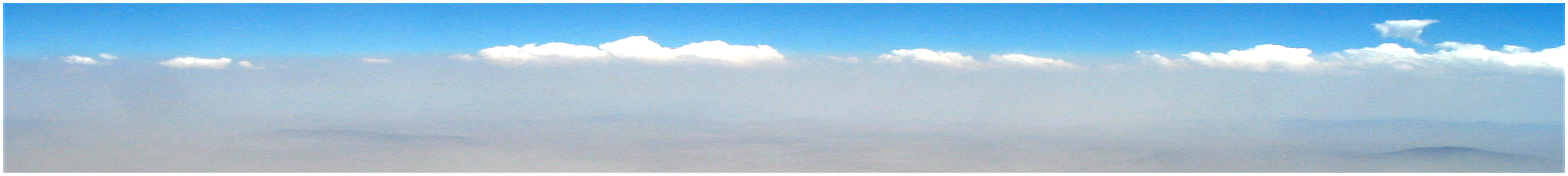


RSP/APS potential for validation of orbital surface BRDF measurements

K. Knobelspiesse, B. Cairns, B. Schmid, M. Roman and C. Schaaf

(Columbia University, GISS, PNNL & Boston University)

January 21, 2009

Recent JGR paper

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, D20105, doi:10.1029/2008JD010062, 2008

Click Here for Full Article

Surface BRDF estimation from an aircraft compared to MODIS and ground estimates at the Southern Great Plains site

Kirk D. Knobelspiesse,[1] Brian Cairns,[1,2] Beat Schmid,[3] Miguel O. Román,[4] and Crystal B. Schaaf[4]

Received 4 March 2008; revised 10 July 2008; accepted 12 August 2008; published 21 October 2008.

[1] Surface albedo, which quantifies the amount of solar radiation reflected by the ground, is an important component of climate models. However, it can be highly heterogeneous, so obtaining adequate measurements are challenging. Global measurements require orbital observations, such as those provided by the Moderate Resolution Imaging Spectroradiometer (MODIS). Satellites estimate the surface bidirectional reflectance distribution function (BRDF), a surface inherent optical property, by correcting observed radiances for atmospheric effects and accumulating measurements at many viewing and solar geometries. The BRDF is then used to estimate albedo, an apparent optical property utilized by climate models. Satellite observations are often validated with ground radiometer measurements. However, spatial and temporal sampling differences mean that direct comparisons are subject to substantial uncertainties. We attempt to bridge the resolution gap using an airborne radiometer, the Research Scanning Polarimeter (RSP). RSP was flown at low altitude in the vicinity of the Department of Energy's Southern Great Plains Central Facility (SGP CF) in Oklahoma during the Aerosol Lidar Validation Experiment (ALIVE) in September, 2005. The RSP's scanning radiometers estimate the BRDF in seconds, rather than days required by MODIS, and utilize the Ames Airborne Tracking Sunphotometer (AATS 14) for atmospheric correction. Our comparison indicates that surface … agree with Best Estimate Radiation Flux (BEFL… at the SGP CF. Since the RSP is an airborne prot… (APS), due to be launched into orbit in 2009, th… for routine BRDF validation.

Citation: Knobelspiesse, K. D., B. Cairns, B. Schmid, M… aircraft compared to MODIS and ground estimates at the … doi:10.1029/2008JD010062.

Knobelspiesse, K.D., B. Cairns, B. Schmid, M.O. Roman, and C.B. Schaaf (2008), **Surface BRDF estimation from an aircraft compared to MODIS and ground estimates at the Southern Great Plains site**, *J. Geophys. Res., 113,* D20105.

Outline

An alternate RSP/APS use:
Validation of MODIS surface BRDF products

Surface BRDF

- Importance for climate modeling
- Definitions and terminology
- Current orbital estimation techniques
- Validation with ground radiometers

Our contribution: RSP measurements during ALIVE

- Experiment details, data sifting
- Estimating BRDF including multiple ground-atmosphere scattering
- Narrow spectral bandpass to broadband conversion

Results

- Validation
- APS potential for routine BRDF validation efforts

Concluding remarks

RSP and Glory-APS

Aerosol Polarimetry Sensor (APS)

- June launch on NASA Glory mission
- Also on Glory: a solar irradiance monitor

Research Scanning Polarimeter (RSP)

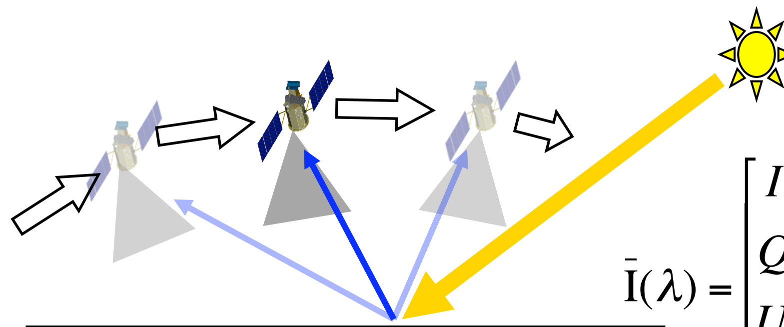
- Airborne prototype of APS

Main goal: Measure aerosols and clouds

… but we will use them to measure the surface

RSP and APS design

- Nine spectral channels, blue to infra-red (410 - 2250 nm)
- Scans along track (in the direction of motion) NOT an imager
- Polarized radiance - I,Q,U components of Stokes vector
- High (0.2%) accuracy for polarized radiances



$$\bar{I}(\lambda) = \begin{bmatrix} I(\lambda) \\ Q(\lambda) \\ U(\lambda) \\ \cancel{V(\lambda)} \end{bmatrix}$$

Aerosol spectral bands: 410nm, 470nm, 555nm, 670nm, 865nm, 1590nm

Other bands: 960nm, 1880nm, 2250nm

Alternate use… surface albedo

IPCC 4AR (2007) summary for policymakers

Instruments such as MODIS, MISR and MERIS can characterize surface albedo… validation?

ALIVE field campaign

Test validation potential with field campaign data

ALIVE (Aerosol Lidar Validation Experiment)

- DOE Southern Great Plains (SGP) site (near Ponca City, Oklahoma)
- September, 2005
- Surface type: rural pasture, late season crops, recently plowed fields

Compare albedo from

Satellite (MODIS)

to

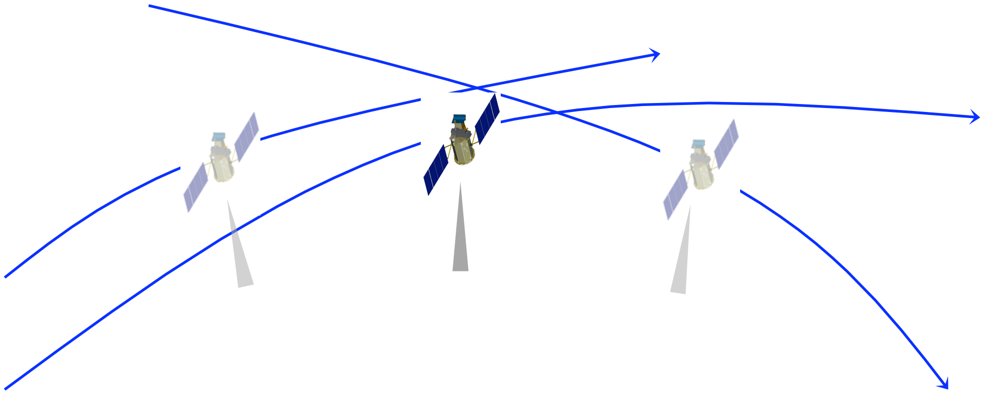
Aircraft (RSP)

to

Ground (SGP radiometers)

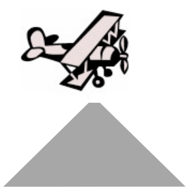
What is albedo?

