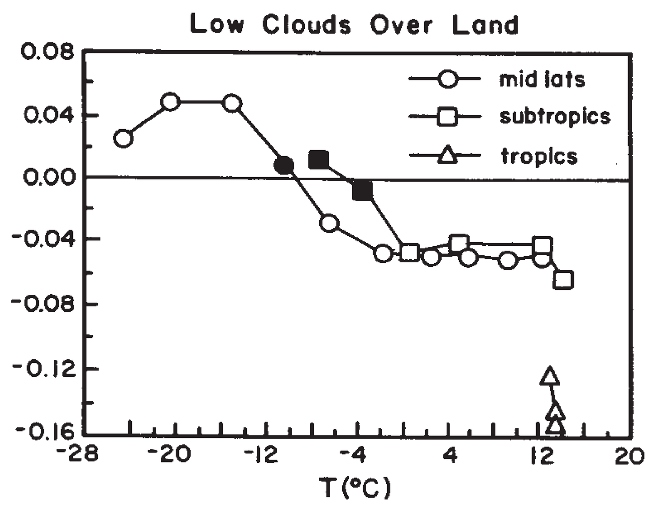
On the Relationship between Cloud Optical Depth and Temperature: Inferences from Ground-based Observations at ARM sites

Yunyan Zhang (zhang25@llnl.gov), Stephen A. Klein & Neil D. Gordon, PCMDI, LLNL

Motivation



Tselioudis et al 1992 based on ISCCP satellite data

The dependence of cloud optical depth on cloud top temperature has been explored using ISCCP satellite data by Tselioudis et al 1992 that cloud optical depth increases with cold temperatures and decreases with warm temperatures. There is a growing interest of using this relationship to evaluate global climate modeling results and study long-term cloud feedback on climate change (Gordon and Klein 2012). However there is a lack of systematic investigation of this relationship based on ground-based observations. To extend the approach in Del Genio and Wolf (2000) on using ARM observation, we revisit this relationship using most updated long-term quality-controlled data to 1) provide a more accurate quantification of this relationship and 2) explore physical mechanisms that determine the relationship.

Data and Methodology

US Department of Energy Atmospheric Radiation Measurement (ARM) program Climate Research Facilities at US Southern Great Plains (SGP) and North Slope of Alaska (NSA) provide a long-term measurement of atmospheric state and cloud's radiative, microphysical and macrophysical properties. We

1. Select single-layer near-overcast (fraction > 90%) low-clouds (< 5km) based on hourly-mean ARSCL cloud fraction.
2. Make use of independent measurement and retrievals of cloud properties to tackle the factors that may contribute to the dependence of cloud optical depth on temperature.

Cloud Optical Depth By Multifilter Rotating Shadowband Radiometer (MFRSR, Min and Harrison 1996; Min et al 2004)

Liquid Water Path by Microwave Radiometer (MWRRET, Turner et al, 2007)

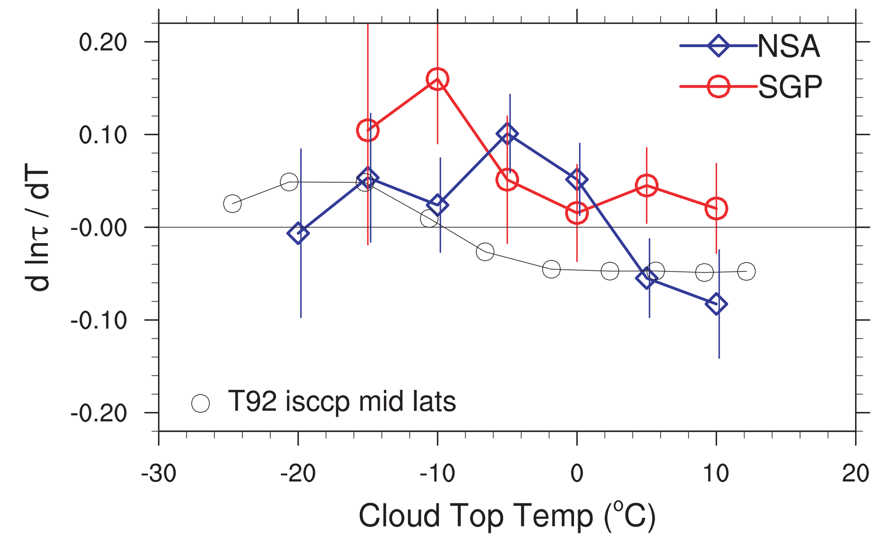
$$\tau = 1.5\delta\mu\Delta z/(\rho_w r_e)$$

