SoWMEX2010@Taipei
Nov. 03, 2010

Validation of the Results of the Cloud-Resolving Model with the Satellite Data of Infrared and Microwave Bands around the Taiwan Region during the Meiyu Season

Taro SHINODA[1], Munehisa K. YAMAMOTO[2], Hirohiko MASUNAGA[1], Masaya KATO[1], Atsushi HIGUCHI[2], Kazuhisa TSUBOKI[1], and Hiroshi UYEDA[1]

[1] Hydrospheric Atmospheric Research Center (HyARC), Nagoya University
[2] Center for Environmental Remote Sensing (CEReS), Chiba University

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Development of a Validation Method for a Cloud-Resolving Model Using Satellite Data of Infrared and Microwave Bands

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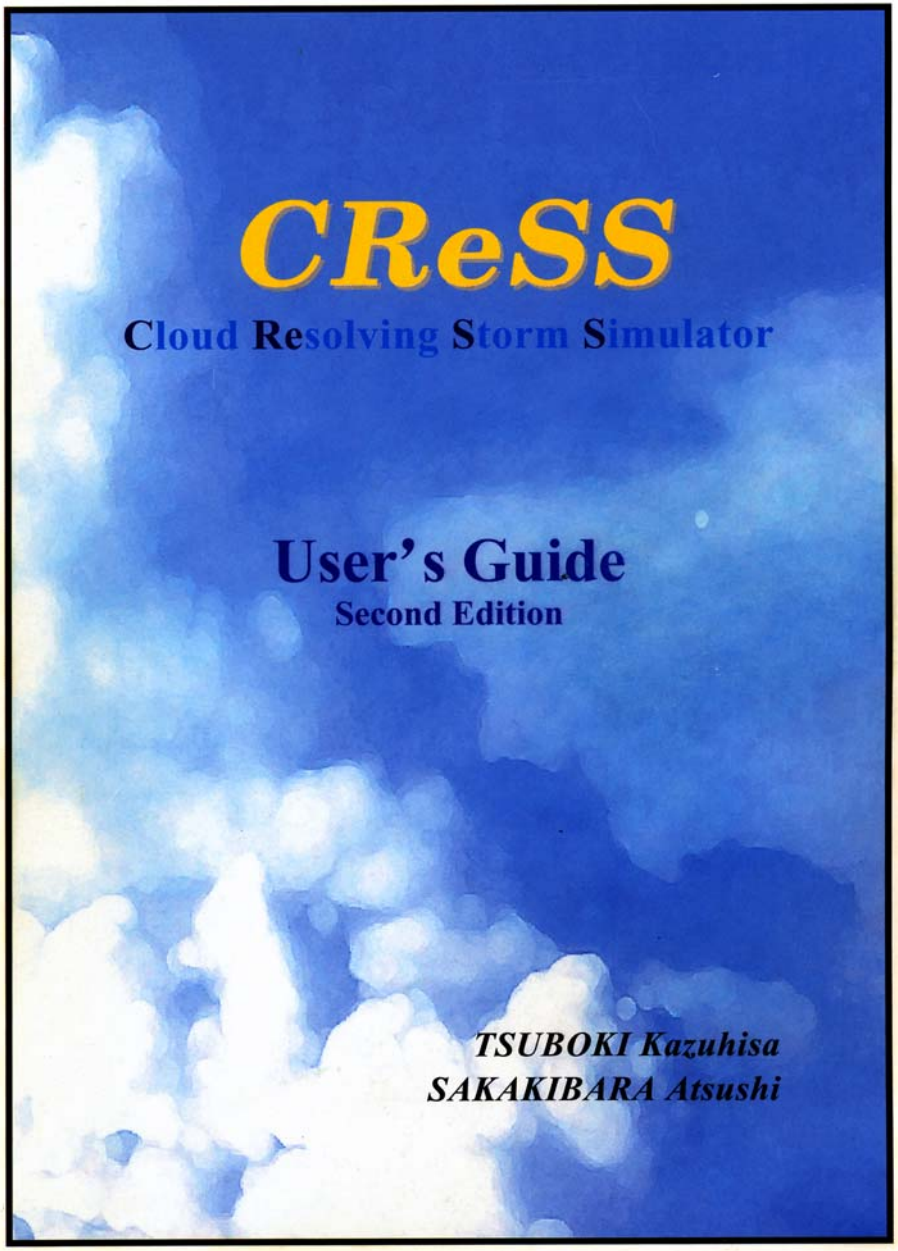
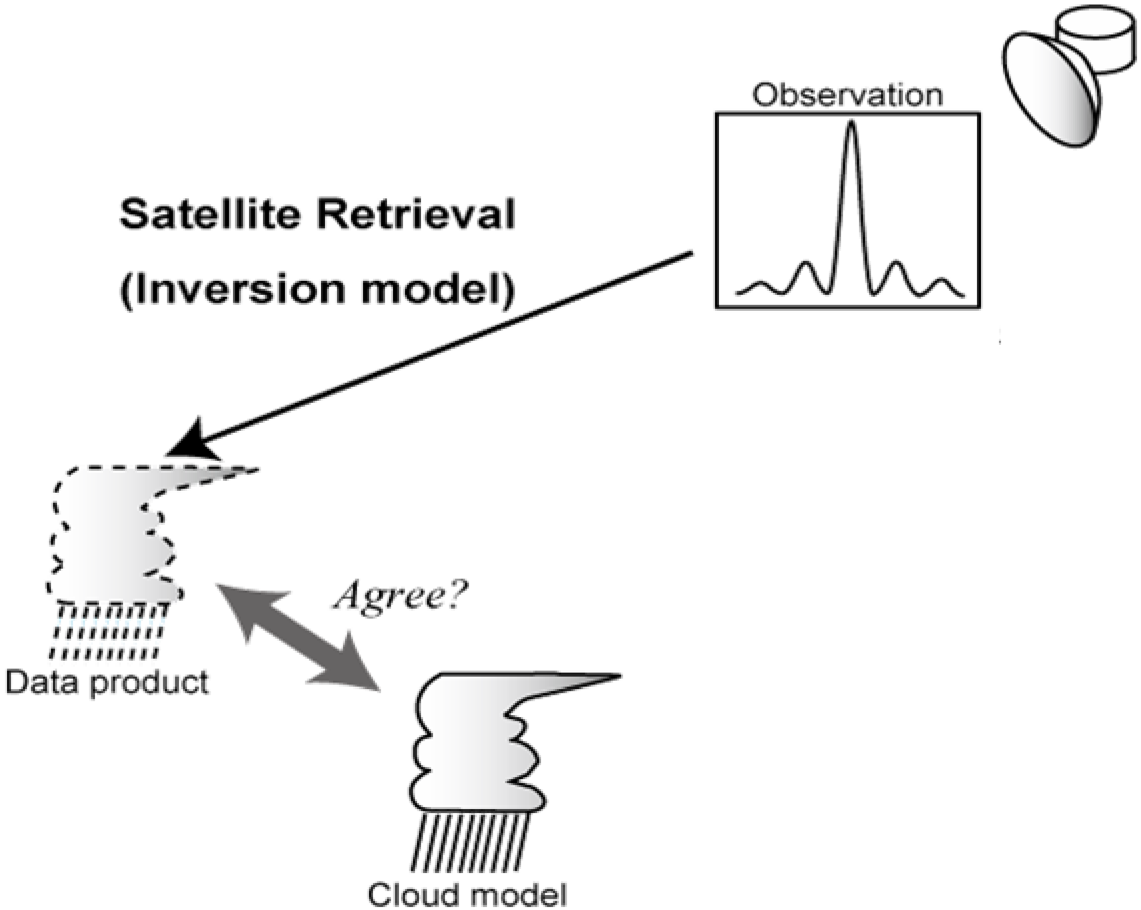
A Cloud Resolving Model (CRM)



- **A Cloud Resolving Models (CRM) explicitly resolve each convective clouds, so it is an useful tool to analyze the structure of cloud and precipitation systems.**
- **We have a CRM named the Cloud Resolving Storm Simulator (CReSS) developed by Dr. Tsuboki.**
- **The CRM has many uncertainties in cloud microphysical processes.**
- **To confirm the accuracy of the CRM, it is useful to compare the results of the CRM simulation with the satellite observation.**

Evaluation of CRM simulations using satellite data

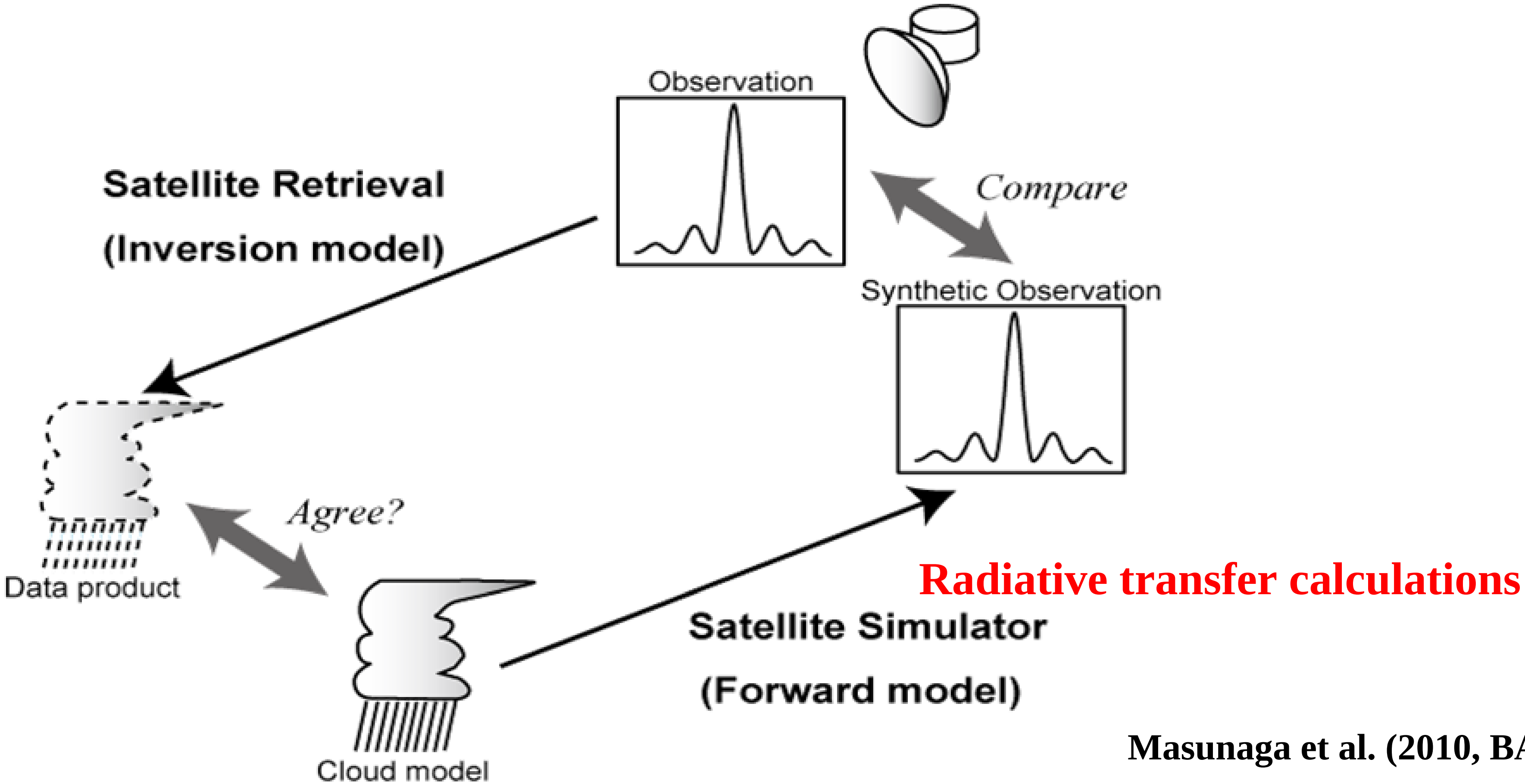


Masunaga et al. (2010, BAMS)

- **The physical parameters simulated by the CRM were compared with those retrieved by the satellite observations.**
- **The retrieved physical parameters could contain their own biases due to uncertainties in the inversion algorithms.**

→ It is difficult to make an evaluation of the CRM using satellite-derived physical parameters.

A satellite simulator



Masunaga et al. (2010, BAMS)

- **A satellite simulator is developed in recent several years.**
- **It estimates satellite-consistent radiances from the model outputs using radiative transfer calculations (forward model).**
- **Direct satellite measurements (radiances) have much less uncertainties than retrieved physical parameters.**

The purpose of this study

The purpose of this study is
to develop a validation method for results of a CRM by comparing brightness temperature (T_{BB}) obtained from the satellite observations with those calculated using the Satellite Data Simulator Unit (SDSU) applied to daily simulation results by the CReSS around the Taiwan region during the Meiyu season in 2010.

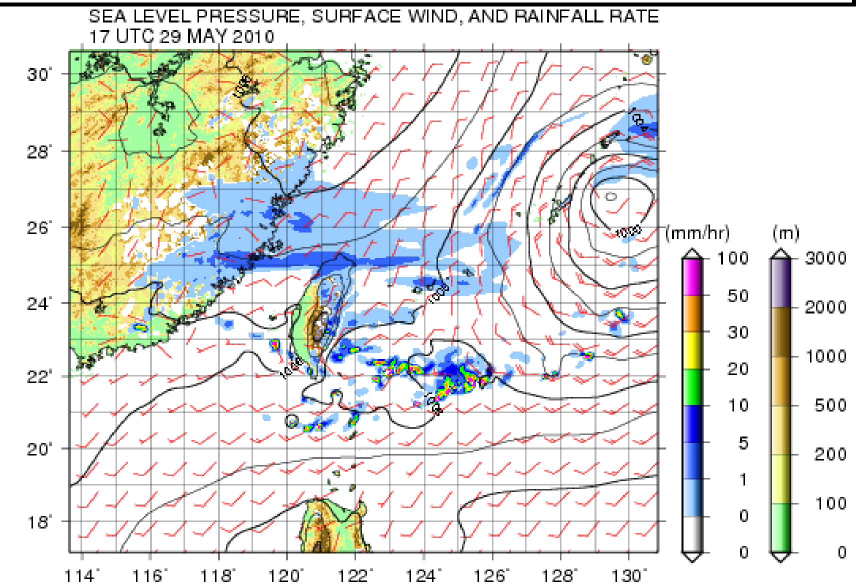
The satellite observation data

- **Infrared (Ch-1, 10.8 μm):**
  by the Multi-functional Transport Satellite (MTSAT)
  Horizontal resolution: 4 km × 4 km
- **Microwave (10.65, 89.0 GHz)**
  by the Advanced Microwave Scanning Radiometer for EOS (AMSR-E)
  Horizontal resolution: 5.9 km × 3.5 km (89.0 GHz)
  51 km × 29 km (10.65 GHz)

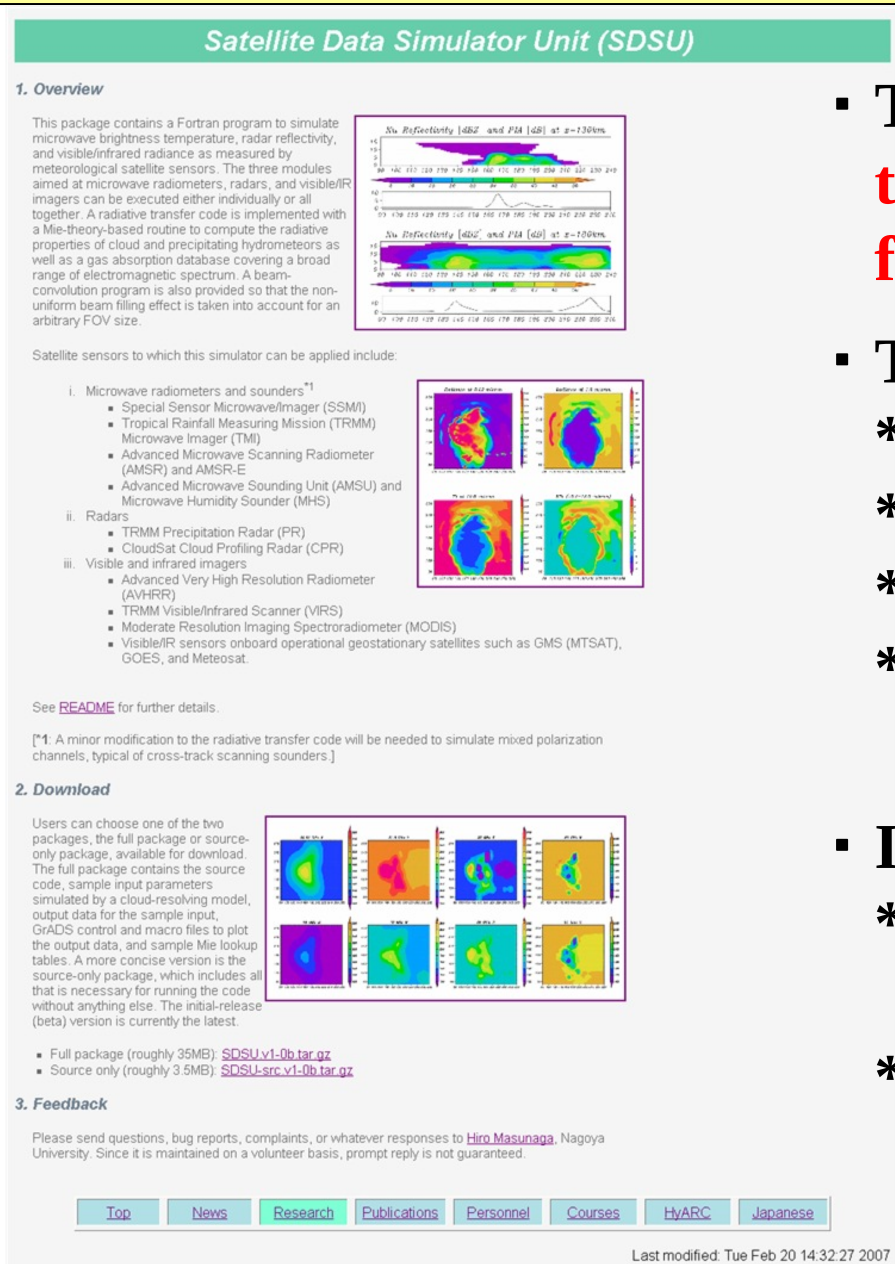
Framework of the simulation

The Cloud Resolving Model	CReSS ver2.3
Turbulent Parameterization	1.5-TKE (Klemp and Wilhelmson 1978)
	Mellor-Yamada Level 2 (Mellor and Yamada 1974)
Surface Parameterization	Bulk method (Louis et al. 1981)
Microphysical Parameterization	Cold rain（6 categories of water substances）
Radiative Parameterization	Included only the solar radiation absorption by cloud
Simulating Area	Horizontal ：700×600
	Vertical ：50 Layers (up to 25.0 km)
Grid Spacing	Horizontal ：2.5 km
	Vertical ：Lowest 100 m, stretching
Time Step	3.0 sec. (non-sonic term)，1.5 sec.（sonic term）
Initial and Lateral Boundary Conditions	GSM (Horizontal resolution ～ 50 km)
Initial Time and Integrated Time	36 hours from 18 Z
Lower Boundary Conditions	SST data provided from JMA (MGDSST)
	GTOPO30 (Horizontal resolution ～ 1 km)
	USGS land-use categories

- **Simulation period:**
  Apr. 27 ～ Jun. 30, 2010
- **Analysis period:**
  May 27 ～ Jun. 16, 2010:
  SoWMEX2010 IOP



The Satellite Data Simulator Unit (SDSU)



Satellite Data Simulator Unit (SDSU)

1. Overview

This package contains a Fortran program to simulate microwave brightness temperature, radar reflectivity, and visible/infrared radiance as measured by meteorological satellite sensors. The three modules aimed at microwave radiometers, radars, and visible/IR imagers can be executed either individually or all together. A radiative transfer code is implemented with a Mie-theory-based routine to compute the radiative properties of cloud and precipitating hydrometeors as well as a gas absorption database covering a broad range of electromagnetic spectrum. A beam-convolution program is also provided so that the non-uniform beam filling effect is taken into account for an arbitrary FOV size.

