Detectability of Arctic Mixed-Phase Clouds using both ground-based and satellite remote sensing

Shaoyue Qiu, Baike Xi and Xiquan Dong, University of Arizona

Sunny Sun-Mack, Pat Minnis, Bill Smith, NASA LaRc

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Motivation and Goals

- Arctic mixed-phase cloud (AMC) is the most frequent cloud type over the Arctic
- AMC properties: long-lasting, liquid layer at cloud top
- Well studied from ground-based observation, have not been evaluated from Satellite observation
- Evaluation of cloud phase classification for CERES Ed4 data with ground-base observations
- Evaluation of CERES Ed4 cloud temperature and cloud height retrieval for Arctic mixed phase cloud

Method

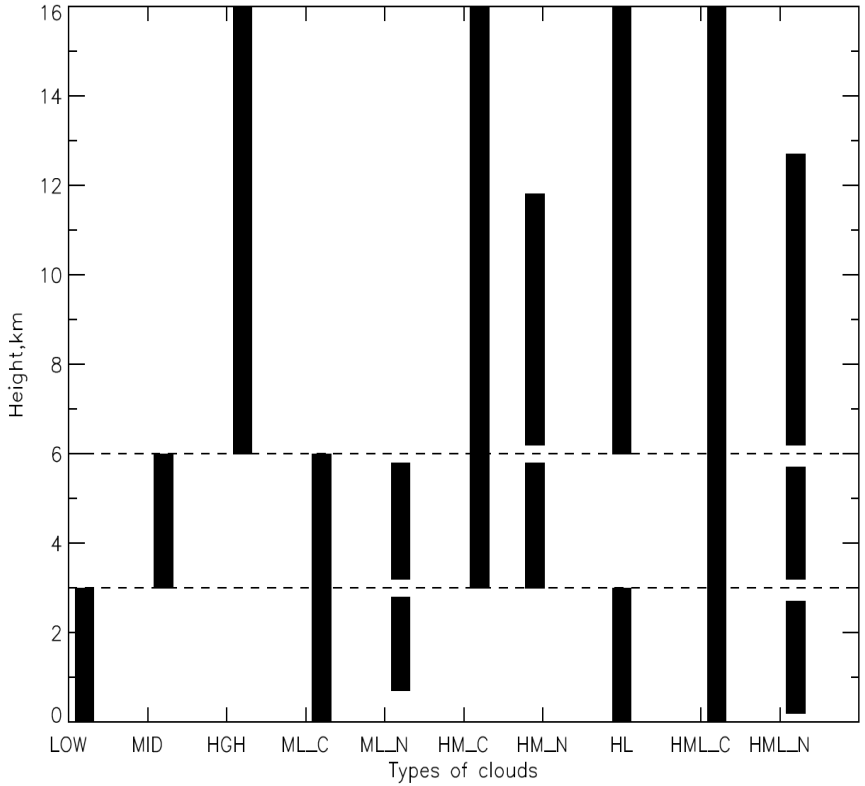


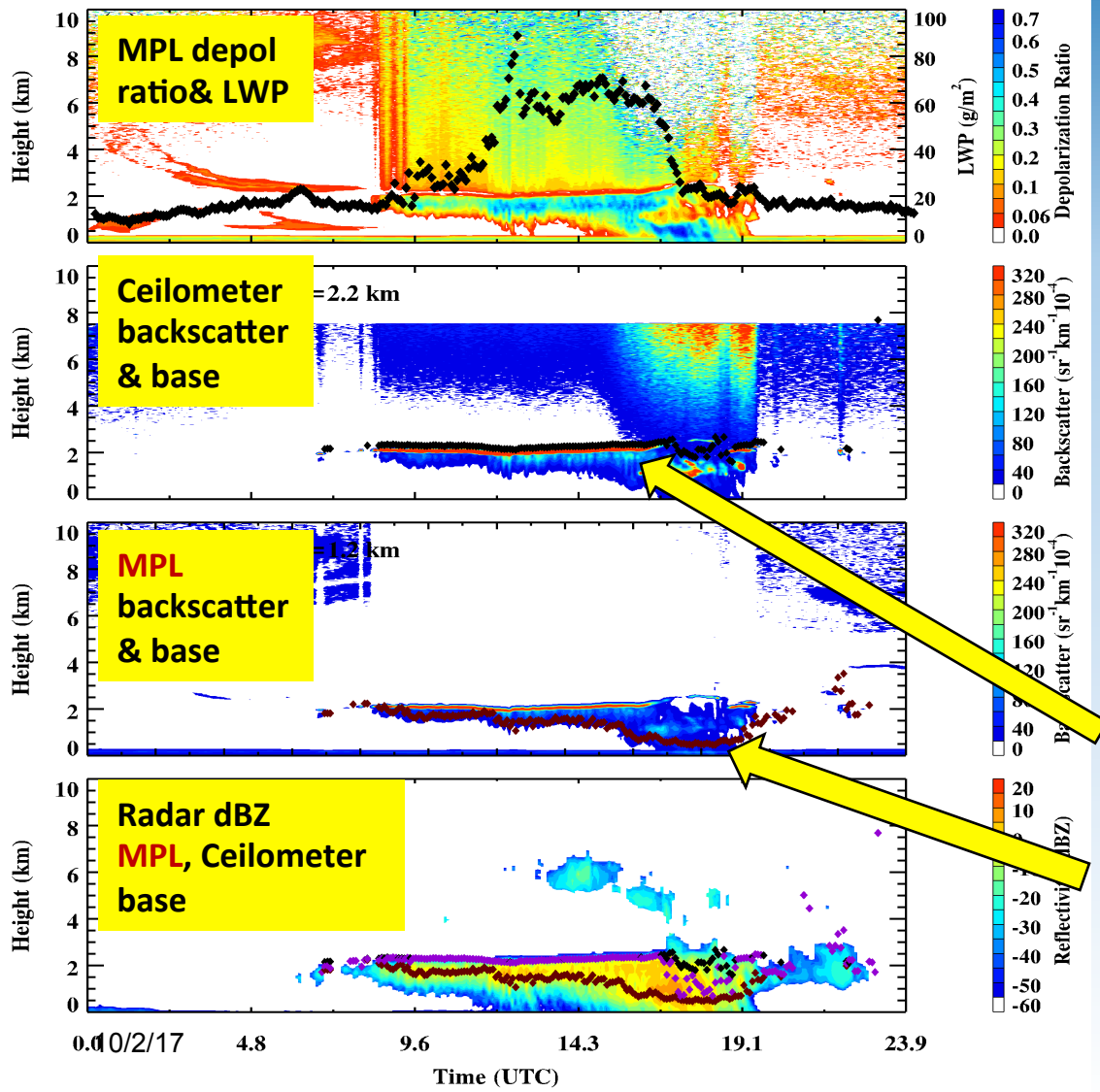
Figure 6. Schematic diagram for categorized clouds by their vertical structures. LOW, single-layered low clouds (<3 km); MID, single-layered middle clouds (3–6 km); HGH, single-layered high clouds (>6 km). C, contiguous clouds; N, noncontiguous clouds. ML, MID over LOW; HM, HGH over MID; and HML, HGN over MID and LOW.

Identify Arctic mixed-phase cloud (AMC) with ground-based obs.

Averaged ground-based obs. over one hour

Find mixed-phase cloud cases CERES has overpasses within 30km x 30km box centered at NSA

Classified clouds to different levels use ground-based observation

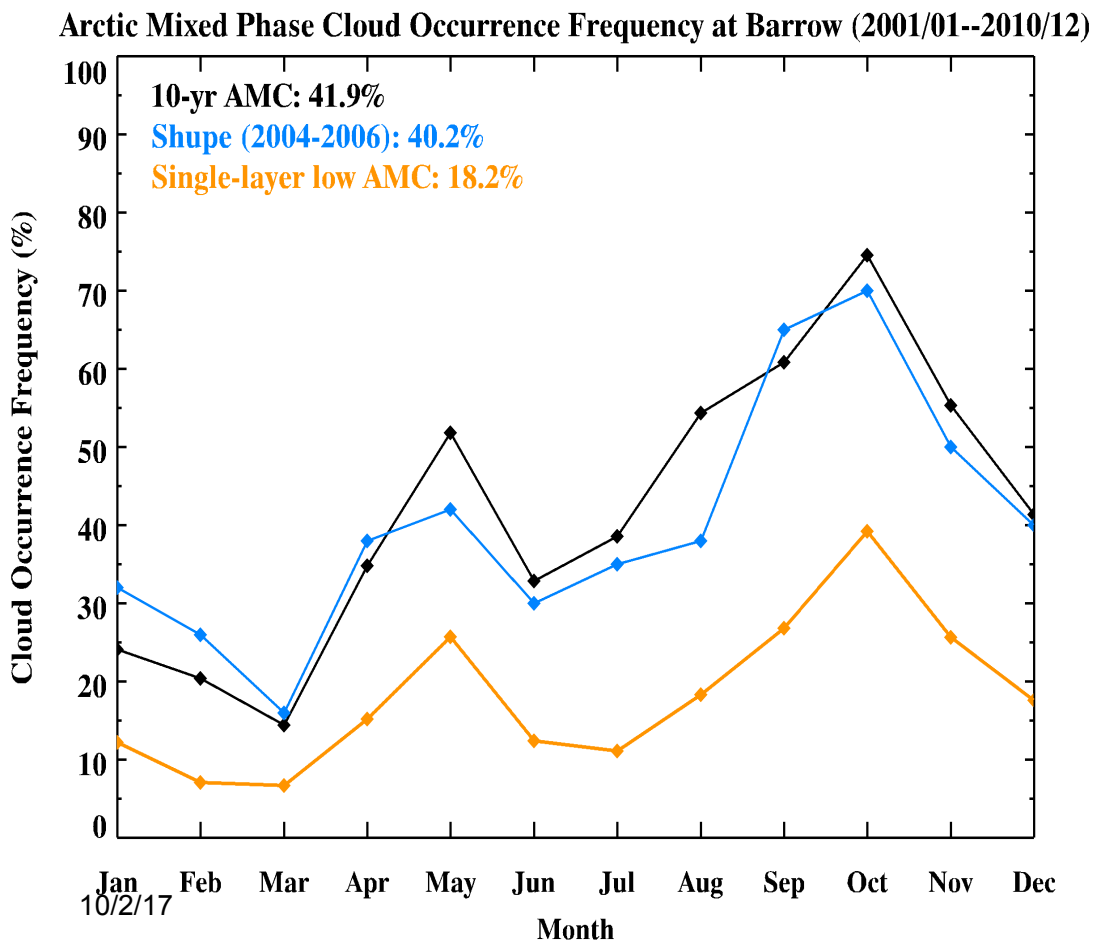


Identify AMC with ground observation

- Based on Shupe (2007)
- Lidar backscatter β > 300 (sr^{-1} km^{-1} 10^{-4}) and MPL depolarization ratio < 0.1
- Or LWP >25 (g m^{-2})
- And T > -40 ℃

- **For low-level stratiform AMC:**
- Ceilometer detects liquid-dominant layer at AMC top
- MPL detects ice-dominant layer below the liquid layer
- Below MPL base: falling ice

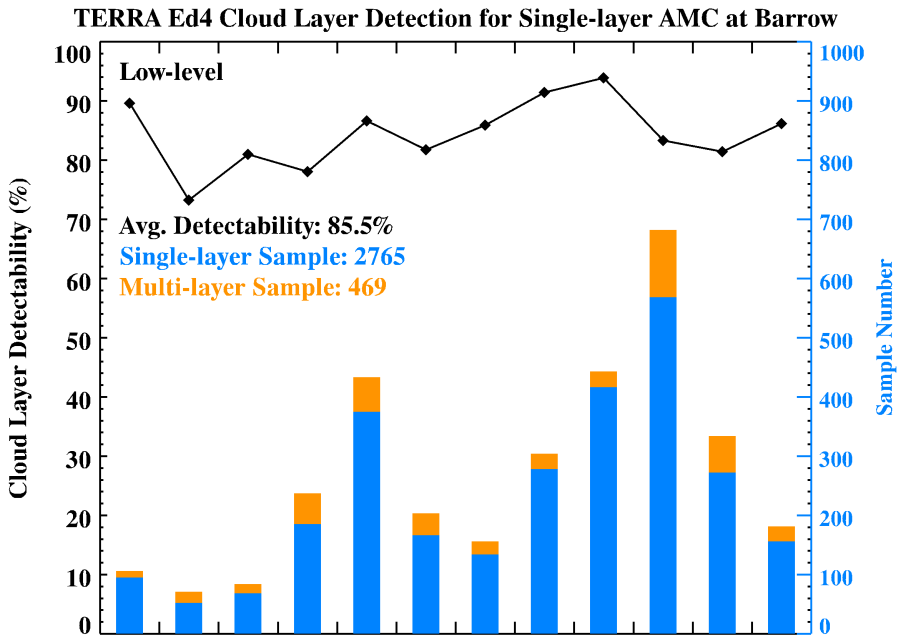
AMC occurrence using Ground-based Observation



