Polarized Markov Chain Line-by-Line Radiative Transfer Tool for AirMSPI Vicarious Calibration

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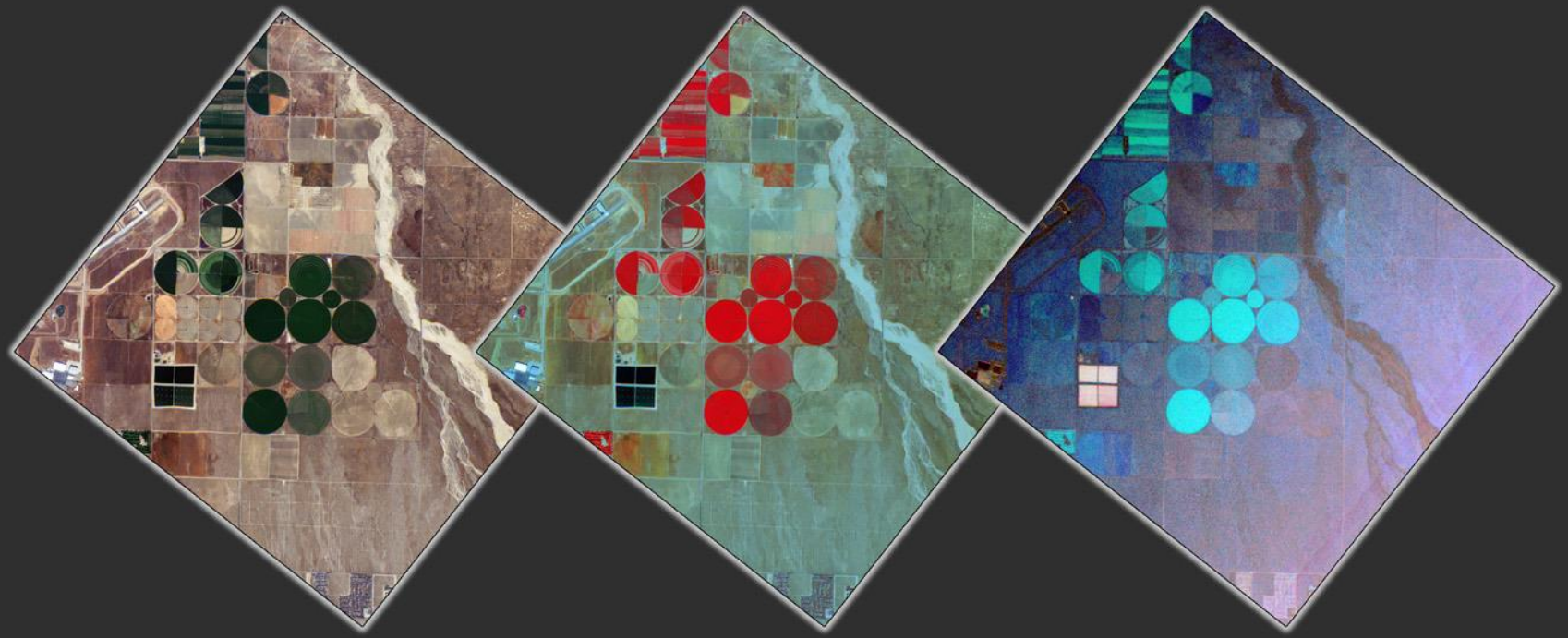
Executive Summary

AirMSPI retrievals, using observations over the AERONET Fresno site, had shown a systematic under-estimate of aerosol optical depth (AOD) by 0.03-0.05 at low aerosol loadings (AOD_{440}~0.08). To investigate this error, we revisited the radiative transfer (RT) modeling component used in the VicCal analysis, which is implemented by running the MODTRAN v5.3.2 code.

The investigation consisted of 1) developing a polarized Markov Chain line-by-line code (pMarCh-LBL) for RT calculation accounting for both aerosols and gaseous absorption; and 2) running pMarCh-LBL for VicCal with the same solar spectra, AirMSPI Spectral Response Function (SRF), measured HDRF, solar and viewing geometry, surface elevation, sensor altitude, and AOD, as used by MODTRAN. In comparing the calculated radiances from the two codes, differences were traced to the neglect of polarization by MODTRAN v5.3.2. This results in a VicCal error of as much as 7% (at 355 nm), which in turn causes the observed AOD retrieval bias. To eliminate this error, pMarCh-LBL is now used for AirMSPI VicCal calculations.