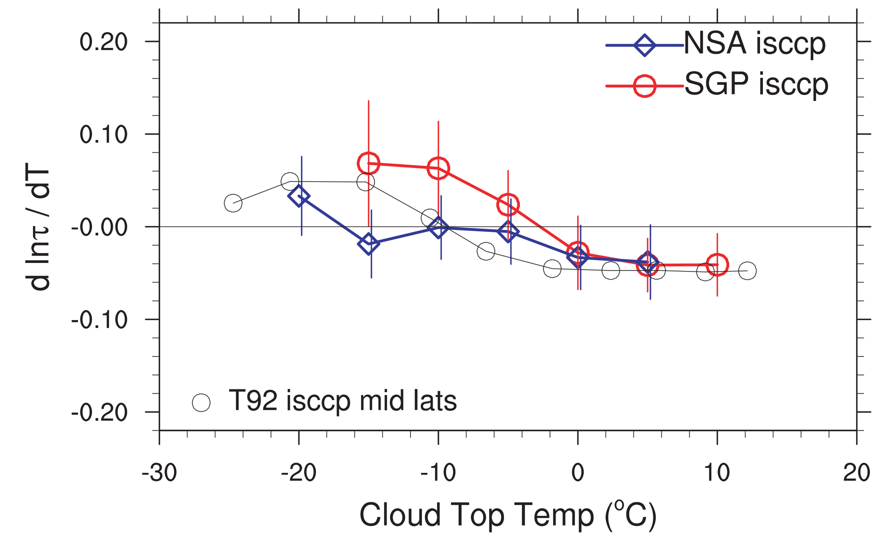
Liquid/ice Water Content & Effective Radius by ARM Cloud Retrieval Ensemble Dataset (ACRED, Zhao et al 2012)

Cloud physical thickness from Active Remote Sensing of Clouds data (ARSCL, Clothiaux et al 2000)

Data Used
- ARM Best Estimate (ARMBE)
- ARM Cloud Retrieval Ensemble Data (ACRED)
- MFRSR cloud optical depth by Q. Min
- Atmospheric temperature by balloon soundings (LSSONDE)
- Cloud base by Ceilometer or Micropause Lidar (MPL)
- Cloud top by Millimeter Cloud Radar (MMCR)
- ARM archived ISCCP cloud product at SGP and NSA site
- Surface Meteorological Observation System (SMOS)
- VISST Cloud products from P. Minnis' group at SGP site
- IPCC CMIP3 model output data

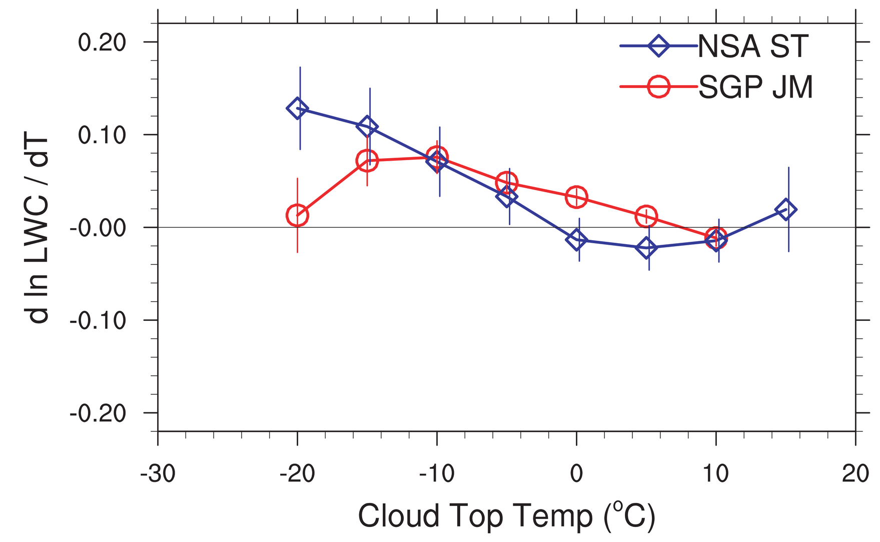
Cld Optical Depth & Temp.

