Evaluation of CERES-MODIS Ed4 Cloud Fraction, Cloud Phase Classification and Cloud Height with ARM Ground Observations

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Publications *(2018)*

- Tian, J., X. Dong, B. Xi, P. Minnis, S. Sun-Mack and W. L. Smith, Jr., **2018**: Comparisons of Water Path in Deep Convective Systems among CERES-MODIS, GOES, and Ground-based retrievals **JGR**, 123. https://doi.org/10.1002/2017JD027498.
- Qiu S., B. Xi and X. Dong, **2018**: Influence of wind directions on thermodynamic properties and Arctic mixed-phase clouds at Barrow, Alaska in autumn season. **Accepted by JGR**.
- Huang, Y., X. Dong, B. Xi and Y. Deng, **2018**: A Survey of the Atmospheric Physical and Dynamical Processes Key to the Onset of Arctic Sea Ice Melting in Spring. **Accepted by Climate Dynamics**
- McHardy, T.M., X. Dong, B. Xi, M. M. Thieman, and P. Minnis, **2018**: Comparison of Daytime low-level Cloud Properties derived from GOES and ARM SGP Measurements. **Submitted to JGR**.
- Tian, J., X. Dong, B. Xi, and C.R. Williams, **2018**: Estimation of Liquid Water Path in Stratiform Precipitation Systems using Radar Measurements. **Submitted to JGR**.
- Dolinar E.K., X. Dong, B. Xi, J.H. Jiang, H. Su, N.G. Loeb, and J.R. Campbell. **2018**: A Record of Global Single-layered Ice Cloud Properties and Associated Radiative Heating Rate Profiles from an A-Train Perspective. **Submitted to Climate Dynamics**.

Outlines

Part I: Cloud fraction and phase detection of CERES-MODIS Ed4 over DOE ARM NSA site;

Part II: Update of the cloud height comparison between CERES-MODIS Ed4 and ARM measurements over NSA site;

Part III: Evaluate IWP retrieved by Terra+NPP Ed1A over MAO site.

Scientific Questions

(1) How does the CERES-MODIS cloud mask perform under different surface conditions and day/night time over the Arctic?

(2) How does the CERES-MODIS phase algorithm perform over the Arctic?

(3) What is the difference between the CERES-MODIS lapse rate (Γ) and the ground truth; and how much does this difference influence the cloud height retrieval?

(4) How close is the Terra+NPP Ed1A retrieved IWP compared with ground-based retrieval for DCS at MAO?

DATA and Methods

ARM

Part I and II:

- 1-h average ground-based observations centered at the time of each satellite overpass
- Cloud radar, micropulse lidar (MPL), ceilometer, microwave radiometer are used for cloud properties retrieval
- Cloud phase are classified using lidar backscatter, MPL depolarization ratio, LWP and cloud temperature from sounding

Part III:

- One hour average of ground-based IWP centered at overpass time.

CERES-MODIS/CCCM

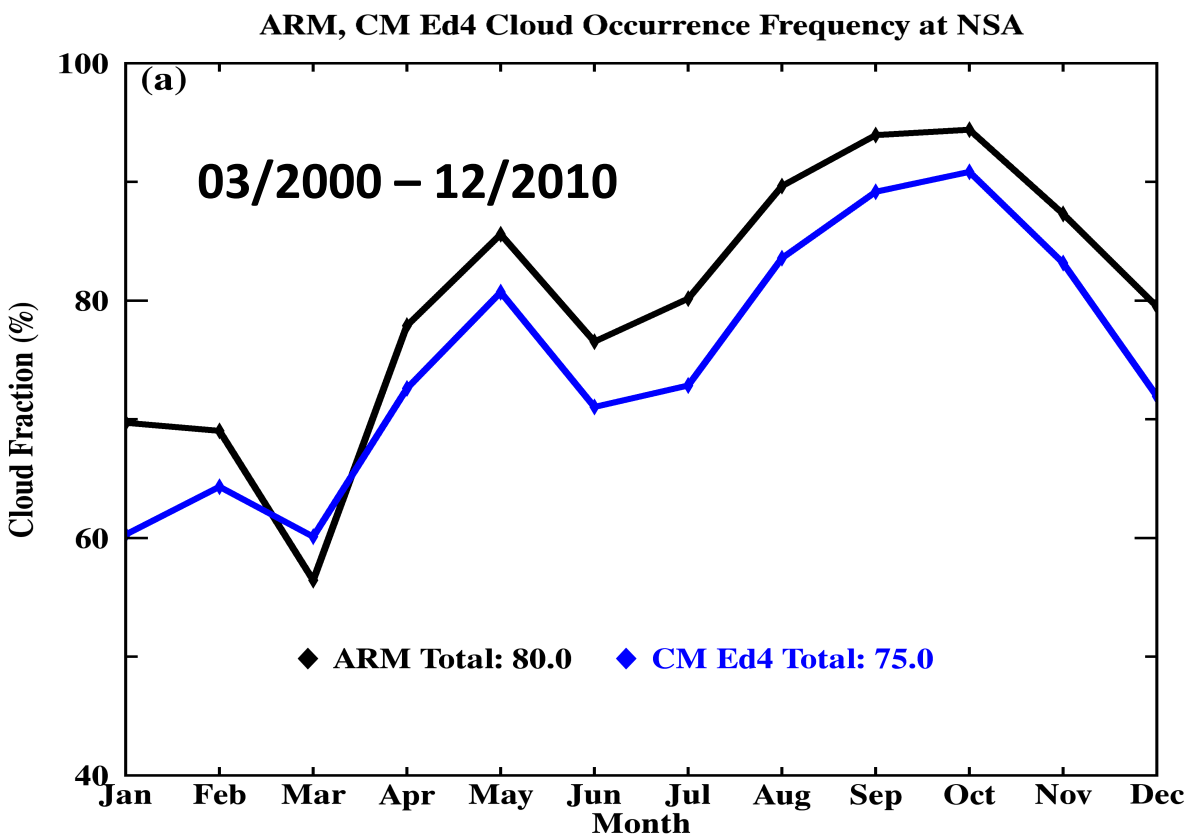
Part I and II:

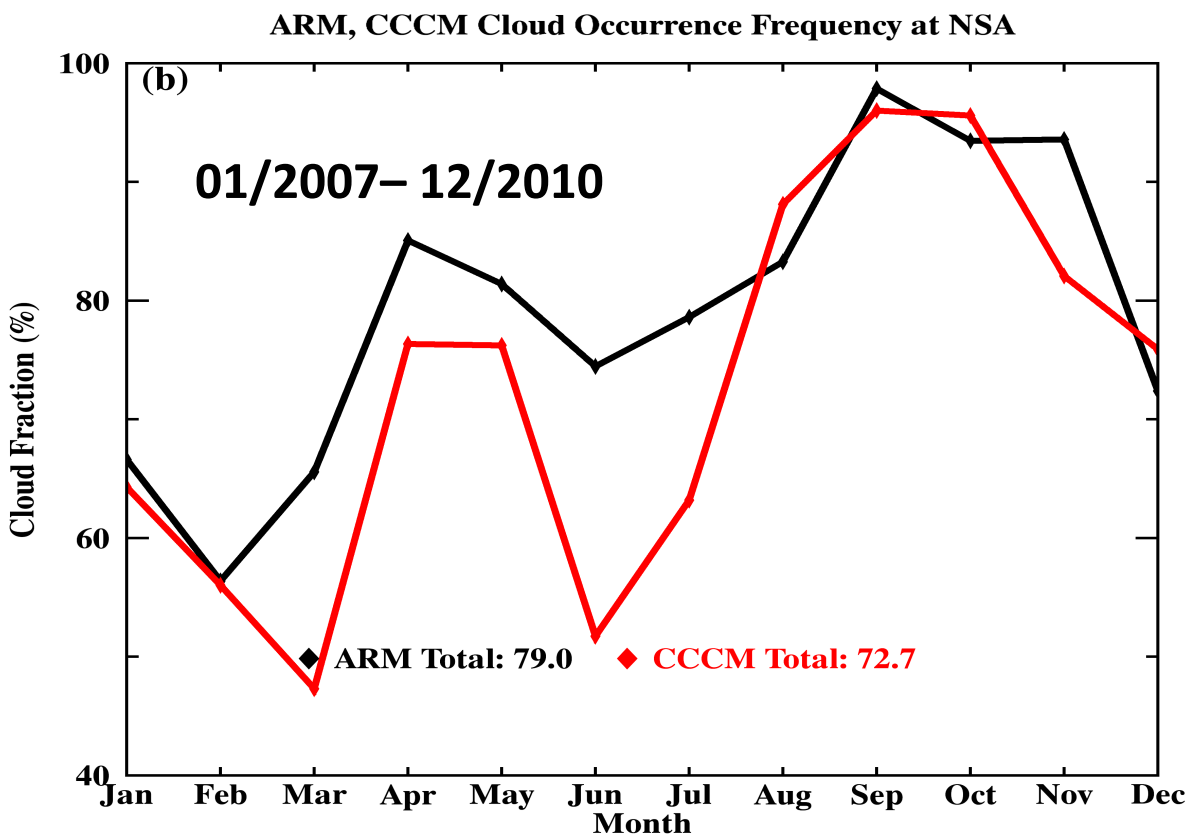
- CERES-MODIS Ed4 SSF data that have overpasses within the 30 ×30 km^2 box centered at ARM site
- CCCM data averaged within 100 ×100 km^2 box;
- CERES-MODIS used the first layer phase classification with 1.2 threshold

