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Contribution to the development of DOE ARM Climate Modeling Best Estimate Data (CMBE) products: Satellite data over the ARM permanent and AMF sites: Final Report

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Contribution to the development of DOE ARM Climate Modeling Best Estimate Data (CMBE) products: Satellite data over the ARM permanent and AMF sites

Final Report

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1. Review of the Scope of Work

1.1 The tasks during the period 04/2010-04/2011

To support the LLNL ARM infrastructure team Climate Modeling Best Estimate (CMBE) data development, the University of North Dakota (UND)'s group will provide the LLNL team the NASA CERES and ISCCP satellite retrieved cloud and radiative properties for the periods when they are available over the ARM permanent research sites. The current available datasets, to date, are as follows: the CERES/TERRA during 200003-200812; the CERES/AQUA during 200207-200712; and the ISCCP during 199601-200806. The detailed parameters list below:

- CERES Shortwave radiative fluxes (net and downwelling)
- CERES Longwave radiative fluxes (upwelling)
  (*: items 1 & 2 include both all-sky and clear-sky fluxes)
- CERES Layered clouds (total, high, middle, and low)
- CERES Cloud thickness
- CERES Effective cloud height
- CERES cloud microphysical/optical properties
- ISCCP optical depth cloud top pressure matrix
- ISCCP derived cloud types (r.g., cirrus, stratus, etc.)
- ISCCP infrared derived cloud top pressures

The UND group shall apply necessary quality checks to the original CERES and ISCCP data to remove suspicious data points. The temporal resolution for CERES data should be all available satellite overpasses over the ARM sites; for ISCCP data, it should be 3-hourly. The spatial resolution is the closest satellite field of view observations to the ARM surface sites. All the provided satellite data should be in a format that is consistent with the current ARM CMBE dataset so that the satellite data can be easily merged into the CMBE dataset.

1.2 The tasks during the period 04/2011-04/2012

The UND's group will provide the required satellite data with the same temporal and spatial resolutions as used for the ARM permanent sites for the following ARM Mobile Facility (AMF) sites during the periods listed below:

- AMF-Monterey: March-September 2005
- AMF-Niamey: January 2006-January 2007
- AMF-German: April-Dember 2007
- AMF-China: May-December 2008
- AMF-Azores: May 2009-December 2010.

In addition to the above tasks, the UND group will help the LLNL team with development of the CMBE dataset which includes both satellite data and ARM ground base measurements for the AMF China and Azores sites. This is an extra task added after the original subcontract was made.

2. Summary of the outcome of the 2-yr (04/2010-04/2012) DOE LLNL ARM subcontract

2.1 Satellite data provided over the ARM Primary Research sites during 1st year period

The purpose of this subcontract was to include in the CMBE products as many as possible satellite observed cloud and radiative properties with stringent quality controls. For this task, three satellite datasets have been processed and provided to LLNL ARM infrastructure team as part of their CMBE products. The first data set is the CERES-MODIS CRS Edition 2 product. The original spatial resolution is the Single Scanner Footprint (SSF) of CERES for radiative fluxes. We then grouped all of the footprints within 1° latitude to 1° longitude grid box centered over the ARM surface sites. The details about the data qualities are discussed in a number of publications [1][2][3]. The second dataset is the GOES VISST/SIST product over the four DOE ARM sites (SGP, MANUS, NAURU, and DARWIN)[4], and the third satellite dataset is the ISCCP data.

Table 1: Summary of ARM sites, available satellite datasets, and delivered dates

Sites	Available data periods	Date delivered	Terra	Aqua	GOES
NSA	2002-2005	Jul. 18, 2010	Yes	yes	N/A
Darwin	2003-2005	Aug. 18, 2010	Yes	yes	Yes
Darwin	2002	Sept. 1, 2010	Yes	yes	No data available
Manus	2003-2005	Oct. 5, 2010	Yes	yes	Yes
Manus	2002	Oct. 5, 2010	Yes	yes	No data available
SGP	2002-2007	Nov. 24, 2010	Yes	yes	Yes
Nauru	2002-2007	Nov. 24, 2010	Yes	yes	2003-2005
Manus	2002-2007	Nov.24, 2010	Yes	Yes	2003-2005
Darwin	2002-2007	Nov. 24, 2010	Yes	Yes	2003-2005
NSA	2003, 2006, 2007	Nov. 24, 2010	Yes	Yes	N/A
NSA	2000, 2001, 2008	Jan. 20, 2011	Yes	No	N/A