We must compare apples to apples…



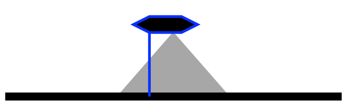
Single view angle satellite (MODIS):

- global
- narrow spectral bands
- fit observations to albedo model
- must accumulate views
- must account for atmosphere



Multiple view angle aircraft (RSP):

- local
- narrow spectral bands
- fit observations to albedo model
- Multiple view angles instantaneously
- must account for atmosphere

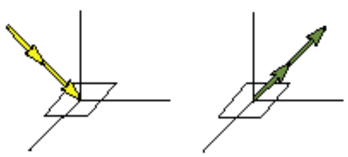
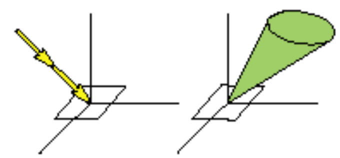
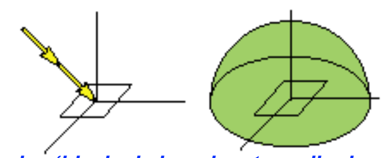
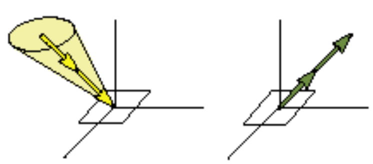
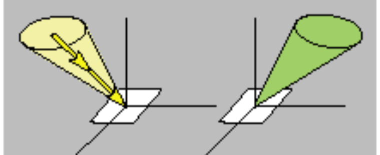
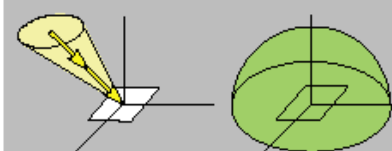
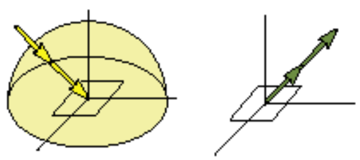
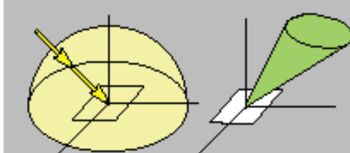
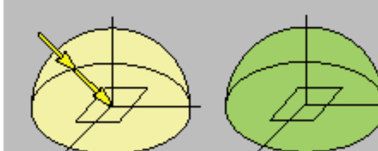


Ground radiometers (BEFLUX):

- point
- broad spectral band
- Observe diffuse upwelling and downwelling, direct downwelling

How is albedo defined?

Table 2
Relation of incoming and reflected radiance terminology used to describe reflectance quantities

Incoming/Reflected	Directional	Conical	Hemispherical
Directional	**Bidirectional reflectance distribution function (BRDF)** 	Directional–conical CASE 2 	**Directional hemispherical reflectance (DHR)**  *also 'black-sky' or planetary albedo*
Conical	Conical–directional CASE 4 	Biconical CASE 5 	Conical–hemispherical CASE 6 
Hemispherical	Hemispherical–directional CASE 7 	Hemispherical–conical CASE 8 	**Bihemispherical reflectance (BHR)**  *also 'white-sky' or spherical albedo*

The labeling with 'Case' corresponds to the nomenclature of Nicodemus et al. (1977). Grey fields correspond to measurable quantities (Cases 5, 8), the others (Cases 1 4, 6, 7, 9) denote conceptual quantities. Please refer to the text for the explanation on measurable and conceptual quantities.

From: **G. Schaepman-Strub, M. Schaepman, T. Painter, S. Dangel, and J. Martonchik. Reflectance quantities in optical remote sensing: definitions and case studies. Remote sensing of environment, 103(1):27–42, 2006.**

How is BRDF defined?

$$\mathrm{BRDF}(\theta_s,\theta_v,\phi_s,\phi_v,\lambda) = \frac{\mathrm{d}L(\theta_s,\theta_v,\phi_s,\phi_v,\lambda)}{\mathrm{d}E(\theta_s,\phi_s,\lambda)}\left[\mathrm{sr}^{-1}\right]$$

L = radiant flux per unit solid angle [W m^{-2} sr^{-1}]

E = irradiance [W m^{-2}]

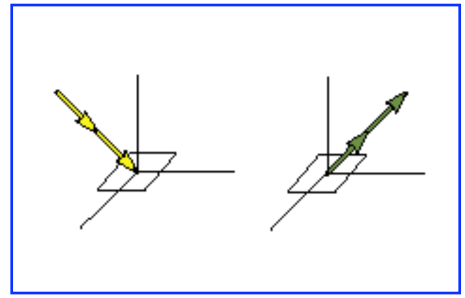
λ= wavelength [nm]

θ_s = solar zenith angle

θ_v = view zenith angle

ϕ_s = solar azimuth angle

ϕ_v = view azimuth angle



BRDF is a theoretical property impossible to measure exactly

Often estimated by fitting observations to reflectance models

DHR and BHR can be estimated by integrating BRDF over view and solar geometries

How is DHR defined?

$$\mathrm{DHR}(\theta_s,\phi_s,\lambda) = \int_0^{2\pi}\int_0^{\pi/2} \mathrm{BRDF}(\theta_s,\theta_v,\phi_s,\phi_v,\lambda)\cos(\theta_v)\sin(\theta_v)\,d\theta_v\,d\phi_v$$

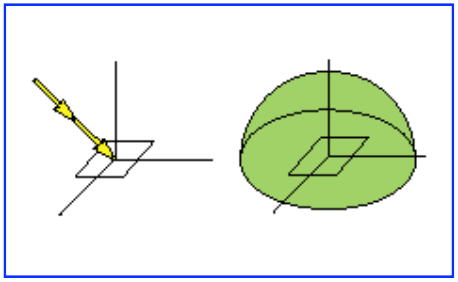
λ= wavelength [nm]

θ_s = solar zenith angle

ϕ_s = solar azimuth angle

θ_v = view zenith angle

ϕ_v = view azimuth angle



DHR is BRDF integrated over viewing geometry

This simplified form of BRDF is often the type used in climate models

A typical assumption (that we make) is that DHR is independent of ϕ_s, reasonable if surface properties have no preferred azimuth orientation

Also known as 'black sky' or planetary albedo

How is BHR defined?

$$\mathrm{BHR}(\lambda) = \int_0^{2\pi}\int_0^{\pi/2}\int_0^{2\pi}\int_0^{\pi/2} \mathrm{BRDF}(\theta_s,\theta_v,\phi_s,\phi_v,\lambda)\cos(\theta_v)\sin(\theta_v)\cos(\theta_s)\sin(\theta_s)\mathrm{d}\theta_v\mathrm{d}\phi_v\mathrm{d}\theta_s\mathrm{d}\phi_s$$

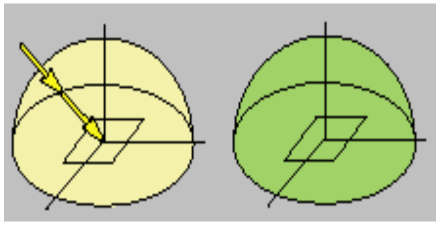
λ= wavelength [nm]

θ_s = solar zenith angle

ϕ_s = solar azimuth angle

θ_v = view zenith angle

ϕ_v = view azimuth angle



BHR is BRDF integrated over solar and viewing geometry

BHR is measured by field radiometers

We will work with BHR_{iso}, which is BHR assuming completely diffuse (isotropic) downwelling irradiance

