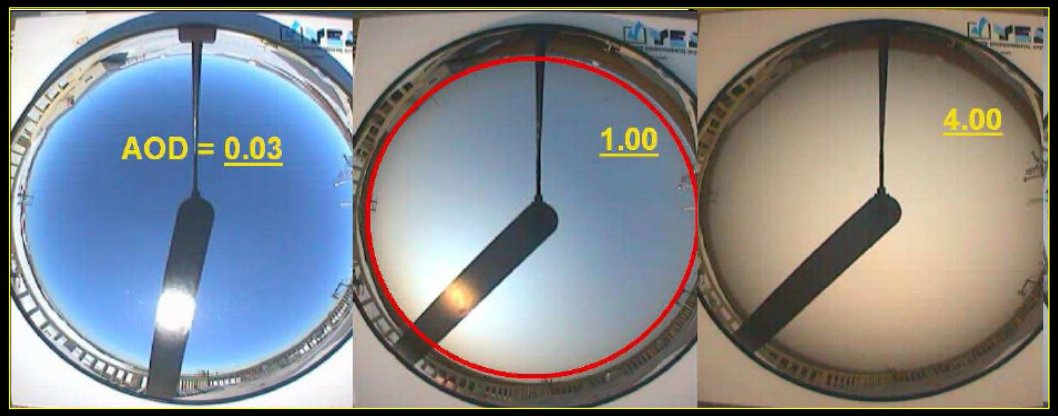
Black-Sky Albedo:
The albedo in the absence of a diffuse component and is a function of solar zenith angle (SZA).

White-Sky Albedo:
The albedo of the scene under perfectly diffuse illumination.

An albedometer measuring frost flowers on young ice.

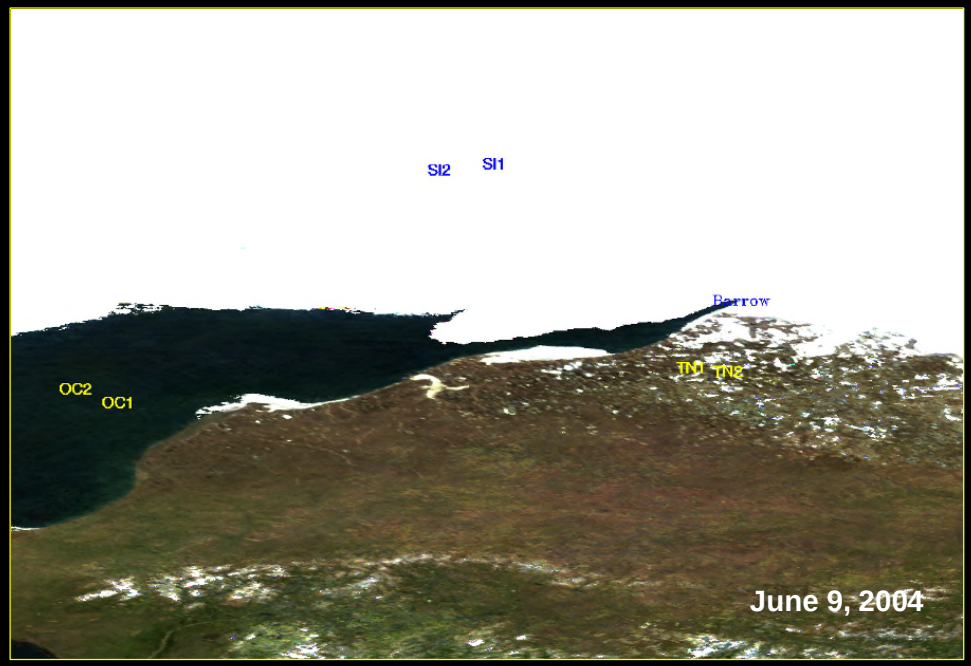
Actual surface albedo, as measured instantaneously by field albedometers, is a continuously varying function of: (1) the specific atmospheric conditions that modulate the incoming solar irradiance; and (2) the intrinsic anisotropic scattering of the surface as determined by the reflected irradiance.

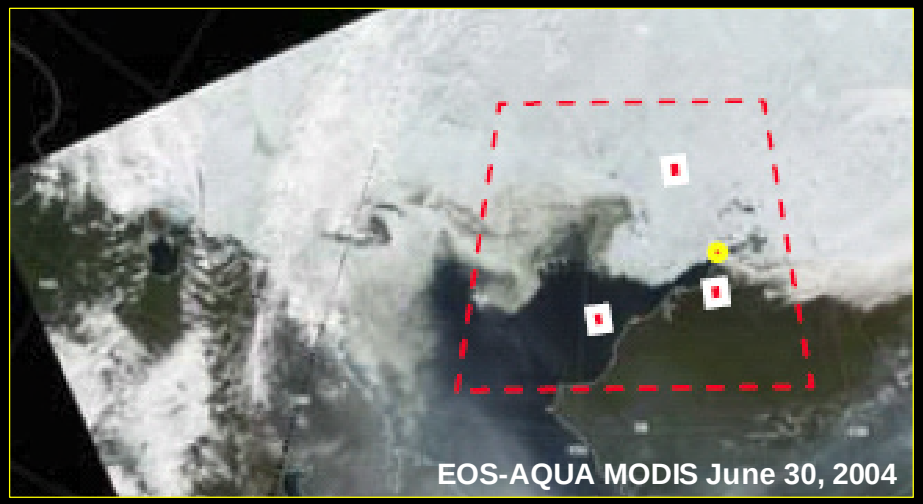
MODIS BRDF/Albedo Product: Dataset Applications

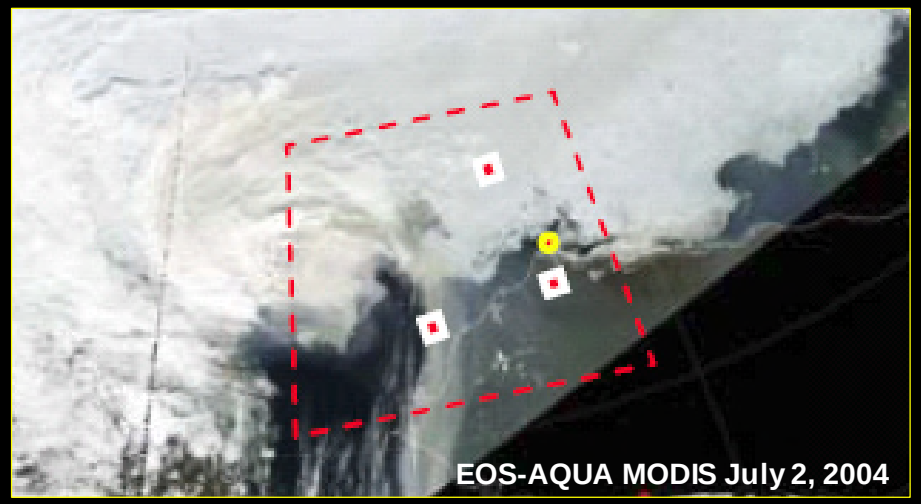


July 22, 2008 (Bloomberg) -- “Smoke spreading across the sky from intense wildfires in North America could act temporarily to blunt the effect of climate change in the Arctic region.”

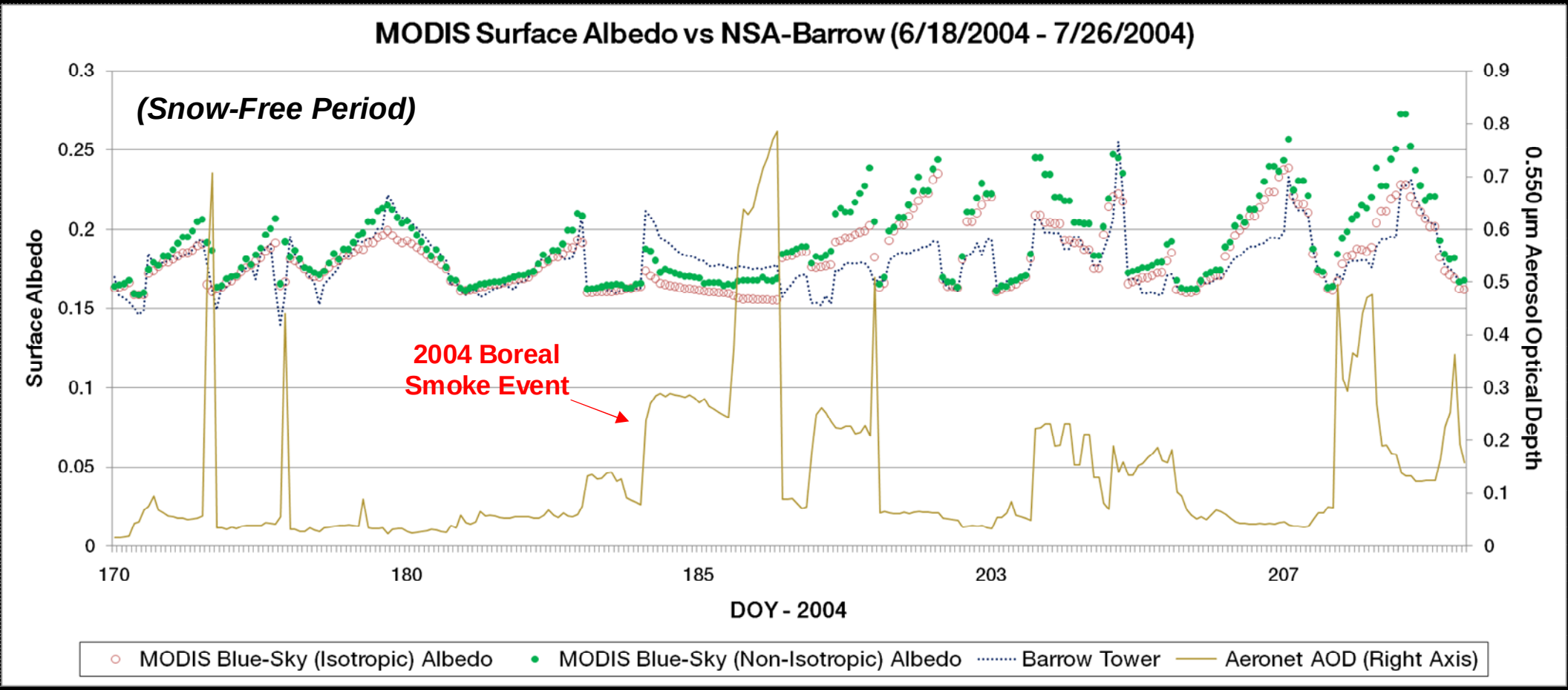
Shortwave (0.3-5.0um) White-Sky Albedo (Pre-Smoke)







Radiative impact of boreal smoke in the Arctic: Observed and modeled



- As production moves from MODIS data to NPP and NPOESS data, user specifications require that production also moves from the current multi-date approach to daily albedo computations.
- Explicit characterization of the fraction of diffuse skylight under realistic scenarios of anisotropic diffuse illumination and multiple scattering helps improve the albedo retrievals under extremely turbid conditions and at high solar zenith angles.

Validation Efforts: "Forest Albedo Paper"

Remote Sensing of Environment 113 (2009) 2476–2498

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journal homepage: www.elsevier.com/locate/rse

The MODIS (Collection V005) BRDF/albedo product: Assessment of spatial representativeness over forested landscapes

Miguel O. Román [a,b,*], Crystal B. Schaaf [b], Curtis E. Woodcock [b], Alan H. Strahler [b], Xiaoyuan Yang [b], Rob H. Braswell [c], Peter S. Curtis [d], Kenneth J. Davis [e], Danilo Dragoni [f], Michael L. Goulden [g], Lianhong Gu [h], David Y. Hollinger [i], Thomas E. Kolb [j], Tilden P. Meyers [k], J. William Munger [l], Jeffrey L. Privette [m], Andrew D. Richardson [n], Tim B. Wilson [k], Steven C. Wofsy [l]

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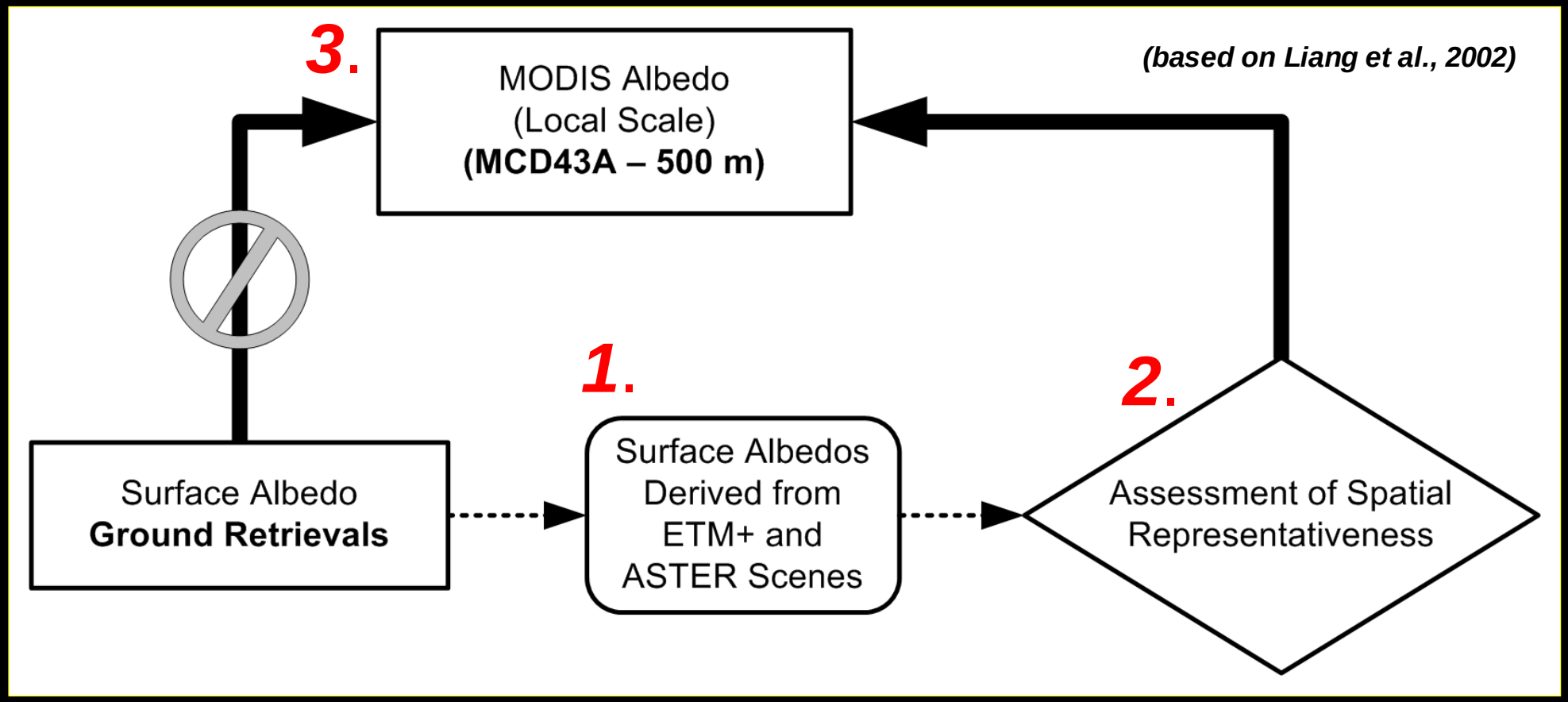
Assessment of Spatial Representativeness

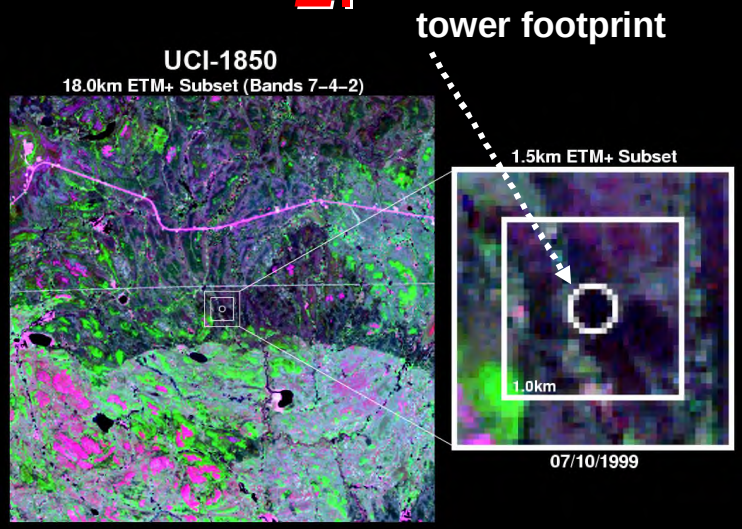


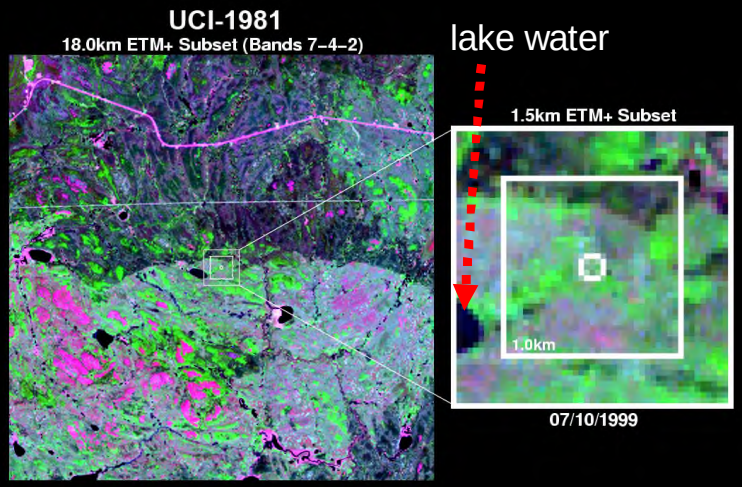
Spatial Representativeness:

The degree to which an *in-situ* measurement is able to capture the intrinsic variability of the surrounding landscape.

Case Study: UCI – Fire Chronosequence

1.