Table 1 lists the ARM surface sites, the available satellite datasets, their availability time periods, and our delivering dates. The NASA satellite datasets were processed with the following four steps. (1) The original Terra and Aqua SSFs were grouped into a 1° x 1° grid box centered on the DOE ARM sites, including Northern Slope of Alaska (NSA), Tropical Western Pacific TWP sites (Manus, Nauru, and Darwin), and Southern Great Plains (SGP). (2) The TERRA and AQUA parameters included in the final products were CERES shortwave (net and downwelling) and longwave (upwelling) radiative fluxes under both clear-sky and all-sky conditions, CERES total, low, mid and high cloud fractions, and cloud effective heights. (3) The TERRA and AUQA parameters were merged with GOES results to provide their diurnal cycles. (4) ISCCP cloud properties, such as cloud optical depth, cloud-top pressure, and cloud types, were also processed and provided to the LLNL ARM infrastructure team. All above four tasks except GOES datasets were performed during the first year agreement, and later on the GOES datasets were added and provided to the LLNL ARM team before the end of 1st year period.

2.2 Extended TERRA and AQUA periods and added ISCCP data during 1st year period

Table 2 summarizes the extended TERRA and AUQA time periods and added on ISCCP dataset over the five permanent ARM surface sites, as well as our delivered dates during the 1st year period.

Table 2: Summary of extended TERRA/AQUA time periods and added ISCCP dataset

Sites	Available data periods	Date Submitted	Terra	Aqua	ISCCP
SGP	1998-2008	Mar. 8, 2011	yes	Up to 200712	2000- 2008
Manus	1998-2008	Mar. 8, 2011	yes	Up to 200712	2000-2008
Nauru	1998-2008	Mar. 8, 2011	yes	Up to 200712	2000-2008
Darwin	1998-2008	Mar. 8, 2011	yes	Up to 200712	2000-2008
NSA	1998-2008	Mar. 8, 2011	yes	Up to 200712	2000-2008

2.3 CERES Flushflux over Shouxian, China to evaluate the ECMWF simulations during 2nd year period

During the second year period, we also processed and provided the diurnal variation of the TOA/surface fluxes and cloud properties over Shouxian, China, during Oct. and Nov. 2008. The TOA and surface fluxes were used in a similar way as before and with a specific defined domain (~1.5° x1.5°) surrounded at Shouxian, China (Figure 1), the domain switched the circle centered on Shouxian, China without changed the size of the previous domain (processed on July 18th, 2011). This dataset was provided to ARM CMBE team on April 19th, 2011. However, with limited overpasses over Shouxian, it is difficult to provide the diurnal cycles of cloud and radiation properties. As a result, we reprocessed the data by using a different beta version of products, which is called Flushflux-TISA Version 2E. The comparison between CERES/MODIS and Flushflux has shown in Figure 2 (provided by Dr. Yunyan Zhang of LLNL) where a mismatch of the diurnal variation between these two datasets was found. After re-processing the Flashflux data, the diurnal cycle comparison between ECMWF, CERES-MODIS and Flashflux has reached a good agreement as shown in Figure 3.

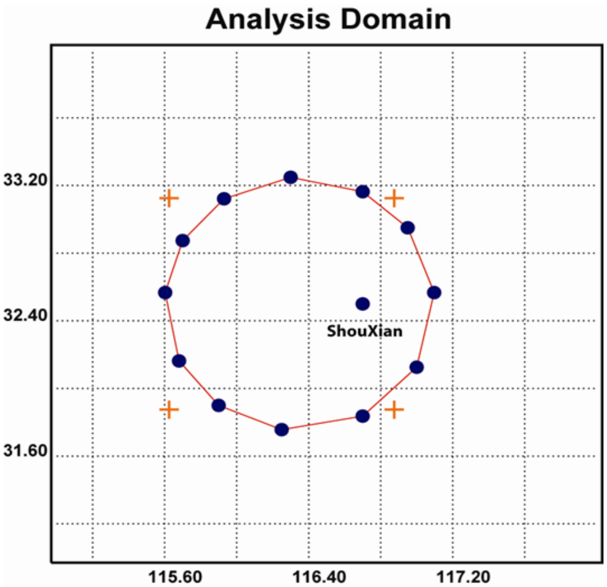

Figure 1. The circle represents the ECMWF domain. The CERES-MODIS data were averaged over a 1.5°x1.5° grid box surrounded by Shouxian. Flashflux data were averaged to the same grid box as CERES-MODIS data. Later we shifted the domain to be centered on Shouxian to match the satellite data (provided by Dr. Yunyan Zhang).