Part III:

- Terra+NPP Ed1A IWP is from 1x1 degree data product;

CERES-MODIS (CM) Ed4, CCCM and ARM NSA Cloud Fractions

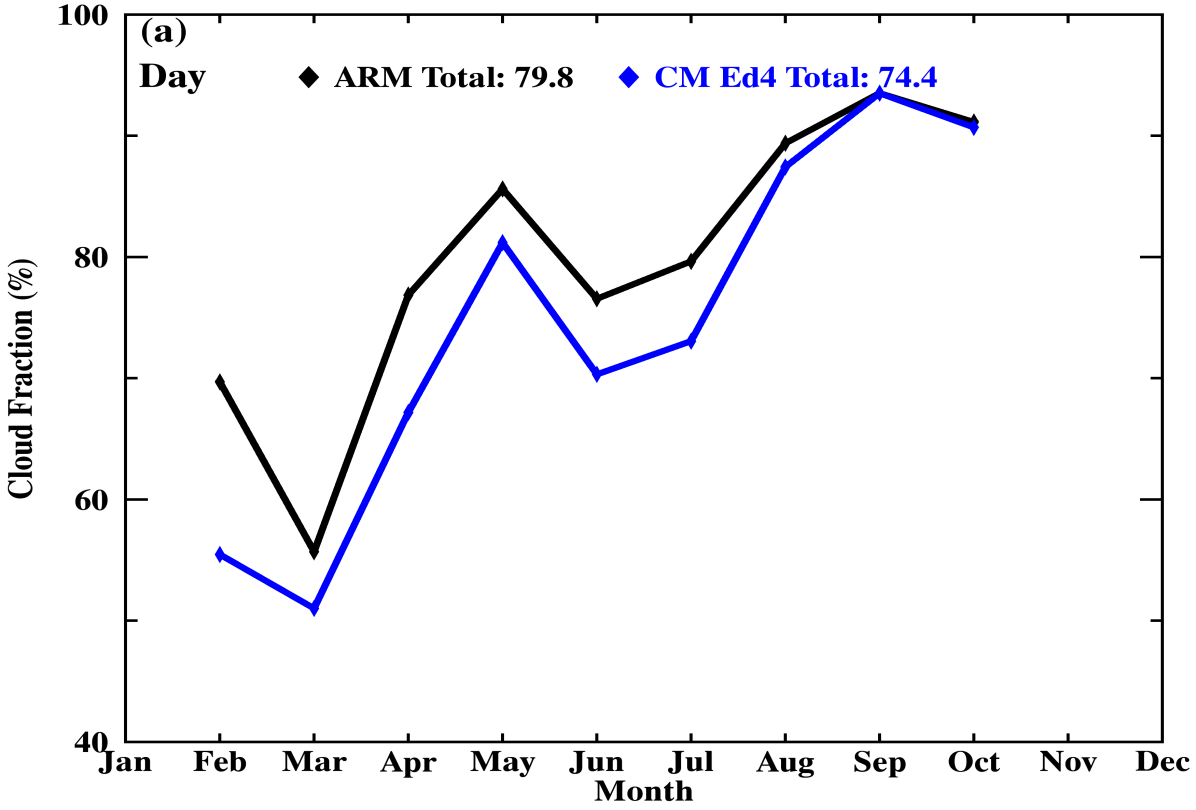




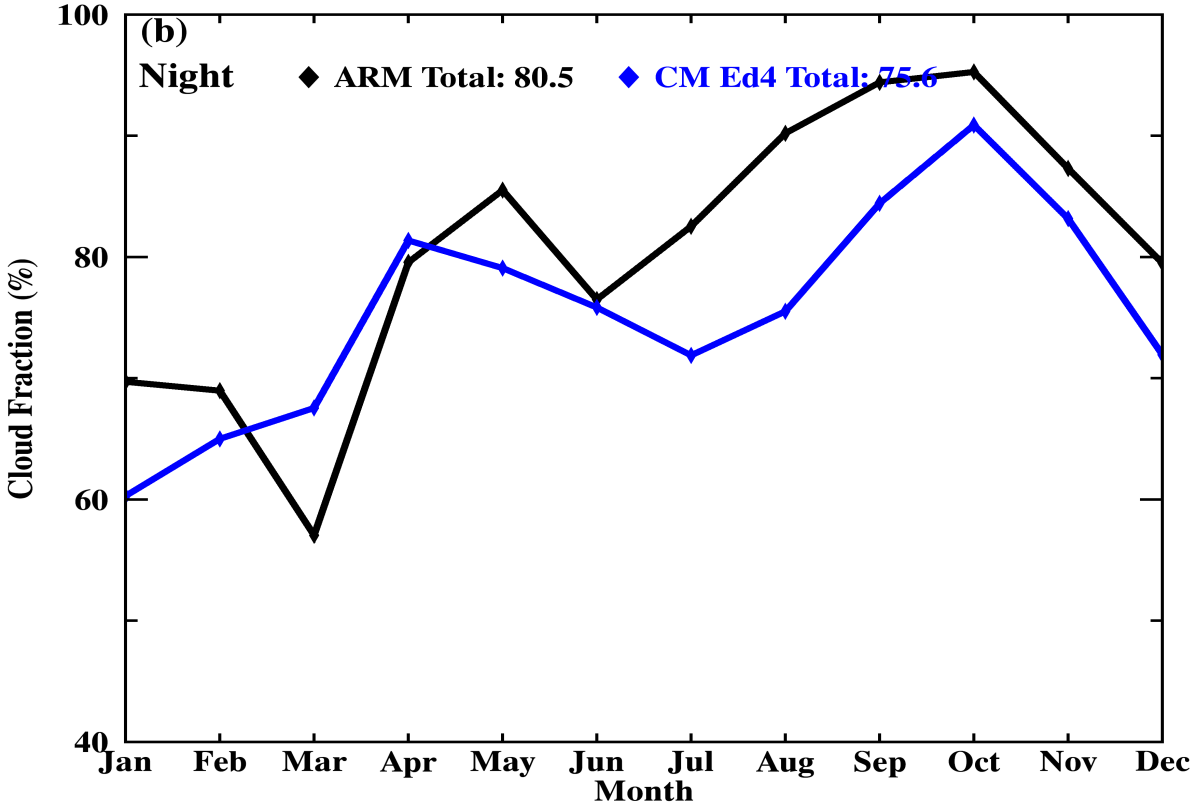
- **CERES-MODIS has 46,486 overpasses; CCCM has 417 overpasses at NSA;**
- **CERES-MODIS monthly mean CFs follow ARM ones with an annual negative bias of 5%.**
- **CCCM has too few overpasses at NSA site to be representative for the seasonal variation.**

CERES-MODIS Ed4 Cloud Fraction for Day and Night

Daytime (SZA < 82°)



Night time (SZA ≥ 82°)



- **41% daytime samples and ~59% nighttime samples;**
- **Daytime CERES-MODIS CFs basically follow their total CFs, but night time CFs have >10% biases in a few months, twilight CFs do not follow ARM CFs**