AirMSPI

Airborne Multiangle SpectroPolarimetric Imager



These AirMSPI images show views of Palmdale, CA acquired on October 7, 2010. The Palmdale Airport, where the ER-2 is based, is at left. The left image is a natural color view produced using intensity data at 445, 555, and 660 nm for the blue, green, and red display. The middle image shows intensity at 470, 660, and 865 nm; vegetated areas appear red due to the high reflectance of leaves in the near-infrared. The right image is DOLP (Degree Of Linear Polarization) at 470, 660, and 865 nm. The highly polarized square feature near lower left is a wastewater treatment facility.

Polarized Markov Chain Line-by-Line (pMarCh-LBL) RT Model

The polarized Markov Chain Line-by-Line RT model (pMarCh-LBL) integrates two components:

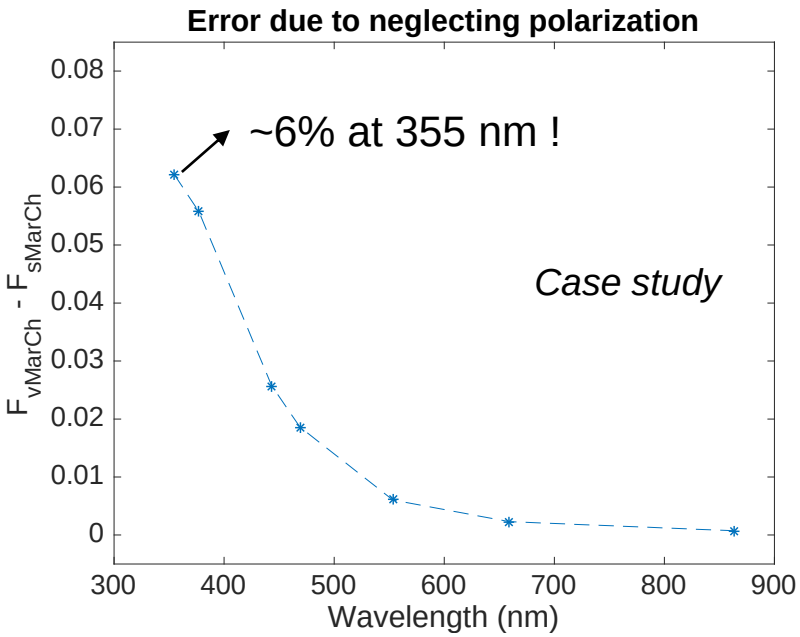
a) Single-line based polarized Markov chain model for radiative transfer in a plane-parallel atmosphere, which is developed by Xu et al. at JPL (cf. Xu et al. Opt. Express 19, 946, 2011; Opt. Lett. 36, 2083-2085, 2011; Appl. Opt. 51, 3491, 2012).
b) Trace-gas absorption spectra from the climatology database for mid-latitude summer and mid-latitude winter. They are output from the LBLRTM v3.2 code (Clough et al. JGR atmos. 97, 15761, 1992; JQSRT 91, 233, 2005).

The trace-gas spectra, AOD, aerosol microphysical properties, and surface HDRF were then used as input into the pMarCh-LBL model. RT modeling is performed at all wavelengths, then band-weighted radiances are computed for the AirMSPI spectral response functions. This analysis was repeated for four VicCal field campaigns.

