

Climatology of aerosol and cloud properties at the ARM sites:

MFRSR combined with other measurements

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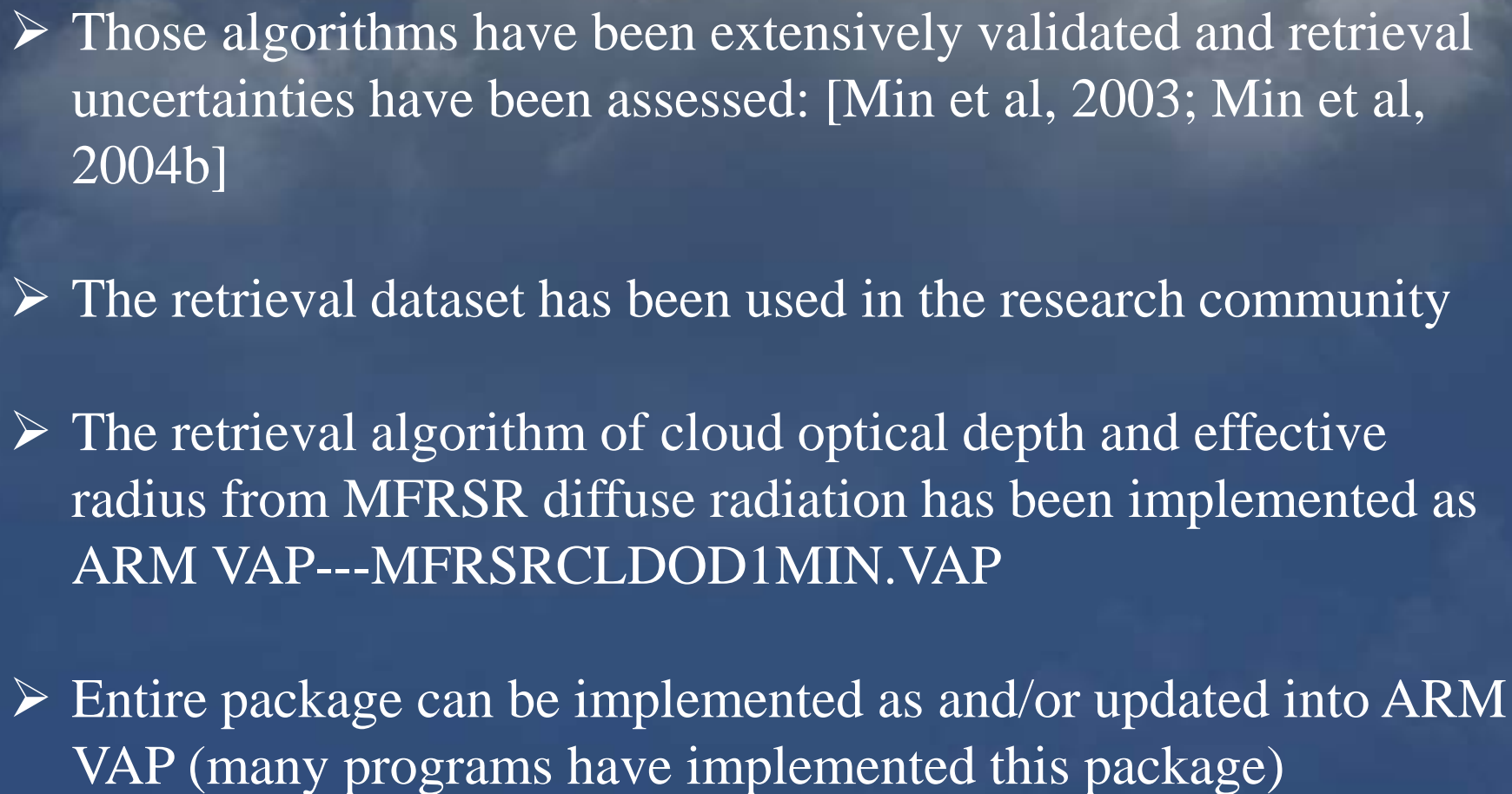
MFRSR:

- Spectral irradiances at 6 six wavelength passbands: 415, 500, 610, 665, 862, and 940nm
- Simultaneously measures direct and diffuse irradiances
- Self-calibration (1% accuracy)
- Deployed at all ARM sites and AMF field campaigns



Applications and retrievals

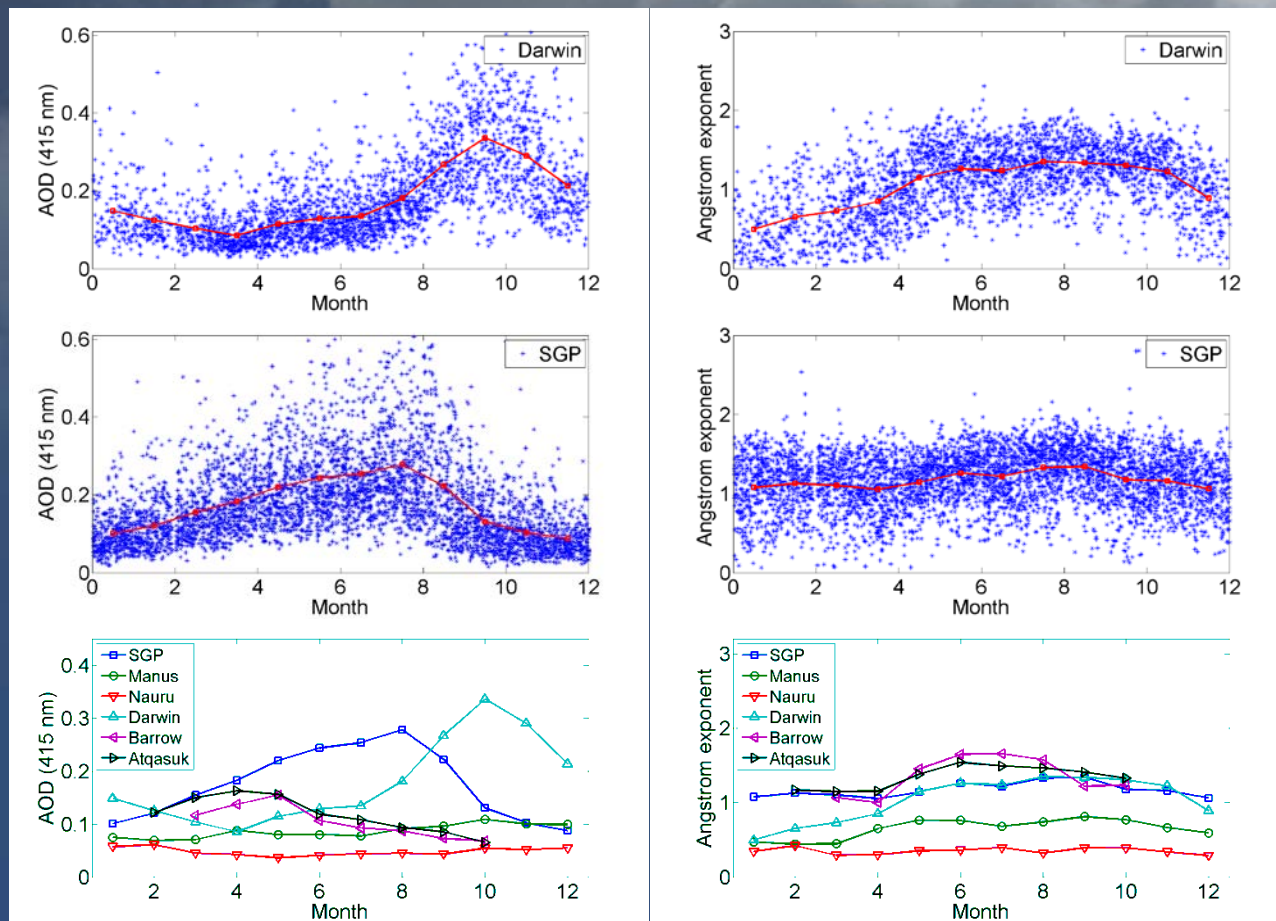
- Radiation:
 - ✓ diffuse/direct
 - ✓ synthesis PAR [Min 2005]
- Monitoring aerosols:
 - ✓ Aerosol optical depth [Min et al, 2004a]
 - ✓ Angstrom coefficients [Min et al, 2004a]
 - ✓ Single scattering albedo (SSA) [Yin et al, 2012]
- Monitoring clouds:
 - ✓ **Optical depth (5 and up) and effective radius from diffuse [Min and Harrison, 1996; Min et al, 2003]**
 - ✓ Optical depths of aerosols and thin clouds (0 ~ 7) from direct beam [Min et al, 2004a; Min et al, 2004b]
 - ✓ Cloud phase for thin clouds [Wang and Min 2008]
 - ✓ Cloud fraction [Min et al. 2008]