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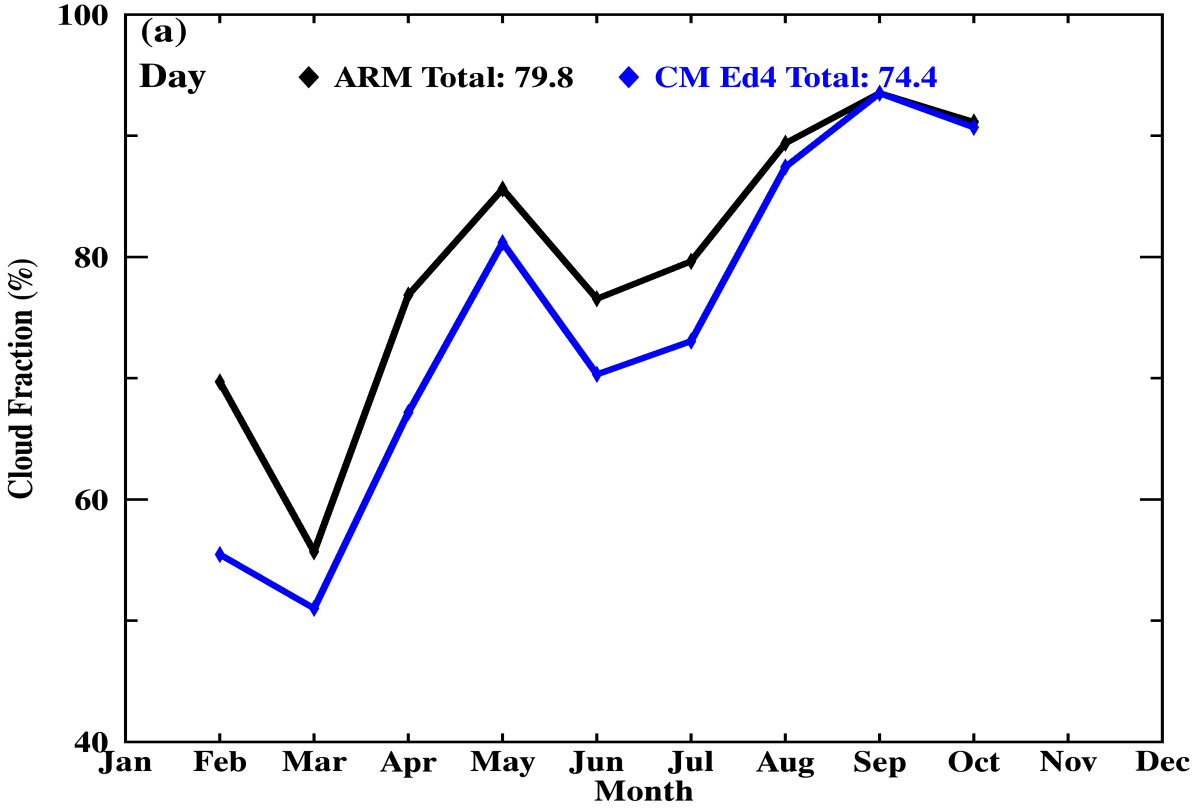
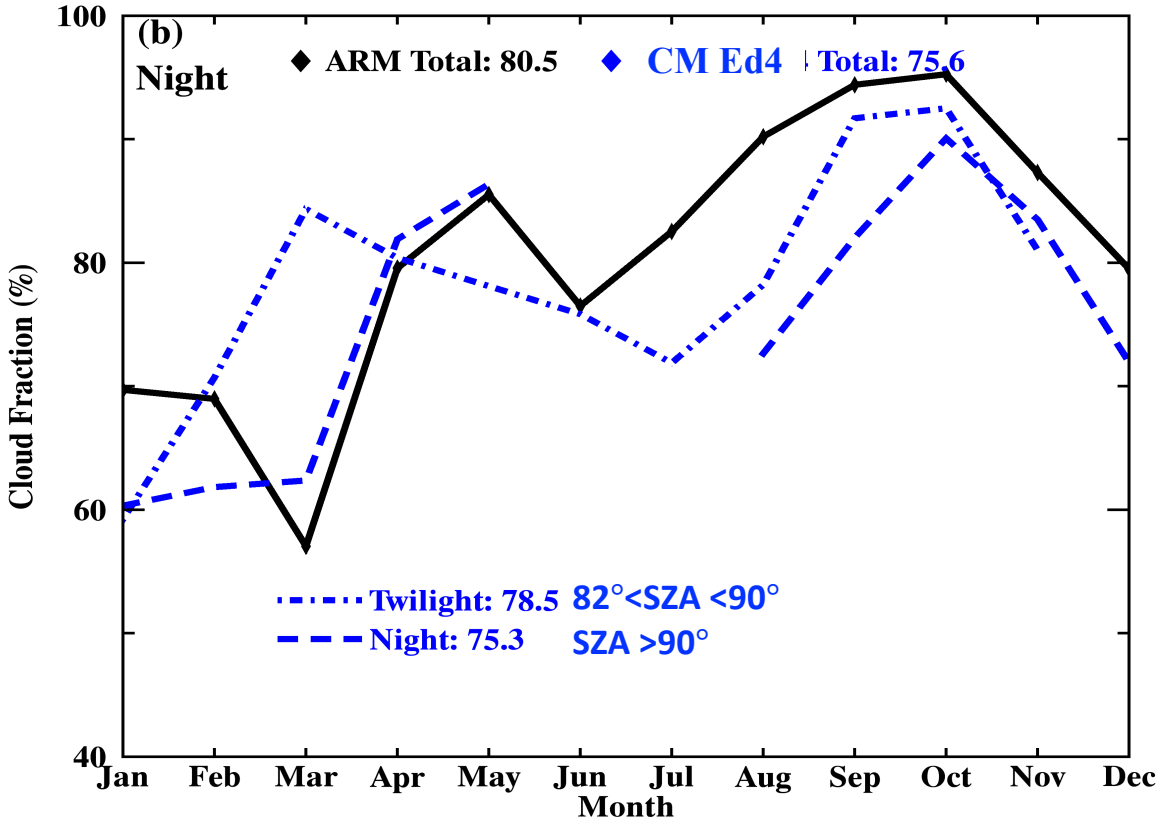


Night time (SZA ≥ 82°)



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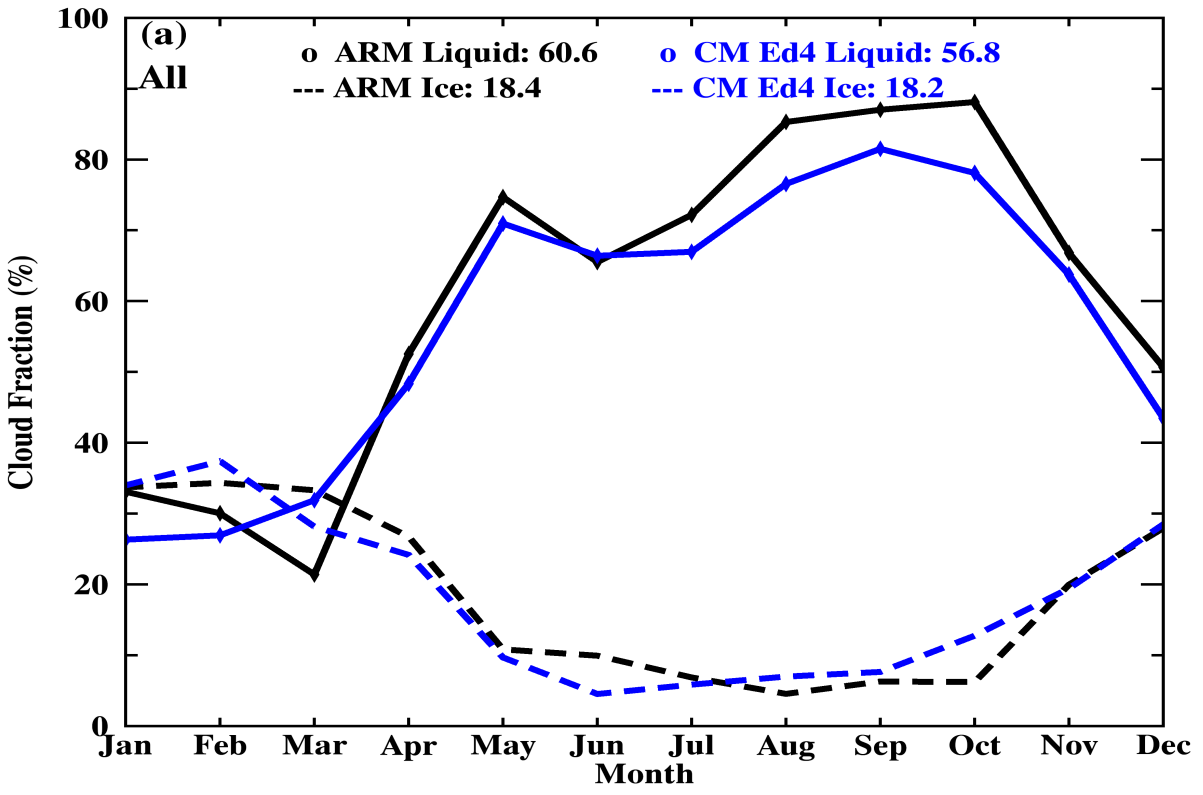
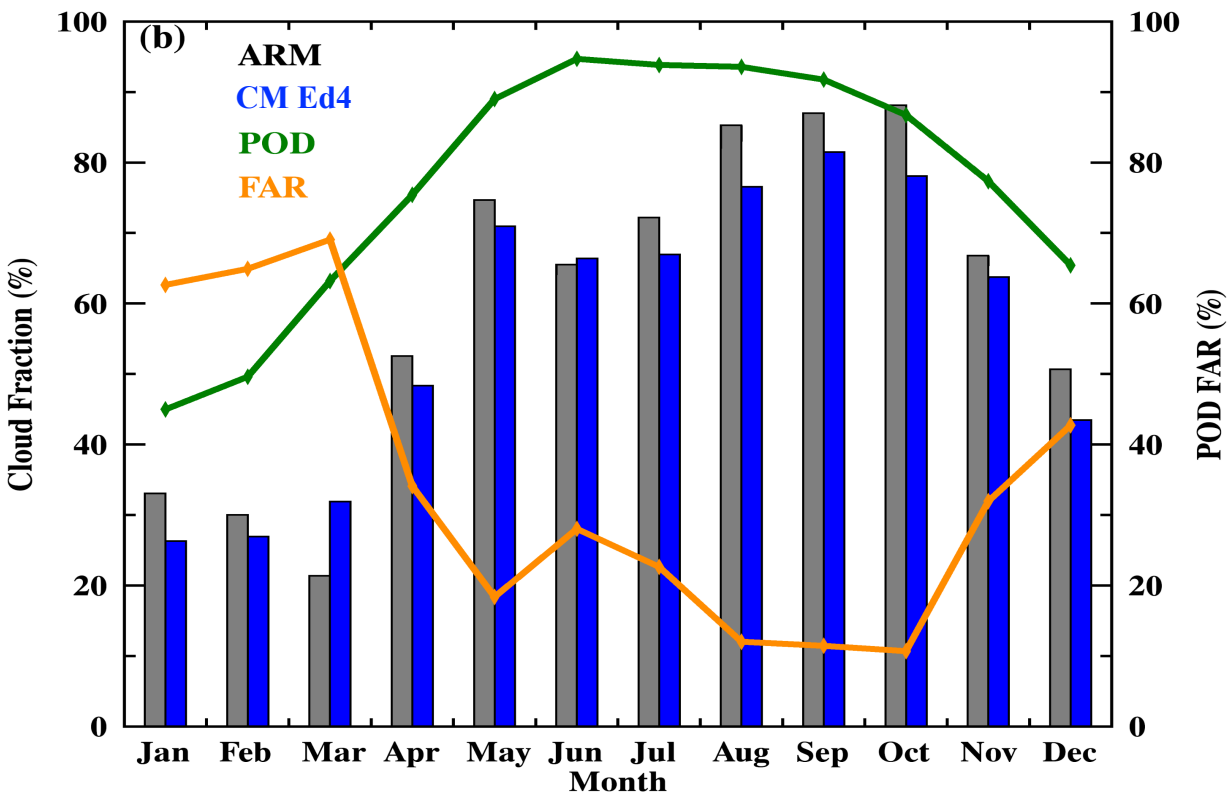
CERES-MODIS (CM) Ed4 Phase Detection ability