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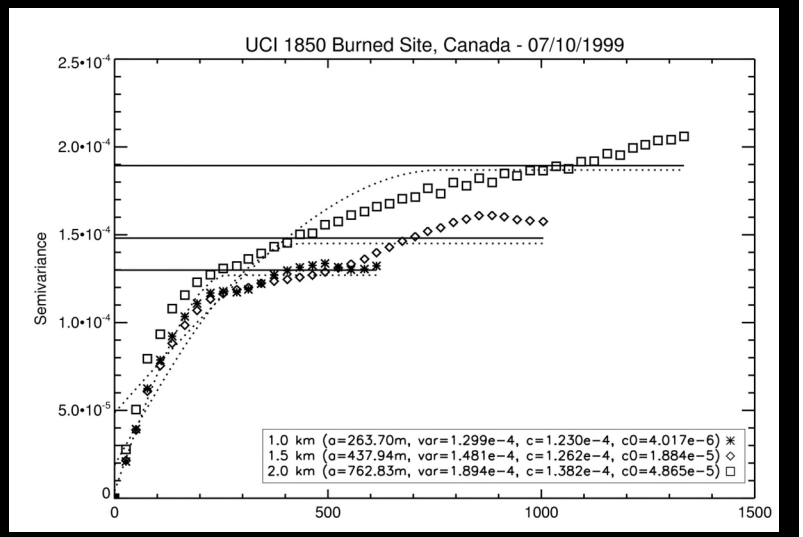

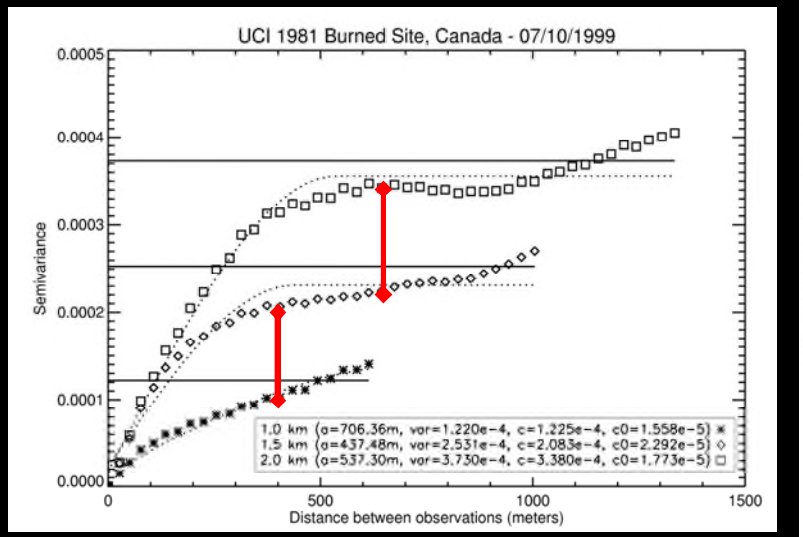

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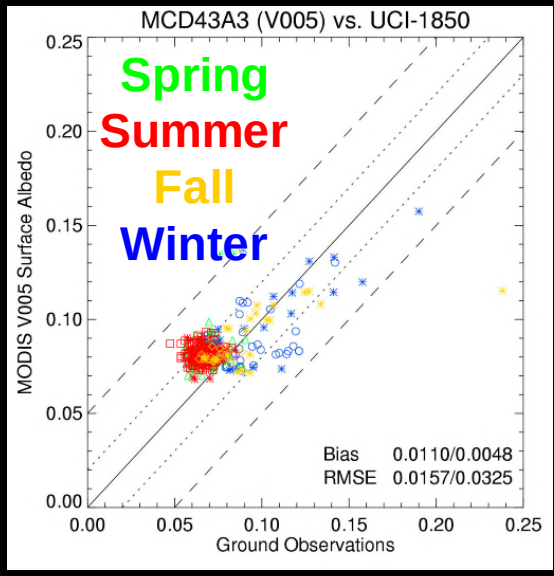
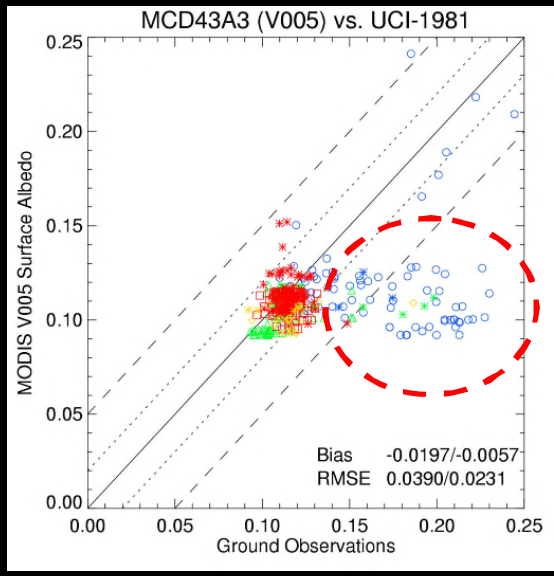
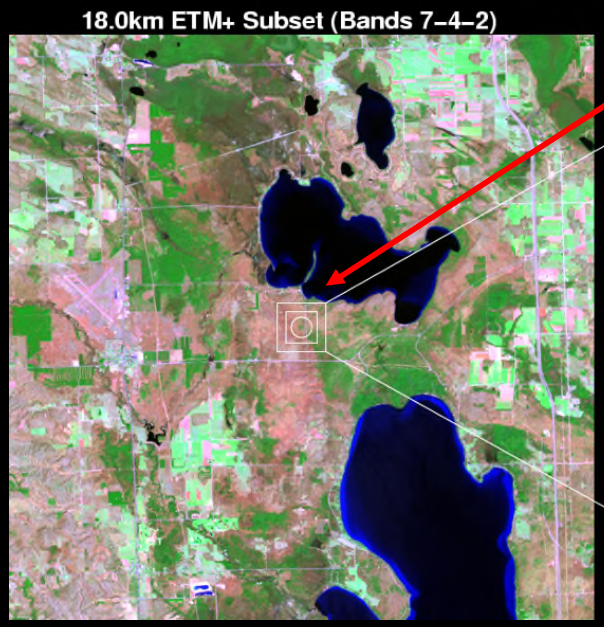


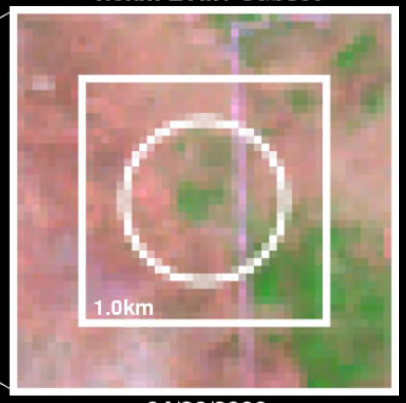


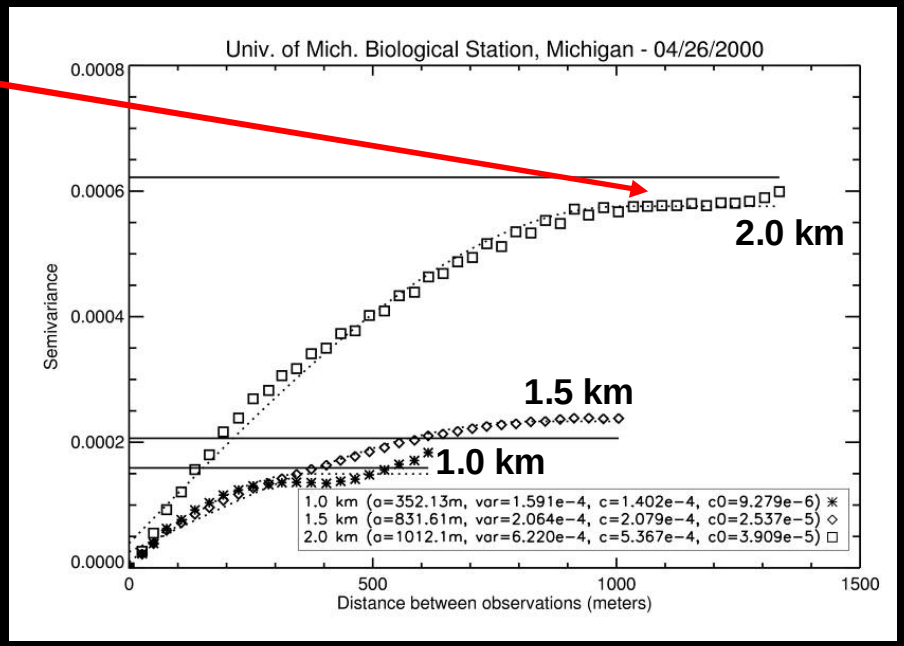
This approach improves our understanding of product uncertainty both in terms of the representativeness of the field data and its relationship to the larger satellite pixel.

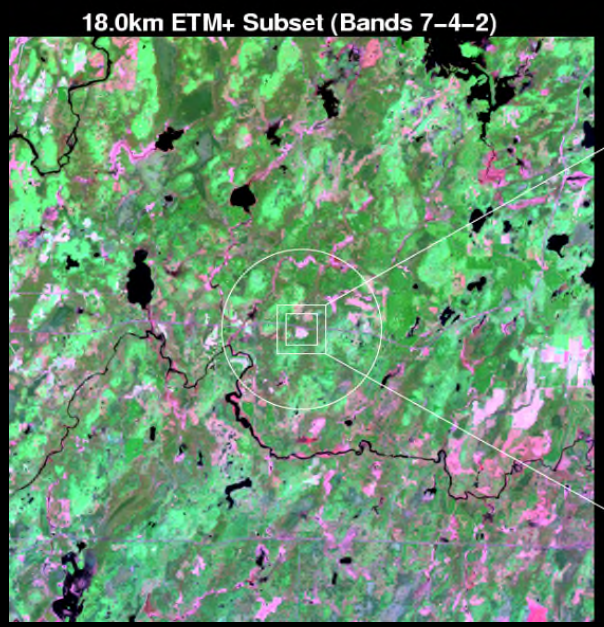
Geostatistics as a Descriptor of Spatial Representativeness



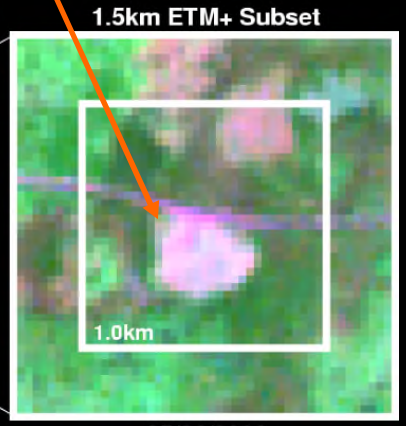
External variability, Leaf-Off Conditions

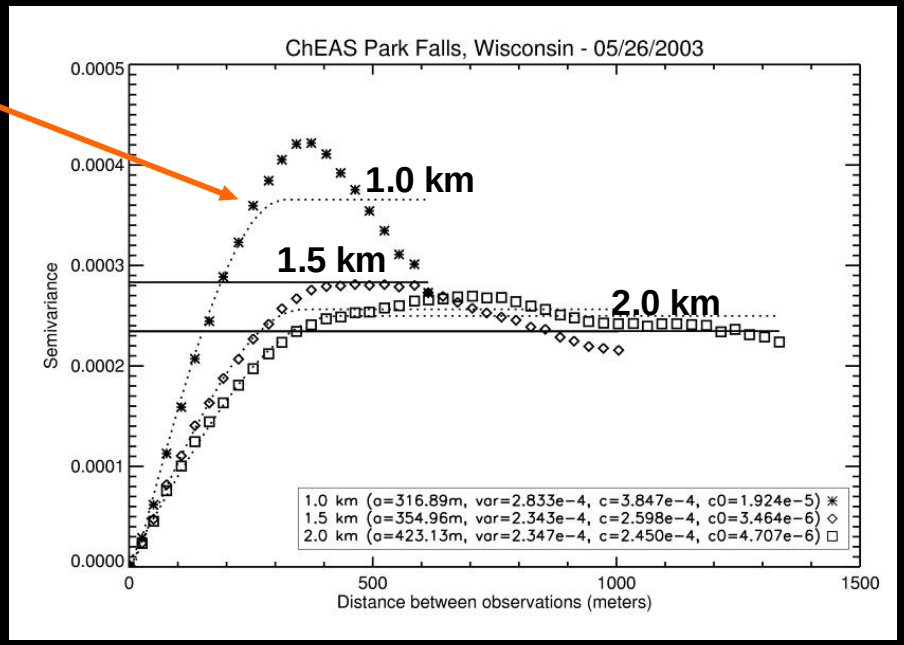




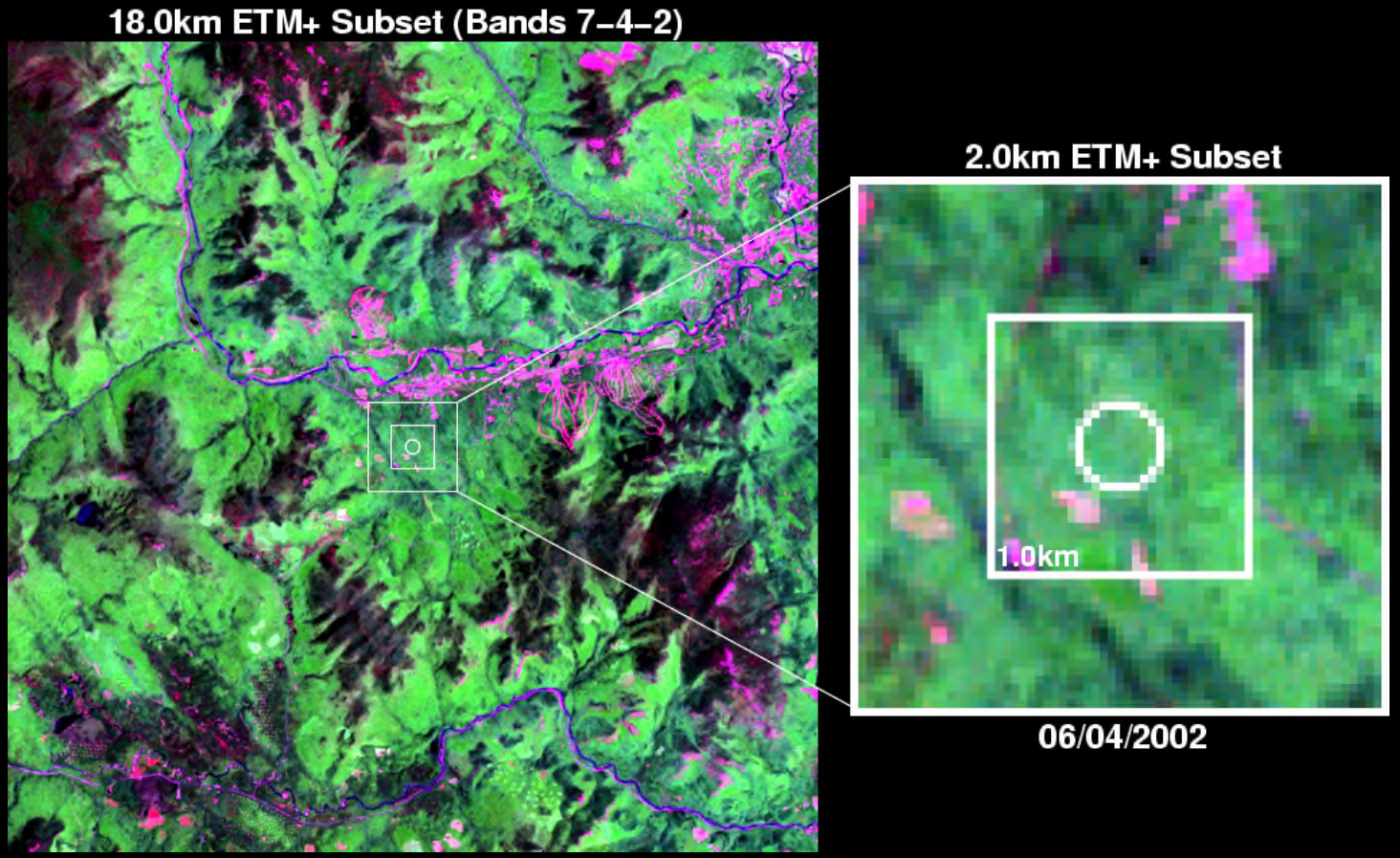


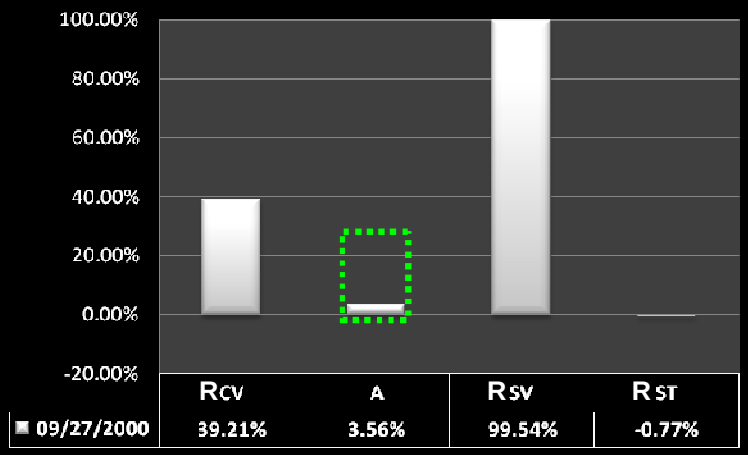
Internal variability, Leaf-On Conditions





Case Study: Bartlett Experimental Forest, NH





-- Key Measures of Spatial Representativeness –

R_{CV} - A measure of ***overall variability*** independent of spatial effects.

A - Measures the ***range of the variogram*** using both the tower and satellite footprints as regions of interest.

R_{SV} - A relative measure of ***structural variability***.

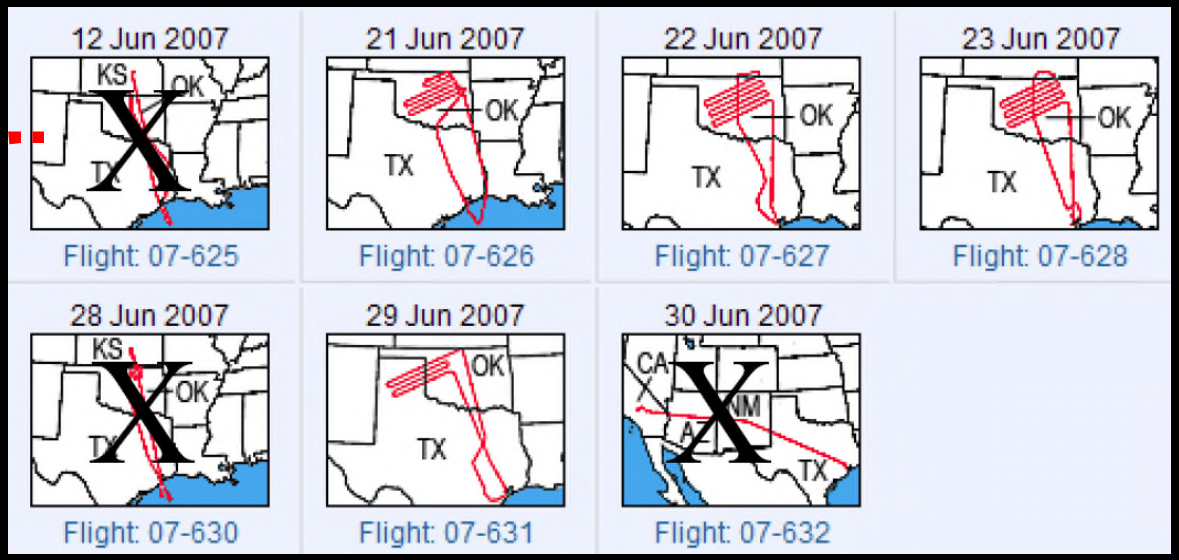
R_{ST} - Measures the relative ***strength of spatial autocorrelation***.