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- Those algorithms have been extensively validated and retrieval uncertainties have been assessed: [Min et al, 2003; Min et al, 2004b]
 - The retrieval dataset has been used in the research community
 - The retrieval algorithm of cloud optical depth and effective radius from MFRSR diffuse radiation has been implemented as ARM VAP---MFRSRCLDOD1MIN.VAP
 - Entire package can be implemented as and/or updated into ARM VAP (many programs have implemented this package)

Long-term MFRSR measurements, combined with other active and passive measurements, at the ARM SGP, TWP, and NSA sites have been processed and analyzed for the climatology of aerosol and cloud optical properties

Data	Instruments or Dataset
Radiance or Transmission	MFRSR
Aerosol optical depth Aerosol Angstrom coefficient	MFRSR ,AERONET
Aerosol extinction coefficients, Aerosol single-scattering albedo	AOS
Cloud optical depth Cloud Fraction Cloud effective radius	MFRSR & MWR
Liquid water path Water vapor path	MWR
Cloud top height, cloud bottom height, cloud thickness, cloud occurrence	ARSCL (MMCR, Lidar, Ceilometer)
Temperature, pressure, relative humidity, surface wind speed , wind direction	MET (SMET)
Precipitation rate	Rain gauge
Surface broadband LW and SW Radiation	BRS
Southern Oscillation Index	Other

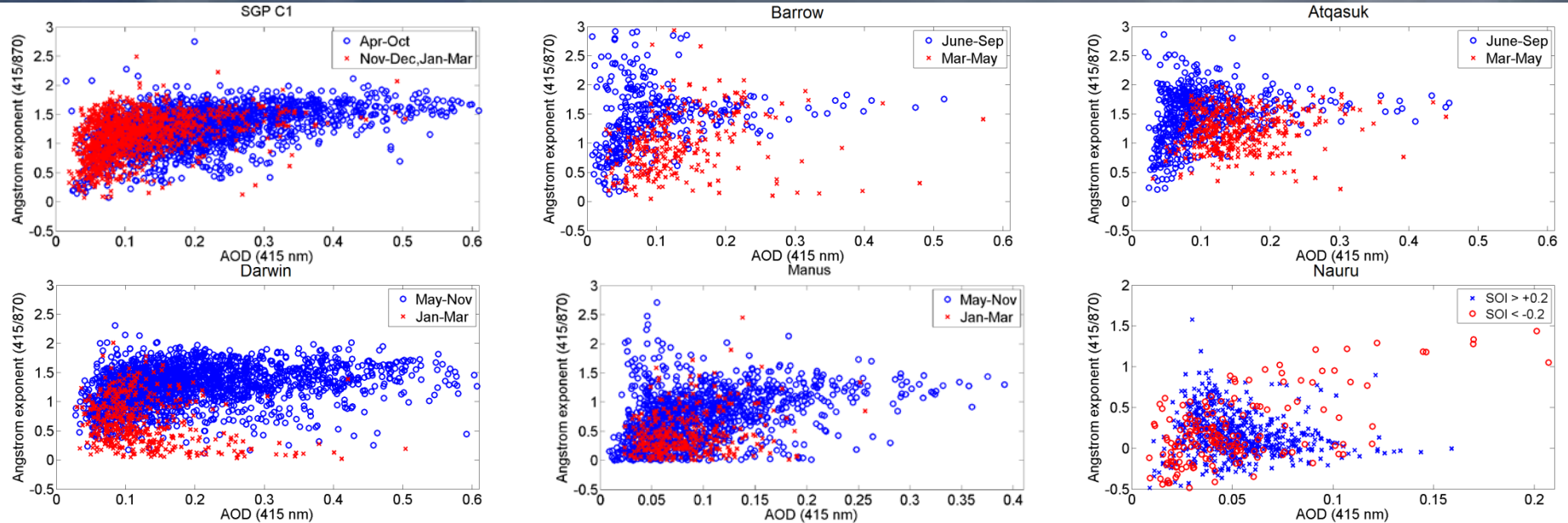
Seasonal variation of Aerosol properties



Darwin site: Biomass burning is dominant in May–Nov. (dry season and 2nd transitional season); Sea salt is substantial in Dec–Apr. (wet season and 1st transitional season).

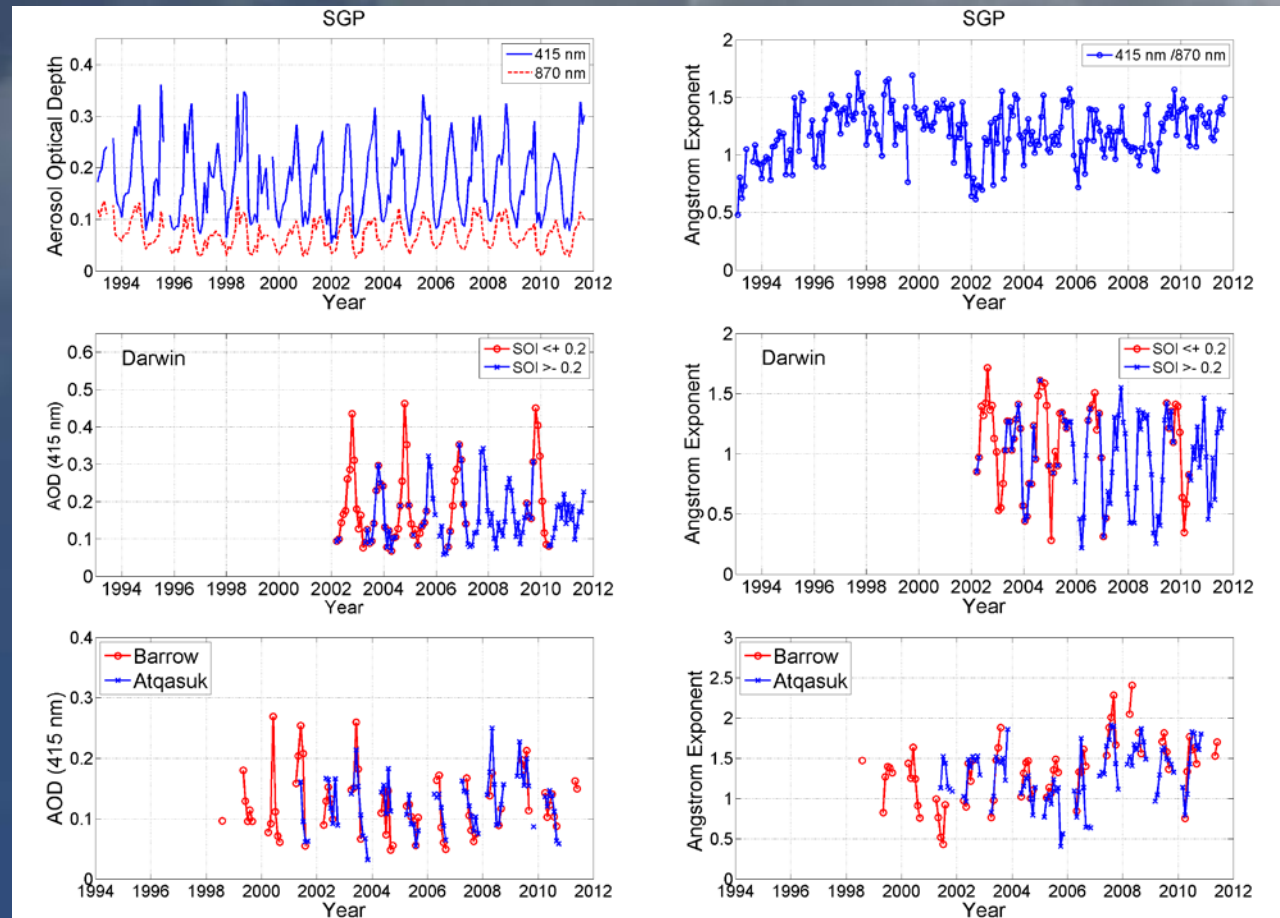
SGP site: Transported industrial pollutant is dominant; and also affected by farming activity.

AOD vs. Angstrom coefficient



Aerosol sources are different at different sites, varying with different seasons or SOI.