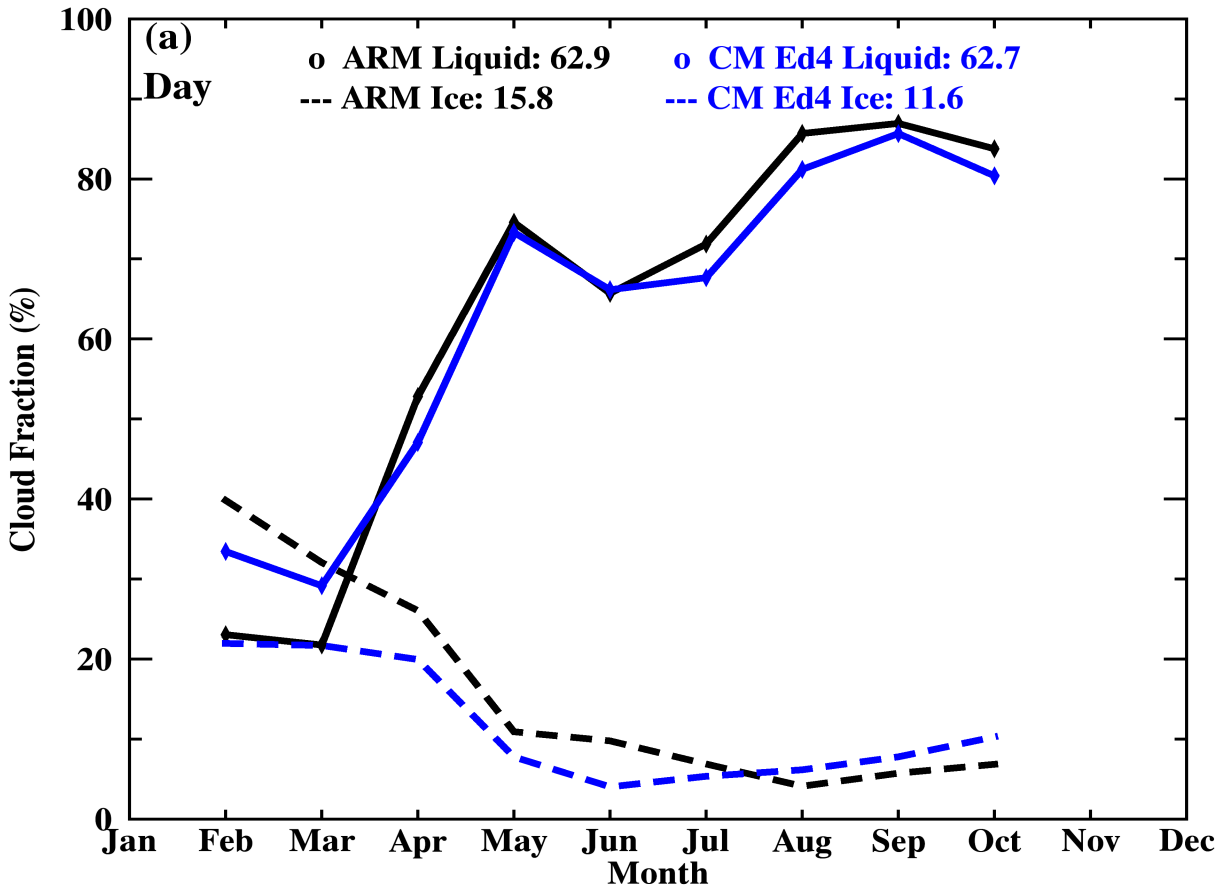


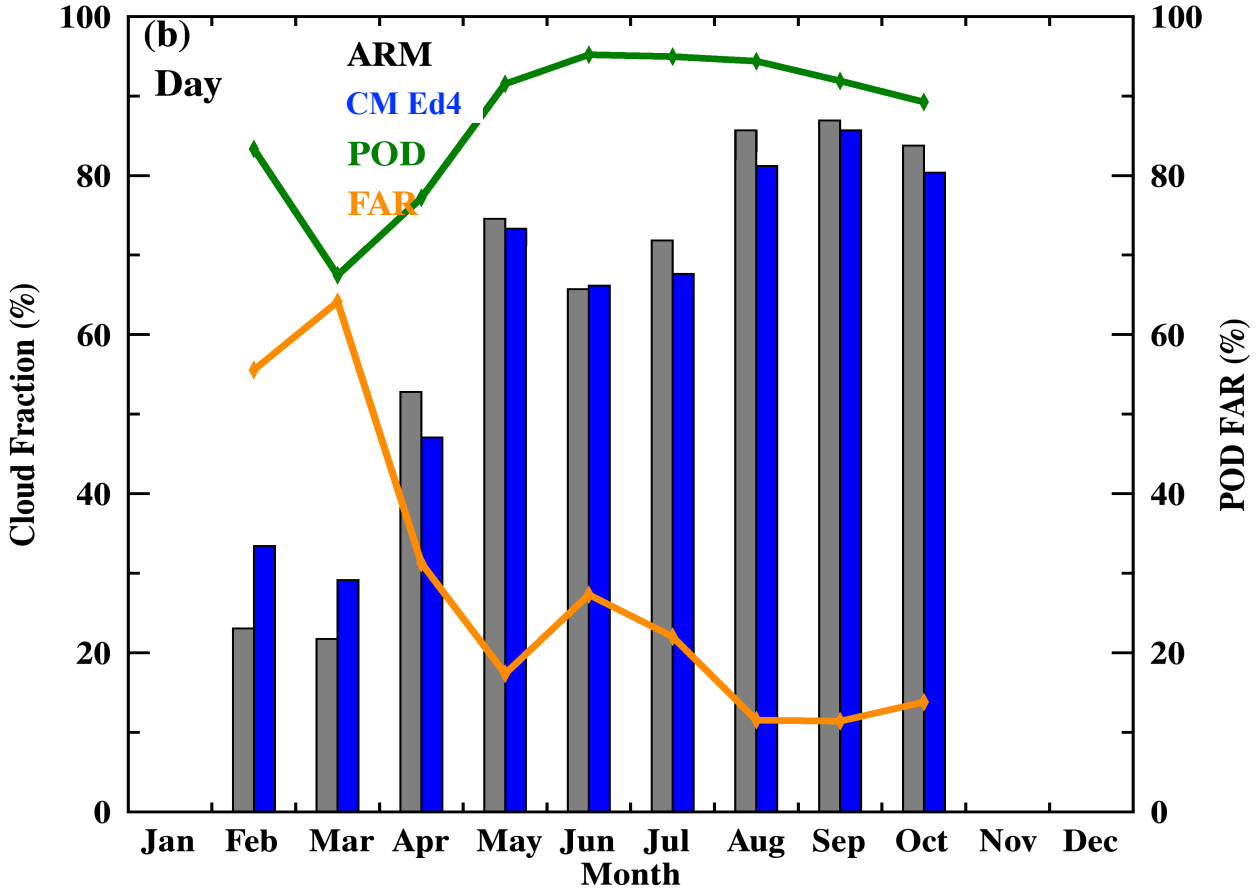


$$\text{POD} = \frac{\#\text{sample (both ARM and CM observed liquid cloud)}}{\#\text{sample (ARM observed liquid cloud)}}$$

$$\text{FAR} = \frac{\#\text{sample (ARM observed Ice or Clear, CM observed liquid cloud)}}{\#\text{sample (CM observed liquid cloud)}}$$