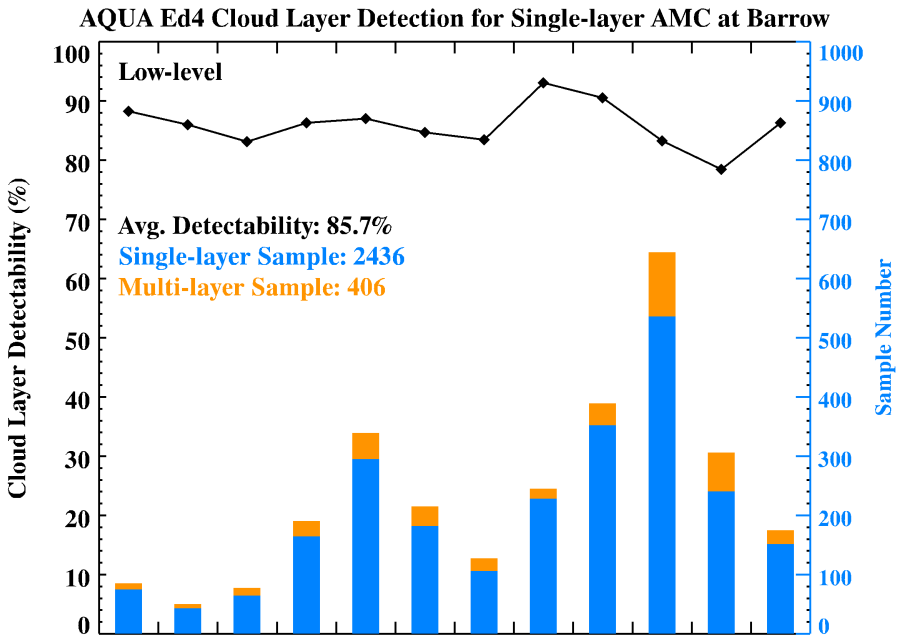
- **Study period: 10 years 2001--2010**
- **Classify single-layer and multi-layer using Radar reflectivity data**
- **Only focus on single-layer low-level mixed phase cloud (C_{top} < 3 km)**

Identification of Cloud Layer with TERRA and AQUA

TERRA Ed4



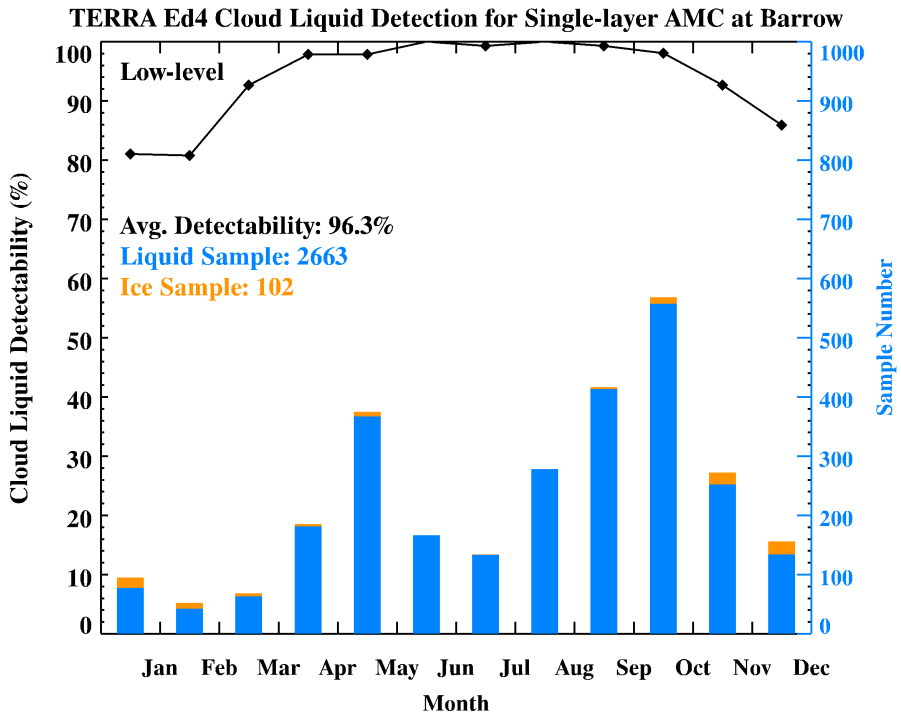
AQUA Ed4



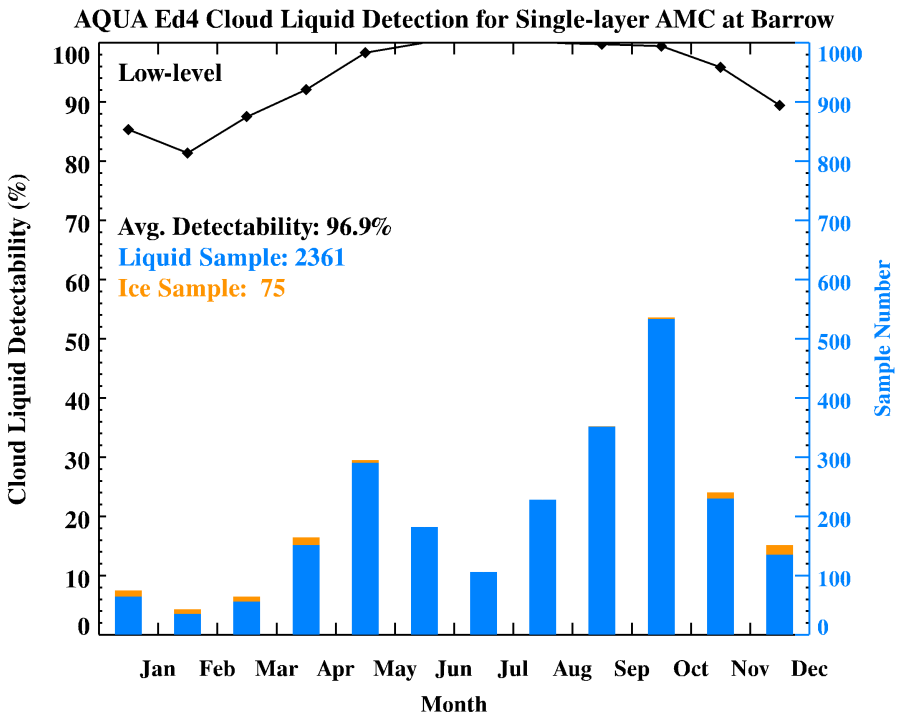
- **When ARM detects single-layer mixed phase cloud, ~85% of time CERES also identify single layer cloud (allow 10% of 2nd layer)**
- **Only cases with both ARM and CERES detect single-layer cloud are selected**

Identification of Cloud Phase with TERRA and AQUA

TERRA Ed4

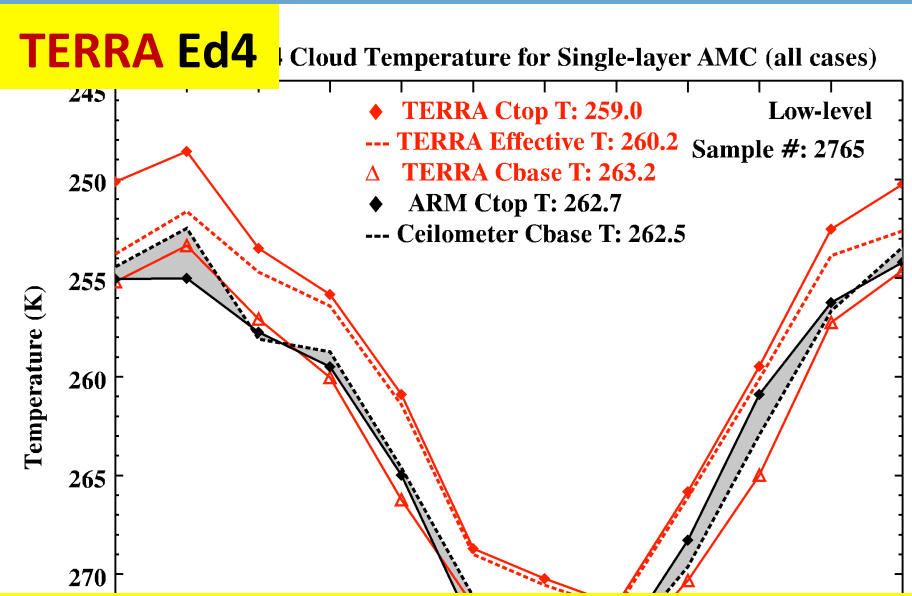


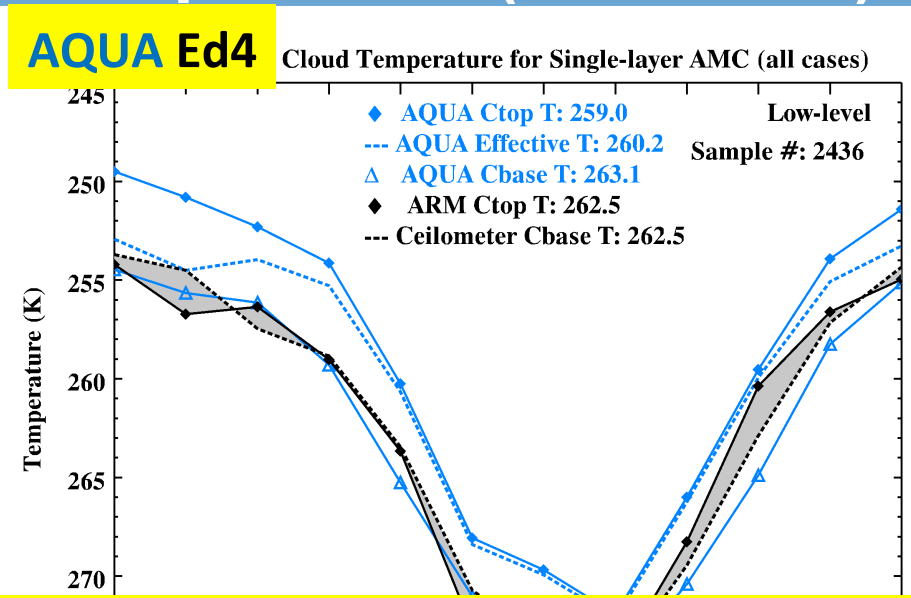
AQUA Ed4



When ARM detect mixed phase cloud, ~96% of time CERES also classified cloud liquid

TERRA and AQUA Cloud Temperature (All Cases)