Also known as 'white sky' or spherical albedo

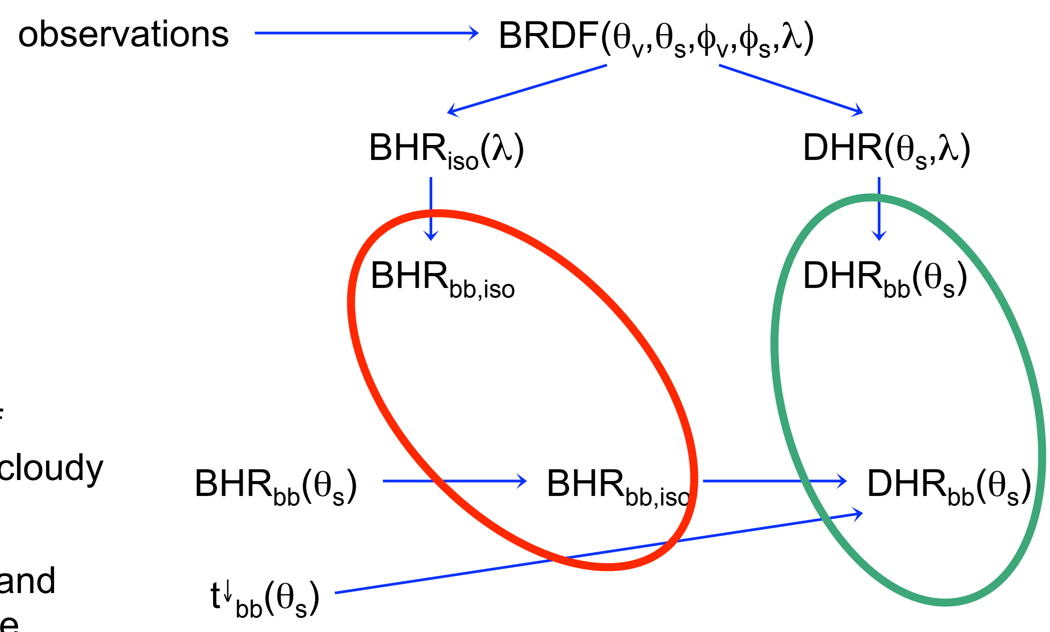
Why all these albedo types?

MODIS & RSP

- Fit observations to model
- integrate geometrically
- integrate spectrally

BEFLUX

- Estimate $BHR_{bb,iso}$ from diffuse ratios of upwelling and downwelling irradiance in cloudy conditions
- Determine DHR using $BHR_{bb,iso}$, direct and diffuse downwelling irradiance and diffuse upwelling irradiance



Characterizing the downwelling irradiance is difficult with varying instrument spatial and temporal scales

MODIS albedo

We use the MODIS MCD43 ‘collection five’ products

- BRDF estimated from 16 days of Terra & Aqua observations
- 500m spatial resolution, 7 narrow spectral bands (470-2130nm)
- BRDF model fitting splits surface interactions into three parts, ie

$$\mathrm{BRDF}(\theta_s,\theta_v,\phi_s,\phi_v,\lambda) \cong f_{iso}(\Lambda) + f_{vol}(\Lambda)K_{vol}(\theta_s,\theta_v,\phi) + f_{geo}(\Lambda)K_{geo}(\theta_s,\theta_v,\phi)$$

- Where

  Λ = instrument spectral band

  $\phi = \phi_v - \phi_s$

  f_{iso} = isotropic scaling parameter

  f_{vol} = volumetric scaling parameter

  f_{geo} = geometric scaling parameter

  K_{vol} = Volumetric (dense vegetation) scattering kernel from *Roujean et al*. [1992] and *Ross* [1981]

  K_{geo} = Geometric (sparse vegetation) scattering kernel from *Wanner et al*. [1995], *Li and Strahler* [1992] and reciprocal form in *Lucht et al.* [2000]

The MCD43 product for each pixel are the three *f* scaling parameters

- This simplifies the BRDF to three parameters

BEFLUX albedo

Best Estimate Flux (BEFLUX)

- Value Added Product (VAP) created from several radiometers
- Located in a pasture at the DOE's Southern Great Plains (SGP) site in central Oklahoma, USA

SGP site, September 20, 2005

Adapted from:
F. Yang. **Parameterizing the dependence of surface albedo on solar zenith angle using atmospheric radiation measurement observations.** In Proceedings of the Sixteenth ARM Science Team Meeting Proceedings, Alburquerque, NM, March 2006.

RSP and ALIVE

Table 1. Low Altitude ALIVE Flight Segments Used for Surface Characterization

	JRF3	JRF4
Date	09/16/2005	09/16/2005
Start time, UTC#	16:32:25	22:09:32
Number of RSP scans	270	41
J-31 Altitude above sea level*	510 m	475 m
Relative sensor-solar azimuth	–45°	156°
Solar zenith angle	43°	62°
AERONET $\tau_a(\lambda = 500$ nm)	0.07	0.05
AATS-14 $\tau_a(\lambda = 499$ nm)	0.06	0.05
sky conditions	clear	clear

* SGP height above seal level is about 315m

local time was five hours earlier

RSP BRDF estimation

RSP observations were fit to the MODIS BRDF models

How to characterize scattering?

- Aerosol effect between aircraft and ground is minimal due to low altitude
- Aerosols above aircraft determined by onboard sun-photometer and high altitude RSP measurements

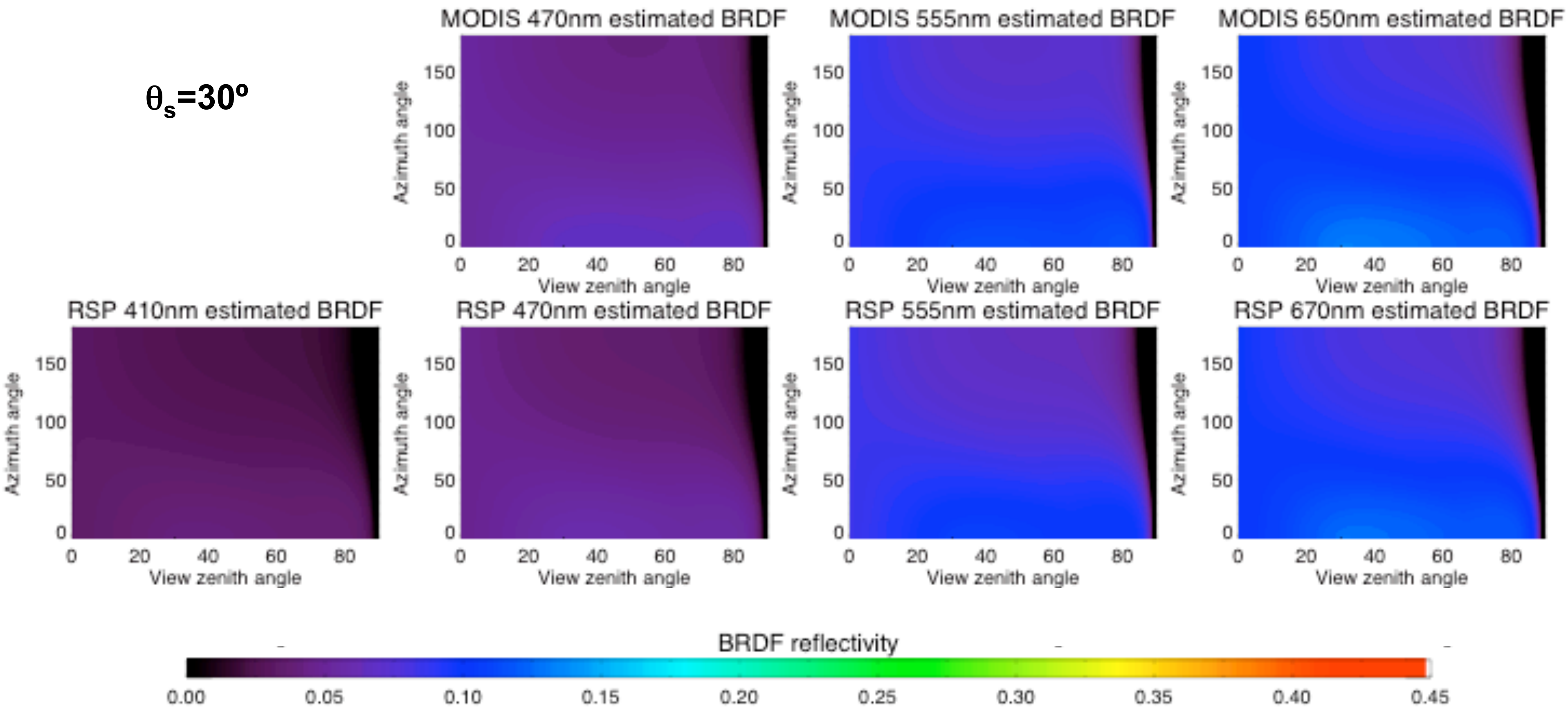
Doubling and Adding method describes atmospheric scattering, but…