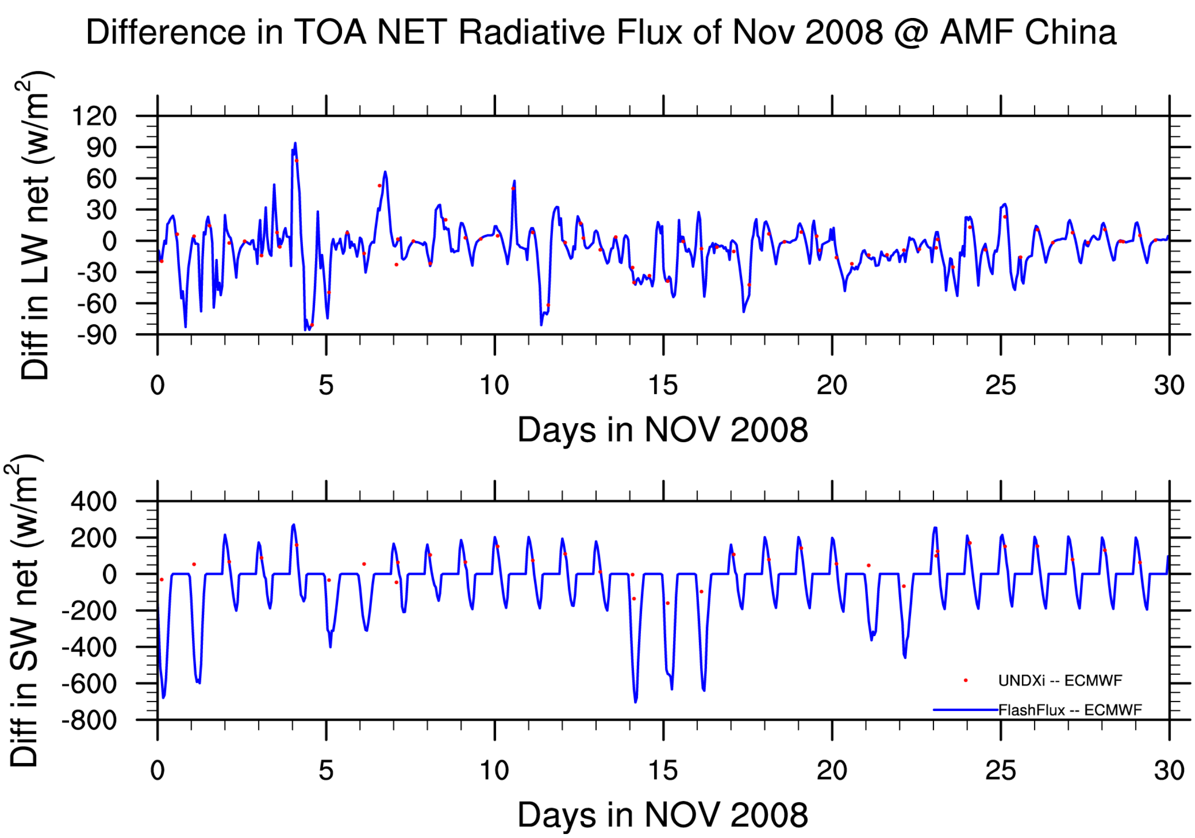

Figure 2. Comparison between the CERES-MODIS and Flashflux data.