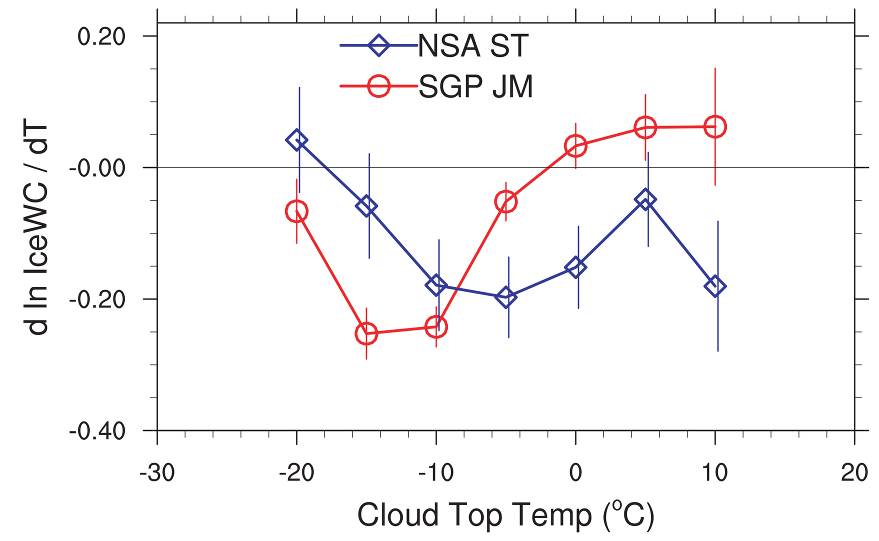




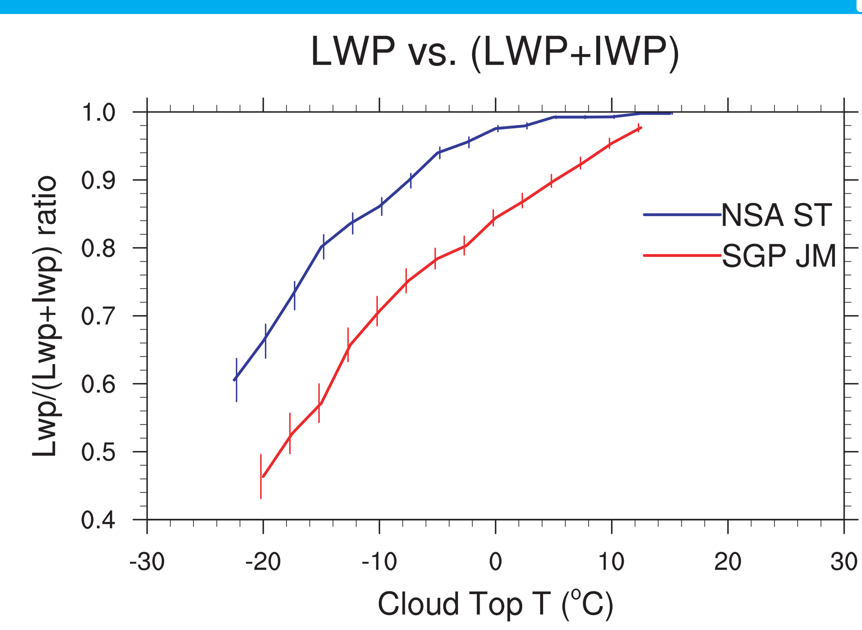
dlnτ / dT ,the logarithmic derivative of cloud optical depth with temperature, is plotted against the cloud-top temperature, which illustrate how the cloud optical depth-temperature relation varies with temperature changes. At least 30 samples are used for calculation in each 15 K interval bin. Vertical bar denotes confidence interval of 95%.