Surface-atmosphere scattering depends on parameters we are attempting to retrieve

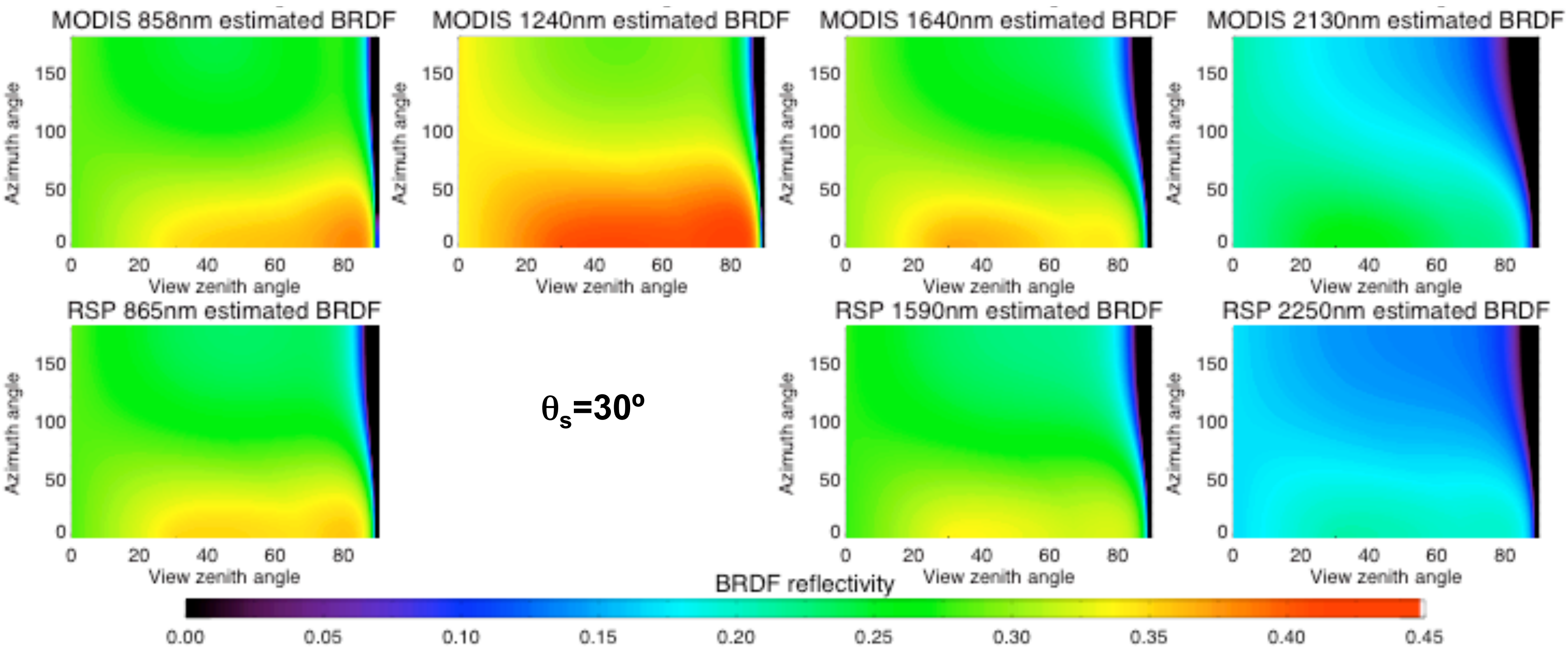
Solution: Iterative approach that initially estimates BRDF assuming no scattering

RSP and MODIS BRDF results

θ_s=30º



RSP and MODIS BRDF results



Spectral integration

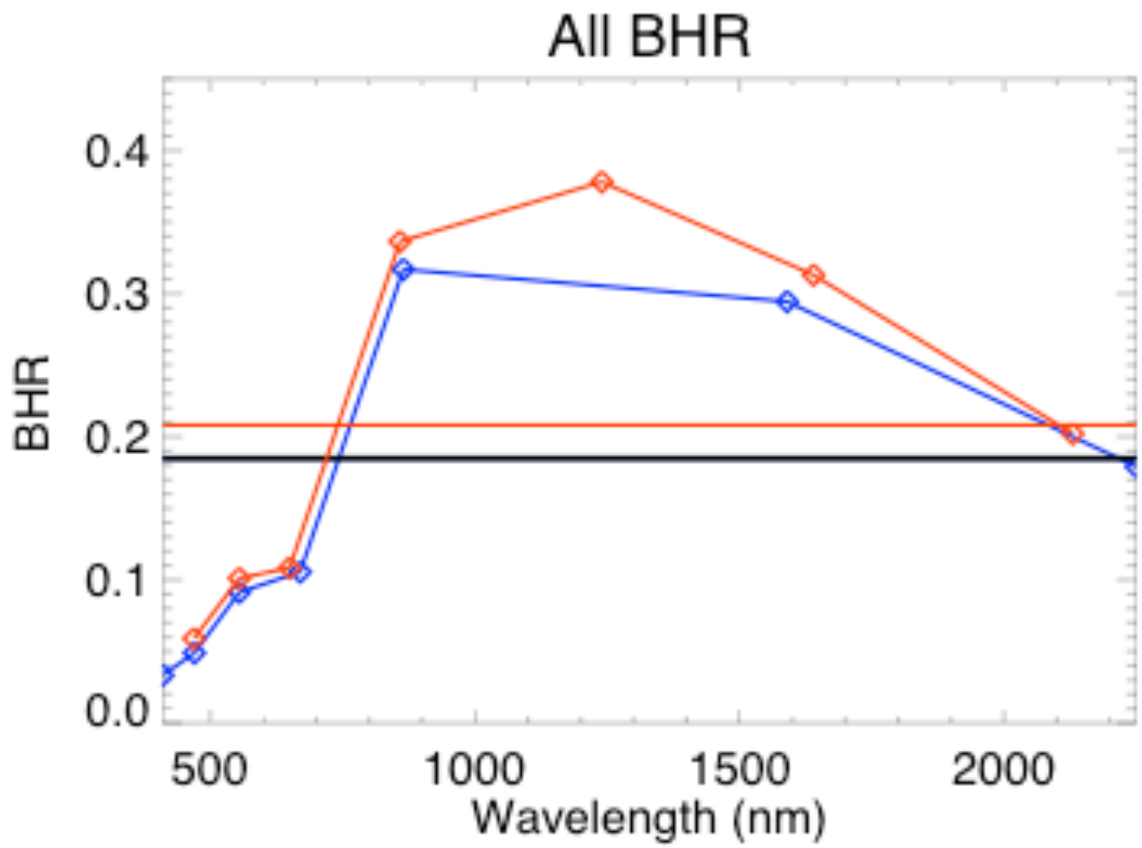
How to integrate spectral DHR and BHR to BEFLUX broadband values?

Method: linearly interpolate DHR or BHR, then integrate weighted by direct solar transmittance associated with previously modeled atmosphere.

$$\mathrm{DHR}_{bb}(\theta_s) = \frac{\int_{400nm}^{2500nm} E_o(\lambda) t(\lambda) \mathrm{DHR}(\theta_s, \lambda) d\lambda}{\int_{400nm}^{2500nm} E_o(\lambda) t(\lambda) d\lambda}$$

