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

Clear and Cloudy Sky Applications

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Radiative Processes Cloud Modeling Joint Working Group
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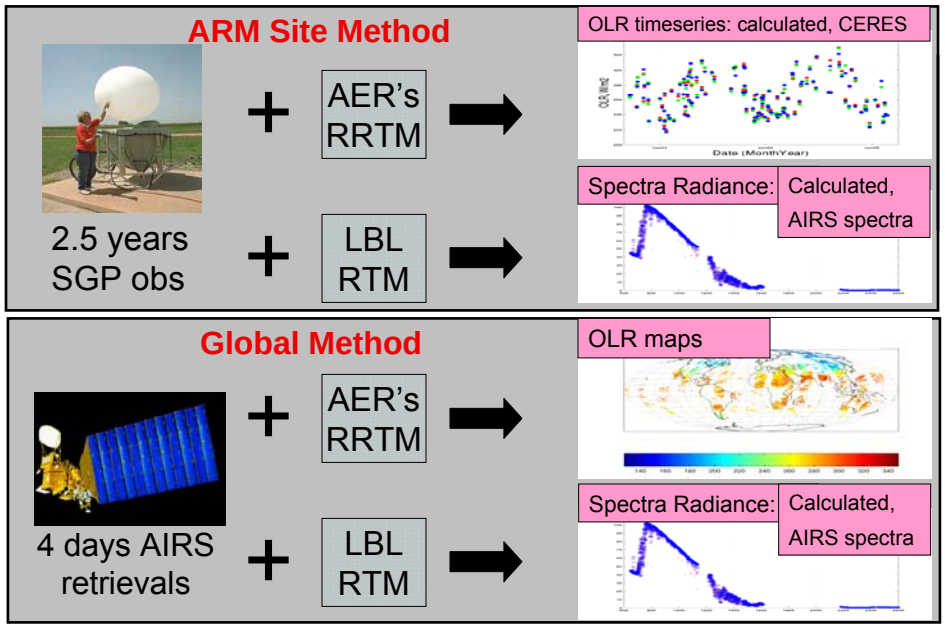
Broad Objectives

- 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

Clear sky OLR validation using AIRS and CERES



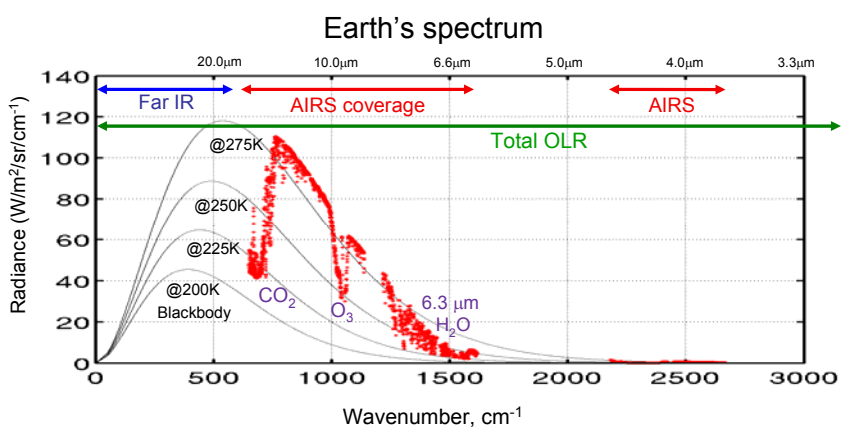
Clear Sky OLR Validation using AIRS and CERES

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 ocean bias is very constant (< -0.4 W/m^2) but the day/night bias varies greatly over some land surface types