Satellite sensors to which this simulator can be applied include:

i. Microwave radiometers and sounders*1
- Special Sensor Microwave/Imager (SSM/I)
- Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI)
- Advanced Microwave Scanning Radiometer (AMSR) and AMSR-E
- Advanced Microwave Sounding Unit (AMSU) and Microwave Humidity Sounder (MHS)

ii. Radars
- TRMM Precipitation Radar (PR)
- CloudSat Cloud Profiling Radar (CPR)

iii. Visible and infrared imagers
- Advanced Very High Resolution Radiometer (AVHRR)
- TRMM Visible/Infrared Scanner (VIRS)
- Moderate Resolution Imaging Spectroradiometer (MODIS)
- Visible/IR sensors onboard operational geostationary satellites such as GMS (MTSAT), GOES, and Meteosat.

See README for further details.

[*1: A minor modification to the radiative transfer code will be needed to simulate mixed polarization channels, typical of cross-track scanning sounders.]

2. Download

Users can choose one of the two packages, the full package or source-only package, available for download. The full package contains the source code, sample input parameters simulated by a cloud-resolving model, output data for the sample input, GrADS control and macro files to plot the output data, and sample Mie lookup tables. A more concise version is the source-only package, which includes all that is necessary for running the code without anything else. The initial-release (beta) version is currently the latest.

- Full package (roughly 35MB): SDSU.v1-0b.tar.gz
- Source only (roughly 3.5MB): SDSU-src.v1-0b.tar.gz

3. Feedback

Please send questions, bug reports, complaints, or whatever responses to Hiro Masunaga, Nagoya University. Since it is maintained on a volunteer basis, prompt reply is not guaranteed.

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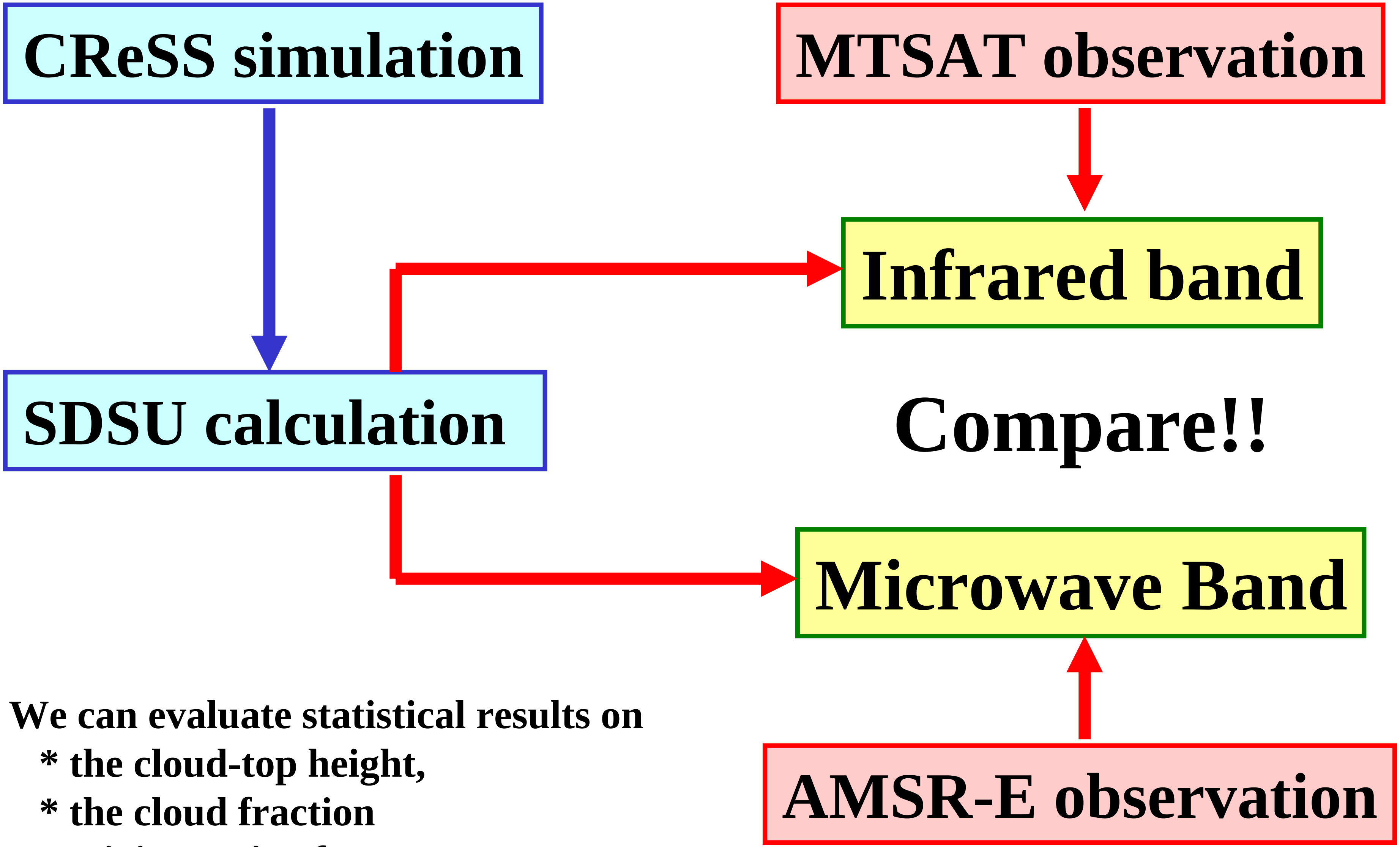
Last modified: Tue Feb 20 14:32:27 2007

- The SDSU is developed **to compute synthetic satellite data from CRM output** by Dr. Masunaga.
- The SDSU is designed to simulate
  - * **microwave brightness temperature**,
  - * radar reflectivity,
  - * visible and near-infrared radiances,
  - * **thermal infrared brightness temperature**.
- Input parameters
  - * P, PT, Qv, Qc, Qr, Qi, Qs, Qg, Ni, Ns, Ng, z
  - * SST, Surface_winds

http://precip.hyarc.nagoya-u.ac.jp/sdsu/sdsu-main.html

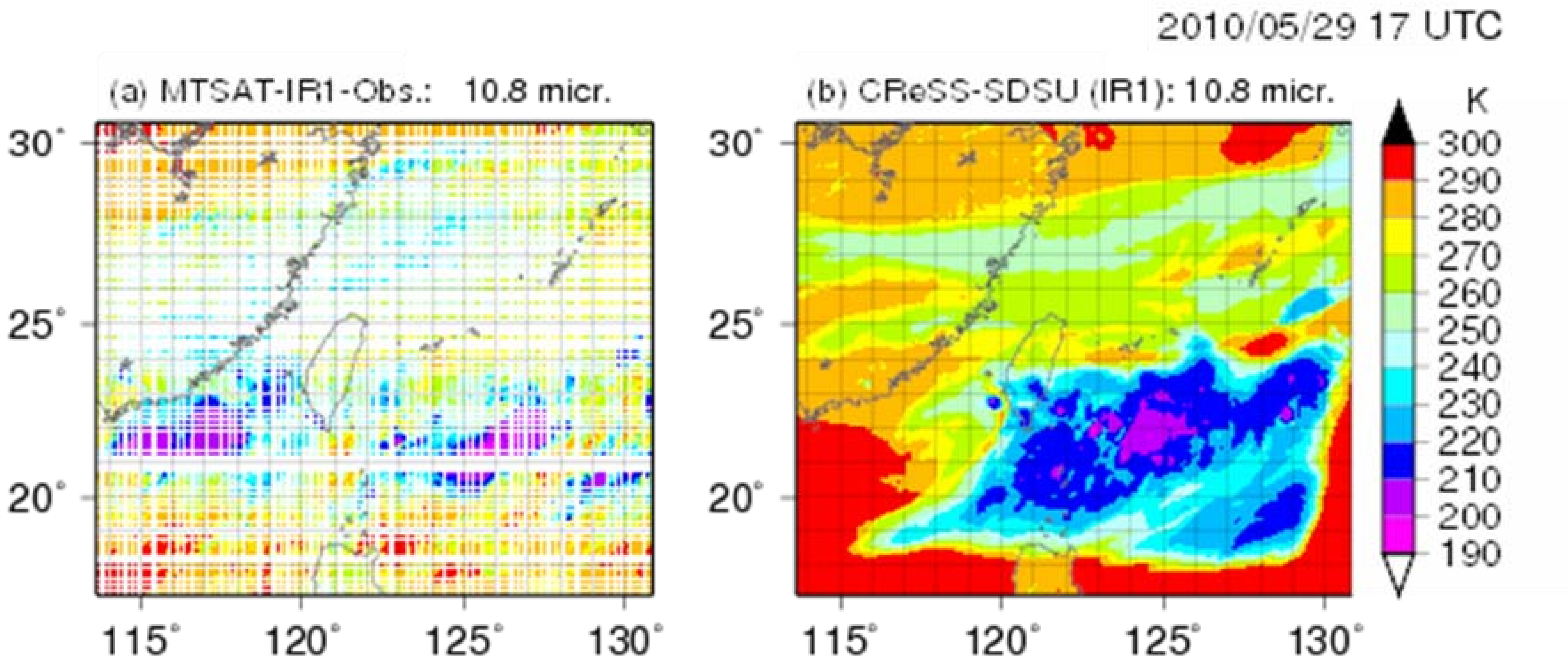
Brief summary of the comparison method in this study



We can evaluate statistical results on

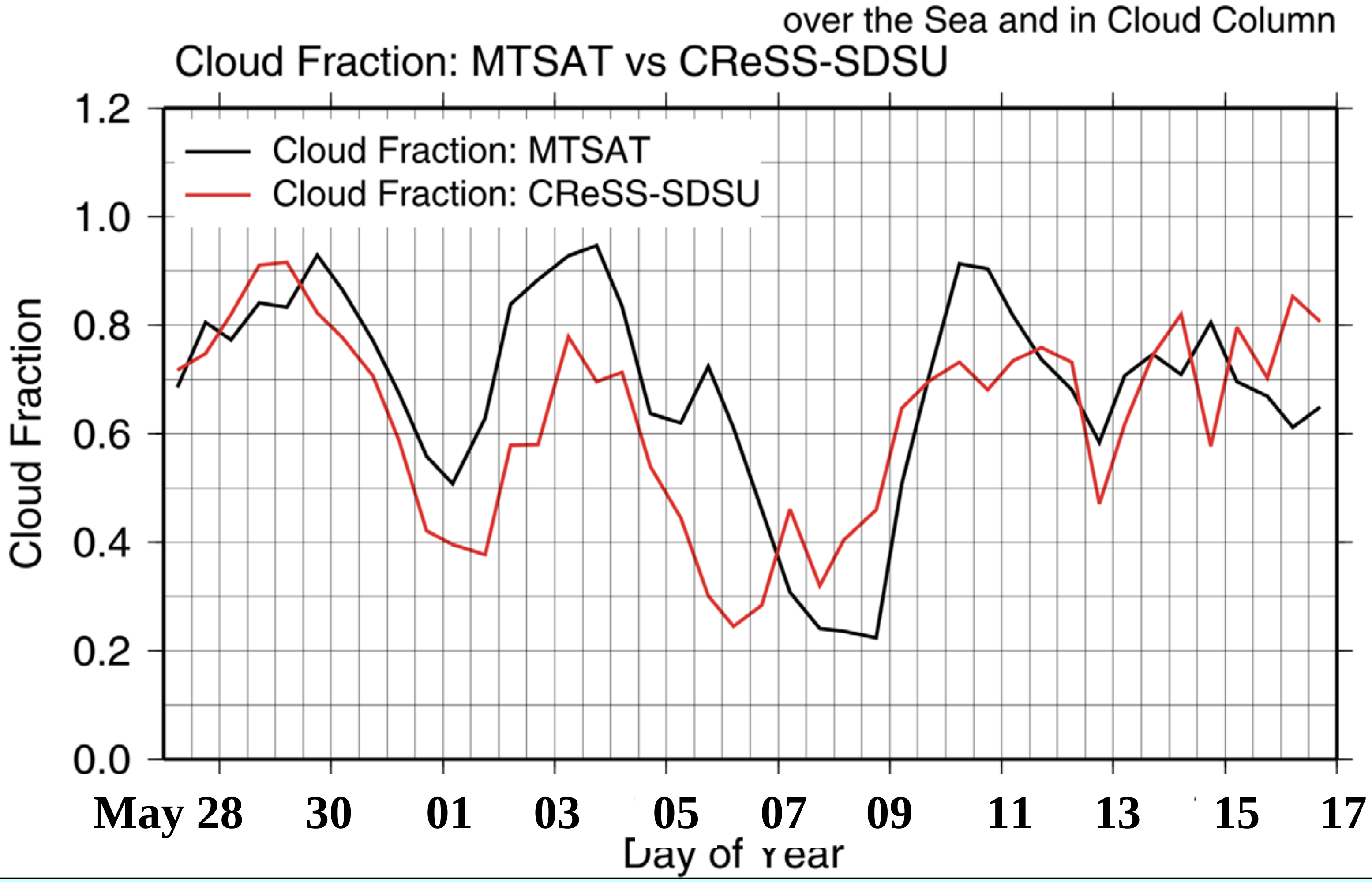
- * the cloud-top height,
- * the cloud fraction
- * mixing ratio of water vapor,
- * mixing ratio and DSD of hydrometeors.

T_{BB}-IR distributions (MTSAT vs CReSS-SDSU)



- **MTSAT obs.: Well-developed MCSs develop over the southeast and southwest of Taiwan.**
- **CReSS-SDSU: Only the southeastern MCS is well reproduced.**
- **The cloud cover is seen over the almost all of the simulation region in the MTSAT obs. and CReSS-SDSU.**

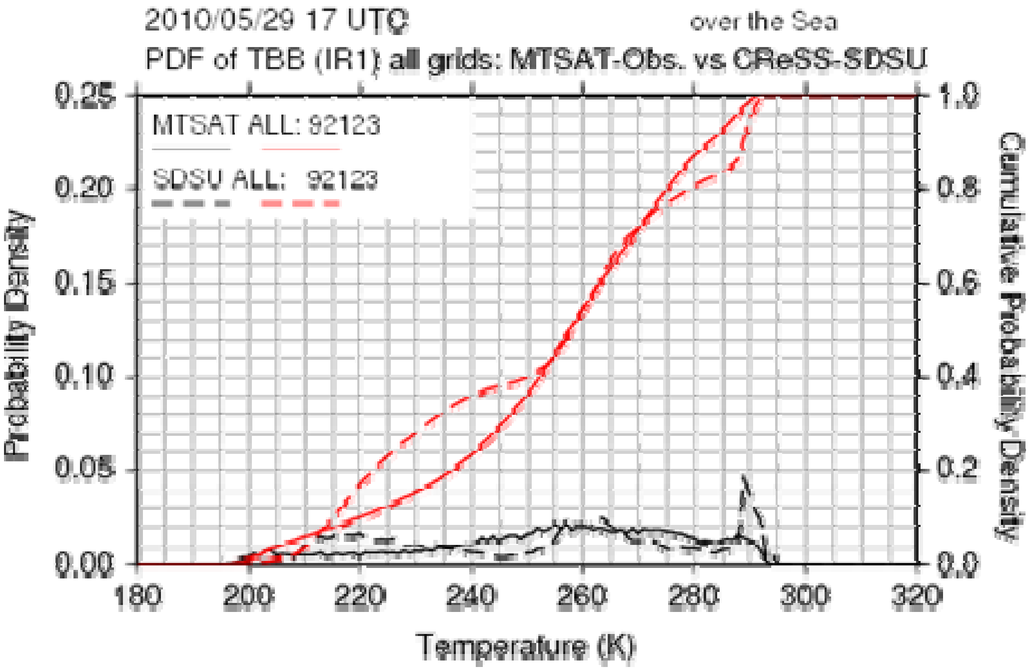
Time series of cloud fraction (MTSAT vs CReSS-SDSU)

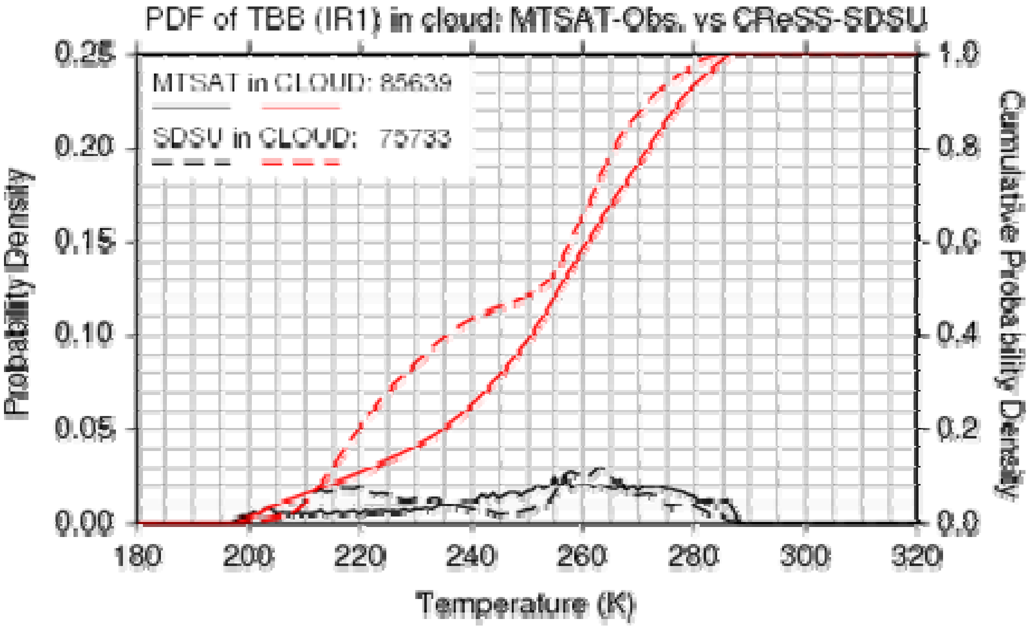


- The variation of the **cloud fraction (CF) is well reproduced**.
- **Difference of CF is small (～ 10%)**, sometimes over 30%.

※ **Definition of the cloud column**: The column whose difference in temperature between the SST and IR TBB is greater than 15 K.

