



ARM Data Products for Climate Model Evaluation

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ARM Technical Director

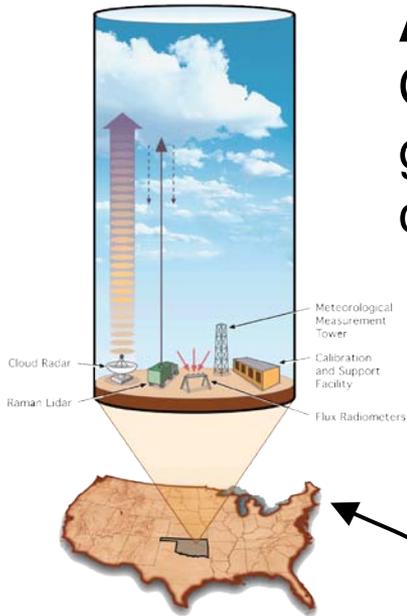
With Extensive Contributions by Shaocheng Xie and Sally McFarlane

Outline

- ARM facility overview
- A model forcing dataset
- The Climate Modeling Best Estimate
- The Radiatively Important Parameters Best Estimate
- The Cloud Retrieval Ensemble Dataset
- New Measurement Capabilities
- Getting started with ARM

ARM Facility and the Atmospheric System Research Program

ARM: The Atmospheric Radiation Measurement Climate Research user facility collects and delivers ground-based observational data for the general climate research community.

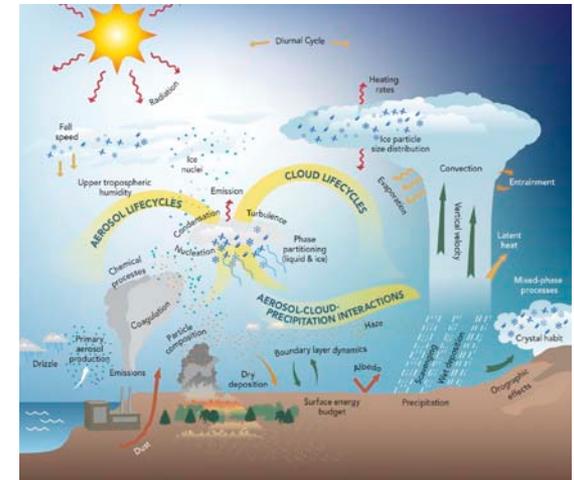


Observations

Goal: Support Improvement of climate models

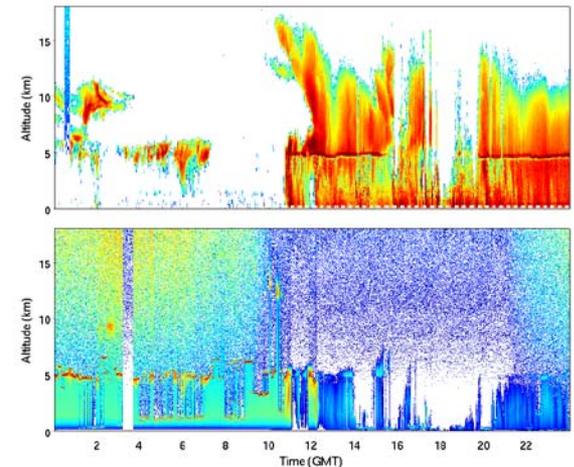
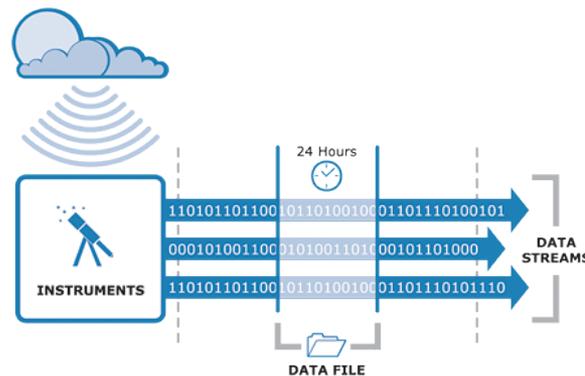
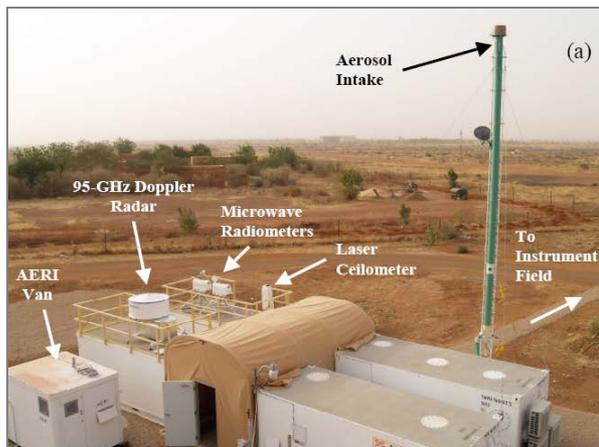
Products and Feedback

ASR: The Atmospheric System Research program conducts climate research based in part on observations conducted with the ARM facility.



