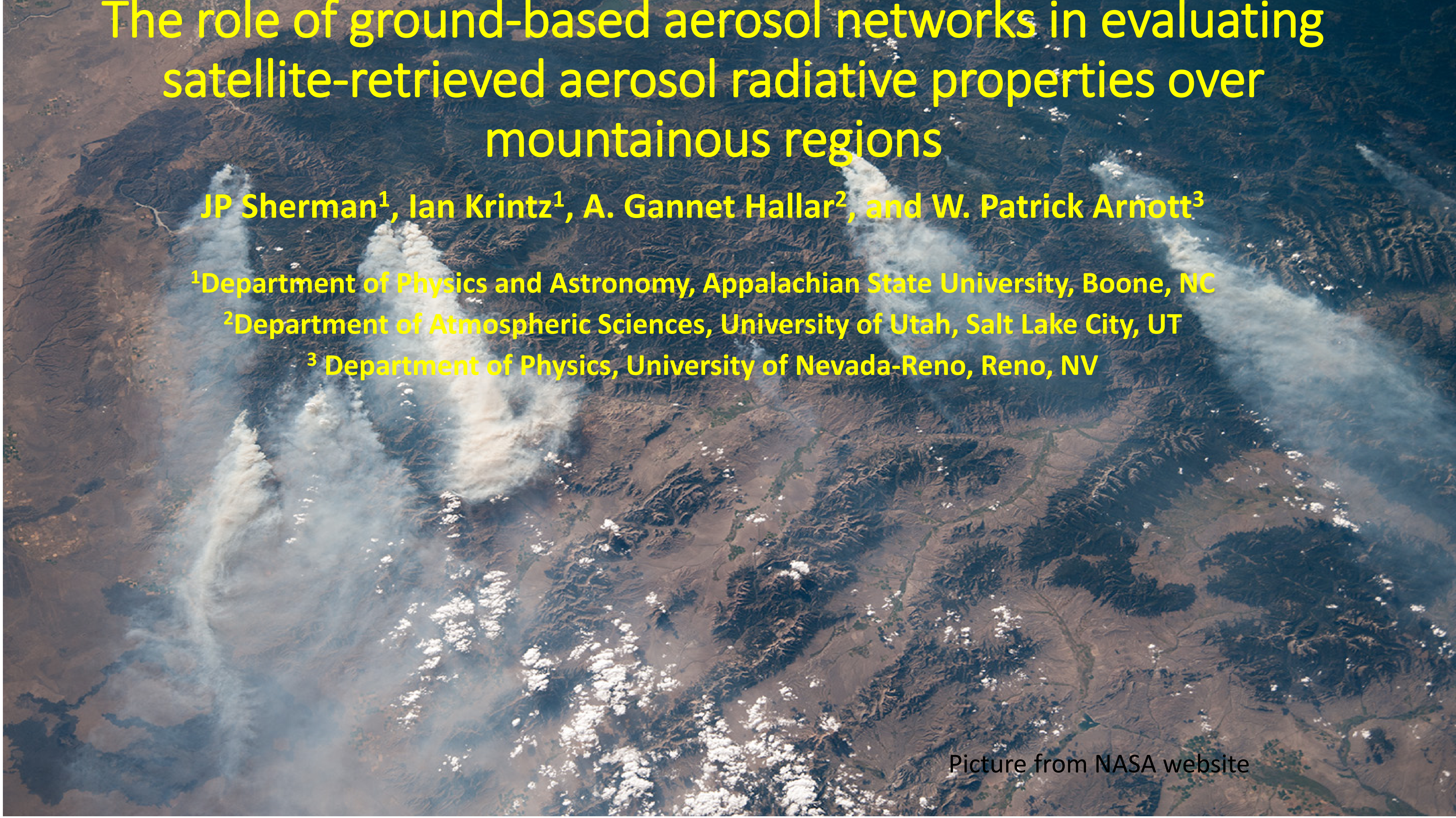
The role of ground-based aerosol networks in evaluating satellite-retrieved aerosol radiative properties over mountainous regions

JP Sherman[1], Ian Krintz[1], A. Gannet Hallar[2], and W. Patrick Arnott[3]

[1]Department of Physics and Astronomy, Appalachian State University, Boone, NC
[2]Department of Atmospheric Sciences, University of Utah, Salt Lake City, UT
[3] Department of Physics, University of Nevada-Reno, Reno, NV



Picture from NASA website

Talk Outline

I. The role of satellites in aerosol monitoring and studies

II. How satellites derive aerosol optical depth

III. Role of ground-based aerosol networks for validating satellite-based AOD

IV. Spatio-temporal collocation method

V. Validation of MODIS and MISR-retrieved AOD over four mountainous U.S. sites

VI. Sample of Results

I. The role of satellites in aerosol monitoring and studies

- Satellites have been used for ~2-3 decades for mapping of dust, fires, and pollution
- They are increasingly used for quantifying aerosol loading (aerosol optical depth-AOD) for estimates of aerosol direct radiative effect and for 'estimating 'surface level particulate matter mass concentrations (air quality studies and regulation)
- Much effort has been made to characterize aerosol properties and particle type from space, although this can only be done semi-qualitatively at current time (Kahn and Gaitley, 2105)
- However, the accuracy of these retrievals depends on several assumptions regarding atmospheric and surface properties, which may or may not hold true for the region under study

II. How satellites retrieve aerosol optical depth (AOD)

- Difficulty lies in separating contributions to TOA radiance from the atmosphere (aerosols, trace gases) from surface contributions
- Deriving AOD from TOA radiances necessitates use of a prescribed aerosol model that likely represents regional aerosol, along with surface type
- Satellite retrieval errors dominated by incorrect aerosol model assumptions (along with cloud contamination) at high AOD and by inadequate surface assumptions at low AOD
- Current AOD uncertainties on order of ~0.05, which still is ~2.5 times larger than that needed to constrain aerosol direct radiative effect to

  1 Wm^{-2} (Sherman and McComiskey, ACP, 2018

- Uncertainties are often much higher over complicated surfaces (deserts, urban, mountain) and are often not even attempted over these terrain types

Image from NASA MODIS website

III. Role of ground-based aerosol networks for validating satellite-based AOD

- Ground-based networks of sunphotometers (NASA AERONET, NOAA Surfrad) are used for global validation of AOD

- Collocated networks (NOAA ESRL) measuring aerosol intensive properties (SSA, particle size) add value because the aerosol model assumptions used by satellite retrieval algorithms can also be examined.
- Many global and regional validation studies but few (no ??) detailed studies for mountain regions

IV. Spatio-temporal collocation method

- Validating satellite-based AOD (or any) retrievals necessitates that the satellite sensor and ‘ground-truth’ instrument ‘see’ the same section of atmosphere, or at least a representative region
- Satellites take a picture of a spatial region while ground-truth instruments take ‘point’ measurements at fixed temporal intervals. ***The level of agreement between the two AOD measurements is dependent on the spatio-temporal collocation of the two measurements***
- Many validation studies use satellite-measured AOD averaged over a 50km x 50km box centered at ground-site, compared with AOD measured by the ground sensor over a 30min window centered at satellite overpass time (Ichoku, 2001).
- *Suitability of this method depends on spatial and temporal aerosol variability, along with variability in elevation,surface type, and AOD within the spatial box*

V. Validation of MODIS and MISR-retrieved AOD over four mountainous U.S. sites

- The current study evaluates AOD retrieved by MODIS and MISR over four mountainous U.S. sites:

(1) Appalachian State University (APP; Boone, NC);

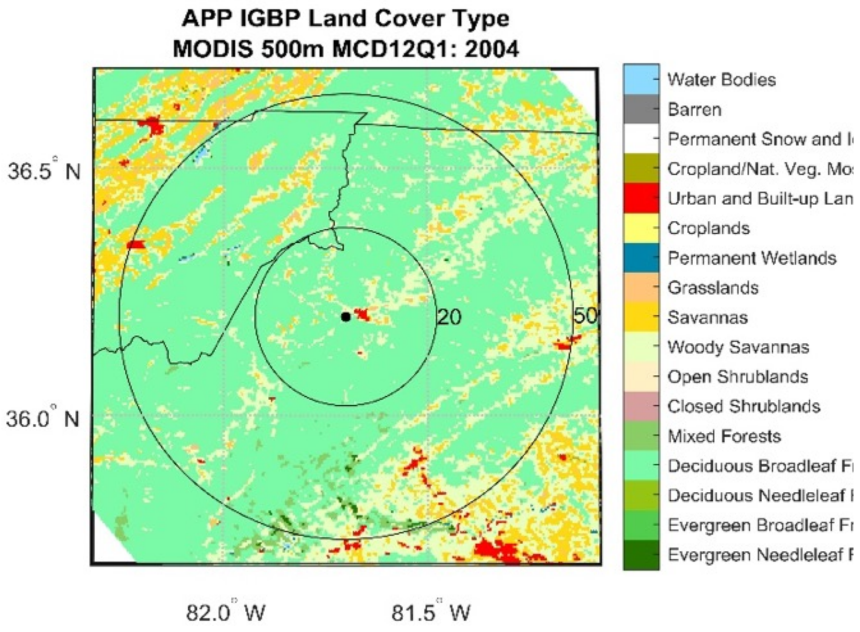
(2) Walker Branch TN (WB);