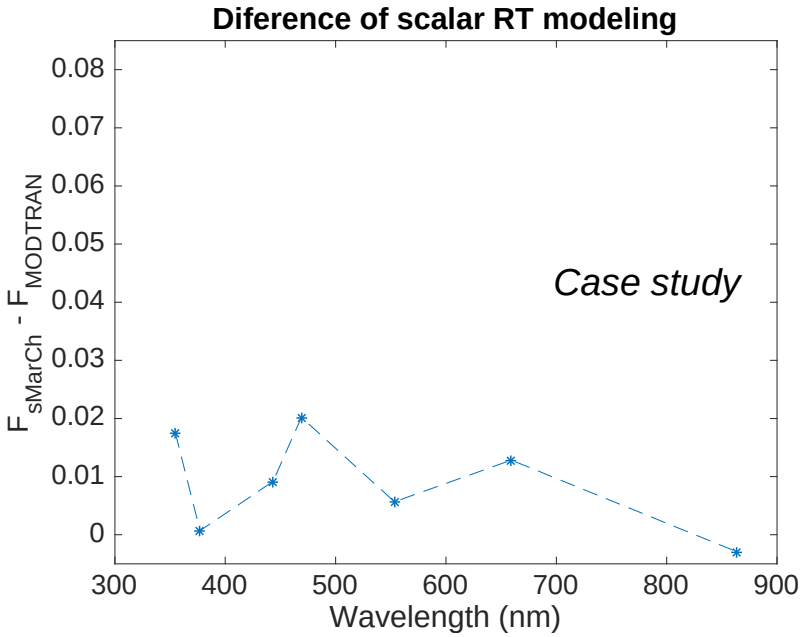
MODTRAN's error source

"Does MODTRAN5 compute polarization radiance vectors? - This capability has yet to be integrated in MODTRAN5." - Berk et al. MODTRAN 5.3.2 User's manual, 2008.