ARM Facility Components

- Research sites – permanent, mobile, and aerial
- Instruments and measurements
- Data processing, data quality, Data Archive
- Field campaigns – ground-based and airborne
- The ARM facility is managed and operated through 9 DOE laboratories



Primary Measurements

Surface: Basic meteorology
Radiative fluxes (up/down;
broadband/spectral)
Heat fluxes
Aerosol optical properties

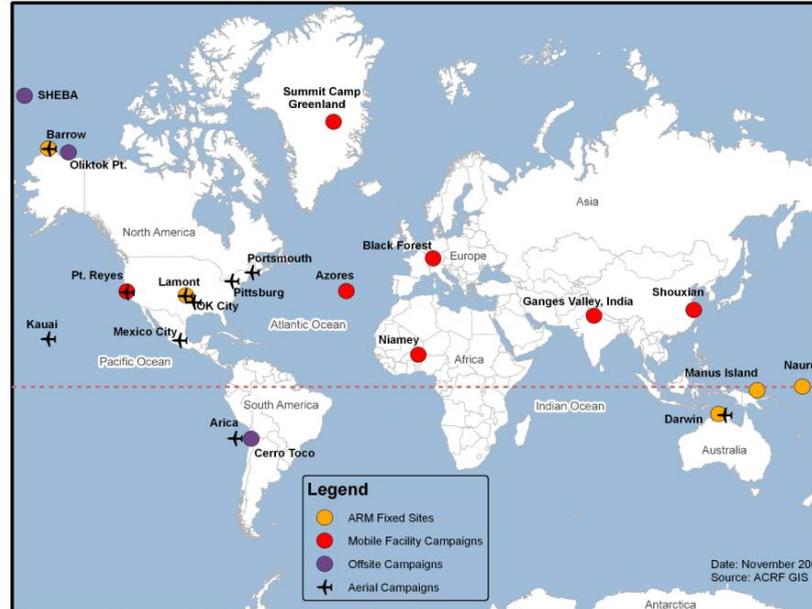
Column: Water vapor
Aerosol optical thickness

Profiles: Basic Meteorology
Cloud Properties
Aerosol properties *

Spatial: Cloud cover



Research Sites



- Southern Great Plains (1993)
- North Slope of Alaska: Barrow (1998) and Atqasuk (1999)
- Tropical Western Pacific: Manus (1996), Nauru (1998), and Darwin (2002)
- First ARM Mobile Facility (2005); Second ARM Mobile Facility (2010)
- ARM Aerial Facility (2007)

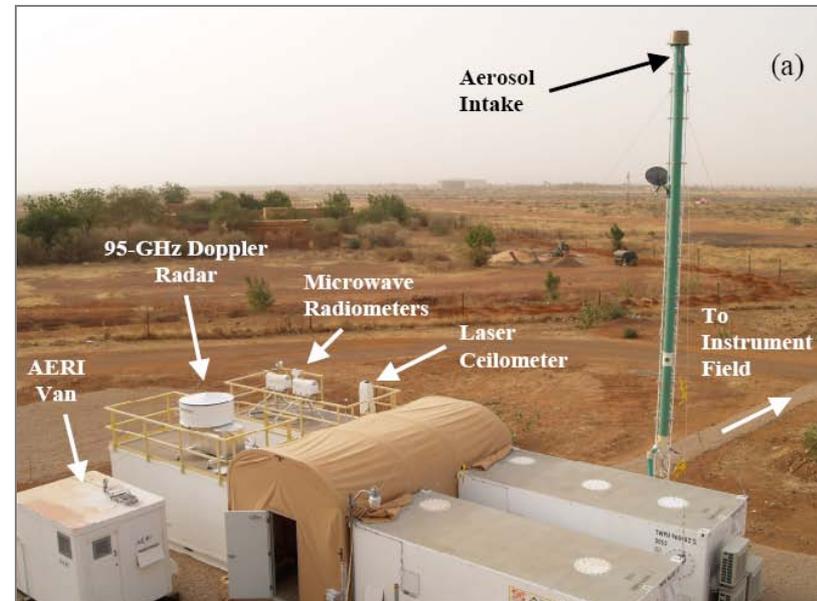
ARM Mobile Facility and Fixed Site Field Campaigns

AMF Deployments

- Point Reyes: Stratocumulus
- Niamey, Niger: Monsoon, aerosol
- Black Forest, Germany: Orographic precipitation
- Shouxian, China: Aerosol-cloud interactions
- Graciosa Island, Portugal (Azores): stratocumulus
- StormVex: Orographic cloud processes

Fixed Site Campaigns

- M-PACE, Barrow: Mixed-phase clouds
- TWP-ICE, Darwin: Tropical convection
- ISDAC, Barrow: Aerosol-cloud interactions
- MC3E, Oklahoma: Mid-latitude convection