Water Content & Temp.

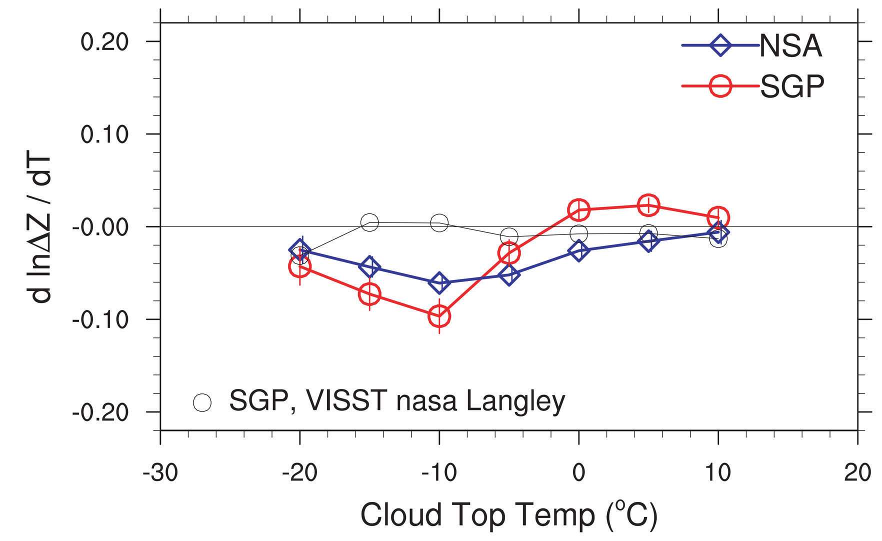




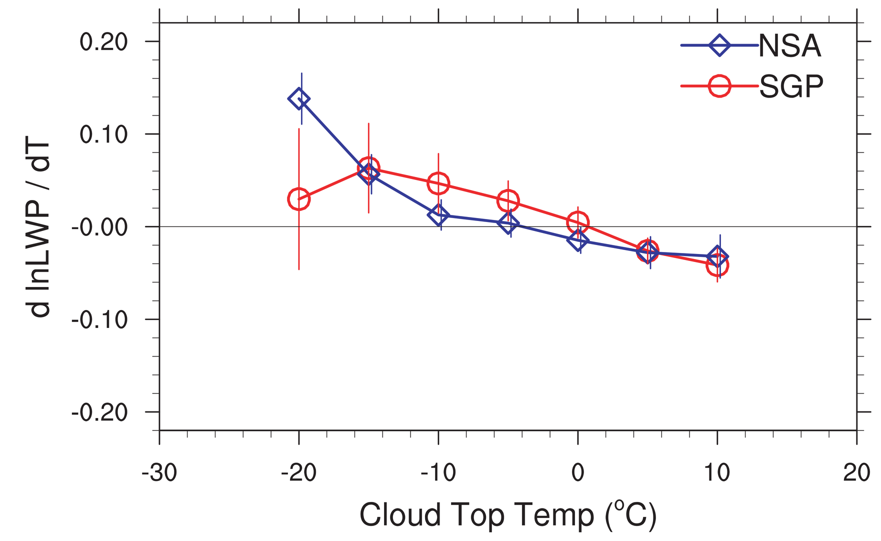
Water/Ice Ratio & Temp.

