Aerosol effects on cloud cover as determined by ground- and space-based sensors

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The problem

- The effect of aerosols on the extent of clouds (2nd indirect effect) remains one of the largest uncertainties in climate science

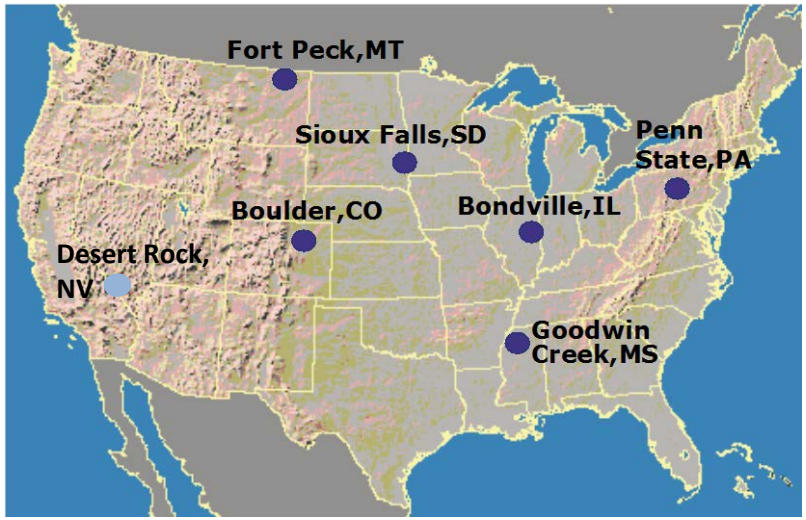
- From satellites, the detection of the collective impact of the microphysical and dynamical effects of aerosols on the macroscopic properties of clouds is possible, but…

- Neither satellites nor models can resolve the microphysical processes that contribute to the cloud fraction - aerosol optical depth (f_c-AOD) relationship

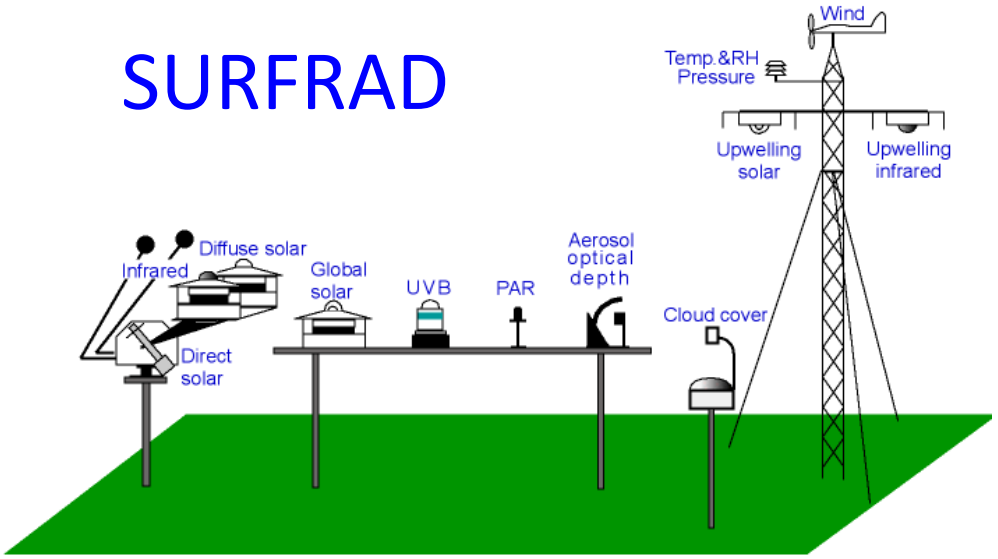
- Many studies have shown an increase in cloud fraction with AOD, particularly for AOD < 0.3 *(beyond 0.3 AOD, the effect of AOD on cloud fraction approaches 0)*
- However, part of that relationship could be from confounding effects:
  - ✓ Scattered radiation off of the sides of clouds
  - ✓ Aerosol humidification in the cloud's environment
  - ✓ Cloud contamination in the AOD retrievals
  - ✓ Vertical overlap of aerosols and clouds
  - ✓ Meteorological covariation
- It is difficult to separate out these effects with satellite data alone
- We believe that surface measurements are better poised to remove some of the confounding effects