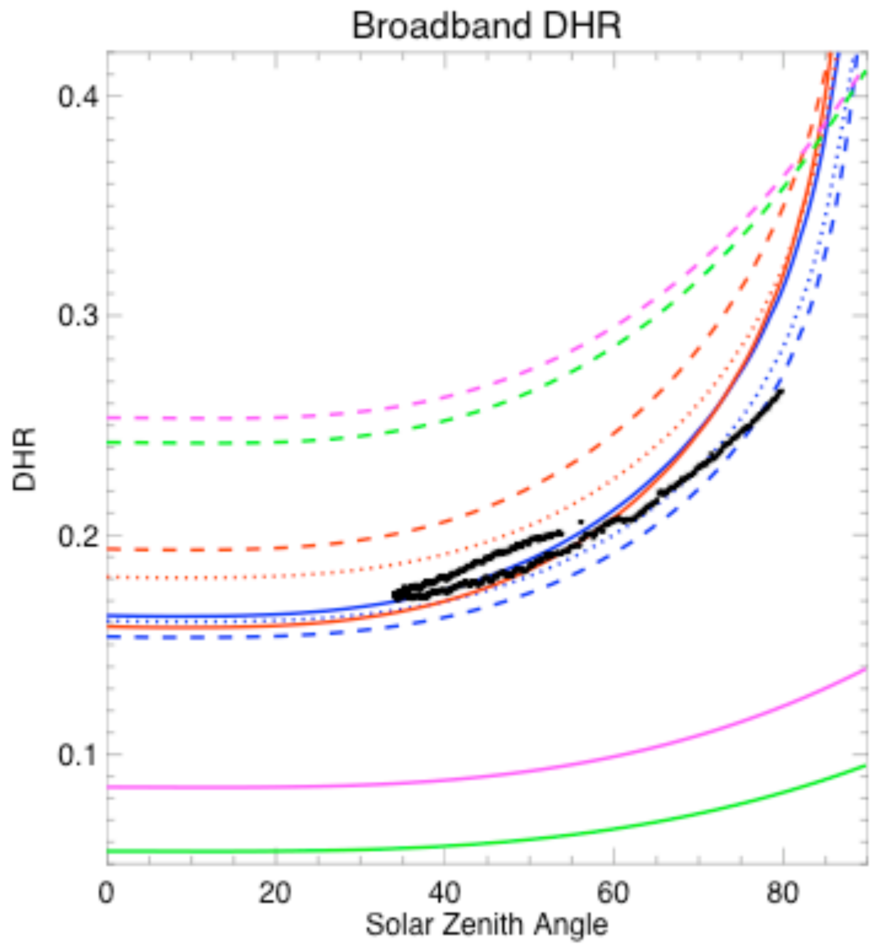
$$\mathrm{BHR}_{bb} = \frac{\int_{400nm}^{2500nm} E_o(\lambda) t(\lambda) \mathrm{BHR}(\lambda) d\lambda}{\int_{400nm}^{2500nm} E_o(\lambda) t(\lambda) d\lambda}$$

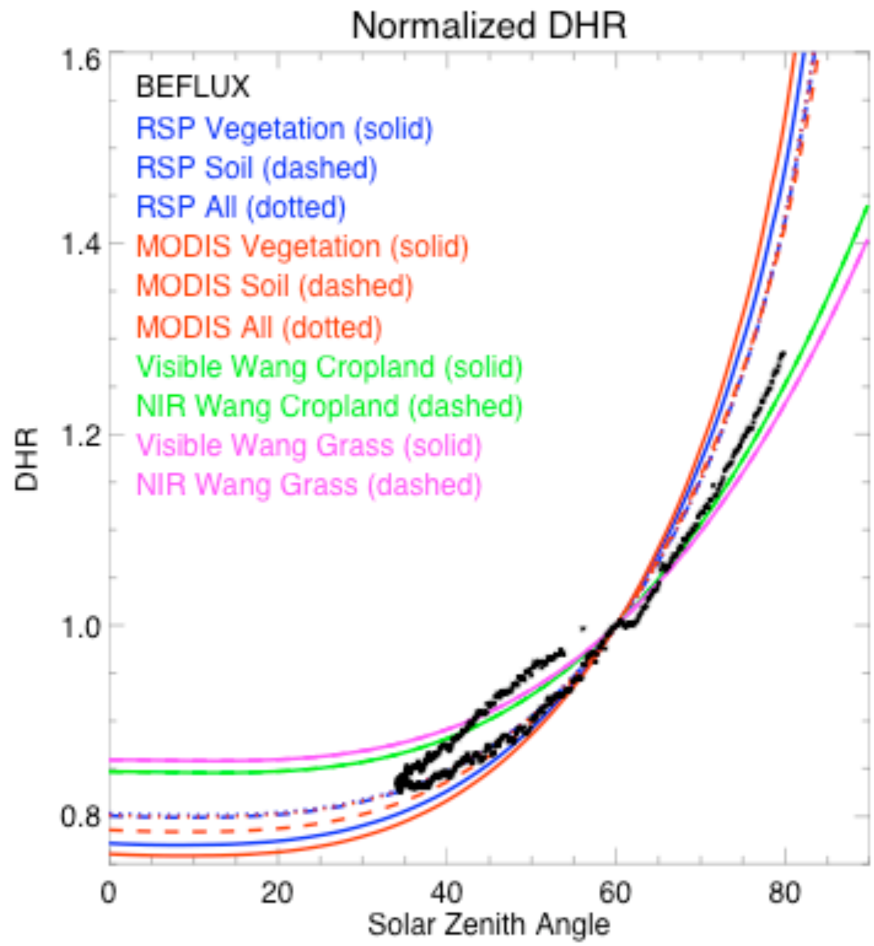
BHR results



MODIS BHR_{bb}=0.208
RSP BHR_{bb}=0.185
BEFLUX BHR_{bb}=0.185

DHR_{bb} results





Normalized DHR: $$nDHR_{bb}(\theta_s) = \frac{DHR_{bb}(\theta_s)}{DHR_{bb}(60^\circ)}$$

Results

BHR

- Highest values, and largest differences, in Near Infra Red (NIR)
- MODIS BHR_{bb} high bias with 'all' related to NIR band RSP doesn't have

DHR

- Good agreement by all three when θ_s<70º.
- Divergence between BEFLUX morning and afternoon DHR expresses variability

nDHR

- Good agreement by all three when θ_s<70º, best with 'all' classes

Conclusion

- **RSP, with its large number of viewing angles, validates the ability of MODIS to retrieve BRDF, DHR and BHR that agrees with ground radiometers when θ_s<70°**
- **Validation is for ONE DAY at the SGP site only**
- **Largest potential problem is the spectral interpolation**

Side note

How does ModelE describe surface albedo?

Is it time to consider using satellite derived albedo climatologies?

Thanks

I was supported during ALIVE by an NSF IGERT graduate student fellowship

BEFLUX data are from the DOE's Atmospheric Radiation Measurement Program (ARM). ARM also funded the ALIVE field campaign

RSP participation during ALIVE was supported by NASA, who also provide MODIS data

Knobelspiesse, K.D., B. Cairns, B. Schmid, M.O. Roman, and C.B. Schaaf (2008), **Surface BRDF estimation from an aircraft compared to MODIS and ground estimates at the Southern Great Plains site**, *J. Geophys. Res., 113,* D20105.

RSP and ALIVE

Yang (2006) compared parameterizations of MODIS to BEFLUX $DHR_{bb}(\theta_s)$ found:

- BEFLUX $DHR_{bb}(\theta_s)$ larger at high solar zenith angles (expected)
- BEFLUX $DHR_{bb}(\theta_s)$ smaller at low solar zenith angles (unexpected)

Source of these differences?

- Spatial / temporal resolution?
- MODIS albedo computation?
  - Not enough view angles?
  - Atmospheric correction?
  - BRDF model appropriate?
- BEFLUX albedo computation?