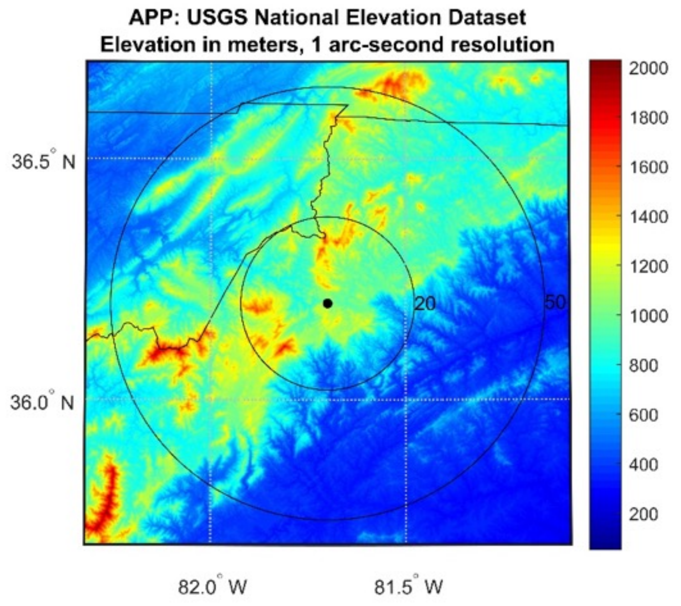
(3) Storm Peak Laboratory (SPL; Steamboat Springs, CO);

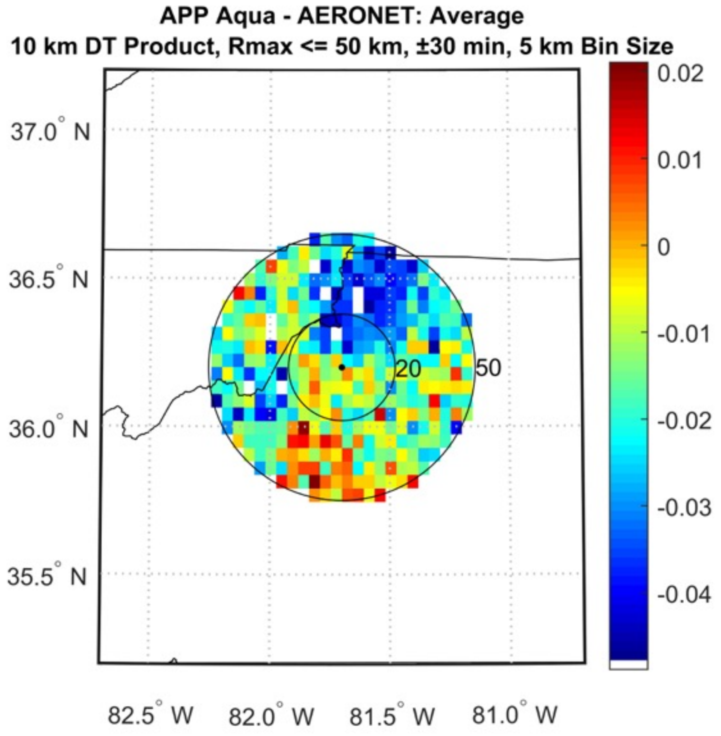
(4) University of Nevada-Reno (Reno).

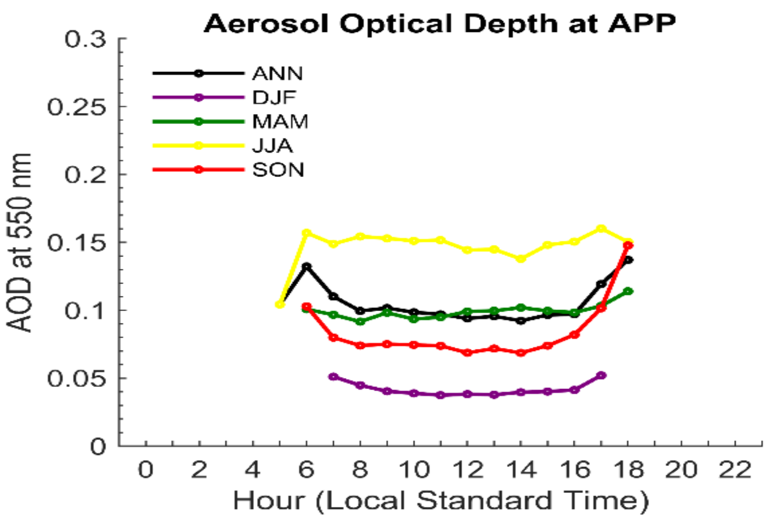
- Each site is home to a NASA AERONET site and/or has a multi-filter rotating shadowband radiometer (MFRSR). The APP and SPL sites are also part of the NOAA ESRL aerosol monitoring network.
- The four sites collectively represent aerosol and terrain types present in mountainous U.S. regions.
- After determining the optimal spatio-temporal window at each site, we evaluate MISR V23 AOD product (4.4km resolution) and 3 MODIS AOD (550nm) retrieval algorithms (a) Dark Target (10km and 3km products); (b)Deep Blue (10km product); and (c) combined DT/DB

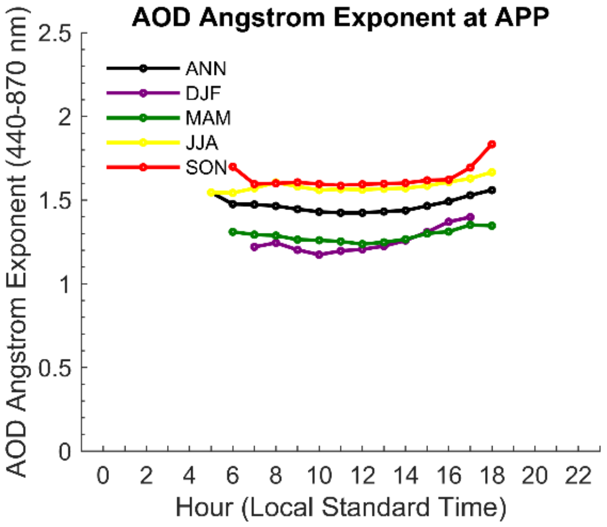
Variability of Aerosol and Surface Properties at APP