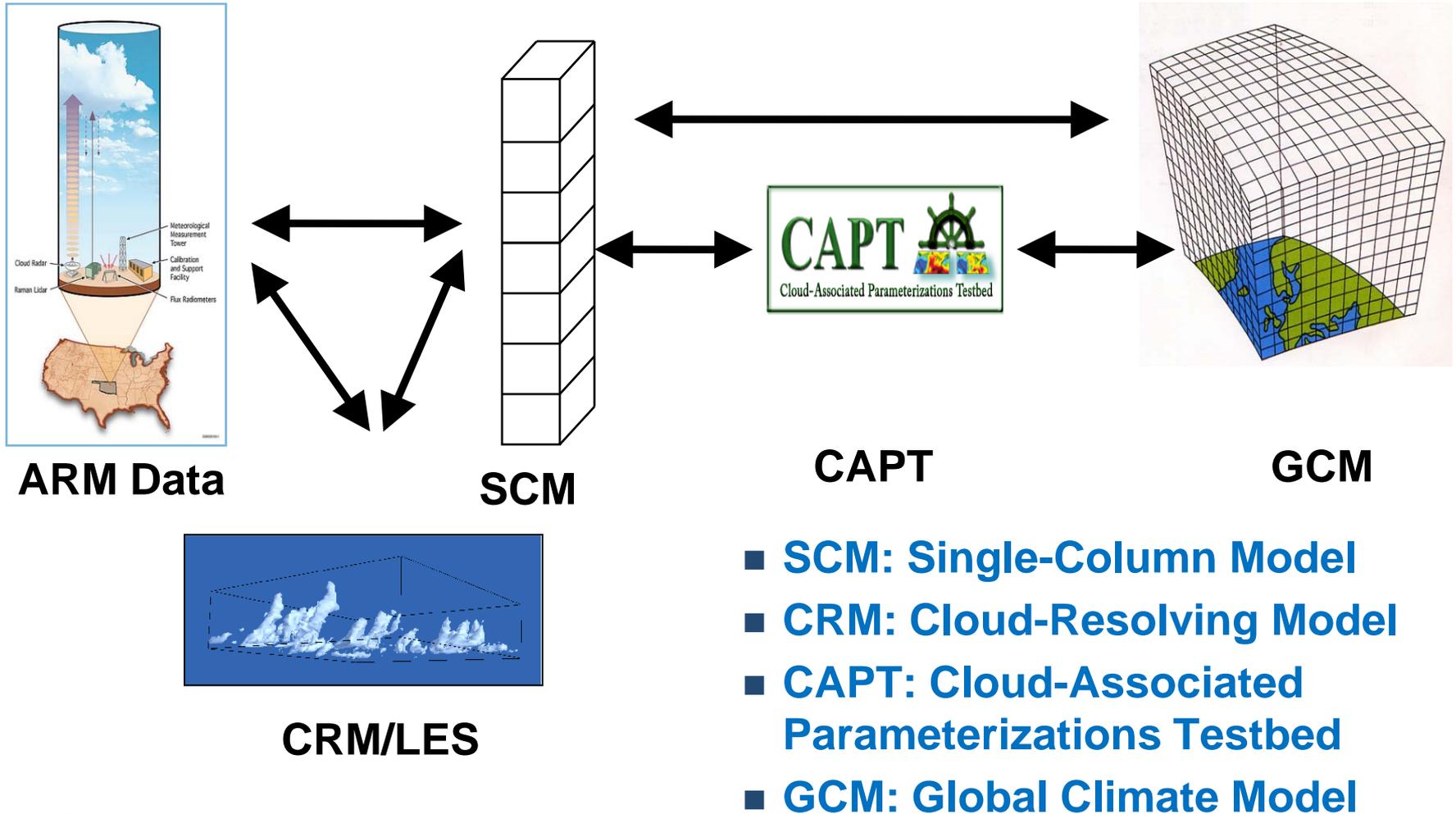


ARM Data for Model Applications

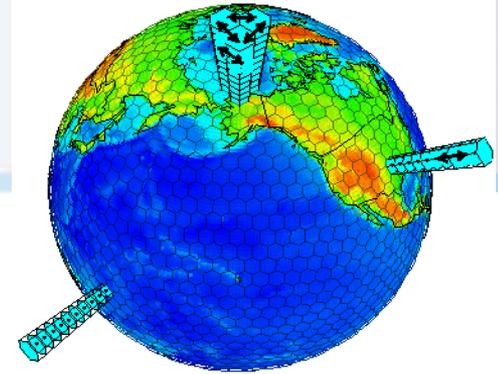
ARM sites provide many useful co-located parameters but they are available at just a few discrete points and the resolution and detail is not well matched to large-scale models.

- How can we link ARM field data and global climate models?
- How can we transform detailed ARM observations into a form that can be easily used by the climate community for model evaluation and development?

The ARM integrated modeling approach



How does the SCM/CRM testbed work?