Interannual variation of Aerosol properties

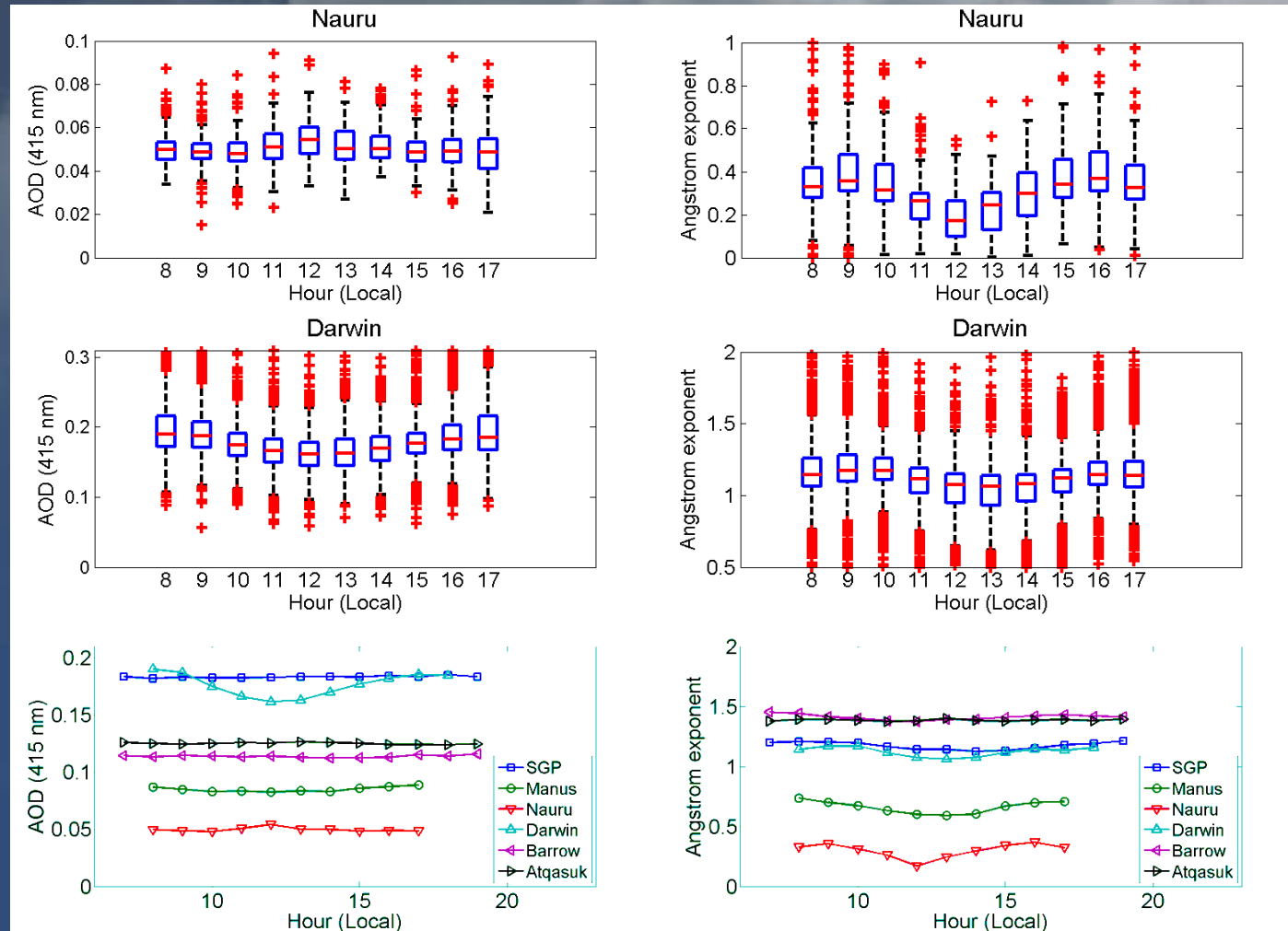


SGP Site: The influence of eruption of Mt. Pinatubo (1991) is significant in 1993~1996.

Darwin site: The influence of Southern Oscillation Index (SOI) is obvious.

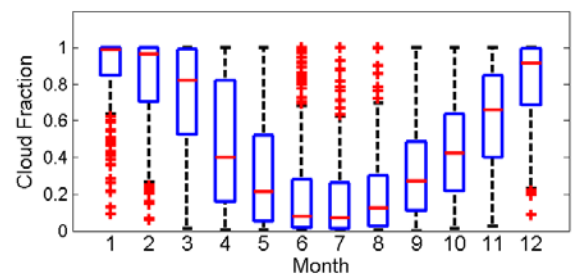
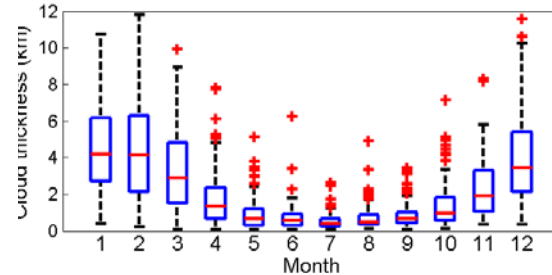
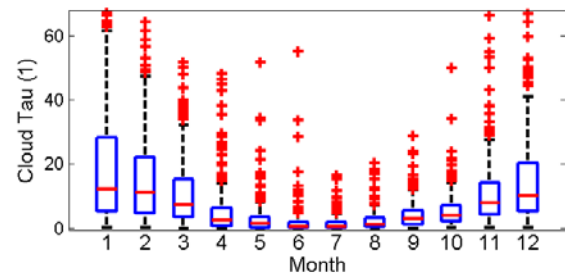
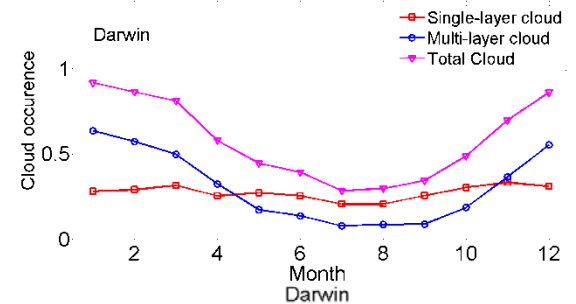
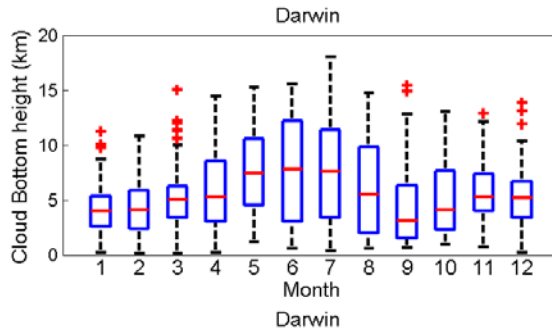
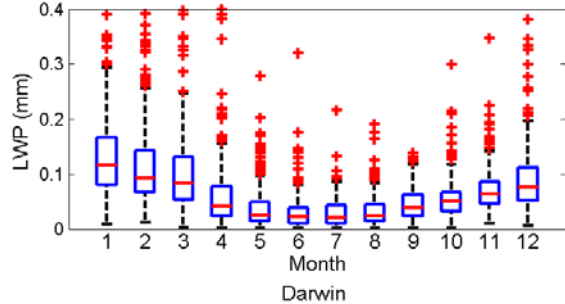
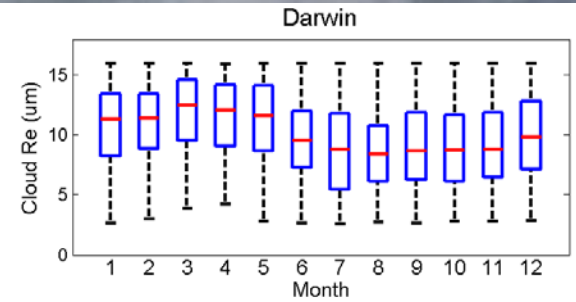
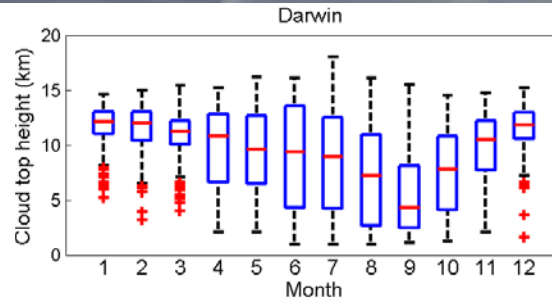
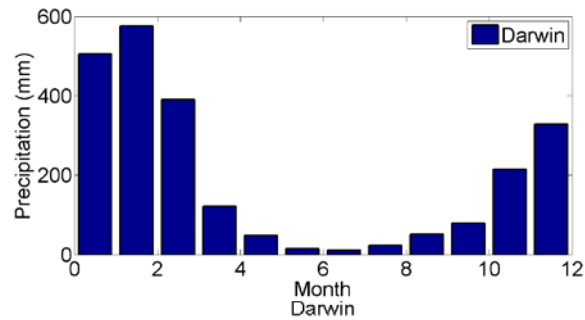
Barrow and Atqasuk: These adjacent sites share the similar significant interannual variation