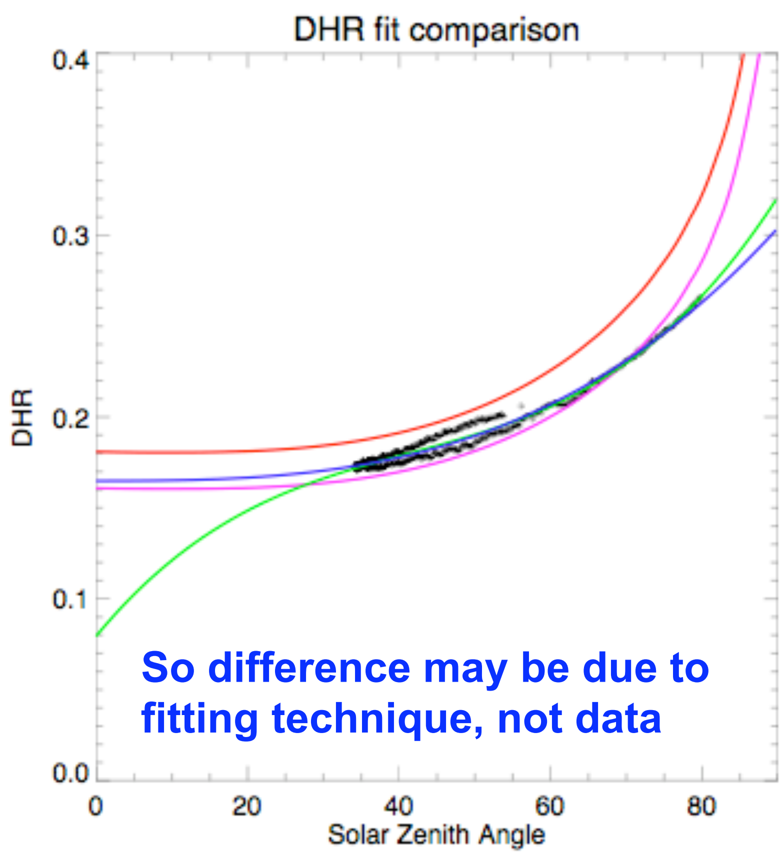
RSP observations during the Aerosol Lidar Validation Experiment (ALIVE) can bridge the resolution and methodological gap.

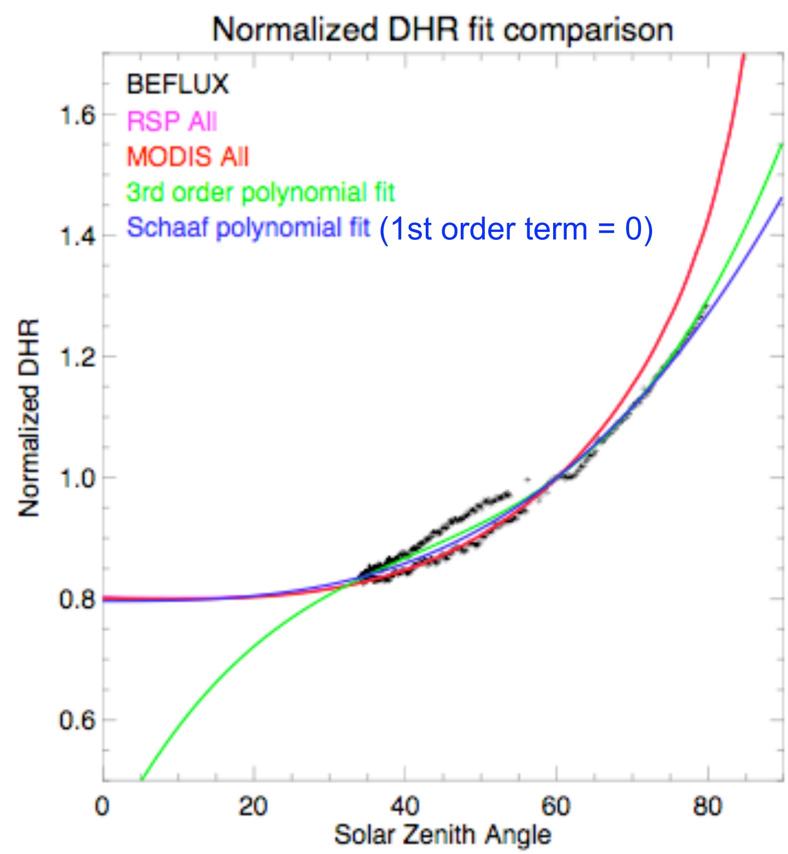
Results

What about MODIS underestimation at low θ_s as in *Yang* [2006] ?

- We don't actually have BEFLUX data at low θ_s…
- …but neither did Yang. He fit a 3rd order polynomial to his data

What happens if we do the same?

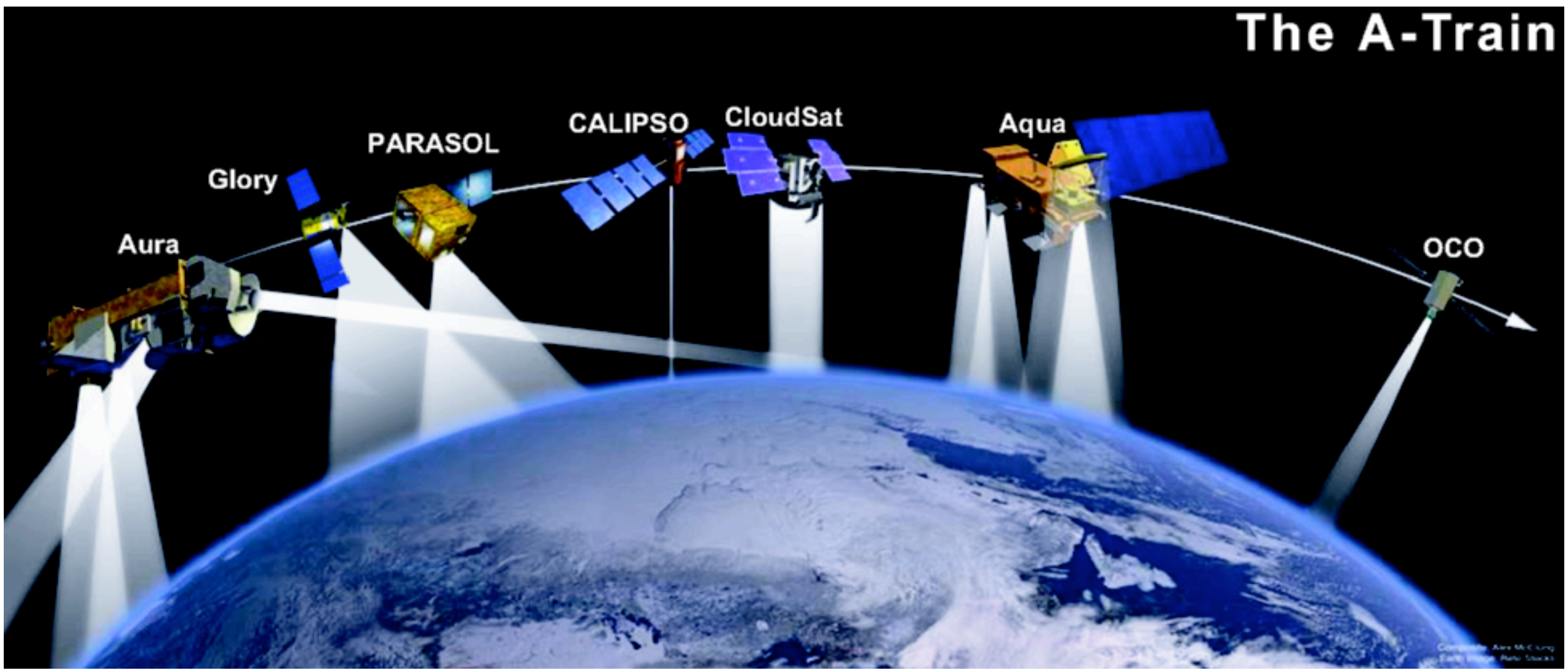




APS validation potential

Glory/APS, since it is in the 'A-train', could be used to regularly validate MODIS BRDF products, using these techniques