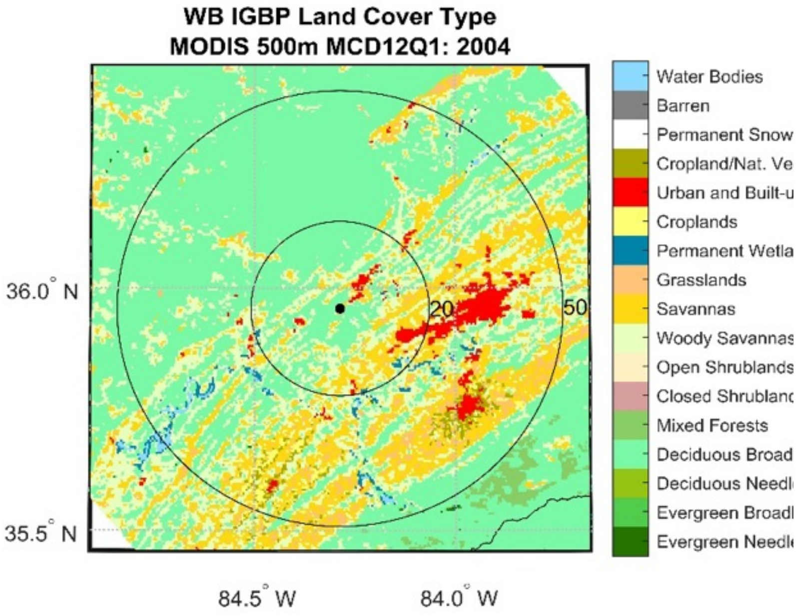


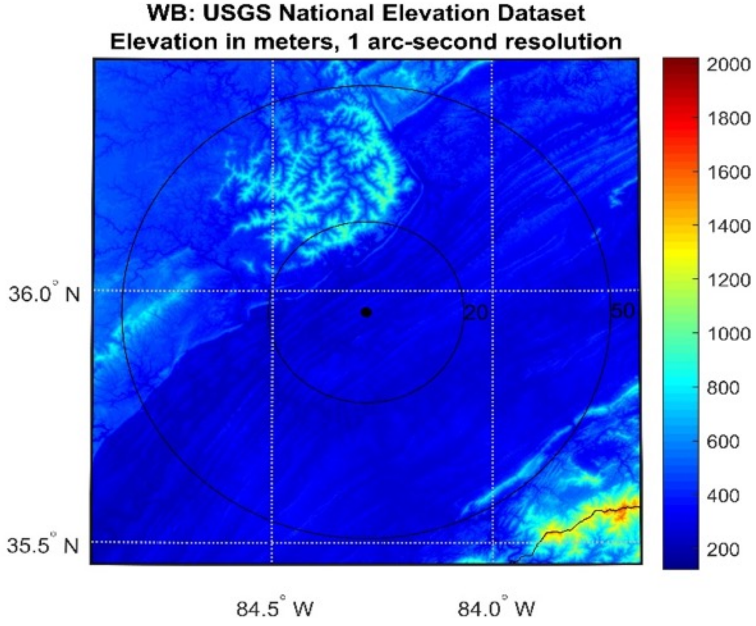


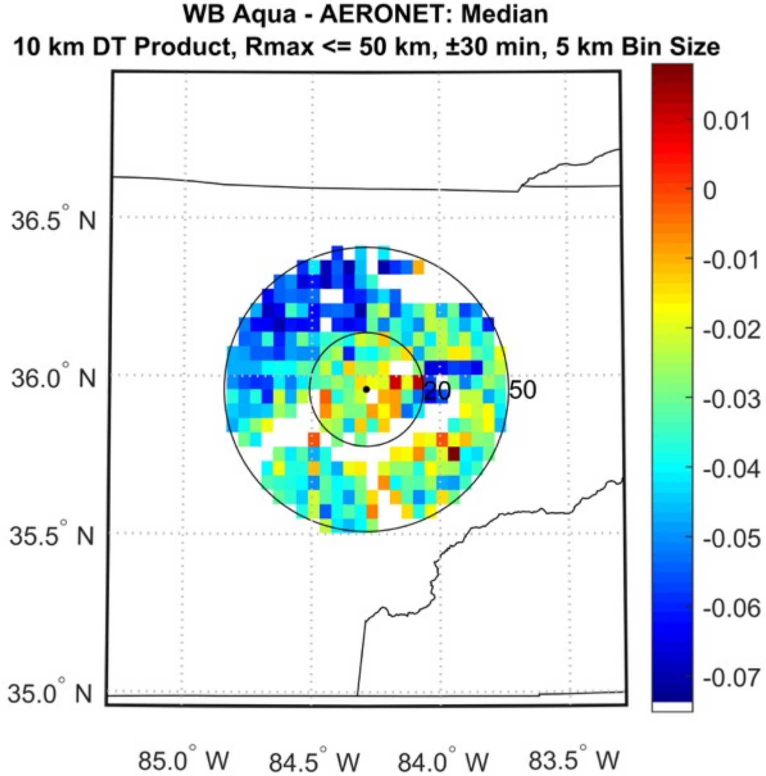


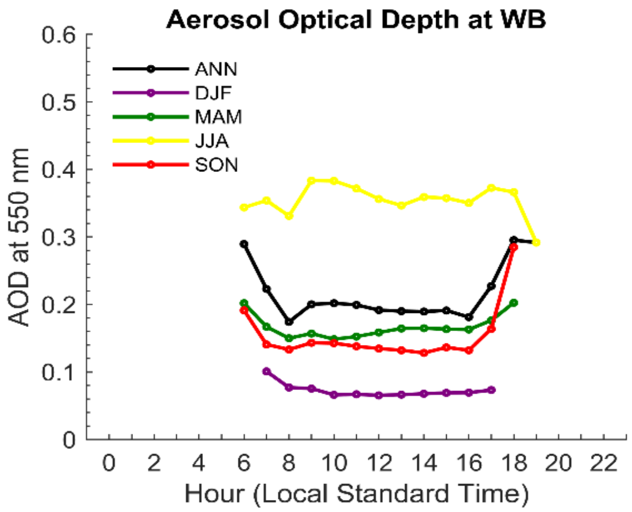


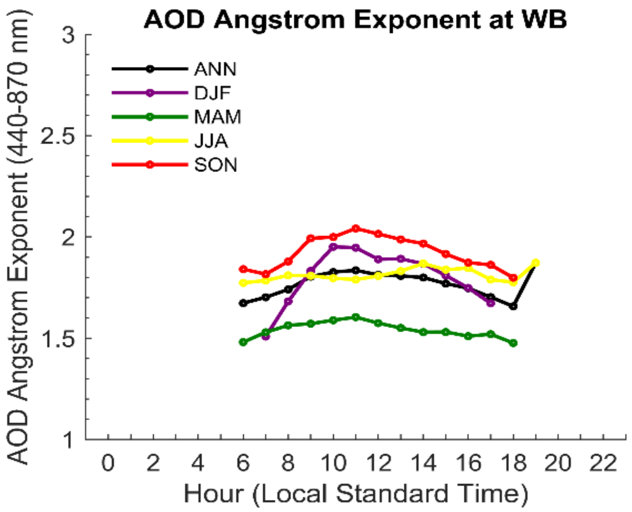
Variability of Aerosol and Surface Properties at Walker Branch (WB)



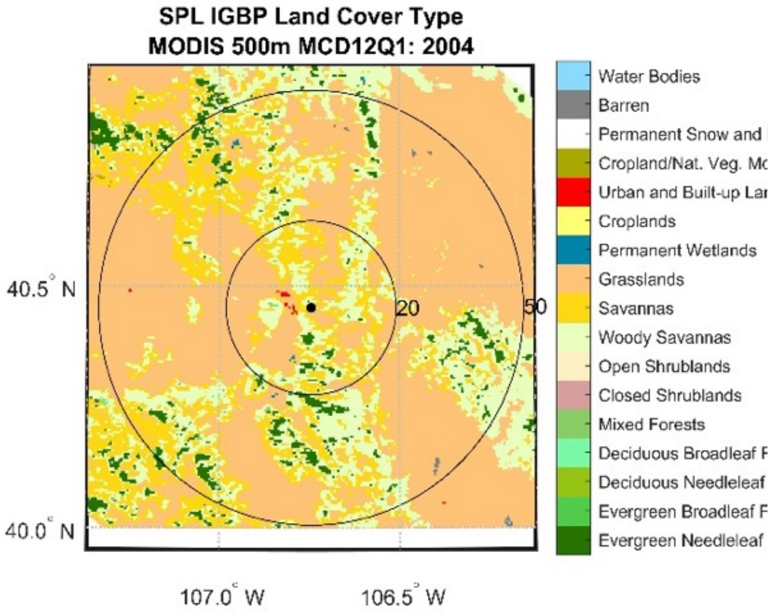


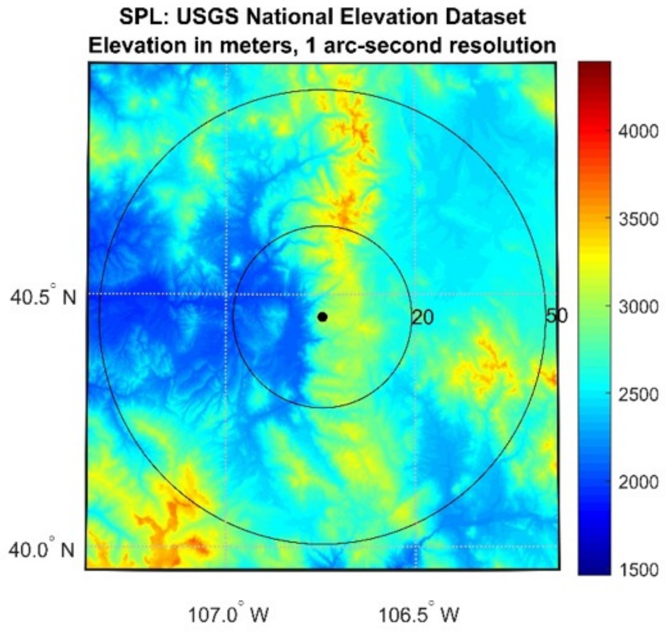


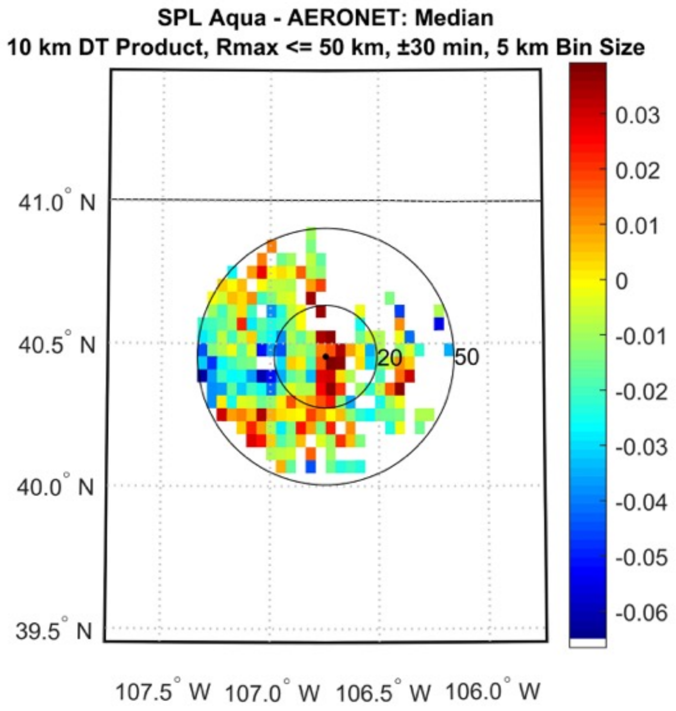


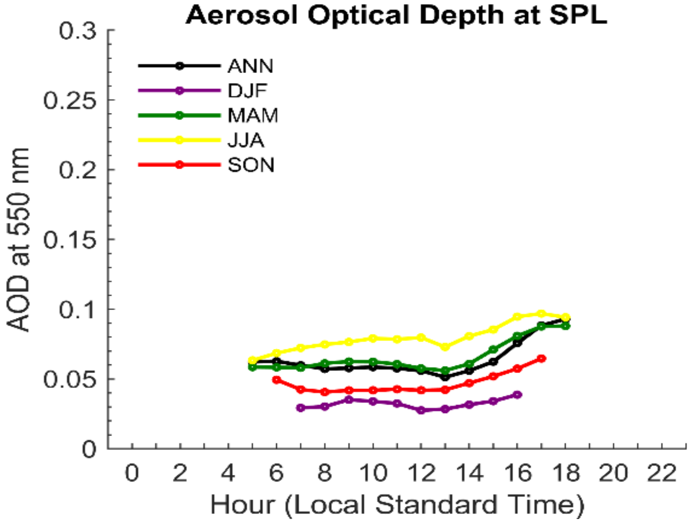


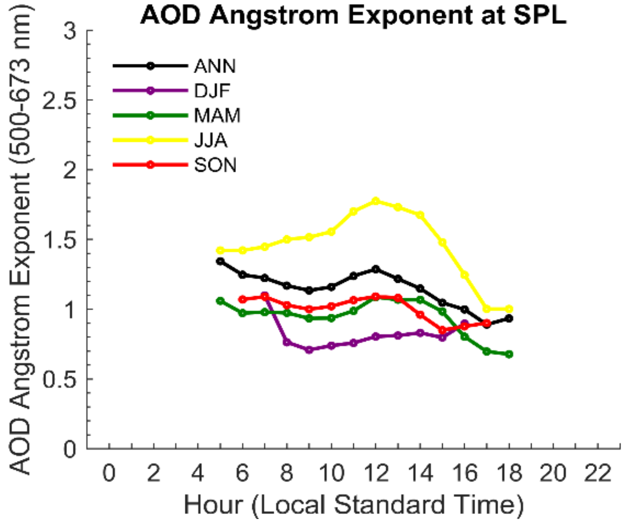
Variability of Aerosol and Surface Properties at Storm Peak Lab (SPL)