The Cloud Absorption Radiometer (CAR) BRDF/Albedo Product: Applications in Terrestrial Ecosystem Modeling and Remote Sensing

***CAR/BU Team*: M. Román, C. K. Gatebe, C. B. Schaaf, R. Poudyal, E. M. Wilcox, and M. D. King.**

In-Situ Measurements of BRDF and Albedo

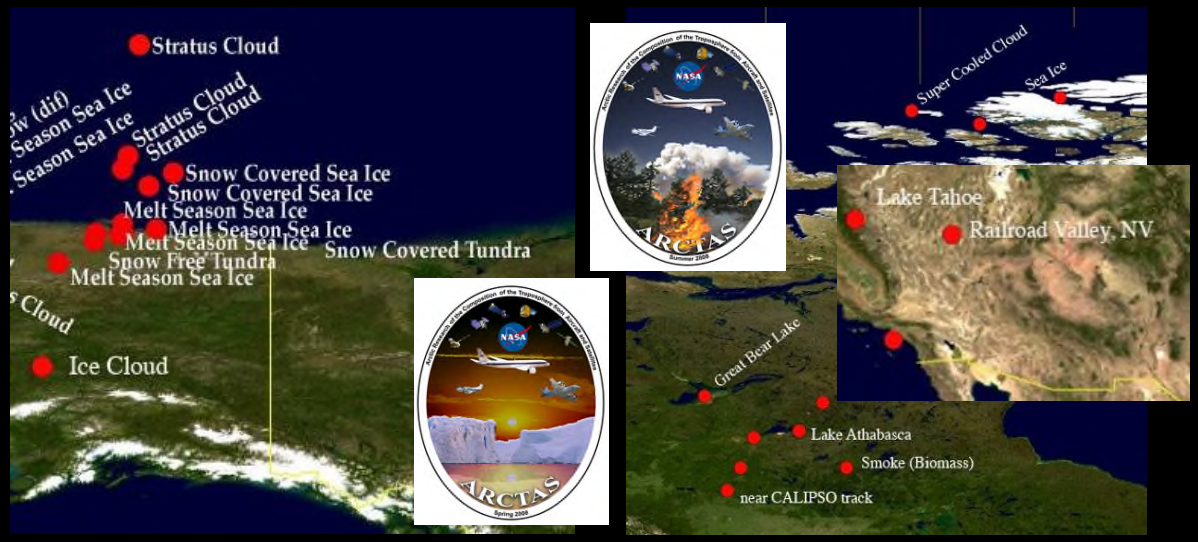
CLASIC-MAS Hybrid Missions



Both aircraft and ground-based retrievals of the BRDF serve as important additional sources of validation for land surface satellite products.

(Photo credits:
Jeff Privette and Michael King)

The CAR BRDF/Albedo Product: Project Goals



Images courtesy of Rajesh Poudyal

Key Science Questions:

- What is the role played by scale in models describing the BRDF and albedo of land surfaces?
- How are disturbance regimes affecting the health and productivity of natural and agricultural resources?

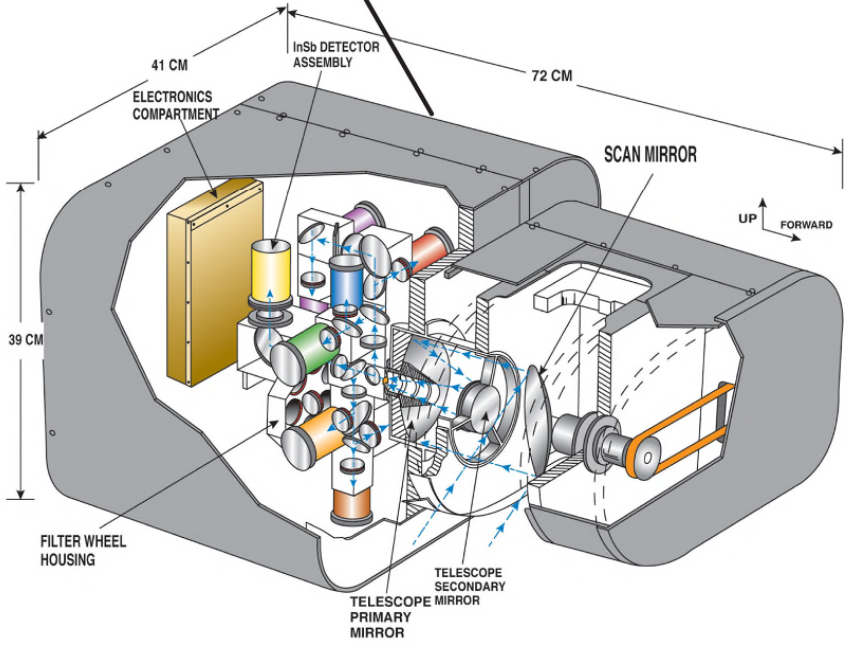
Technical Objectives:

- To calibrate, complement, and enhance the interpretation of global terrestrial datasets.
- To recreate the measurement methodology, spatial coverage, and data processing protocols employed by current and future satellite sensors.

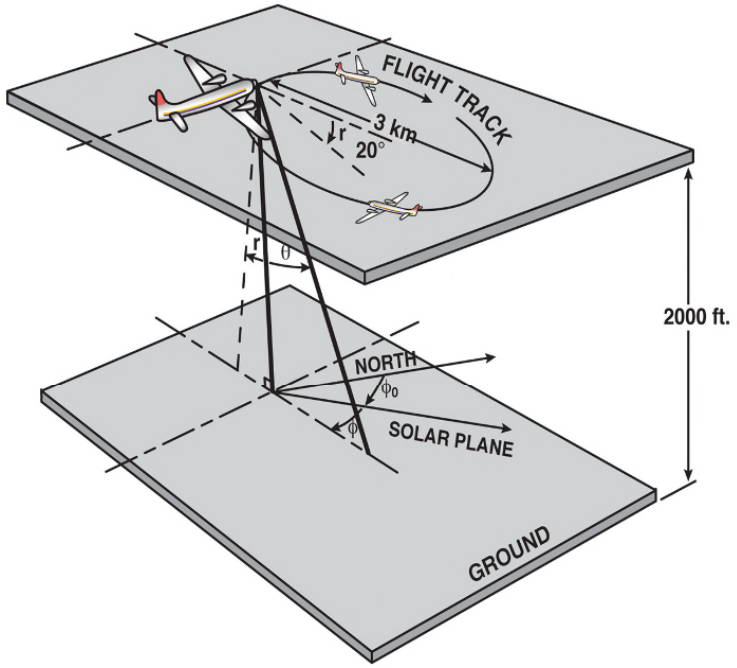
CAR Instrument Highlights

a. Jetstream-31 Aircraft

b. CAR Schematic



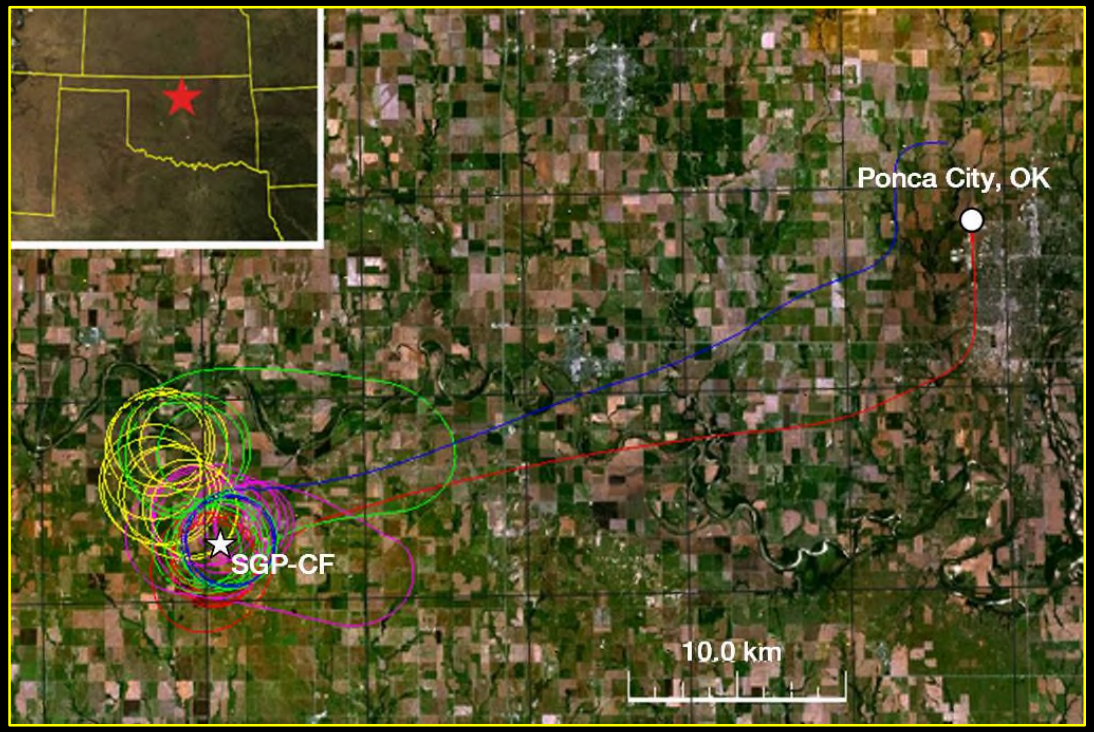
c. BRDF Flight Track



d. Cloud Absorption Radiometer (CAR) Parameters

Angular scan range	190°
Instantaneous field of view	17.5 mrad (1°)
Pixels per scan line	382
Scan rate	1.67 scan lines per second (100 rpm)
Spectral channels (μm; bandwidth (FWHM))	14 [a] (8 continuously sampled and last six in filter wheel): 0.340(0.009), 0.381(0.006), 0.472(0.021), 0.682(0.022), 0.870(0.022), 1.036(0.022), 1.219(0.022), 1.273(0.023), 1.556(0.032), 1.656(0.045), 1.737(0.040), 2.103(0.044), 2.205(0.042), 2.302(0.043)

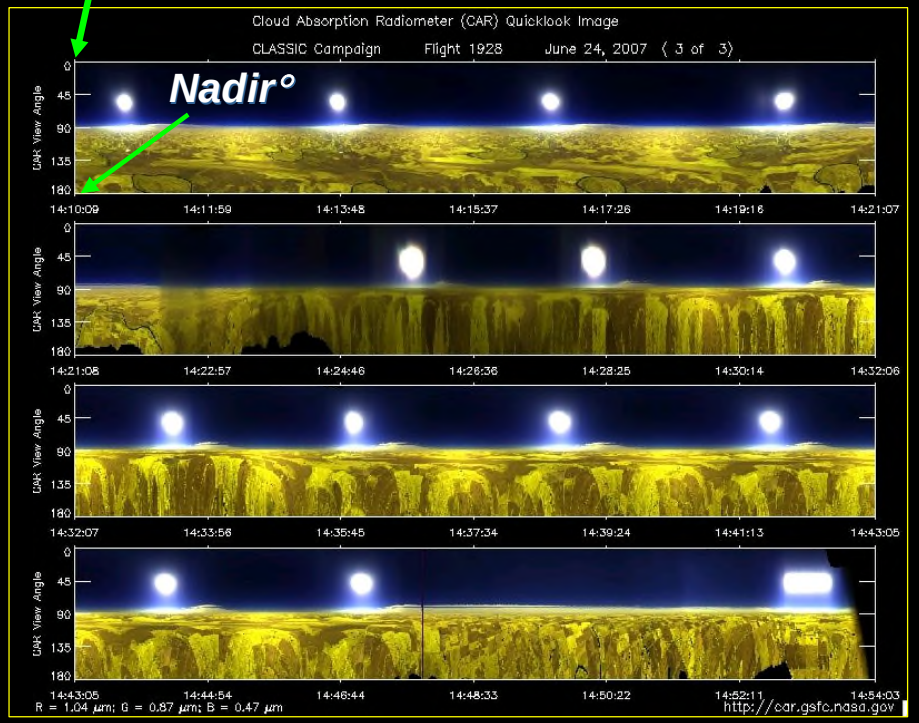
CLASIC Flight #1928 : Flight Segment Details



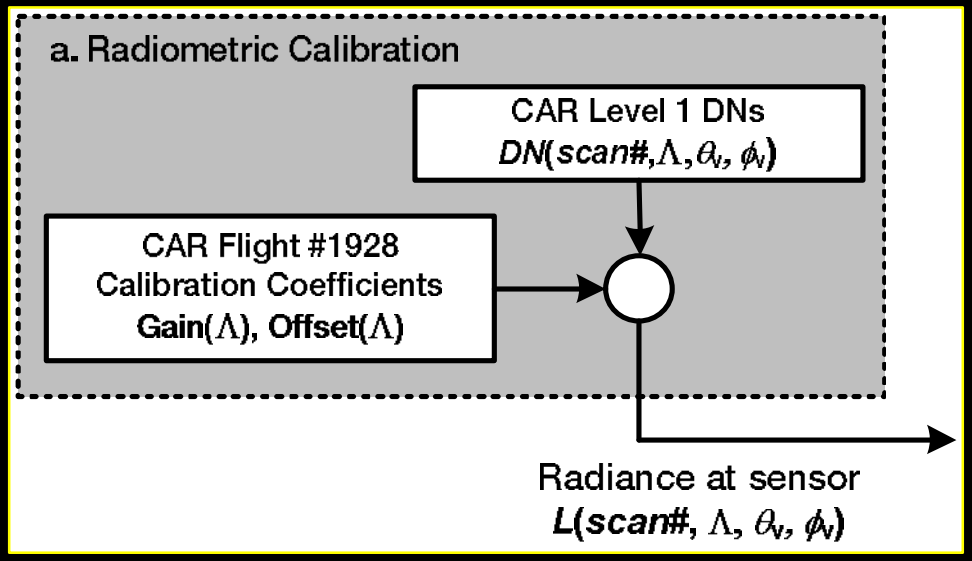
Zenith°

Nadir°

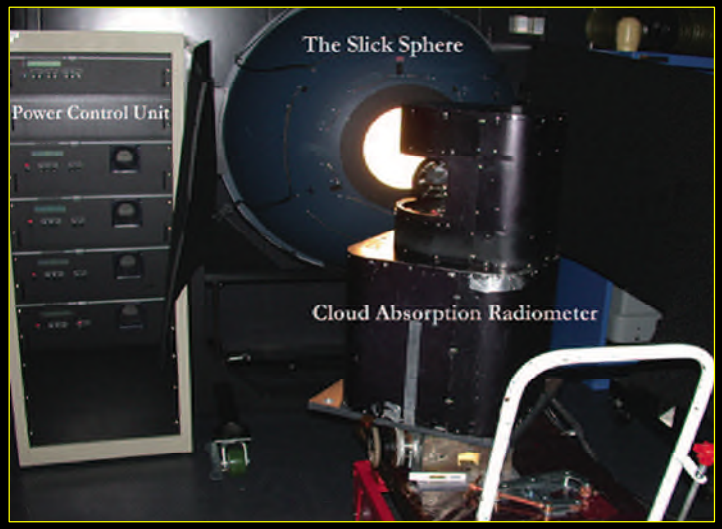
Imagery from CAR



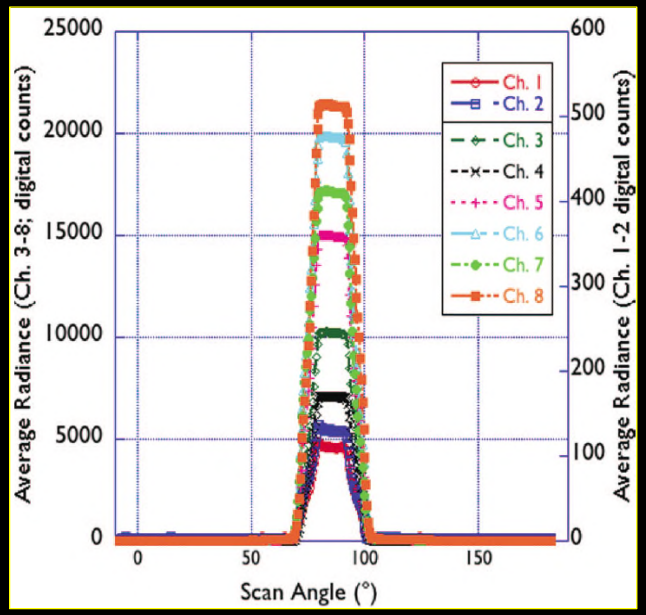
CAR BRDF/Albedo Product – Algorithm Development, Stage I:



NASA-GSFC Radiometric Calibration Facility

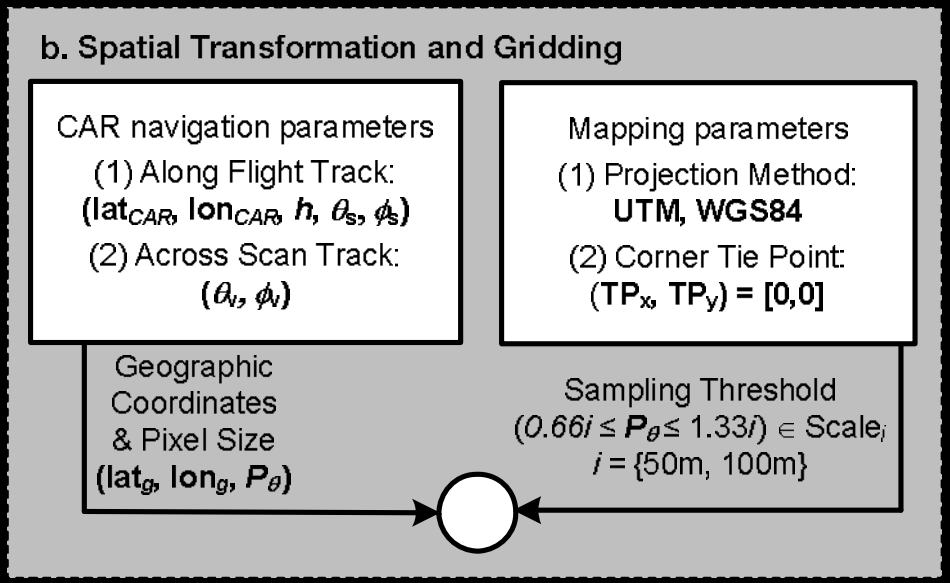


▲ Setup for integrating sphere source to determine the CAR's responsivity across its angular scan range.