Our Job

“Advection Forcing” computed from observations

“Physics” computed from:

- CRM explicitly
- SCM parameterizations

$$\frac{\partial s}{\partial t} = -V \cdot \nabla s - \omega \frac{\partial s}{\partial p} + L(c - e) - \frac{\partial \overline{\omega' s'}}{\partial p} + Q_{rad}$$

$$\frac{\partial q}{\partial t} = -V \cdot \nabla q - \omega \frac{\partial q}{\partial p} + (e - c) - \frac{\partial \overline{\omega' q'}}{\partial p}$$

SCM/CRM Case Studies

Toward Improving Model Cloud Parameterizations

- ▶ **ARM Case 1 – SGP Summer 1995 IOP***: focus on methodologies for use in SCMs and CRMs (*Ghan et al., 2000*)
- ▶ **ARM-GCSS Case3 – SGP Summer 1997 IOP**: advance our understanding of midlatitude continental convection (*Xie et al. 2002, Xu et al. 2002*)
- ▶ **ARM-GCSS Case 4 – SGP Spring 2000 IOP**: Frontal clouds (*Xie et al. 2005, Xu et al. 2005*)
- ▶ **ARM-GCSS M-PACE: Arctic Clouds** (*Klein et al. 2009, Morrison et al. 2009*)
- ▶ **ARM-GCSS case 5 – Darwin Jan-Feb 2006 IOP**: Tropical Clouds (*Fridlind et al. 2010*)

*IOP = Intensive Operations Period (aka field campaign)

Beyond Case Studies

Long-term Continuous Forcing Data

Using NWP analyses constrained with surface and TOA observations through the variational analysis, we are able to produce multi-year continuous forcing data to support:

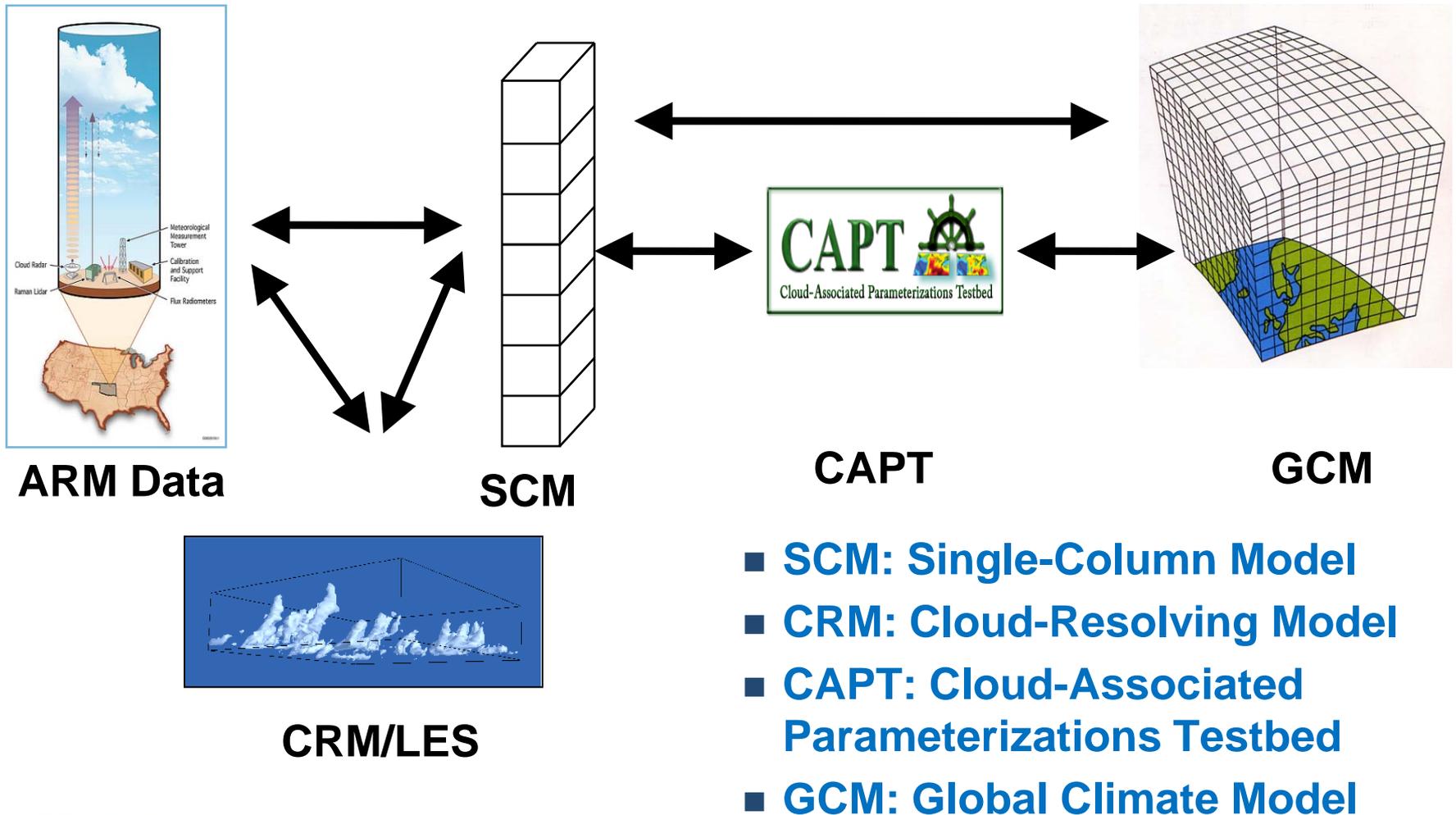
- **statistical studies (e.g., FASTER)**
- **address the issues with uncertainties in the forcing data**