PDF of T_{BB}-IR (MTSAT vs CReSS-SDSU)

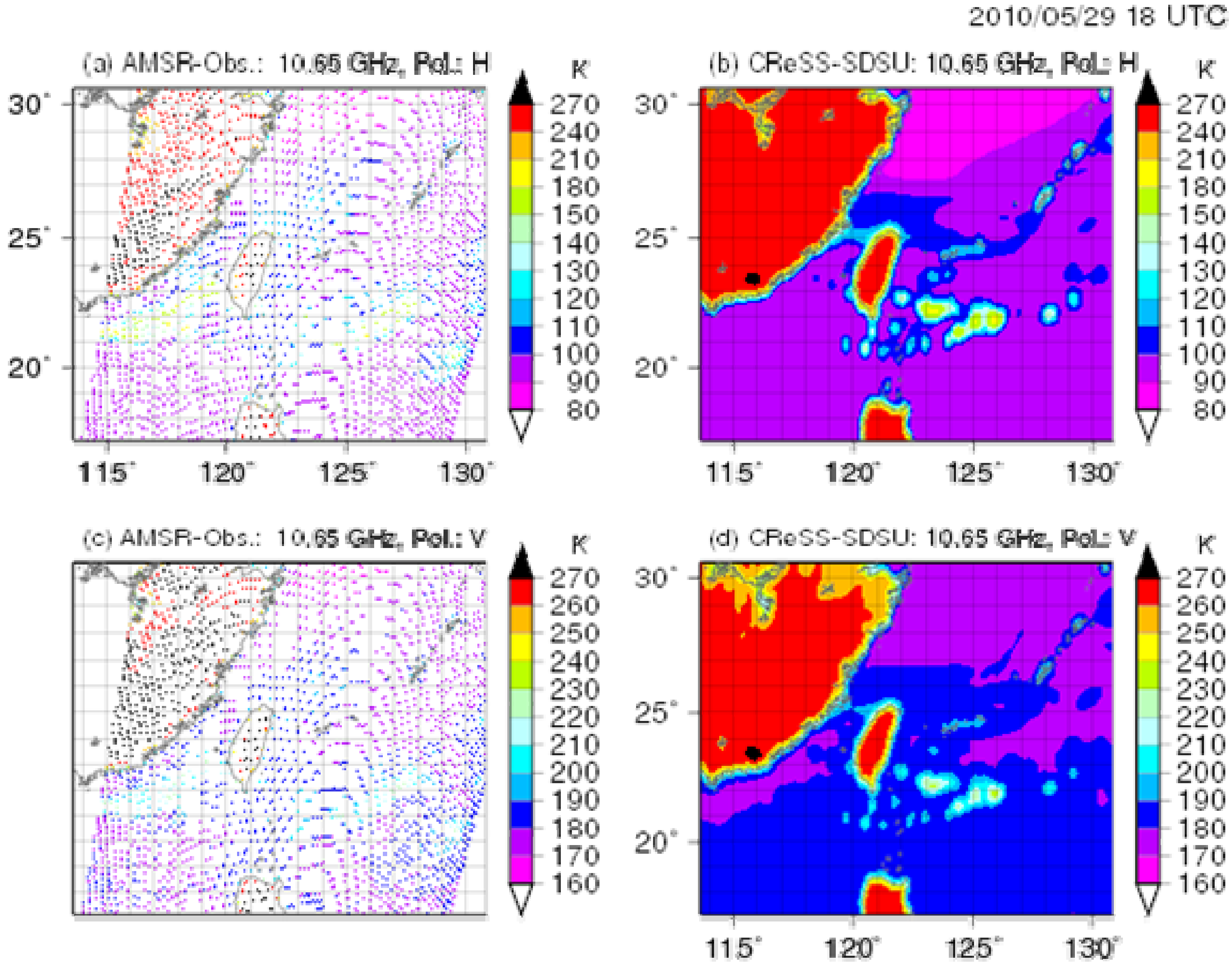




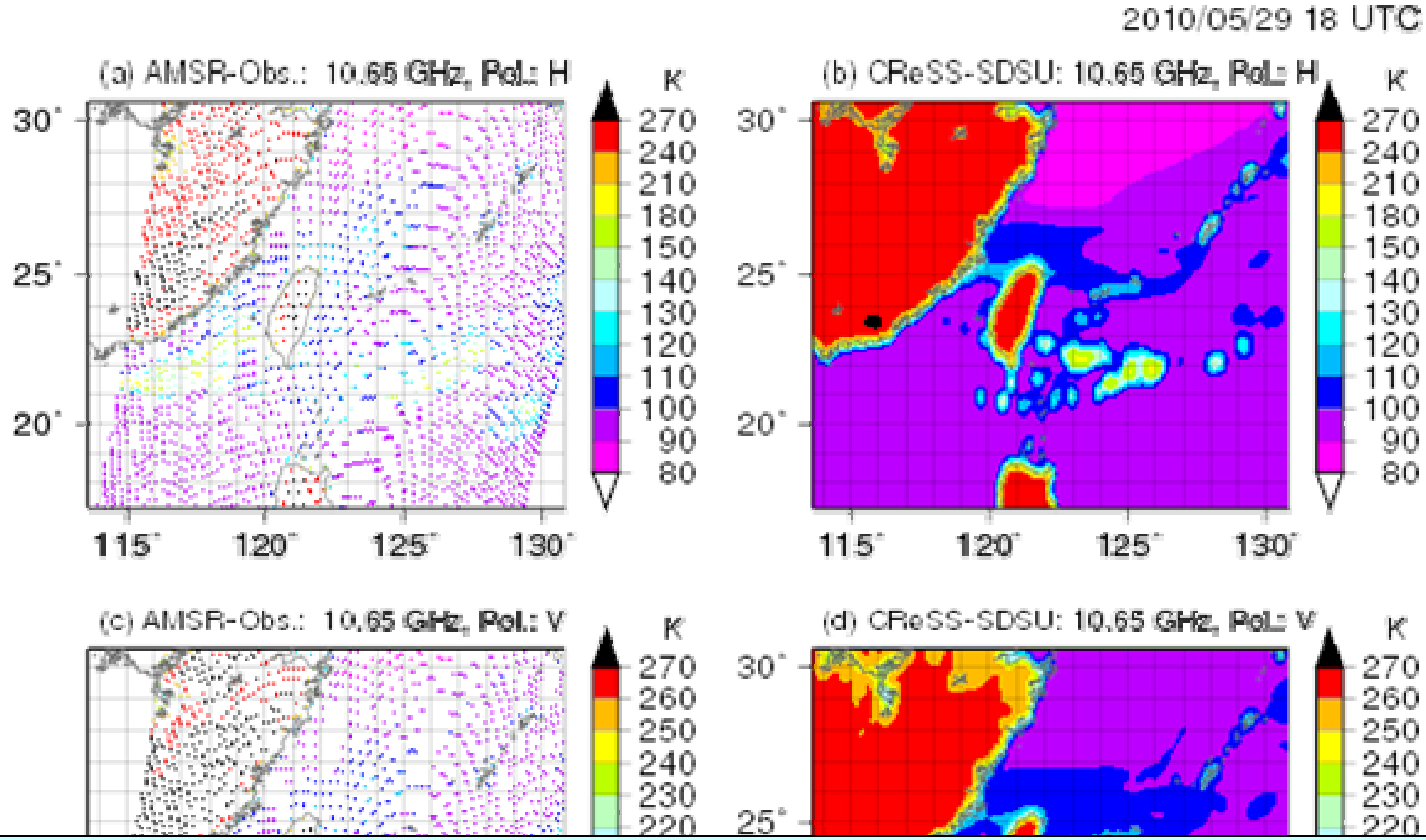
Solid lines: MTSAT obs.
Broken lines: CReSS-SDSU
Black: PDF
Red: Cumulative PDF

- **On May 29:**
Frequency of upper clouds is quite large in the simulation.
→ The simulation cannot be reproduced the distribution of cloud-top height.

T_{BB}-MW 10.65 GHz distributions (AMSR-E vs CReSS-SDSU)

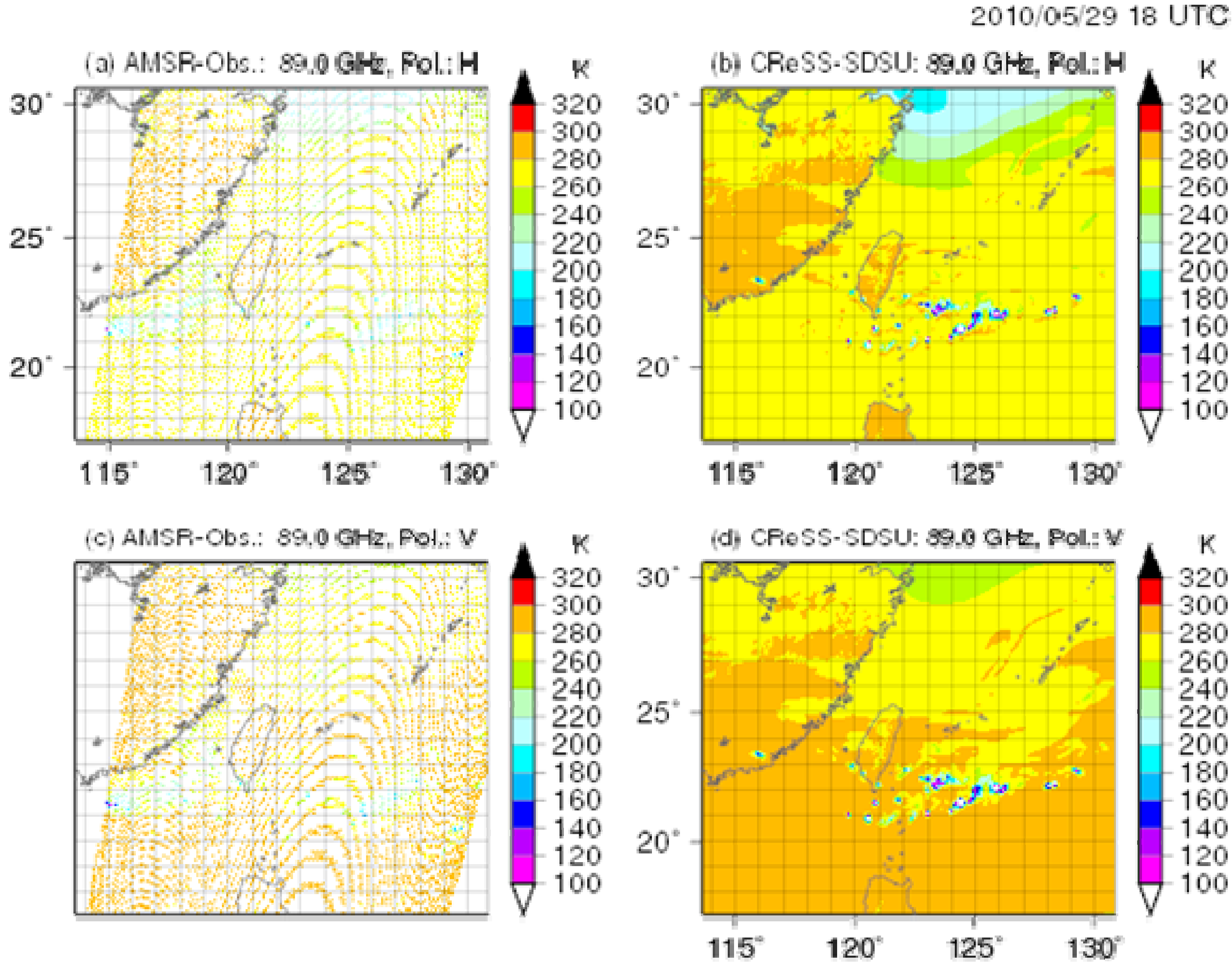


T_{BB}-MW 10.65 GHz distributions (AMSR-E vs CReSS-SDSU)

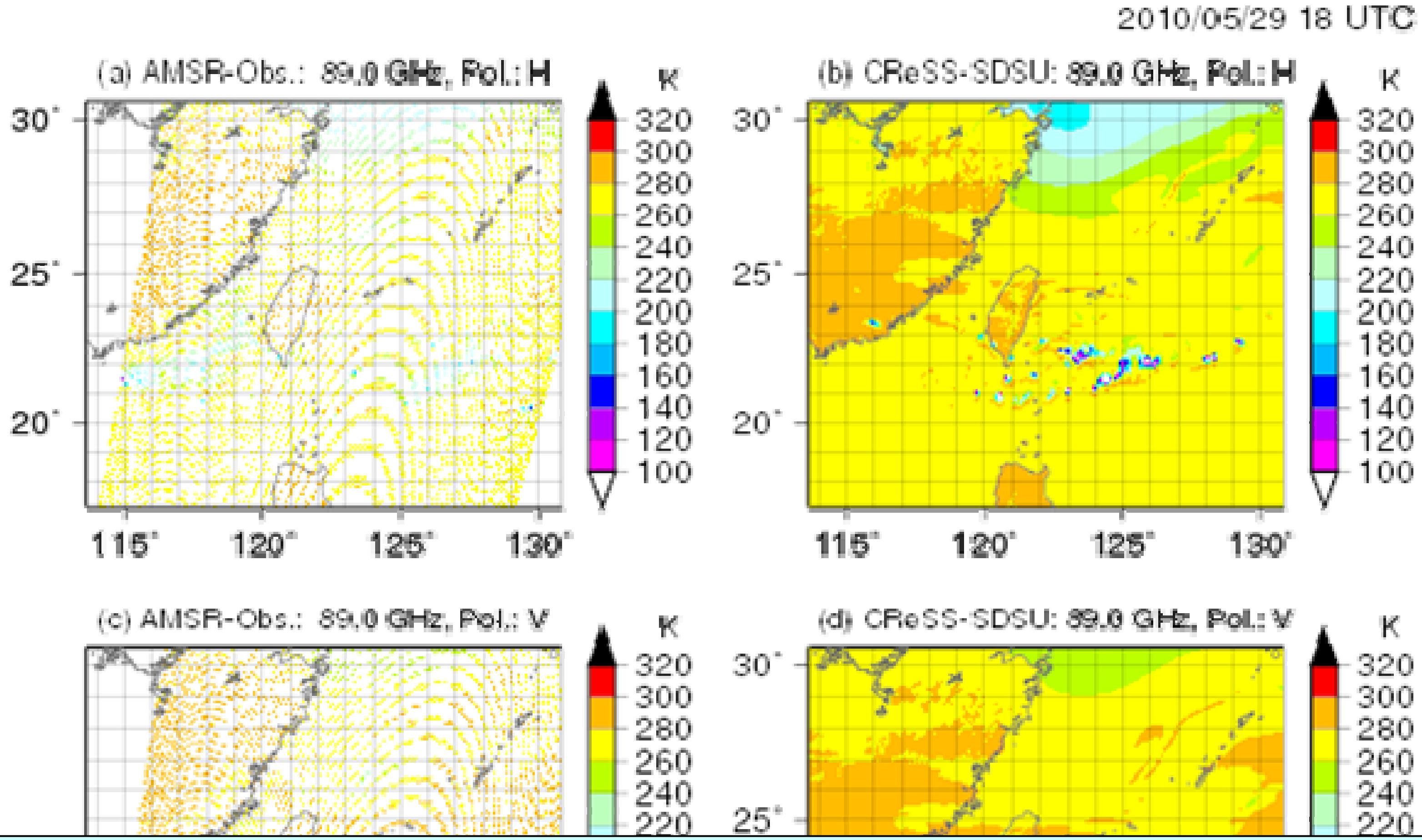


- This frequency (10.65 GHz) is sensitive to heavy rainfall area shown by higher T_{BB} exceeding 120 K for horizontal polarization.
- High T_{BB} areas are seen in the MCSs.
- High T_{BB} areas are reproduced in the simulation in southeast of Taiwan (T_{BB} exceed 180 K).

T_{BB}-MW 89GHz distributions (AMSR-E vs CReSS-SDSU)

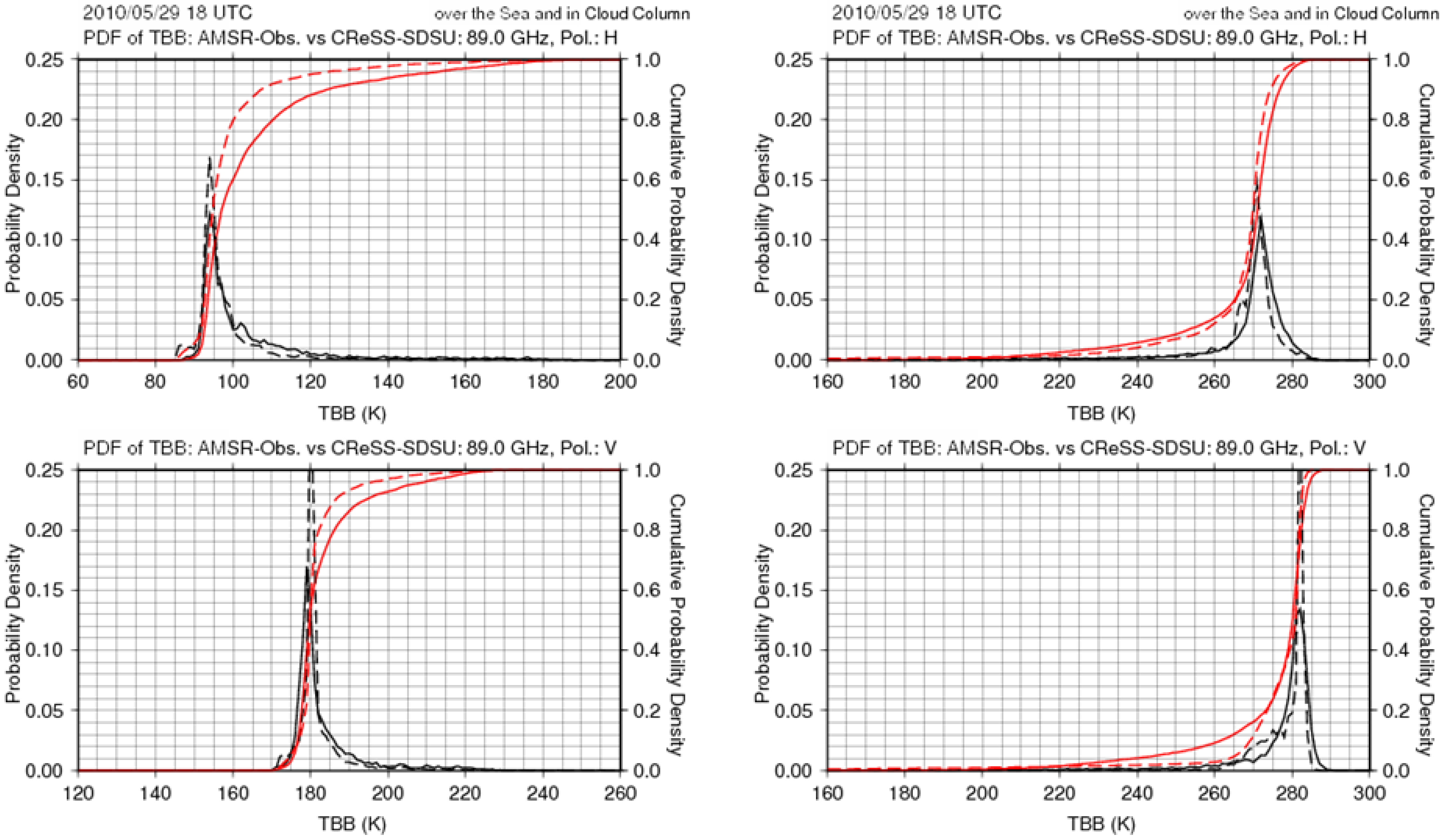


T_{BB}-MW 89GHz distributions (AMSR-E vs CReSS-SDSU)



- **This frequency is sensitive to small-size ice particles in the upper.**
- **If large amount of ice particle exists, T_{BB} shows small values.**
- **Low T_{BB} areas are seen in the MCSs.**
- **Low T_{BB} areas are reproduced in the simulation in the southeast of Taiwan (T_{BB} is less than 100K).**

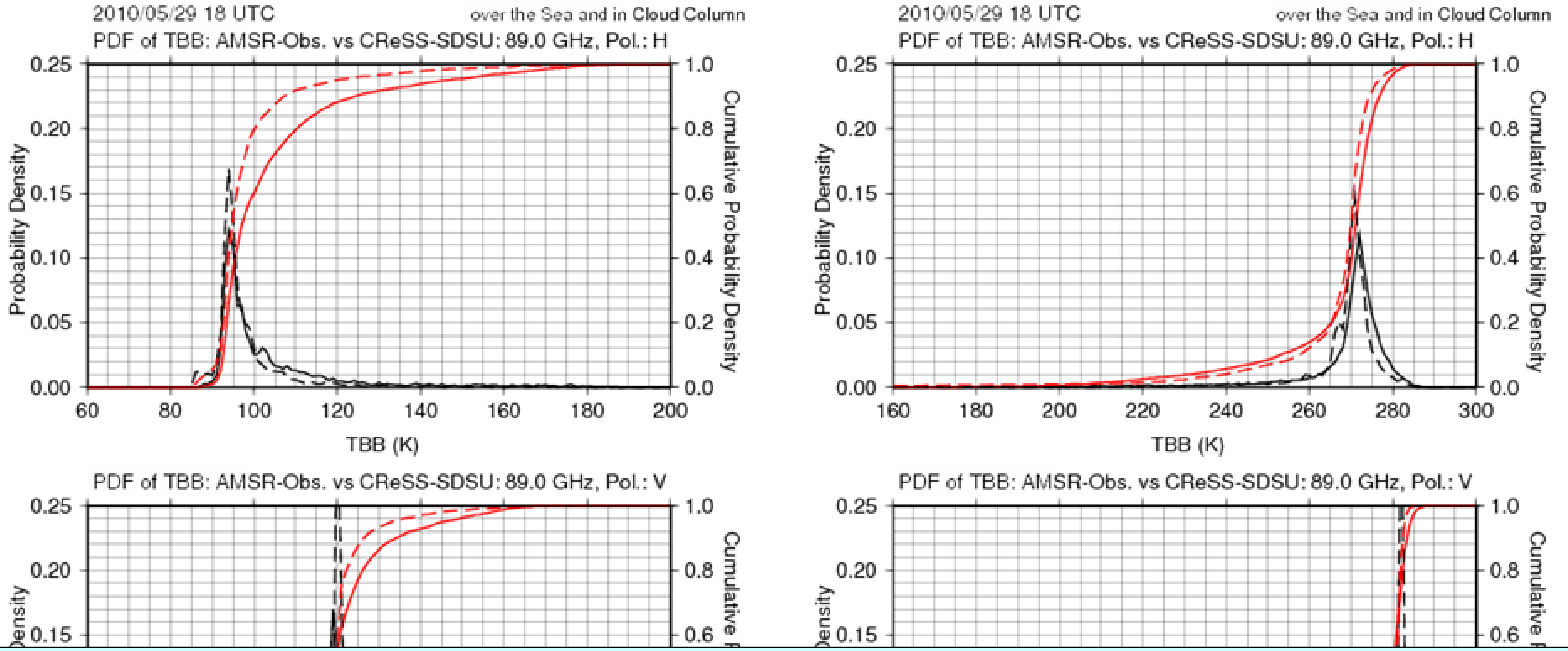
PDF of T_{BB}-MW 10.65 and 89.0 GHz (AMSR-E vs CReSS-SDSU)



Solid lines: AMSR-E obs.
Broken lines: CReSS-SDSU

Black: PDF
Red: Cumulative PDF

PDF of T_{BB}-MW 10.65 and 89.0 GHz (AMSR-E vs CReSS-SDSU)



- **For 10.65 GHz H-pol.: Frequency of simulated T_{BB} over 120 K is quite small compared with the AMSR-E observation.**

→ This should be attributed to the failure of the reproduction of the southwest MCS in the simulation.