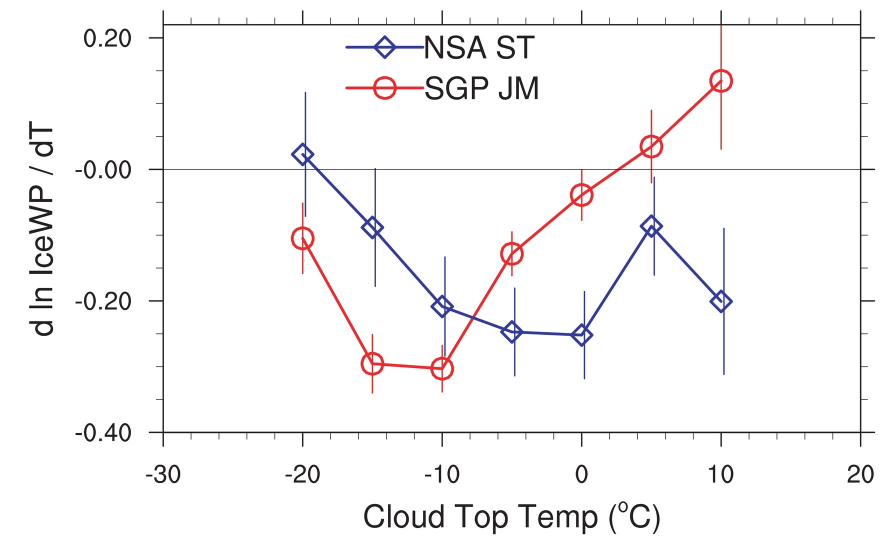


Cloud Thickness & Temp.

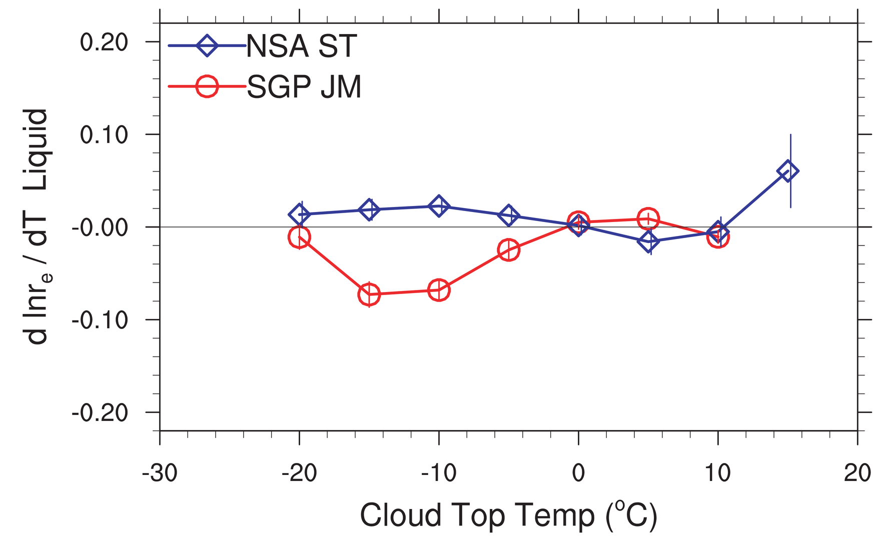


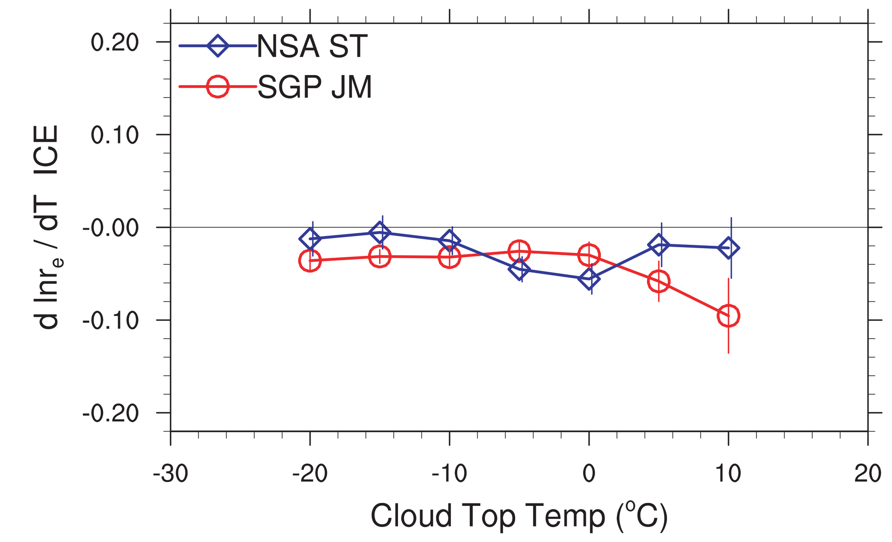
Water Path & Temp.