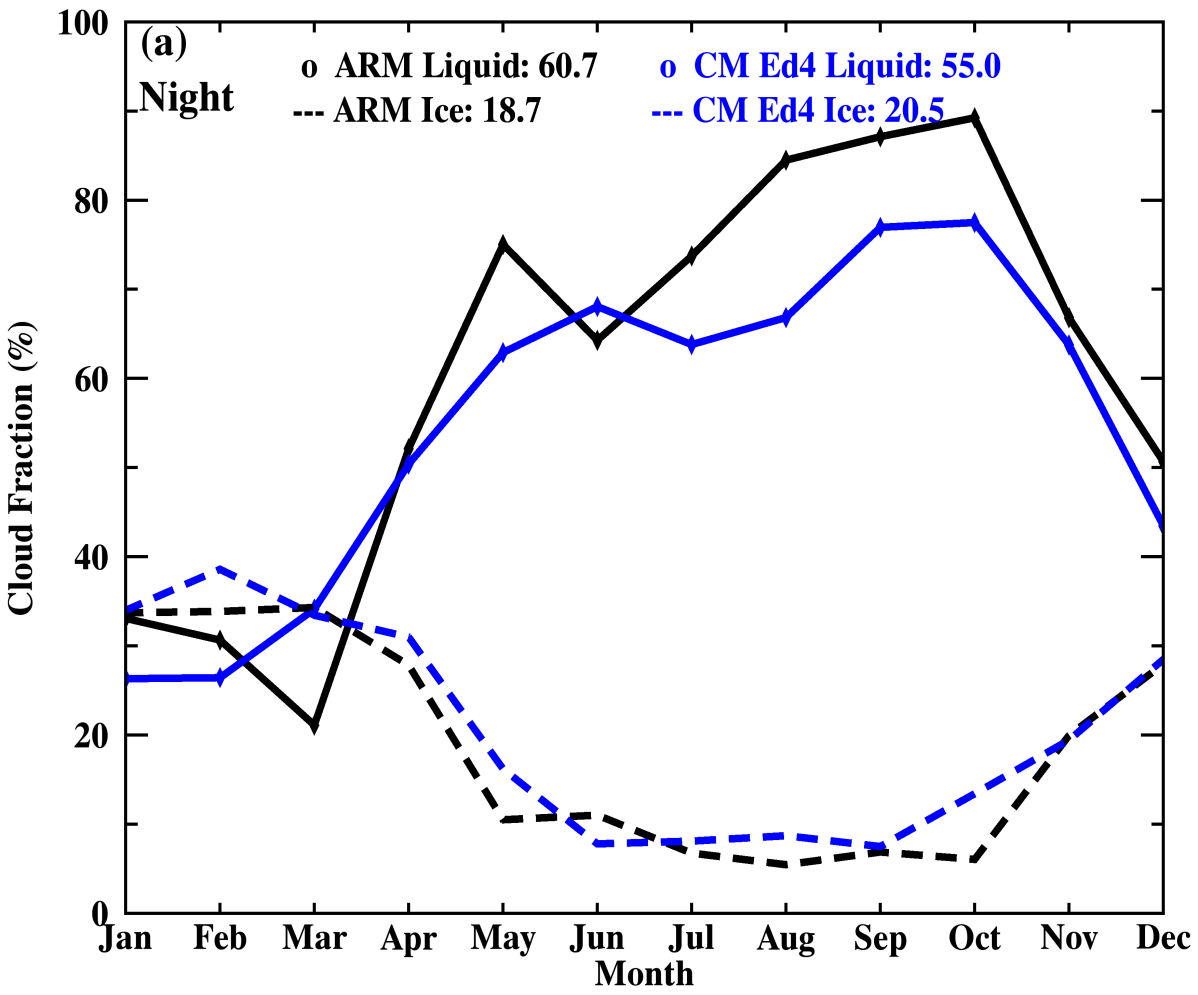
CERES-MOSIS Ed4 Phase detection—Daytime (SZA < 82°)

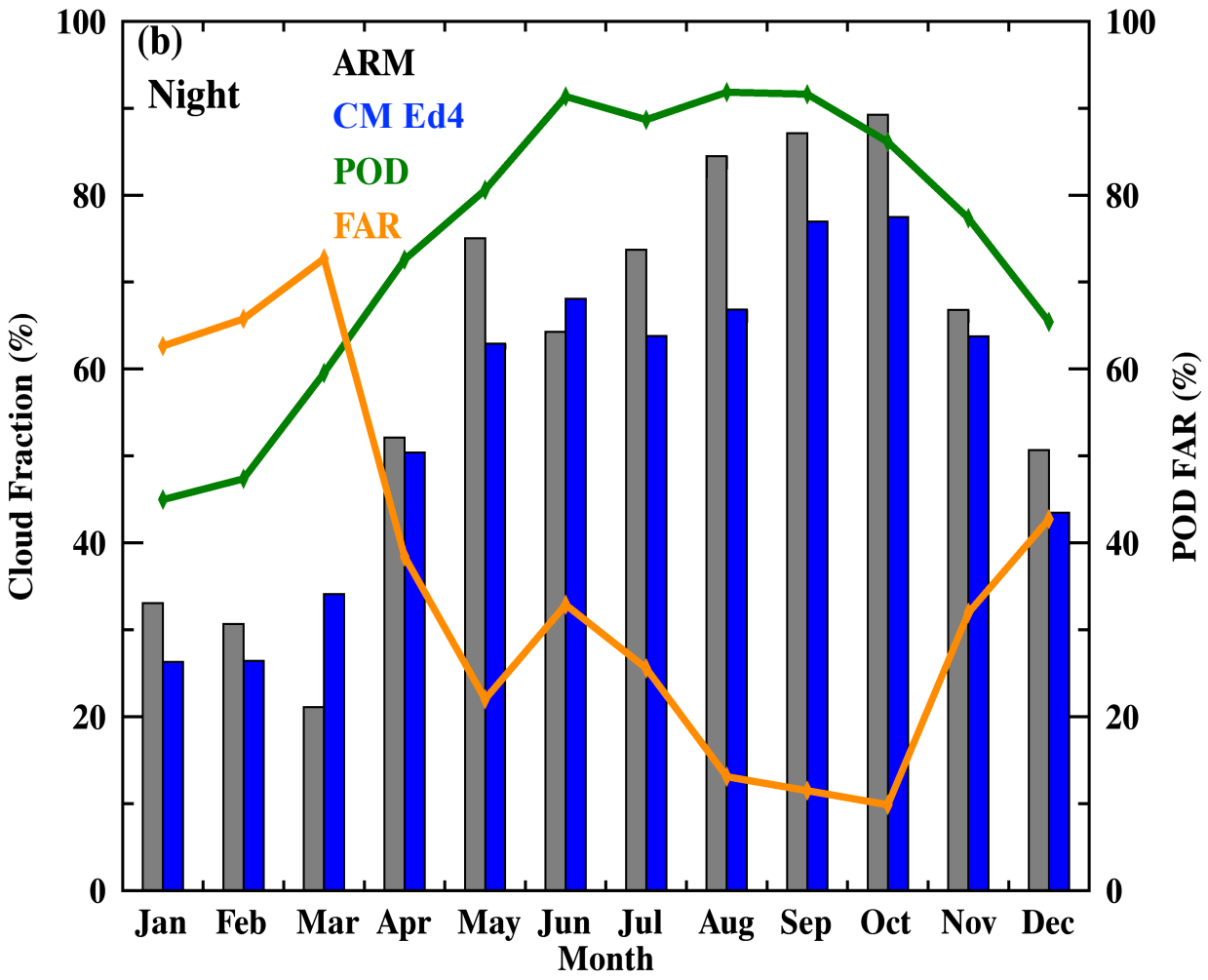




- **CERES-MODIS liquid CFs agree with ARM ones within 0.2%, ice CFs have -4.2% bias**
- **CM Phase classification agrees with ARM from May to October (POD>90%, FAR<30%)**
- **In February and March, CM has more liquid and less ice clouds compared with ARM**