- **For 89 GHz H-pol.: The PDF shape is quite resembled.**

※ This does not show the good reproduction of the ice clouds in the upper troposphere.

The L2 distance

- To confirm the accuracy of the CRM quantitatively, Eitzen and Xu (2005) developed a comparison method using the L2 distance (Cha and Srihari 2002).
- The L2 distance is used to measure the difference between two PDFs.

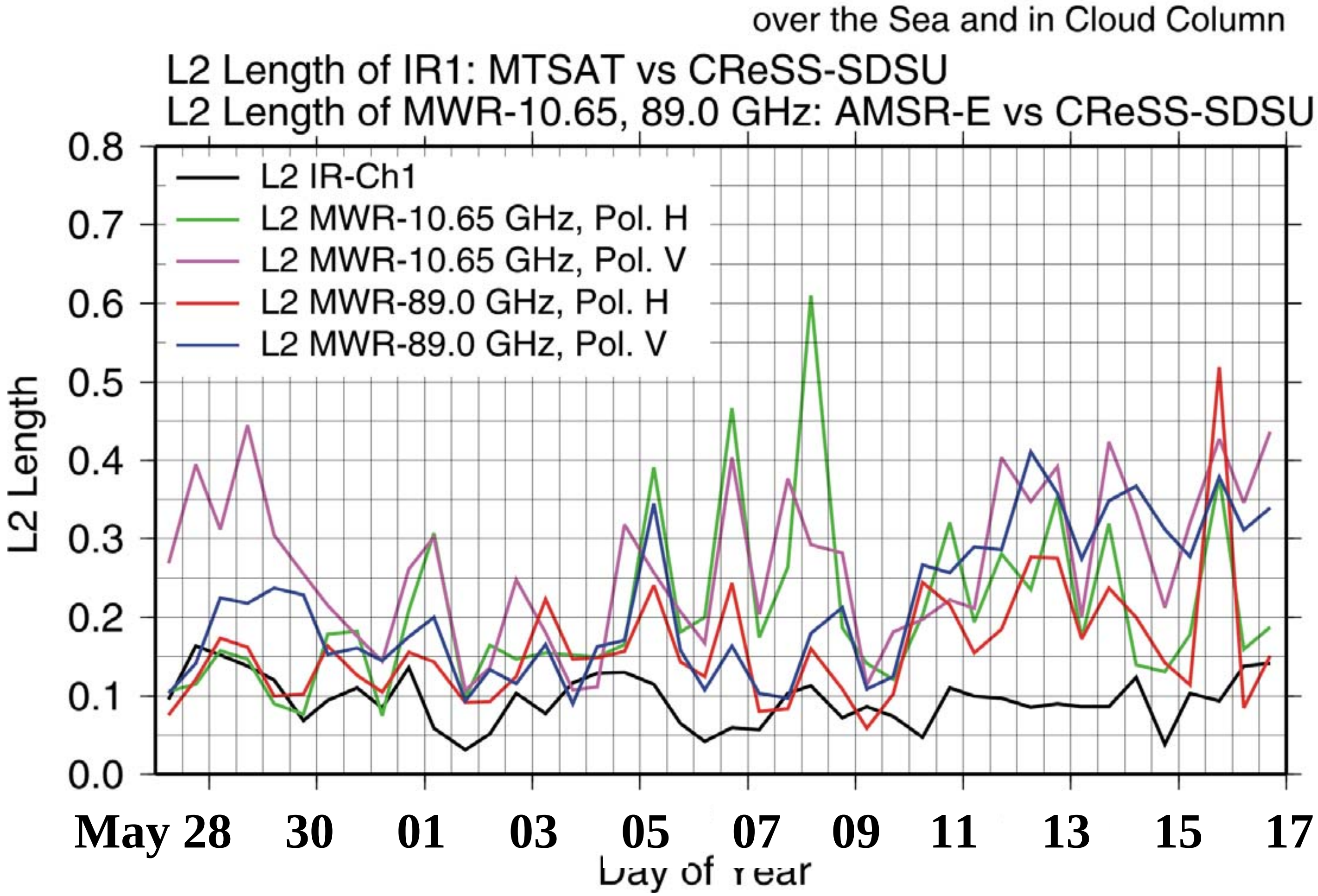
$$L2 = \Delta x \left\{ \sum_{i=1}^{N} [f(x_i) - g(x_i)]^2 \right\}^{1/2}$$

$$\sum_{i=1}^{N} f(x_i)\Delta x = \sum_{i=1}^{N} g(x_i)\Delta x = 1.$$

f(x) , *g(x)* : Normalized PDFs for T_{BB}

- We have calculated the L2 distance of PDFs for
  - Infrared band (ch-1),
  - 10.65 GHz microwave band in the H-pol. and V-pol.,
  - 89.0 GHz microwave band in the H-pol. and V-pol.
- Small L2 distance represents the well reproduction.

Time series of the L2 distance



- We have not evaluated the L2 distance yet.
- This method would be useful to validate the sensitivity experiments by changing the horizontal grid resolution or a cloud microphysical scheme.

Summary

- **We are developing the validation method for a CRM using the satellite data.**
- **This study shows the comparison between T_{BB}s for infrared and microwave bands obtained from the satellite observation and that calculated using the CReSS-SDSU during the Meiyu season in 2010.**

- **The variation of the cloud fraction is well reproduced.**
- **Frequency of cloud-top height is more difficult, but this value is improved compared with the 2008-2009 winter season (not shown).**

→ The finer horizontal grid resolution should be quite effective to correct the cloud fraction.

- **Horizontal distribution of microwave T_{BB} is reproduced in MCSs.**

※ Detailed analysis for microwave bands should be conducted.

Future Plan

- **We have a plan to calculate radar reflectivity for TRMM-PR and CloudSAT using the SDSU.**

→ Making CFAD and PDF at each level

→ L2 length validation

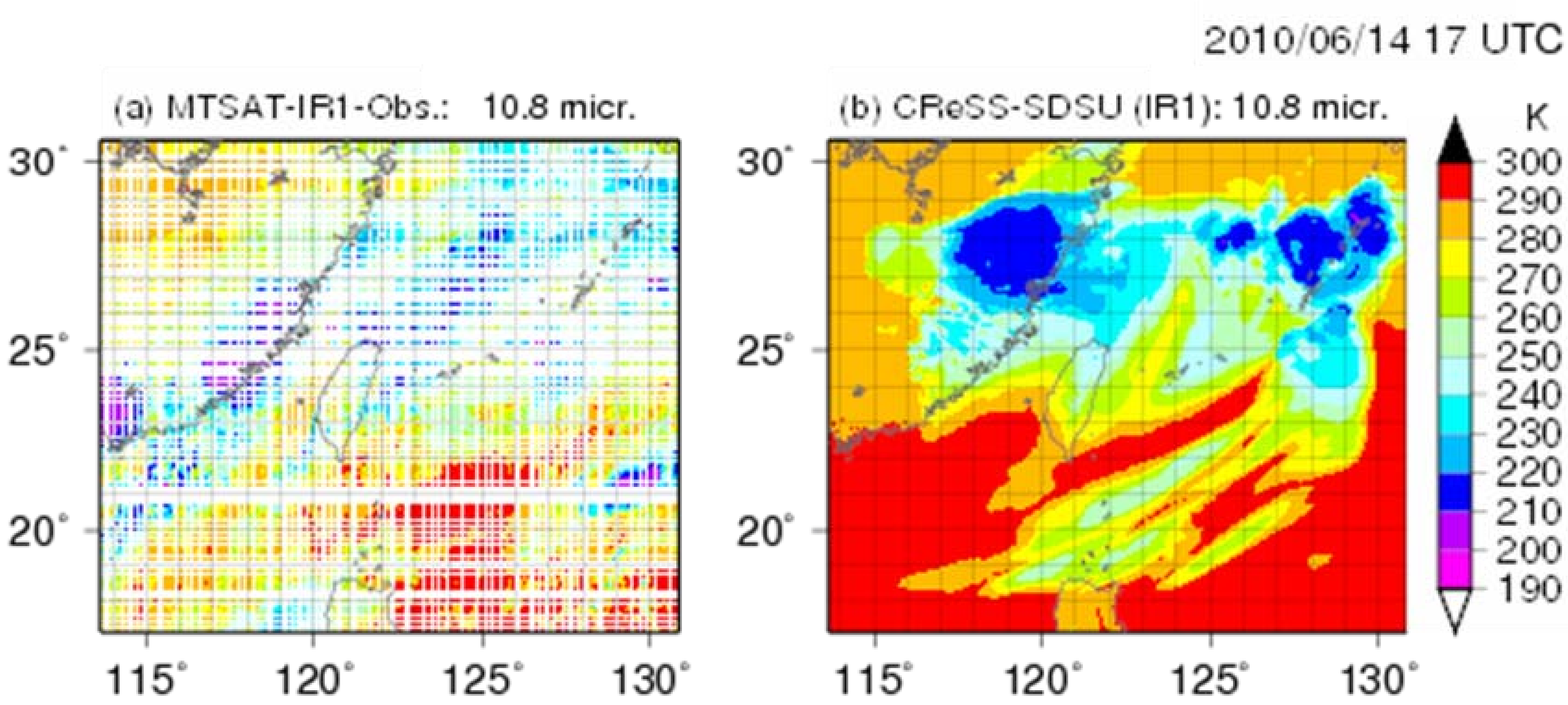
- **Sensitivity experiments by using finer horizontal grid resolution and/or changing cloud microphysical schemes should be needed (e.g., simulation in SoWMEX-2008, grid resolution was 4 km).**

→ The L2 distance method should be useful to evaluate them.


Thank you for you kind attention!!

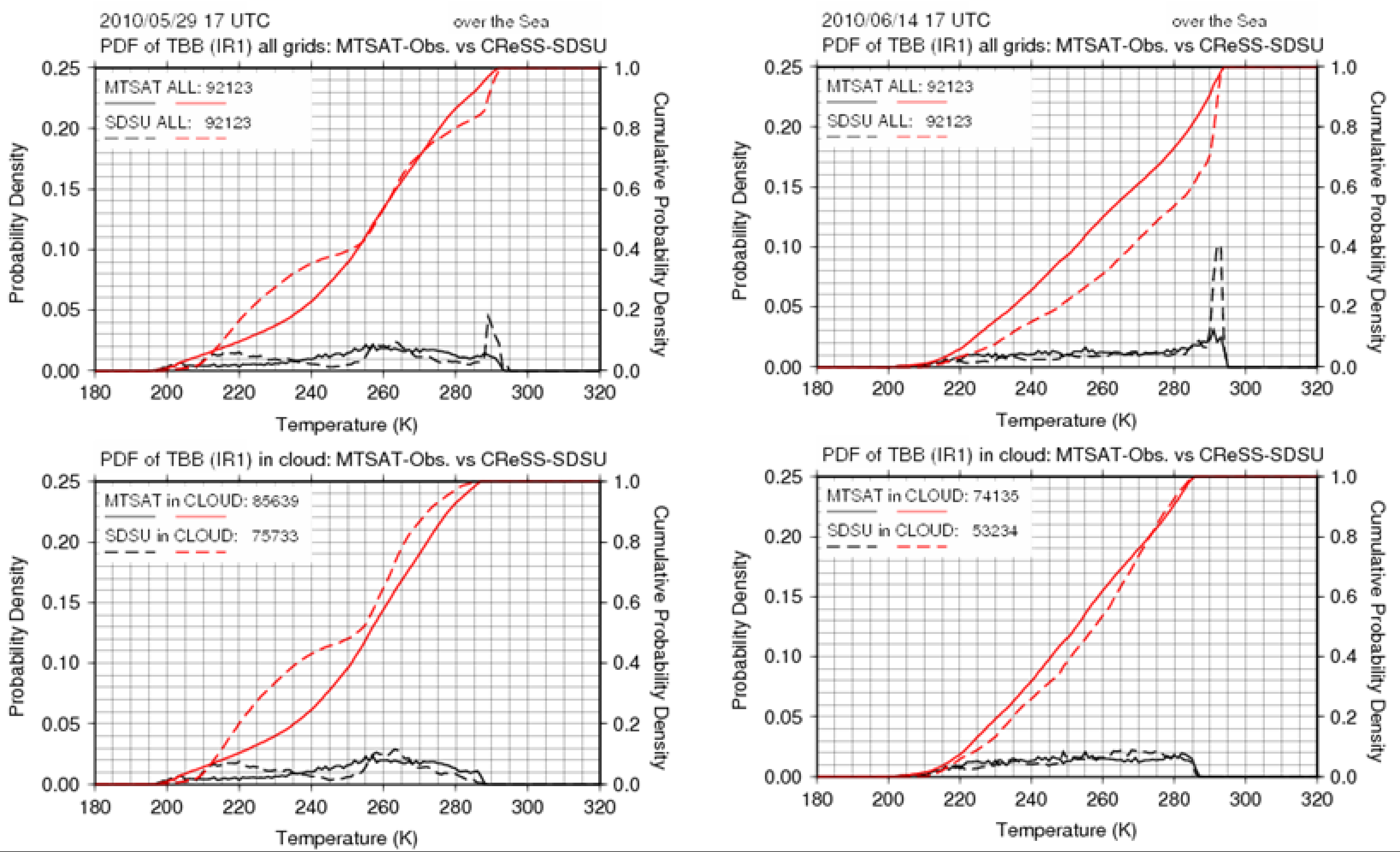
Backup Slides

T_{BB}-IR distributions (MTSAT vs CReSS-SDSU)



- MTSAT obs.: A high cloud region is expanded from southern China to Okinawa (Meiyu frontal region).
- CReSS-SDSU: The cloud band and cloud fraction (CF) is well-reproduced.
- The cloud pattern (high cloud area) is different from each other.

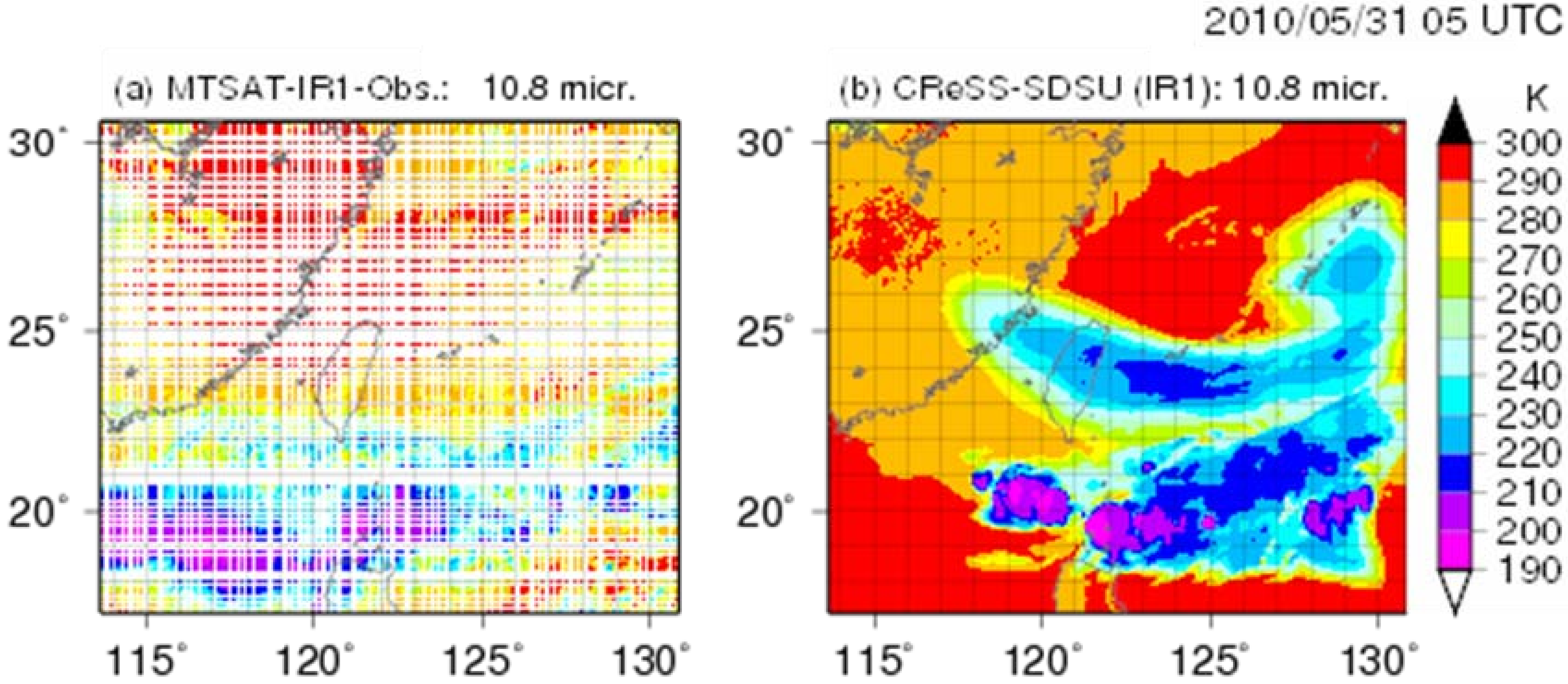
PDF of T_{BB}-IR (MTSAT vs CReSS-SDSU)



- May 29: Frequency of upper clouds is quite large in the simulation.

→ The simulation cannot be reproduced the distribution of cloud-top height.

- June 14: The PDF shape is quite same!