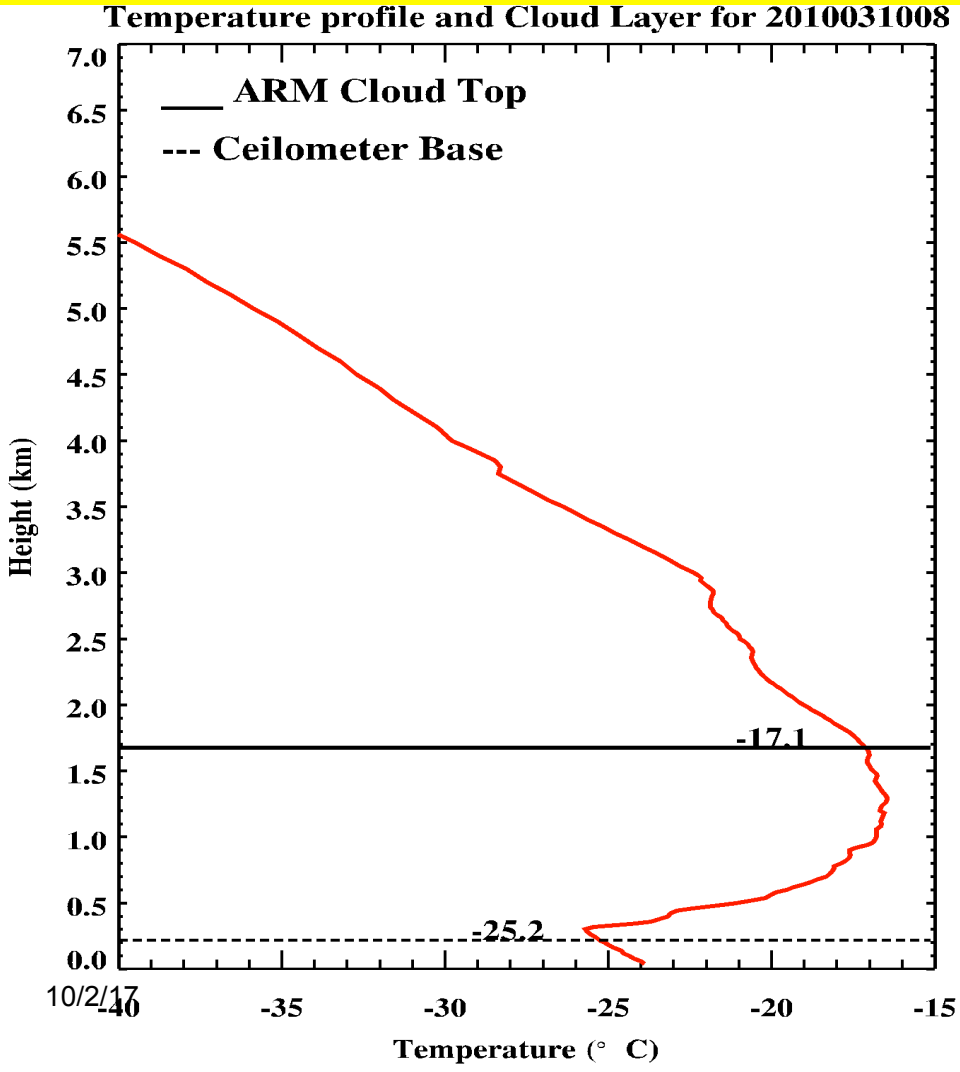




- **Due to frequent T inversion in the Arctic PBL, ARM cloud top temperature(♦) is close to cloud base temperature (---)**
- **Classified cases into *with* overturning (defined as cloud top temperature warmer than cloud base temperature) and *without Overturning***

- ***T_{eff} and T_{top} for Terra and Aqua have very similar monthly***

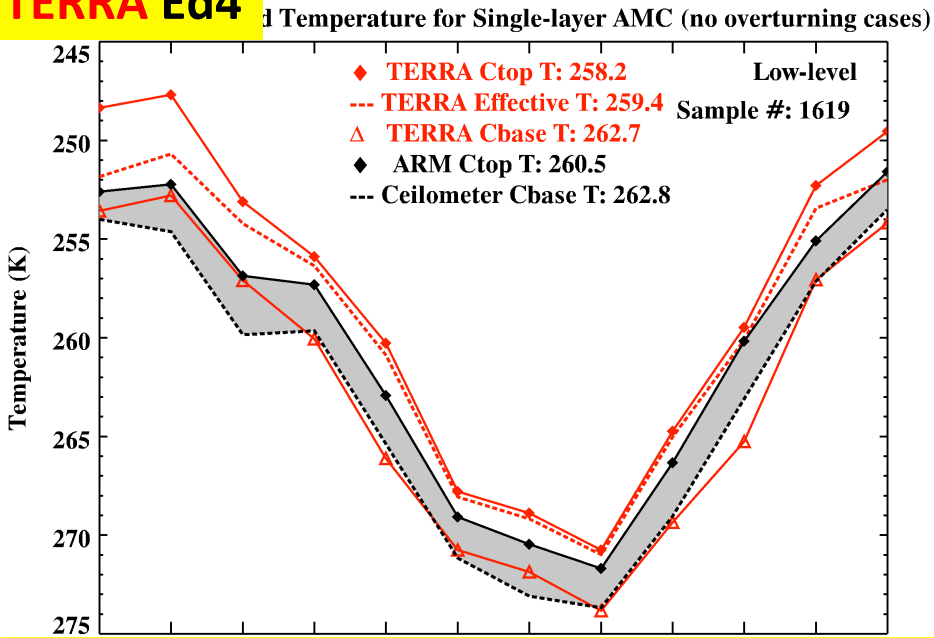
Definition of cloud Overturning condition for AMC



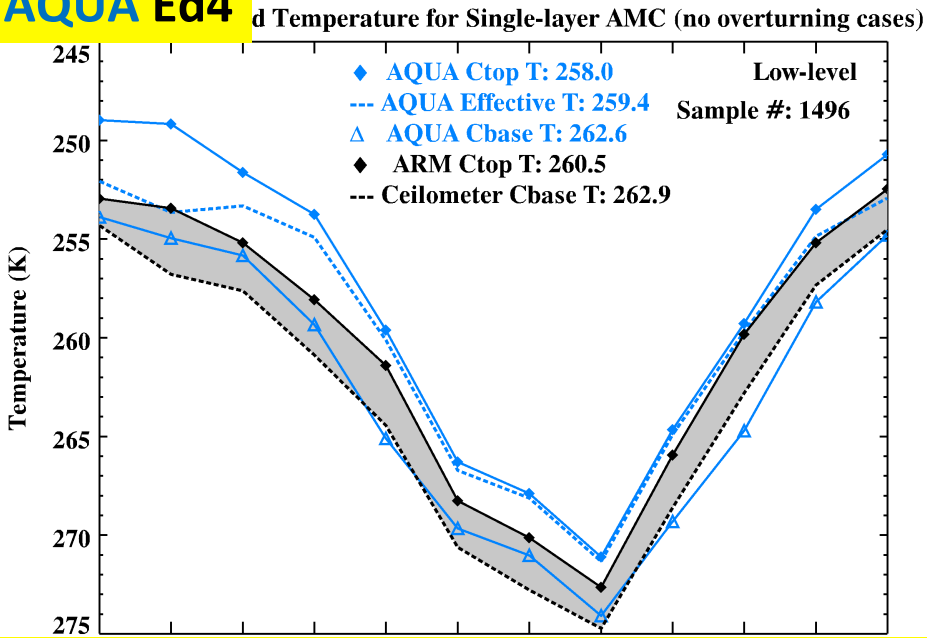
- Terra overpass at NSA;
- Both Terra and ARM measured single layer low level liquid phase cloud
- From sounding, $T_{top} > T_{base}$

TERRA and AQUA Cloud Temperature (No Overturning Cases)

TERRA Ed4



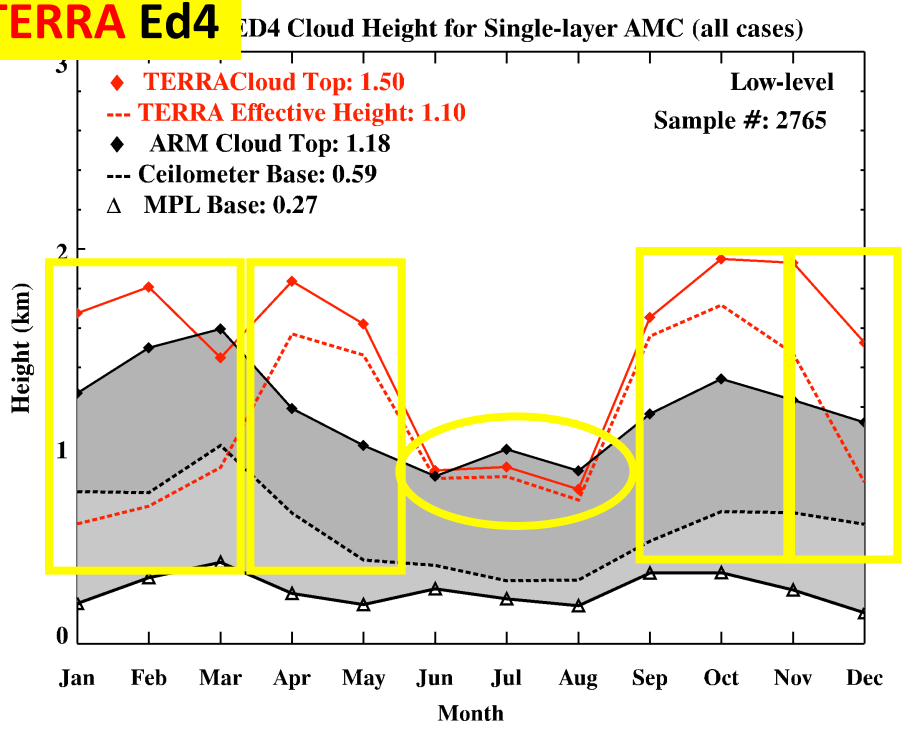
AQUA Ed4



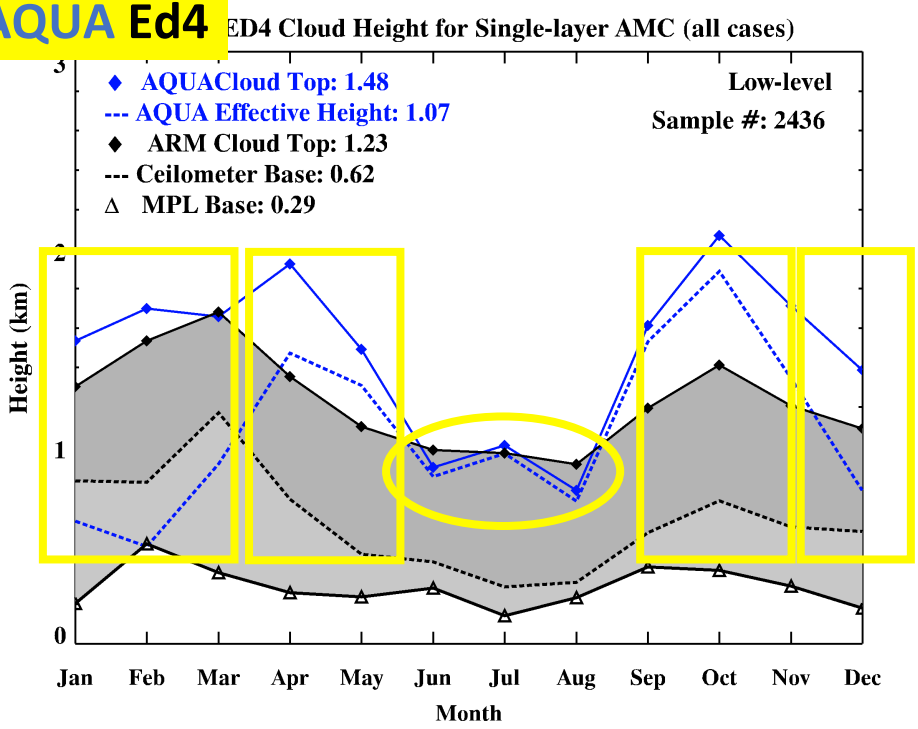
- **When focus on no overturning cases (~60% of all cases), ARM cloud top ~2 K colder than base T**
- **Both Terra and Aqua Cloud base temperatures agree well with cloud base temperature at ceilometer measured base height,**
- **But CERES cloud effective and top temperatures colder than ARM cloud top T**

TERRA and AQUA Cloud Height (All Cases)