Diurnal variation of aerosol properties



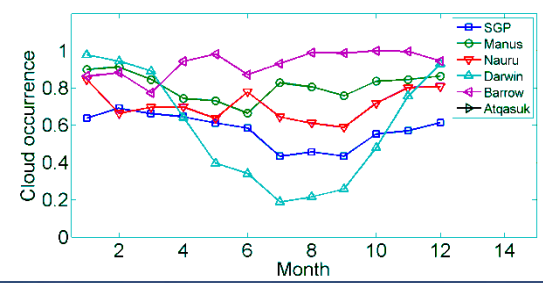
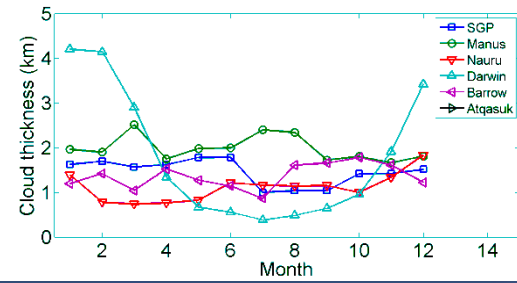
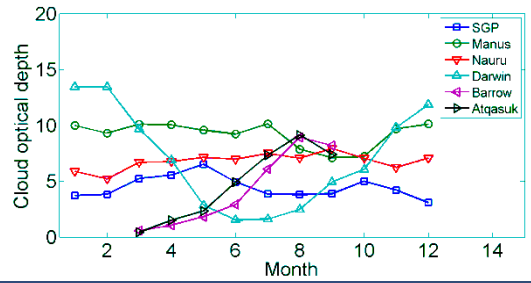
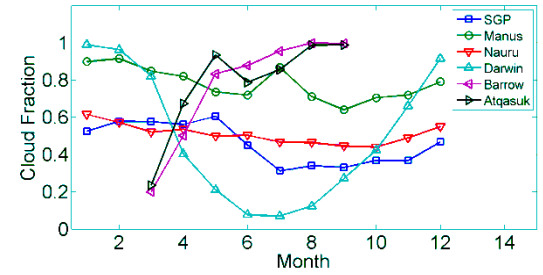
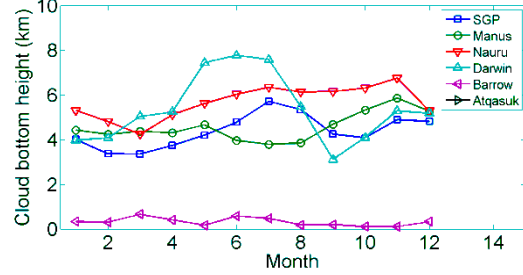
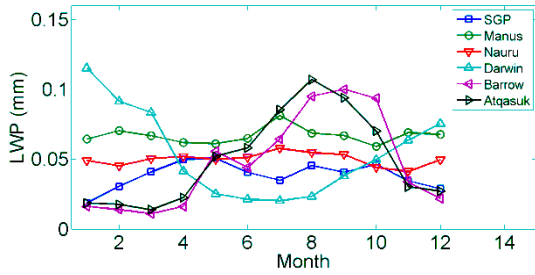
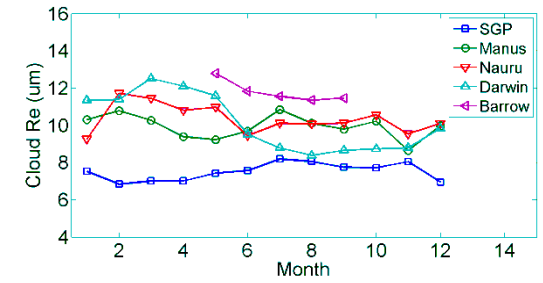
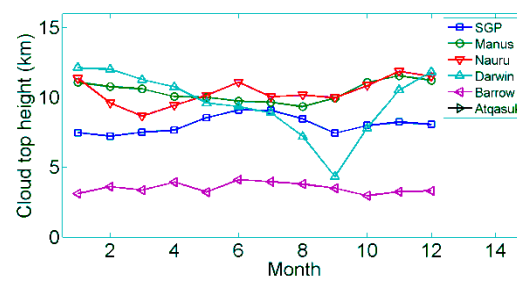
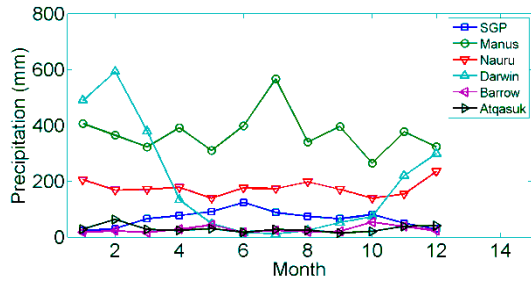
- ✓ Nauru site: Sea salt dominates, which is correlated with surface wind speed (peak in the middle of day).
- ✓ Darwin site: Local pollutant (vehicular emission) and sea salt (wind) affect the diurnal variation.
- ✓ SGP, Barrow, and Atqasuk sites: No obvious diurnal variation

Seasonal variation of cloud properties (Darwin)

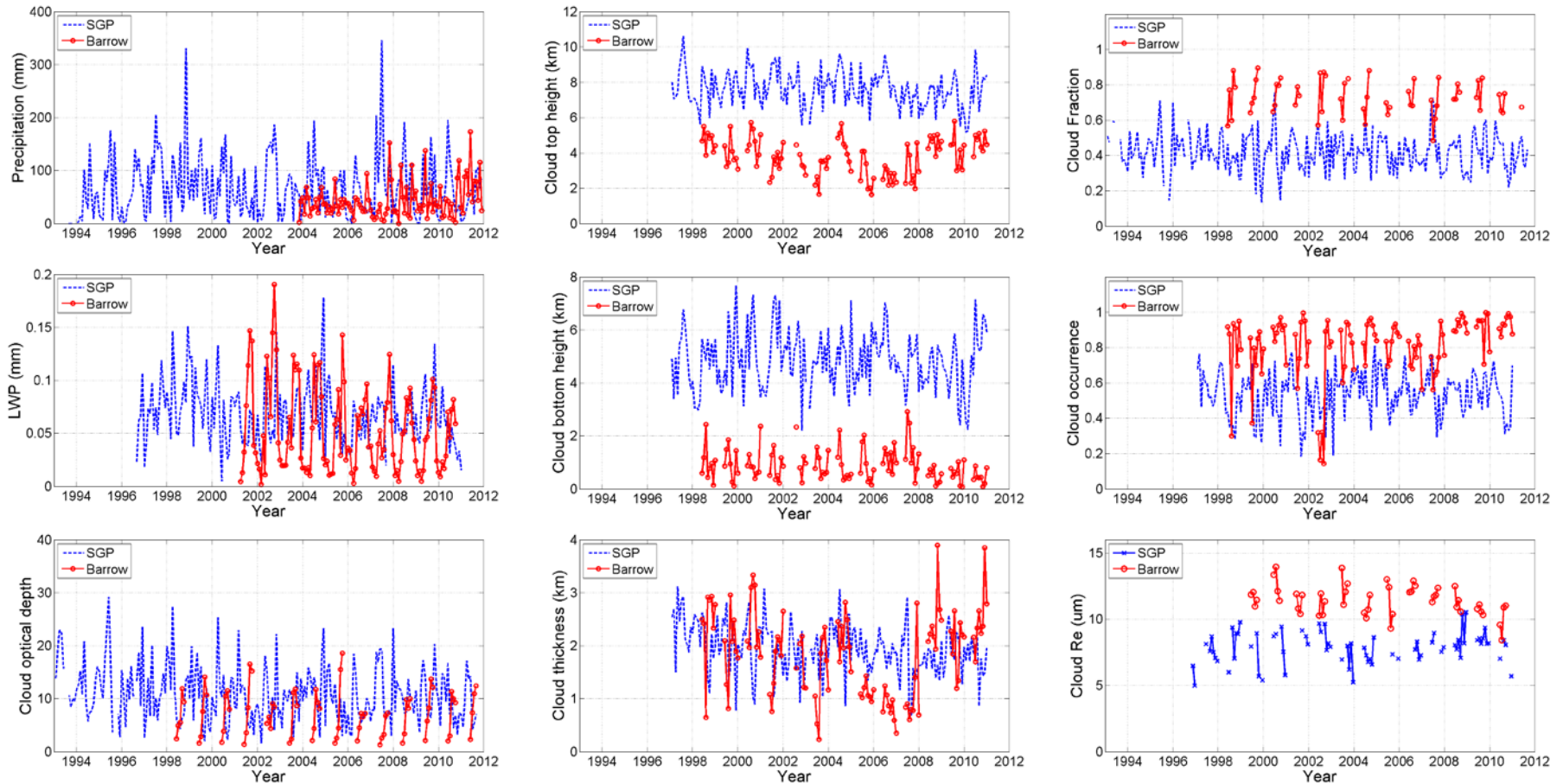


Due to the difference between wet season and dry season, seasonal variation of cloud properties is significant at the Darwin Site