AIRS Spectral Flux Analysis

$$Flux = \iint radiance \quad d(wavenum\ .)\ d(s.angle\ )$$



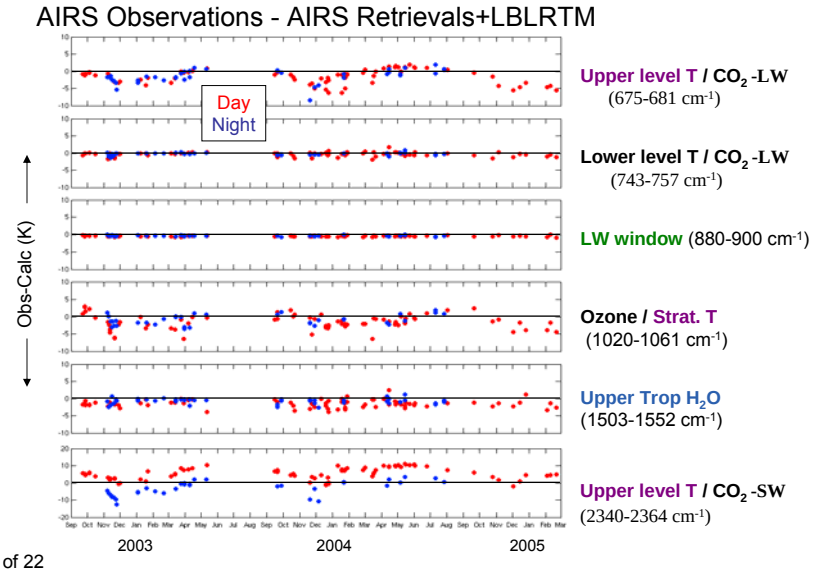
AIRS Spectral Flux Analysis

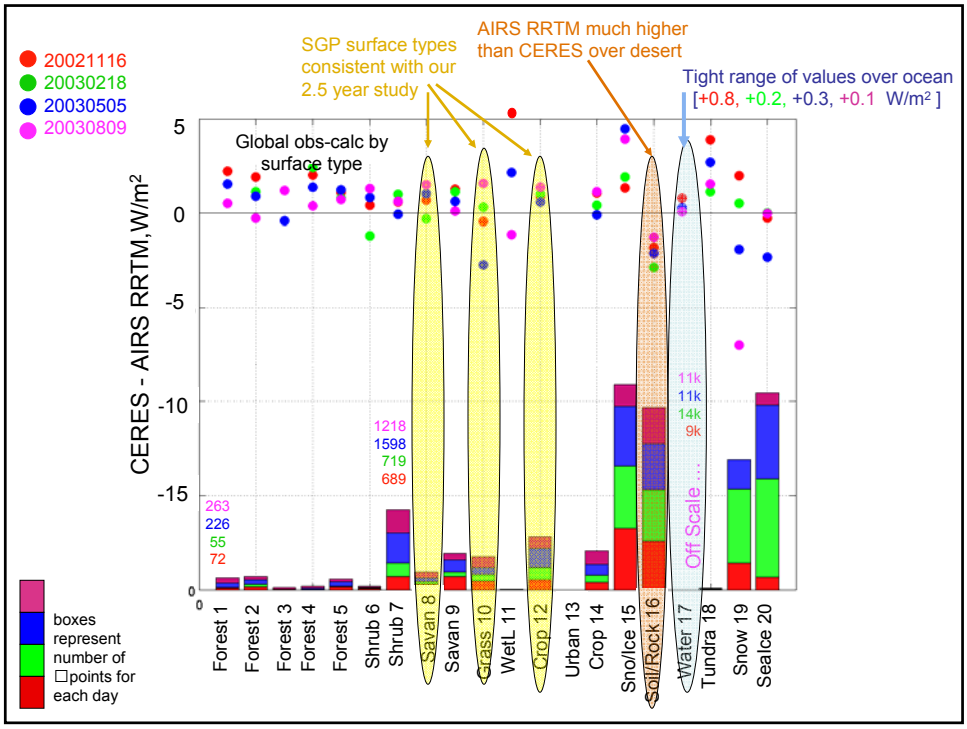
Spectral Coverage	Weight %	Flux W/m^2	Percent Residual Definition	%
Total OLR	100	263	100 * (CERES - AIRS RRTM) / CERES	0.2
AIRS spectra	54	144	$100*(F_{AIRS\ obs} - F_{AIRS\ calc}) / F_{AIRS\ obs,}$	0.3
Far IR	45	116		[0.1-0.5]

Assuming CERES errors are similar throughout the entire spectrum, and that there are no cancellation of errors between CERES and RRTM, we can infer the error in the far IR. (Our analyses show that CERES and AIRS agree in the window channels to approximately 0.1%).

AIRS Spectral Radiance Analysis

AIRS Observations - AIRS Retrievals+LBLRTM





Clear sky OLR validation using AIRS and CERES

- Clear sky OLR comparison between AIRS RRTM and CERES is EXCELLENT
- AIRS hyperspectral provides a check on surface conditions/atmospheric profiles, and estimations of far IR errors
- Current work includes extending this method to cloudy skies

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History

BBHRP collaboration of all working groups which produces vertical profiles of fluxes and heating rates to drive climate models

BBHRP primarily cloud radar (MMCR) based logic for cloud properties

Motivation

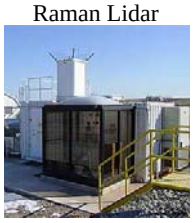
Cloud radar combined with Raman lidar are needed to characterize cirrus clouds well.

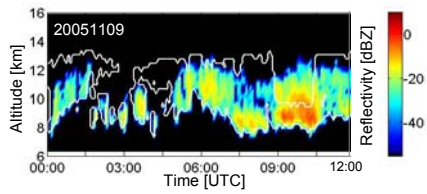
The impact of lidar information on the heating rates & fluxes can be substantial.