**SGP – RUC analysis constrained by ARM
1999-2009 (11 years)**

**TWP-Darwin – ECMWF analysis constrained by C-POL
radar precipitation**

**Three wet seasons: 11/03/04 - 04/06/05; 11/10/05 – 04/30/06;
10/12/06 – 04/19/07**

The ARM integrated modeling approach



- **SCM: Single-Column Model**
- **CRM: Cloud-Resolving Model**
- **CAPT: Cloud-Associated Parameterizations Testbed**
- **GCM: Global Climate Model**

Issues With Standard ARM Data

- Data from approximately 400 instruments stored in well over 1000 datastreams, one day at a time
- Required geophysical quantities generally exist in multiple data streams
- Obtained by different instruments, derived using different algorithms, and reviewed with different levels of data quality assurance
- Temporal and spatial resolutions are much higher than a typical resolution used in climate model output

It can be difficult for an outside user such as a climate modeler to find the ARM data products that best meet their research needs.

The Climate Modeling Best Estimate Data Product (CMBE)

Assembling those fields that are often used in climate model evaluations from the highest quality of data ARM has available for many years into one single data file with a temporal resolution (one hour) comparable to climate model output.

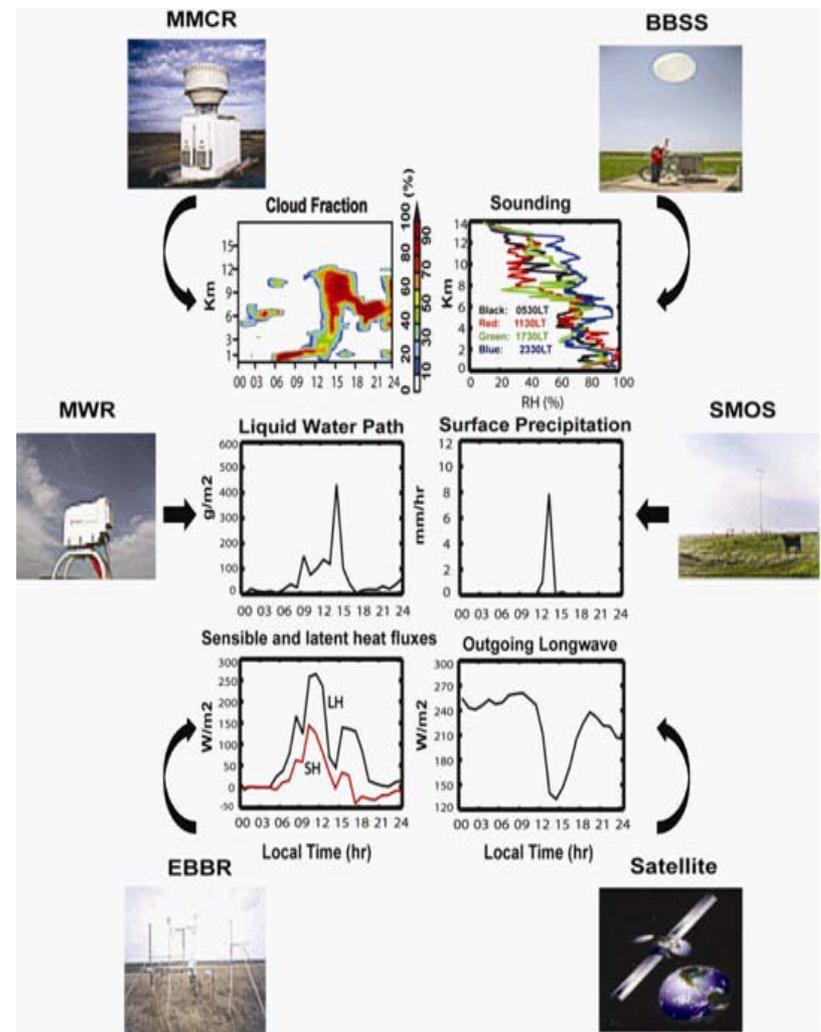
- **Reduce the challenge of finding fields from different data streams in the ARM archive**
- **Encourage greater use of ACRF data by the modeling community**

