Angular Distribution of Total and Polarized Land Surface Reflectance Measured by AirHARP

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Background and Motivation

The anisotropic total and polarized reflectance of a terrestrial surface are often characterized by the bidirectional reflectance and polarization distribution functions (BRDF and BPDF). A variety of semi-empirical BRDFs and BPDFs have been developed[1, 3-4]. In real applications, these functions are often used singly or linearly combined to form a bidirectional reflection model (BRM). Proper consideration of such a model is important in remote sensing for both surface and atmospheric retrievals, especially for those from multi-angular backscatter and/or polarimetric measurements. However, it is often unclear what surface parameters should be included as retrieval parameters.

The Hyper-Angular Rainbow Polarimeter (HARP) instruments are designed and built at *UMBC Earth and Space Institute* to make multiangle multi-spectral polarimetric measurements from a wide 94° cross-track FOV (60 unique view angles at 670 nm, and 10-20 at 440, 550, & 870 nm). Currently, there are three polarimeters based on the HARP concept:

Air HARP | HARP CubeSat | HARP2 PACE

Airborne System	Launch – Nov 2019	2022-23
• Ground calibration often • 40m resolution • Deployed in NASA LMOS and ACEPOL campaigns	• Lower SNR • 4 km resolution • Limited data set: 1 snapshot/day	• Improved SNR • Better calibration • 3 km resolution • Global coverage in 2 days

Research Objectives

- Evaluate different BRDF/BPDF models for desert and vegetation surfaces with recently collected AirHARP observations
- Potentially improve BRM parameterization and representations (such as in terms of kernel non-linear parameters) in surface & atmosphere retrieval design

Method

Forward Radiative Transfer Modeling

BRDF + BPDF
- Amplitudes
- Parameters

→ UNL-VRTM[2-3]
- VLIDORT[4]
- Rayleigh & Gas
- Aerosols

→ AirHARP I, Q/I, U/I

L-BFGS-B Optimized Inversion

BRDF considered:
- Ross-Li[5]
- Rahman-Pinty-Verstraete (RPV)[6]

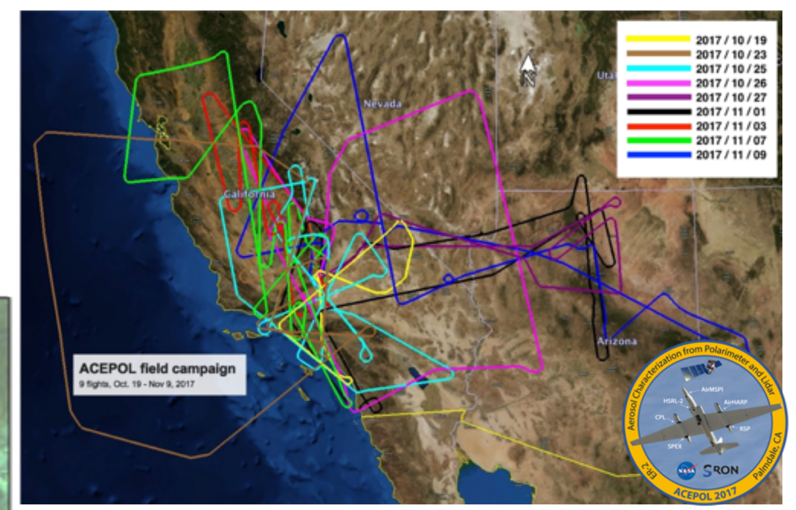
BPDF considered:
- Maignan-Breon models[7]
- Modified Fresnel[1]

Inversion:
- Online Jacobians for surface & aerosol
- Option for simultaneous aerosol retrieval