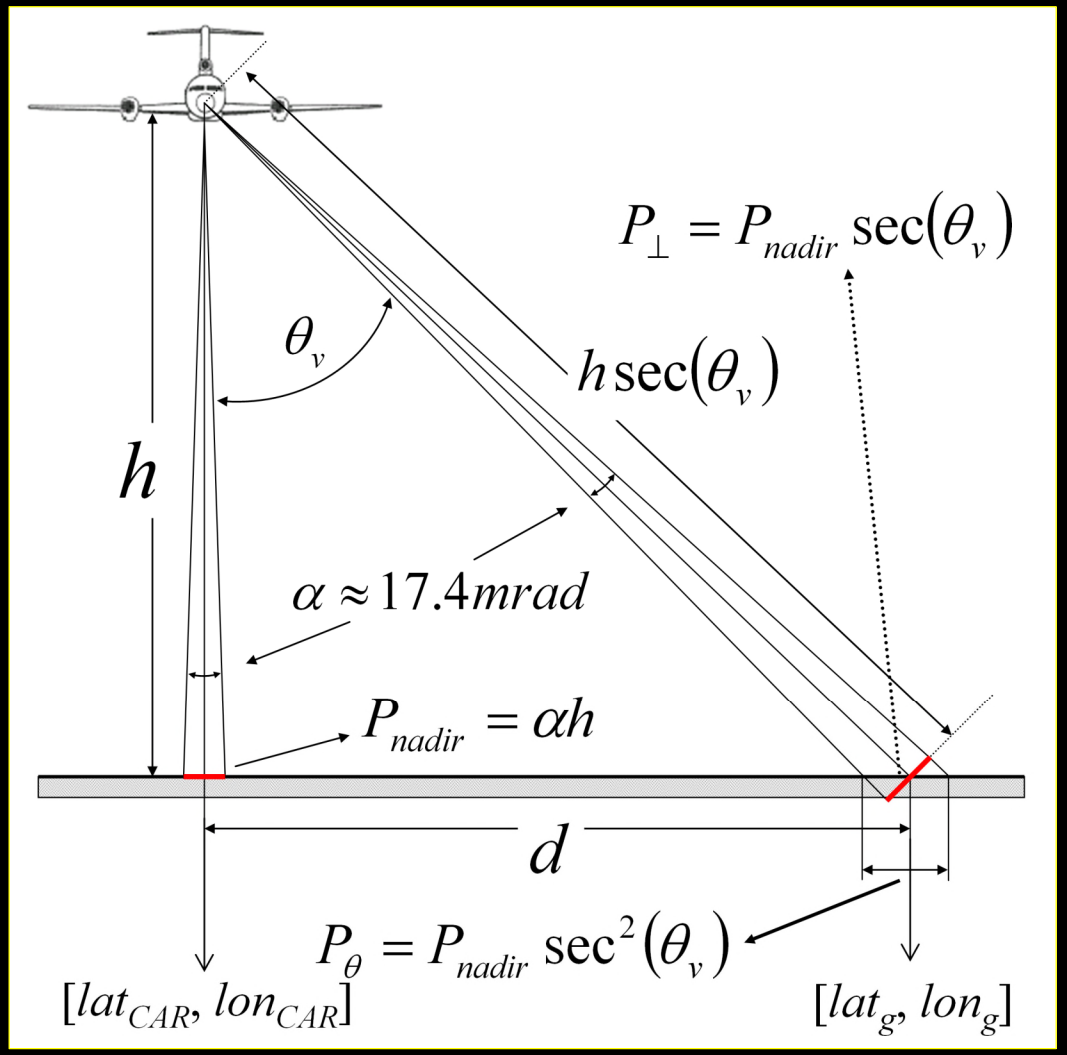
◄ Spectral radiance output from the integrating sphere as measured by CAR at 0.5° intervals across the 190° scan range.

CAR BRDF/Albedo Product – Algorithm Development, Stage II:



The CAR instrument is actively stabilized by a sophisticated navigation system.

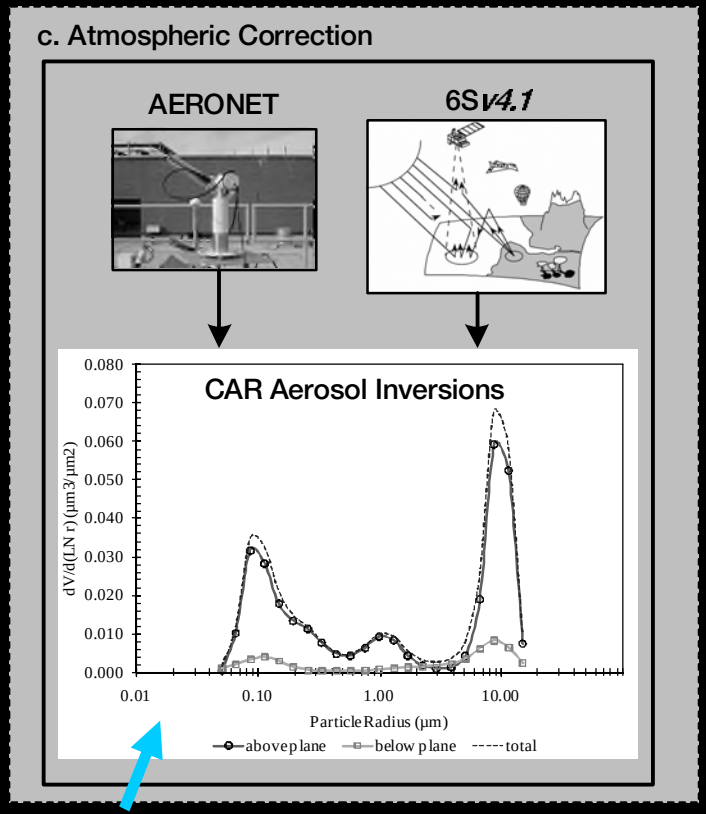
Each mirror-scan is accompanied by high-frequency navigation data, which allows for excellent geolocation accuracy (< 1m).



CAR BRDF/Albedo Product – Algorithm Development, Stages III - V:

III. Atmospheric Correction:

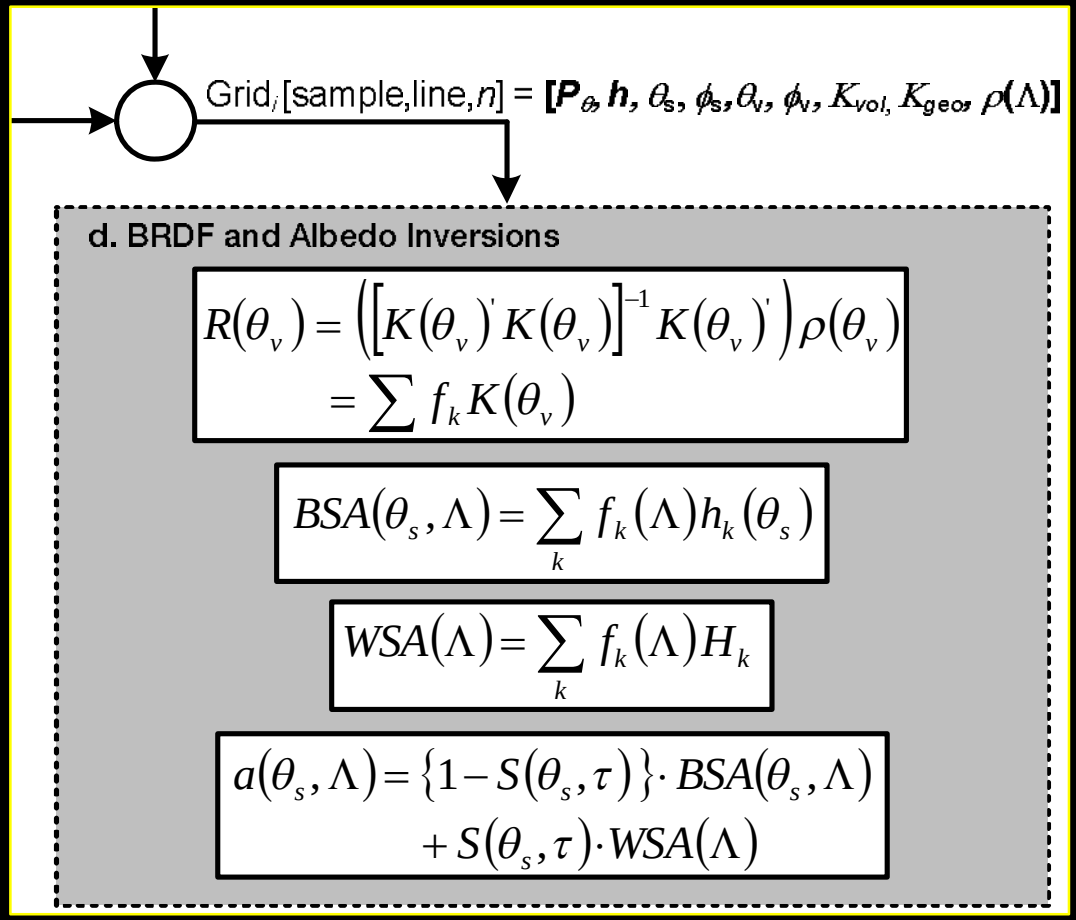
- Directional surface reflectances are derived by removing the effects of atmospheric absorption and scattering using the 6SV code.



Aerosol column particle volume size distribution retrieved from the CAR during CLASIC Flight #1928.

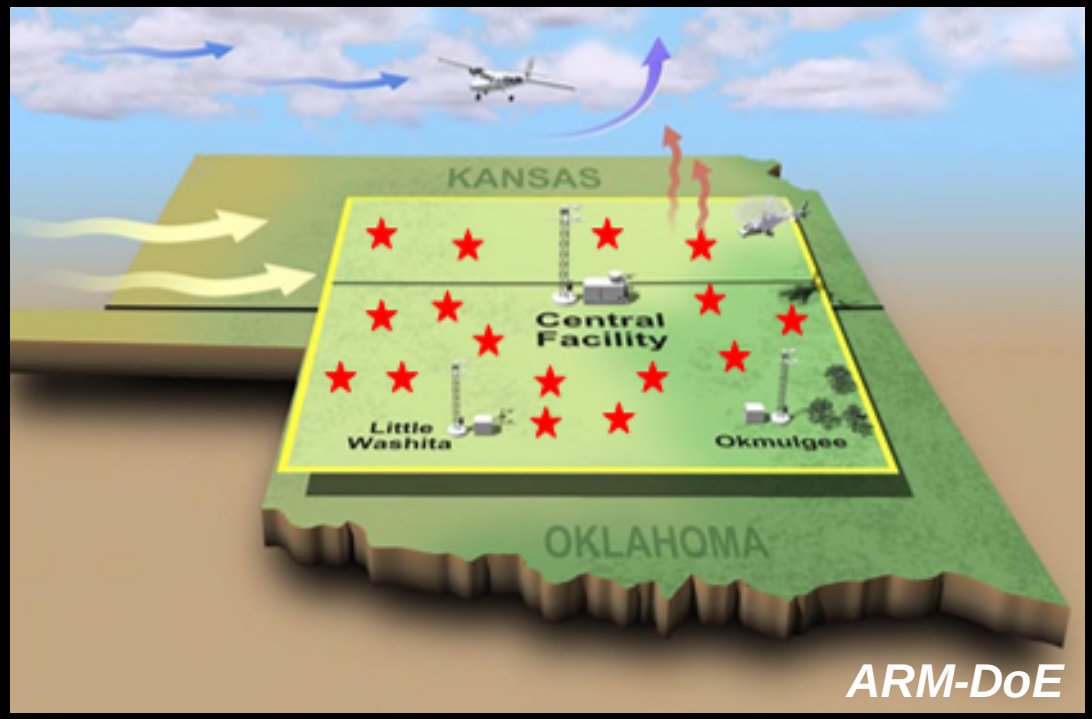
IV. BRDF and Albedo Model Inversions:

- BRDF kernel model parameters and surface albedos are extracted for each CAR spectral channel.



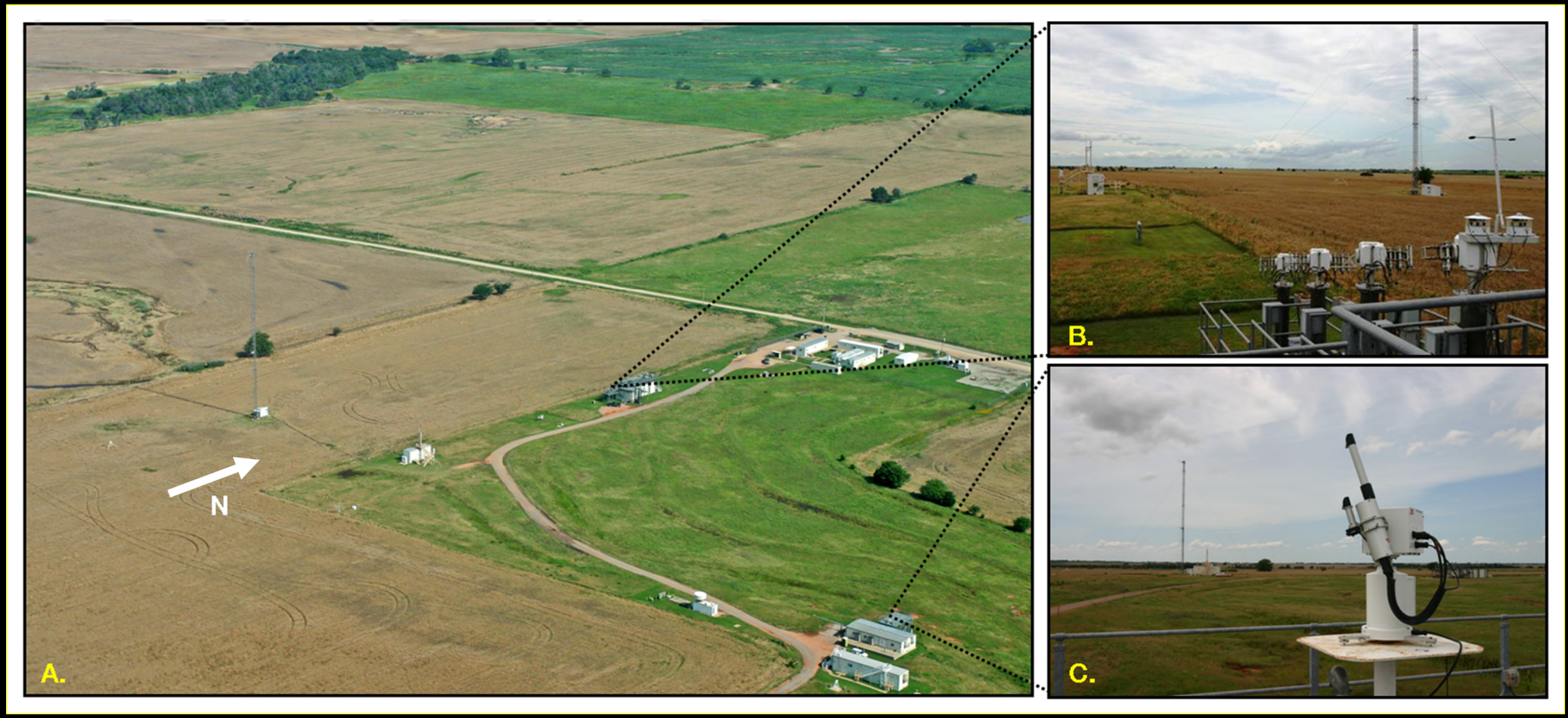
Case Study: The ARM Southern Great Plains (SGP)

- Direct measurements of key terrestrial essential variables require significant instrumental deployment in areas where *in-situ* data are scarce.
- It is clearly not feasible to provide such “ground-truth” information to assess the errors in global satellite observations, and thus provide the necessary quality controls required by rigorous modeling efforts.



The ARM Southern Great Plains (SGP) is one of the few regions on Earth where field and tower measurements are spatially distributed across a large region.

Case Study: ARM Central Facility - CAR Flight #1928

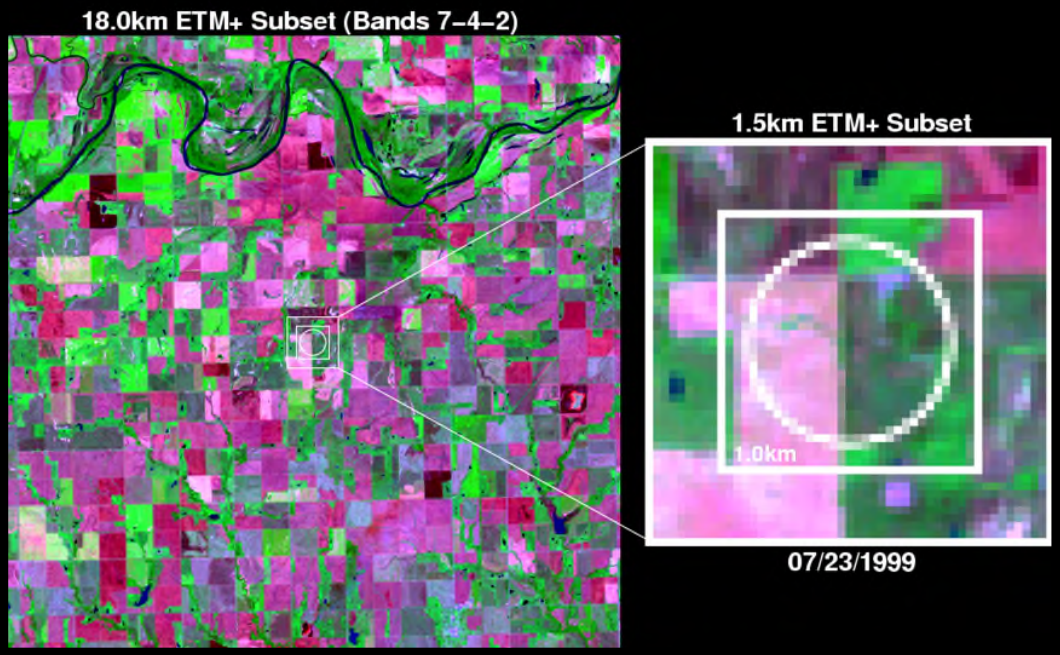


A. Bird's eye view of the ARM-Southern Great Plains Central Facility (SGP-CF).

B. Facing southwest atop the Radiometric Calibration Facility.

C. Facing west atop the Guest Instrument Facility.

Spatial Representativeness of the SGP-Central Facility



ETM+ subset centered at the ARM Central Facility's 60 m Radiation Tower.