Seasonal variation of cloud properties at all sites

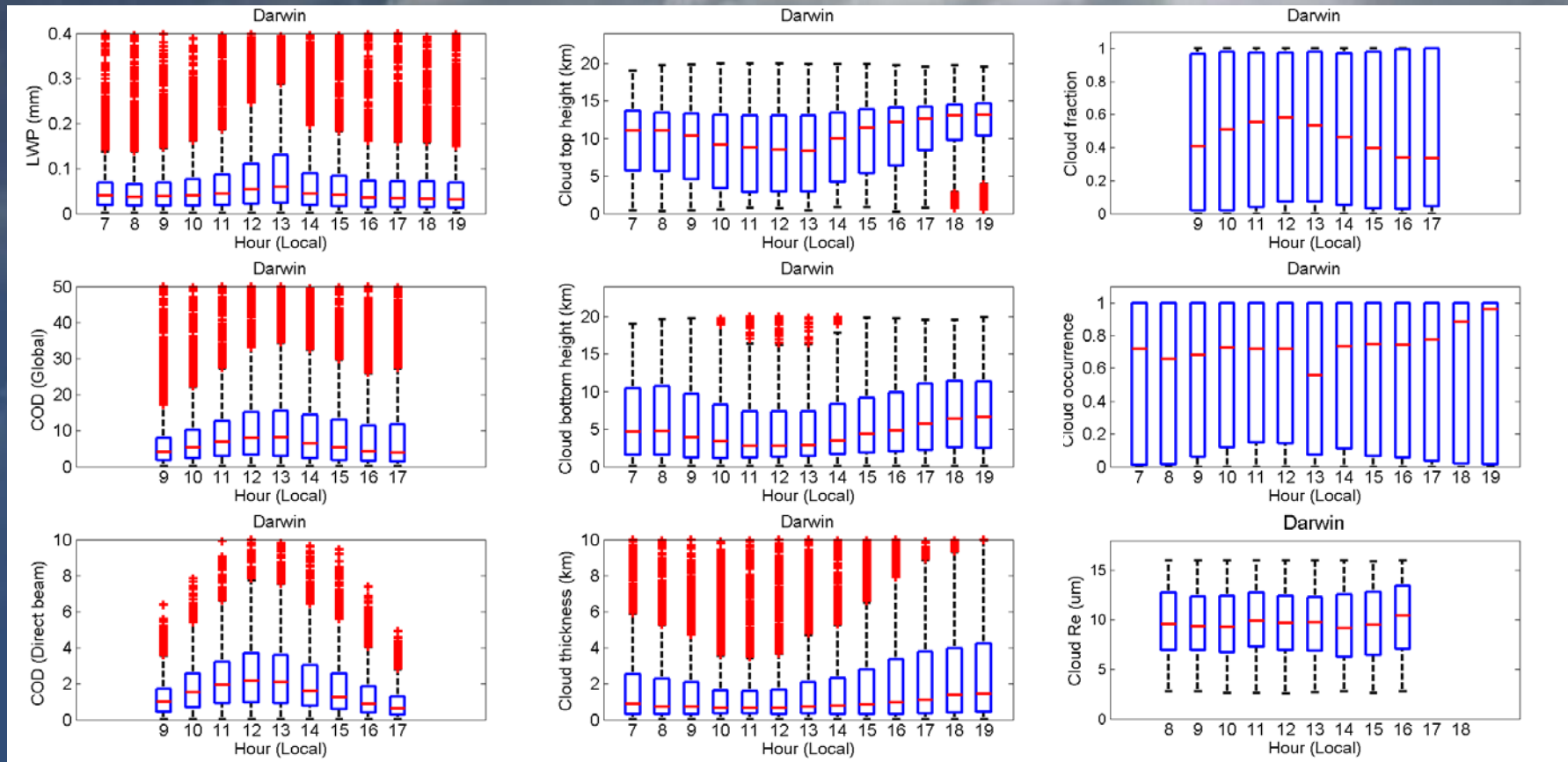


Interannual variation of cloud properties



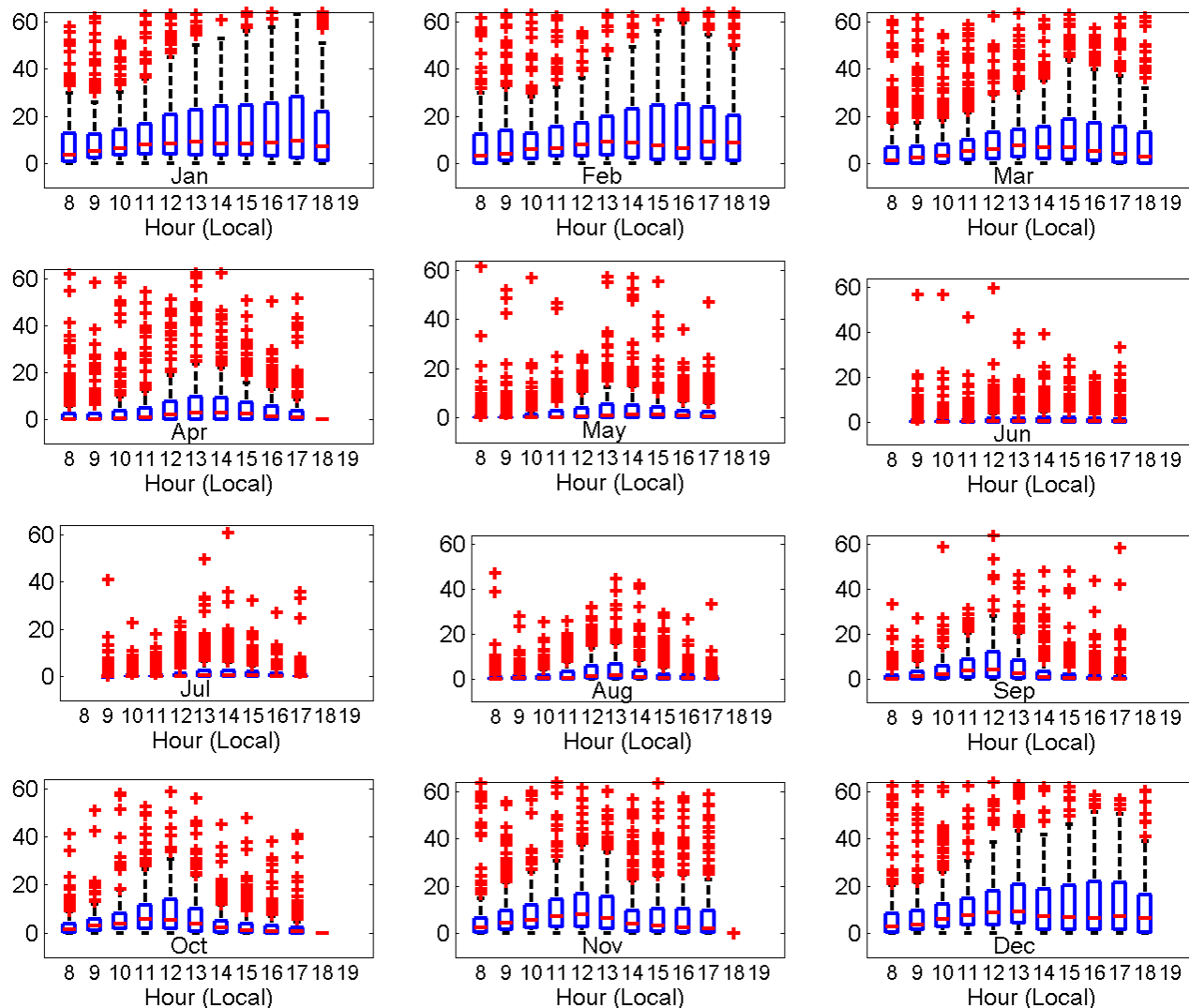
- ✓ SGP site: Slightly decreasing trends of LWP, cloud optical depth, and cloud thickness in 1993-2002.
- ✓ Barrow site: Some changes of interannual variation in cloud optical depth, effective radius, cloud top height and cloud thickness

Diurnal variation of cloud properties (Darwin)