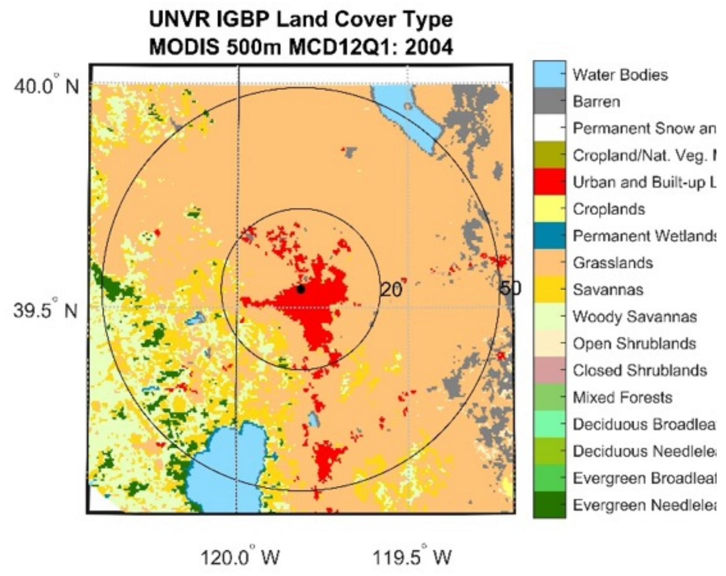


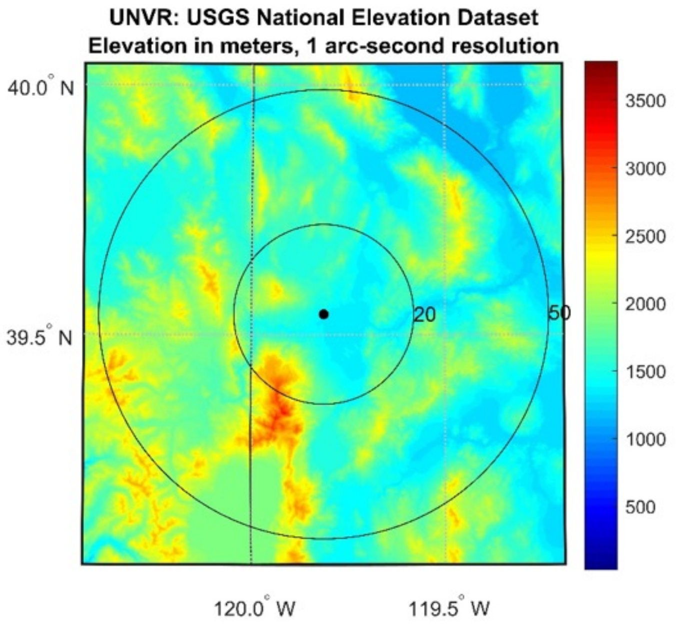


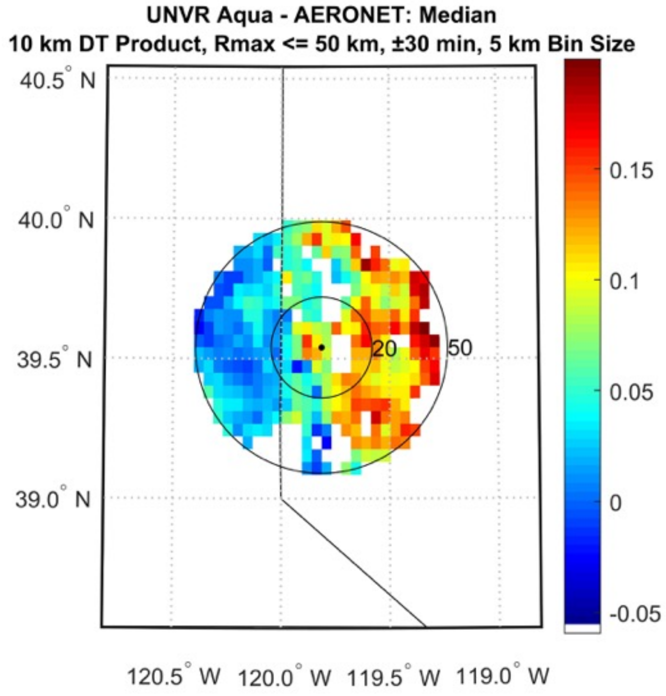


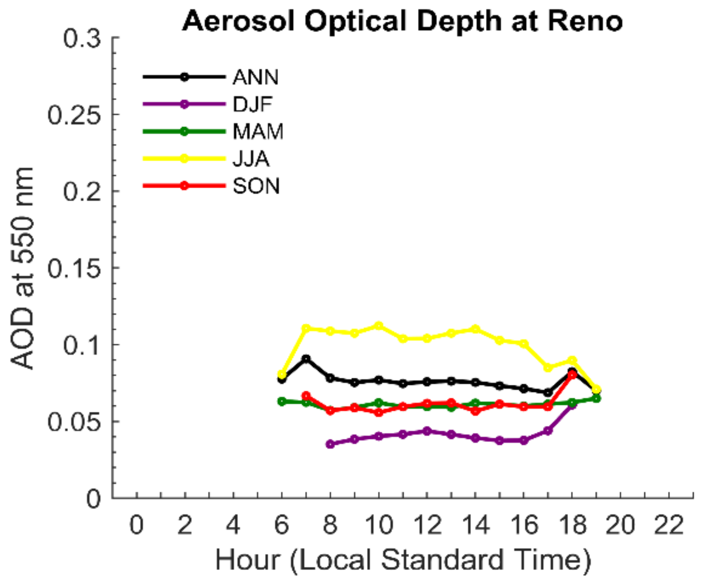


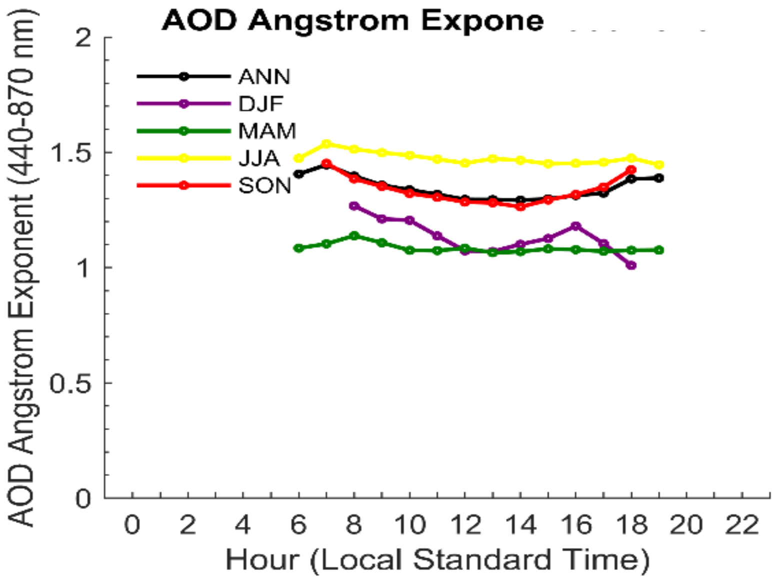
Variability of Aerosol and Surface Properties at Nevada-Reno (Reno)