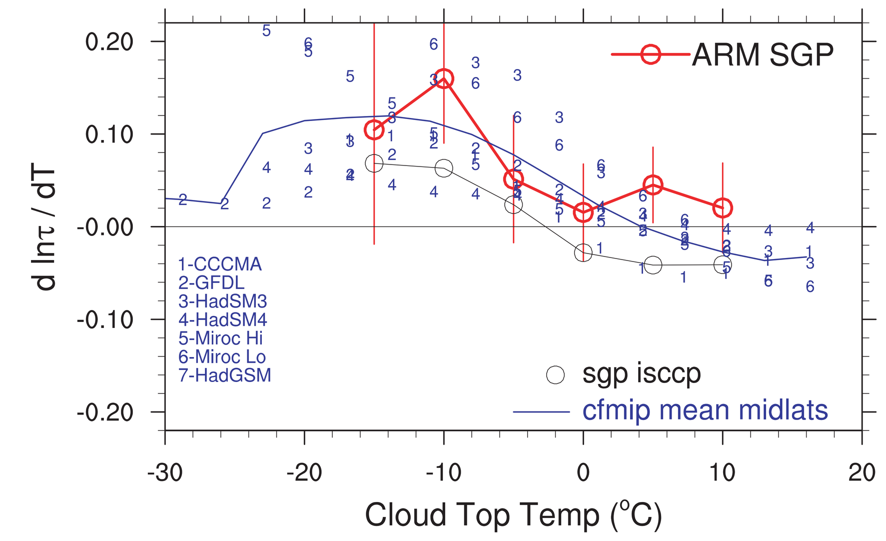
Effective Radius & Temp.