2010/05/31 05 UTC
(a) MTSAT-IR1-Obs.: 10.8 micr.
(b) CReSS-SDSU (IR1): 10.8 micr.
K
300
290
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20°
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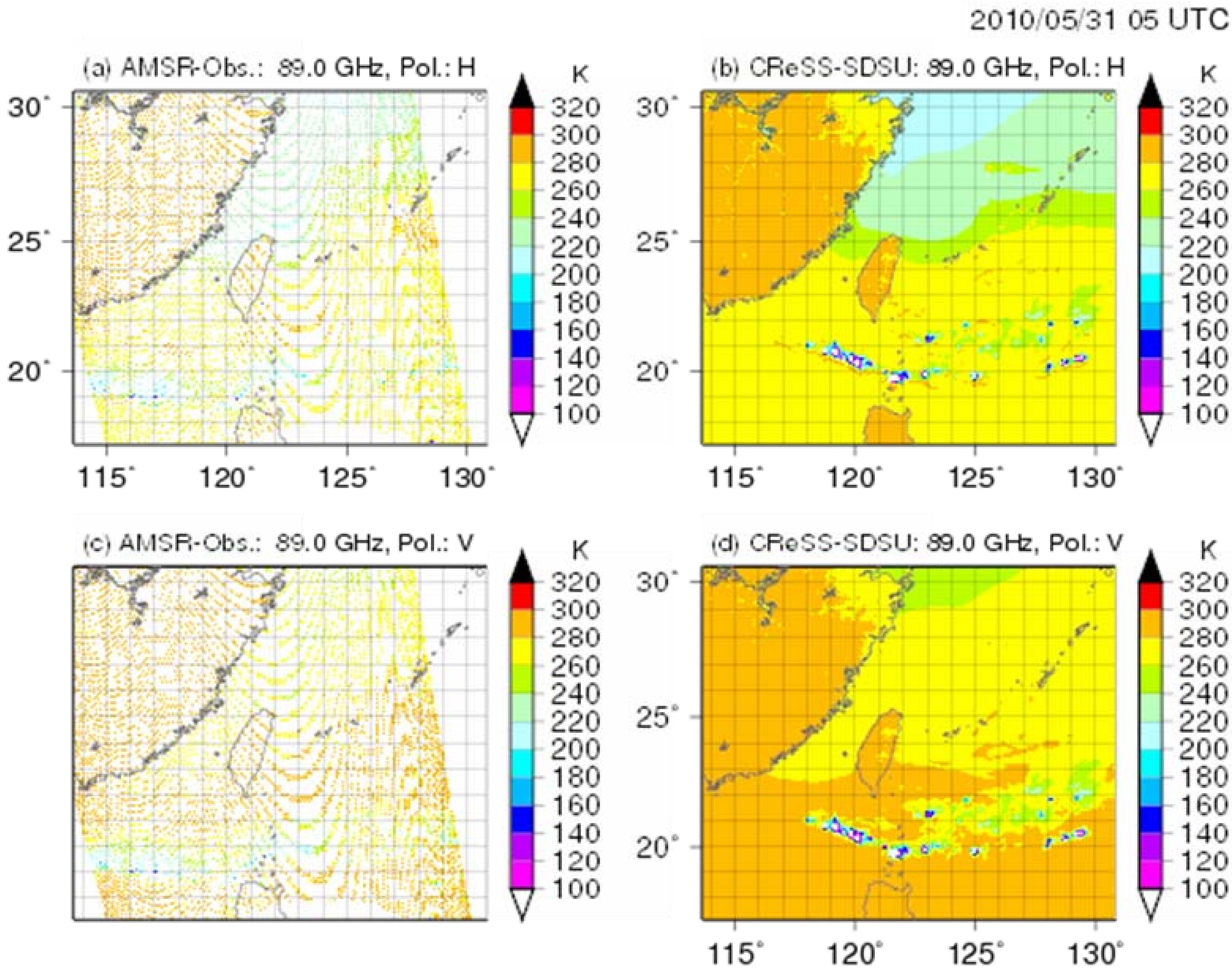
120°
125°
130°



2010/05/31 05 UTC
(a) AMSR-Obs.: 89.0 GHz, Pol.: H
(b) CReSS-SDSU: 89.0 GHz, Pol.: H
(c) AMSR-Obs.: 89.0 GHz, Pol.: V
(d) CReSS-SDSU: 89.0 GHz, Pol.: V
K
320
300
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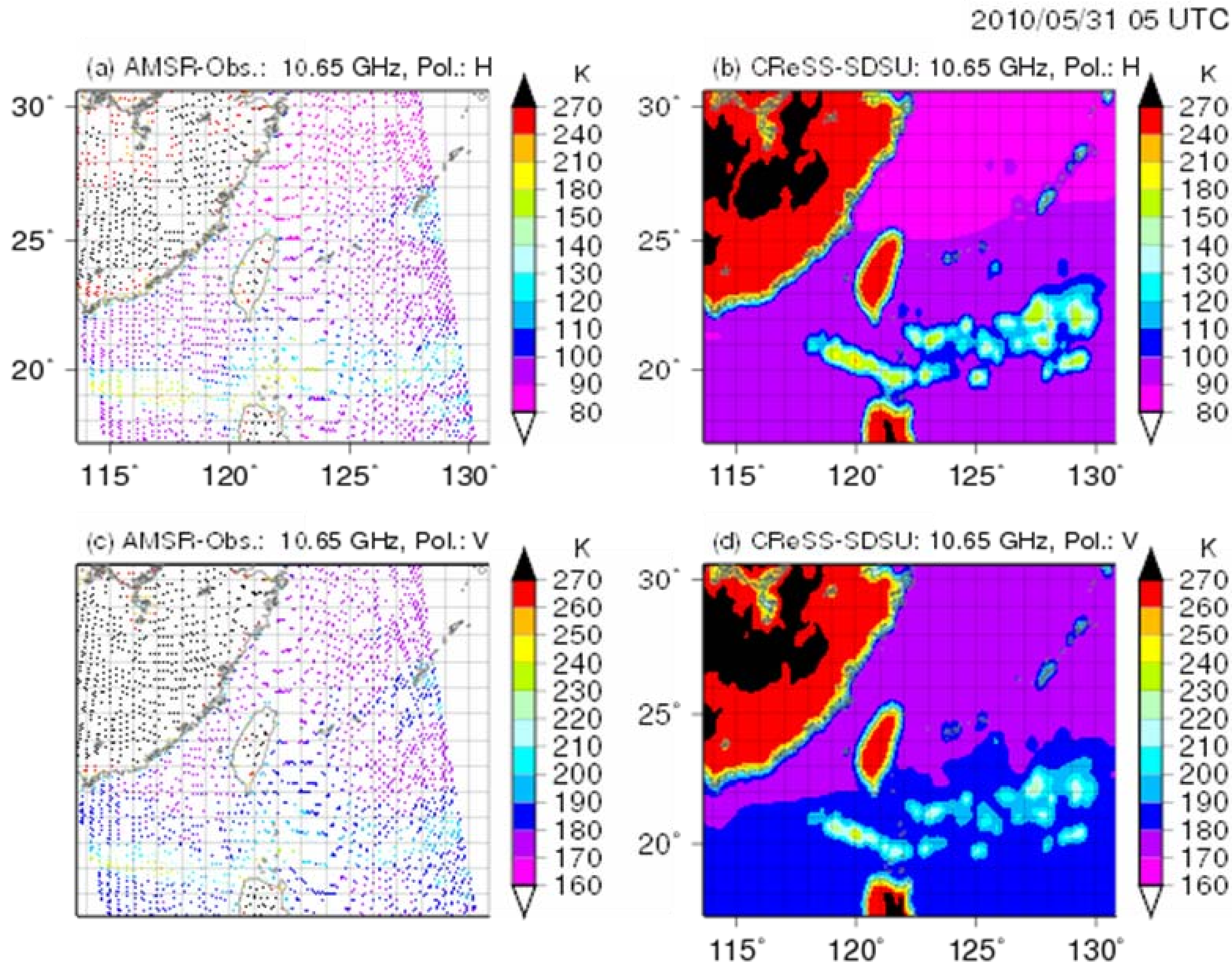
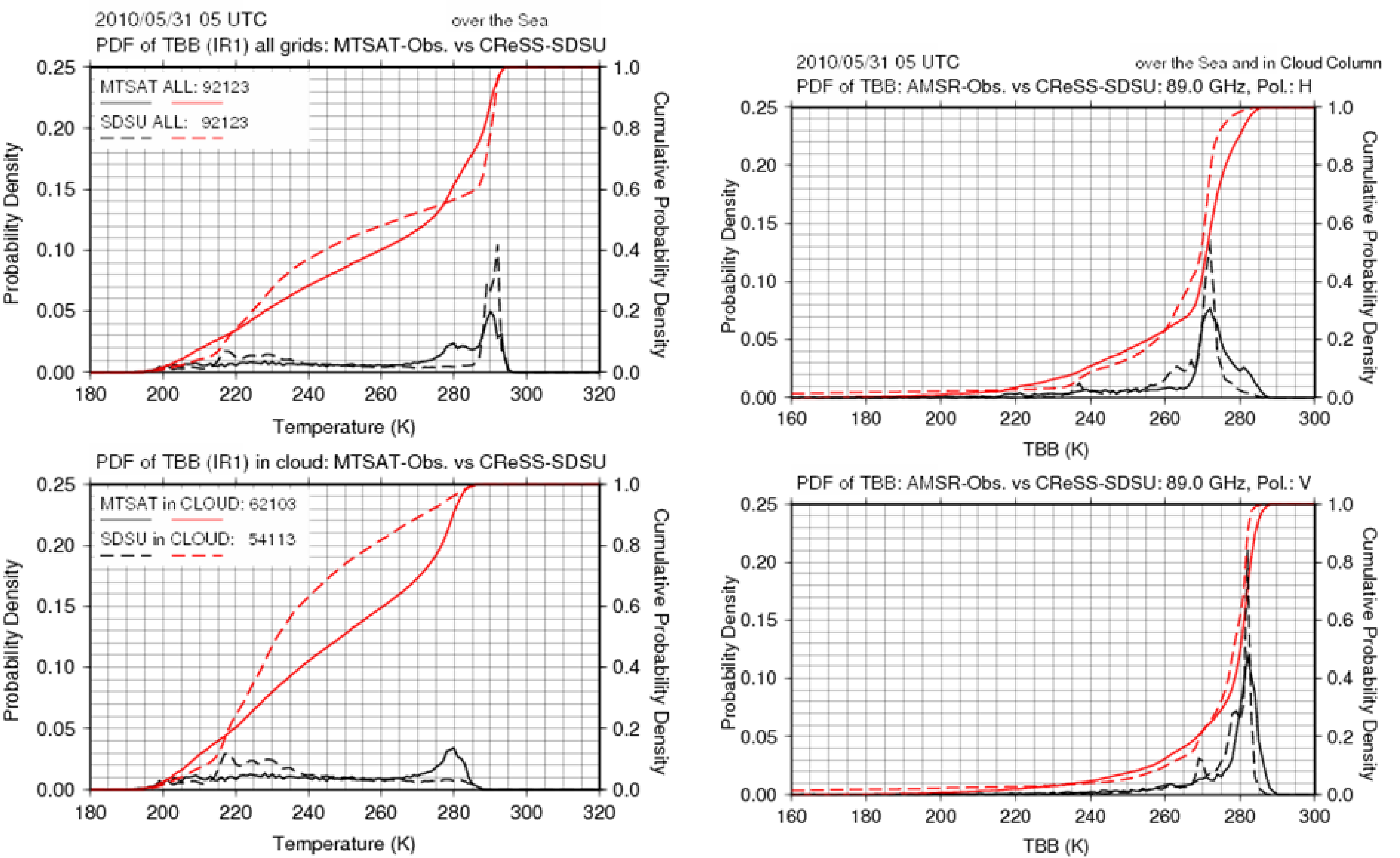
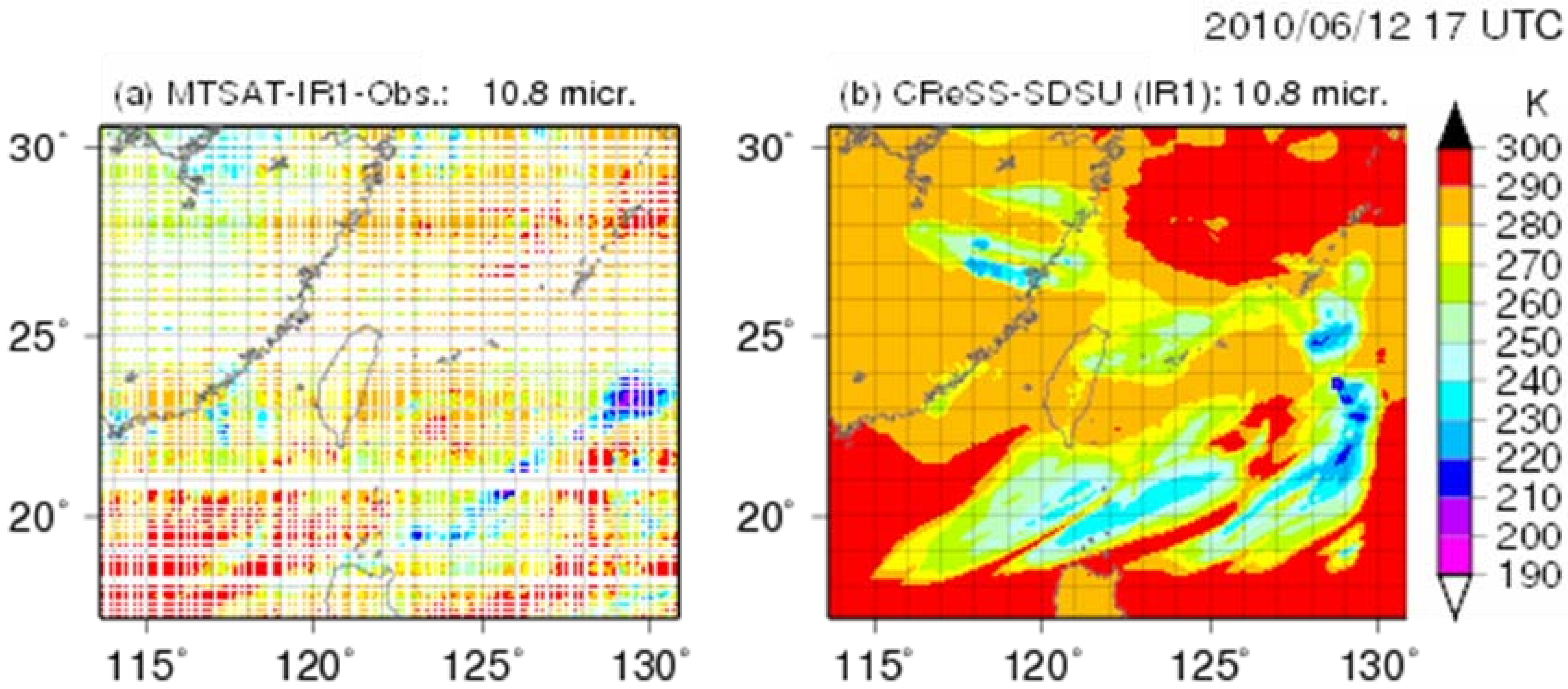

2010/05/31 05 UTC
(a) AMSR-Obs.: 10.65 GHz, Pol.: H
(b) CReSS-SDSU: 10.65 GHz, Pol.: H
(c) AMSR-Obs.: 10.65 GHz, Pol.: V
(d) CReSS-SDSU: 10.65 GHz, Pol.: V
K
270 240 210 180 150 140 130 120 110 100 90 80
270 260 250 240 230 220 210 200 190 180 170 160
30° 25° 20°
115° 120° 125° 130°



2010/05/31 05 UTC
over the Sea
PDF of TBB (IR1) all grids: MTSAT-Obs. vs CReSS-SDSU
MTSAT ALL: 92123
SDSU ALL: 92123
Probability Density
Cumulative Probability Density
Temperature (K)
PDF of TBB (IR1) in cloud: MTSAT-Obs. vs CReSS-SDSU
MTSAT in CLOUD: 62103
SDSU in CLOUD: 54113
Probability Density
Cumulative Probability Density
Temperature (K)
2010/05/31 05 UTC
over the Sea and in Cloud Column
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: H
Probability Density
Cumulative Probability Density
TBB (K)
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: V
Probability Density
Cumulative Probability Density
TBB (K)



2010/06/12 17 UTC
(a) MTSAT-IR1-Obs.: 10.8 micr.
(b) CReSS-SDSU (IR1): 10.8 micr.
K
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115°
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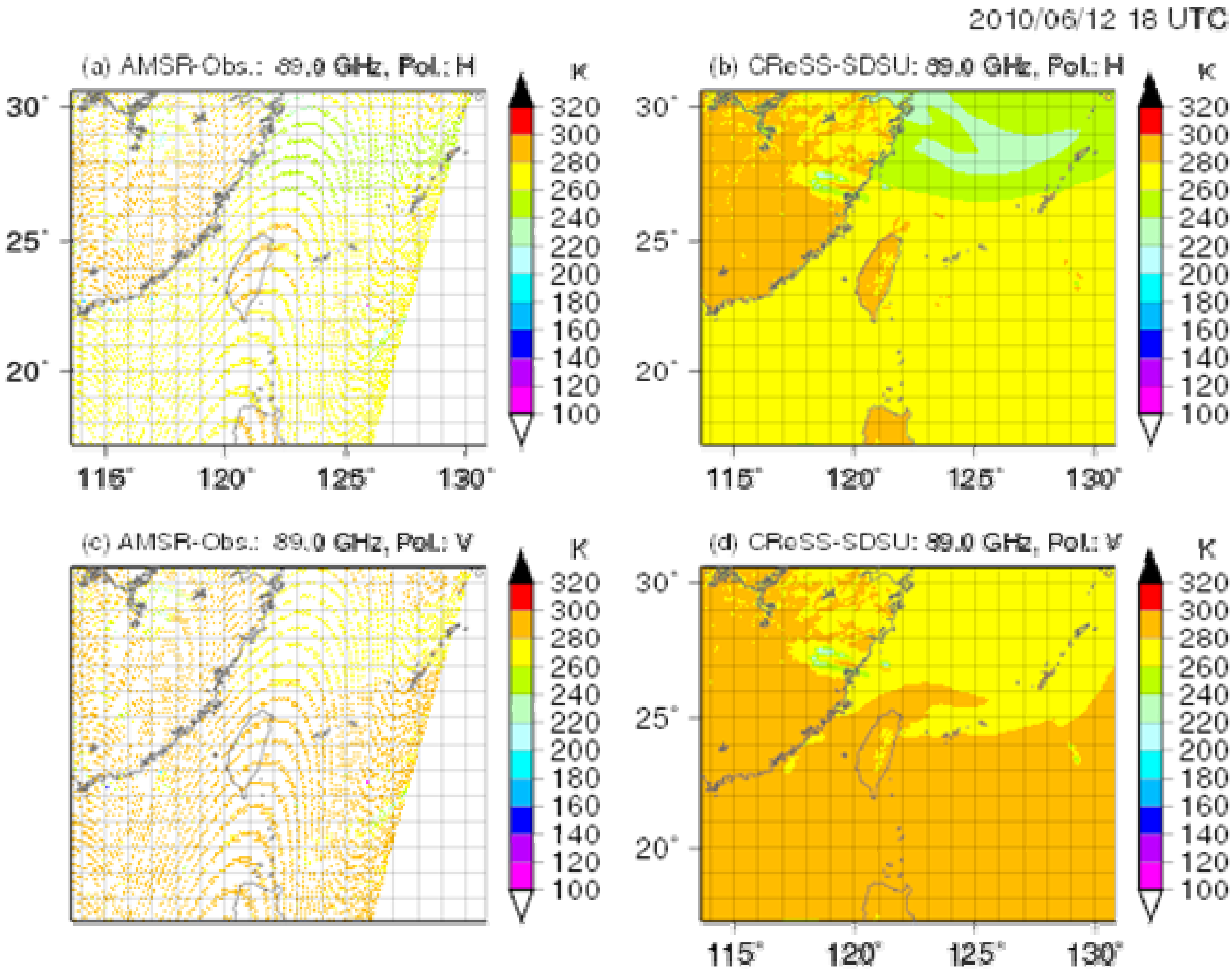
130°


