Validation of CRTM by using CloudSat data

Yong Chen

Fuzhong Weng, Yong Han and Quanhua Liu

Joint Center for Satellite Data Assimilation

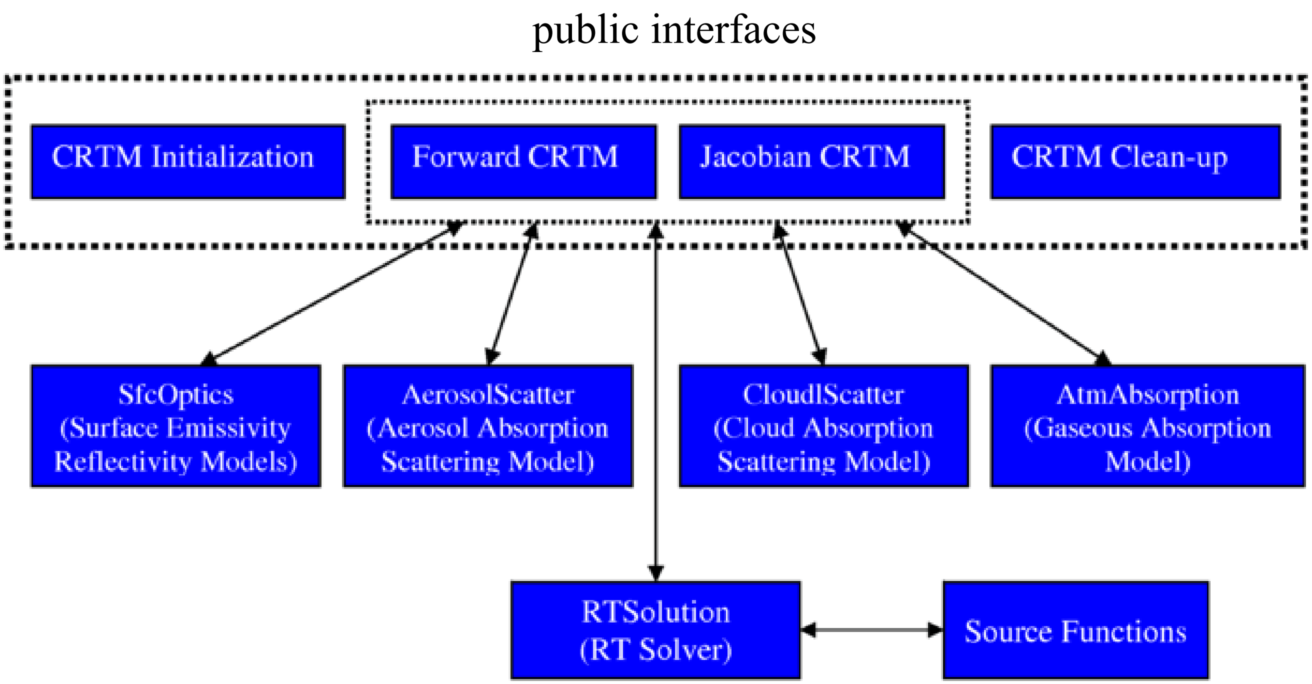
JCSDA 6th Workshop, June 10-11, 2008 BWI Holiday Inn

OUTLINE

- Background
- Methodology
- Validation Results
- Summary/Future work

JCSDA CRTM

Community Radiative Transfer Model



- Input profiles: temperature, water vapor and ozone profiles at user defined layers, and optionally, water content and mean particle size profiles with up to 6 cloud types.
- Surface emissivity: computed internally or supplied by user.
- Frequency coverage: MW and IR