We approached the 2nd indirect effect from the top and bottom

MODIS level 2 AOD and cloud fraction data



SURFRAD

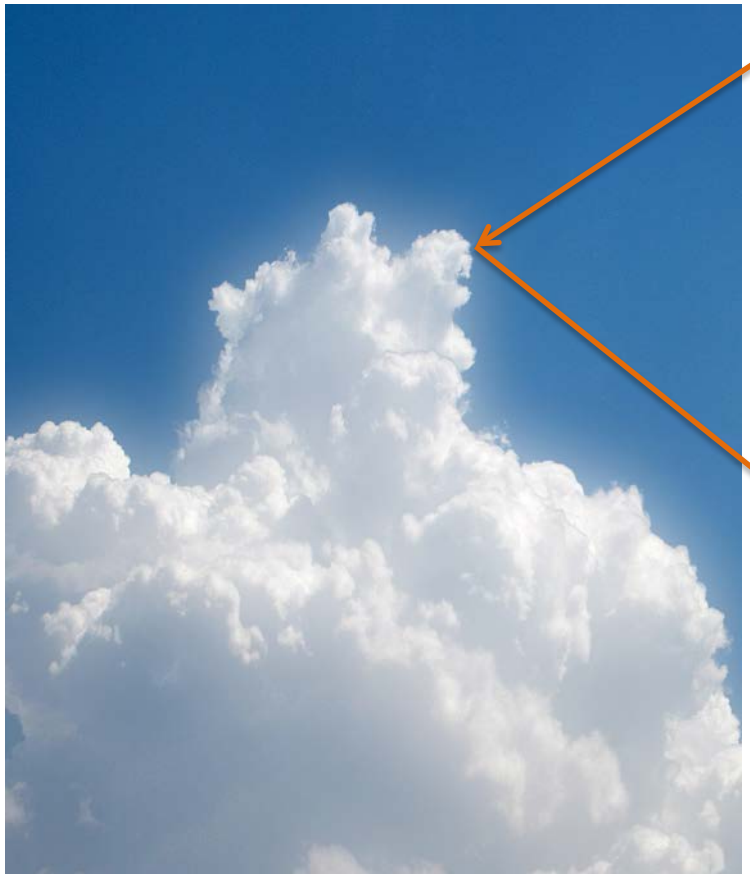


Data

- 2006 through 2011
- MODIS 10-km resolution 550-nm AOD retrievals over a 50 km^2 area centered on each SURFRAD site
- MODIS 5-km cloud fraction retrievals averaged over each 10-km AOD pixel
- SURFRAD cloud screened 500-nm AOD, interpolated to 550-nm using the Angstrom relationship, and cloud fraction from the Total Sky Imager
- AOD was restricted to values < 0.3, and only opaque cloud fractions were considered

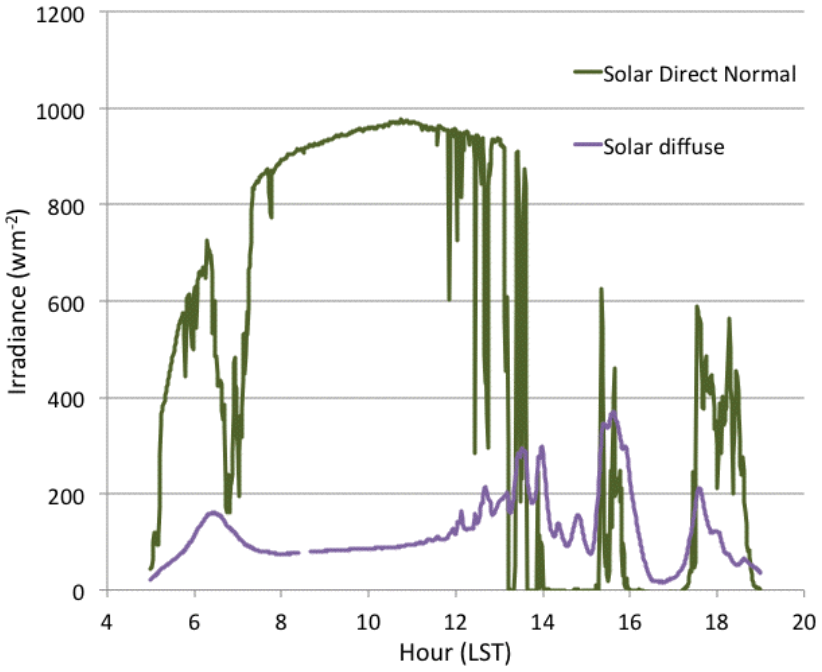
Sun photometer measurements are sensitive to the transition zone near cloud edges