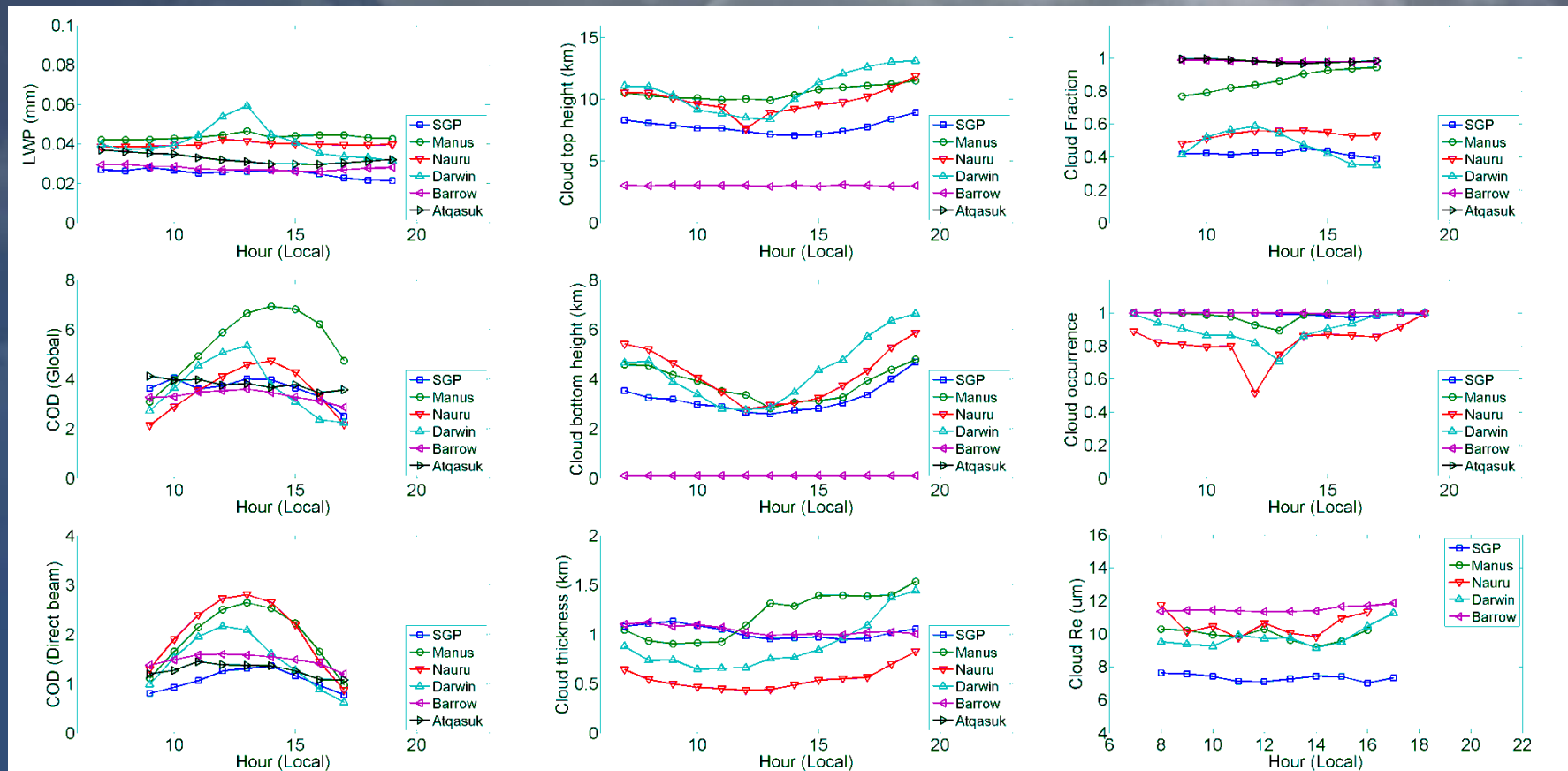
- ✓ Darwin site: Diurnal variation of cloud properties, and diurnal variation changes with season: Wet season vs. Dry season

Diurnal variation of cloud properties (Darwin)



In wet season (Dec to Mar), COD increases in AM, and remains or slightly decreases in PM; in other seasons, COD is much smaller, and the peaks always occurs in the middle of day.

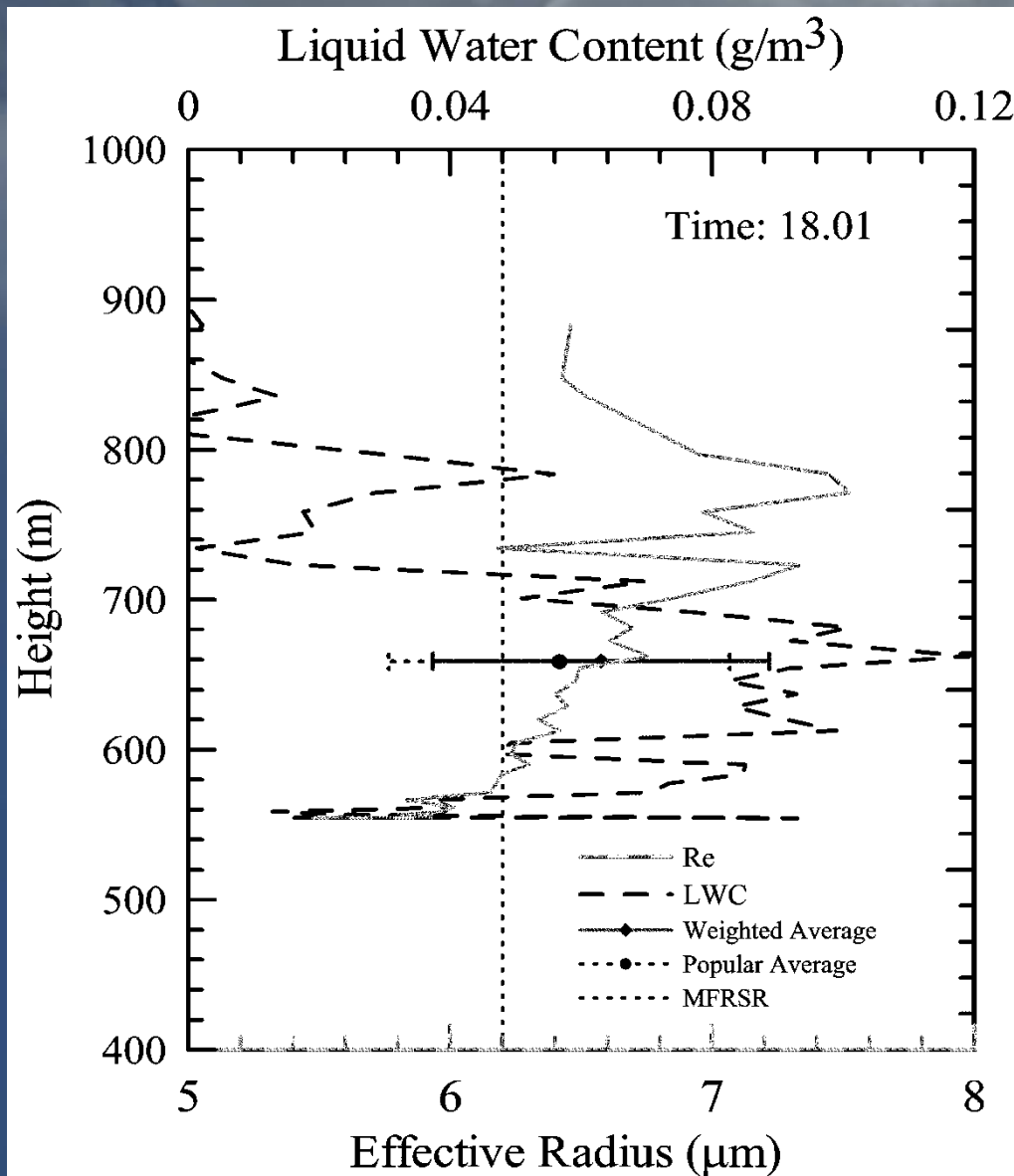
Diurnal variation of cloud properties at all sites



- ✓ The diurnal variations of cloud properties in Tropics (Manus, Nauru, and Darwin) are significant and similar;
- ✓ The diurnal variation at the SGP site is obvious but weaker than that at the TWP sites.
- ✓ The diurnal variation of cloud properties at the Barrow site is insignificant;

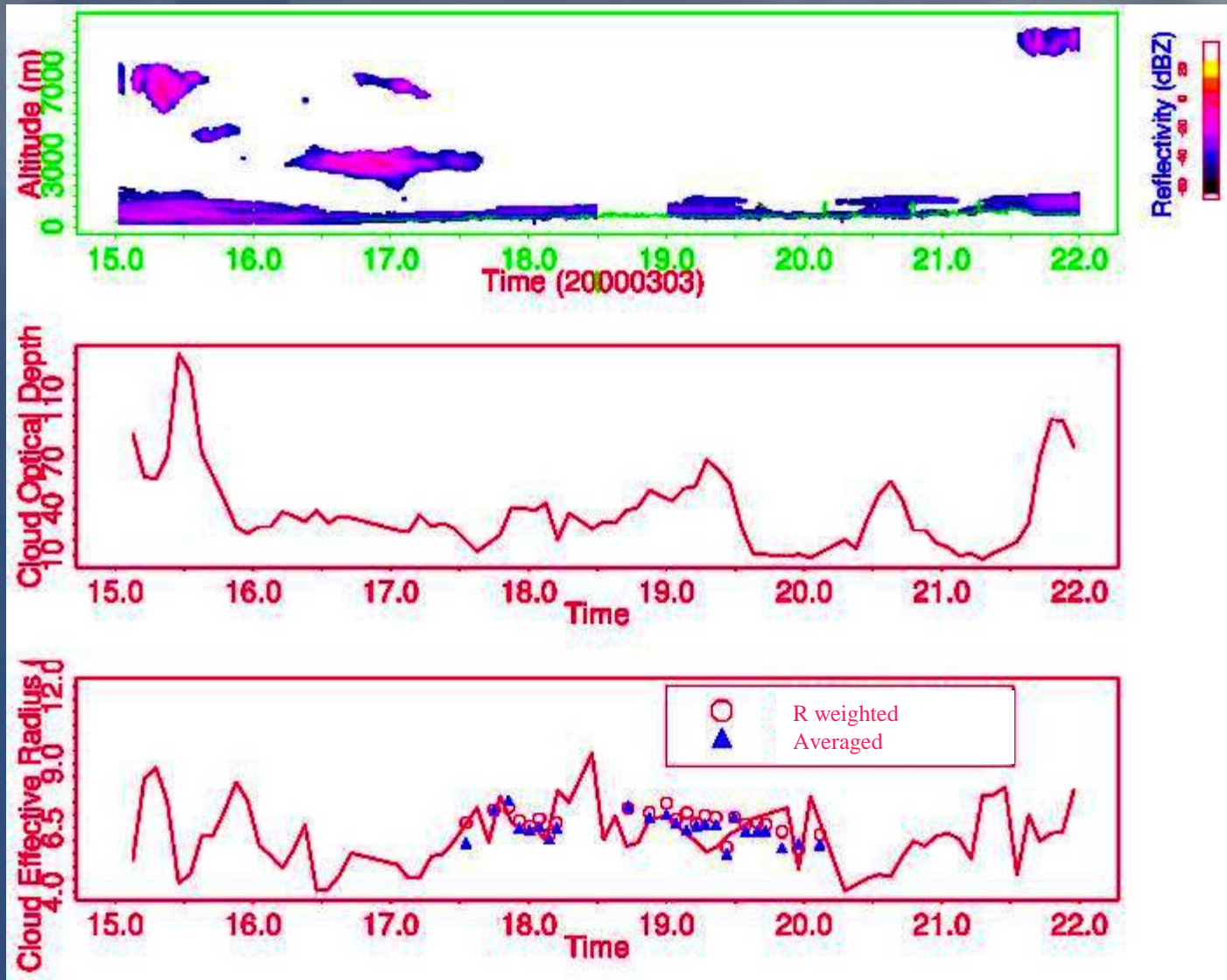
A photograph of a bright blue sky filled with large, white, fluffy cumulus clouds. The clouds are concentrated in the upper half of the frame, with the lower half being a clear, deep blue. The text is centered in the upper-middle part of the image.