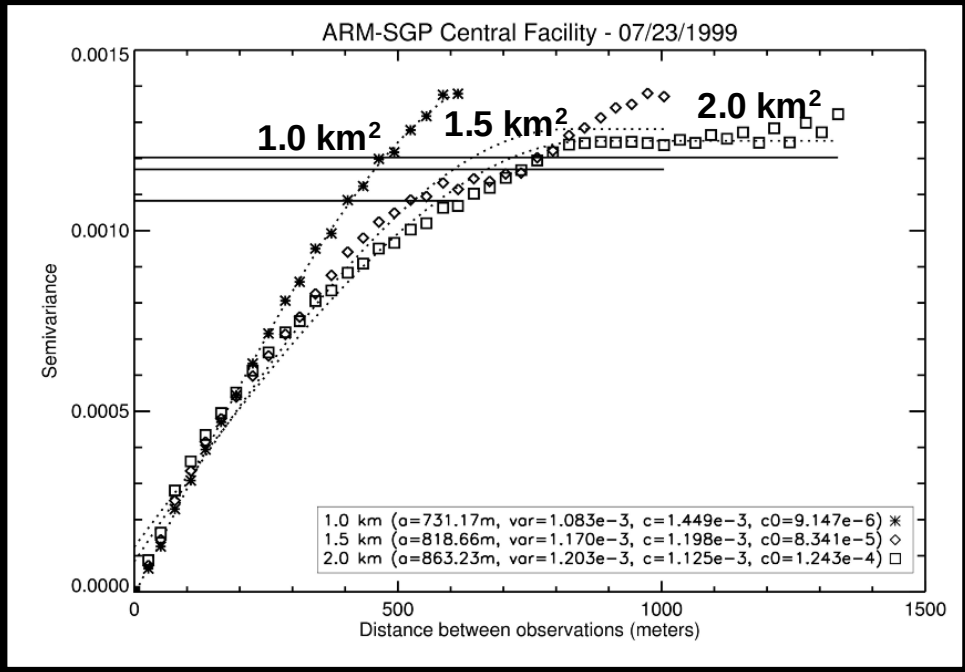
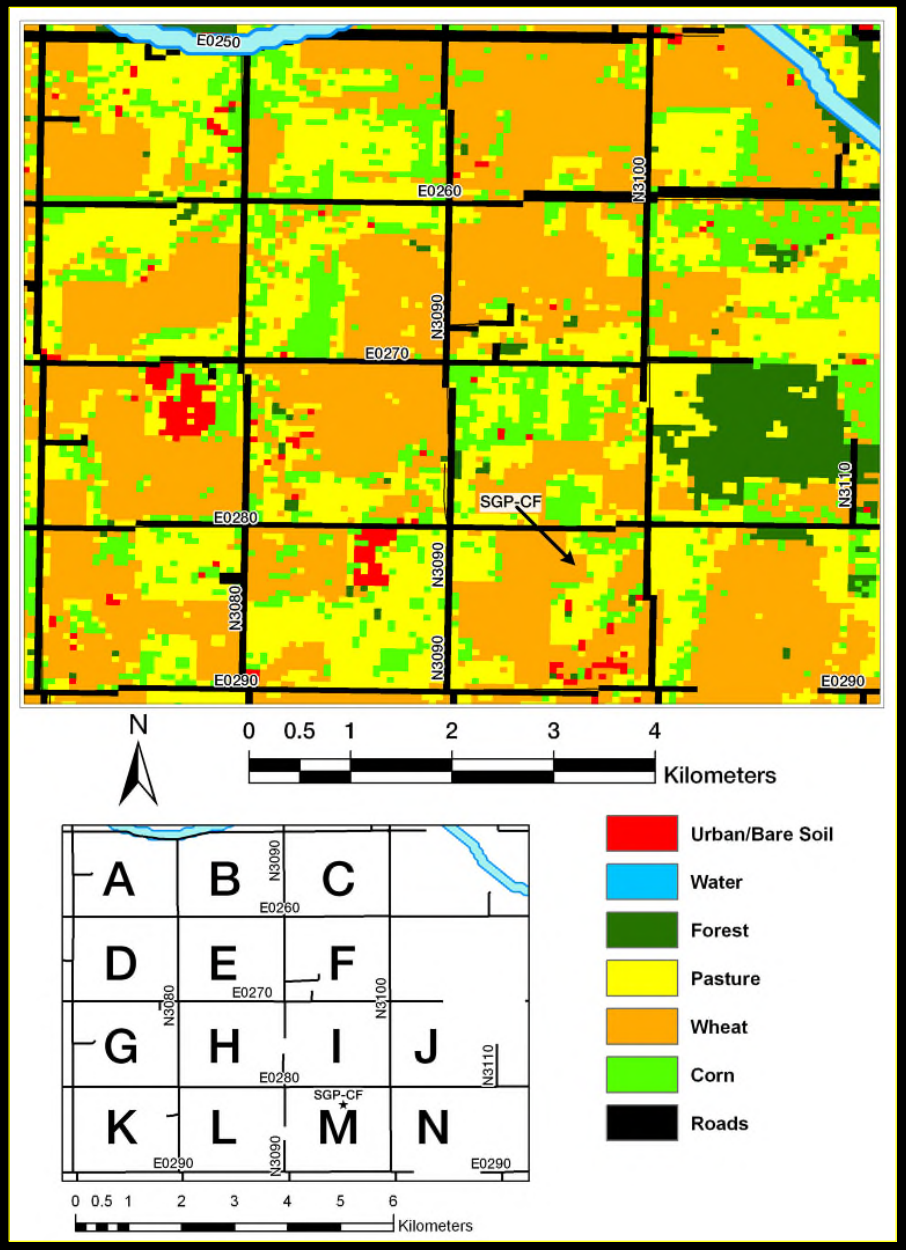


Image variograms of surface albedo using 1.0 km^2 (asterisks), 1.5 km^2 (diamonds), and 2.0 km^2 (squares) ETM+ subsets.

Assessments of spatial representativeness at the SGP-Central Facility during the CLASIC-IOP indicate that the surface conditions inside the footprint of the 60 m flux tower are significantly different from the surrounding region extending to a MODIS pixel.

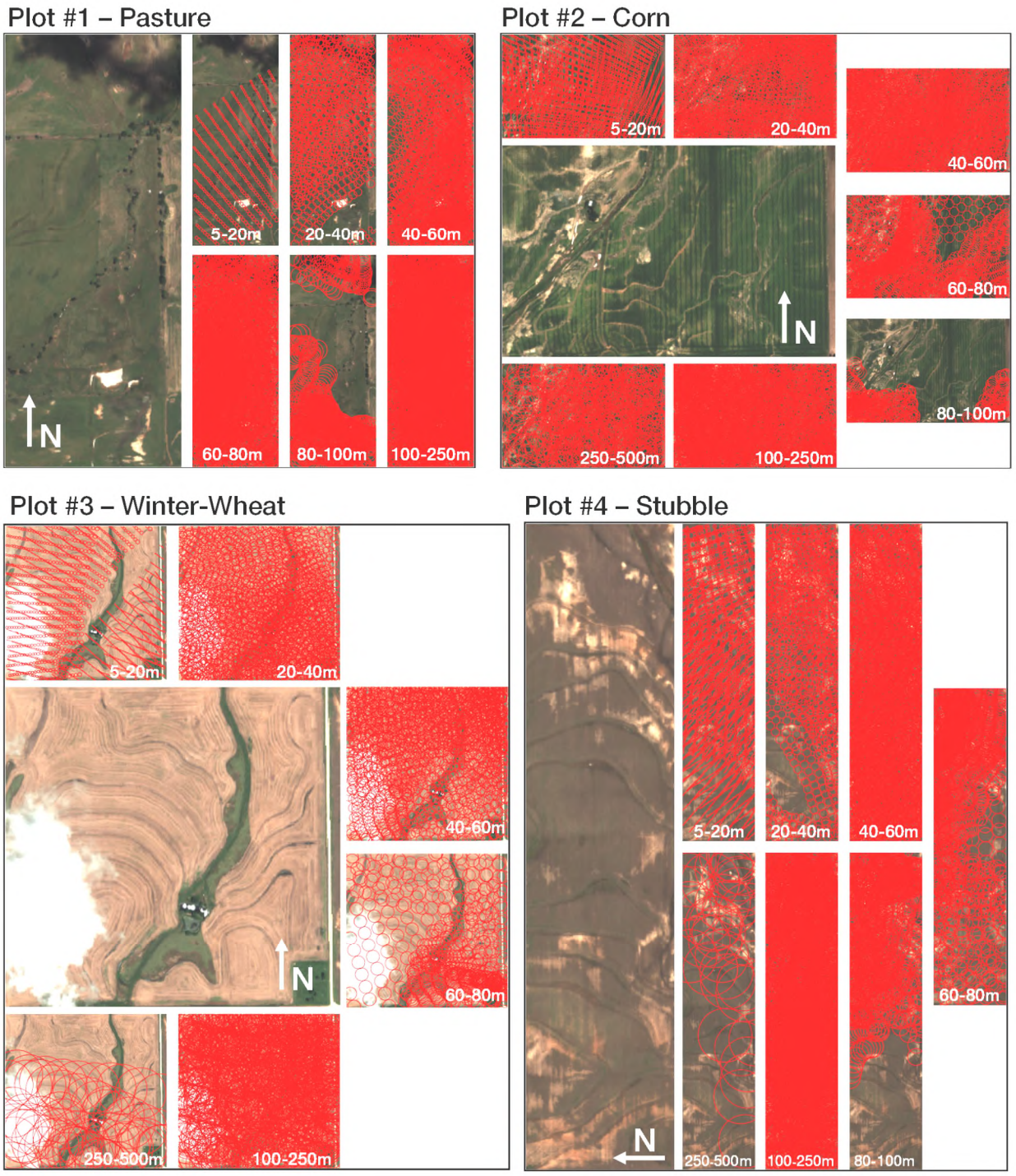
CLASIC Flight #1928: Land Cover Characteristics



- **ARM-CLASIC Flight #1928 Goals:**
  - *To reconstruct areal-mean, nadir-normalized, and angular indexes of vegetation structure directly from CAR at multiple spatial scales .*
  - *To compare areal-mean retrievals of the BRDF between the CAR and MODIS sensors.*
  - *To derive the average BRDF obtained by CAR for typical land cover types in the SGP-CF area.*

▲ AWiFS 56 m land cover map (Lamont, Oklahoma).

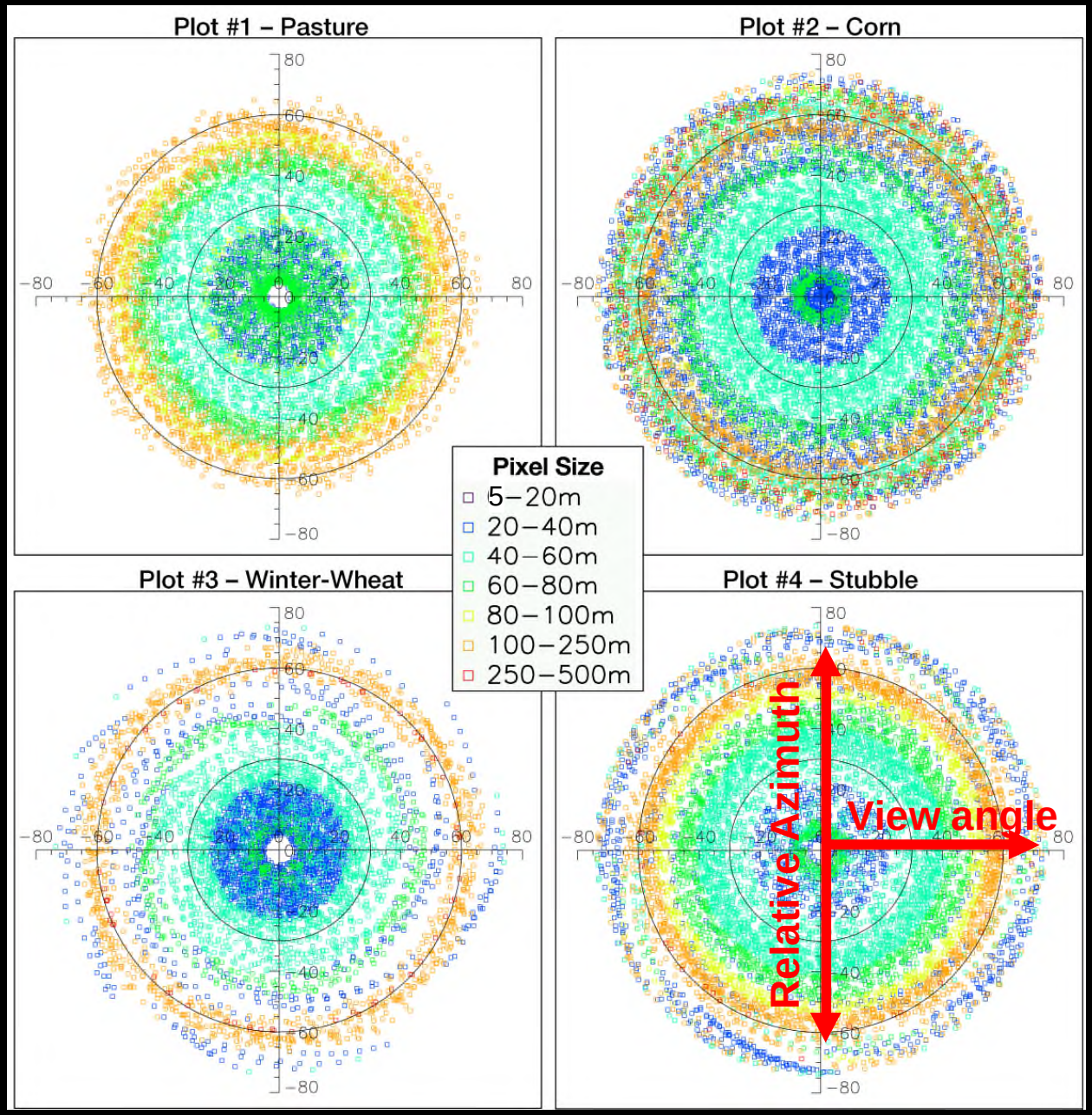
Direct Retrievals from CAR



It is useful to estimate the impacts of the uncertainties in the BRDF directly on the higher-level (reflectance-based) measures themselves, as the errors are not spatially and/or spectrally independent.

These assessments can be enhanced by deriving vegetation indexes (e.g. NDVI and EVI) from CAR at increased spatial scales and under a wide range of viewing and illumination conditions.

Direct Retrievals from CAR (cont.)



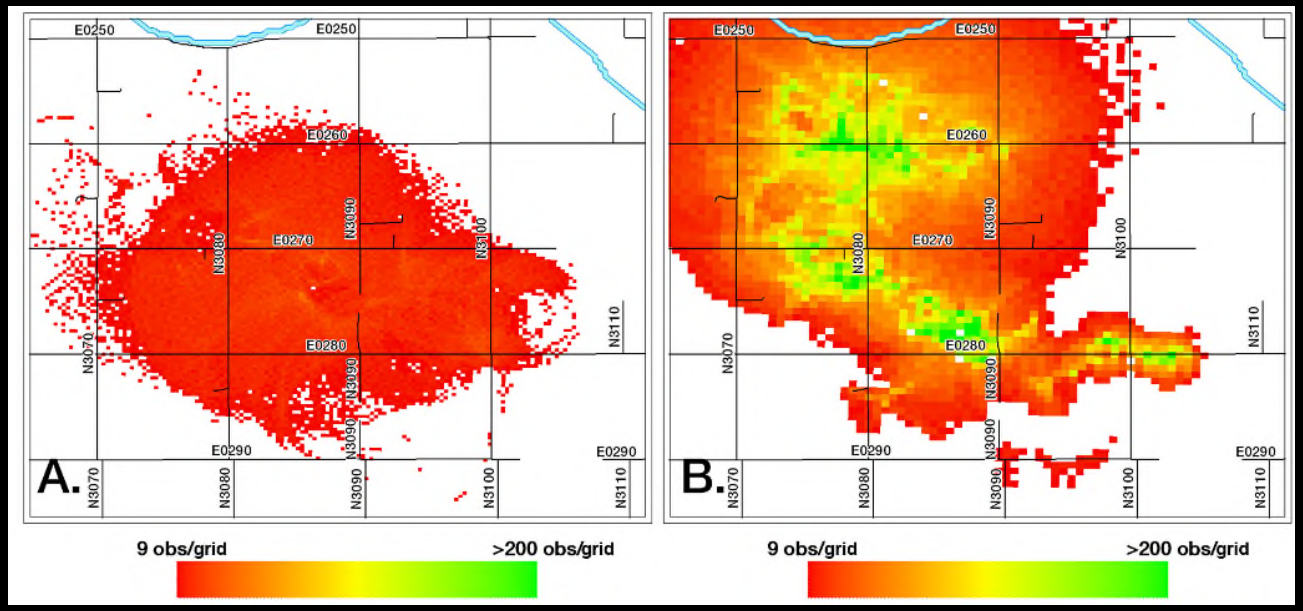
The angular sampling efficiency of CAR measurements can also be used to extract information about the directional structure of the landscape.

Angular indexes e.g. NDHD use the relative magnitude of the ‘darkspot’ to the ‘hotspot’ reflectances to characterize the anisotropic behavior of the land surface.

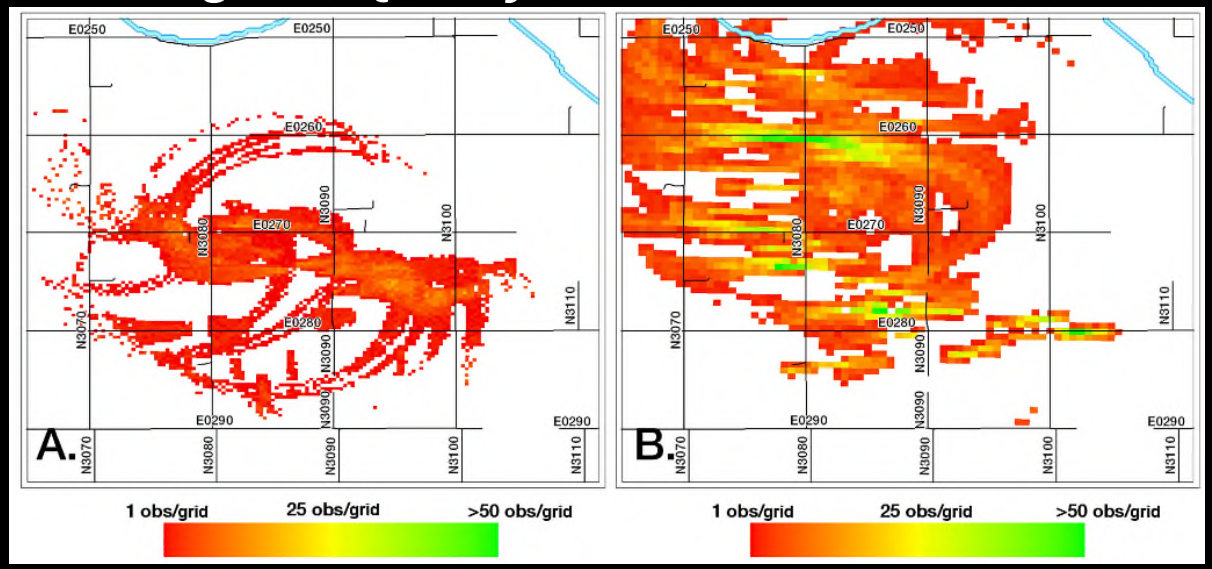
Both ***in-situ*** and **modeled** estimates of NDVI, EVI, and NDHD were derived from CAR retrievals.

Quality Assurance Fields

Frequency maps indicating the number of CAR observations when using spatial intervals defined by 50 m (A.) and 100 m (B.) grid cells.