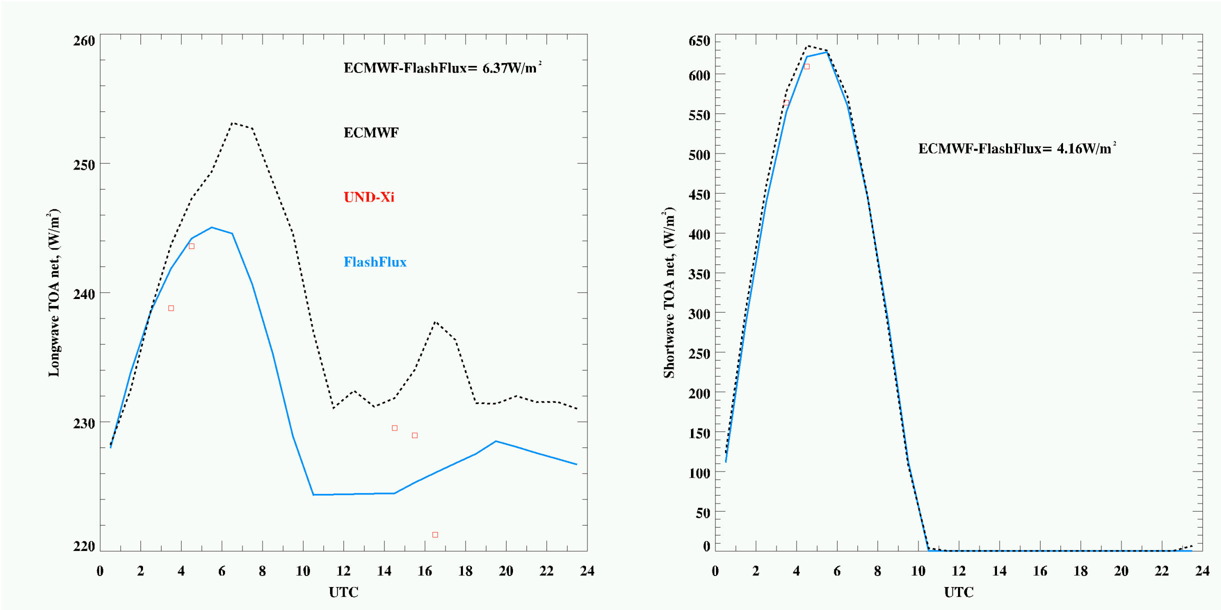

Figure 3. Evaluation of ECMWF simulated TOA shortwave and longwave net fluxes using CERES observations over Shouxian, China during Nov. 2008.

2.4 Provided TRMM precipitation over ARM sites during 2nd year period

In response to a special request from the LLNL ARM team, we processed the TRMM retrieved precipitation over selected ARM permanent sites and mobile facility sites to support their CMBE and large-scale forcing developments. To evaluate the TRMM retrieved precipitation over the SGP site (2°X2° grid box centered on the SGP) using Oklahoma MESONET measurements during January 2000 to December 2009. As illustrated in Figure 4, TRMM measurements can basically catch the monthly variations even with a few overpasses per day. A few months of results have large differences to OK MESONET results, for example, the TRMM monthly averaged precipitation during June 2008 was much higher than that measured by MESONET, while during September 2009, it was much lower than that measured by MESONET. All of the differences between these two measurements can be accounted for by the sampling and diurnal variation of the precipitation issues. During the data processing, we also found a data processing error from TRMM. Therefore we sent our feedback to TRMM researchers and suggested them to fix this problem. After the data error was corrected, we re-ordered the data on May 25, 2011 and re-processed them. Although the precipitation retrieved by TRMM and measured by MESONET agree well over the SGP region, this conclusion is not universal and may not be valid in other regions, such as tropical regions where diurnal variations are very strong.