Xie et al. 2010, BAMS

Current Contents of CMBE

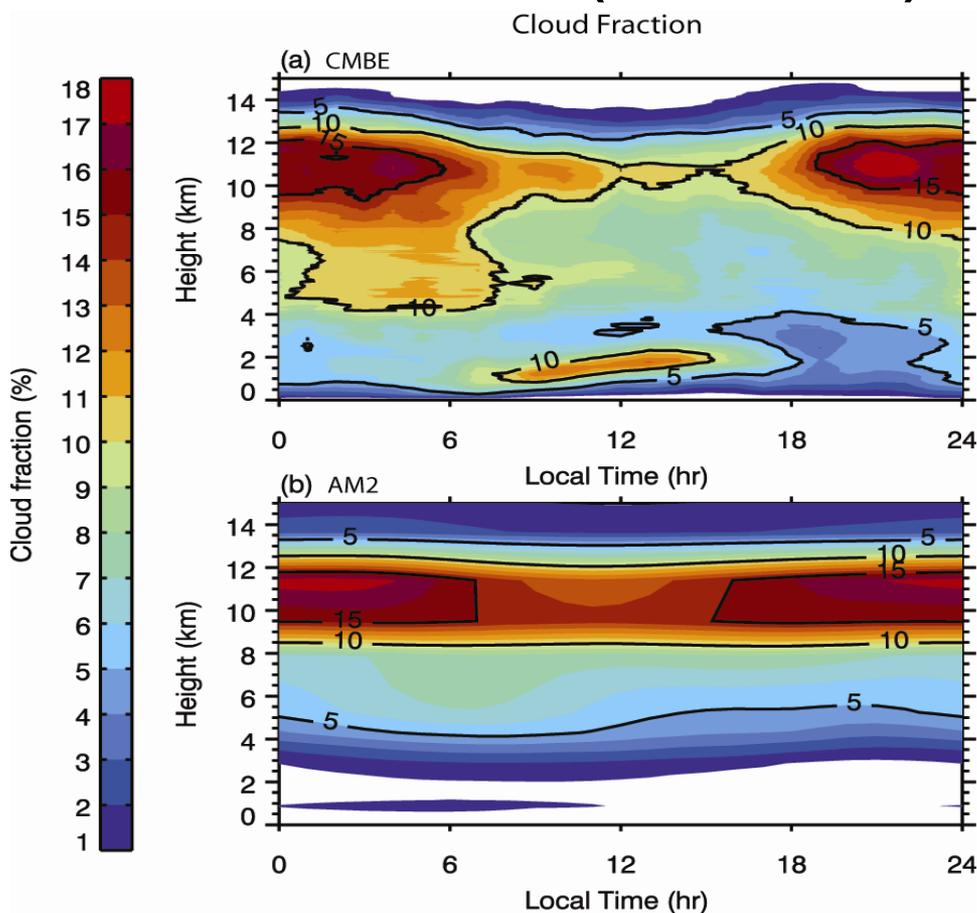
- **CMBE-CLDRAD**
 - Cloud fraction profiles
 - Total clouds
 - LWP/PW
 - Surface radiative fluxes
 - TOA radiative fluxes
 - Satellite retrieved clouds
- **CMBE-ATM**
 - Soundings
 - NWP analysis data
 - Surface heat fluxes
 - Surface precipitation
 - Surface temp, RH, and winds
- **CMBE-cloud microphysics**
(to be added ...)

An Integrated Data Product



CMBE Used to Examine Cloud Fraction Summer Diurnal Cycle at SGP

Cloud Fraction: JJA (1996 – 2007)



AM2 is unable to reproduce the development of shallow convection during the day

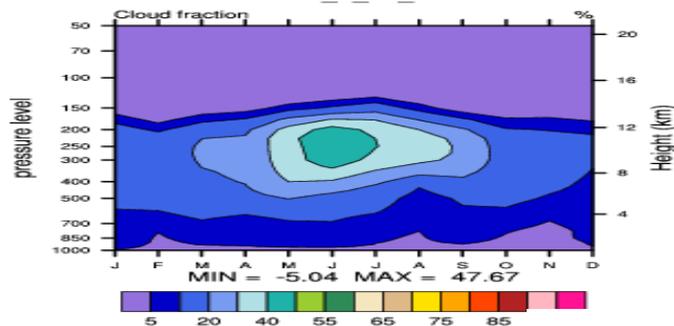
This is also true for most GCMs, e.g., CAM3.

This model error is closely related to deficiencies in model cumulus parameterizations, which fail to correctly capture the diurnal cycle of deep convection

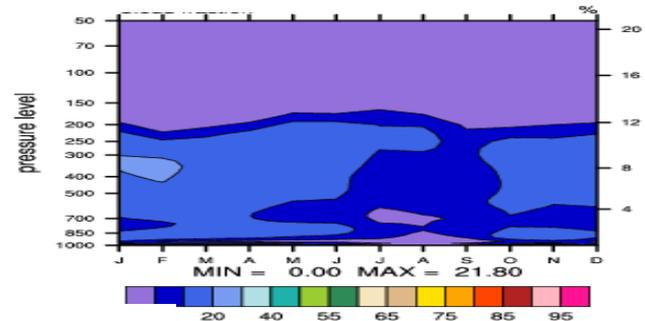
CMBE used in the NCAR Diagnostic Package

Clouds at SGP: CAM3 vs. ARM

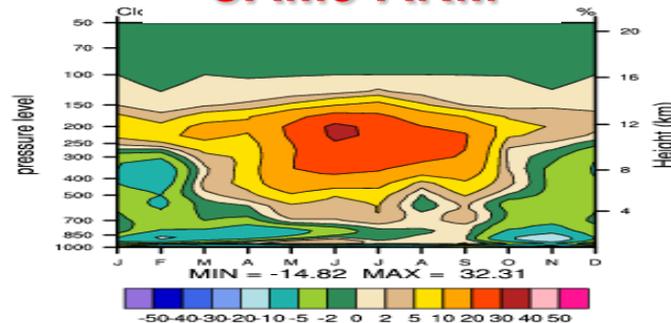
CAM3



ARM



CAM3-ARM



CAM3 produces too much high cloud in warm season (May-Sept) and less mid- or low-level cloud in cold season (Oct. – April) at SGP