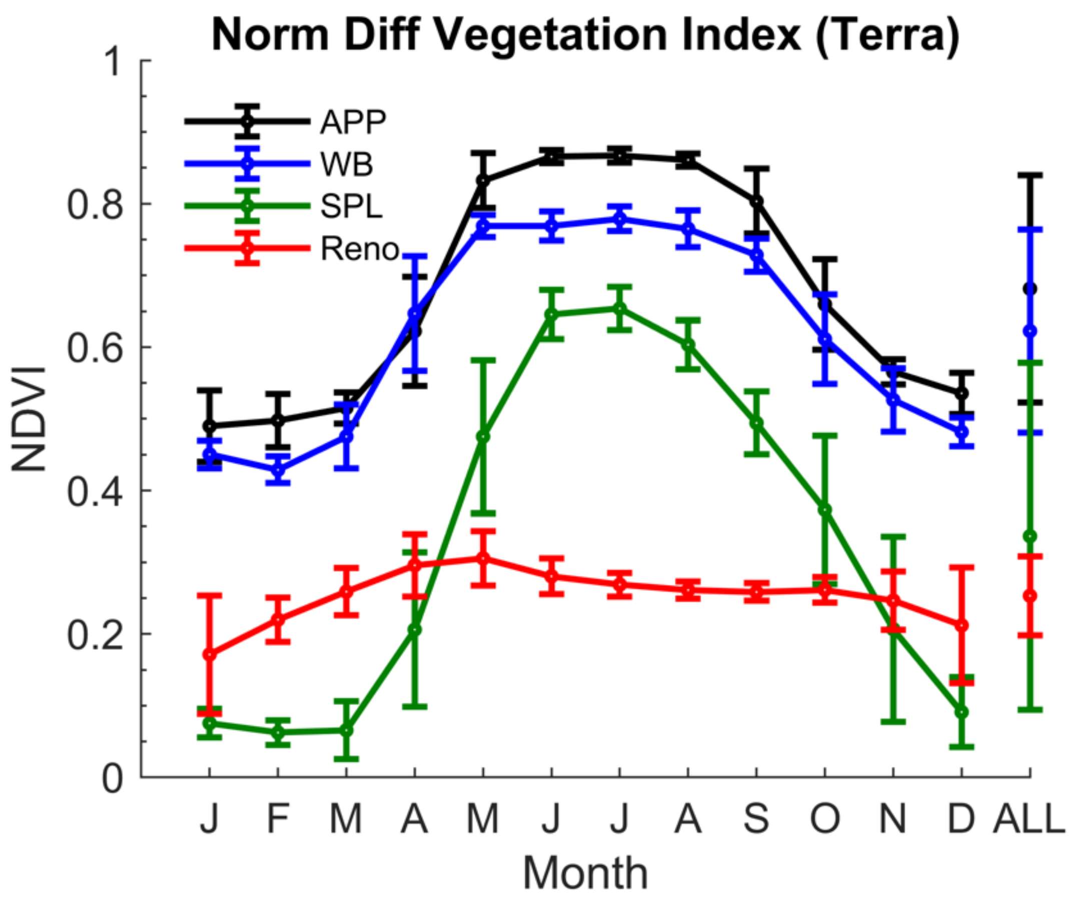






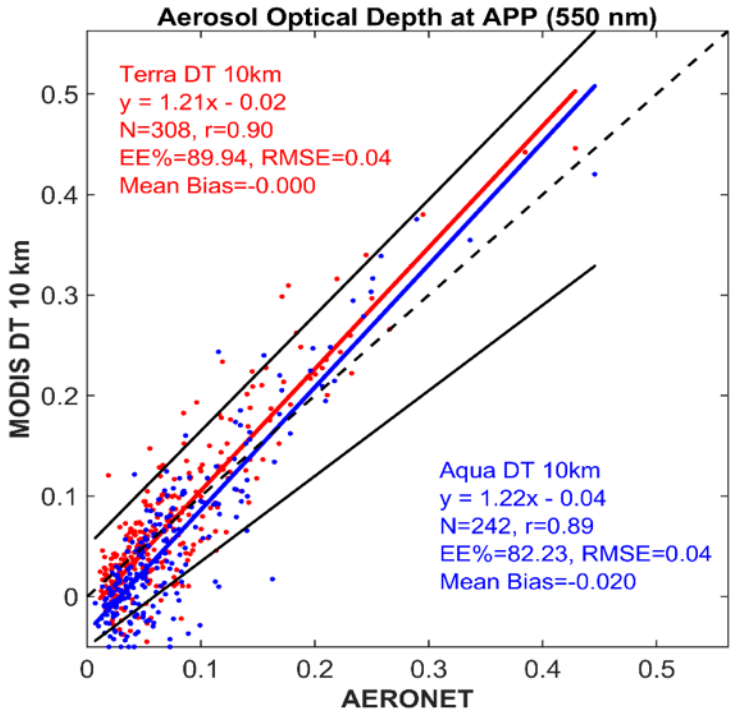
Annual cycle of Normalized Differential Vegetation Index (NDVI) at all sites

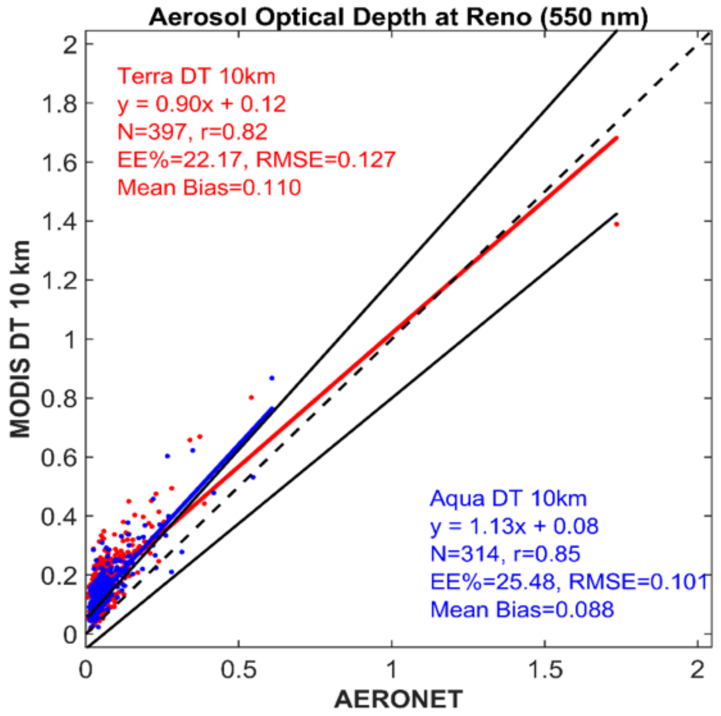
- NDVI is calculated as the ratio of difference divided by sum of two MODIS IR bands (typically 1.64 µm and 1.24µm
- NDVI values of >0.60 indicate dense, dark, green vegetation while those below ~0.20-0.30 indicate dormant or sparse vegetation
- MODIS DT algorithm (DB algorithm) should perform better at for sites/seasons with higher NDVI values (lower NDVI values)



Determining choice of optimal spatial and temporal windows and their sensitivity

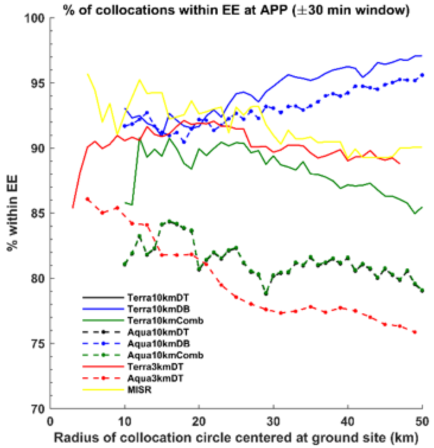
- Once preliminary understanding of spatial aerosol and surface variability and temporal aerosol variability is obtained, linear regressions of spatially-averaged satellite AOD versus temporally-averaged sunphotometer AOD are performed for various spatial and temporal windows to determine the optimal choices
- Examples of spatial window optimization for MODIS Dark Target 10km AOD validation provided below (at 1 hour temporal window)