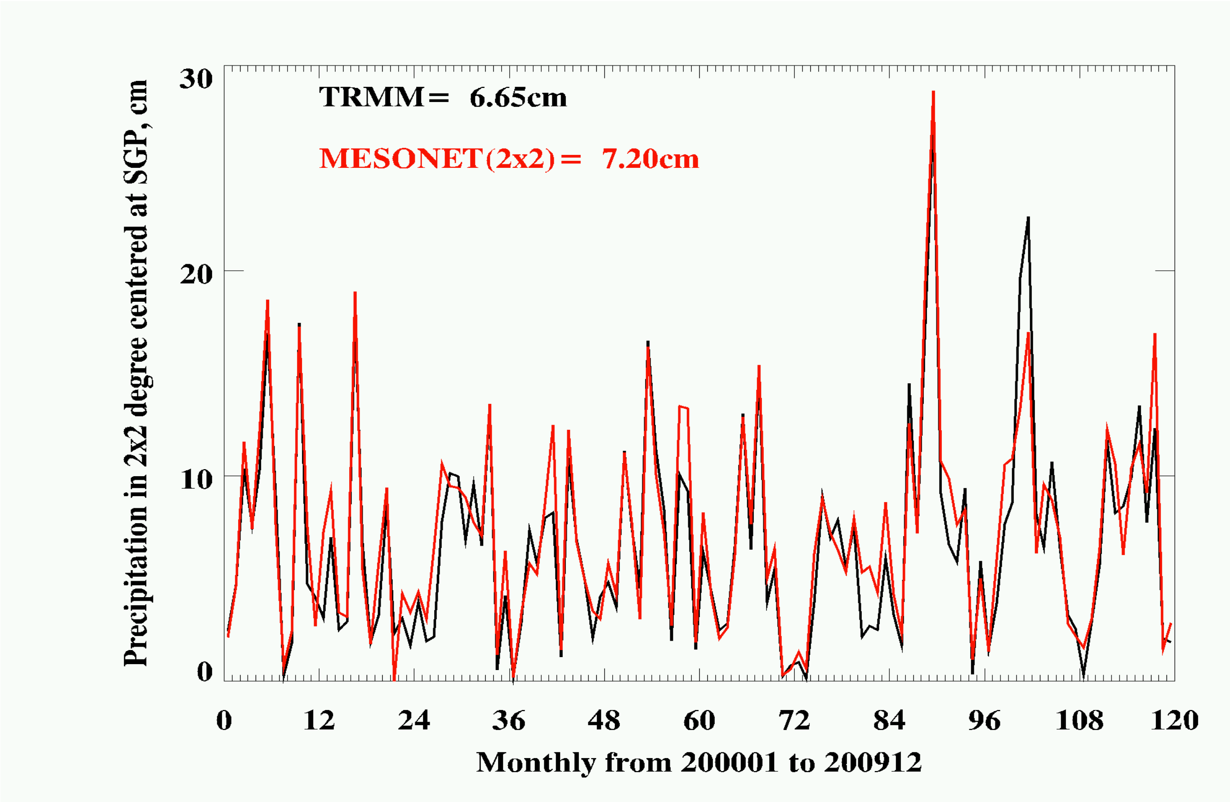

Figure 4. Comparison of TRMM 3B42 precipitation results with Oklahoma MESONET rain gauge measurements over the SGP (2°X2° grid box centered on the SGP) during the period 01/2000-12/2009.

Table 3: Summary of available TRMM precipitation periods and delivered dates

Sites	Time periods	Date submitted	Re-submitted based on Dr. McCoy's suggestion
SGP	2000-2010	May 26, 2011	Jun. 3, 2011
TWPC1	2000-2010	May 26, 2011	Jun. 3, 2011
TWPC2	2000-2010	May 26, 2011	Jun. 3, 2011
TWPC3	2000-2010	May 26, 2011	Jun. 3, 2011

2.5 AMF ground-based measurements at Shouxian, China, and Azores during 2nd year period

There were additional tasks beyond the scope of work originally defined in the subcontract. They were requested by the LLNL ARM team to support various cloud modeling studies conducted in the DOE ASR program. One example is the development of CMBE for the AMF China and Azores. During the data processing for the two DOE ARM AMF sites, there were a number of different measurements available for each site. The initial work was to figure out what measurements or simulations can be used to generate similar products as those for ARM permanent sites. We spent significant effort to analyze similar datasets, such as ECMWF vs. NCEP simulations, ECOR vs. MET measurements, etc. After selecting the data sets, we also checked the data quality of these measurements. Even with Dr. McCoy's programs, which were used for processing DOE ARM data over the permanent sites, we had to spend significant efforts to substitute the appropriate data into the programs.