Cirrus Cloud Characterization

Raman Lidar & Cloud Radar

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



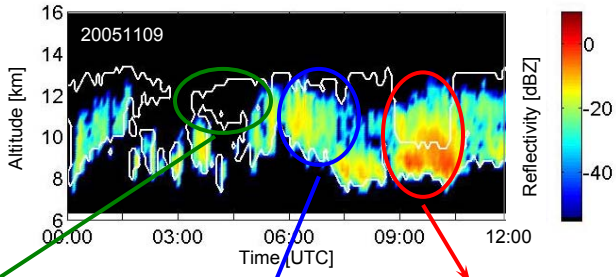


To better characterize thin cirrus use Radar + Lidar

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
   - 20040917 - 20071231

Approach

Merged (Radar+Lidar) Dataset



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

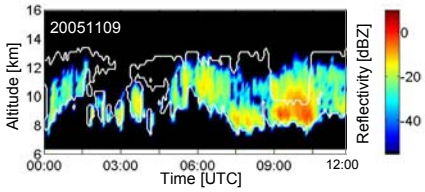
Radar Data Only (Lidar attenuated)
- Z-IWC power law
- T function of r_e

} MICROBASE BBHRP logic

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

Approach

Merged (Radar+Lidar) Dataset



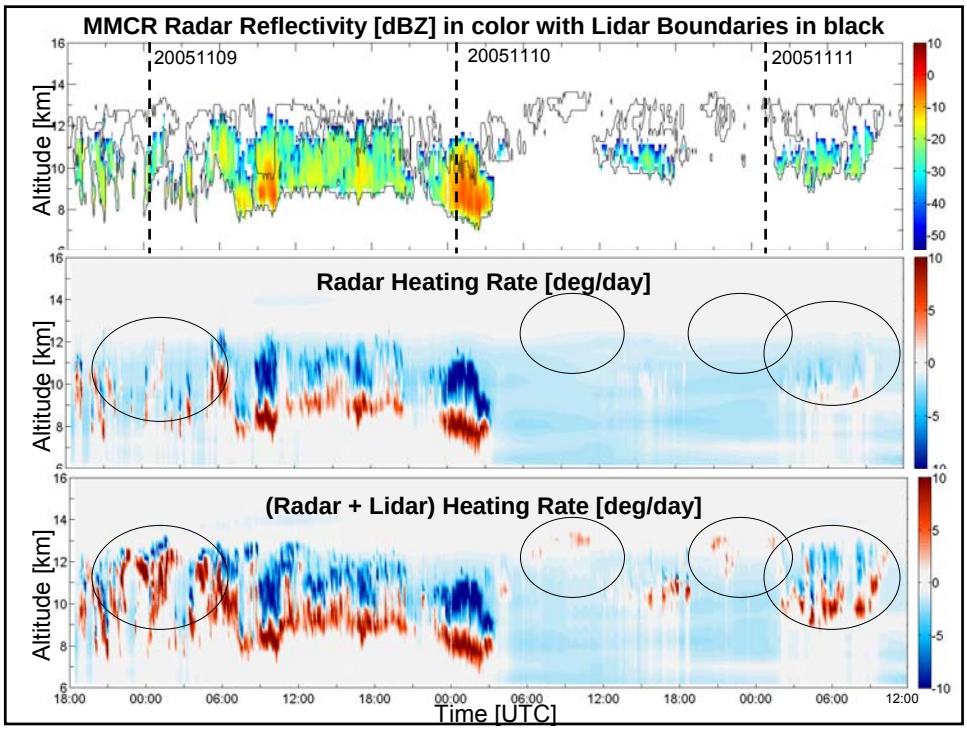
Sondes

MWR

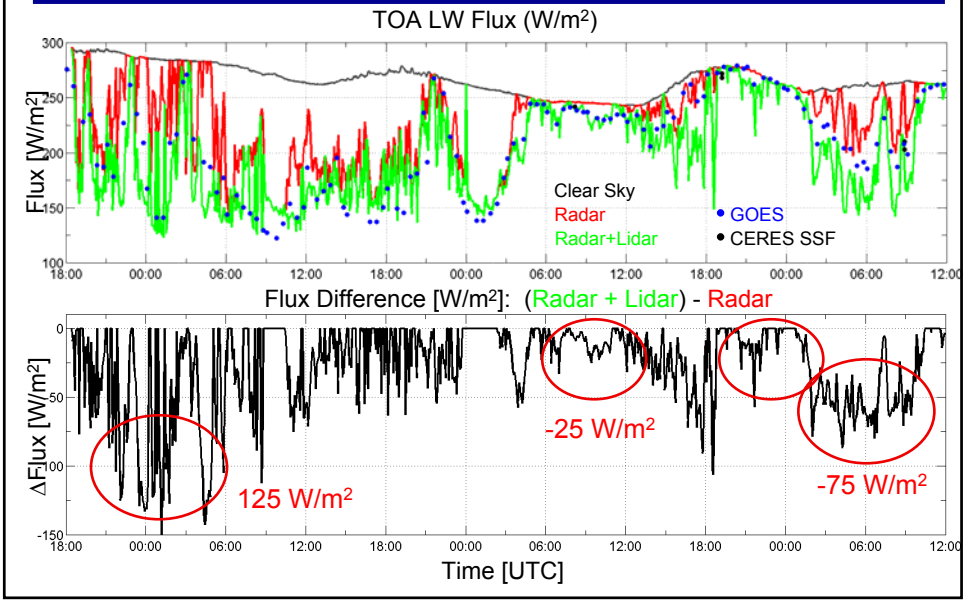
Radiation Station

RRTM_LW

IR Radiative Fluxes and Heating Rates



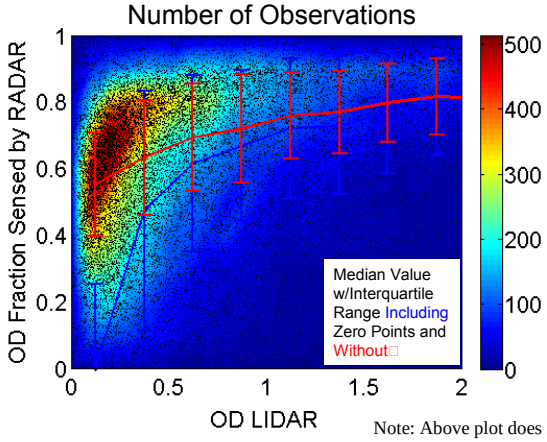
3 Day Case Study



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 the 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 radar plus Raman Lidar
- These products should be used within ARM for climate model studies and evaluations

Overall Summary

- We have demonstrated that Clear Sky TOA OLR is understood at the ARM sites, and globally, to the level of ~1 W/m^2