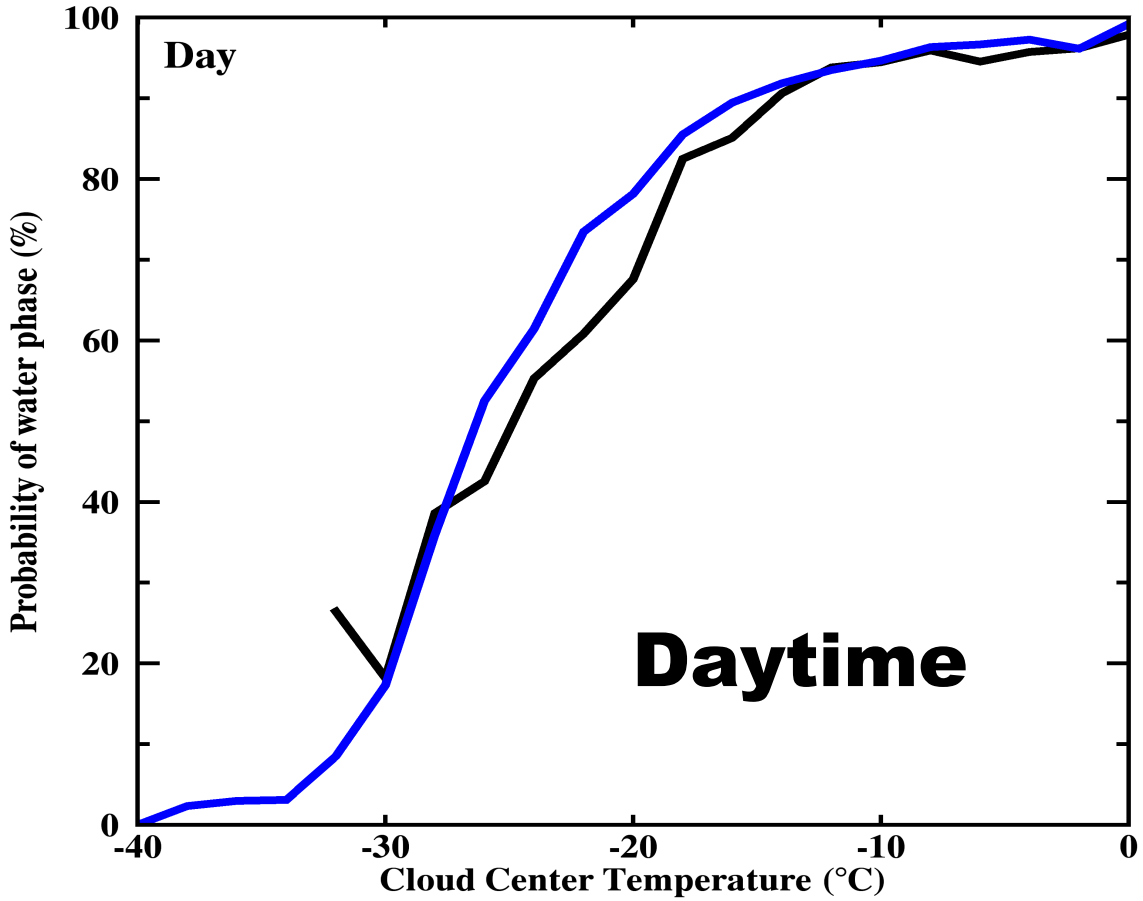
CERES-MODIS Ed4 Phase detection—Night time (SZA ≥ 82°)

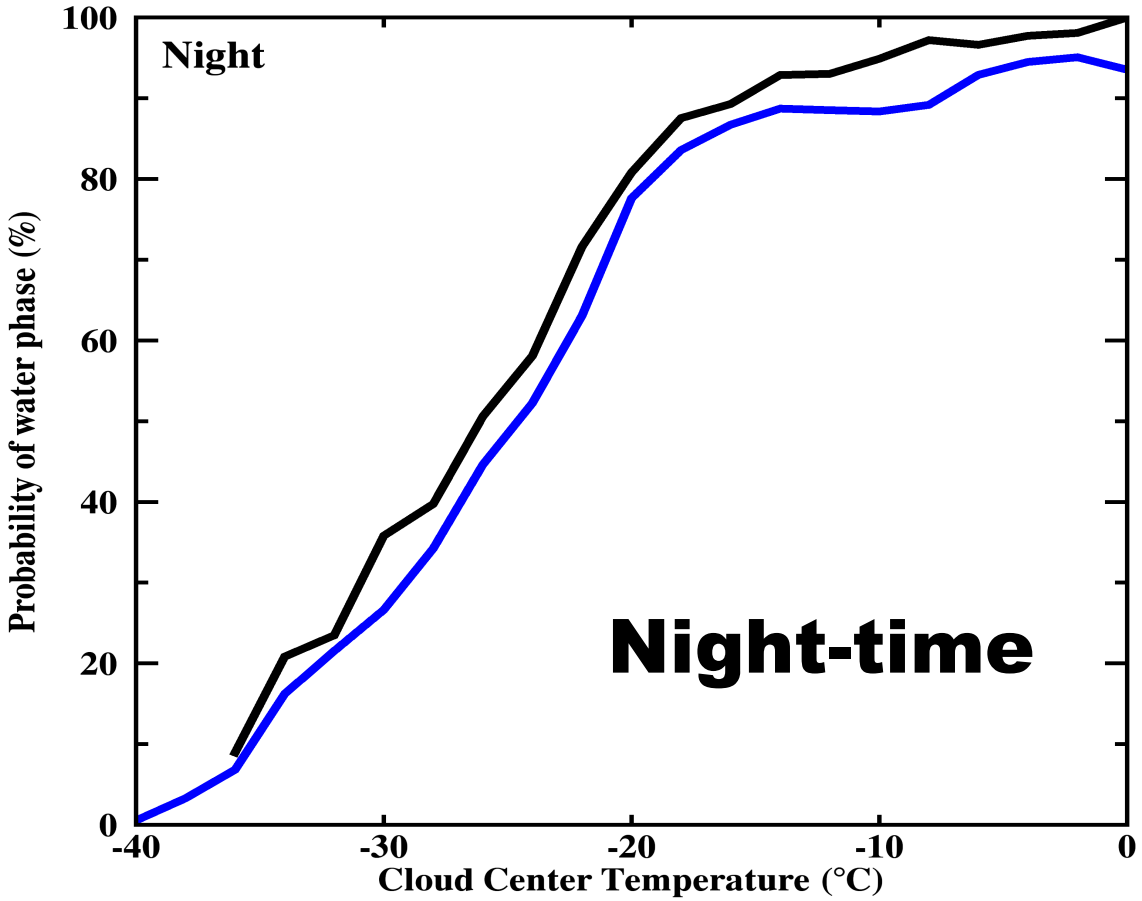




- **CERES-MODIS phase algorithm has -5.7% liquid cloud bias, and +1.8% ice cloud bias because CM has lower liquid partition at nighttime;**
- **The PODs are >80% and the FAR <30% from May to October.**

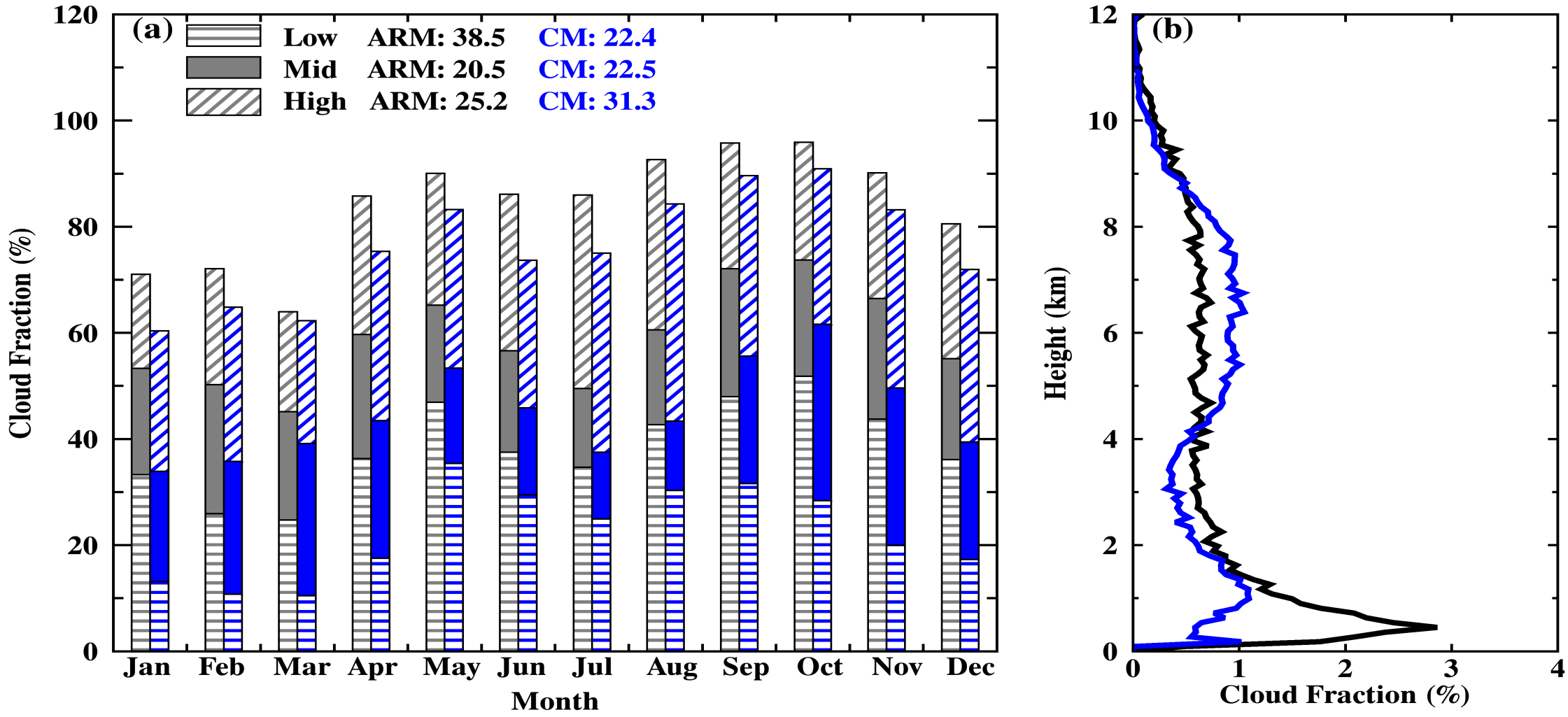
Liquid phase fraction as a function of temperature