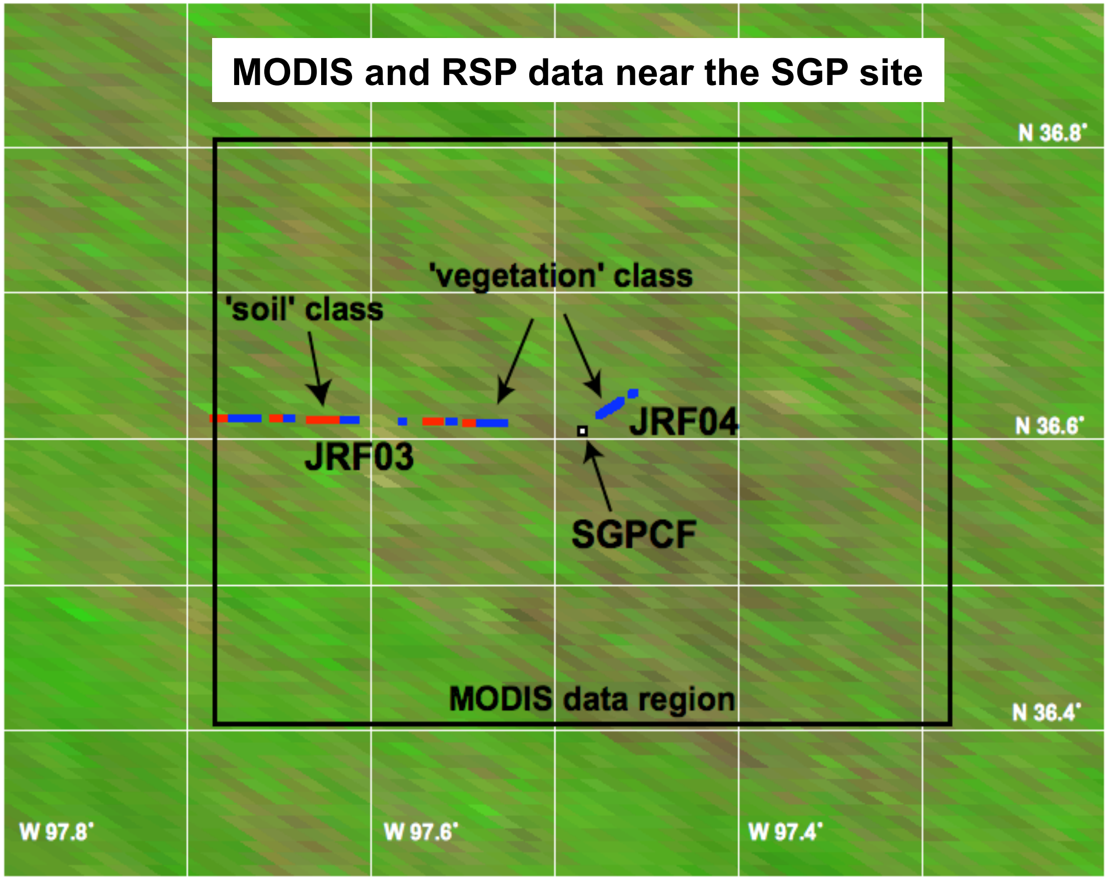
- Classification could be abandoned for downscaled pixel to pixel comparison
- Spectral integration could be avoided by directly comparing similar bands (550, 650, 860, 1640 & 2120nm)



RSP and ALIVE

Aerosol Lidar Validation Experiment (ALIVE)

- North-central Oklahoma (SGP site) in September, 2005
- Main goal: validation of aerosol vertical profiles from recently updated LIDAR instruments at SGP
- Jetstream-31 aircraft payload:
  - RSP
  - NASA Ames Airborne Tracking 14-channel Sun Photometer (AATS-14)
- Aircraft flew several low altitude flights, ideal for surface albedo characterization



RSP BRDF estimation

Observation at aircraft altitude modeled as follows

(neglecting geometry and integration notation)

Measured by RSP
From doubling-adding model
Desired value

$$\rho^{o} = \rho^{a} + S$$

$$S = \left(t^{\uparrow} + T^{\uparrow}\right)\rho^{g}\left(t^{\downarrow} + T^{\downarrow}\right) + \left(t^{\uparrow} + T^{\uparrow}\right)\left[\rho^{g}\sum_{i=1}^{\infty}\left(\rho^{g}\rho^{a*}\right)^{i}\right]\left(t^{\downarrow} + T^{\downarrow}\right)$$

ρ^{o} = reflectance at aircraft altitude

ρ^{a} = path reflectance;

S = total reflectance due to ground interaction

T = diffuse downwelling (↓) or upwelling (↑)

$\rho^{g}\Sigma(\rho^{g}\rho^{a*})^{i}$ = multiple ground-atmosphere interaction

ρ^{a*} = path reflectance looking up

ρ^{g} = ground reflectance

t = direct downwelling (↓) or upwelling (↑)

We are attempting to find ρ^{g}

Then fit it to BRDF models to retrieve kernel weights, f_i

RSP BRDF estimation

1. **Estimate ground reflectance neglecting diffuse and multiple scattering**

$$\rho_1^g = \frac{\hat{S}}{t^{\uparrow}t^{\downarrow}} = \frac{\rho^o - \rho^a}{t^{\uparrow}t^{\downarrow}}$$

$\hat{S}$ is from measurements

2. **Fit ground reflectance estimate to BRDF kernel model**

$$\rho_1^g \approx \rho_1^{g,k} = f_{iso,1} + f_{vol,1}K_{vol} + f_{geo,1}K_{geo}$$

3. **Estimate S using modeled BRDF**

$$S_1 = \left(t^{\uparrow} + T^{\uparrow}\right)\rho_1^{g,k}\left(t^{\downarrow} + T^{\downarrow}\right) + \left(t^{\uparrow} + T^{\uparrow}\right)\left[\rho_1^{g,k}\sum_{i=1}^{\infty}\left(\rho_1^{g,k}\rho^{a*}\right)^i\right]\left(t^{\downarrow} + T^{\downarrow}\right)$$

4. **Compare measured and modeled S to get new ground reflectance**

$$\rho_{p+1}^g = \left[\frac{\hat{S}}{S_p}\right]\rho_p^{g,k} = \gamma_p\rho_p^{g,k}$$

5. **Repeat steps 2-4 until γ approaches 1.0**

Data Classification

Classification

- Reduce spatial resolution and coverage differences between instruments
- Different instruments may see different combinations of bare or pre-harvest fields, shrubs, and other land types
- Perhaps it is best to divide data by land surface type and compare this?

Classification criteria: Aerosol Resistant Vegetation Index (ARVI)

- Similar to NDVI but intended to account for aerosols, Kaufman and Tanre, [1992]
- Used after correction for gases, screening of high zenith angle data, and removal of boundary pixels.

