High Spectral Resolution IR & Raman Lidar Observations for the ARM program:

Clear and Cloudy Sky Applications

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Cloud Properties & Aerosol Working Group
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Broad Objectives

- Assess and improve the ability of ARM site observations and radiative transfer modeling to represent cloud radiative properties
- Assess how well cloudy sky radiation is represented in climate models

Accomplishments

- **Clear sky OLR validation using AIRS and CERES**
  - *Validation of Observed and Computed Clear Sky OLR using CERES and AIRS*, paper submitted to JGR, Sept 2008
- **Cirrus Cloud Characterization using Raman Lidar & Radar**
  - *Improving Cirrus Cloud Characterization with Raman Lidar Measurments at Southern Great Plains*, in preparation

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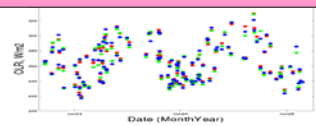
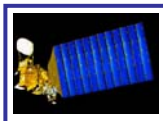
Clear sky OLR validation using AIRS and CERES

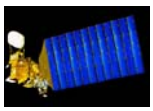
ARM Site Method & Global Method

SGP obs → RRTM → OLR: Calculated vs CERES

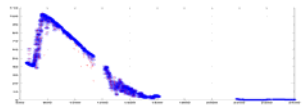




AIRS Retrievals → RRTM → OLR: Calculated vs CERES



AIRS Retrievals → LBLRTM → Radiances: Calculated vs AIRS



Clear Sky OLR Validation using AIRS and CERES

RRTM calculations of clear sky OLR agree with CERES observations to ~1 W/m^2 with an uncertainty of ~1 W/m^2

- True at SGP over 2.5 years
- True globally (with some *understood* regional exceptions) for four study days
- True using ARM data as input to RRTM
- True using AIRS sounding retrievals as input to RRTM
- True over most CERES surface types
  - Large exceptions over desert and ice/snow
  - Day/night <u>ocean</u> bias is very constant (< -0.4 W/m^2) but the day/night bias varies greatly over some <u>land</u> surface types

AIRS hyperspectral provides a check on surface conditions/atmospheric profiles, and estimations of far IR errors

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Motivation

- How to best characterize thin cirrus?
- SGP Raman Lidar provides direct measurements of extinction
  - HSRL is only other Lidar capable of this measurement worldwide

History

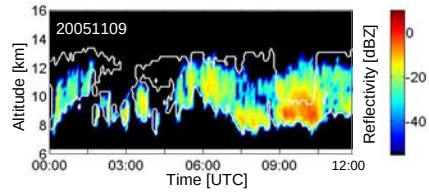
- Extension of previous work, which assessed ARM Broad Band Heating Rate Profiles (BBHRP) under clear-sky conditions
- BBHRP produces vertical profiles of fluxes and heating rates to drive models
- BBHRP primarily cloud radar based logic for cloud properties

Cirrus Cloud Characterization

Raman Lidar & Cloud Radar

Cloud Radar (MMCR) | Raman Lidar | Merged (Radar+Lidar) Dataset

+

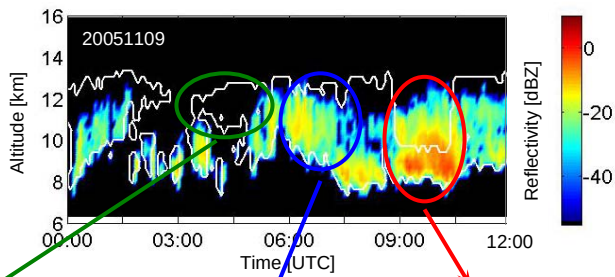


1. Derive extinction profiles from Raman Lidar
2. Produce merged Radar + Lidar dataset
   - 5 min time resolution
   - 300 m vertical resolution between 6-16 km
   - September 2004 - 2007

To better characterize thin cirrus use Radar + Lidar

Approach

Merged (Radar+Lidar) Dataset



Lidar Data Only
- Direct measurements of lidar extinction and assumed small r_e

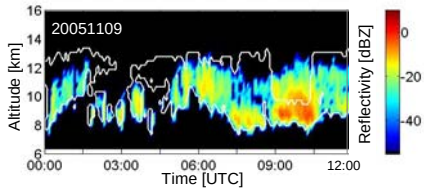
Radar Data Only (Lidar attenuated)
- Z-IWC power law
- T function of r_e

} MICROBASE BBHRP logic

Radar + Lidar Data
- Direct measurements of lidar extinction and (radar+lidar) derived r_e