  (demonstrating the use of high spectral resolution and "AERI in the sky")

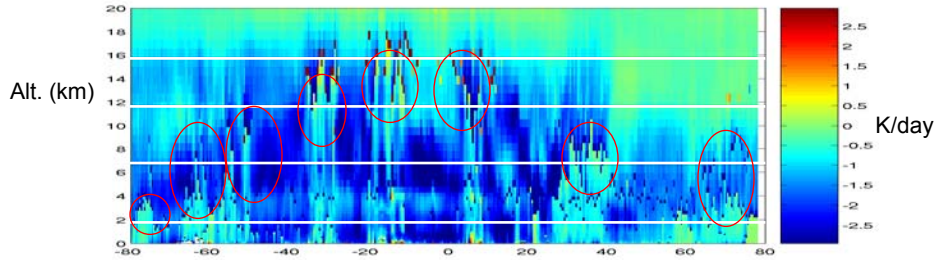
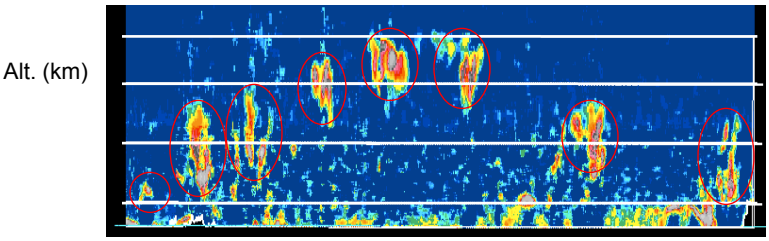
- We have used unique Raman Lidar observations to provide a significantly improved understanding of cirrus clouds at the ARM SGP site

Next Steps

- Combine clear sky and cloudy sky methodology to produce cloudy sky heating rates and fluxes for global climate model assessments, with a focus on cirrus:
  - Using the SGP Raman Lidar products, assess the use of AERI and MPL to produce accurate cirrus cloud characterization, and extend the cirrus cloud characterization studies to the other ARM sites.
  - Analogous to our global clear sky work, use global AIRS, Calipso, and Cloudsat observations to provide global heating rate and flux products. Use ARM site products for evaluation.
  - Perform evaluations of climate model cloud products, heating rates and fluxes using these new products.

Extending clear sky, global method to all sky conditions.

Heating Rates calculated with RRTM using AIRS retrievals.



Calipso backscatter cross section