VicCal error caused by MODTRAN's neglect of polarization

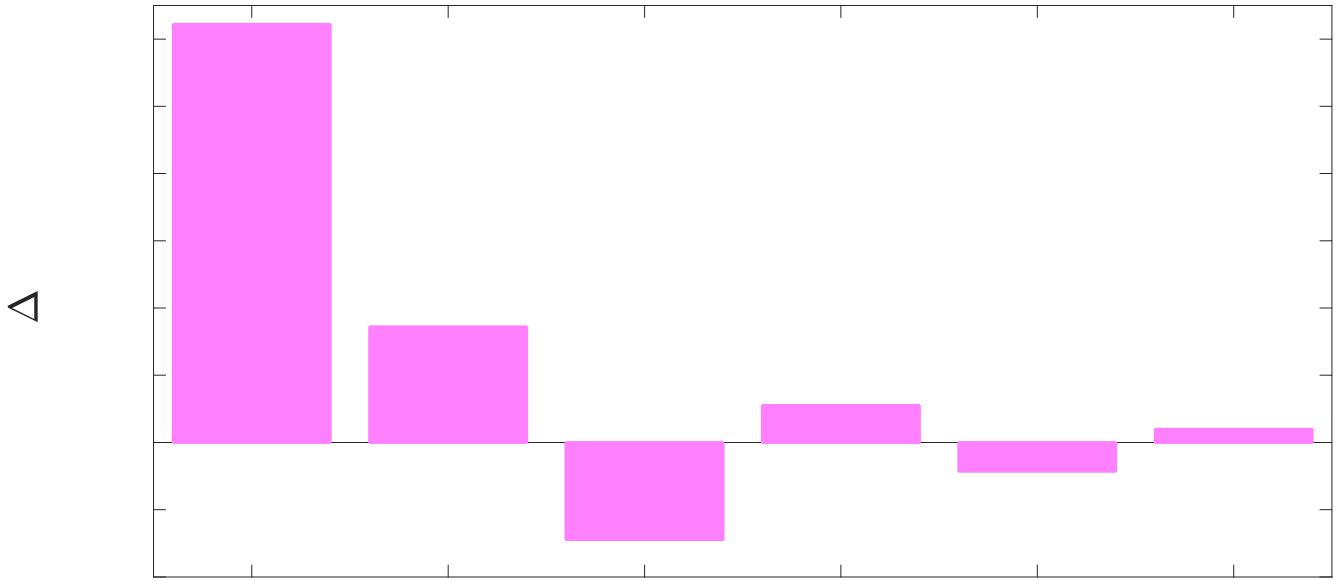


Computed by vector and scalar Markov chain RT model

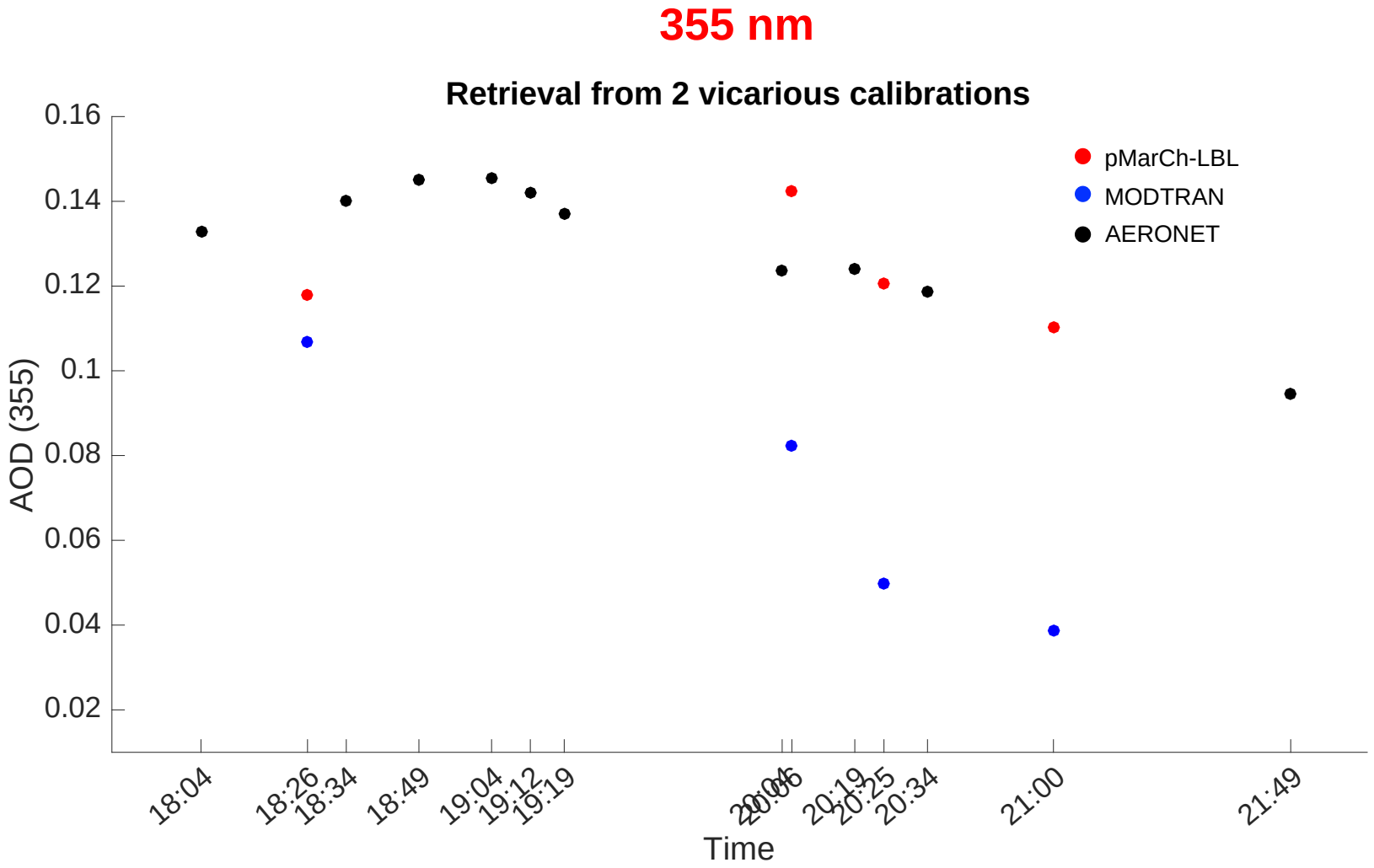


Computed by MODTRAN and scalar Markov chain RT model

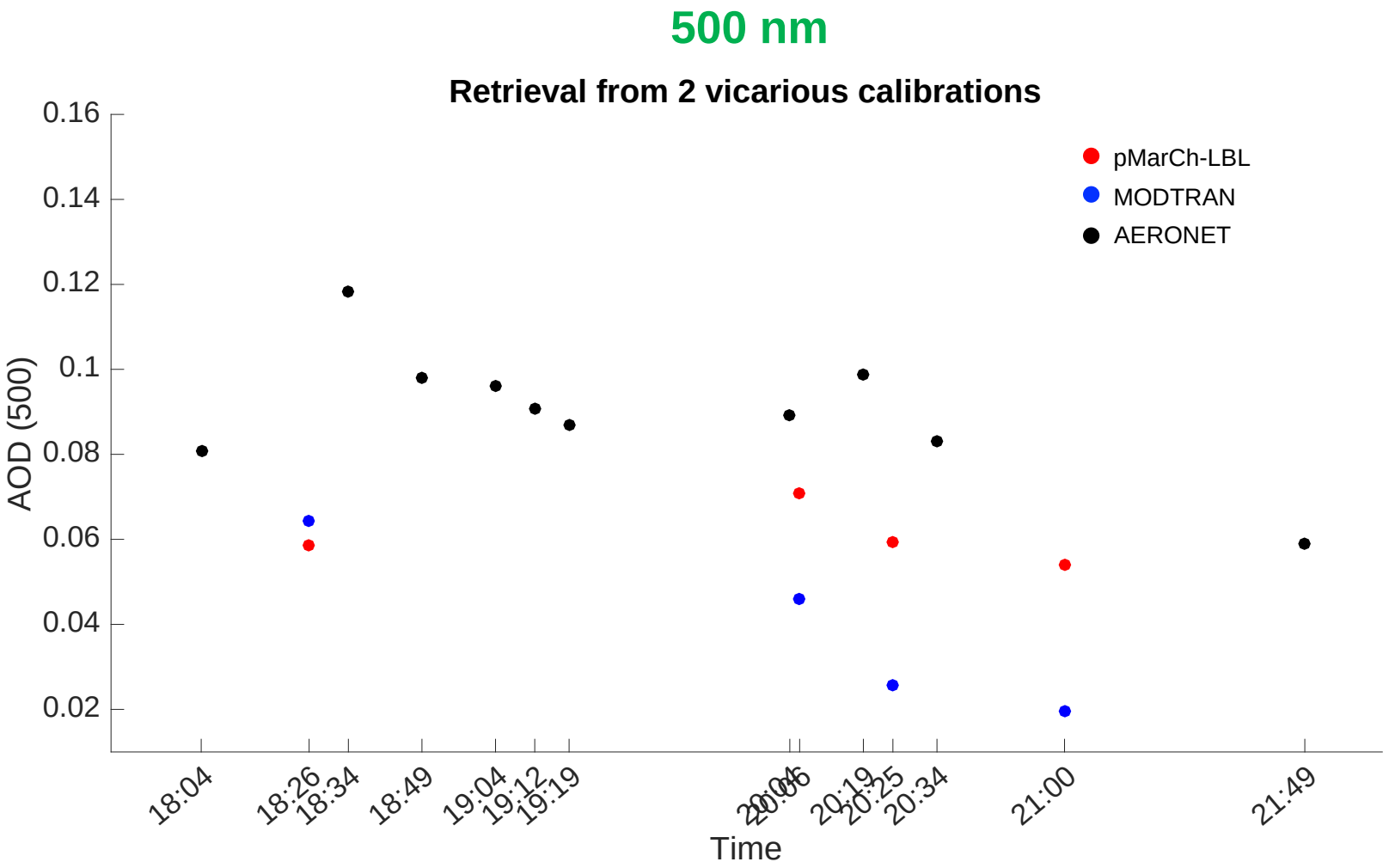
Impact of other modeling errors



Improved AOD retrieval from using pMarCh-LBL model



Improved AOD retrieval from using pMarCh-LBL model (cont'd)



Updated VicCal radiance from pMarCh-LBL RT model

ImPACT (AOD 0.066 at 550 nm, sza 23º)

Wave (nm)	354.768	377.142	443.239	469.018	553.353	659.256	863.314	931.373
$L_{MODTRAN}$	67.76	66.64	105.89	111.98	109.44	100.08	68.97	27.89
$L_{pMarCh-LBL}$	72.47	69.19	108.14	115.16	110.72	99.85	67.89	27.43
Ratio	1.070	1.038	1.021	1.028	1.012	0.998	0.984	0.984

PODEX (AOD 0.042 at 550 nm, sza 36º)

Unit of L: (W m^{-2} Sr^{-1} um^{-1})

Wave (nm)	354.768	377.142	443.239	469.018	553.353	659.256	863.314	931.373
$L_{MODTRAN}$	60.77	57.70	93.90	106.00	119.30	134.20	98.30	39.20
$L_{pMarCh-LBL}$	62.87	59.99	96.57	105.76	121.92	135.78	99.93	39.30
Ratio	1.035	1.040	1.028	0.998	1.022	1.012	1.017	1.003