Validations of retrieval algorithms



The FSSP
 measurements on
 Citation aircraft
 On March 3, 2000
 at the ARM SGP
 site

Validation with in-situ measurements at the ARM SGP site on March 3, 2000

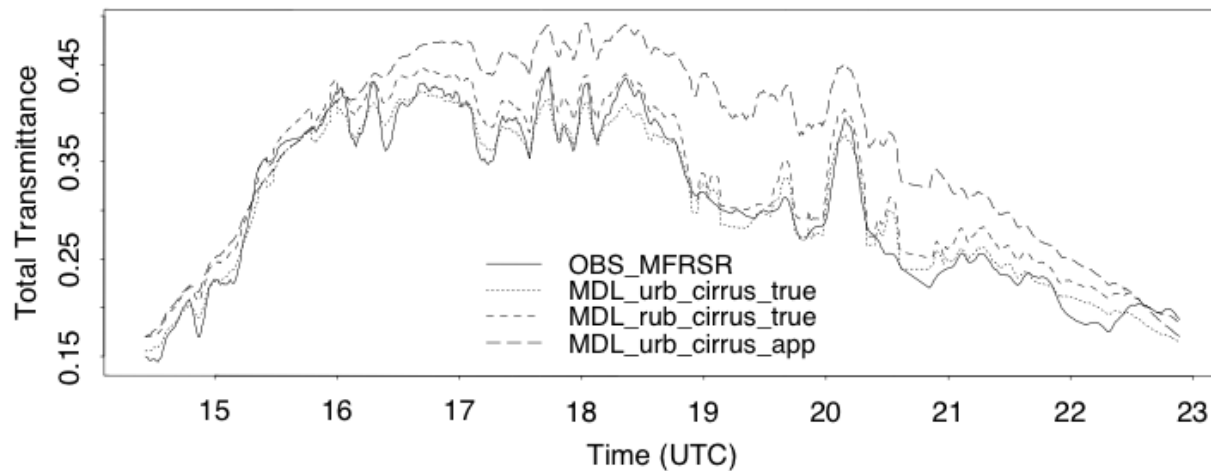
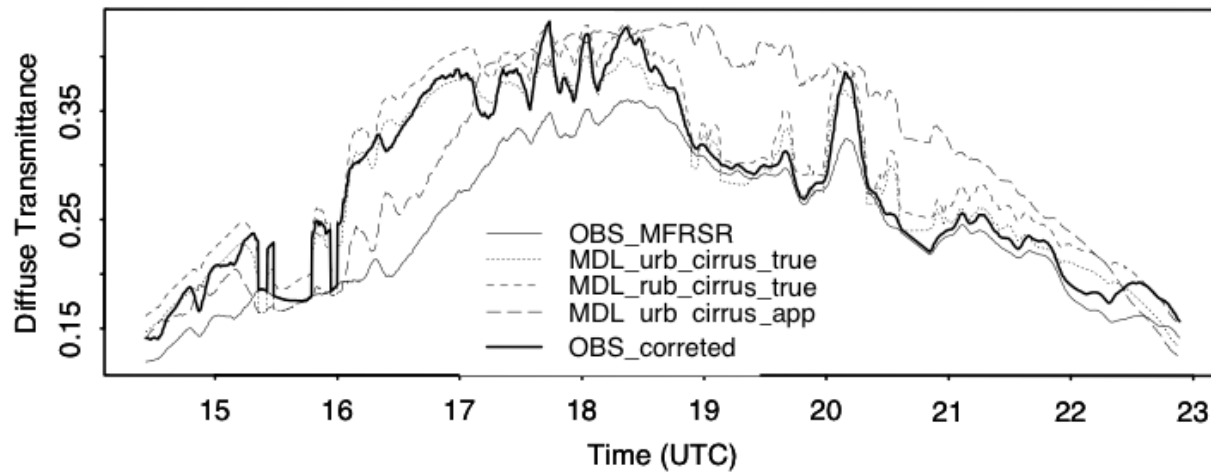


Mean effective radius and cloud optical depth over six ascent and descent profiles

	FSSP (size-weighted)	FSSP (simple-averaged)	LWP 147.9 g/m²	LWP (+) 167.9 g/m²	LWP (-) 127.9 g/m²
Effective Radius (μm)	6.74 ± 0.35	6.60 ± 0.51	6.43 ± 0.45	7.24 ± 0.66	5.60 ± 0.24
Optical Depth			36.7	37.2	36.2

- Low surface albedo at 415 nm
- No gaseous interference
- Calibration (1%)

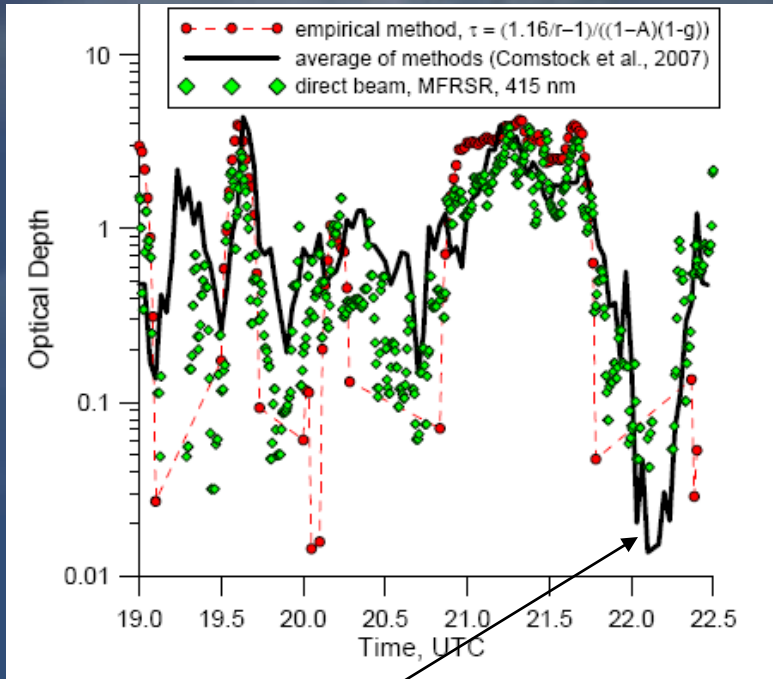
A closure study based on retrieved cirrus cloud optical depth