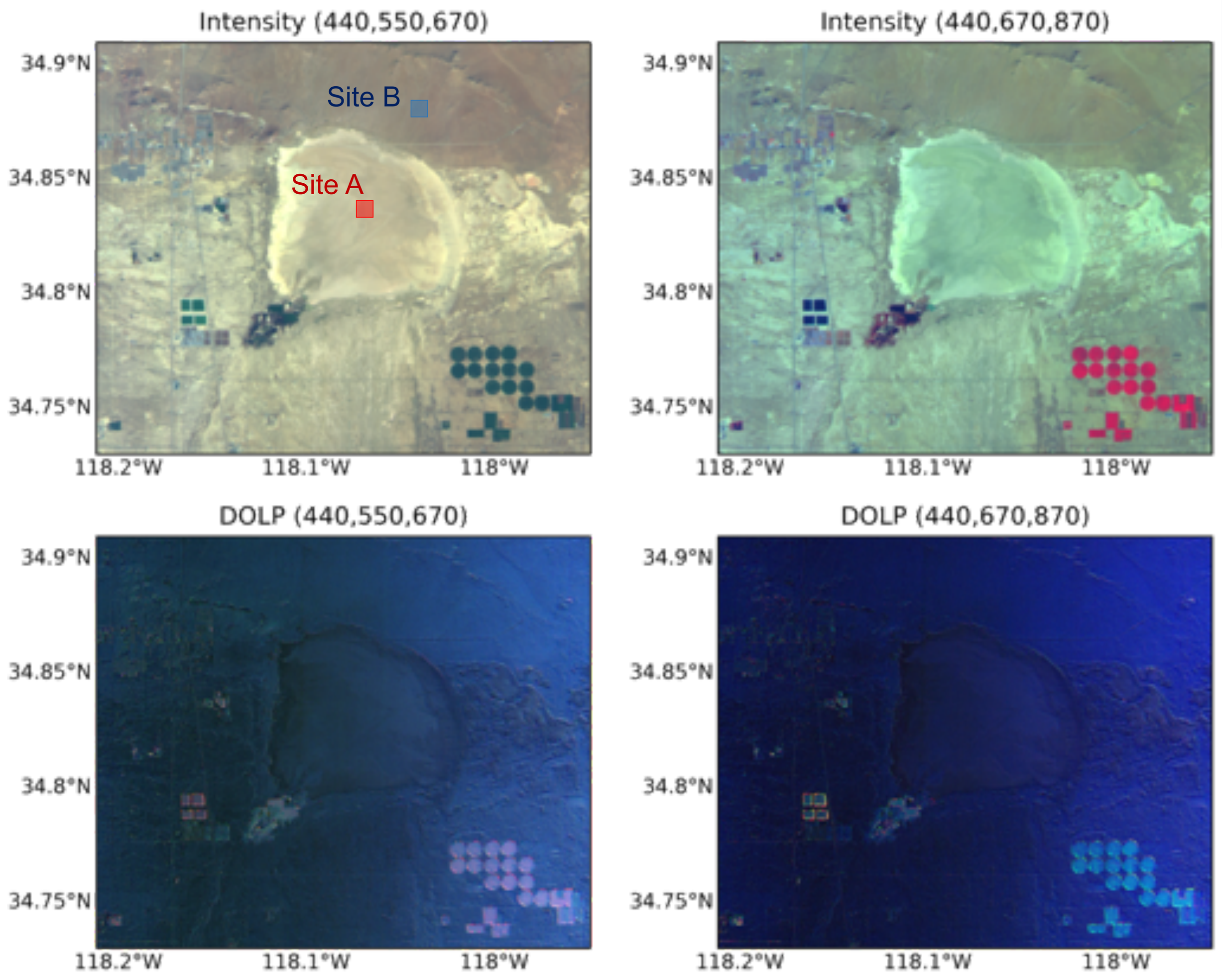
More about UNL-VRTM: https://unl-vrtm.org

NASA ACEPOL Campaign

AirHARP Joined NASA Aerosol Characterization from Polarimeter and Lidar (ACEPOL) campaign in October – November 2017. Observations over 40 scenes have been collected and processed.