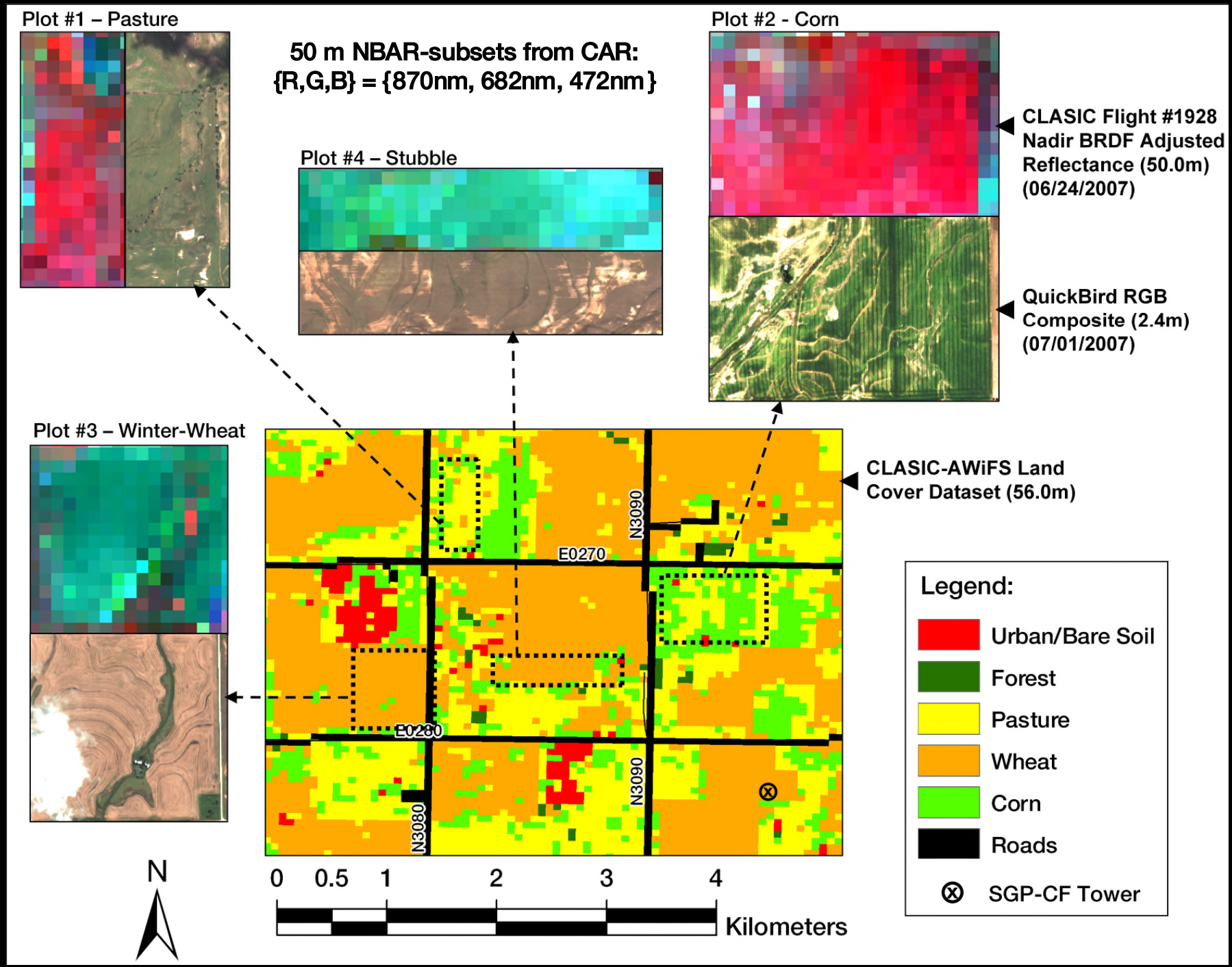


Highest Quality Retrievals from CAR



Fraction of CAR observations (from above) that are within ±10° of the principal solar plane.

Model-Based (BRDF) Retrievals from CAR



...Some (Very Preliminary) Results

Plot #3 (Wheat)											
1. Sample Size	% of Sample	Mean Pixel Size	Direct Method: Mean BRFs			Direct Method: Shape Indicators		Direct Method: Vegetation Indexes			
			Band3	Band4	Band5	NDHD-Band4	NDHD-Band5	NDVI@nadir	EVI@nadir	Mean NDVI	Mean EVI
3141	34.35%	7.12	0.0513	0.1048	0.1945	0.9533	0.8078	0.3013	0.1687	0.3304	0.1533
2596	28.39%	34.93	0.0473	0.0965	0.1842	0.9234	0.8225	0.3178	0.1749	0.3716	0.2423
1830	20.02%	46.95	0.0408	0.0819	0.1543	0.9234	0.8078	0.3057	0.1347	0.3639	0.2383
505	5.52%	67.32	0.0238	0.0508	0.0937	0.4234	0.4825	0.2826	0.0962	0.3784	0.2623
1006	11.00%	174.96	0.0281	0.0605	0.1081	0.5275	0.7210	0.3215	0.0994	0.3177	0.279
65	0.71%	260.07	0.0267	0.0598	0.1055	0.1736	0.1388	0.2934	0.0978	0.2478	0.1925

2. 3.

Mean Pixel Size	RTLSR Model Uncertainty			RTLSR Model: NBAR			RTLSR Model: Shape Indicators		RTLSR Model: NBAR Vegetation Indexes			
	Band3	Band4	Band5	Band3	Band4	Band5	NDHD-Band4	NDHD-Band5	NBAR-NDVI	NBAR-EVI	NBAR-NDVI	NBAR-EVI
7.12	0.0178	0.0253	0.0459	0.032	0.0795	0.1486	0.2393	0.2329	0.3027	0.1406	0.3027	0.1406
34.93	0.0138	0.0214	0.0438	0.0319	0.0752	0.1404	0.0229	0.2346	0.3026	0.1342	0.3026	0.1342
46.95	0.0083	0.014	0.0305	0.0294	0.0616	0.1189	0.3558	0.2457	0.3171	0.1214	0.3171	0.1214
67.32	0.0004	0.0007	0.0033	0.0209	0.0435	0.0901	0.2536	0.3241	0.3487	0.1027	0.3487	0.1027
174.96	0.0024	0.0055	0.0118	0.0236	0.0493	0.0886	0.1933	0.1879	0.2852	0.0865	0.2852	0.0865
260.07	0.0005	0.0012	0.0013	0.0262	0.0586	0.1042	0.2662	0.2617	0.2801	0.098	0.2801	0.098

	Band3	Band4	Band5	NDHD-Band4	NDHD-Band5	NBAR-NDVI	NBAR-EVI	NBAR-NDVI	NBAR-EVI
Weighted Sample Mean	**0.0438**	**0.0897**	**0.1678**	**0.8572**	**0.7755**	**0.308**	**0.1515**	**0.3495**	**0.2157**
Spatial Uncertainty (Abs. Units)	0.0164	0.0311	0.061	0.4374	0.3409	0.0184	0.049	0.0514	0.0433
RTLSR: Total Uncertainty (Abs. Units)	0.0199	0.0391	0.0704	0.6941	0.6569	0.0306	0.0505	0.0447	0.114

The impact of the uncertainties associated to these multi-scale retrievals depends on:

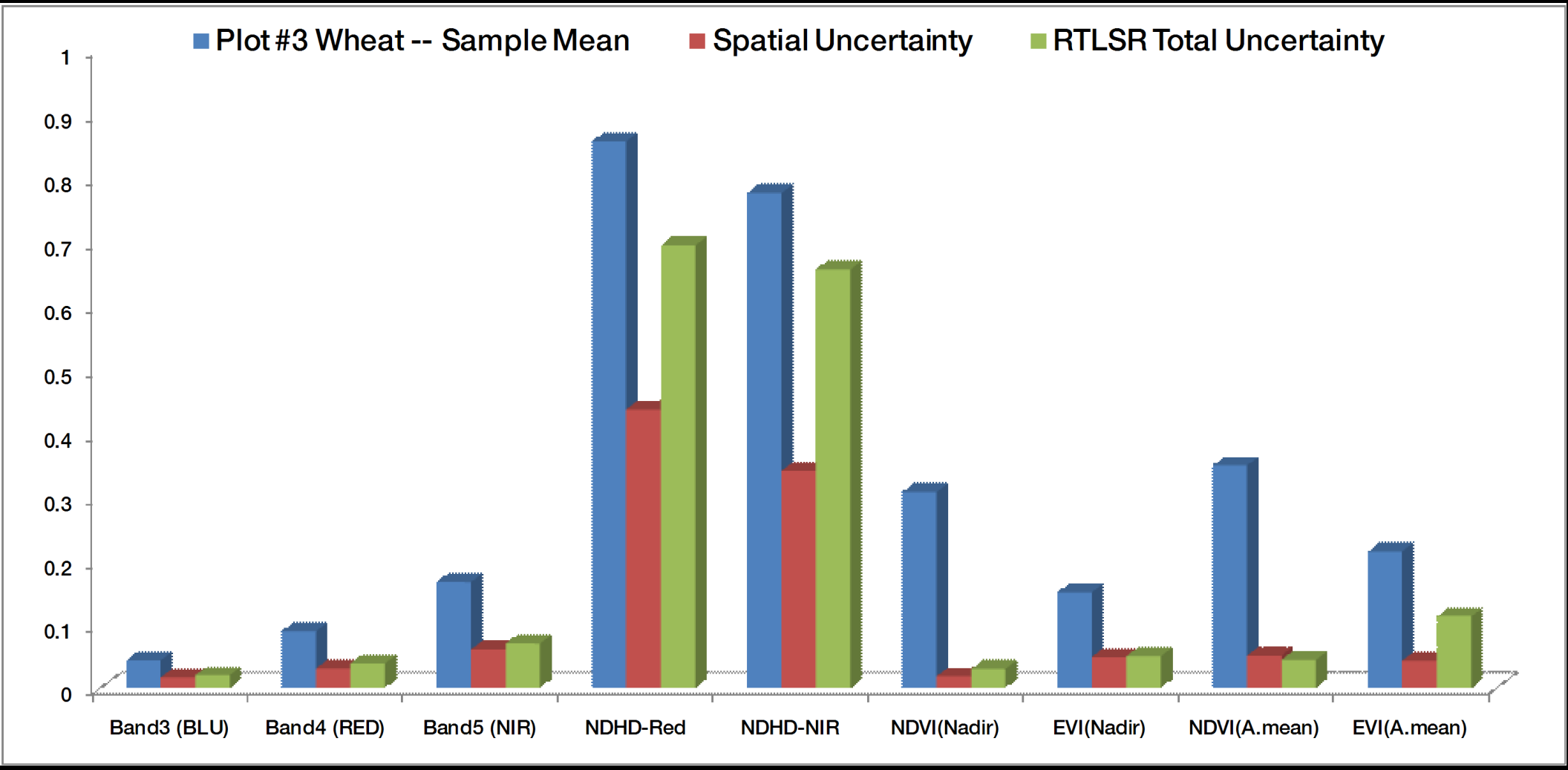
(1.) The number of samples obtained for a particular spatial threshold.

(2.) Retrieval quality (both measured and model-based).

(3.) The degree to which directional effects are minimized (i.e. by way of):

(a) NBAR-based retrievals -- $\theta_{view} = 0°$; $\theta_{solar} = 0°$.
(b) Nadir-adjusted retrievals -- $\theta_{view} = 0°$; $\theta_{solar} = [0\text{-}80°]$.
(c) Areal-mean retrievals -- $\theta_{view} = [0\text{-}80°]$ $\theta_{solar} = [0\text{-}80°]$.

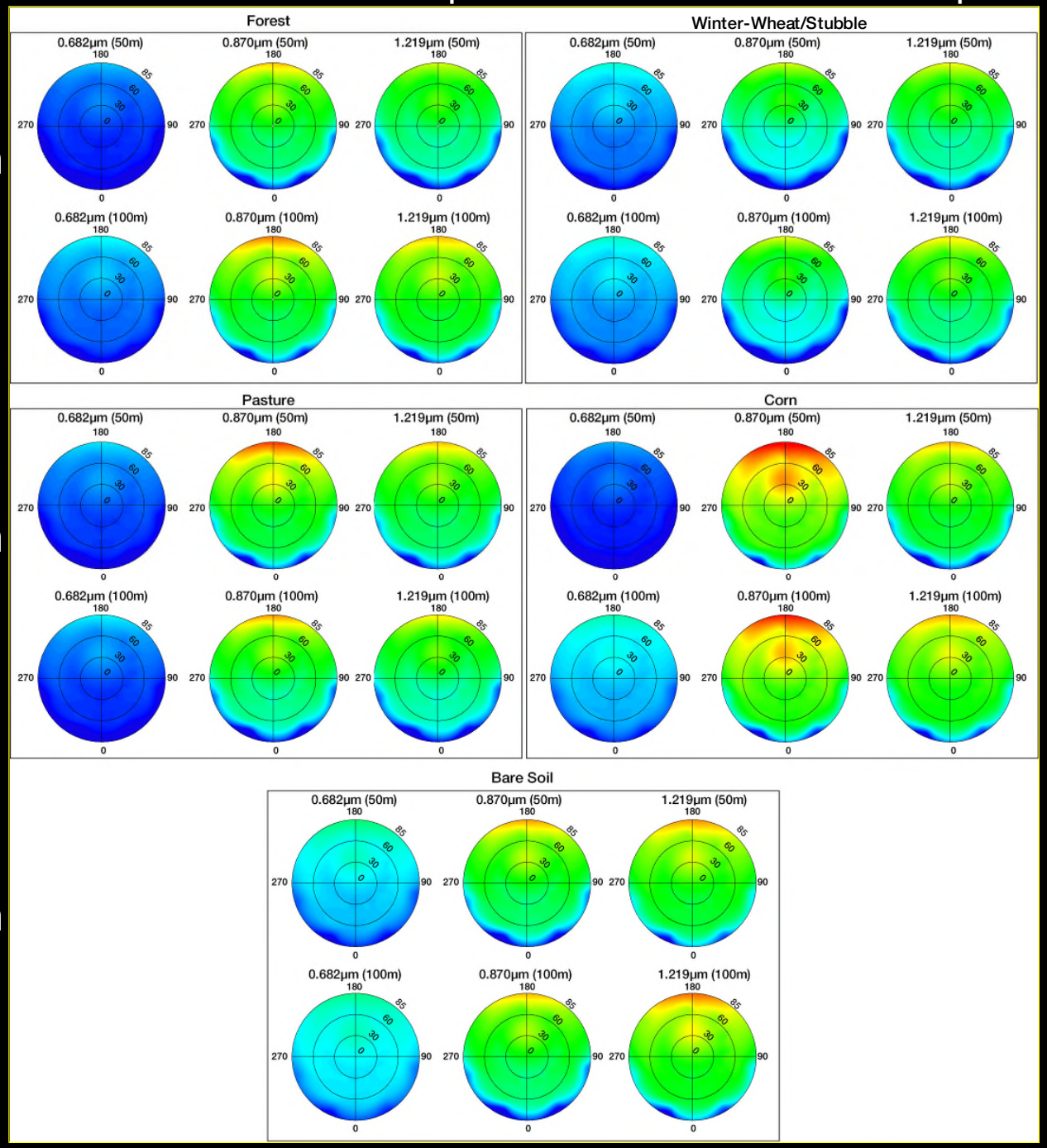
Preliminary Results (cont.)



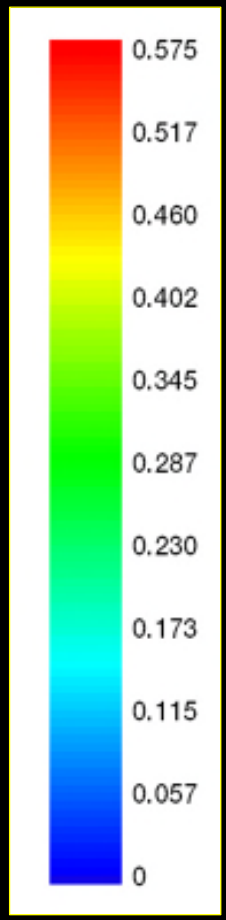
Multiscale assessments of the BRDF are key to understanding the effects of scale (spatial resolution) on higher-level surface biophysical properties (e.g. vegetation indexes, surface albedo, LAI/FPAR, burned area, land cover, and land cover change).

This upscaling methodology can characterize the measurement, scaling, and analytical errors from several ecosystems across the sampling domain observed by CAR.

Narrowband BRDF Retrievals of Archetypal Landscapes



Spectral BRDFs for selected CAR channels obtained over various land cover types at the ARM Central Facility.



