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
09/28/2017
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

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 $\beta > 300 \text{ (sr}^{-1} \text{ km}^{-1} 10^{-4})$ and MPL depolarization ratio $< 0.1$
- Or LWP $> 25 \text{ (g m}^{-2})$
- And $T > -40 \, ^\circ C$
- 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 ($C_{\text{top}} < 3$ km)
When ARM detects single-layer mixed phase cloud, ~85% of time CERES also identify single layer cloud (allow 10% of 2\textsuperscript{nd} layer)

Only cases with both ARM and CERES detect single-layer cloud are selected

\[10/2/17\]
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.

10/2/17
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 variations.
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, $T_{\text{top}} > T_{\text{base}}$
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
• 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
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 \((\varepsilon) = 1 - e^{-\tau}\)

\[ L = (1 - \varepsilon) L_{sfc} + \varepsilon L_{eff} \]

When \(\tau \geq 4\) or 5, \(\varepsilon = 0.982\) or 0.993 then the background surface will not have much effect on the radiance. The higher frequency of \(\tau < 4\) or 5 happened during the April/May/Sept/Oct.
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 $T_{SSF}$ of SSF.
With the 2\textsuperscript{nd} layer CF =0\%, 26\% less samples than All cases
With the 2nd layer CF =0% and no overturning, 57% less samples than All cases
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 $T_{\text{eff}}$ can cause the $T_{\text{top}}$ 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 $T_{\text{eff}}$ (Terra/Aqua) is $\sim 2.5/2.3$ K lower than $T_{\text{top}}$ (ARM), and $H_{\text{eff}}$ (Terra/Aqua) 80/160 meters lower than $H_{\text{top}}$ (ARM).
- Without overturning cases $T_{\text{eff}}$ is $\sim 0.5$ K lower than ARM measured $T_{\text{top}}$.
- 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.
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, 2\textsuperscript{nd} layer $\tau=0$)

- TERRA: -4.15
- AQUA: -4.10

Lapse Rate ($^\circ$ C/km) vs. Month

Month: Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec
Calculation of Cloud Height with Plank Function and Effective Temperature $\tau<6$

When $\tau<6$

Plank Function

$$L(\lambda,T) = C_1/\lambda^5(\exp(C_2/\lambda T +1)$$

$$T_{\downarrow top} = L\lambda - 1 [0.99 L\lambda(T_{\downarrow eff})]$$

Inverse Planck Function:

$$T(\lambda,L\lambda) = c_2/\lambda \ln(c_1/\lambda^5 L\lambda + 1)$$

When $\tau\geq 6$

$$H_{\downarrow top} = H_{\downarrow eff} + H_{\downarrow 0}$$
Classify clouds into different levels with MPL cloud base and Radar cloud top
TERRA and AQUA cloud temperature (overturning cases)

**TERRA Ed4**

- TERRA Ctop T: 260.0
- TERRA Effective T: 261.4
- TERRA Cbase T: 263.8
- ARM Ctop T: 265.2
- Ceilometer Cbase T: 262.1
- MPL Cbase T: 262.8

**AQUA Ed4**

- AQUA Ctop T: 260.3
- AQUA Effective T: 261.4
- AQUA Cbase T: 263.9
- ARM Ctop T: 265.3
- Ceilometer Cbase T: 262.3
- MPL Cbase T: 263.2

10/2/17
TERRA Ed4 Cloud Effective Height & Cloud Top Height

**TERRA Ed4 All-level**

TERRA Cloud Top: 2.43
TERRA Effective height: 1.96
ARM Cloud top: 2.18
MPL Cloud base: 0.35
Ceilometer Cloud base: 0.81
Sample #: 3457

**TERRA Ed4 Deep cloud**

TERRA Cloud Top: 5.28
TERRA Effective height: 4.55
ARM Cloud top: 5.56
MPL Cloud base: 0.64
Ceilometer Cloud base: 1.4
Sample #: 587.

10/2/17
The graphs show the relationship between temperature (K) and specific humidity (g/kg) as a function of height (km) for two different cases (a) and (b). The shaded regions indicate the 'liquid-dominant' area, with a transition layer labeled 'Falling ice'. The specific humidity values range from 0.0 to 1.6 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
- **AQUA Cloud Top height:** 1.5
- **AQUA Effective height:** 1.3
- **ARM Cloud top:** 1.1
- **MPL Cloud base:** 0.27
- **Ceilometer Cloud base:** 0.55

**Height (km)**

UTC (Hour)

10/2/17