2010/06/12 18 UTC
(a) AMSR-Obs.: 89.0 GHz, Pol.: H
(b) CReSS-SDSU: 89.0 GHz, Pol.: H
(c) AMSR-Obs.: 89.0 GHz, Pol.: V
(d) CReSS-SDSU: 89.0 GHz, Pol.: V
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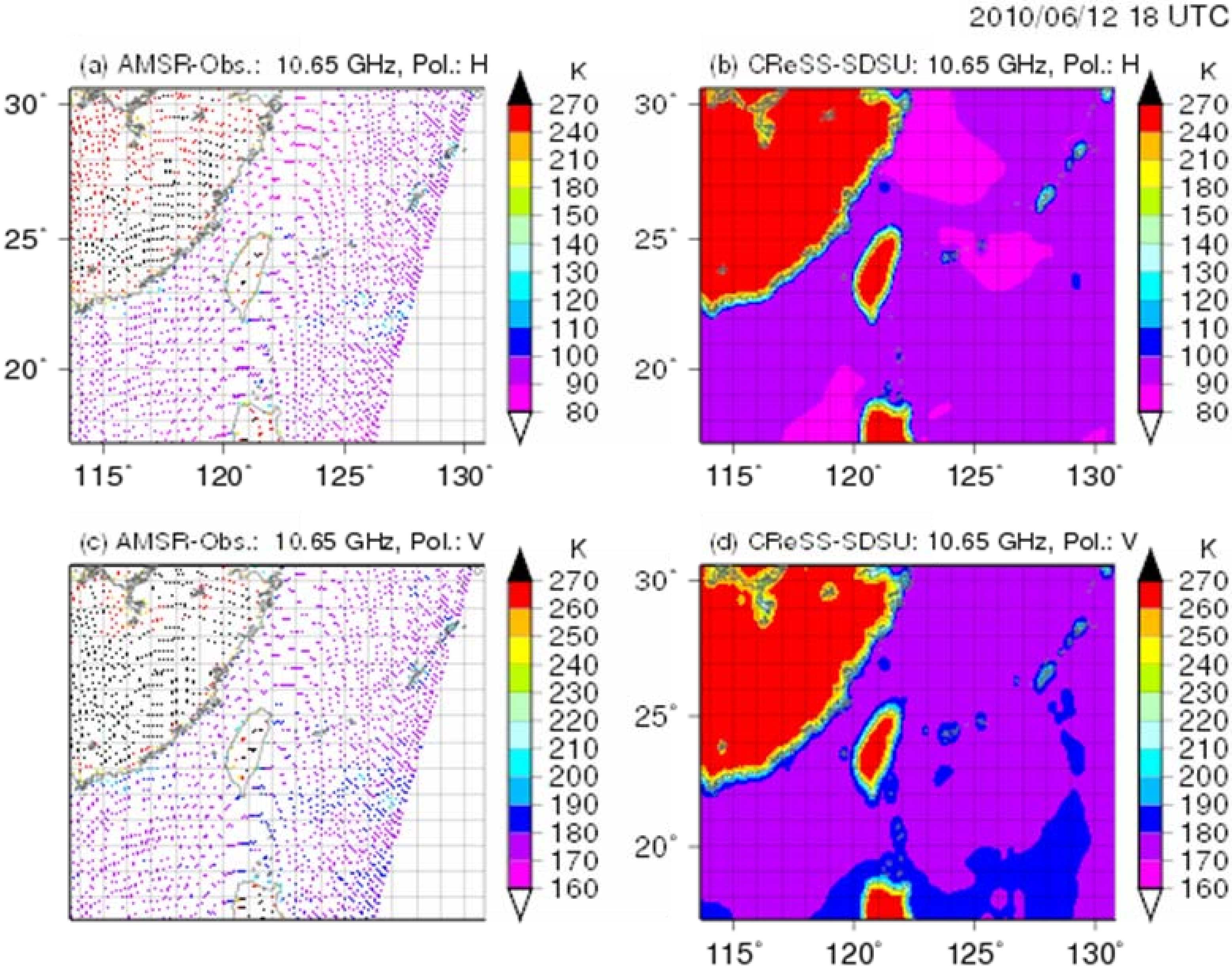
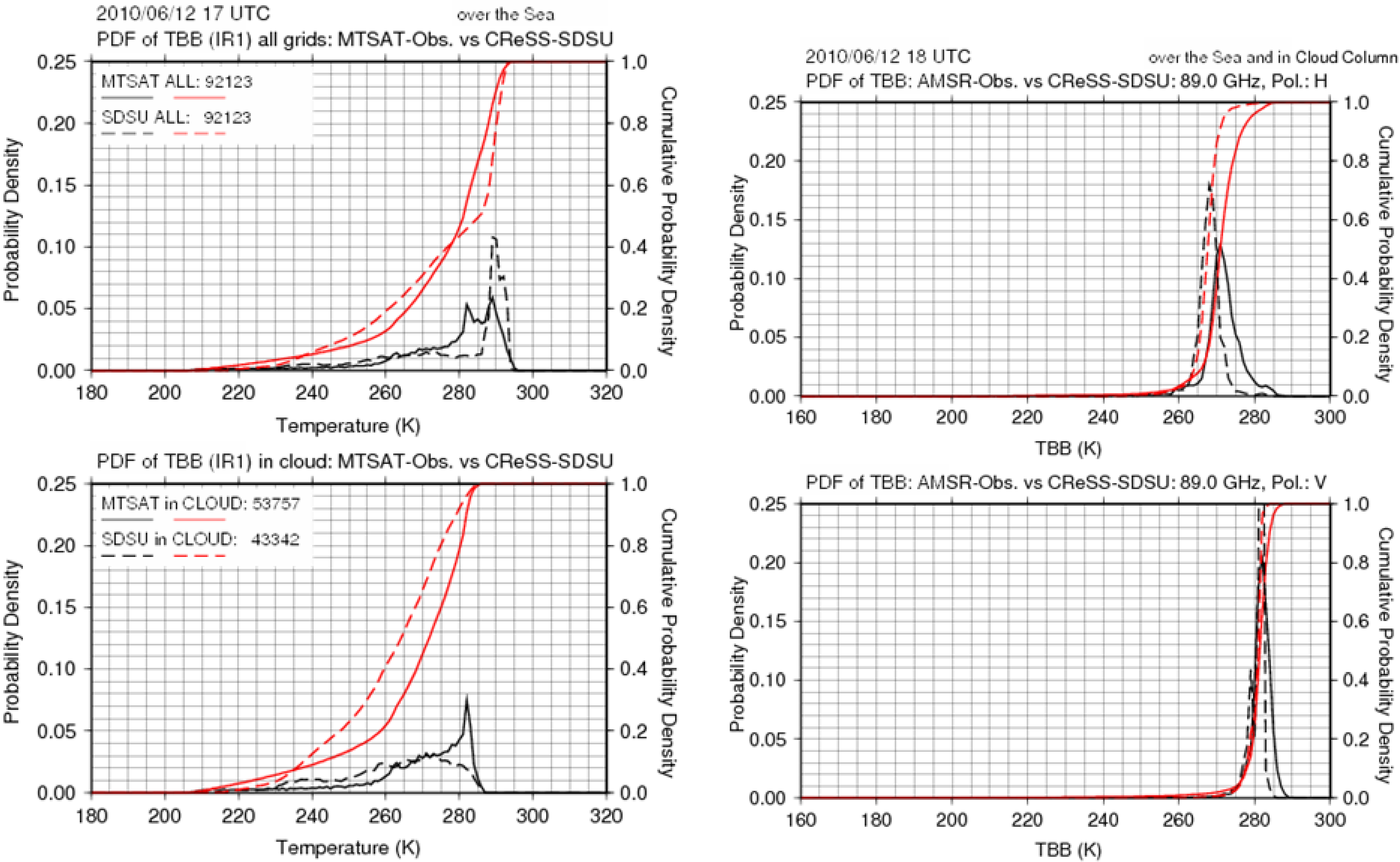
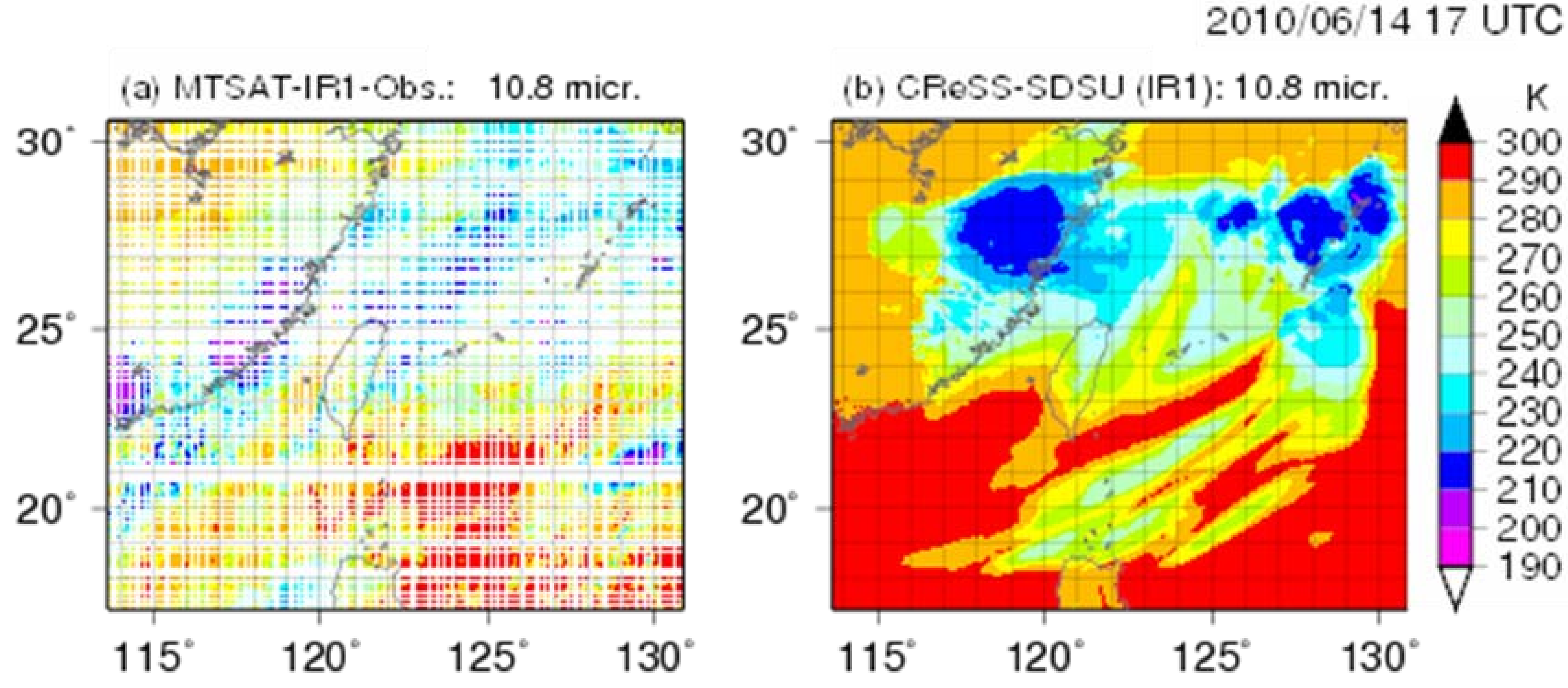


2010/06/12 18 UTC
(a) AMSR-Obs.: 10.65 GHz, Pol.: H
(b) CReSS-SDSU: 10.65 GHz, Pol.: H
(c) AMSR-Obs.: 10.65 GHz, Pol.: V
(d) CReSS-SDSU: 10.65 GHz, Pol.: V
K
270 240 210 180 150 140 130 120 110 100 90 80
270 260 250 240 230 220 210 200 190 180 170 160
30° 25° 20°
115° 120° 125° 130°


2010/06/12 17 UTC
over the Sea
PDF of TBB (IR1) all grids: MTSAT-Obs. vs CReSS-SDSU
MTSAT ALL: 92123
SDSU ALL: 92123
Probability Density
Cumulative Probability Density
Temperature (K)
PDF of TBB (IR1) in cloud: MTSAT-Obs. vs CReSS-SDSU
MTSAT in CLOUD: 53757
SDSU in CLOUD: 43342
2010/06/12 18 UTC
over the Sea and in Cloud Column
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: H
TBB (K)
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: V


2010/06/14 17 UTC
(a) MTSAT-IR1-Obs.: 10.8 micr.
(b) CReSS-SDSU (IR1): 10.8 micr.
K
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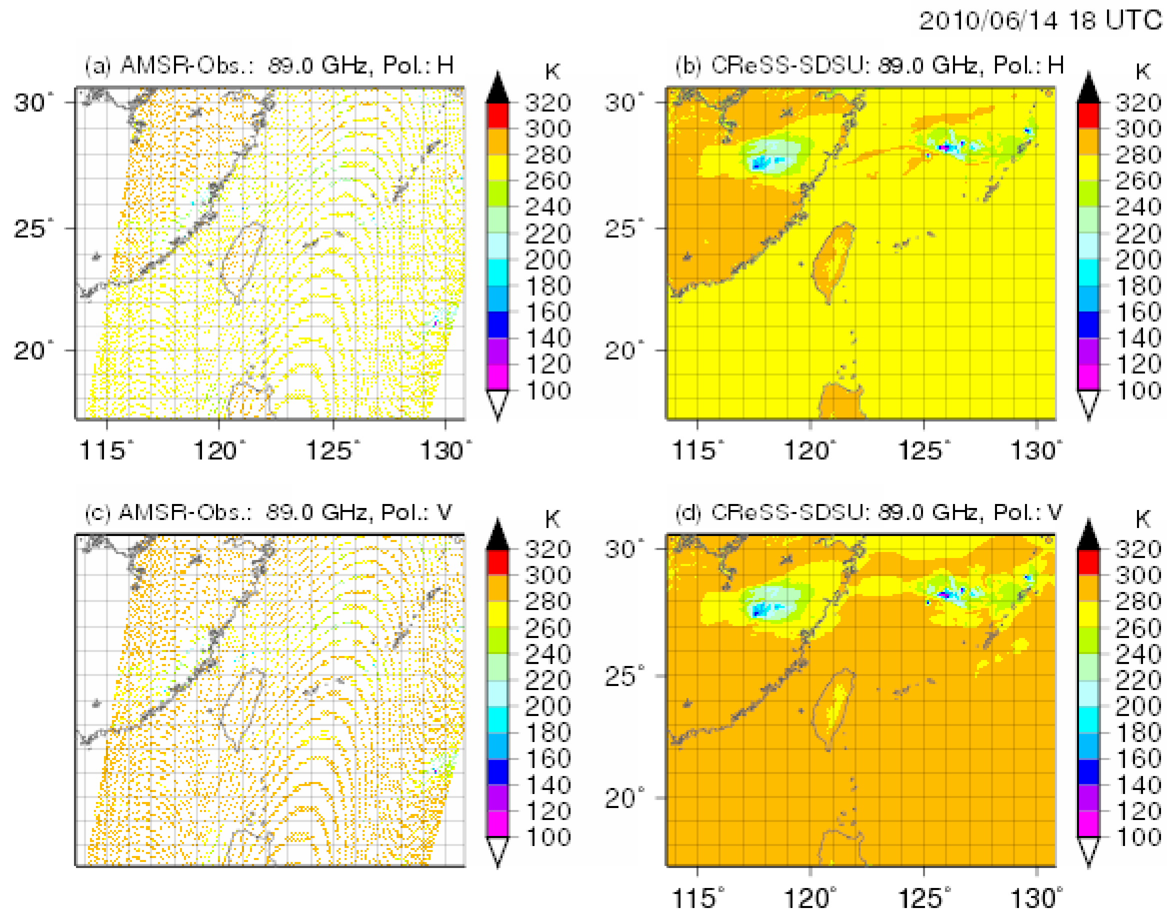
2010/06/14 18 UTC
(a) AMSR-Obs.: 89.0 GHz, Pol.: H
(b) CReSS-SDSU: 89.0 GHz, Pol.: H
(c) AMSR-Obs.: 89.0 GHz, Pol.: V
(d) CReSS-SDSU: 89.0 GHz, Pol.: V
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25°
20°
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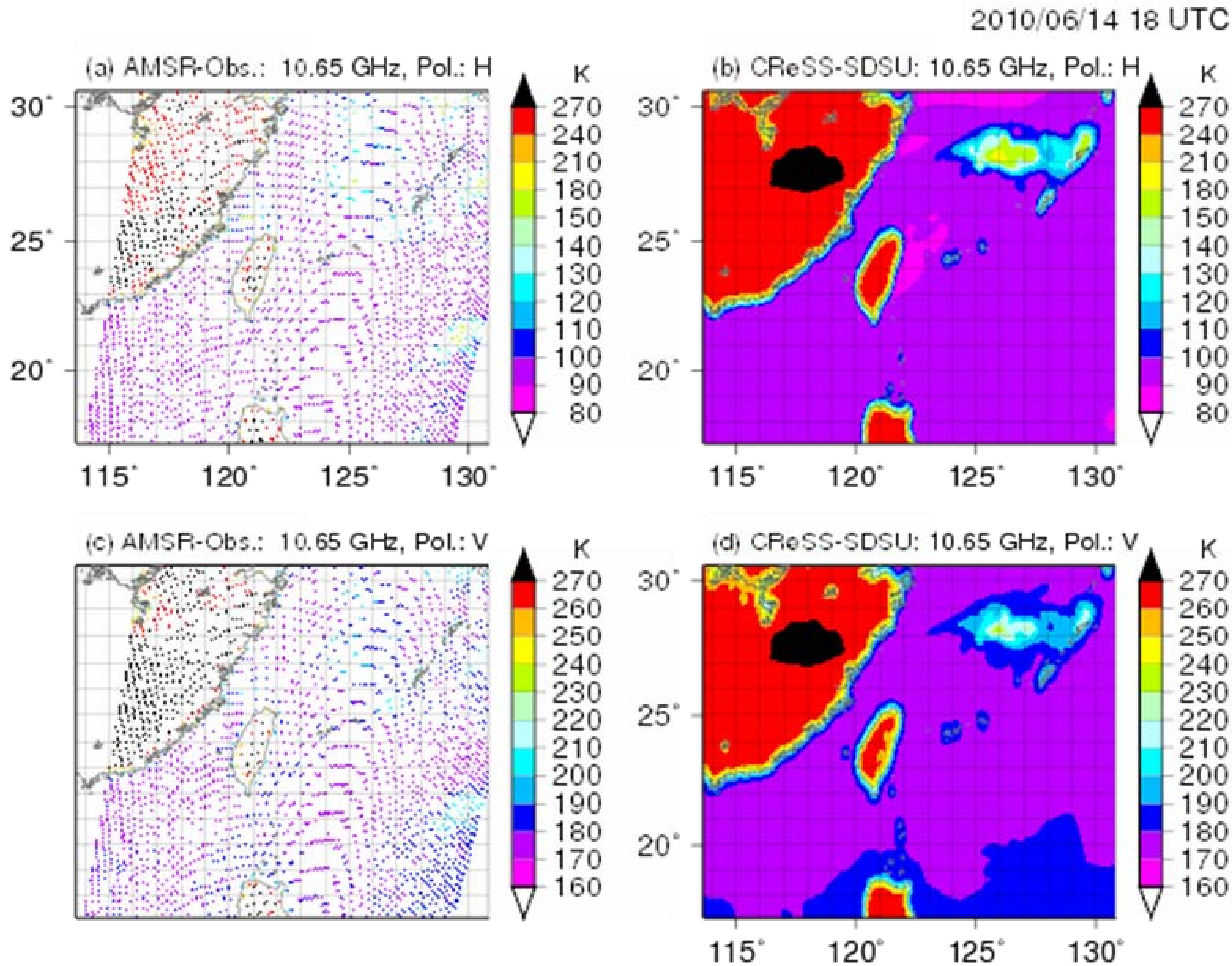
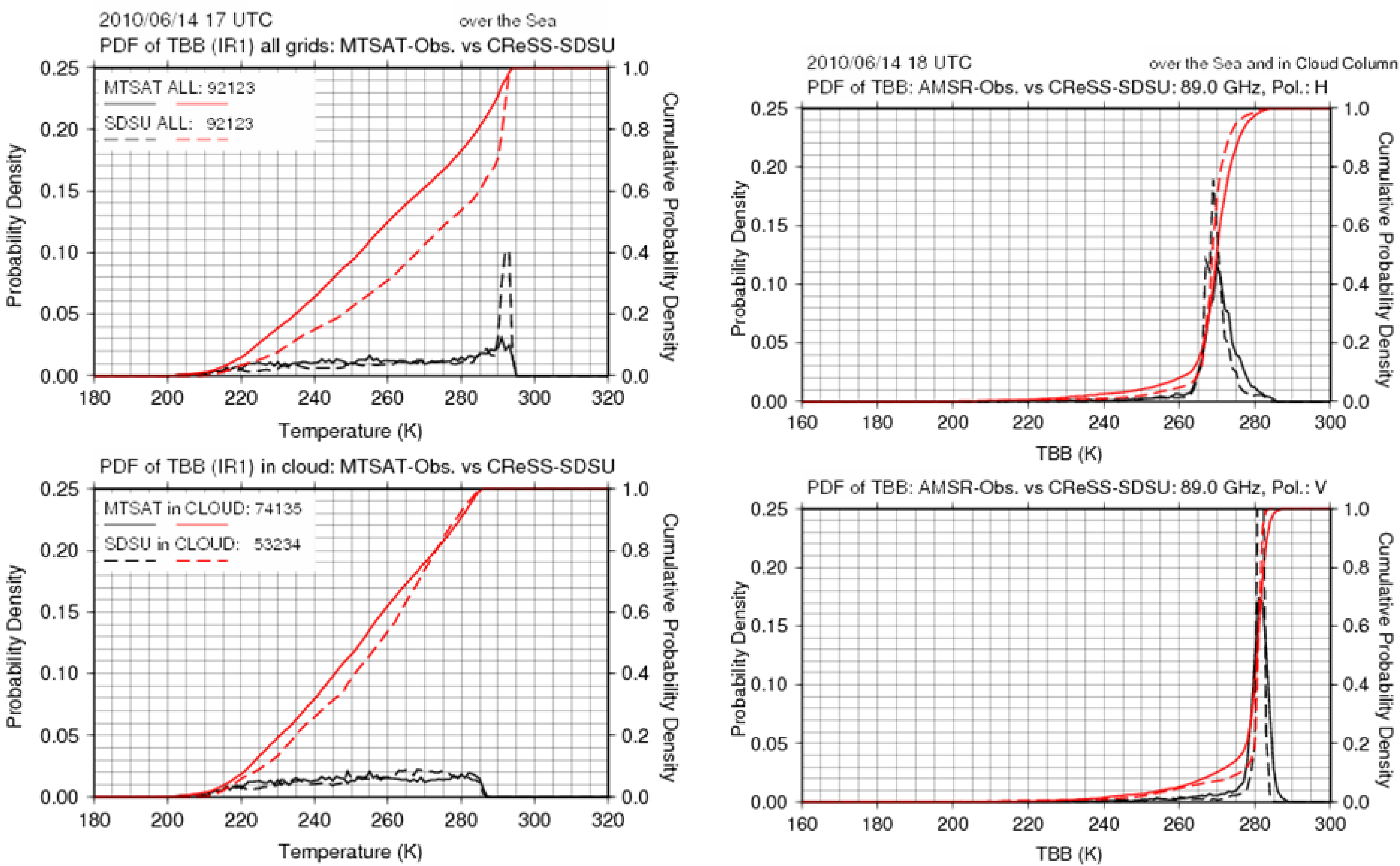
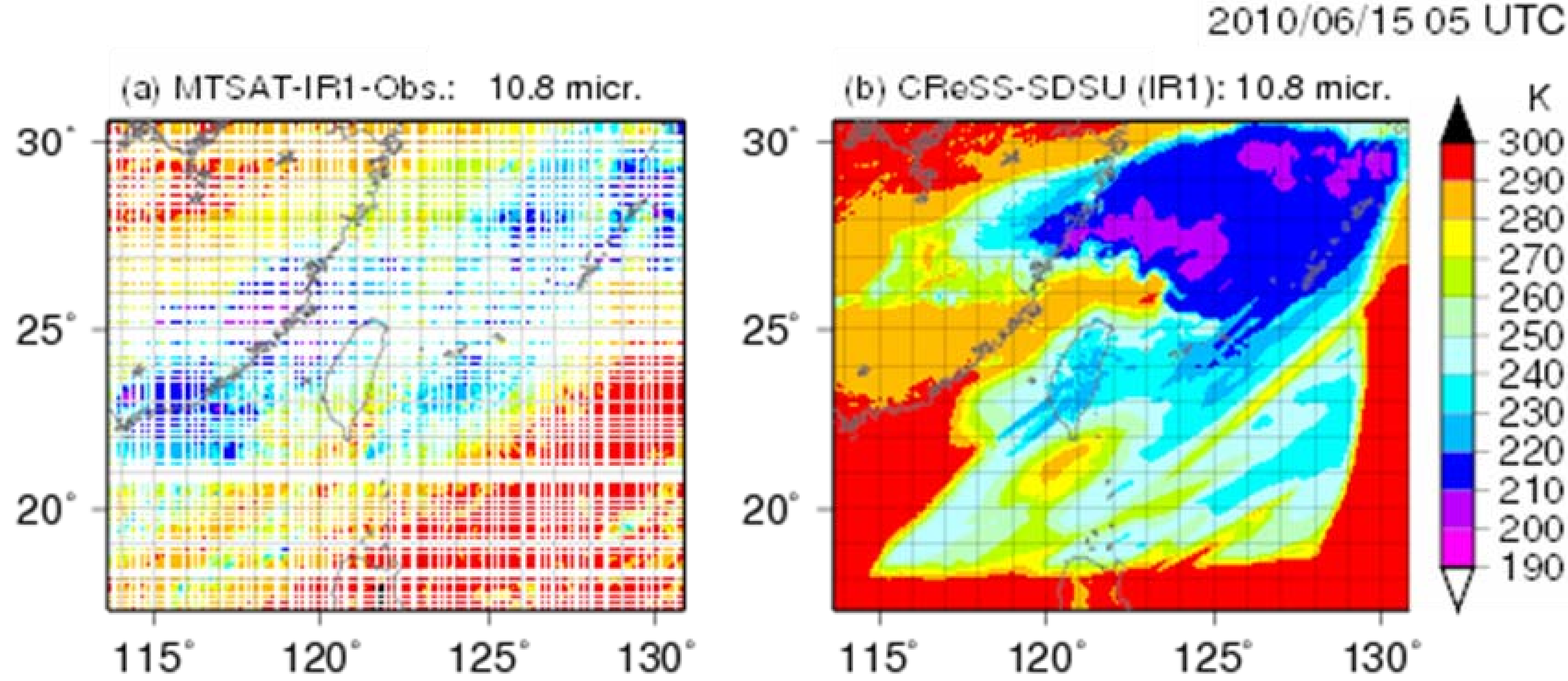
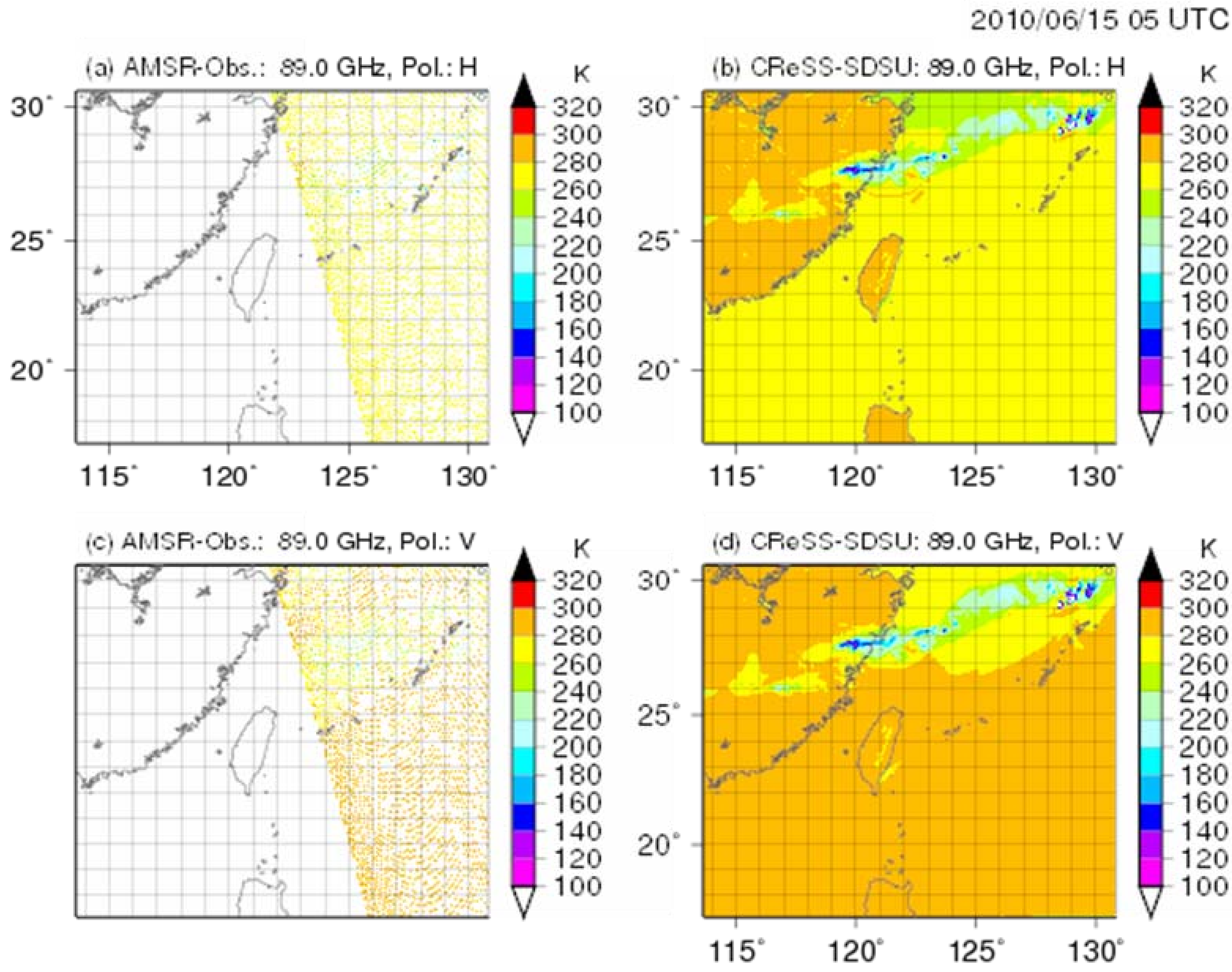
130°