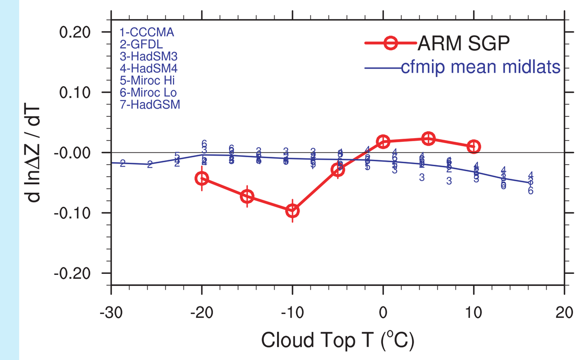


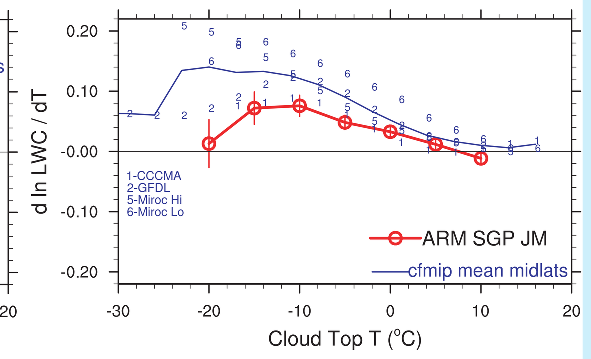


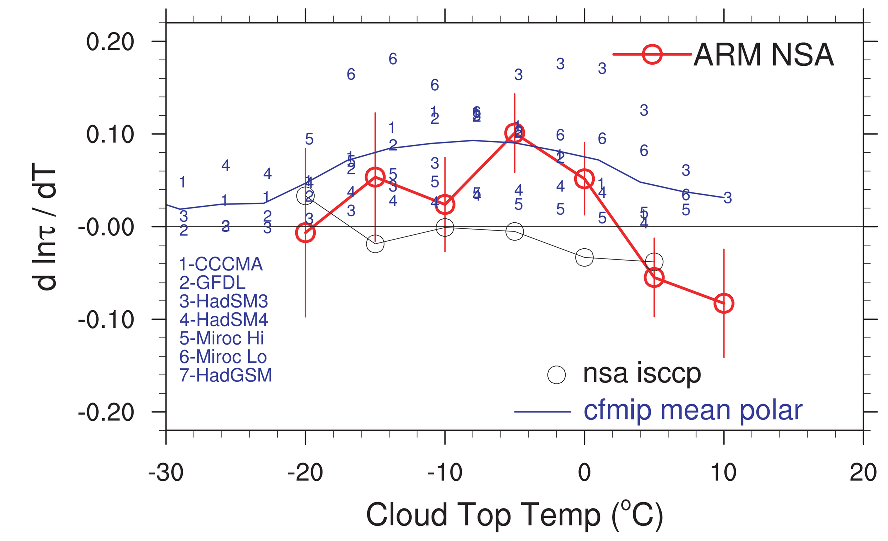
At SGP site, retrievals of liquid (ice) water content and liquid (ice) effective radius by Mace's algorithm (e.g. Mace et al 2002) are used for calculation; at NSA site, retrievals based on Shupe-Turner's algorithm (e.g. Turner et al 2007; Shupe et al 2005) are used for calculation. There are some differences if based on other retrieval algorithms (not shown here).

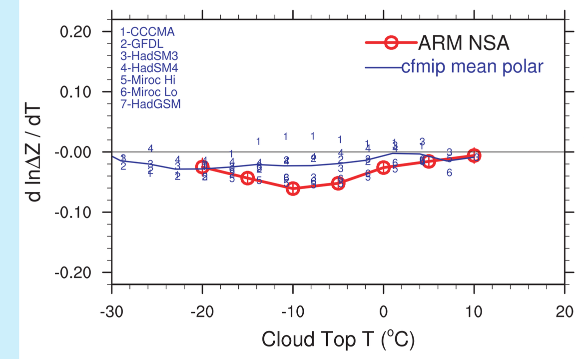
ARM data vs Climate Model

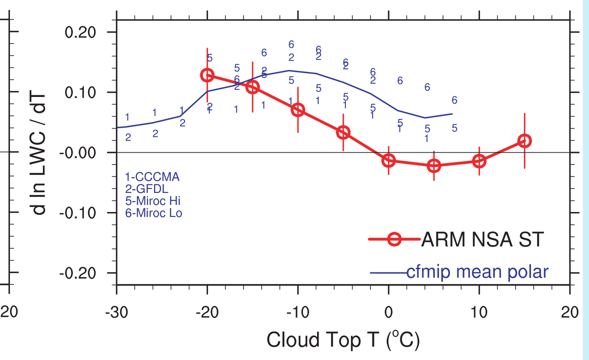












Summary and Future Work

ARM data are used to quantify the dependence of cloud optical depth on temperature and to explore major components that contribute to this relationship. We find the dependence of liquid water path and liquid water content on temperature likely to play a dominating role, however further investigation on the water/ice partition and retrievals on particle size is necessary. There is uncertainties if different retrieval algorithms are used. ARM data are also used to evaluate CMIP3/CFMIP model results and majority of the models capture this relation well. However inconsistency exists in the dependence of cloud physical thickness and cloud liquid water content on the cloud temperature. Recent satellite data such as ISCCP and VISST are also used for comparison.

Next, we plan to
1. Further examination of the difference between retrieval algorithms
2. Include other independent measurement of cloud optical depth, such as retrievals from AERONET or MPL (Chiu et al 2010) to quantify the uncertainties in the measurement of cloud optical depth
3. CFMIP model output at ARM sites will be used for more accurate model evaluation instead of latitudal band data
4. Further analysis on different environmental conditions such as coupled or decoupled sub-cloud layers

This work is supported by DOE's Office of Science Regional and Global Climate Modeling program and Atmospheric System Research program. Thanks to Q. Min, C. Chiu, C. Zhao, R. McCoy, and S. Xie for discussions on the data.
This work was supported performed under the auspices of the U.S. Department of Energy at Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. LLNL-POST-624063