CMBE in the Earth System Grid

- Evaluate IPCC models
- Facilitate the use of ARM in a broader community
- Currently available through the ORNL Gateway

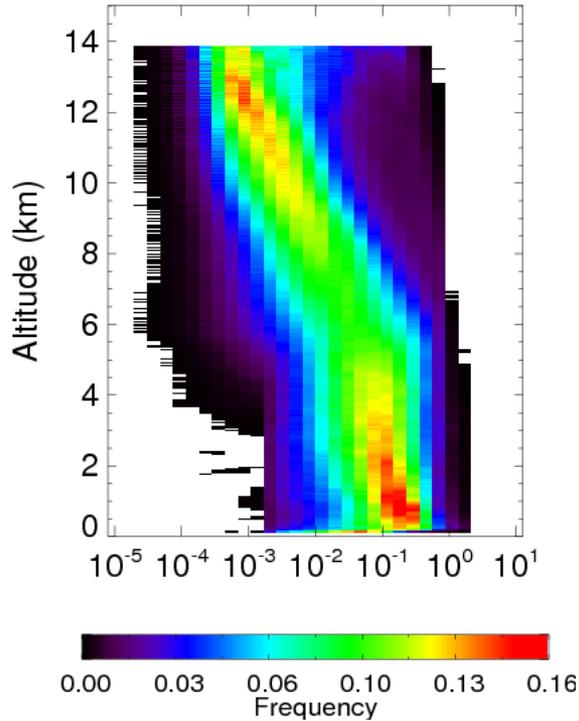


The ESG is the next generation infrastructure that enables distributed data analysis through sharing of climate model output data (IPCC and other) and observational data sets

Radiatively Important Parameters Best Estimate (RIPBE)

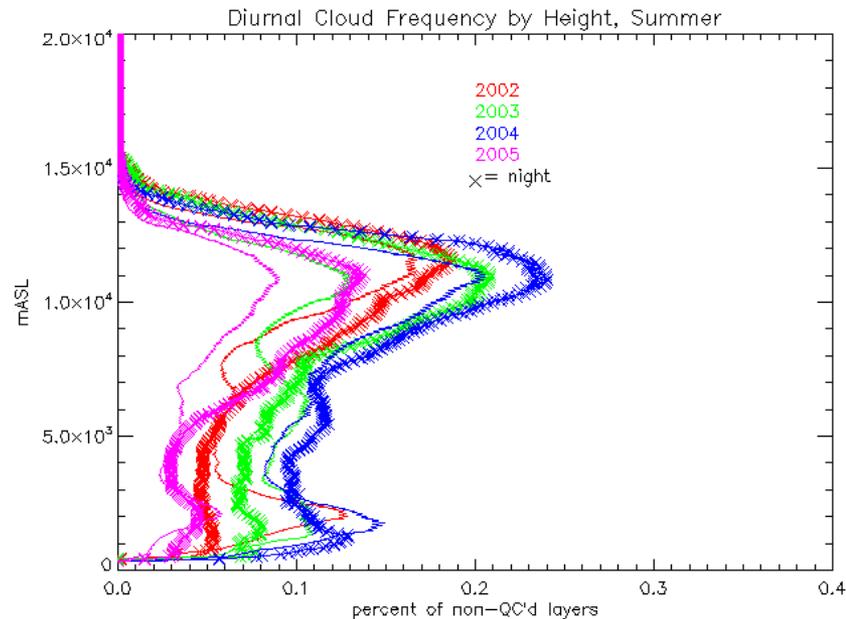
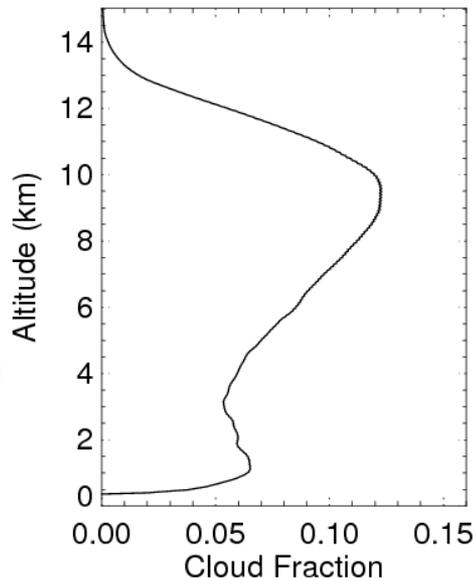
- Combines all radiatively important parameters (water vapor, temperature ozone, surface albedo, aerosol and clouds) required to run a radiation code on a uniform vertical and temporal grid
- Includes quality control (QC) and data source information on each variable
- Outcomes:
 - Provide a set of clearly defined, commonly gridded inputs for the Broadband Heating Rate Profile (BBHRP) project.
 - Facilitate the use of BBHRP as a retrieval development testbed
 - Complement to the Climate Modeling Best Estimate (CMBE) VAP

Detailed Information about Radiatively Important Components of the Atmosphere



Frequency distribution of cloud condensed water (liquid+ice) content over Oklahoma.