Approach

Merged (Radar+Lidar) Dataset



Sondes

MWR

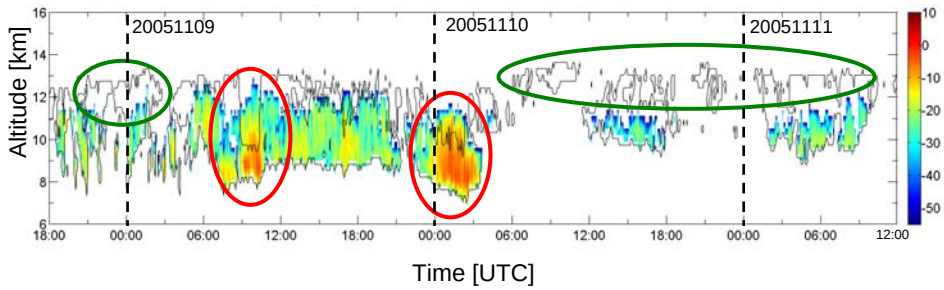
Radiation Station

aer RRTM_LW

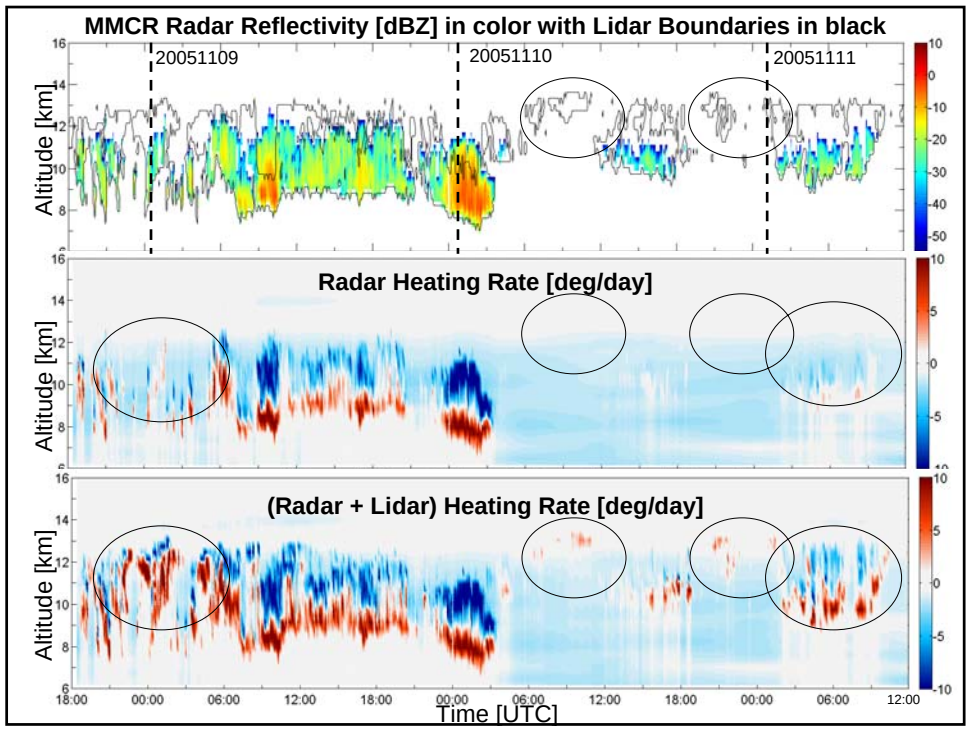
IR Radiative Fluxes and Heating Rates

3 Day Case Study

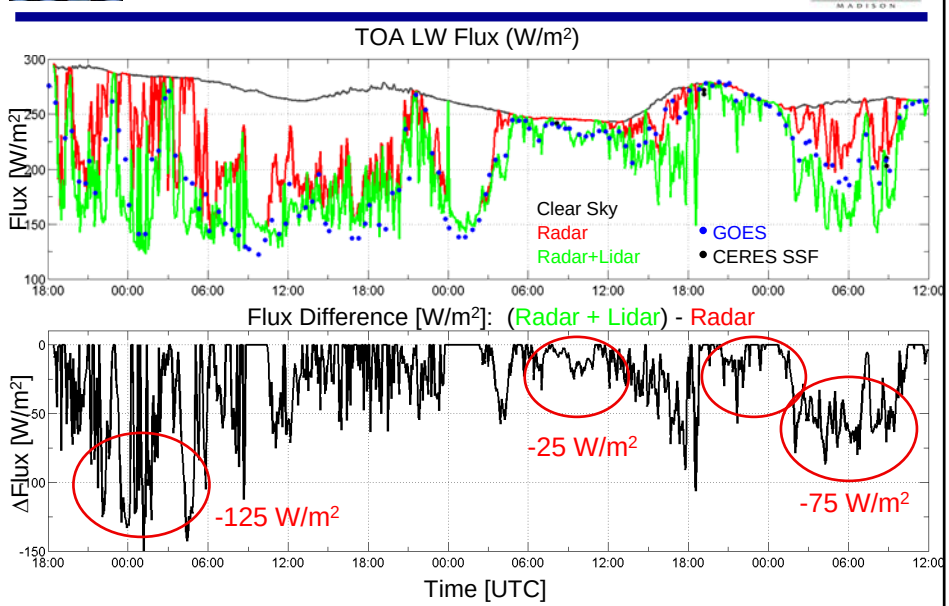
MMCR Radar Reflectivity (color) overlaid with Lidar Boundaries (black)