- Aerosols swell near cloud edges due to humidification
- There can be 3-D effects from scattered photons off of the sides of clouds

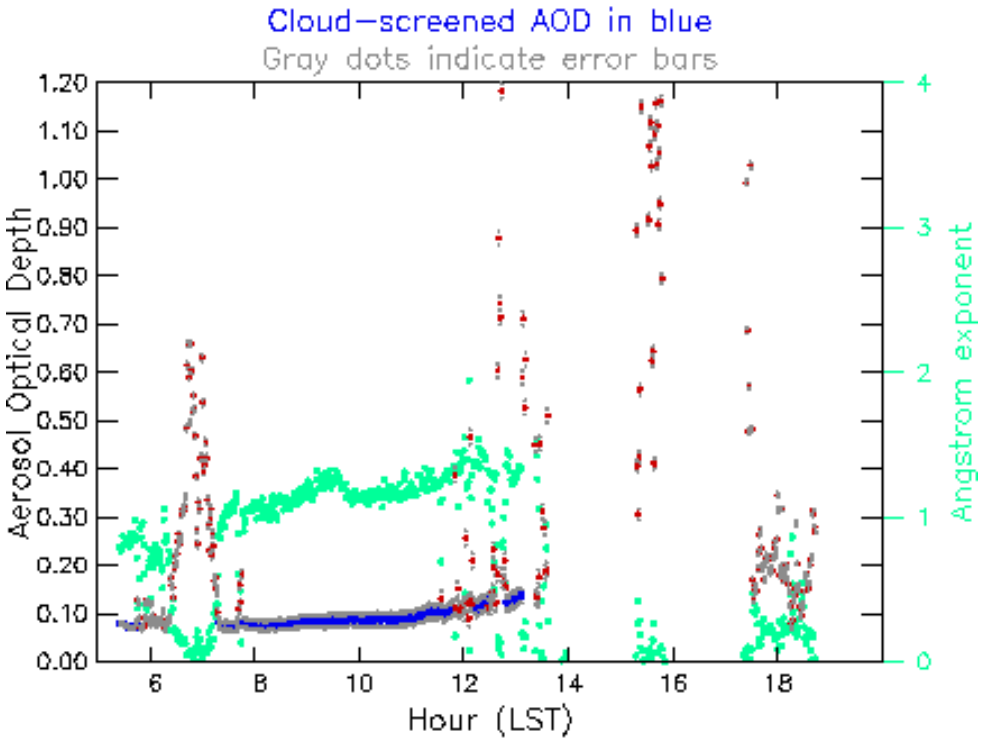


Aerosol Optical Depth Cloud screening

Table Mountain SURFRAD 26 June 2014

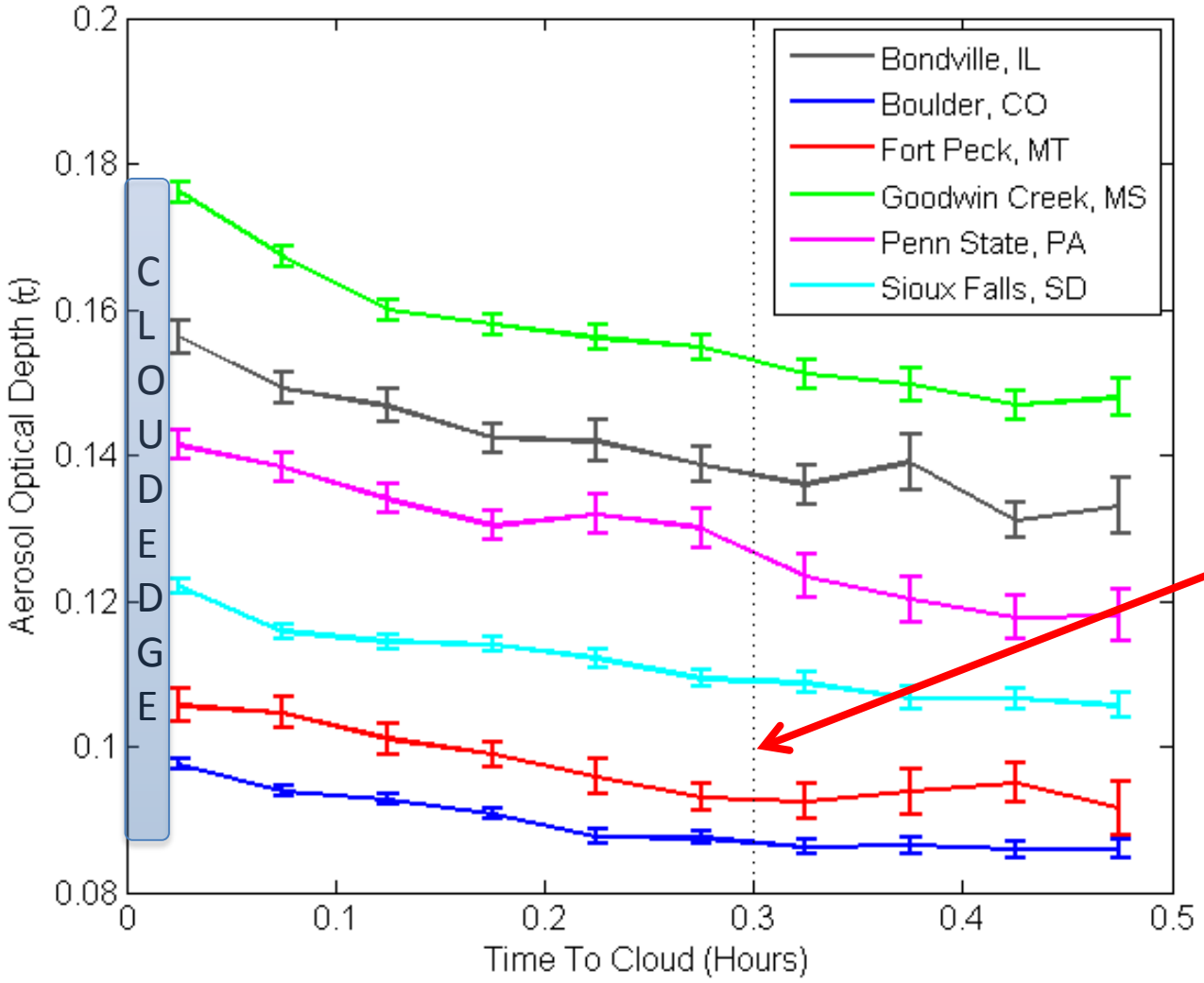


SURFRAD solar measurements



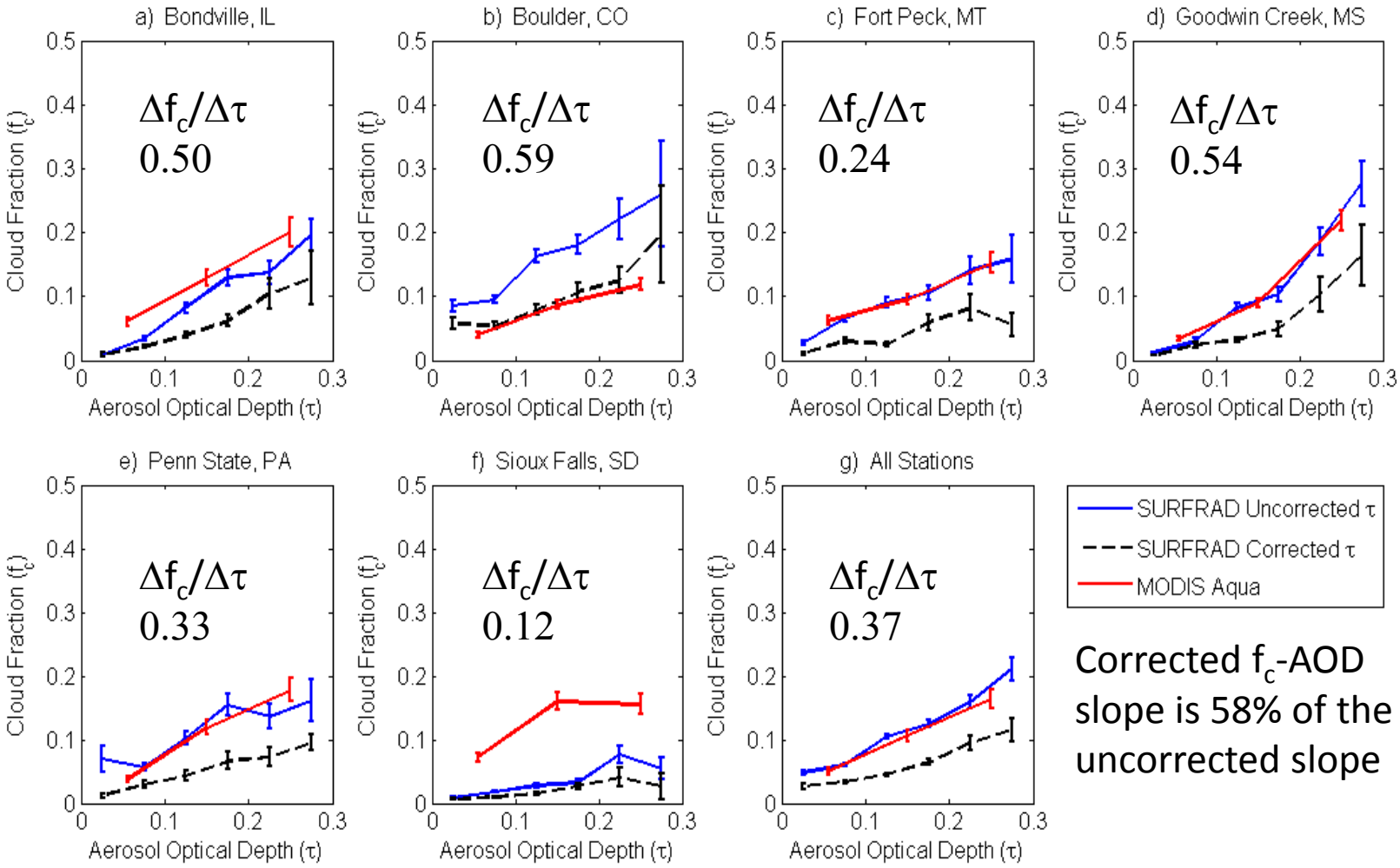