TERRA Ed4



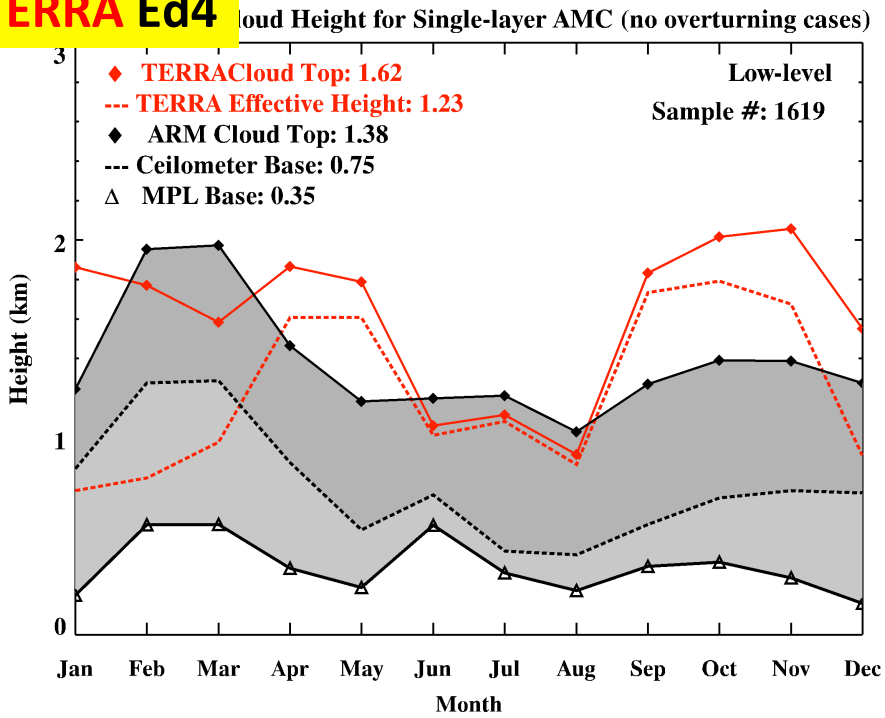
AQUA Ed4



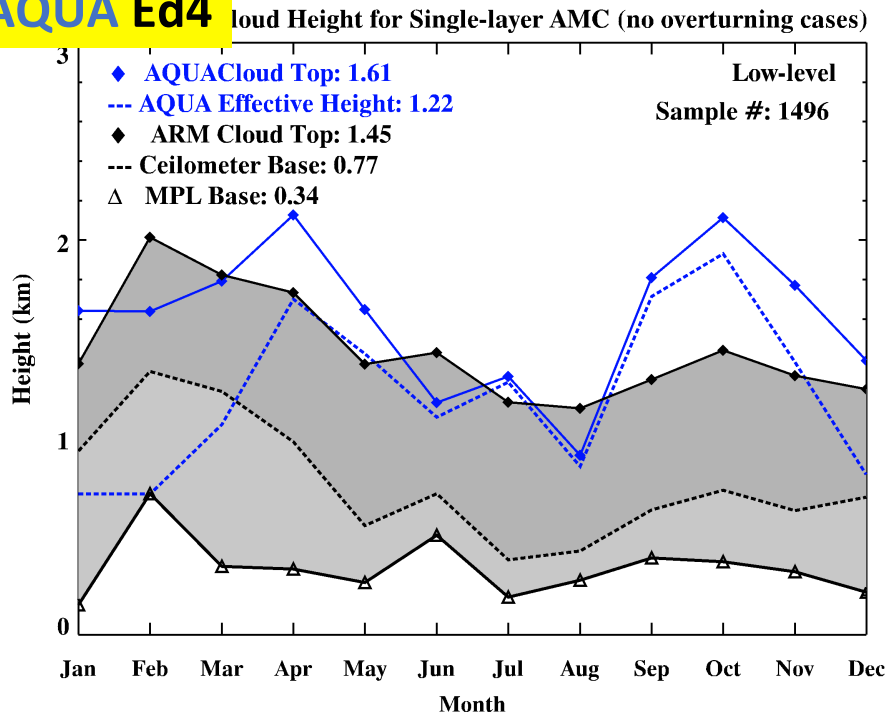
- With Effective temperature colder than ARM T_{top} year round, both Terra and Aqua effective height lower than ARM Cloud top in winter,
- and higher than ARM top in spring and autumn
- Best height retrieval from June to August

TERRA and AQUA Cloud Height (No Overturning Cases)

TERRA Ed4



AQUA Ed4



- **When focus on no overturning cases, all cloud height increase, but does not change the pattern**

When the cloud is not a blackbody, what the cloud height retrieval will be

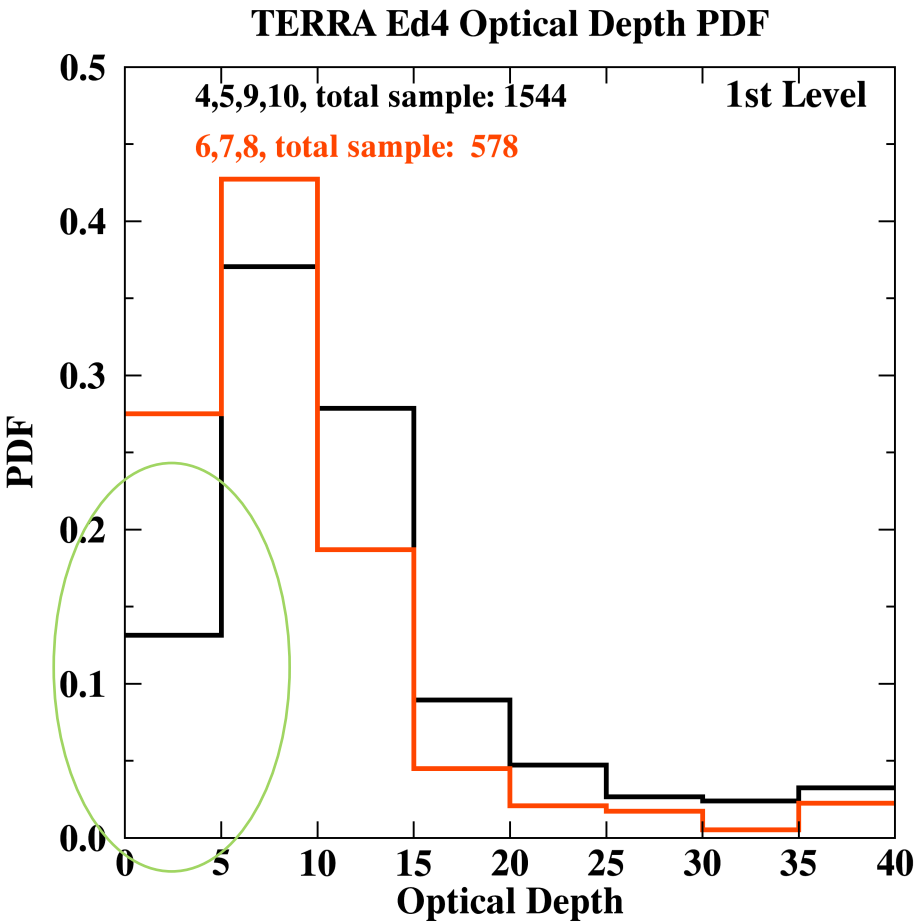
The emissivity (ε) =1- $e^{-\tau}$

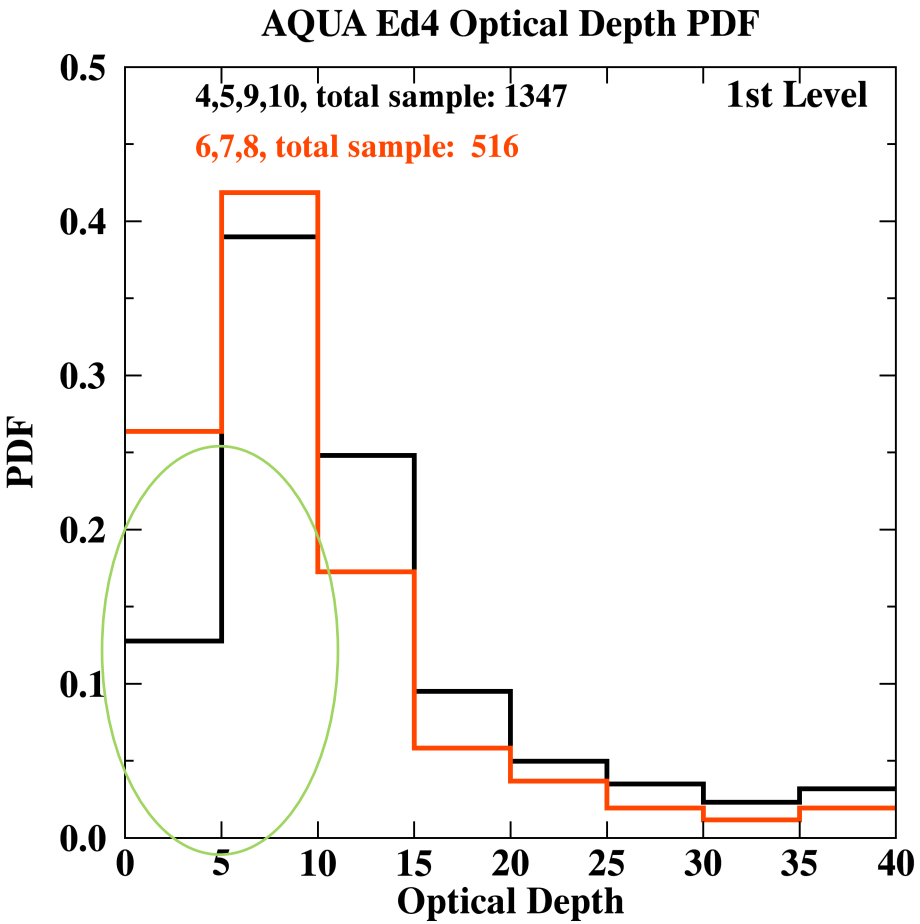
$$L=(1-\varepsilon)Lsfc+\varepsilon Leff$$

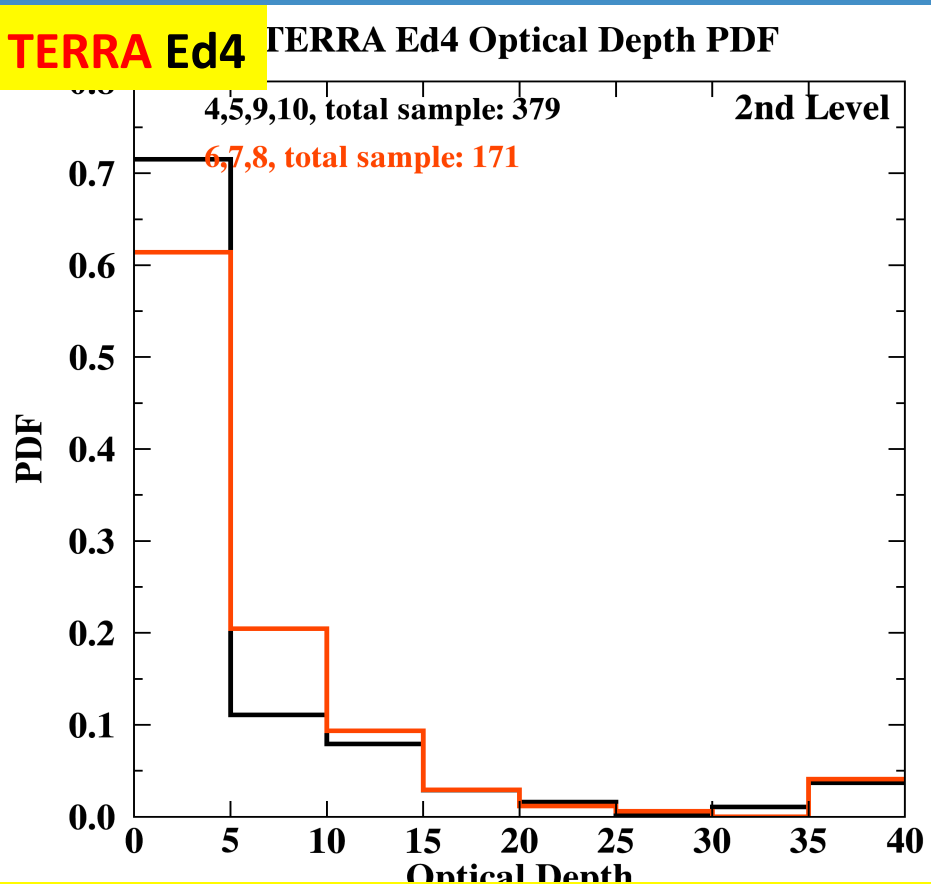
When $\tau \geq$ 4 or 5, ε=0.982 or 0.993 then the background surface will not have much effect on the radiance. The higher frequency of τ < 4 or 5 happened during the April/May/Sept/Oct.