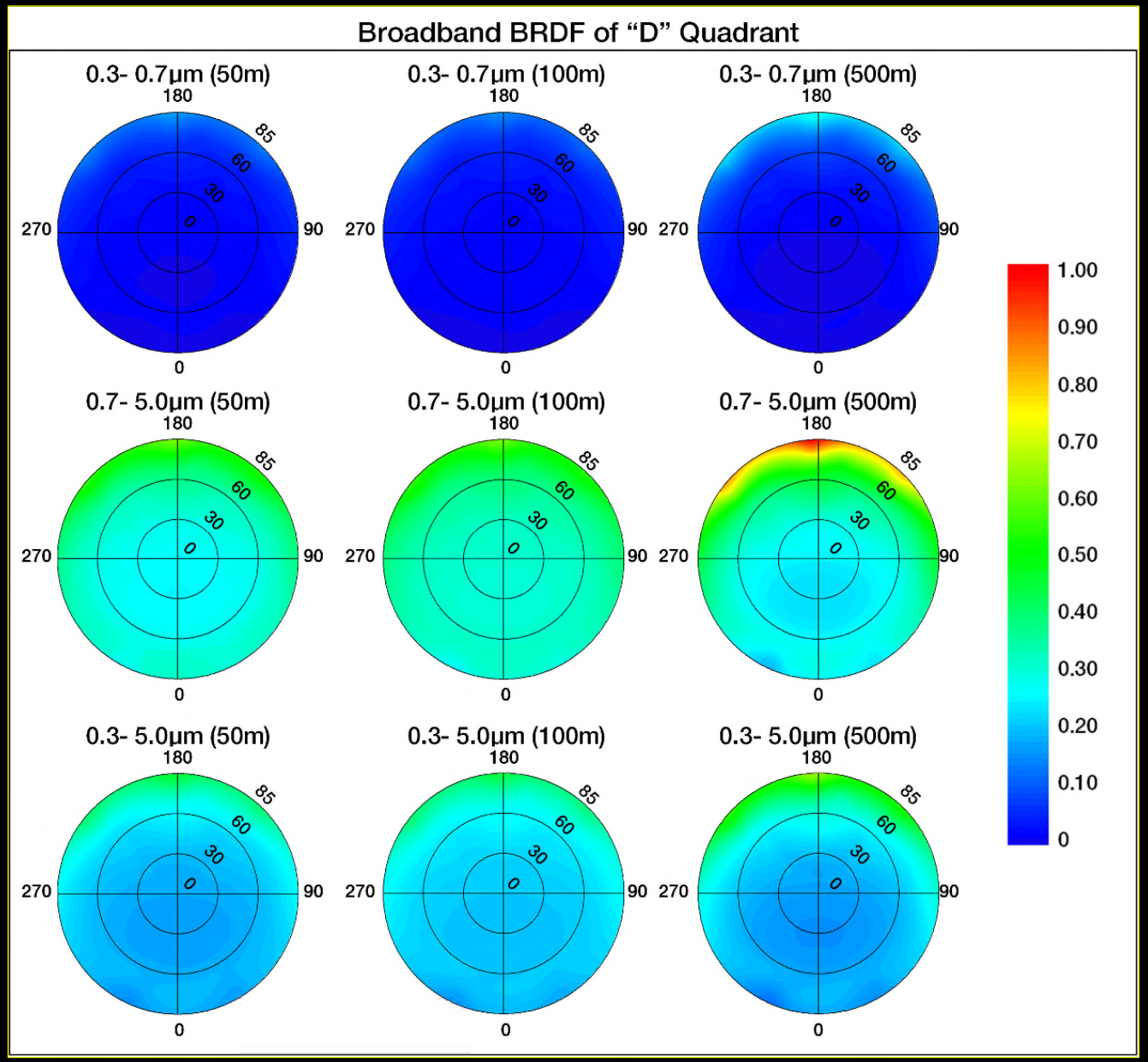
*Areally-Weighted **Broadband** BRDFs from CAR and MODIS*

CAR (50 m) CAR (100 m) MODIS (500 m)

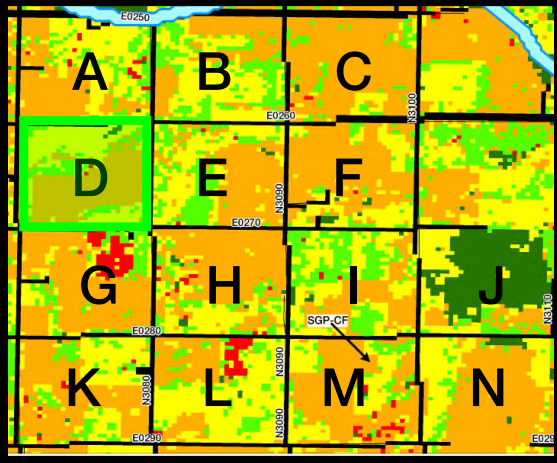
VIS

NIR

SW

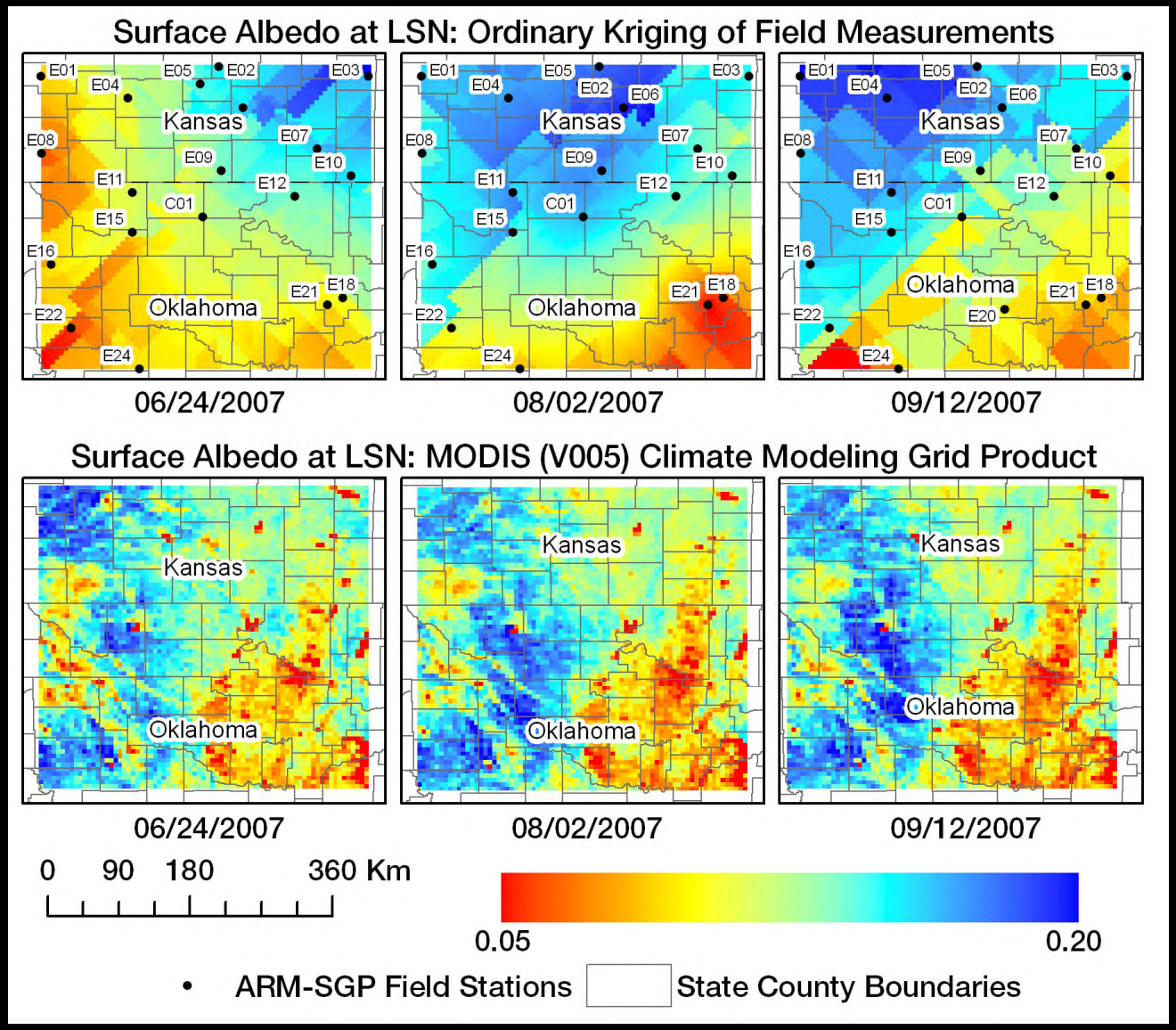


Areal-mean comparisons between the CAR and MODIS instruments.



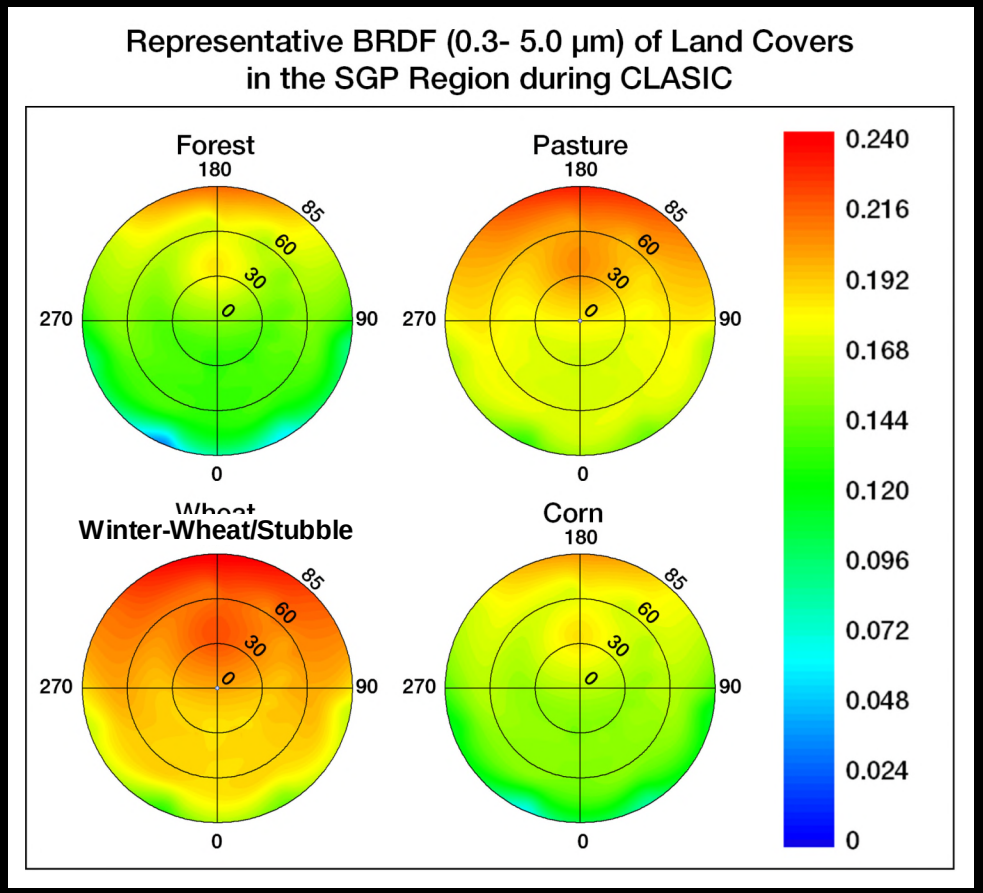
Mapping Uncertainty Beyond a “Single-Pixel”

Spatial Characterization Efforts: Current Challenges

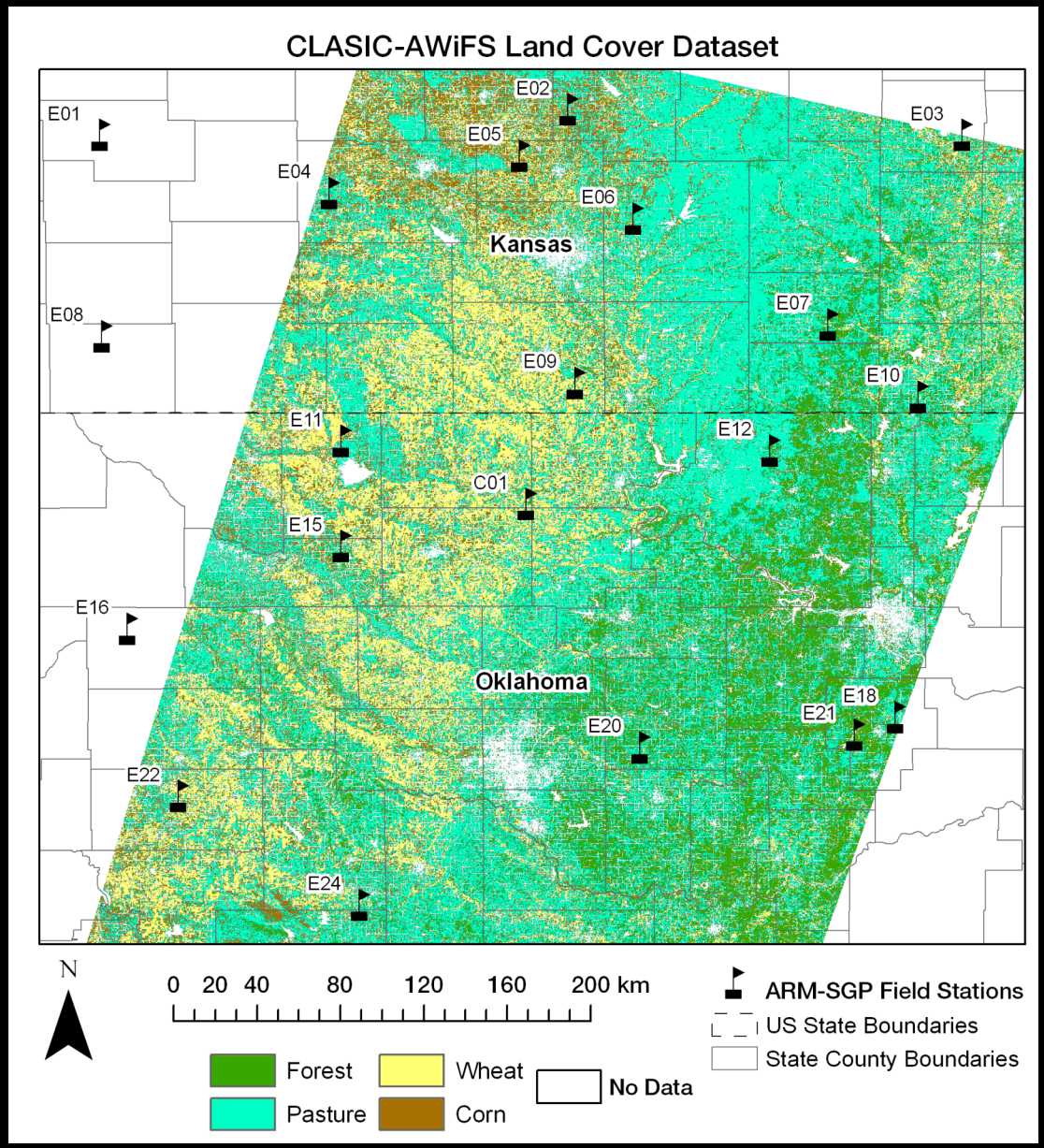


The large uncertainties that plague satellite-to-field data comparisons remains a barrier to our understanding of the Earth surface processes that they describe; and of how multi-scale changes due to anthropogenic activity can affect climate.

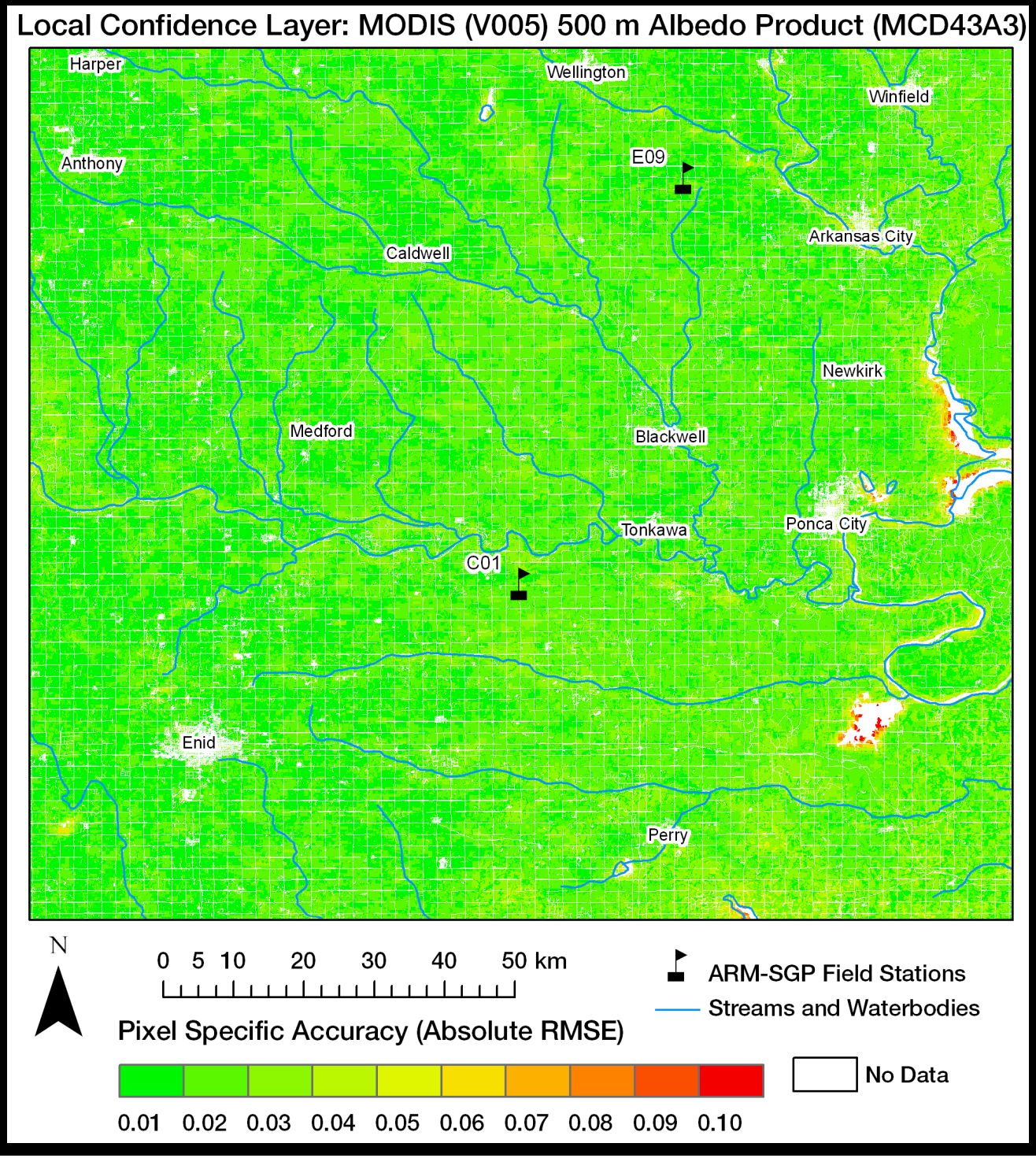
Uncertainty Mapping and Spatial Characterization Efforts: Improved Aggregation Method



RTLSR BRDF model inversions of archetypal landscapes in the SGP region were derived from spatially-consistent directional surface reflectances obtained from CAR. These datasets can be used to constrain and validate model behavior at regional scales (>1.0km).



Spatial Characterization Efforts: Confidence Layer

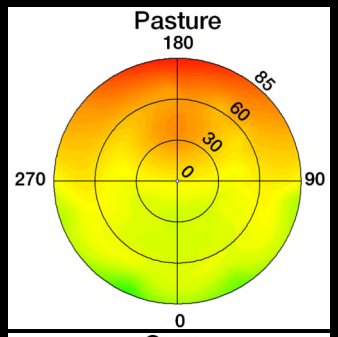


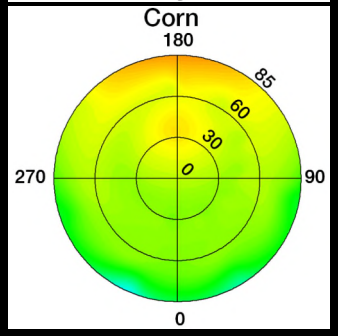
Confidence Layer – Key Attributes:

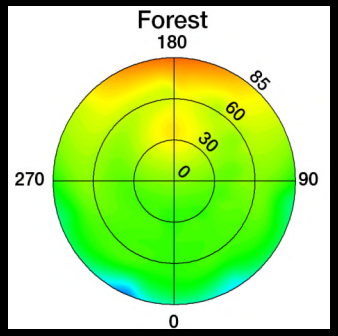
- Provides a measure of pixel-specific accuracy.
- Quantifies the systematic bias and uncertainty in surface albedo retrievals from satellite sensors.
- Can be assimilated into regional and global modeling schemes.