- CERES-MODIS uses first layer effective temperature; ARM use cloud center temperature
- Similar to previous results, night-time CERES-MODIS phase algorithm under-estimates liquid phase fraction

CERES-MODIS Ed4 Cloud Fraction for Different Levels

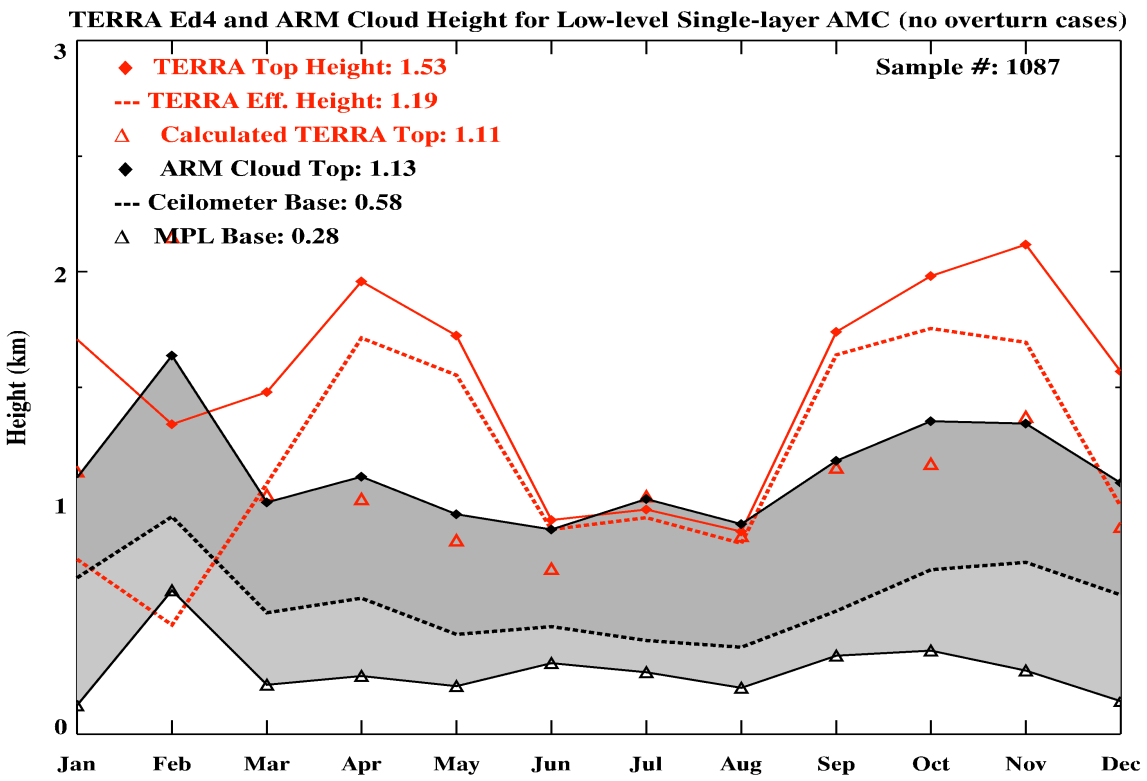


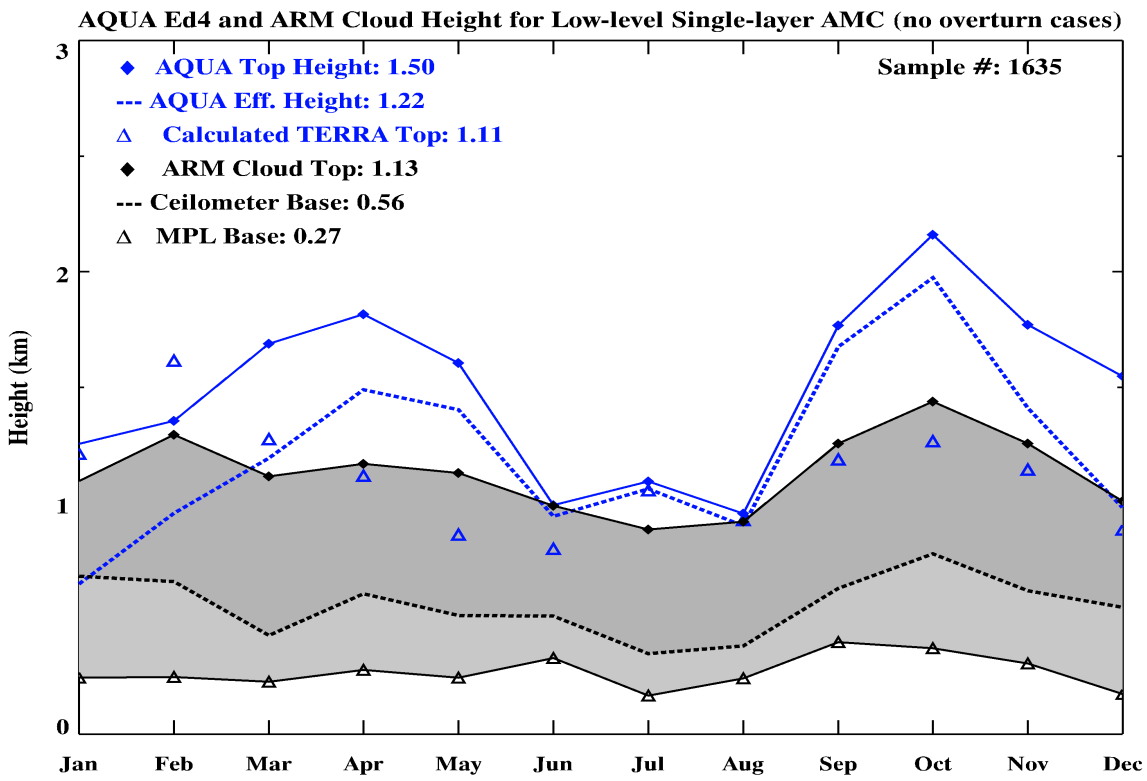
CM has ~16% less low clouds, 2% more middle clouds, and ~6% more high clouds than ARM. Further study may need to explain the differences, for example, day/night time diff.