Table 4: Summary of AMF (at Shouxian, China) measurements and dates processing and submitting data

Variables	observations	datastream	Availability-periods	Processed date
SH, LH	ECOR	30ecor	20080506-20081228	Nov. 3, 2011
Cloud fraction, Cloud vertical distribution	MPL	30smplcmask1zwang	20080515-20081228	Nov. 3, 2011 Dec. 5, 2011
RH, u, v, P, T, rainrate	MET	metS1	20080520-20081228	Nov. 3, 2011
LWP, PWV	MWR	mwrlos	20080508-20081224	Oct. 31, 2011
swdn,swup, swdir,swdif, swift,lwdn, lwup	PSP,PIR	qcrad1long	20080516-20081228	Oct. 31, 2011
Wind speed and wind direction, P, T, lon, lat	Balloon-borne sounding system (BBSS)	sondewnpn	20080514-20081228	Dec. 4, 2011
Cloud fraction	Total sky imager	tsiskycover	20080508-20081228	Oct. 31, 2011
Products	**Time periods**	**submitted**		
CMBE_ATM	200805-200812	Dec.20,2011		
CMBE_CLD	200805-200812	Dec.20, 2011		

Table 5: Summary of AMF (at Azores) measurements and dates processing and submitting data

Variables	observations	datastream	Availability-periods	Processed date
SH, LH	ECOR	30ecor	20090501-20101011	Apr. 19, 2012
Cloud fraction	MPL	30smplcmask1zwang	20090411-20110105	Nov. 3, 2011 Dec. 5, 2011
RH, u, v, P, T, rainrate	MET	metS1	20090414-20110106	Nov. 3, 2011
LWP, PWV	MWR	mwrlos	20090501-20101231	Oct. 31, 2011
swdn,swup, swdir,swdif, swift,lwdn, lwup	PSP,PIR	qcrad1long	20090416-20110106	Oct. 31, 2011
Wind speed and wind direction, P, T, lon, lat	Balloon-borne sounding system (BBSS)	sondewnpn	20090416-20110106	Dec. 4, 2011
Cloud fraction	Total sky imager	tsiskycover	20090414-20101021	Oct. 31, 2011
Cloud base height	ceilometer	vceil25k	20090413-20100106	Nov. 1, 2011
Cloud vertical distribution, cloud heights	WACR	wacr	20090605-20110106	Mar. 21, 2012 Apr. 8, 2012
Products	**Time periods**	**submitted**		
CMBE_ATM	200905-201012	Apr. 19, 2012		
CMBE_CLD	200905-201012	Apr. 19, 2012		

Note: the revised programs can be available for the future AMF data processing. No VISST retrievals are available for all the AMF sites at this moment.

2.6 Evaluation of CMBE CLDRAD data during 2nd year period

Another contribution to CMBE products is to evaluate hourly mean Cloud Fraction (CF) in the CLDRAD product at the ARM sites. Because an independent data source and longer time period are required to perform the evaluation, therefore we used MACE PI products at the SGP site in this study [4][5][6][8]. Figure 5 shows the data availability for both CLDRAD and MACE PI products. We used QC source to discriminate two situations. QC =1 represents both MMCR and MPL available within an hour, and QC =2 represents only MMCR available. Comparisons with the Mace PI products during a select period revealed a negative bias in total CF of CLDRAD, especially during the early years of remote sensing at the ARM SGP site (prior to 2002) as demonstrated in Figure 6.