Updated VicCal radiance from pMarCh-LBL RT model

Cal-Water (AOD 0.057 at 550 nm, sza 59º)

Wave (nm)	354.768	377.142	443.239	469.018	553.353	659.256	863.314	931.373
$L_{MODTRAN}$	44.43	42.00	62.62	67.46	59.55	53.66	37.82	13.64
$L_{pMarCh-LBL}$	42.44	40.59	61.62	64.81	59.19	53.17	37.89	13.29
Ratio	0.955	0.967	0.984	0.961	0.994	0.991	1.002	0.975

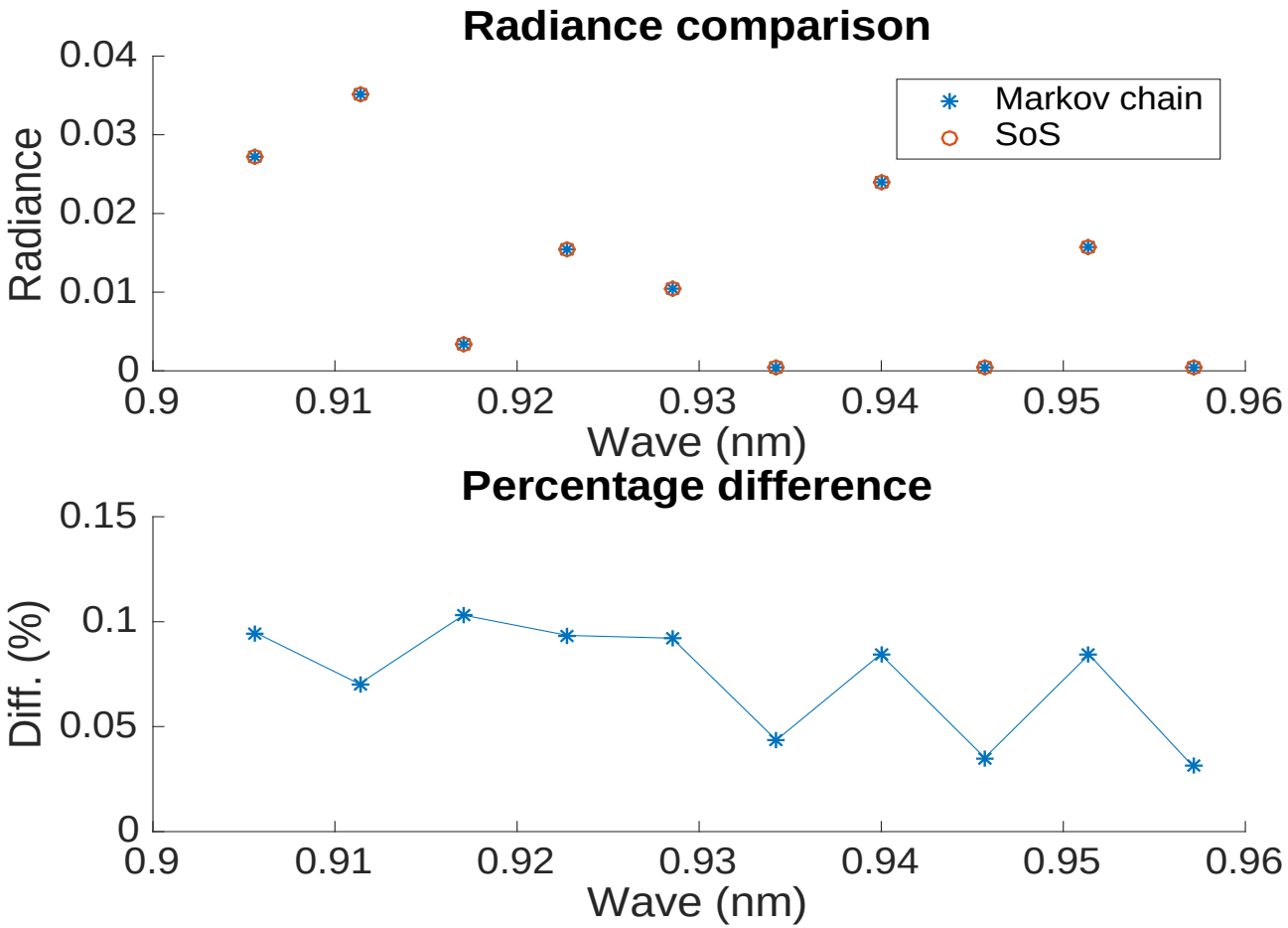
SEAC4RS (AOD 0.036 at 550 nm, sza 50º)