2. Update for CM Arctic mixed-phase cloud height

Recalculate CM Z_{top} (Δ) using ARM sounding T profile

$$Z_{eff} = \frac{T_{eff}(CM) - T_{sfc}(ARM)}{\Gamma}$$





- **The recalculated CM Z_{top} (Δ) use T_{eff}(CM), T_{sfc}(ARM) and ARM monthly mean lapse rates. ΔZ_{top} decreases from ~400 m to 20 m;**
- **RMSE: Terra: decreases from 0.97 to 0.57; Aqua: decreases from 0.83 to 0.4;**
- **The ARM monthly mean lapse rates:**

Γ\Mon	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
(K/km)	-3.9	-3.5	-5.0	-5.3	-7.9	-6.8	-6.2	-6.7	-7.2	-7.5	-5.7	-5.3

CERES-MODIS and ARM Sounding Lapse rates

Daytime

Γ\Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
ARM	---	---	-5.1	-5.7	-7.9	-7.0	-6.6	-7.2	-7.6	-8.2	---	---	-6.9
TERRA	-6.9	-6.8	-7.0	-7.0	-7.0	-6.6	-7.0	-6.3	-5.4	-7.3	-7.1	-6.9	-6.7

Nighttime

Γ\Mon	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
ARM	-4.0	---	---	-5.3	-7.5	-6.2	---	-6.5	-7.0	-7.3	-5.4	-5.4	-6.0
TERRA	-7.2	-7.2	-7.3	-7.2	-7.1	-7.1	-7.1	-6.9	-6.2	-7.2	-7.3	-7.4	-7.1

For single layer low-level mixed-phase clouds:

$$\text{ARM lapse rate } (\Gamma_{arm}) = (T_{center}-T_{sfc})/(Z_{ceter}-Z_{sfc}) \quad \text{(samples>10)}$$

- **Daytime: Although annual mean lapse rates are close to each other, there are large monthly variations in Spring and Fall seasons.**
- **Nighttime: CM over-estimates lapse rates for most of months except for May and September**

Recalculate CM Z_{top} (Δ) using ARM and CM lapse rate

Daytime

	ARM Z_{top}	Terra Z_{top}	Z_{top} (ARM T_{sfc}, Γ_{arm})	Z_{top} (ARM T_{sfc}, Γ_{CM})
Annual Mean	1.08	1.47	1.00	1.03
Bias	/	0.39	-0.08	-0.05
RMSE	/	0.89	0.51	0.56

Night Time

	ARM Z_{top}	Terra Z_{top}	Z_{top} (ARM T_{sfc}, Γ_{arm})	Z_{top} (ARM T_{sfc}, Γ_{CM})
Annual Mean	1.06	1.63	0.96	0.83
Bias	/	0.57	-0.25	-0.18
RMSE	/	1.00	0.57	0.60

Recalculate Z_{top} (Terra) using CM T_{eff}, Γ_{arm} and Γ_{CM} with ARM T_{sfc};

- **Both recalculated Z_{top} have smaller bias than CM Z_{top} compared to ARM Z_{top}**
- **Recalculated Z_{top} changes 3% (13%) using ARM and CM lapse rate for day (night) time; it changes 30% (50%) using ARM and GMAO T_{sfc} for day (night) time**
- **Probably bias in T_{sfc} cause the CM cloud height bias**

ΔT_{sfc} adjustment to force Z_{top}(CM) = Z_{top}(ARM) when using either Γ_{arm} or Γ_{CM}

Daytime

ΔT_{sfc}, °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Γ_{arm}			-0.2	-0.2	-0.8	-1.3	0.2	-0.4	-0.4	-1.9		
Γ_{CM}			-2.2	-1.5	-0.0	-0.9	-0.1	+0.4	+2.0	-0.7		

Nighttime

ΔT_{sfc}, °C	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Γ_{arm}	0.1			-1.2	-1.1	-0.4		-0.5	-0.05	-1.2	0.2	-1.0
Γ_{CM}	-3.4			-3.3	-0.9	-0.9		-0.8	+0.8	-1.2	-2.4	-3.2

If CM products keep using Γ_{CM} then the adjustment of T_{sfc} can be as follows: during the daytime, ΔT_{sfc} ranges from -2.2 to +2.0 degree and during nighttime ranges from -3.4 to +0.8 degree. Most of them are negative except three marked in yellow.

Conclusions

Part I:

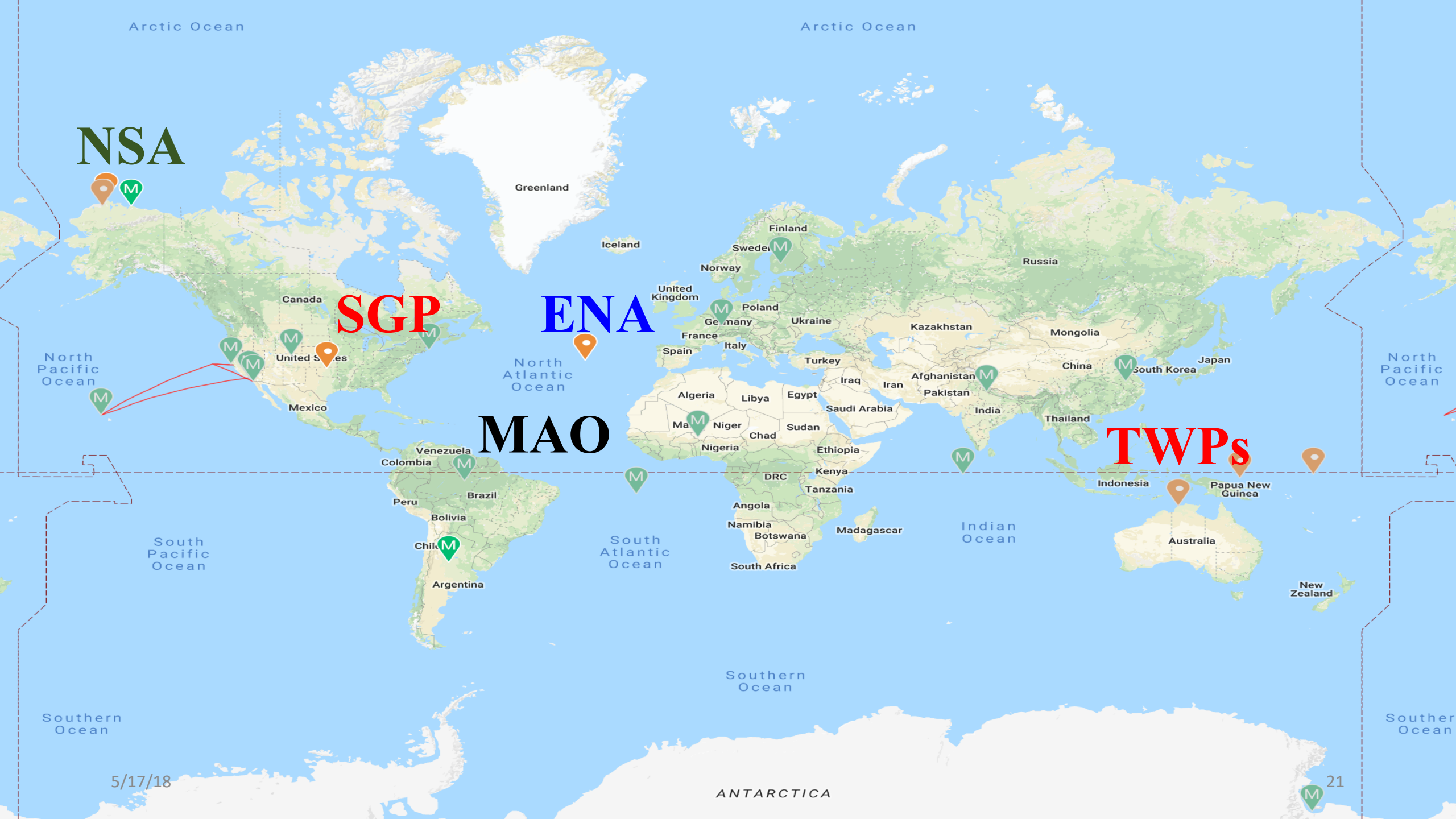
- **CERES-MODIS Ed4 cloud mask over the Arctic agrees well with ground-based observation. The annual CF bias is of -5% for both day and night time, but the daytime CFs from both measurements follow the similar seasonal variations;**
- **CERES-MODIS Ed4 phase detection also agrees well with ground-based phase classification from lidar, radar, MWR observations; the liquid CF bias is -3.8%, and the ice CF bias is -0.2%;**
- **CM daytime liquid CF is slightly higher but night time is lower than ARM;**
- **CM has ~16% less low clouds, ~6% more high clouds than ARM, similar mid clouds as ARM.**

Part II:

- **Although Γ_{CM} differs from Γ_{arm}, T_{sfc} is a more important factor for getting correct Z_{top}.**

3. Evaluate IWP for GoAmazon (Tropical) cases using Terra+NPP Ed1A product in 1x1 degree grid over MAO

Jingjing Tian


NSA
SGP
ENA
MAO
TWPs
Arctic Ocean
Arctic Ocean
Greenland
Iceland
Finland
Sweden
Norway
Russia
United Kingdom
Poland
Germany
Ukraine
Kazakhstan
Mongolia
France
Spain
Italy
Turkey
China
South Korea
Japan
Canada
United States
North Pacific Ocean
North Atlantic Ocean
Iraq
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Pakistan
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Thailand
Algeria
Libya
Egypt
Saudi Arabia
Mali
Niger
Sudan
Chad
Nigeria
Ethiopia
Mexico
Venezuela
Colombia
Kenya
DRC
Tanzania
Indonesia
Papua New Guinea
Brazil
Peru
Bolivia
Angola
Namibia
Botswana
Madagascar
Indian Ocean
South Pacific Ocean
South Atlantic Ocean
Chile
Argentina
South Africa
Australia
New Zealand
Southern Ocean
Southern Ocean
Southern Ocean
ANTARCTICA

TERRA+NPP IWP