500-nm Aerosol optical depth

Composite AOD sorted by “time-to-cloud” for all SURFRAD sites considered (2006-2011)



6%-11% AOD enhancement near cloud

Quantification of the 2nd indirect effect



Corrected f_c-AOD slope is 58% of the uncorrected slope

Quantification of aerosol forcing at the surface

Data used: AOD < 0.3 and corrected for near-cloud effects

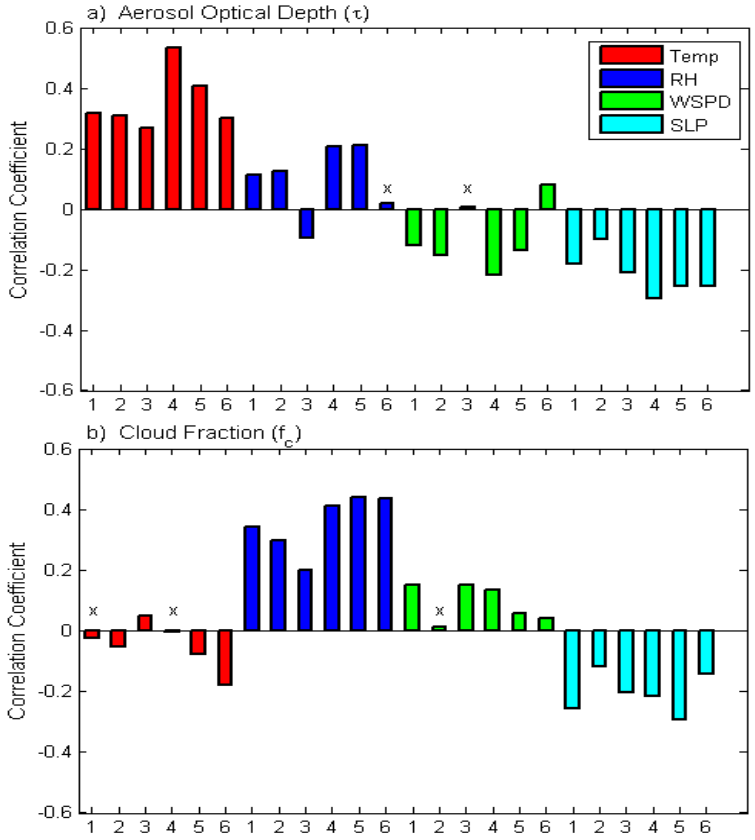
Solar zenith angle	Net solar radiative forcing (W/m^2)	Net Total solar+IR radiative forcing (W/m^2)
15° - 25°	-67	-30
25° - 35°	-53	-17
35° - 45°	-48	-11
45° - 55°	-52	-20
55° - 65°	-38	-10
65° - 75°	-47	-19
75° - 85°	-14	+7
Weighted average over all solar zenith angles	**-51**	**-19**