Unit of L: (W m^{-2} Sr^{-1} um^{-1})

Wave (nm)	354.768	377.142	443.239	469.018	553.353	659.256	863.314	931.373
$L_{MODTRAN}$	51.93	49.30	79.40	89.20	98.60	108.90	79.50	30.20
$L_{pMarCh-LBL}$	53.22	51.13	82.52	90.31	102.28	111.89	81.99	30.56
Ratio	1.025	1.037	1.039	1.012	1.037	1.028	1.031	1.011

Benchmarking (Backup)

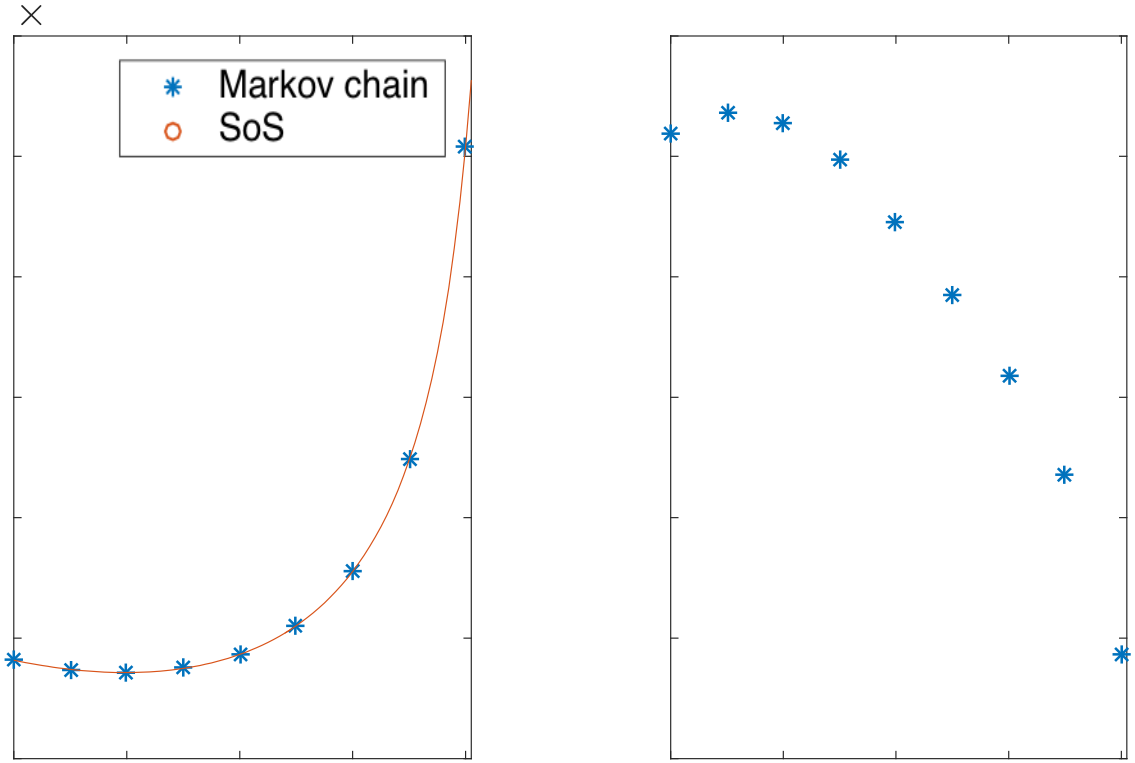
pMarCh-LBL Benchmarking



SoS: Successive order of scattering (Credits: Dr. Peng-Wang Zhai, UMBC, 2016)

Wavelength in water vapor band, Nadir viewing Lambertian surface

pMarCh-LBL Benchmarking (cont'd)



SoS: Successive order of scattering (Credit: Dr. Peng-Wang Zhai, UMBC, 2016)

Single wavelength
Off-nadir viewing
Lambertian surface