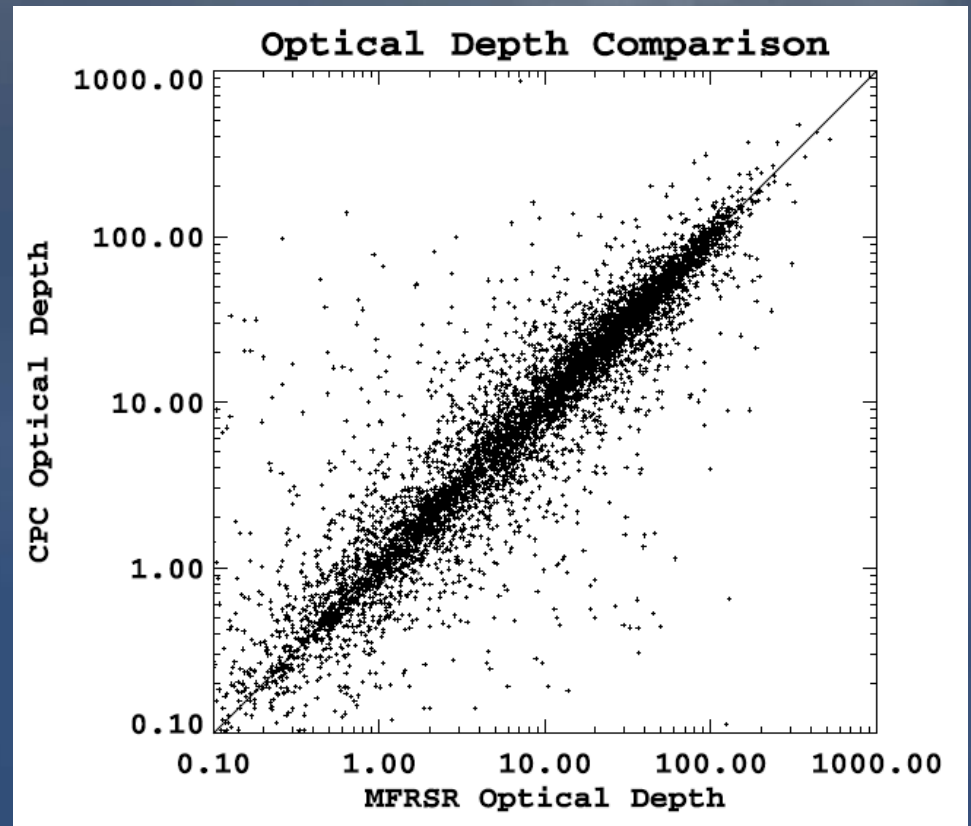
$$I_{corr}^{dif} = I_{obs}^{dif} + \mu_0 (\exp[-\tau^P / \mu_0] - \exp[-\tau^T / \mu_0])$$

Validations for Other Surface Measurements

Thin cirrus (direct beam algorithm)



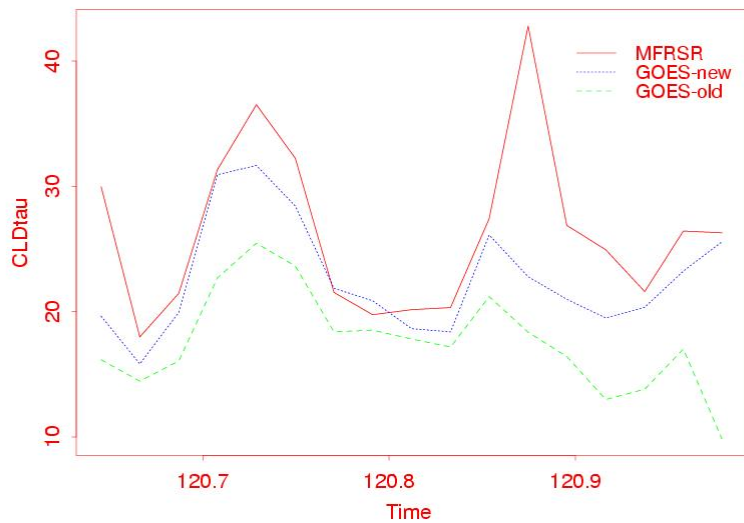
Thin and thick clouds (direct/diffuse algorithm)



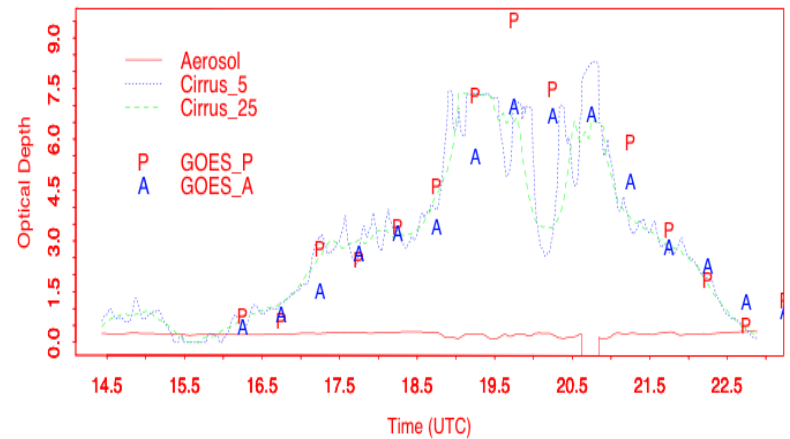
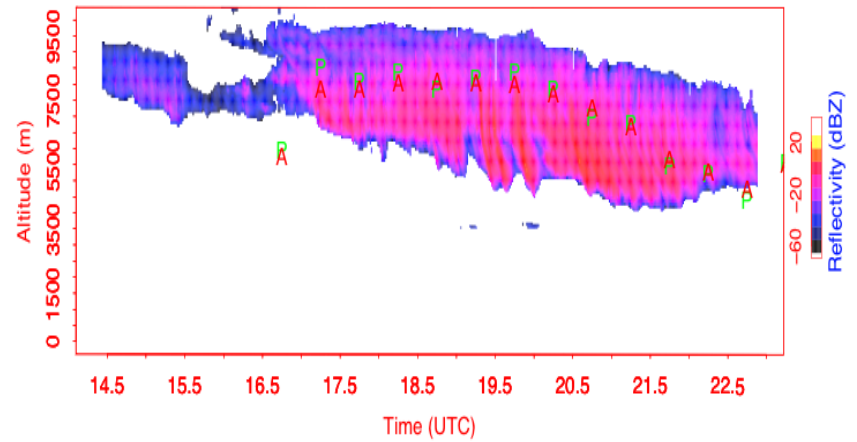
Average for all Lidar and Radar retrievals

Validations for Satellite Retrievals

Cloud Optical Depth at ARM SGP Site (940430)



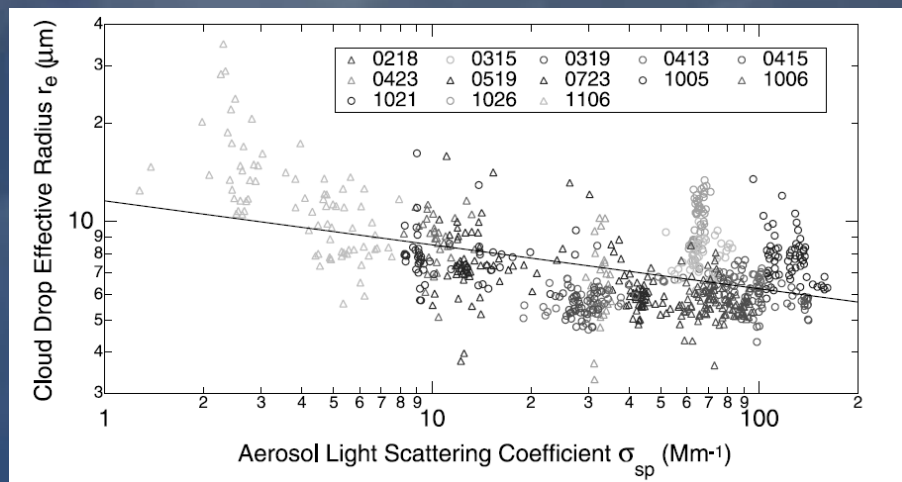
Thick clouds



Thin clouds

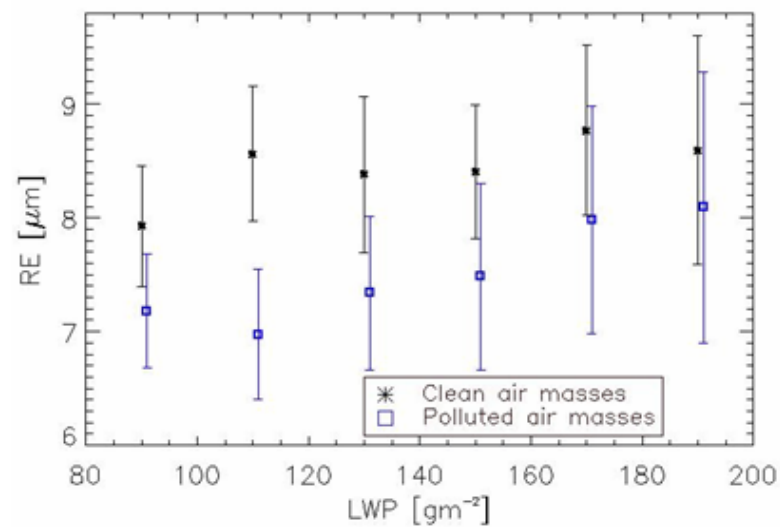
Aerosol indirect effects:

HU BCCSO site



ARM SGP site

a



b