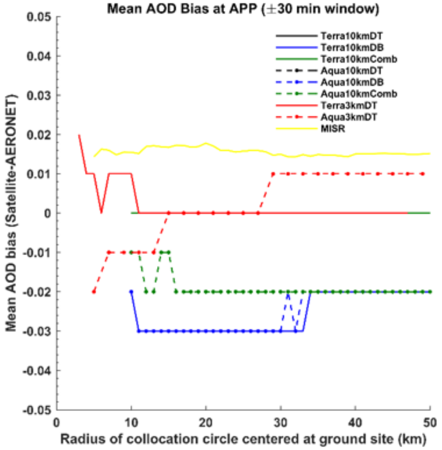




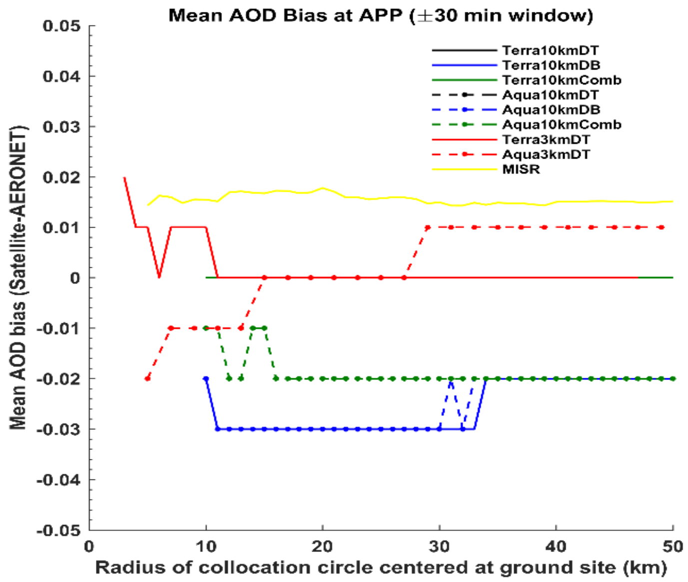
Sample of Results

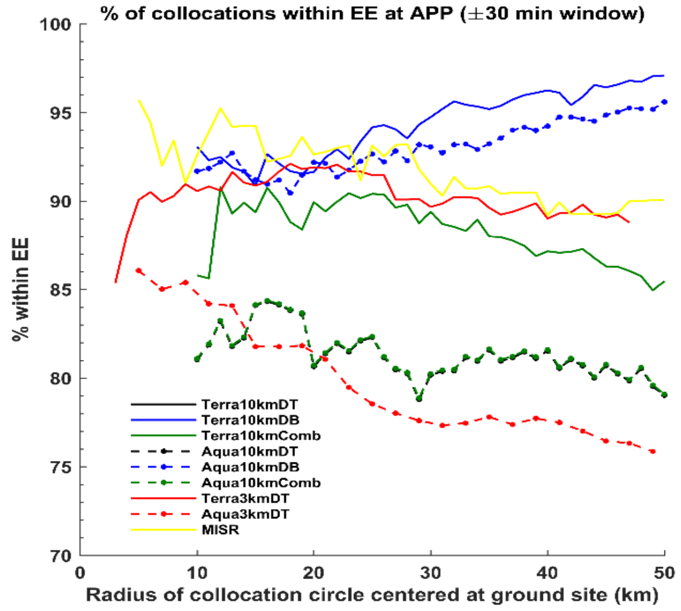
- Statistical parameters from regressions were next plotted as function of spatial window radius (for various time windows) to determine the optimal spatio-temporal window
- For most satellite sensors/ground sites, there was a very weak dependence of satellite/sunphotometer AOD agreement on temporal window. In general, a 1 hour window centered on satellite overpass time yielded best satellite-sunphotometer AOD agreement.
- Dependence of spatial window on the statistical parameters from satellite/sunphotometer collocations was in general fairly weak, although there were some exceptions (ex: MISR). In general, the use of a ~12 km radius (centered at ground site) yielded best results for the higher spatial resolution products (ex: MISR, MODIS 3k)
- MISR and MODIS Terra DT products yielded better agreement with sunphotometers than MODIS Aqua products (which yielded small negative offsets) .
- MODIS Aqua AOD tended to be ~0.02-0.03 less than Terra AOD, consistent with other studies (Gupta et al., 2018)
- MODIS DT algorithm outperformed DB at all sites except Reno, which is not surprising given the brighter, less vegetative terrain at Reno.
- MODIS DB 10km product significantly underestimated AOD for all but the lowest AOD values (< 0.05) at APP, SPL