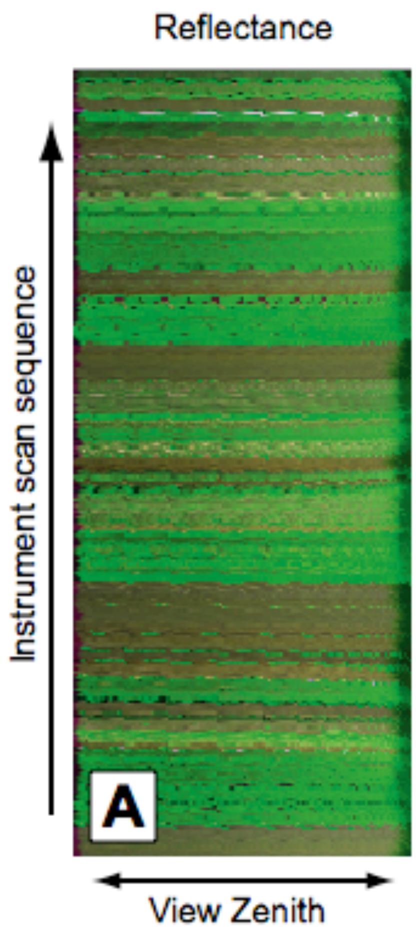
Three classes

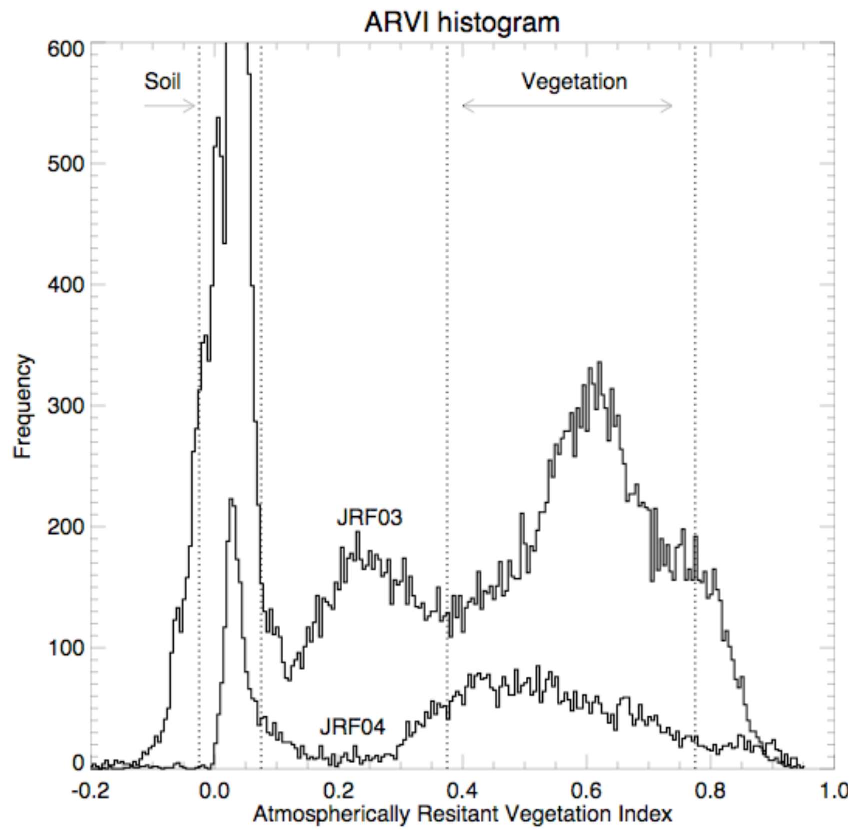
- 'Soil' representing low ARVI
- 'Vegetation' representing high ARVI
- 'All' representing all but extreme ARVI values

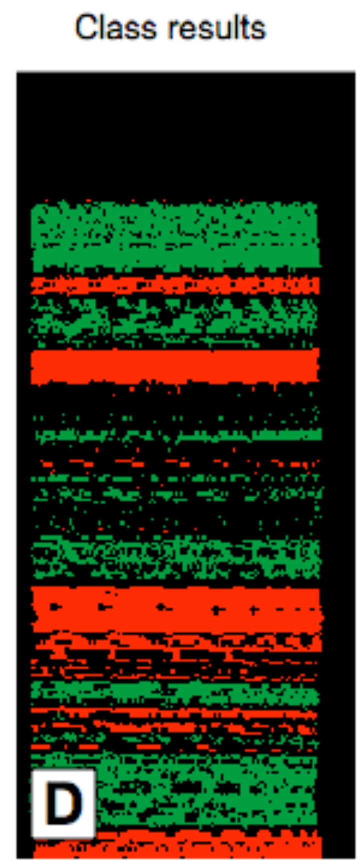
Classification performed on both RSP and MODIS data

Data Classification

Data were screened several ways, then classified broadly



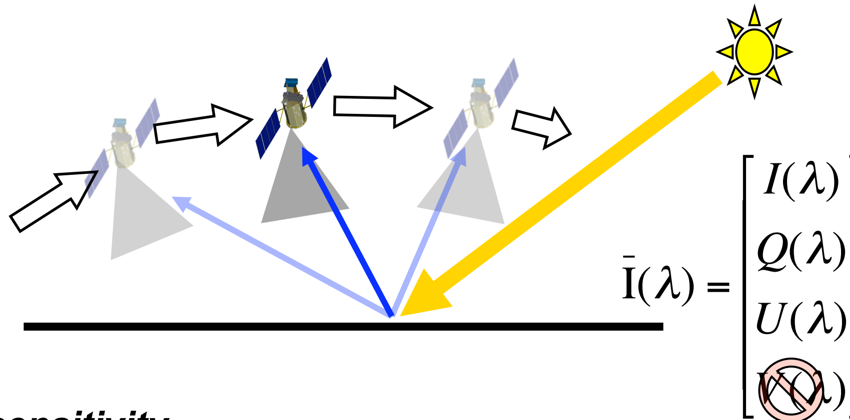




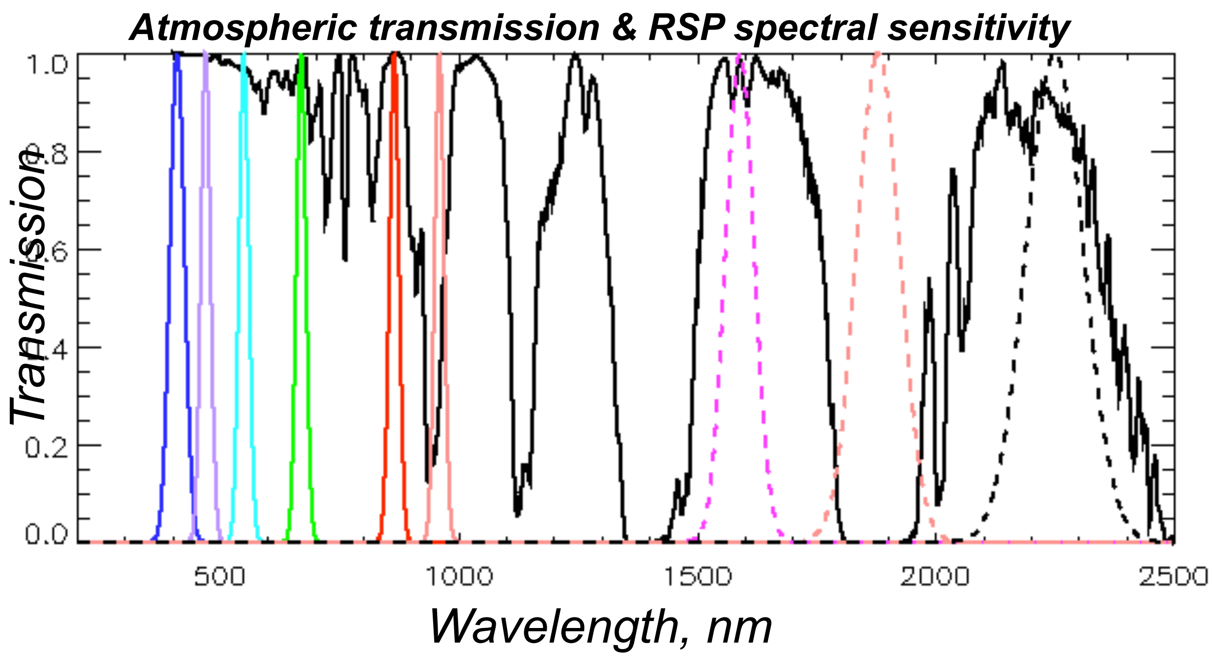
The Next Generation *RSP and APS*

RSP and APS design

- Nine spectral channels, blue to infra-red (410 - 2250 nm)
- Scans along track (in the direction of motion)
- Polarized radiance - I,Q,U components of Stokes vector
- High (0.2%) accuracy for polarized radiances



Circular polarization: two orders of magnitude smaller than linear polarization when source is unpolarized



RSP Aerosol channels:
410nm, 470nm, 555nm, 670nm, 865nm, 1590nm

Other Channels:
960nm, 1880nm, 2250nm

The Next Generation: *RSP and APS*

Comparison with current instruments

Instrument	Visible bands	IR bands	Multiple view angles	Polarized
AVHRR	0.63, 0.86µm (wide bands)	3.7µm	no	no
MODIS	0.47, 0.55, 0.65, 0.86µm	1.24,1.64, 2.12µm	no	no
MISR	0.45, 0.56, 0.67, 0.87µm	no	9 from ±70º	no
POLDER	0.49, 0.67, 0.86µm	no	12 from ±60º	I,Q,U, Limited accuracy
APS	0.41, 0.44, 0.56, 0.67, 0.87µm	0.91,1.37,1.61, 2.20µm	~250 from +60º to -70º	I,Q,U, 0.2% accuracy

Another technique?

B. Pinty, A. Lattanzio, J. Martonchik, M. Verstraete, N. Gobron, M. Taberner, J. Widlowski, R. Dickinson, and Y. Govaerts. **Coupling Diffuse Sky Radiation and Surface Albedo**. *Journal of the Atmospheric Sciences*, 62(7): 2580–2591, 2005.

Present methodology for creating *true* BHR from DHR and BHR_{iso}.

Comparison could be made at the level of BEFLUX observations, with no further processing of ground radiometer data needed…