Cloud absorption/scattering model

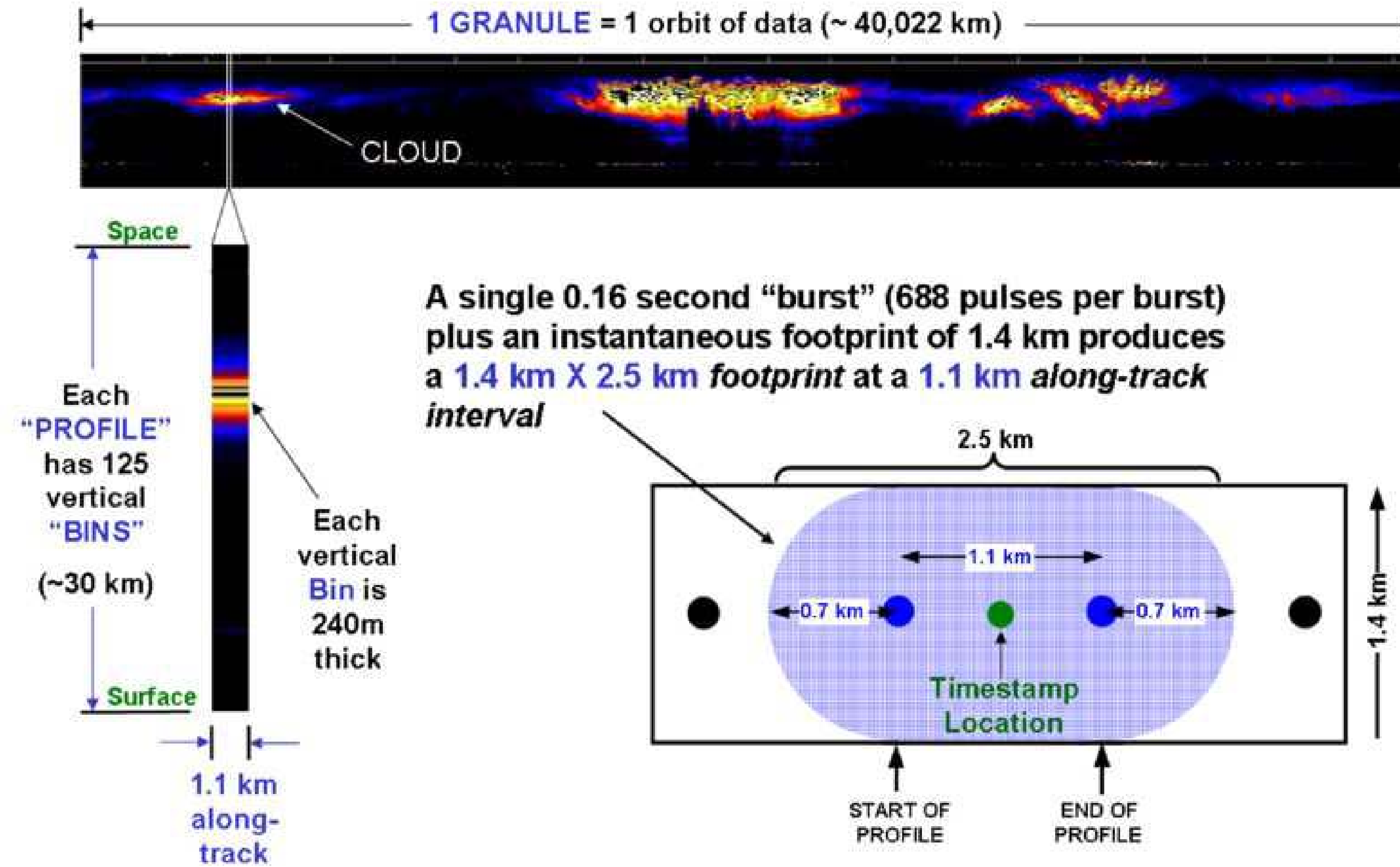
- **Currently in operation:**
  - Six cloud types: water, ice, rain, snow, graupel and hail
  - NESDIS lookup table: mass extinction coefficient, single scattering albedo, asymmetric factor and Legendre phase coefficients. Sources:
    - IR: spherical water cloud droplets (Simmer, 1994); non-spherical ice cloud particles (Liou and Yang, 1995; Macke et al., 1996; Mishchenko et al., 2000; Baum et al., 2005, Yang et al., 2005).
    - IR: Mie scattering, a modified gamma size distribution are assumed for the water clouds. The ice cloud particles are assumed as nonspherical hexagonal columns and with gamma size distribution.
    - MW: spherical cloud, rain and ice particles (Simmer, 1994).
    - MW: The Mie theory is assumed in all calculations for spherical liquid and ice water cloud particles, and modified gamma size distributions.

Radiative transfer solver: Currently in operational code:

Advanced Adding and Doubling (ADA) method (Liu and Weng, 2006)

CloudSat Data Set

The primary CloudSat instrument is a 94 GHz, nadir-pointing, Cloud Profile Radar (CPR) which measures the power backscattered by clouds as a function of distance from the radar. CloudSat, launched on 28 April 2006, flies in a sun-synchronous orbit at an 89^o inclination angle, and a nominal altitude of 705 km.