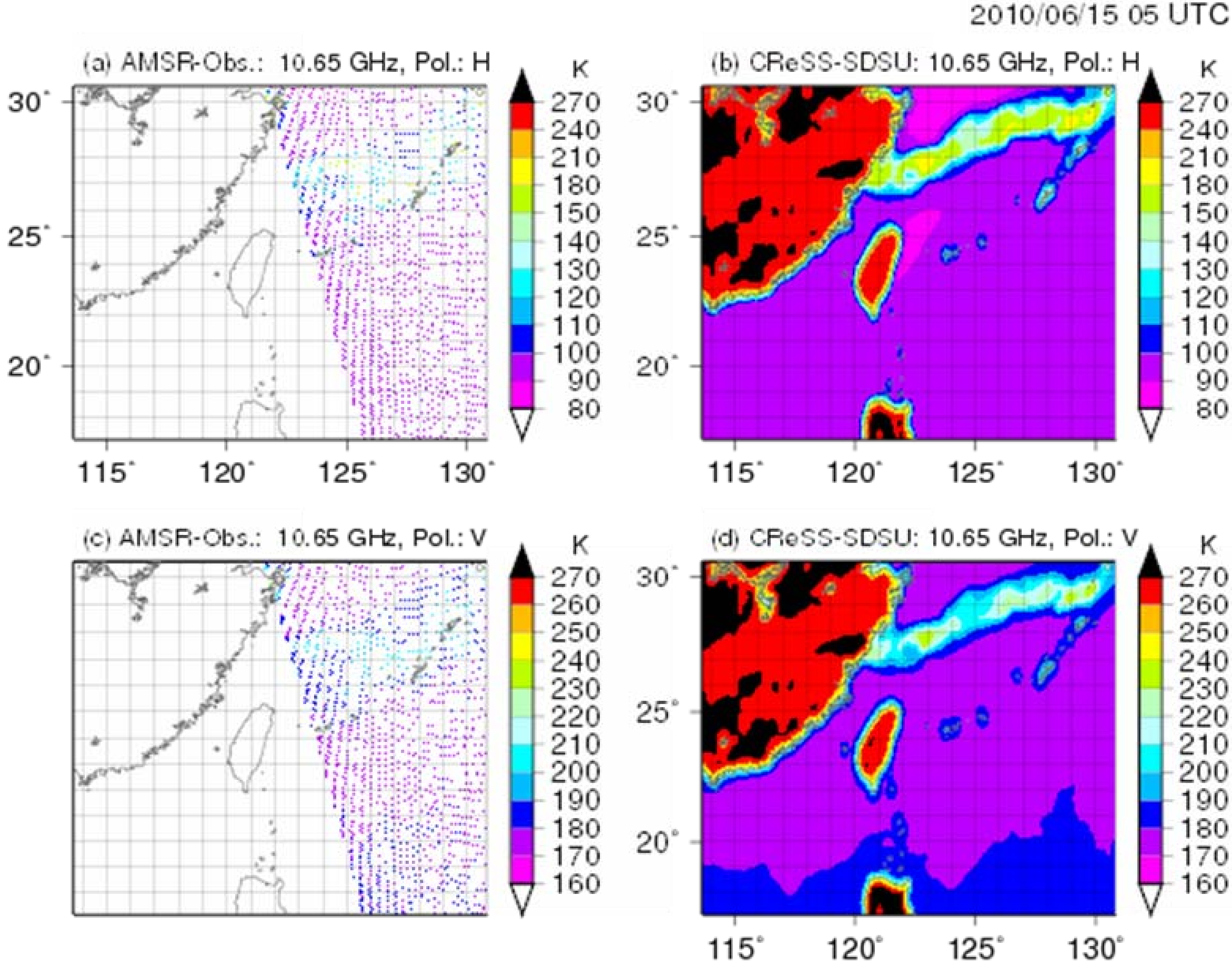


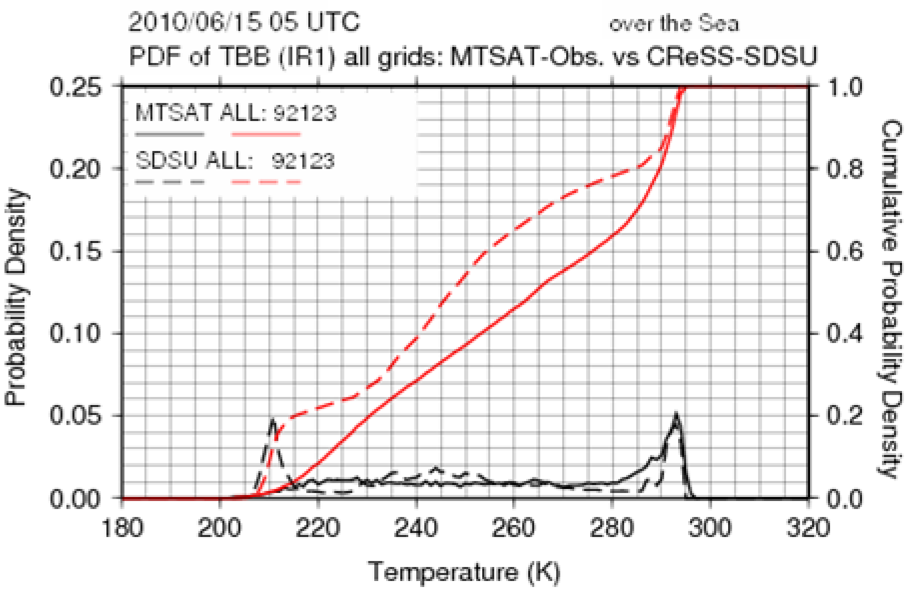
2010/06/14 18 UTC
(a) AMSR-Obs.: 10.65 GHz, Pol.: H
(b) CReSS-SDSU: 10.65 GHz, Pol.: H
(c) AMSR-Obs.: 10.65 GHz, Pol.: V
(d) CReSS-SDSU: 10.65 GHz, Pol.: V
K
270
240
210
180
150
140
130
120
110
100
90
80
270
260
250
240
230
220
210
200
190
180
170
160
30°
25°
20°
115°
120°
125°
130°

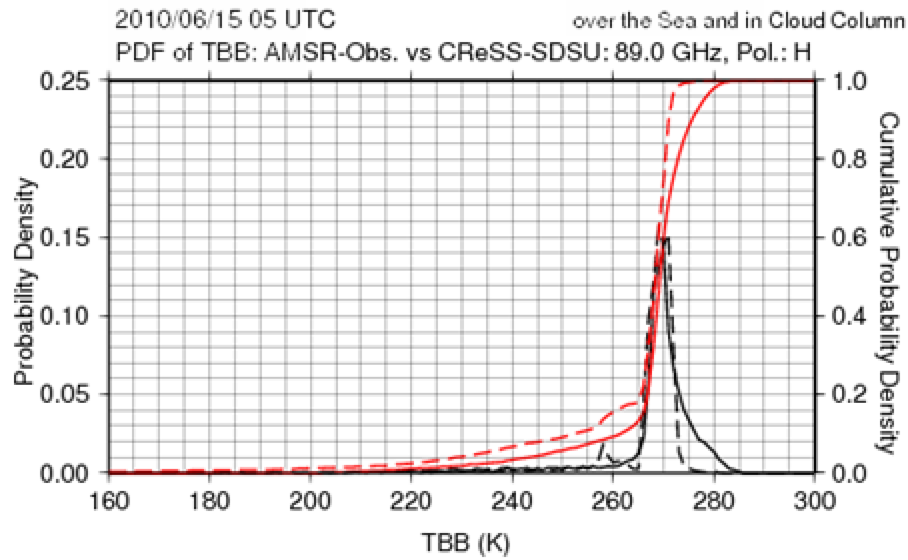

2010/06/14 17 UTC
over the Sea
PDF of TBB (IR1) all grids: MTSAT-Obs. vs CReSS-SDSU
MTSAT ALL: 92123
SDSU ALL: 92123
Probability Density
Cumulative Probability Density
Temperature (K)
PDF of TBB (IR1) in cloud: MTSAT-Obs. vs CReSS-SDSU
MTSAT in CLOUD: 74135
SDSU in CLOUD: 53234
Probability Density
Cumulative Probability Density
Temperature (K)
2010/06/14 18 UTC
over the Sea and in Cloud Column
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: H
Probability Density
Cumulative Probability Density
TBB (K)
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: V
Probability Density
Cumulative Probability Density
TBB (K)

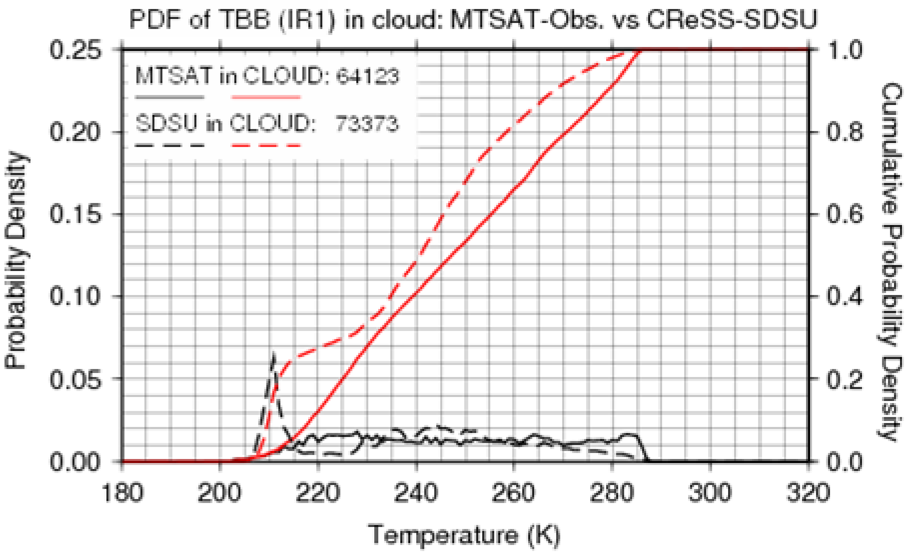

2010/06/15 05 UTC
(a) MTSAT-IR1-Obs.: 10.8 micr.
(b) CReSS-SDSU (IR1): 10.8 micr.
K
300
290
280
270
260
250
240
230
220
210
200
190
30°
25°
20°
115°
120°
125°
130°

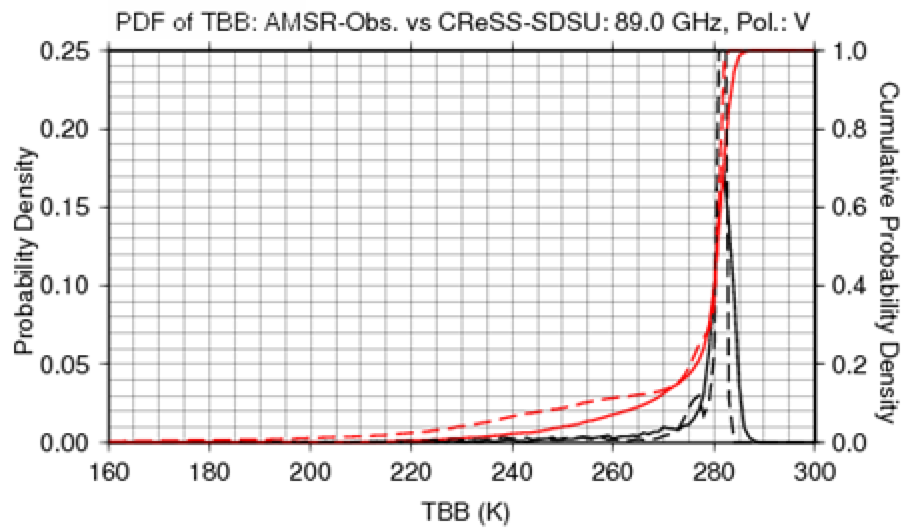

2010/06/15 05 UTC
(a) AMSR-Obs.: 89.0 GHz, Pol.: H
(b) CReSS-SDSU: 89.0 GHz, Pol.: H
(c) AMSR-Obs.: 89.0 GHz, Pol.: V
(d) CReSS-SDSU: 89.0 GHz, Pol.: V
K
320
300
280
260
240
220
200
180
160
140
120
100
30°
25°
20°
115°
120°
125°
130°