High temporal and vertical resolution cloud and aerosol properties provide the means to calculate a variety of statistical representations of column parameters.



ARM Measurements

Put data on common
time, height grid

RIPBE

PI Cloud
Retrieval

RRTM Model

RRTM Model

Another RT Model

Heating Rate and Surface/TOA
Flux Inter-comparisons

ARM

CLIMATE RESEARCH FACILITY

Cloud Retrieval Ensemble Dataset (CRED)

9 ARM Ground-Based Cloud Retrievals

SITE	RETRIEVALS	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SGP	MICROBASE		Yellow	Purple										
	MACE		Purple											
	CLOUDNET								Purple			Purple		
	DENG		Purple	Yellow										
NSA	MICROBASE						Purple							
	SHUPE_TURNER								Yellow	Purple	Yellow		Yellow	
	WANG			Purple										
TWP C1	MICROBASE				Yellow	Purple	Yellow	Purple						
	COMSTOCK						Purple							
	DENG			Yellow	Purple									
TWP C2	MICROBASE						Purple	Yellow	Purple					
	COMSTOCK						Purple							
	DENG		Yellow	Purple										
TWP C3	MICROBASE							Yellow		Yellow		Purple		
	COMSTOCK										Purple	Purple	Purple	Purple
	CLOUDNET									Purple	Purple	Purple	Purple	Purple
	DENG								Yellow	Purple	Purple	Purple	Purple	Purple
	PROTAT_RadLid								Yellow	Purple	Purple	Purple	Purple	Yellow

Note that Purple bar means whole year, yellow bar means partial year.

- **Contain:**
 - LWC/LWP/Re_liq
 - IWC/IWP/Re_ice
 - Optical depth
- **Multiple years**
- **SGP, NSA, TWP sites**
- **CMBE resolution: 45m, hourly data**
- **Web Page for quick plots**
- **Technical report**
- **More data are coming**
- **First version is under review and will be released soon!**

Courtesy Shaocheng Xie

Recovery Act: Introduction

- DOE Office of Science investments in instrumentation and research infrastructure to support the instrumentation and the associated increase in data volume and complexity
- 3-dimensional measurements of cloud scale dynamics, microphysics, and precipitation
- Enhanced measurements of atmospheric aerosol composition and chemistry
- Enhance measurement base to bridge new knowledge into climate models

<http://www.arm.gov/about/recovery-act>



Making use of ARM data

Order data from the ARM archive:

<http://www.archive.arm.gov>

Propose a deployment of the mobile facility or aircraft:

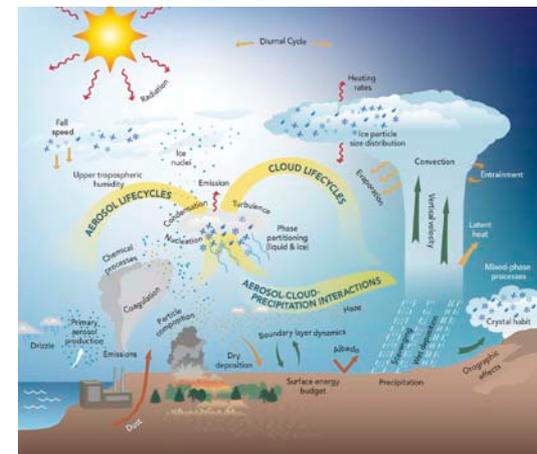
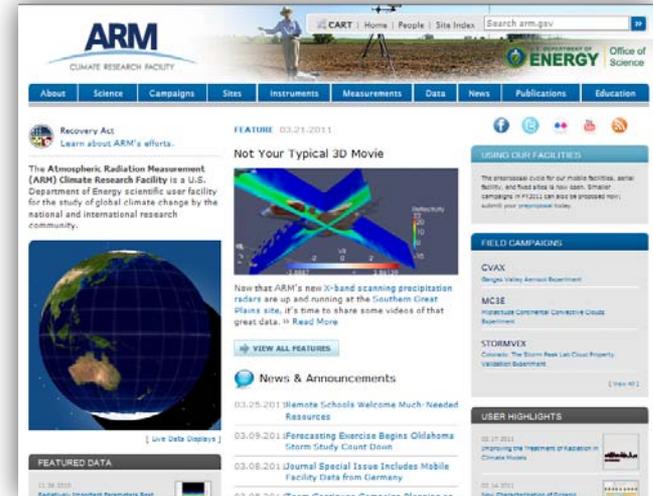
<http://www.arm.gov/campaigns/>

Engage in discussions of new data products
And research applications through the ASR

working groups: <http://asr.science.energy.gov/>

Major upcoming meetings:

- Fall ASR working group meeting
September 12-16, Annapolis, MD
- Spring ASR Science team meeting
March 12-16 Crystal City, VA.



Or contact me: Jim.Mather@pnl.gov