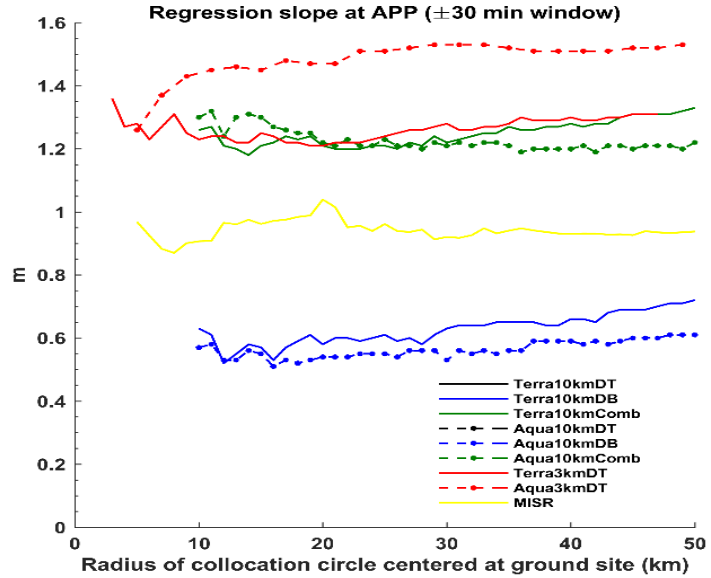


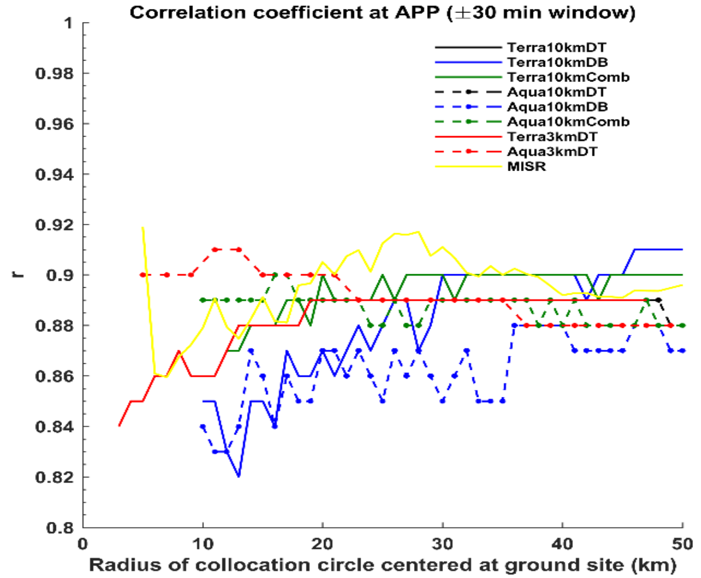


Spatio-temporal window optimization at APP

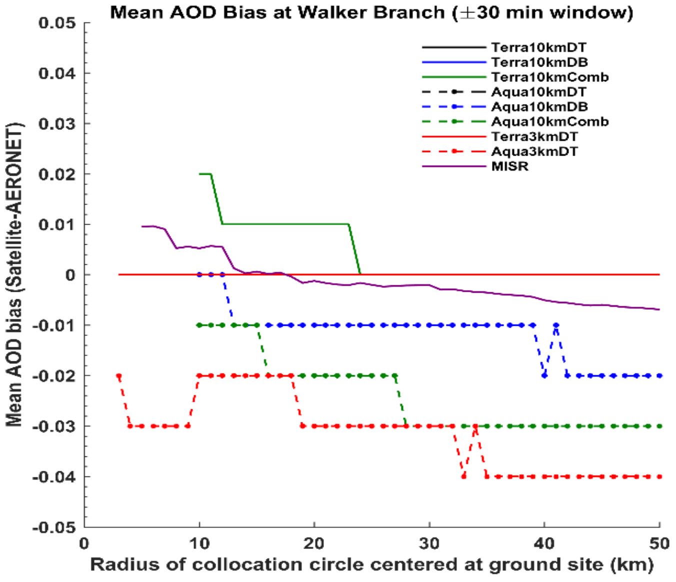


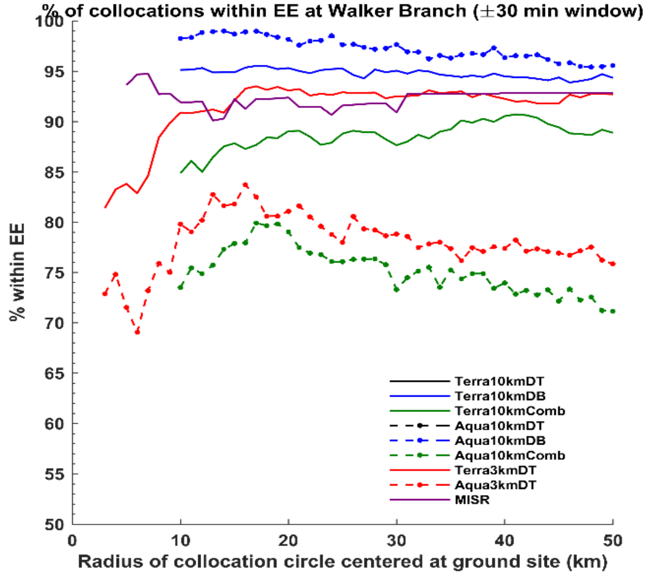


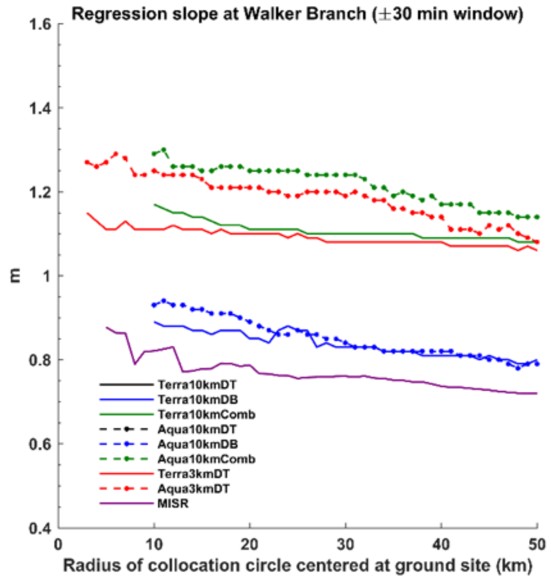


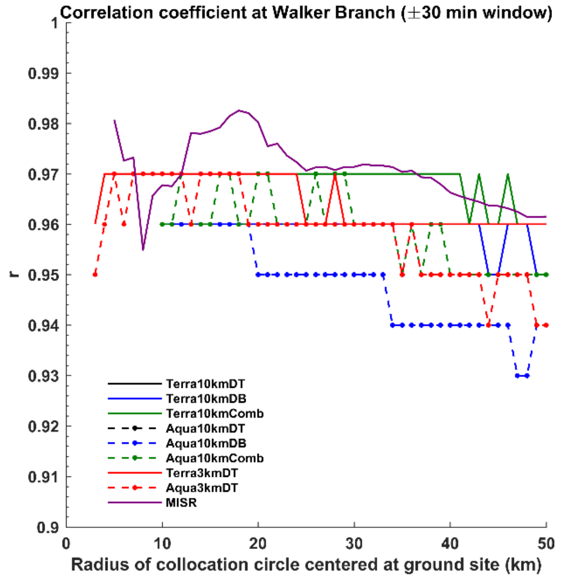


Spatio-temporal window optimization at WB

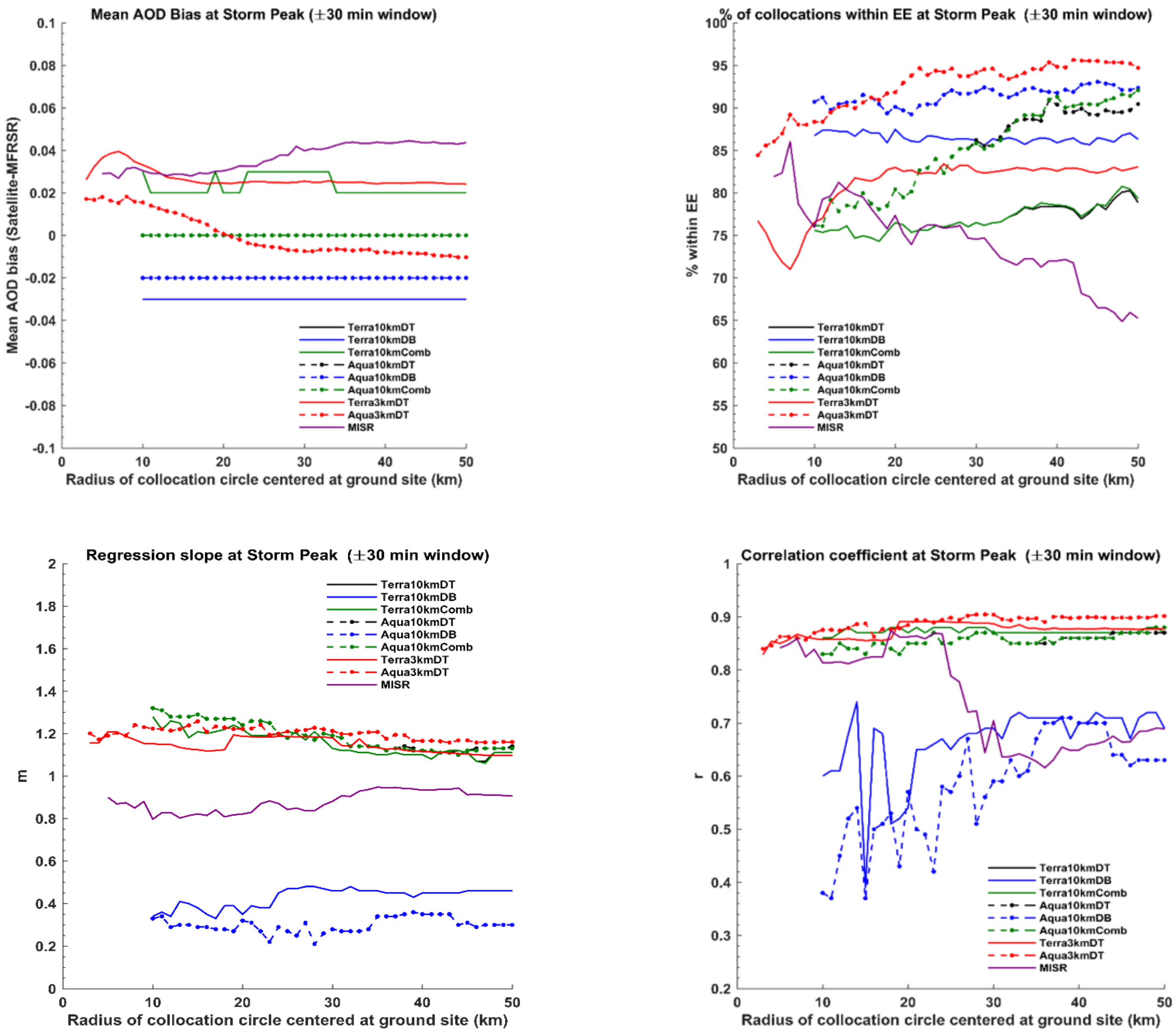




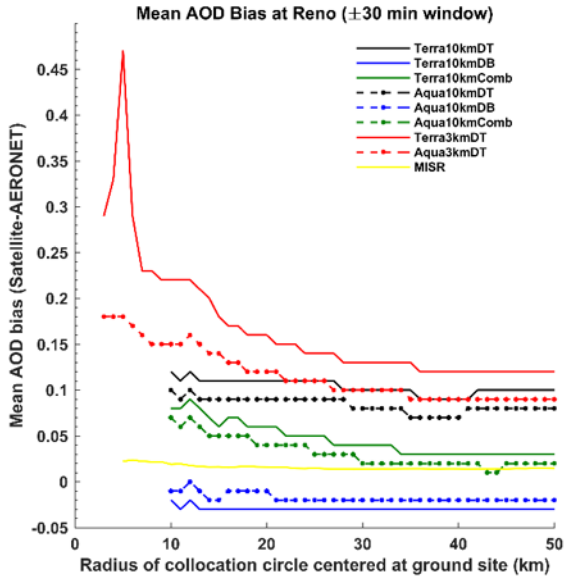


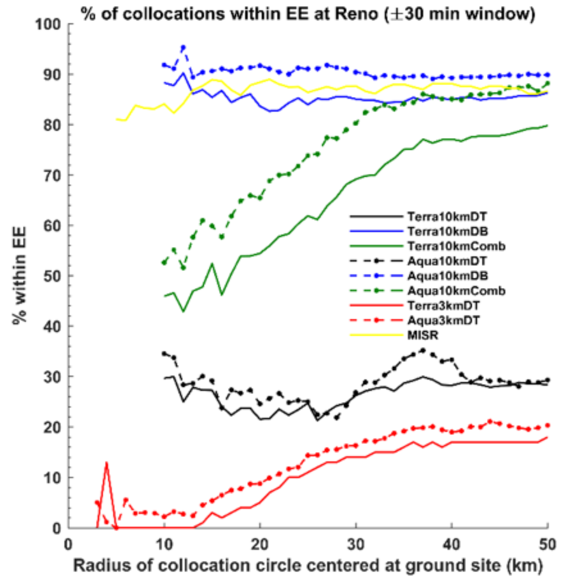


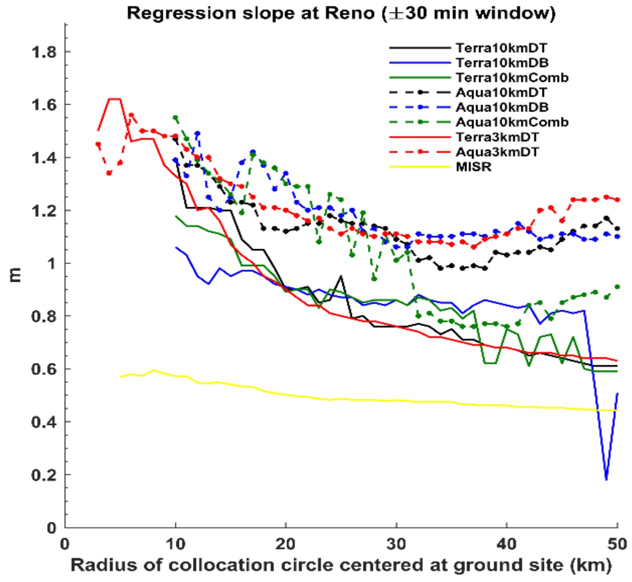
Spatio-temporal window optimization at SPL