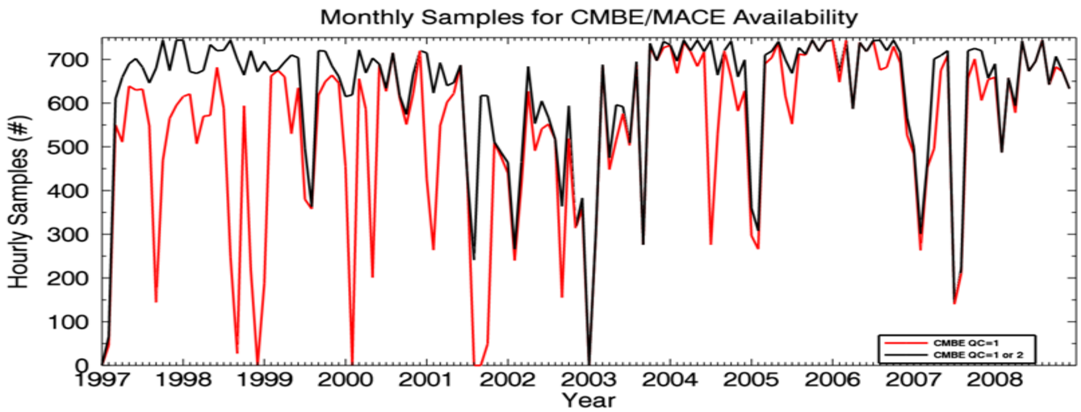

Figure 5: Monthly 1-hr samples for both CMBE and MACE PI products at the ARM SGP site from January 1997 to December 2008. QC =1 represents both MMCR and MPL available within an hour, and QC =2 represents only MMCR available (provide by Dr. Aaron Kennedy).

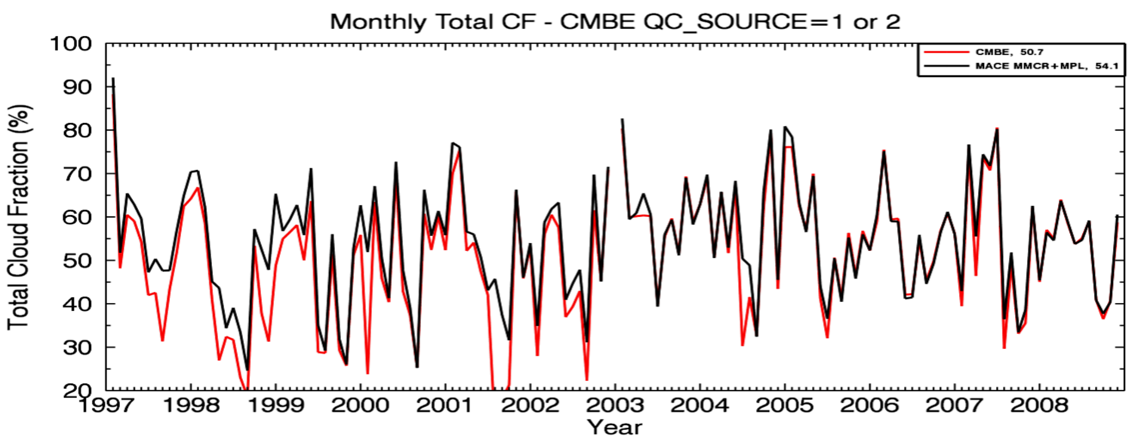

Figure 6, Comparison between CMBE cloud fraction (QC=1 or 2) and MACE PI products at the ARM SGP site during the period January 1997-December 2008 (provide by Dr. Aaron Kennedy).

To identify which product was correct, we reprocessed the ARSCL VAP to 5-min and hourly intervals in a fashion similar to the CMBE algorithm (using similar QC flags). Comparisons between the three products were performed from 1997-2008 and were presented in a talk entitled "Comparisons of CF at the ARM SGP Site" in Sept 2011 during the 2011 Fall ASR workgroup meeting and discussed with Dr. Shaocheng Xie via personal communications and emails.

In this study, we found CMBE had noticeably less CF during the period 1997-2002 compared to our reprocessed ARSCL data. Investigation of specific cases found the culprit for this bias. During time periods of MPL downtime, the MMCR cloud mask in CMBE was missing many cases of clouds with bases >6km. The exact reason for the missing MMCR clouds was traced to the screening of the cloud mask by ceilometer data. In its original form, CMBE removed all clouds below laser cloud base when the ceilometer identified clear sky. Unfortunately, when the

MPL was not operational (which occurred frequently before 2003), the Belfort ceilometer frequently reported clear sky when in fact, there were clouds above its operational limit. This study has led to an improvement of cloud fraction in CMBE, which is used in a couple of publications [3][7].

3. Summary

In summary, we have successfully completed this two-year subcontract with the LLNL ARM infrastructure team and delivered all the required satellite data products to LLNL in support of the development of the highly desired Climate Modeling Best Estimate data. In addition, we also responded various data requests that were not originally defined in the subcontract from the LLNL ARM team. Particularly, we have worked with the LLNL team to create the CMBE data for the AMF China and Azores to support various cloud modeling studies in the DOE Atmospheric System Research program.

4. References

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