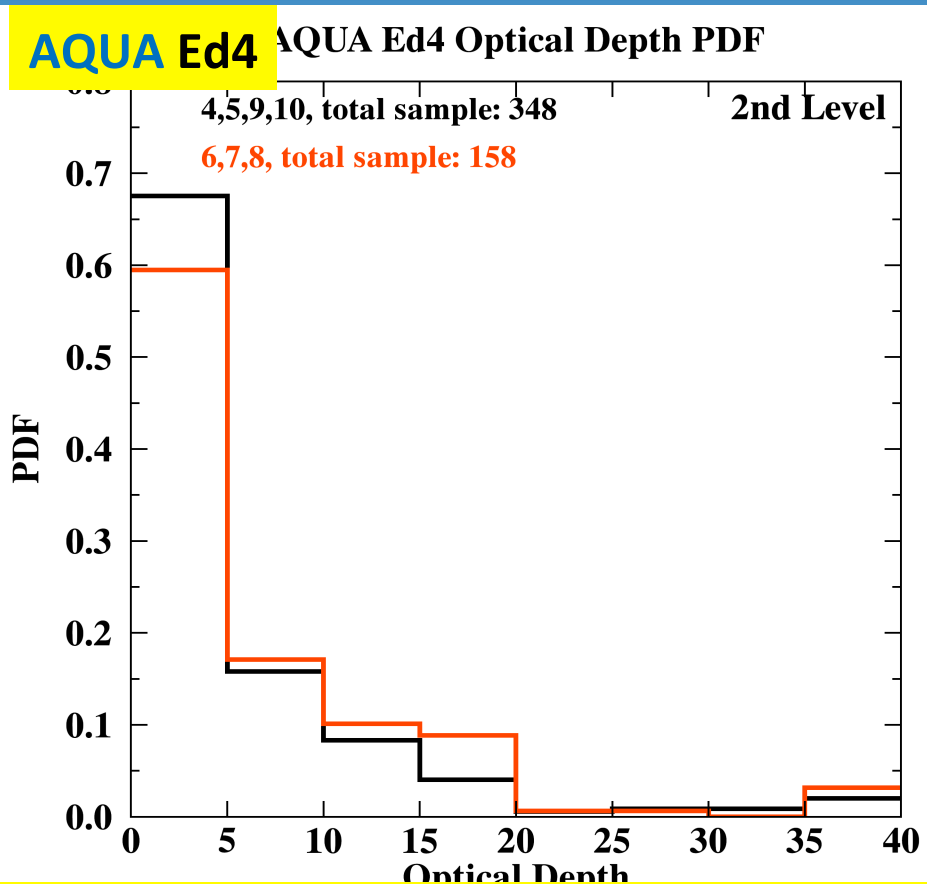
TERRA Ed4

AQUA Ed4



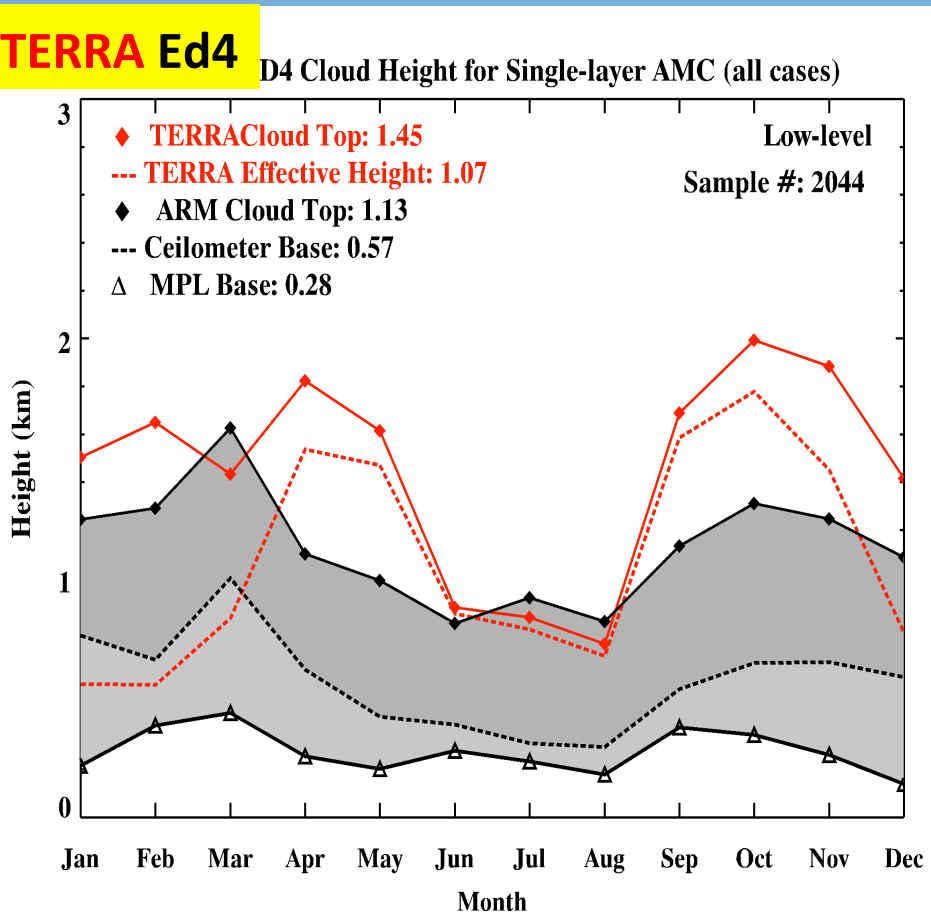


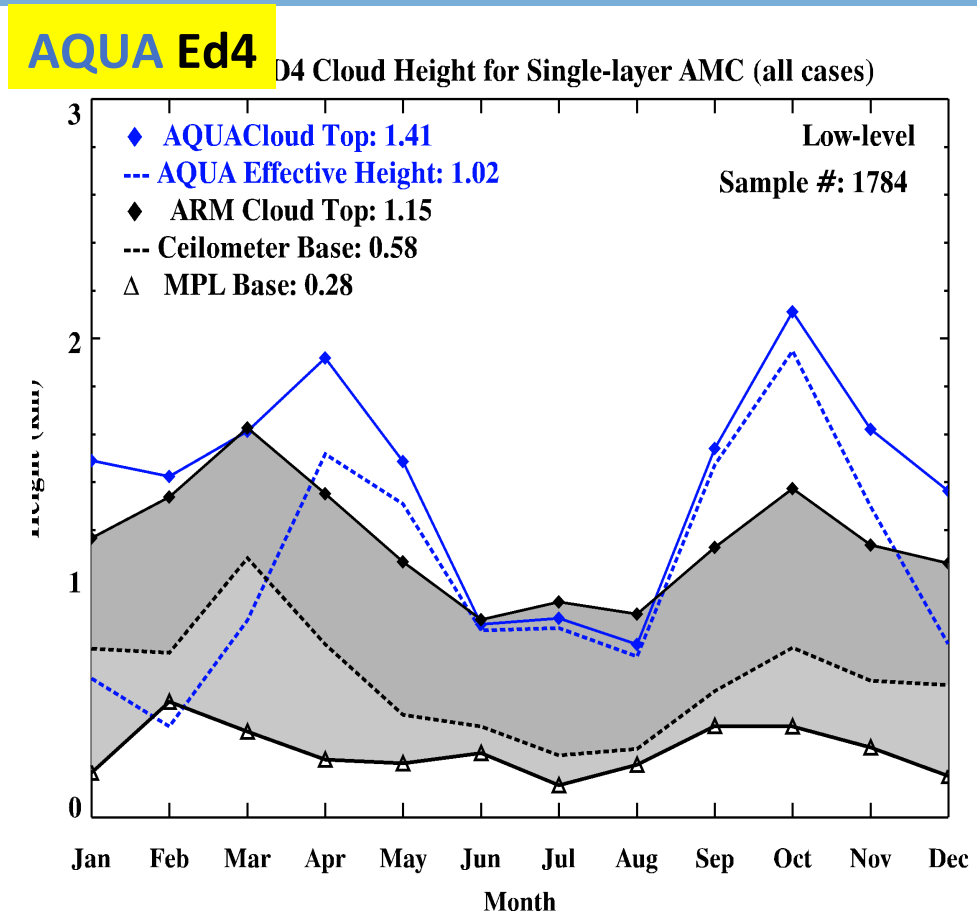




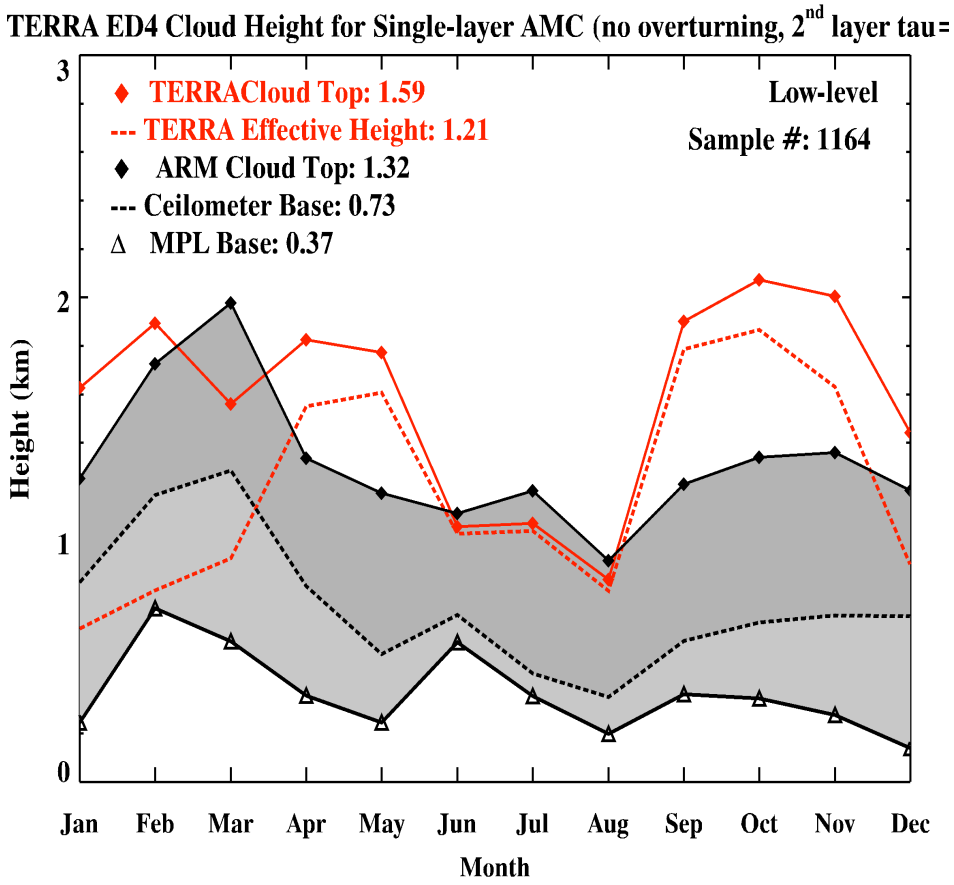
Even we allowed 10% 2nd layer in CERES, it is single layer dominate retrieval, we do not use this layer information when we do the comparison. The question is whether the upper layer T_B will affect the $T_{\ldots}$ of SSF

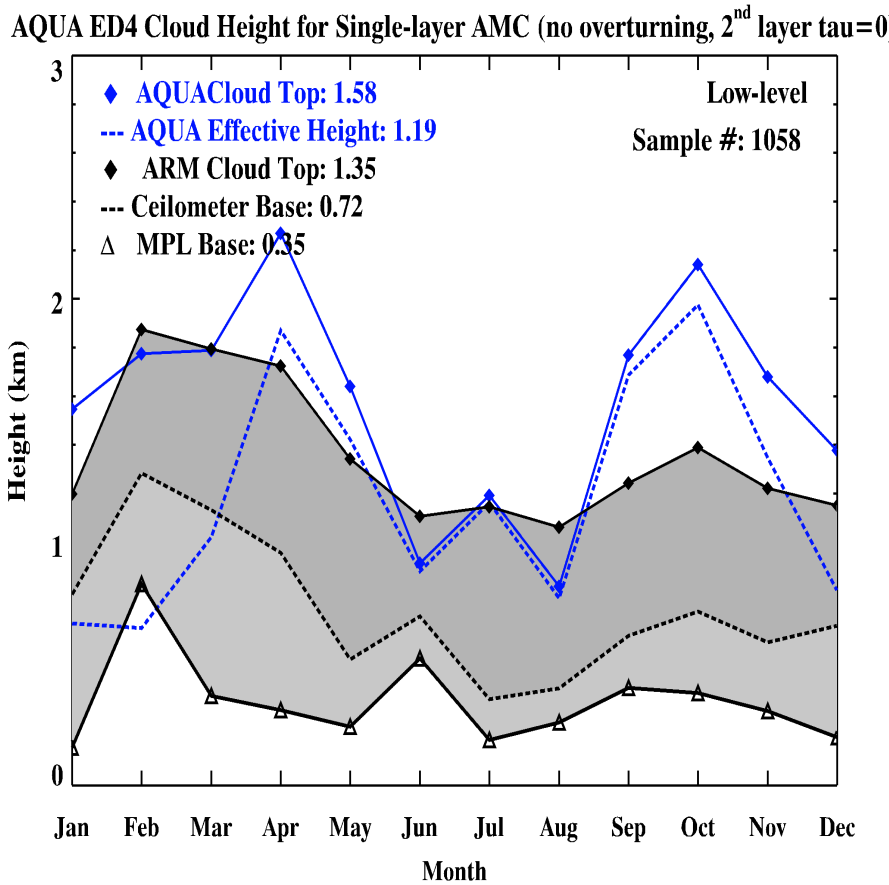
With the 2nd layer CF =0%, 26% less samples than All cases