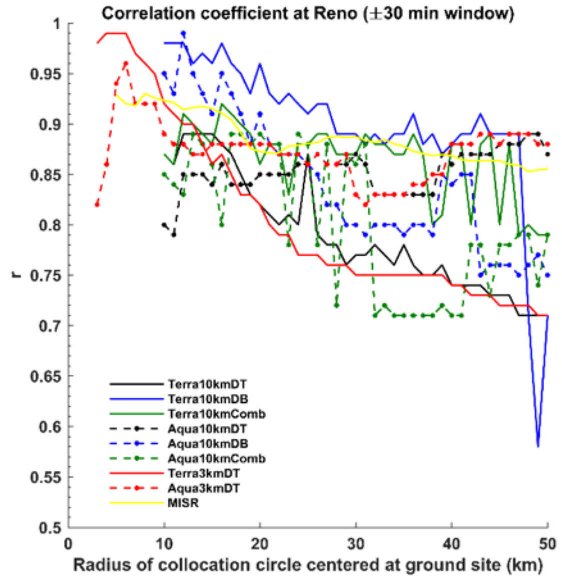


Spatio-temporal window optimization at Reno

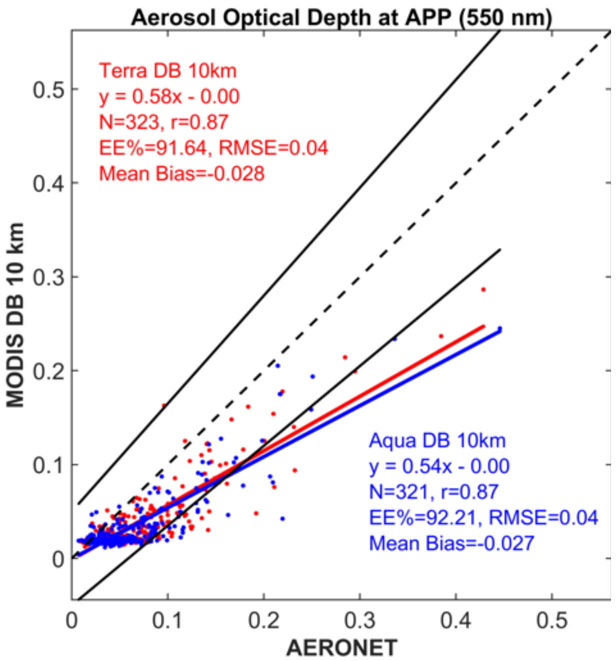


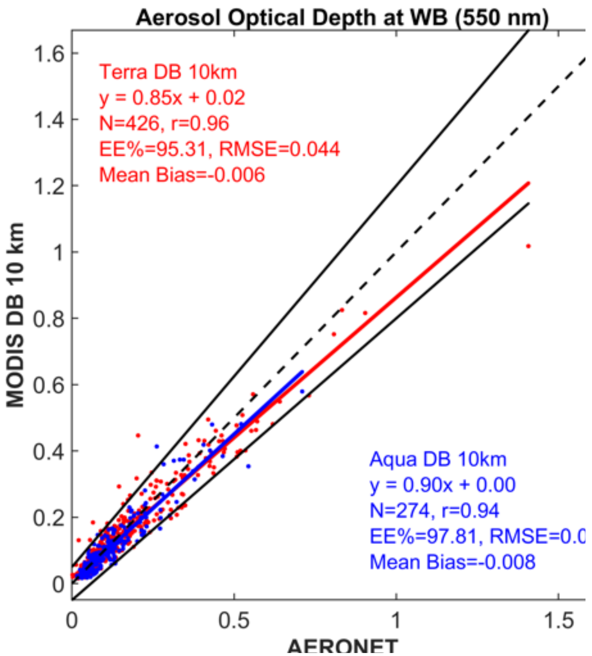


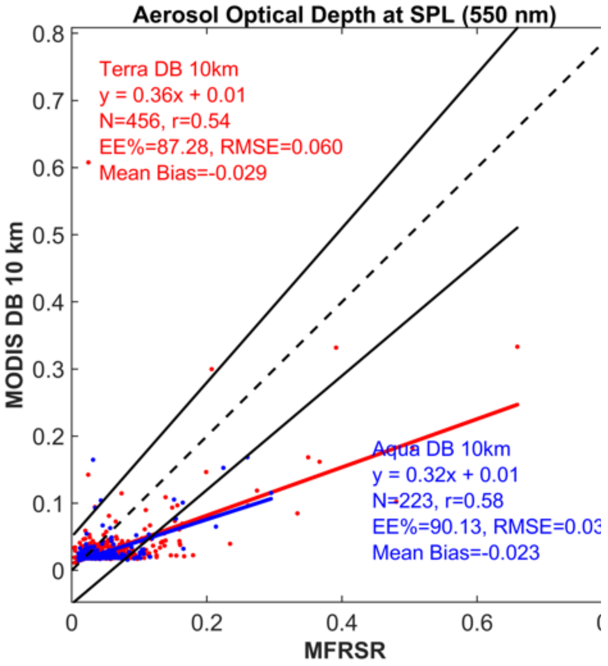


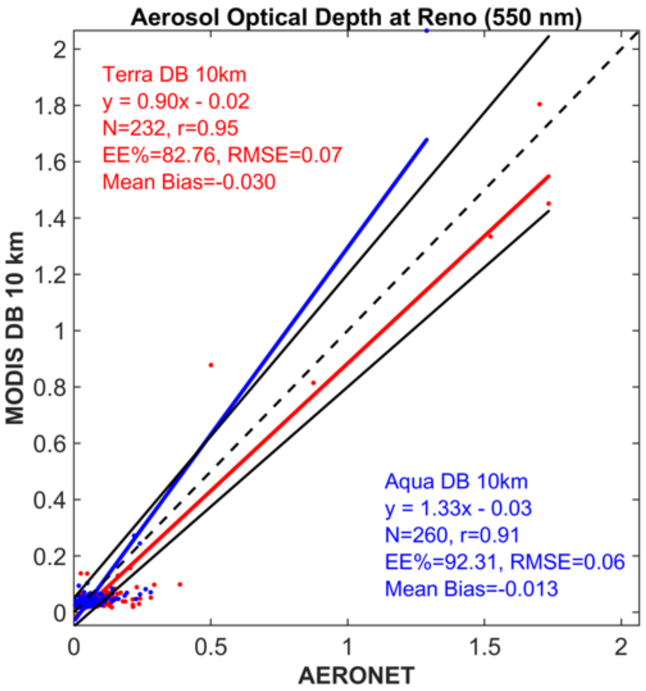


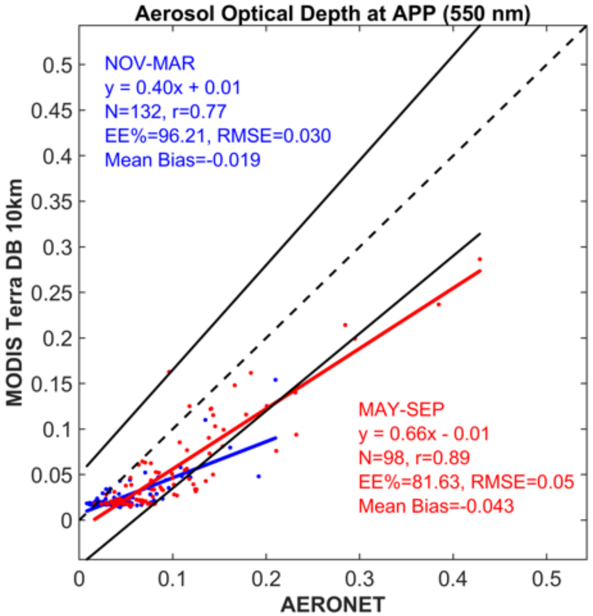
MODIS DB AOD underestimation for higher AOD (except at WB)

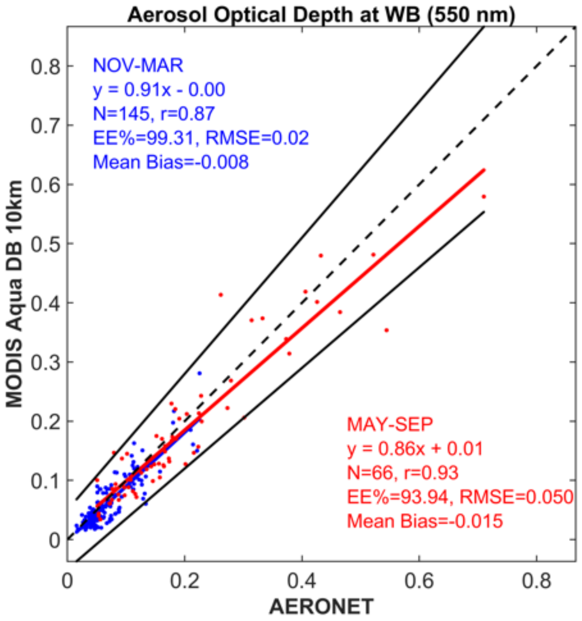


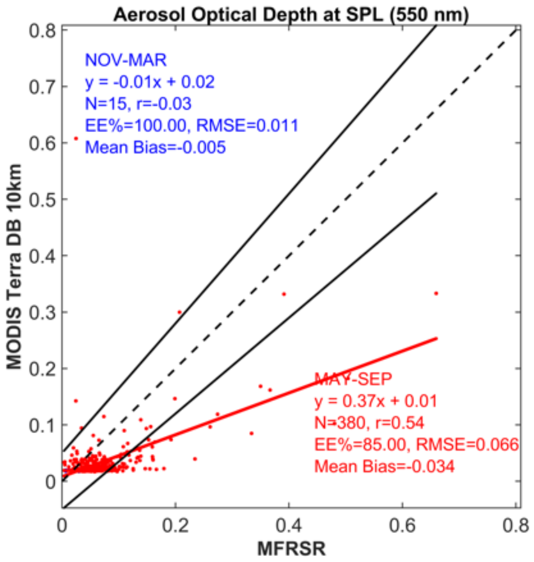


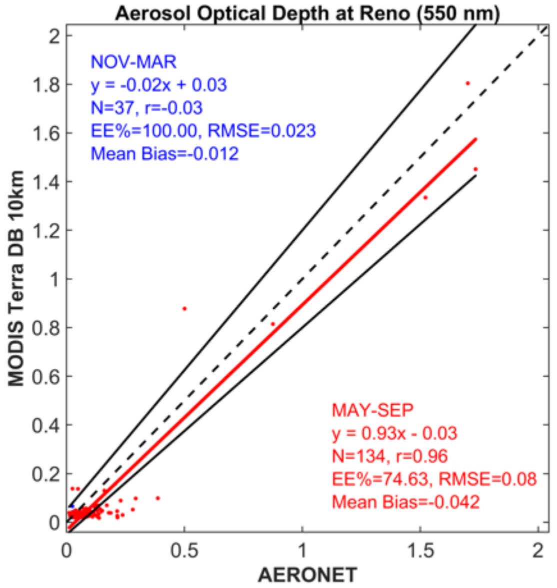












Acknowledgements

- Appalachian State University (APP) Graduate Research Assistantship Mentoring fellowship (funding for Ian Krintz)
- APP MS student Hunter Suthers
- APP College of Arts and Sciences electronic technician Michael Hughes and machinist Dana Greene, for help with APP facilities establishment and infrastructure
- Robert Levy and Pawan Gupta of NASA GSFC MODIS Science Team, for helpful comments and insights