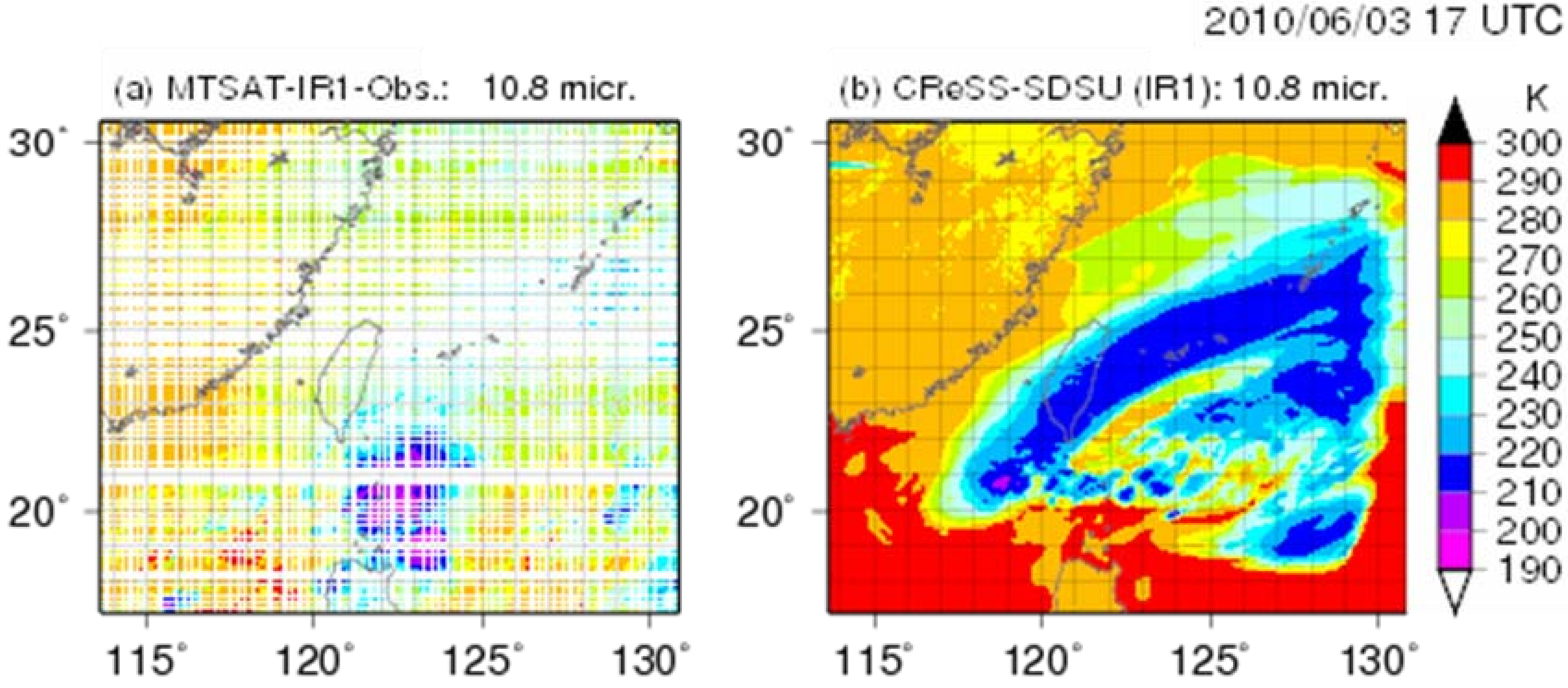

2010/06/15 05 UTC
(a) AMSR-Obs.: 10.65 GHz, Pol.: H
(b) CReSS-SDSU: 10.65 GHz, Pol.: H
(c) AMSR-Obs.: 10.65 GHz, Pol.: V
(d) CReSS-SDSU: 10.65 GHz, Pol.: V
K
270
240
210
180
150
140
130
120
110
100
90
80
K
270
260
250
240
230
220
210
200
190
180
170
160
30°
25°
20°
115°
120°
125°
130°

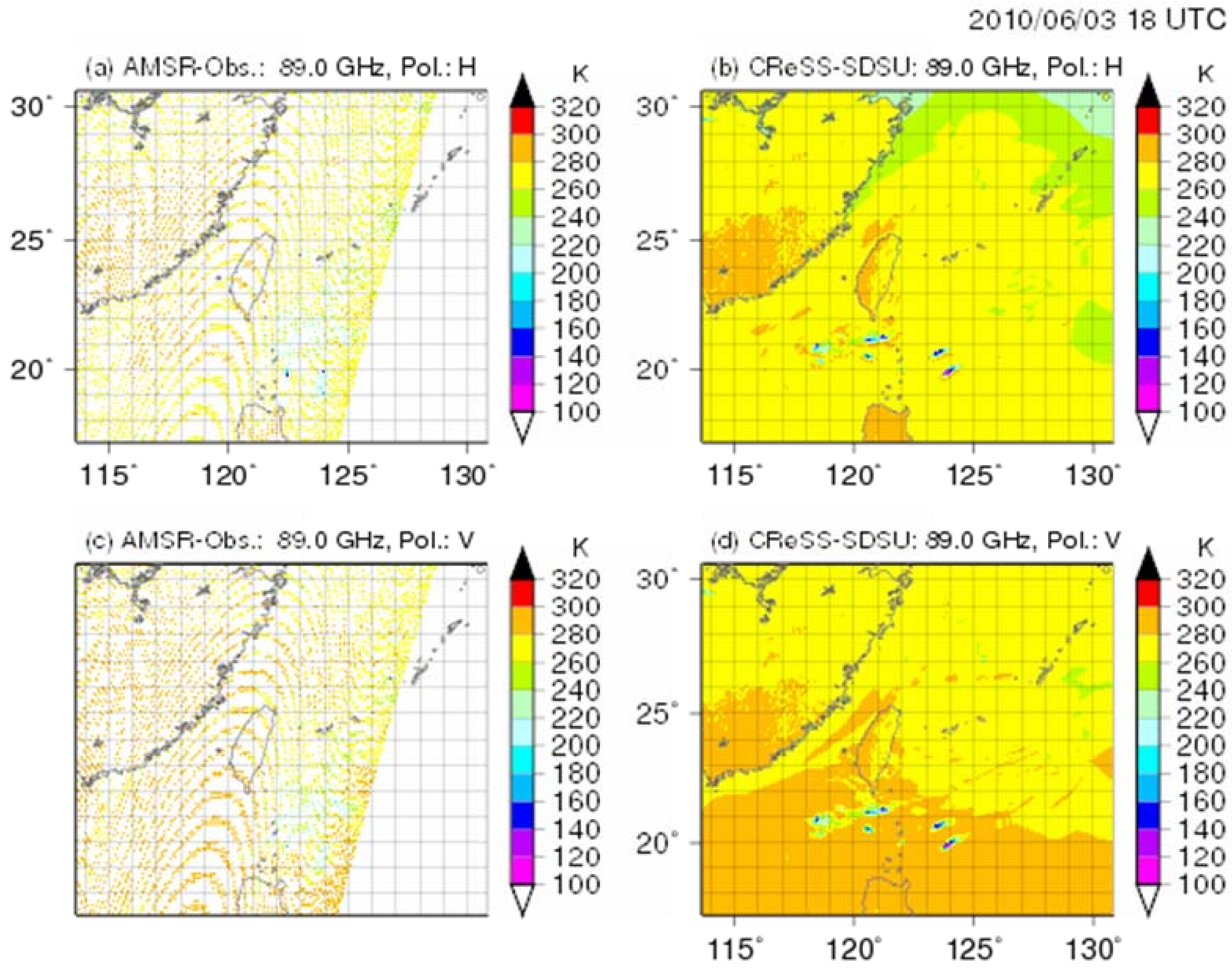

2010/06/15 05 UTC
over the Sea
PDF of TBB (IR1) all grids: MTSAT-Obs. vs CReSS-SDSU
MTSAT ALL: 92123
SDSU ALL: 92123
Probability Density
Cumulative Probability Density
Temperature (K)
0.25
0.20
0.15
0.10
0.05
0.00
1.0
0.8
0.6
0.4
0.2
0.0
180
200
220
240
260
280
300
320


2010/06/15 05 UTC
over the Sea and in Cloud Column
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: H
Probability Density
Cumulative Probability Density
TBB (K)
0.25
0.20
0.15
0.10
0.05
0.00
1.0
0.8
0.6
0.4
0.2
0.0
160
180
200
220
240
260
280
300

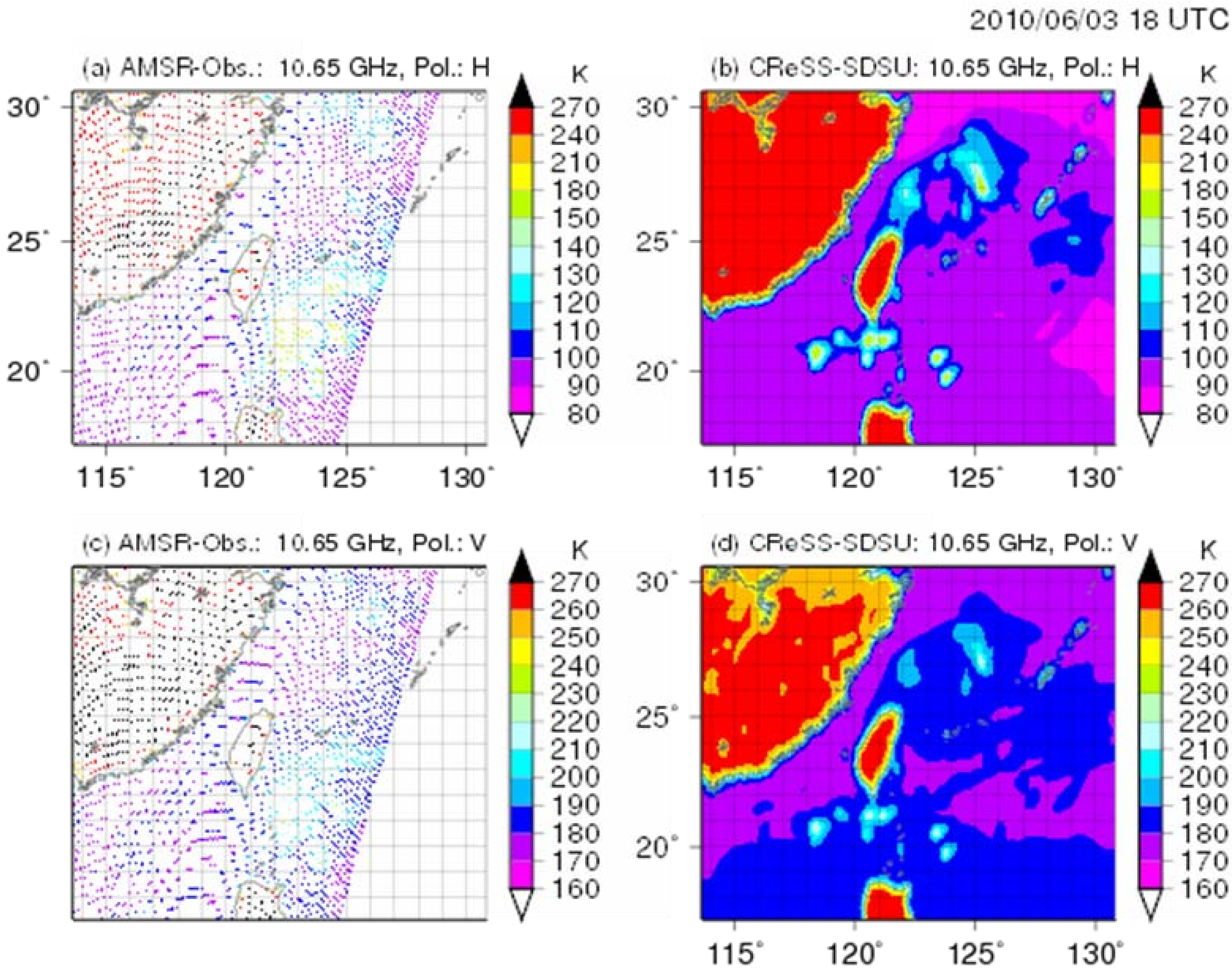

PDF of TBB (IR1) in cloud: MTSAT-Obs. vs CReSS-SDSU
MTSAT in CLOUD: 64123
SDSU in CLOUD: 73373
Probability Density
Cumulative Probability Density
Temperature (K)
0.25
0.20
0.15
0.10
0.05
0.00
1.0
0.8
0.6
0.4
0.2
0.0
180
200
220
240
260
280
300
320


PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: V
Probability Density
Cumulative Probability Density
TBB (K)
0.25
0.20
0.15
0.10
0.05
0.00
1.0
0.8
0.6
0.4
0.2
0.0
160
180
200
220
240
260
280
300

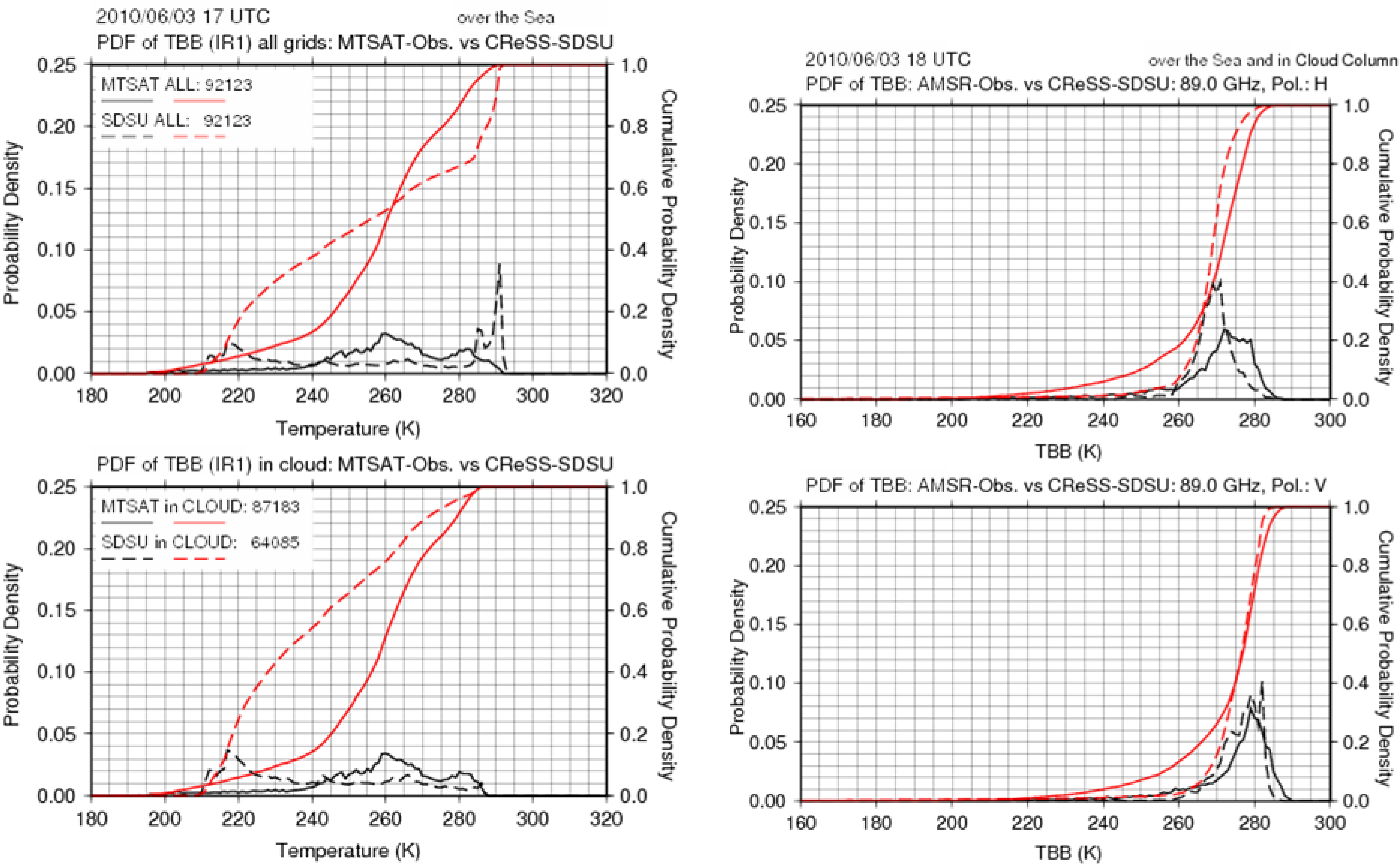

2010/06/03 17 UTC
(a) MTSAT-IR1-Obs.: 10.8 micr.
(b) CReSS-SDSU (IR1): 10.8 micr.
K
300
290
280
270
260
250
240
230
220
210
200
190
30°
25°
20°
115°
120°
125°
130°



2010/06/03 18 UTC
(a) AMSR-Obs.: 89.0 GHz, Pol.: H
(b) CReSS-SDSU: 89.0 GHz, Pol.: H
(c) AMSR-Obs.: 89.0 GHz, Pol.: V
(d) CReSS-SDSU: 89.0 GHz, Pol.: V
K
320
300
280
260
240
220
200
180
160
140
120
100
30°
25°
20°
115°
120°
125°
130°



2010/06/03 18 UTC
(a) AMSR-Obs.: 10.65 GHz, Pol.: H
(b) CReSS-SDSU: 10.65 GHz, Pol.: H
(c) AMSR-Obs.: 10.65 GHz, Pol.: V
(d) CReSS-SDSU: 10.65 GHz, Pol.: V
K
270
240
210
180
150
140
130
120
110
100
90
80
K
270
260
250
240
230
220
210
200
190
180
170
160
30°
25°
20°
115°
120°
125°
130°


2010/06/03 17 UTC
over the Sea
PDF of TBB (IR1) all grids: MTSAT-Obs. vs CReSS-SDSU
MTSAT ALL: 92123
SDSU ALL: 92123
Probability Density
Cumulative Probability Density
Temperature (K)
PDF of TBB (IR1) in cloud: MTSAT-Obs. vs CReSS-SDSU
MTSAT in CLOUD: 87183
SDSU in CLOUD: 64085
2010/06/03 18 UTC
over the Sea and in Cloud Column
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: H
TBB (K)
PDF of TBB: AMSR-Obs. vs CReSS-SDSU: 89.0 GHz, Pol.: V

T_{BB}-MW 89GHz distributions (AMSR-E vs CReSS-SDSU)

In the horizontal polarization (H-Pol.),

- **The T_{BB} distribution is roughly reproduced well in the simulation.**
- **The area whose T_{BB} is about 200-220 K in the simulation is smaller than that in the satellite observation.**
- **There are band-shaped regions whose T_{BB} is greater than 220 K in the southeastern region of the SJ in the simulation.**

T_{BB}-MW 89GHz distributions (AMSR-E vs CReSS-SDSU)

In the vertical polarization (V-Pol.),

- **These correspond to the band-shaped relatively lower T_{BB} regions (less than 220 K) in the vertical polarization.**
- **These regions do not correspond to the satellite observation.**

T_{BB}-MW 89GHz differences (AMSR-E vs CReSS-SDSU)

- **The band-shaped high T_{BB} regions in the H-pol. correspond to the excessive existence of water vapor and/or liquid water.**
- **That low T_{BB} regions in the V-pol. correspond to the excessive existence of ice particles.**
- **These represent the excessive water vapor and hydrometeor existence by the development of snow clouds along the convergence zones.**