- Case study characterized by single layer cirrus
- 2 time periods where radar seeing more than lidar
- MMCR radar missing significant upper level cirrus



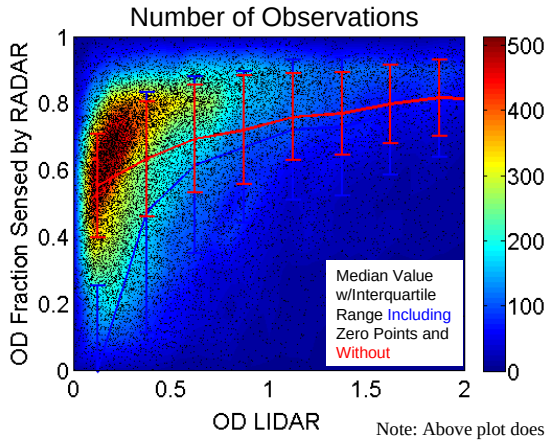
3 Day Case Study



2+ Year Study

Dataset: 17 Sep. 2004 - 31 Dec. 2006

- Removed known time periods when MMCR problematic
- When Lidar NOT attenuated …



Note: Above plot does NOT display the points when Lidar sees cloud and Radar does not.

Summary

- Raman Lidar and HSRL are unique and provide direct measurement of cloud extinction profile
- Implemented an operational cloud extinction algorithm for SGP Raman Lidar and have produced a long term dataset of cirrus cloud extinction at the SGP site
- The MMCR radar is missing significant upper level cirrus
- The optimal product at SGP should be based on the combination of Cloud Radar plus Raman Lidar
- These products should be used within ARM for climate model studies and evaluations

Overall Summary

- Unique Raman Lidar observations provide a significantly improved understanding of cirrus clouds at the ARM SGP site
- Clear Sky TOA OLR is understood at the ARM sites, and globally, to the level of ~1 W/m^2

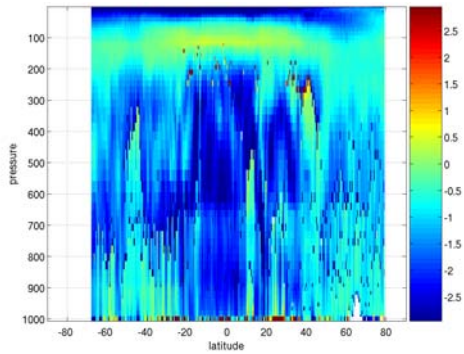
Next Steps

Produce cloudy sky (cirrus) heating rates and fluxes for GCM assessments:

- Assess the use of AERI and MPL at SGP
  - Produce accurate cirrus cloud characterization
  - Extend cirrus cloud characterization to other ARM sites
- Use global AIRS, Calipso, and Cloudsat observations to provide global heating rate and flux products
- Perform evaluations of climate model cloud products, heating rates and fluxes using these new products

Next Steps

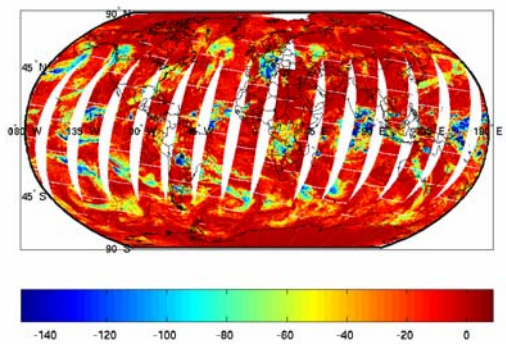
Heating Rate Profiles: 16 November 2002, Night



Zonal mean cloudy sky heating rate profiles calculated with RRTM using AIRS retrievals.

Next Steps

Cloud Forcing: 16 November 2002, Night



TOA cloud forcing (cloudy – clear OLR) [W/m^2] computed using global AIRS retrievals.

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