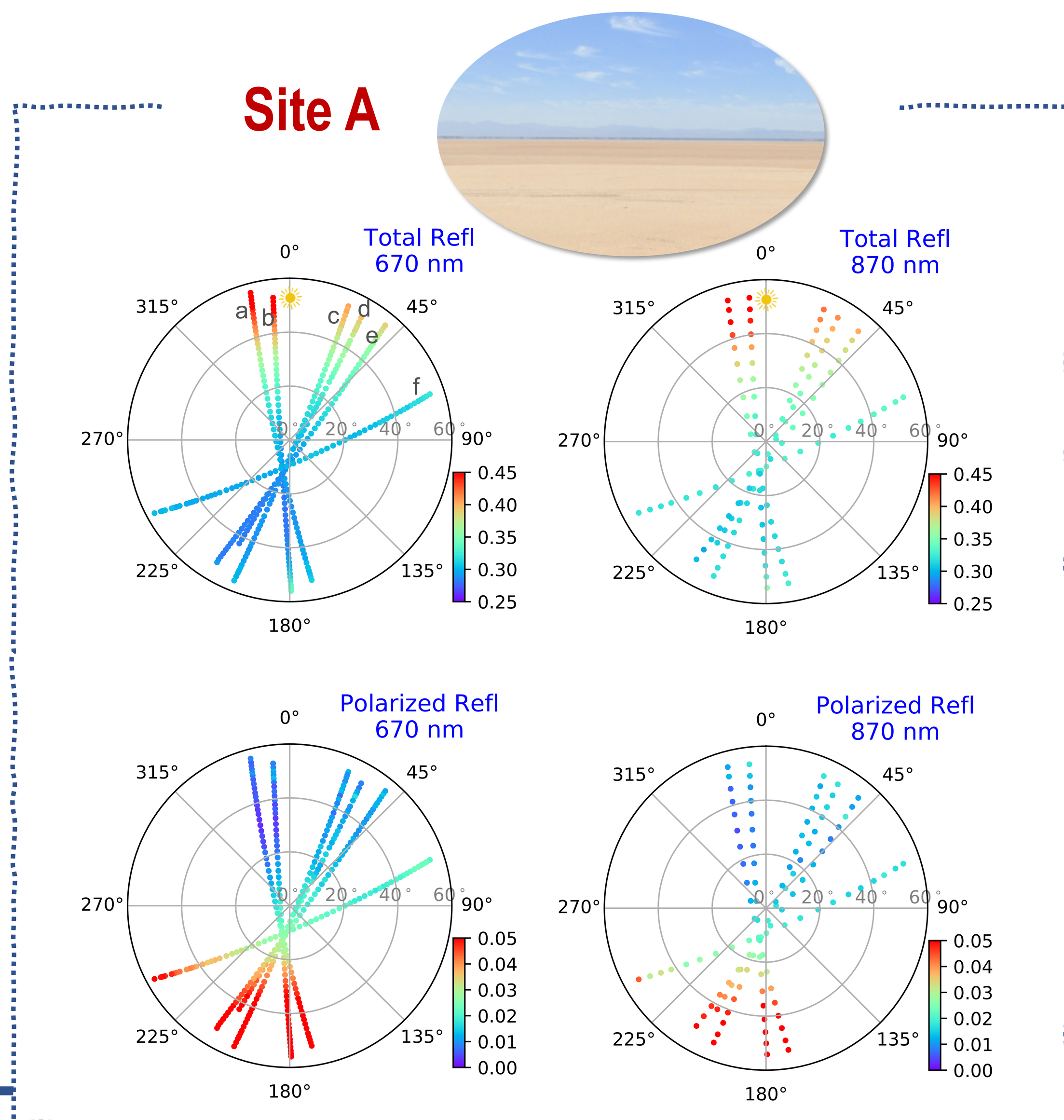


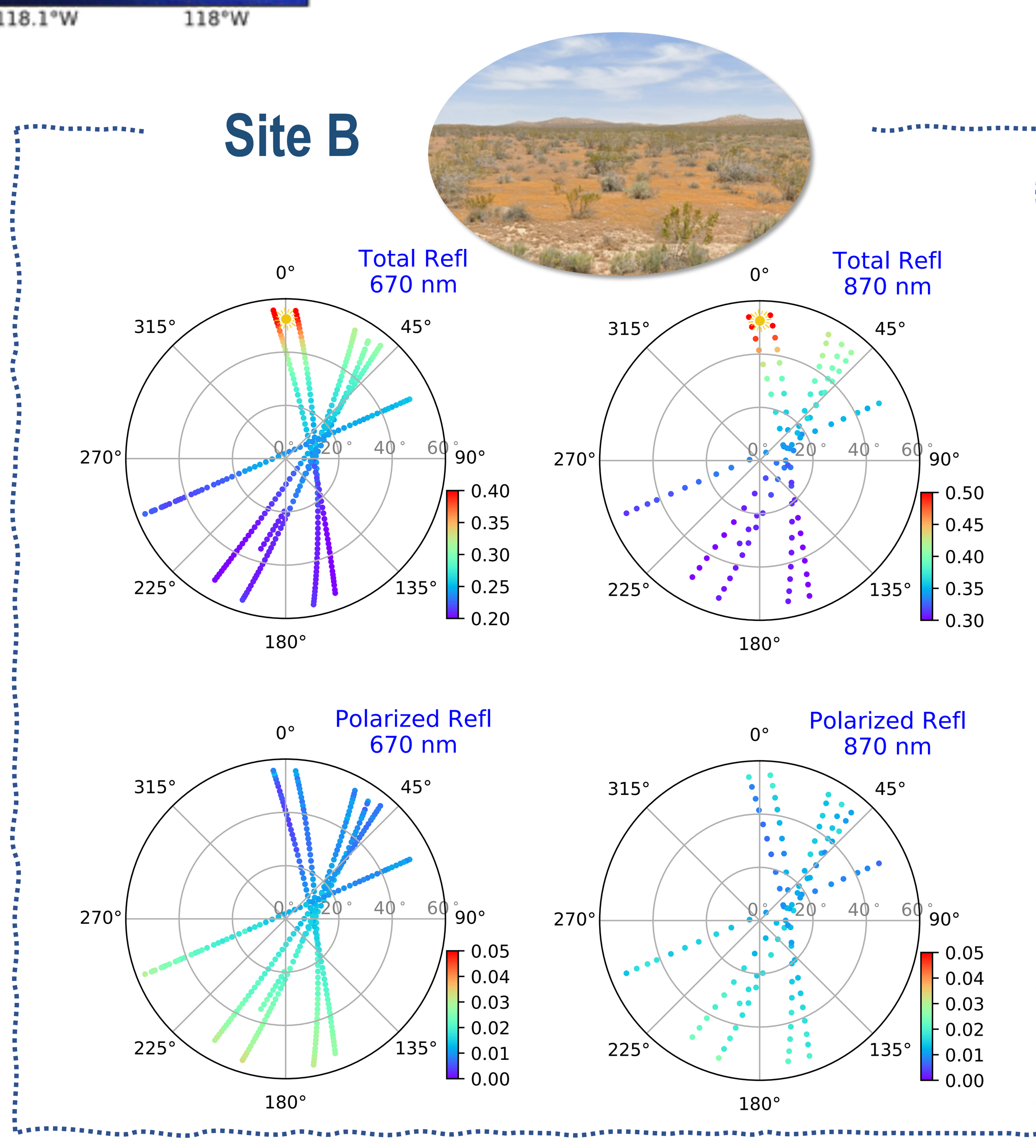
ER-2 flight tracks during ACEPOL
Courtesy: Kirk Knobelspiesse



Left: AirHARP RGB composites using the spectral intensity and the degree of linear polarization (DOLP) acquired on Oct 25, 2017 over Rosamond Dry Lake, California.
More AirHARP Quick looks can found at: https://sites.google.com/view/airharp-acepol