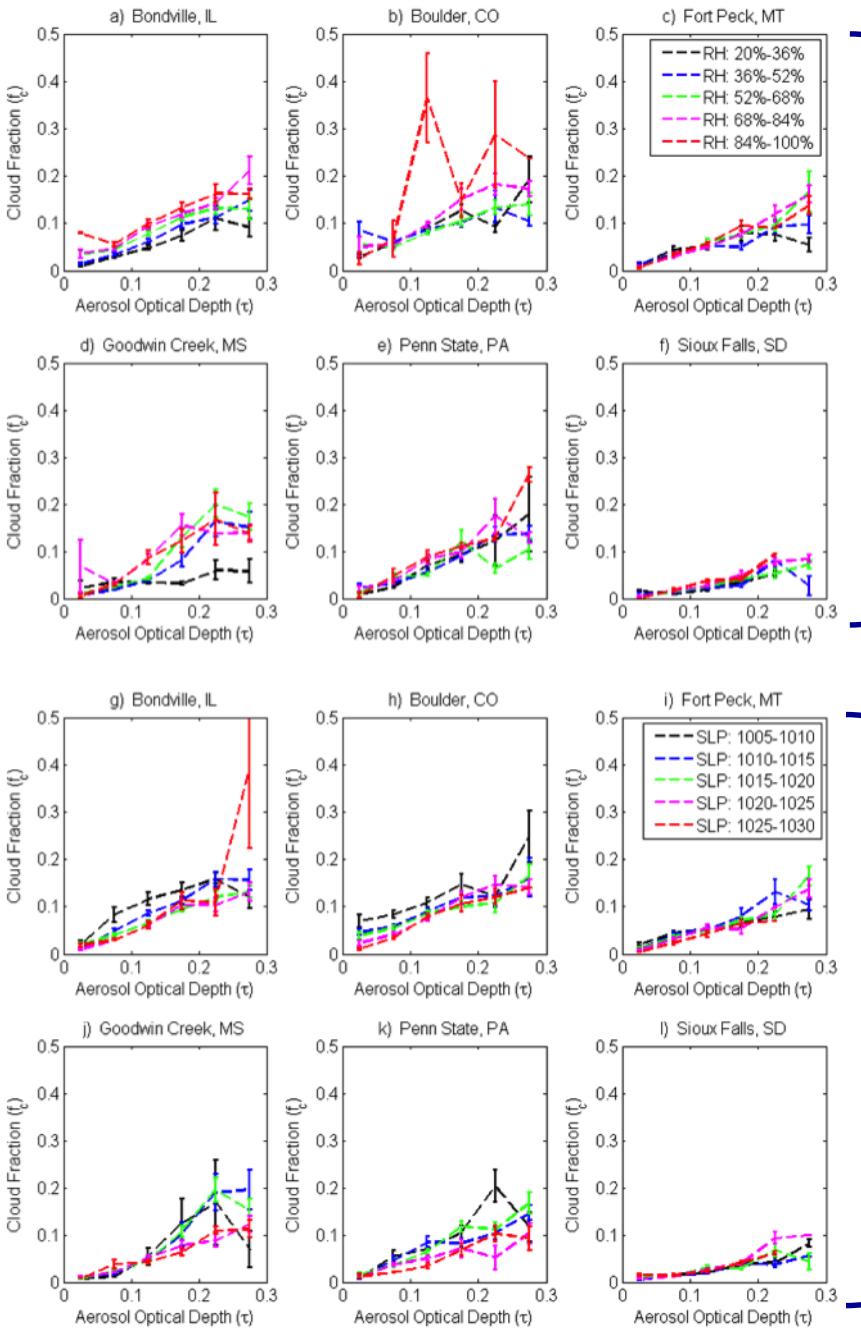
Summary

- All stations show cloud fraction increasing with AOD: $\Delta f_c/\Delta\tau$ ranges from 0.12 to 0.59, mean 0.37 (AOD < 0.3)
- The cloud fraction-AOD relationship is ~42% greater when confounding effects in AOD retrievals are not removed.
- Satellite data gives the same result as cloud-contaminated AODs, therefore satellite-based studies may overestimate the magnitude of the 2nd indirect effect by ~42%
- On average, aerosols over the U.S. reduce surface net solar radiation by 51 Wm^{-2} and surface total net radiation by 19 Wm^{-2}, and therefore have an overall cooling effect

Meteorological covariation

Tested: Air temperature
Wind speed
Relative humidity
Sea level pressure





Composite Angstrom exponent sorted by "time-to-cloud"