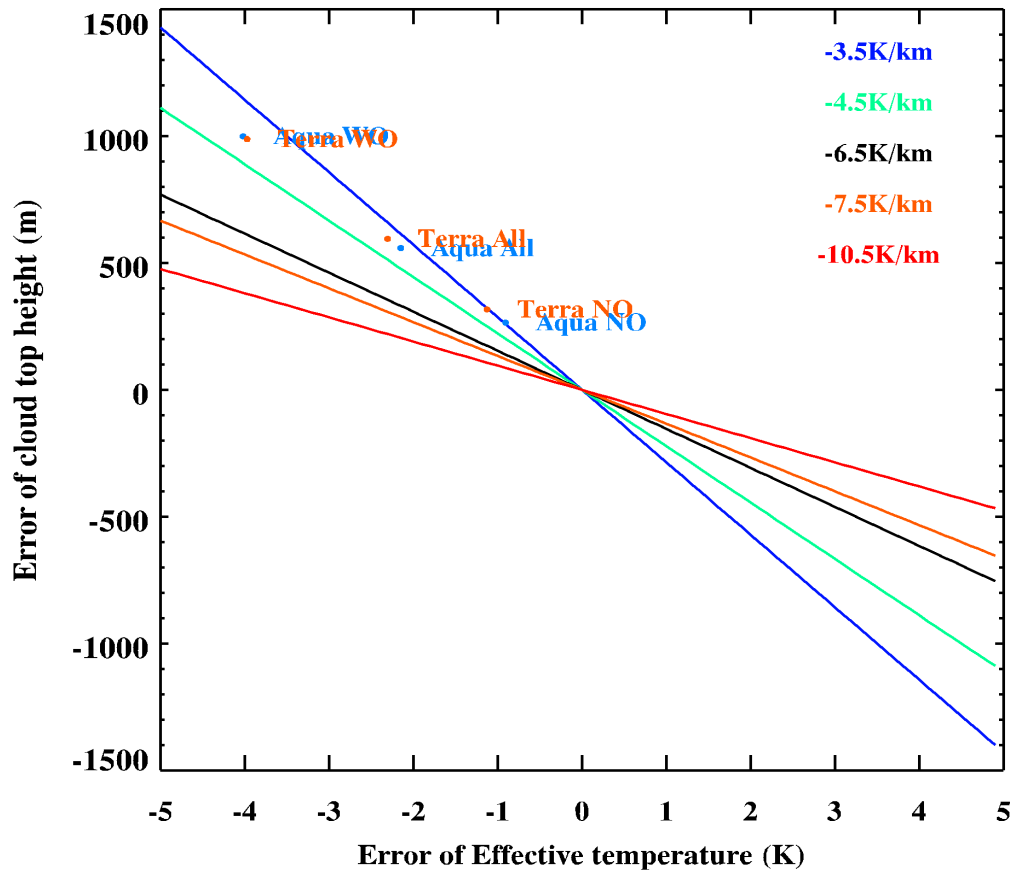


With the 2nd layer CF =0% and no overturning, 57% less samples than All cases





Theoretical Calculation of Cloud Height with Different Lapse Rates



- The annual mean lapse rate: -4.24±2.30 K/km
- Based on this lapse rate and Terra and Aqua measured effective temperature, the Terra and Aqua Cloud effective height should be ~ 300 meters lower than ARM measured cloud top
- With overturning, the error of T_{eff} can cause the T_{top} as large as ~1000 meters

Summaries and conclusions

- Both Terra and Aqua can detect more than 85% of low level AMC
- Both Terra and Aqua can identify over 96% of liquid phase of AMC
- The annual mean T_{eff} (Terra/Aqua) is ~2.5/2.3 K lower than T_{top} (ARM), and H_{eff} (Terra/Aqua) 80/160 meters lower than H_{top} (ARM).
- Without overturning cases T_{eff} is ~.5 K lower than ARM measured T_{top}
- When the optical thickness is less than 4 or 5 then the cloud emissivity will be less than 1. The T_B will be affected by background surface, so the T_B will the less than the true one,

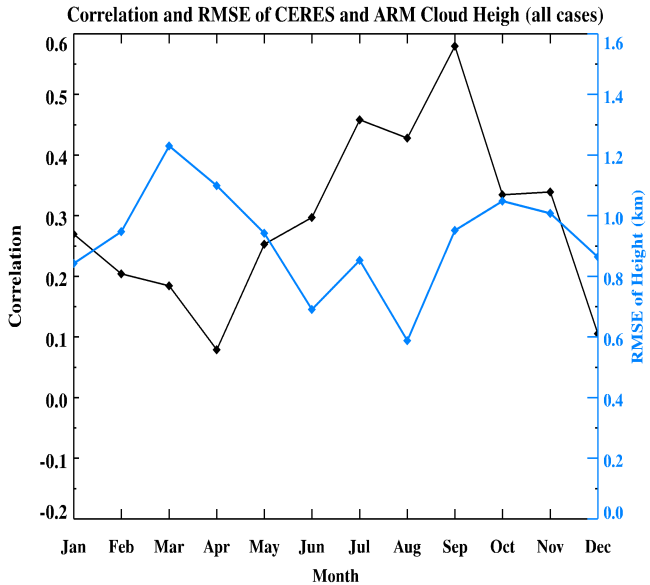
Future works for this study

- Calculate and apply the monthly lapse rate when the AMC happens and investigate whether it will can be reduced the RMS;
- Calculate and apply the daytime/nighttime lapse rate when AMC happens;
- Look closely for all the cases when it optical thickness is less than 5.

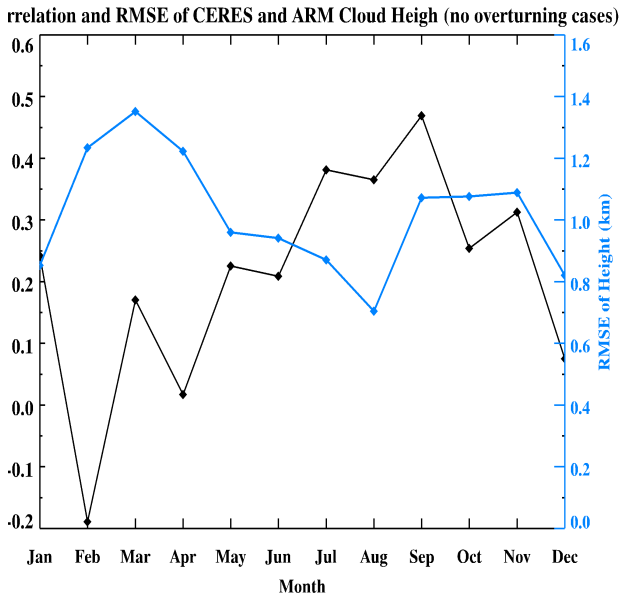
BACKUP

Correlation and RMSE for TERRA , AQUA combined Cloud Height Vs. ARM Cloud Height

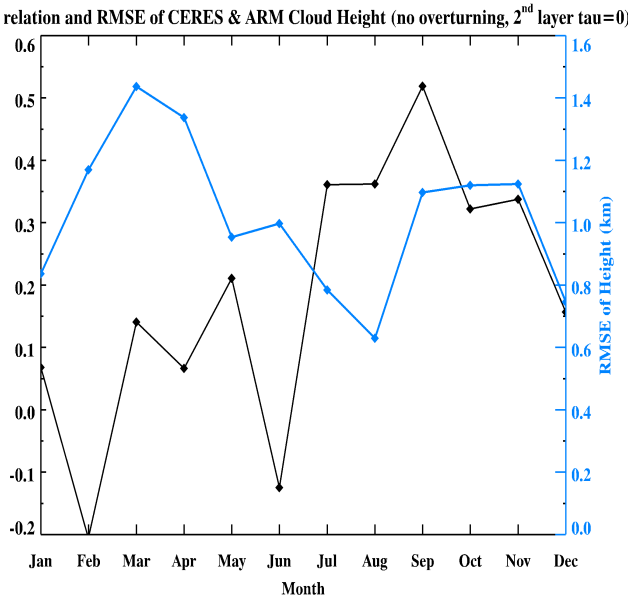
All Cases



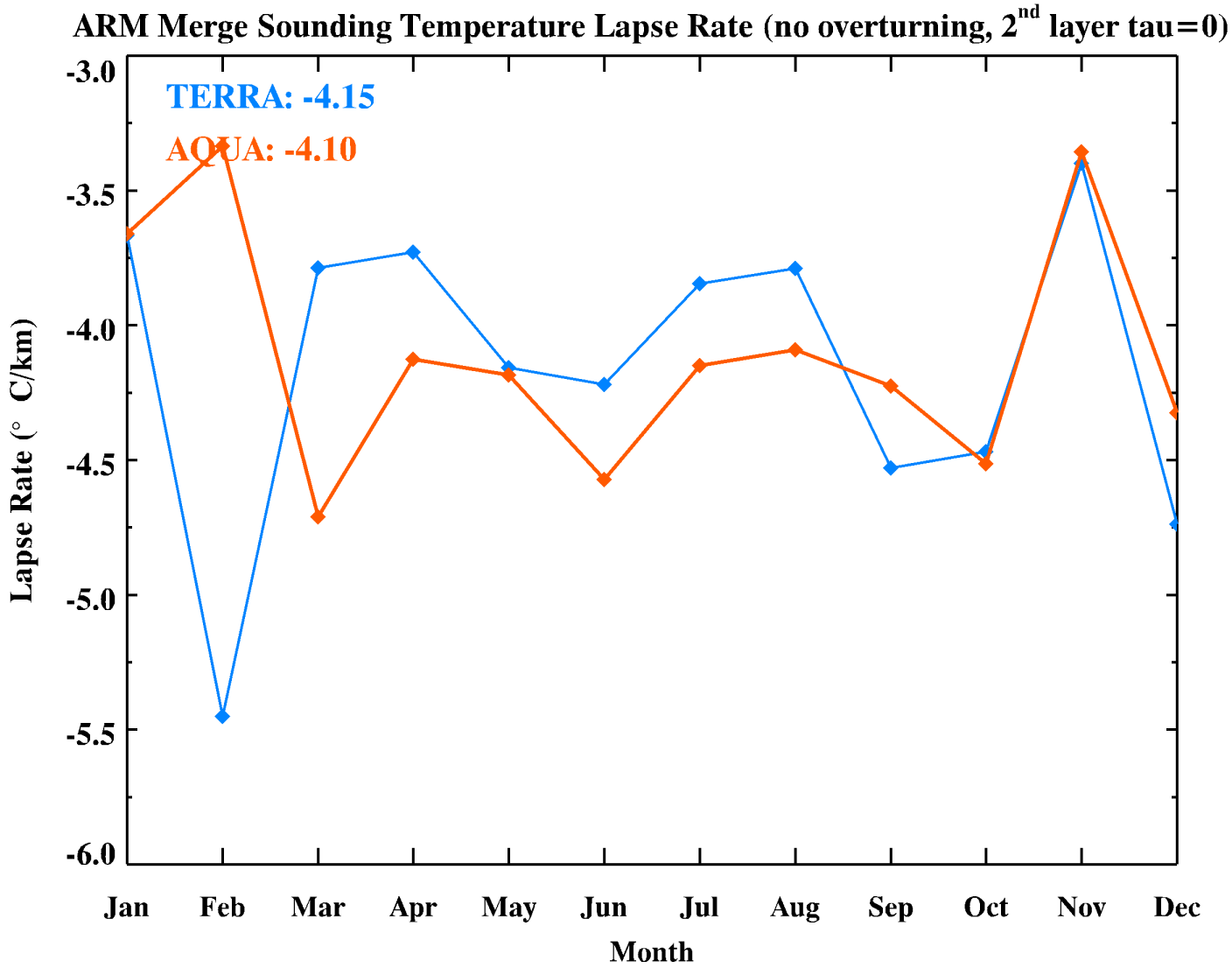
No Overturning



No Overturning, 2nd Layer τ=0



Both correlation and RMSE are worse for neither no overturning cases nor no overturning and tau=0 cases.