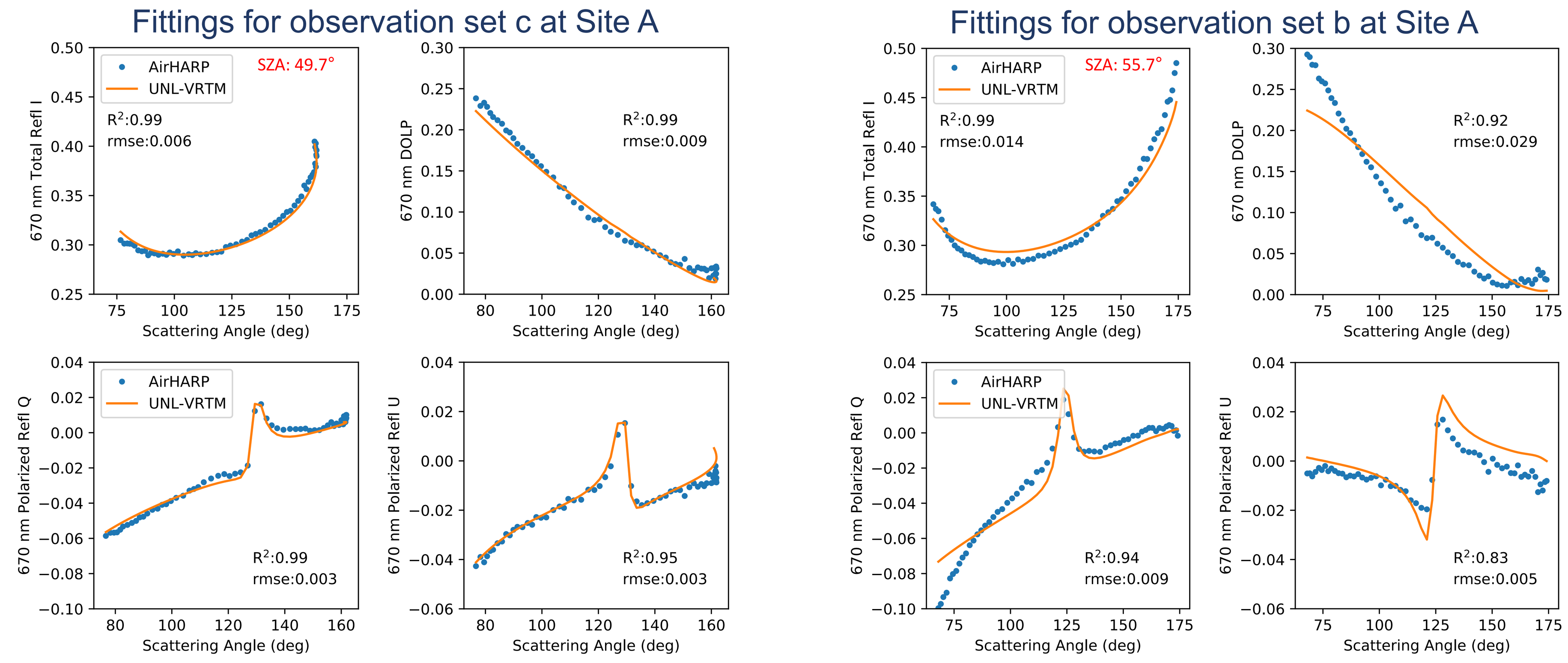
Below: Polar plots of aircraft-level total & polarized reflectance from 6 overpasses for 5x5 AirHARP pixels at sites A & B. Sun is placed at 0° relative azimuth, and solar zenith angles from 47° to 56°.





Preliminary BRM Fittings

- BRM = αRoss-Li + βMaignan-Breon, only α and β are constrained from all observations at Site A
- Figures below shows fittings of total and polarized reflectance for two different scans
- This BRM model fails to capture the angular distribution of DOLP at large solar zenith angles



Future Work

- Conduct retrievals for BRM's amplitudes & relevant nonlinear parameters (such as surface refractive index) for additional combinations of BRDF/BPDF kernels from AirHARP measurements over the Mojave desert and the vegetation surfaces.
- Evaluate the performance of different BRMs for different surface types, and then seek ways to improve the BRM representation
- Provide recommendations on "what parameters should be put in the state vector" for designing HARP surface & atmosphere retrieval algorithms

References & Acknowledgements

[1] Litvinov P, Hasekamp O, Cairns B (2012) *Remote Sens Environ* 115: 781-792
[2] Wang J et al (2014). *J Quant Spectrosc Radiat Transf* 146:510–528
[3] Xu X, J Wang (2019), in *Springer Series in Light Scattering Volume 4*, ed A. Kokhanovsky, Springer
[4] Spurr R, Christi M (2019), in *Springer Series in Light Scattering Volume 3*, ed A. Kokhanovsky, Springer
[5] Wanner W, Li X, Strahler AH (1995) *J Geophys Res Atmos* 100:21077–89
[6] Rahman H, Pinty B, Verstraete M (1993) *J Geophys Res* 98:20791–20801
[7] Maignan F, Breon F-M, Fdle E, Bouvier M (2009) *Remote Sens Environ* 113:2642–2650

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