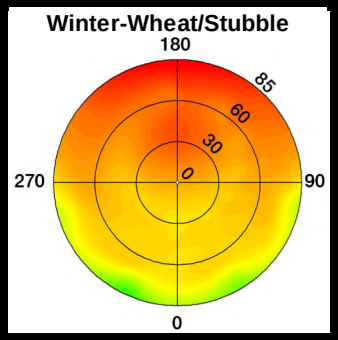
Spatial Characterization Efforts: Confidence Layer

Measured Conditions

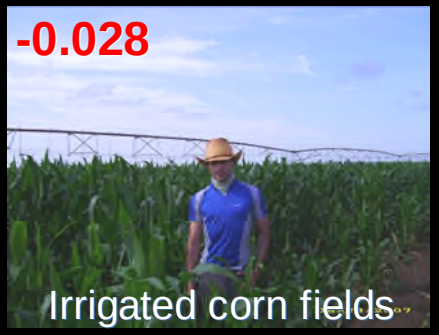


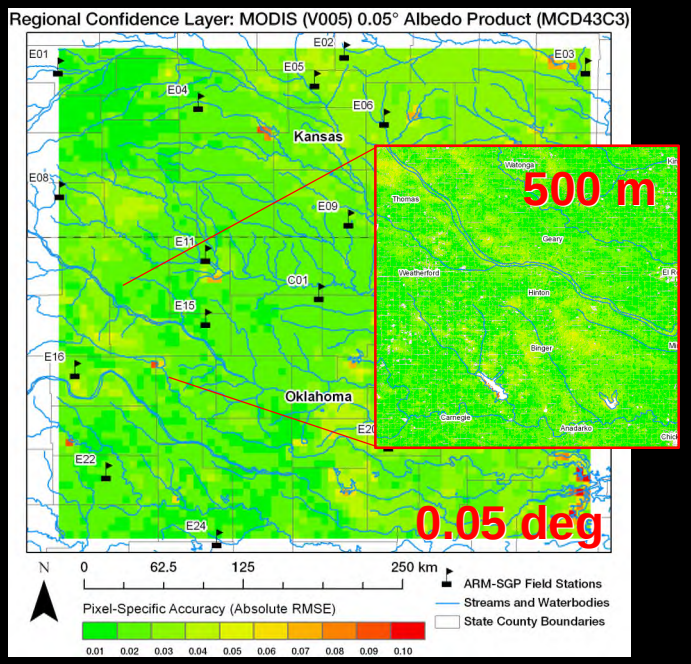






Anomalous Conditions



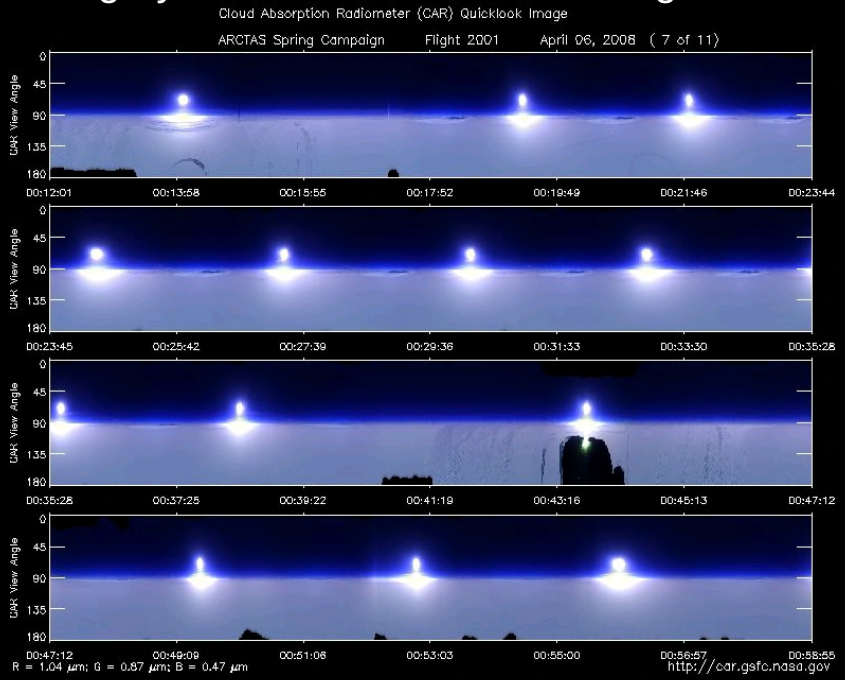


Systematic errors can be largely reduced by quantifying the differences in directional reflectance at the multiple spatial scales at which global land products are commonly utilized.

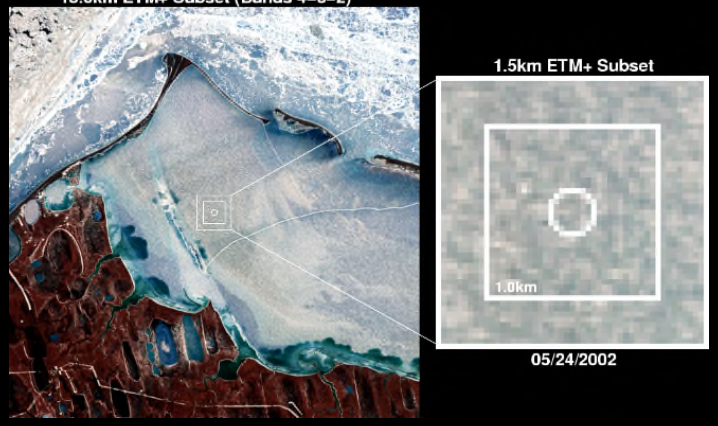
Upcoming Cal/Val Activities

CAR BRDF/Albedo Products: Ongoing Efforts

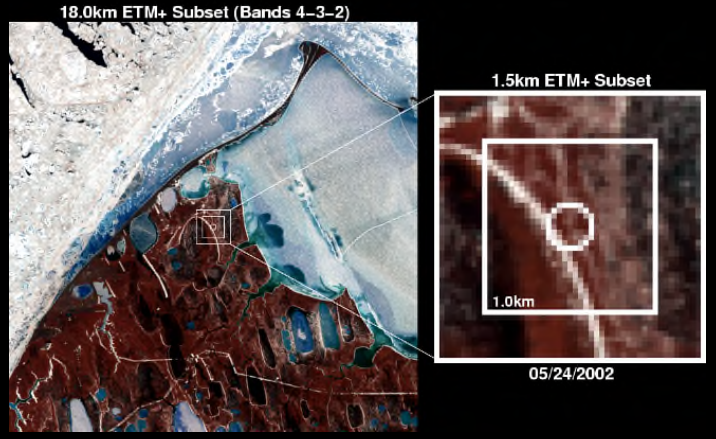
Imagery from CAR Instrument - Flight #2001

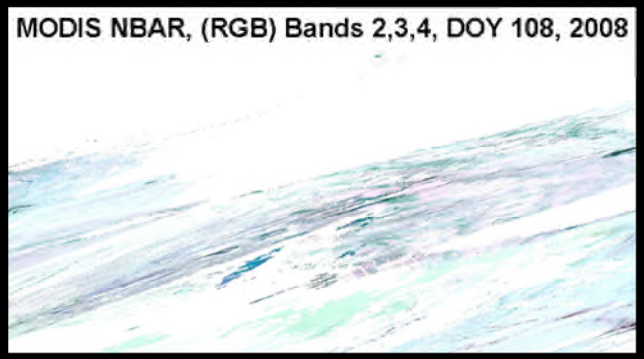


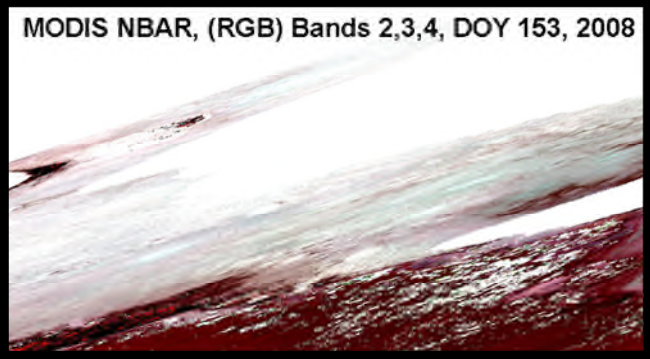
Elson Lagoon Surface Site



NSA-Barrow Site





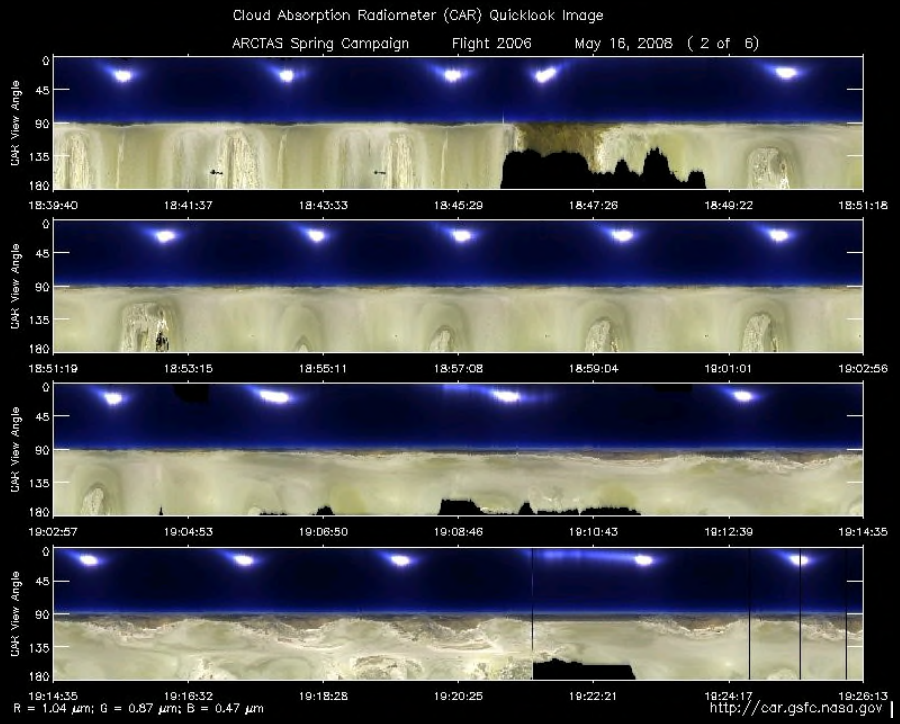


The ARCTAS campaign offers a rare opportunity to validate snow albedo retrievals derived from satellite sensors against field measurements and aircraft observations throughout the rapidly changing conditions of spring melt in the Arctic.

***ARCTAS Snow Albedo Team*: R. A. Kahn, D. K. Hall, C.K. Gatebe, A. Lyapustin, M. Román, C.B. Schaaf, and Z. Wang.**

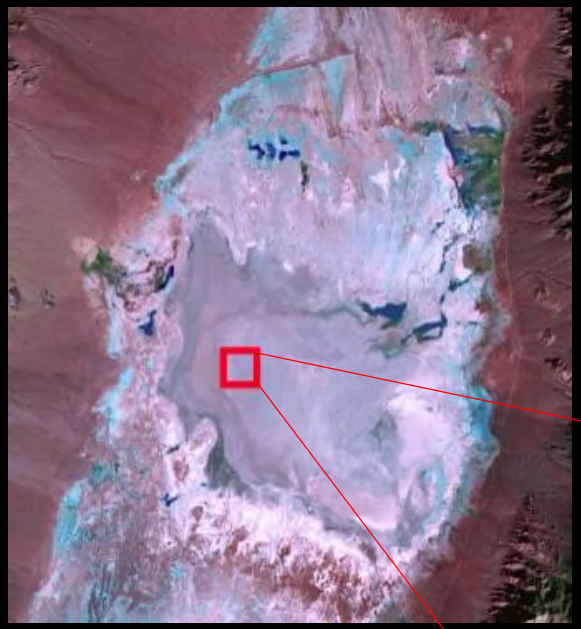
CAR BRDF/Albedo Products: Future Efforts

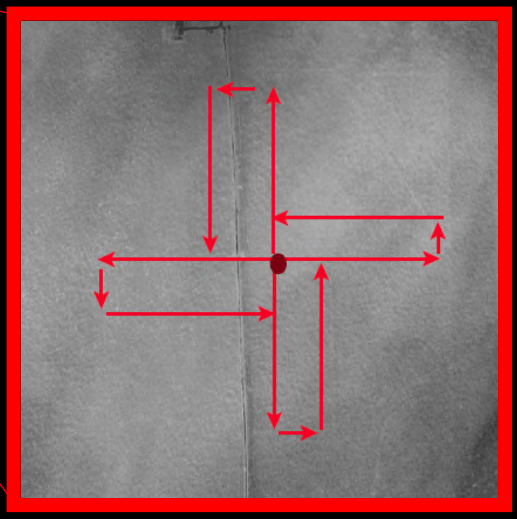
Imagery from CAR Instrument - Flight #2006



ARCTAS Flight #2006 goals included (1) testing active roll correction for the CAR instrument; and (2) conducting BRDF measurements at Railroad Valley Playa during a Terra satellite overpass (seen here).

Railroad Valley Playa





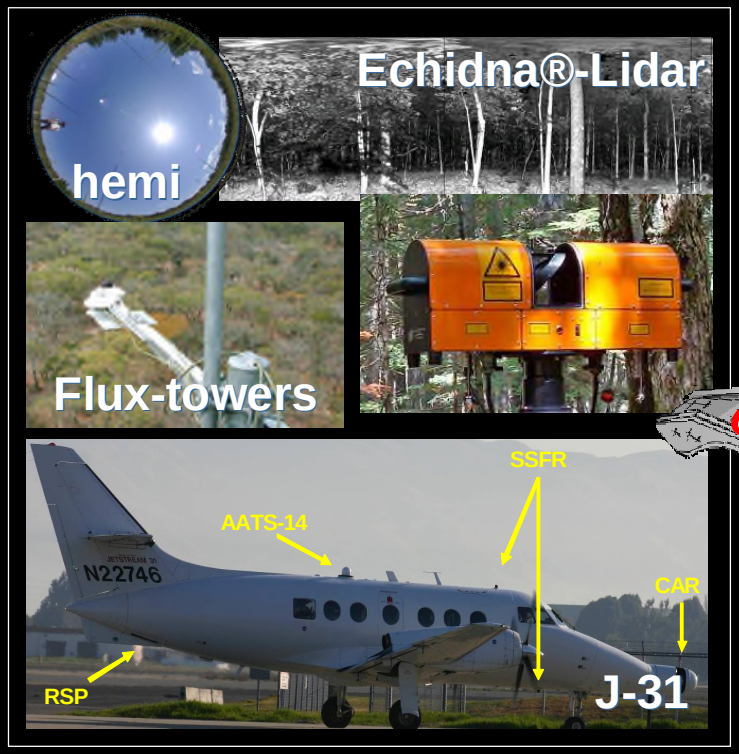
Images Courtesy of Kurt Thome (GSFC)

Technical Objective: To improve vicarious calibration exercises by addressing the higher-order spatial and directional uncertainties specific to these natural environments.

Final Thoughts

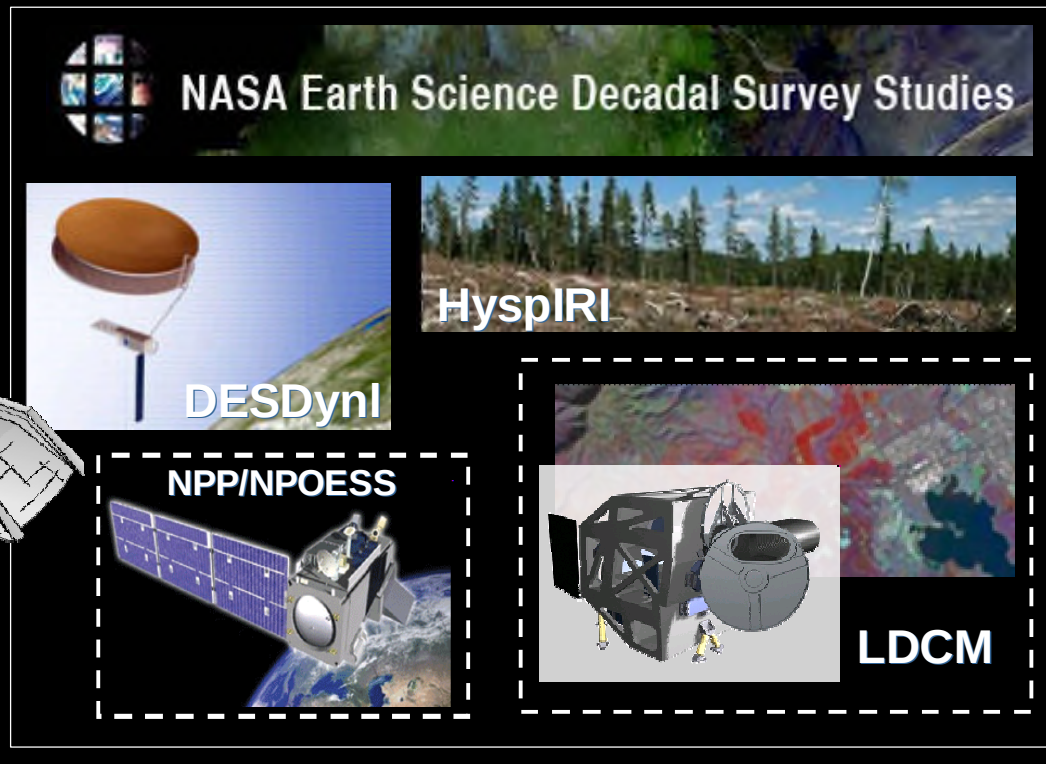
- In the coming decade NASA's Earth Science Division will be facing a challenge to implement venture class missions to incorporate an optimal mix of space-based and suborbital sensor platforms.
- A complete characterization of terrestrial essential climate variables will leverage opportunities in these missions by providing a key source of ground-truth data throughout pre- and post-launch Cal/Val activities.

In-Situ and Airborne Science Platforms…



Cal / Val

… In Support of NASA's Earth Science Projects



Recent/Upcoming Publications

Stone, R. S., G. P. Anderson, E. P. Shettle, E. Andrews, K. Loukachine, E. G. Dutton, C. Schaaf, and M. Román (2008), Radiative impact of boreal smoke in the Arctic: Observed and modeled, *J. Geophys. Res.*, 113, D14S16, doi:10.1029/2007JD009657.

Román, M., Schaaf, C.B., Woodcock, C.E., Strahler, A.H., Braswell, R.H., Curtis, P.S., Davis, K.J., Gu, L., Goulden, M.L., Hollinger, D.Y., Kolb, T.E., Meyers, T.P., Munger, J.W., Privette, J.L., Richardson, A.D., Wilson, T.B., & Wofsy, S.C. (2009). The MODIS BRDF/Albedo Product: Assessment of Spatial Representativeness over Forested Landscape, *Remote Sensing of Environment, 113,2476-2498.*

Román, M., Schaaf, C.B., Anderson, G.P., Gao, F., Lewis, P., Privette, J.L., Strahler, A.H., & Woodcock, C.E. (2009). Assessing the Coupling between Surface Albedo derived from MODIS and the Fraction of Diffuse Skylight over Spatially-Characterized Landscapes, *Remote Sensing of Environment, Submitted.*

Román, M., Gatebe, C.K., Schaaf, C.B., & King, M.D. (2009). Characterization of Directional Surface Reflectance Properties from Airborne Measurements over the US Southern Great Plains during the 2007 CLASIC Experiment, *In Preparation.*

Román, M., B., S.C., Woodcock, C.E., Cosh, M., & Strahler, A. (2009). Development of a Confidence Layer for the MODIS BRDF/Albedo Product at Southern Great Plains Site, *In Preparation.*