ARM Merge Sounding Temperature Lapse Rate (no overturning, 2nd layer tau=0)
TERRA: -4.15
AQUA: -4.10
Lapse Rate (° C/km)
-3.0
-3.5
-4.0
-4.5
-5.0
-5.5
-6.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Calculation of Cloud Height with Plank Function and Effective Temperature τ<6

When τ<6

Plank Function

$$L(\lambda,T)=C1/\lambda 5(\exp(C2/\lambda T+1)$$

$$T\downarrow top=L\lambda-1\ [0.99L\lambda(T\downarrow eff)]$$

Inverse Planck Function:

$$T(\lambda,L_\lambda)=c2/\lambda\ln(c1/\lambda 5L\lambda+1)$$

When τ≥6

$$H\downarrow top=H\downarrow eff+H\downarrow 0$$

Single-layer low-level case:

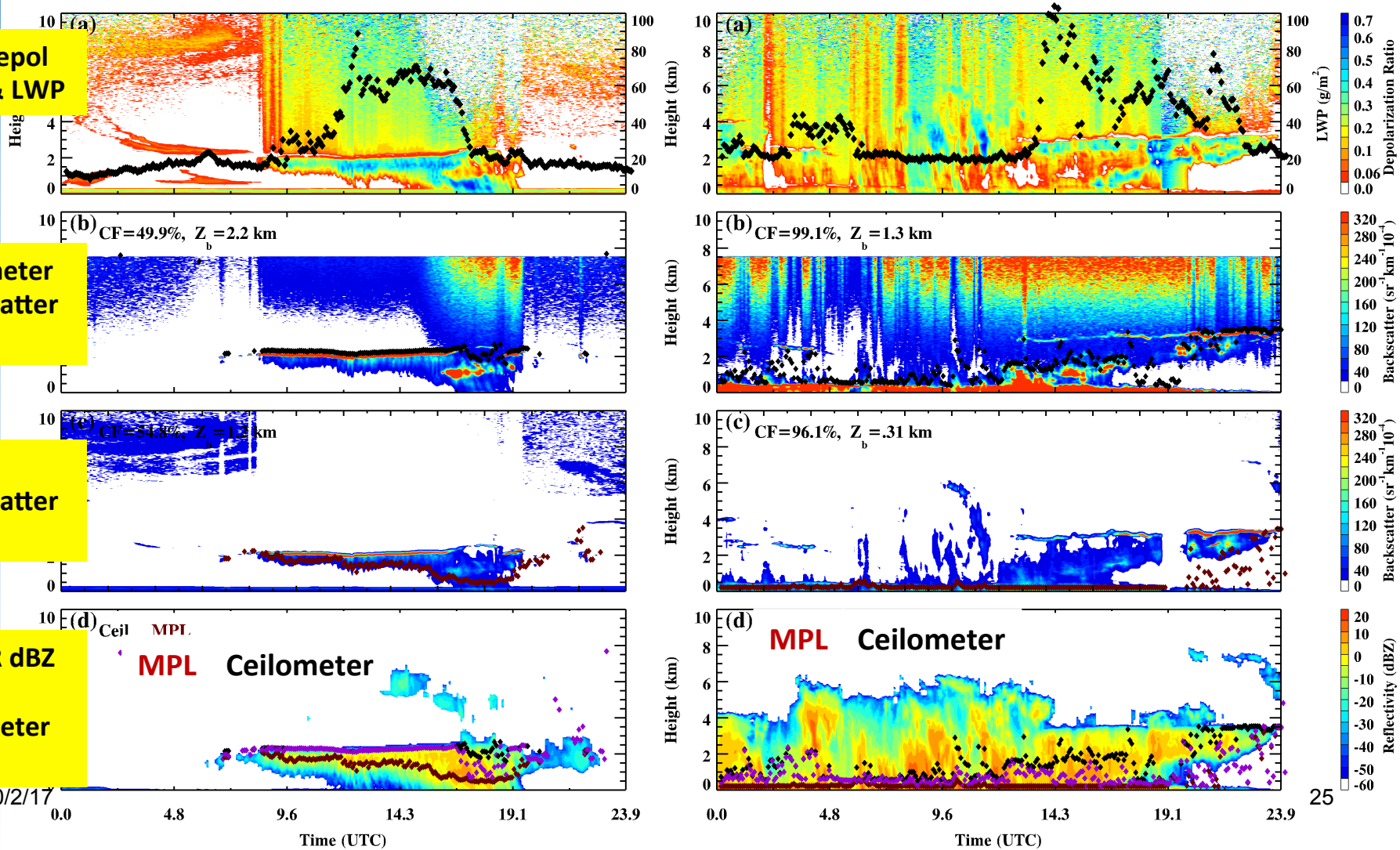
Single-layer deep cloud case:

MPL depol ratio & LWP

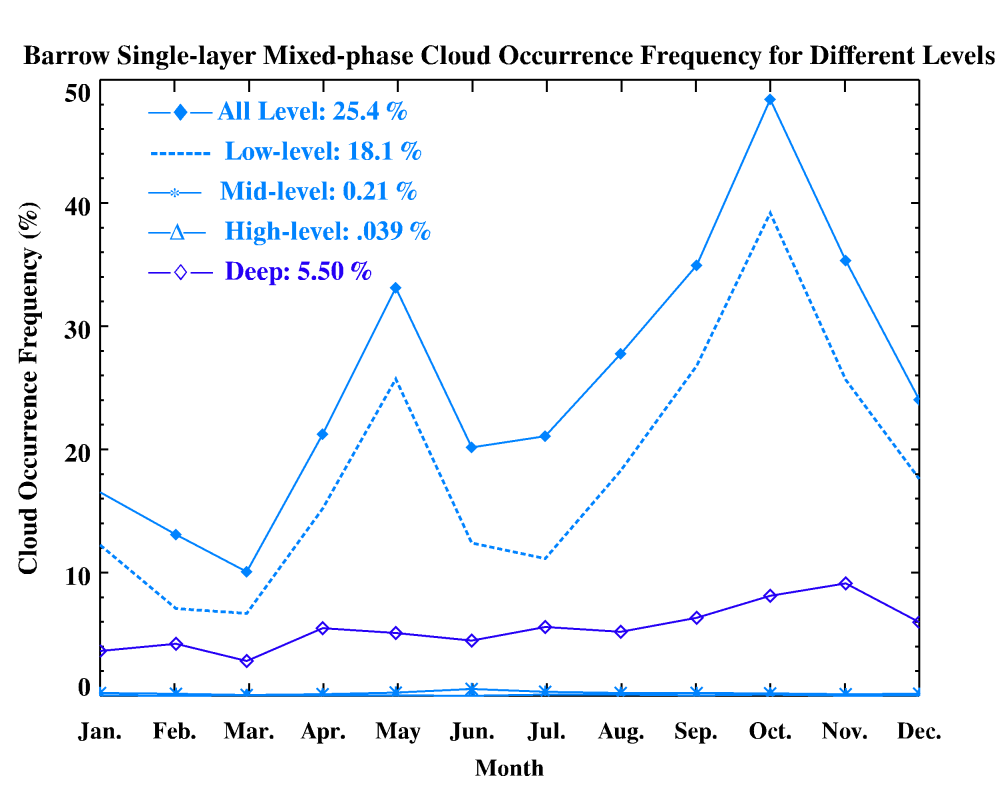
Ceilometer backscatter base

MPL backscatter base

MMCR dBZ MPL, ceilometer base

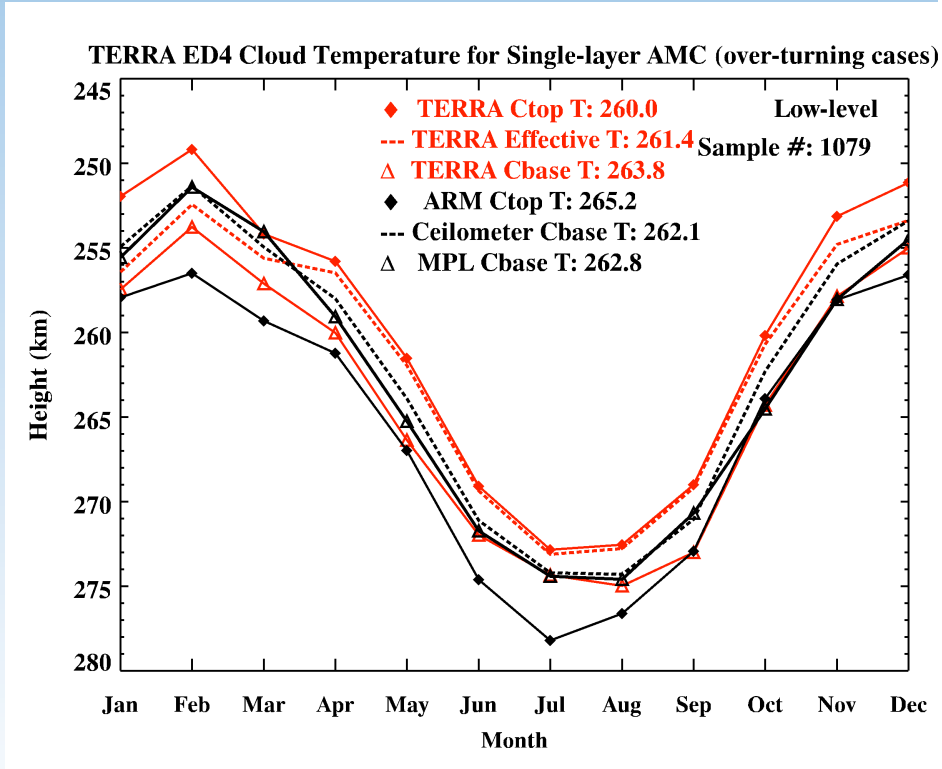


Classify clouds into different levels with MPL cloud base and Radar cloud top

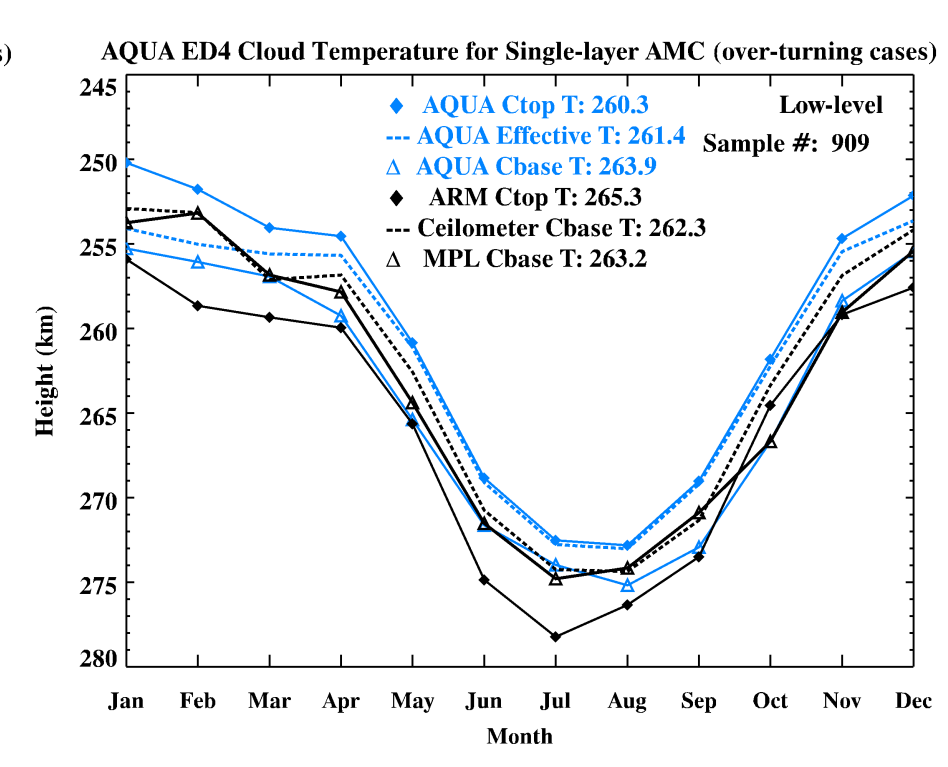


TERRA and AQUA cloud temperature (overturning cases)

TERRA Ed4

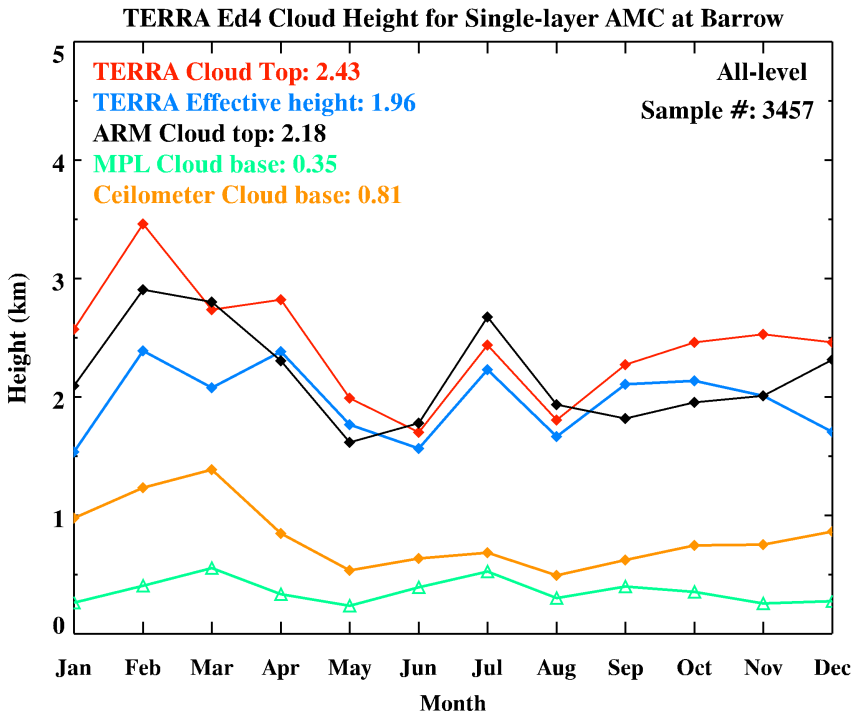


AQUA Ed4

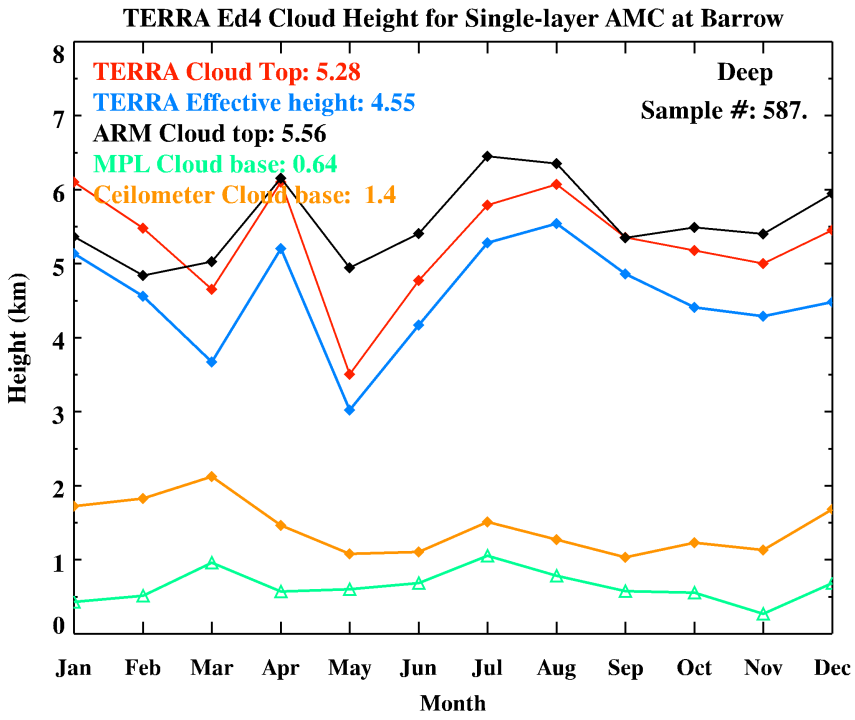


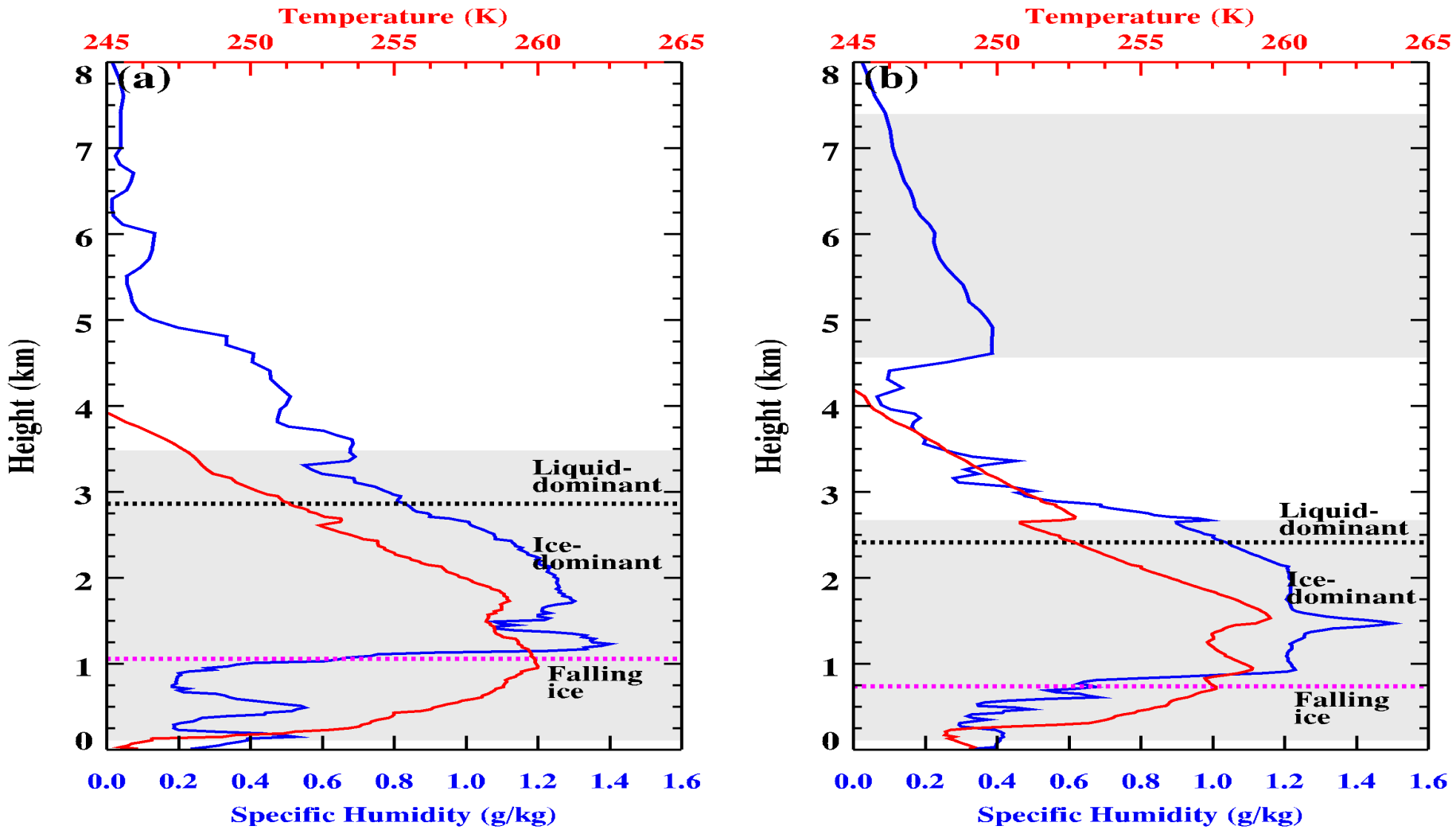
TERRA Ed4 Cloud Effective Height & Cloud Top Height

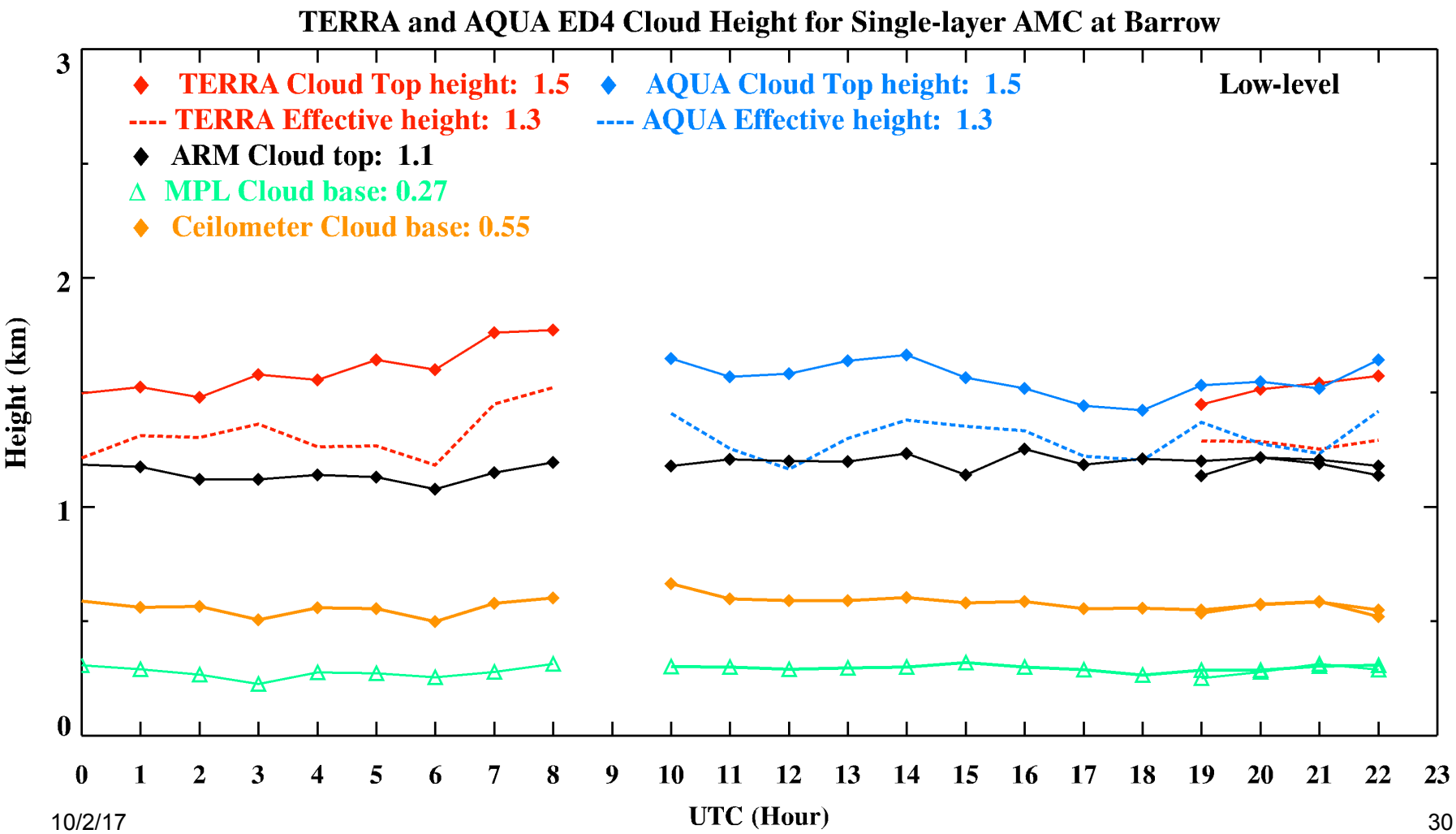
TERRA Ed4 All-level



TERRA Ed4 Deep cloud




Temperature (K)
245
250
255
260
265
(a)
(b)
Height (km)
0
1
2
3
4
5
6
7
8
Liquid-dominant
Ice-dominant
Falling ice
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Specific Humidity (g/kg)


TERRA and AQUA ED4 Cloud Height for Single-layer AMC at Barrow
TERRA Cloud Top height: 1.5
TERRA Effective height: 1.3
ARM Cloud top: 1.1
MPL Cloud base: 0.27
Ceilometer Cloud base: 0.55
AQUA Cloud Top height: 1.5
AQUA Effective height: 1.3
Low-level
Height (km)
UTC (Hour)
0
1
2
3
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23