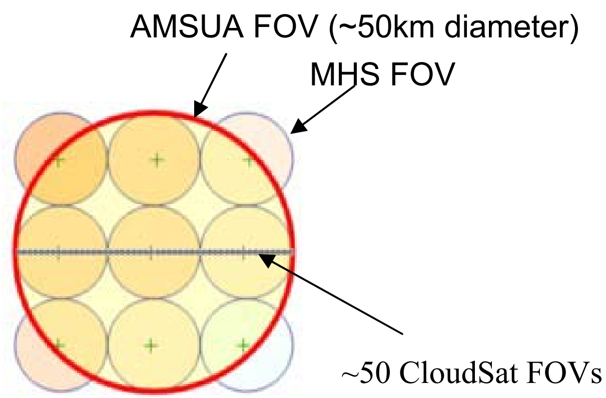
CloudSat Data Set

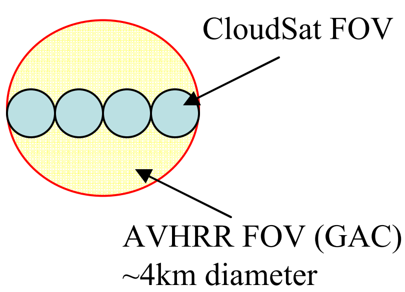
CloudSat Standard Data Products

	Product	Product Description
	1B-CPR	Radar Backscatter Profiles
	2B-GEOPROF	Cloud Geometrical Profile
√	2B-CLDCLASS	Cloud Classification
√	2B-CWC-RO	Cloud Water Content (Radar-only)
√	ECMWF-AUX	ECMWF profile
	2B-TAU	Cloud Optical Depth
	2B-LWC-RVOD	Cloud Liquid Water Content (Radar-Visible Optical Depth)
	2B-IWC-RVOD	Cloud Ice Water Content (Radar-Visible Optical Depth)
	2B-FLXHR	Fluxes and Heating Rates
	2B-GEOPROF-LIDAR	Radar-Lidar Cloud Geometrical Profile
	2B-CLDCLASS-LIDAR	Radar-Lidar Cloud Classification

Validation using CloudSat data (non-precipitating weather)

- CloudSat data (Afternoon satellite, Local time ascending node 1:31pm):
  - Cloud Geometrical Profile: 2B-GEOPROF
  - Cloud Classification: 2B-CLDCLASS
  - Cloud Liquid/ICE Water Content & particle size: 2B-CWC-RO
- Temperature, water vapor and O_3 profiles and surface state variables:
  - ECMWF analysis data set: ECMWF-AUX
  - NCEP surface analysis data set
- NOAA 18 data (Afternoon satellite, Local time ascending node 1:38pm):
  - AMSUA Level 1B and Level 2 data set
  - MHS Level 1B and Level 2 data set
  - AVHRR/3 Level 1B (GAC) data set

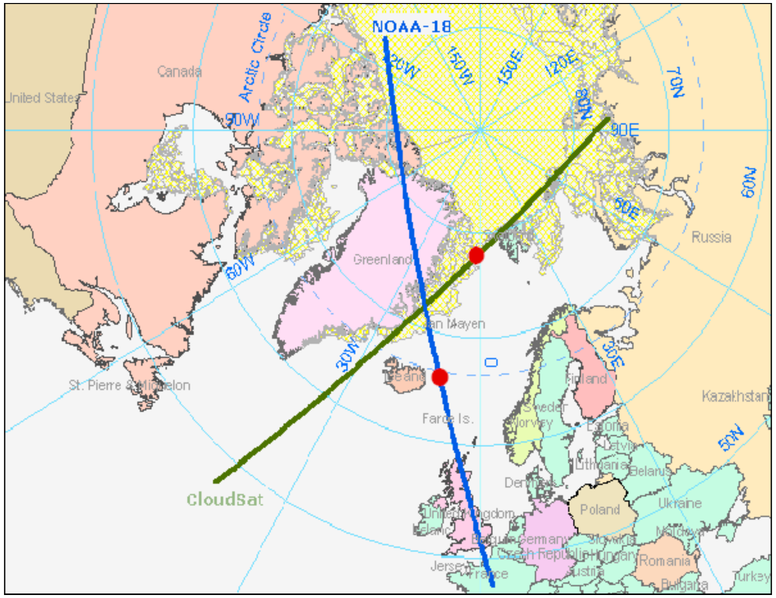


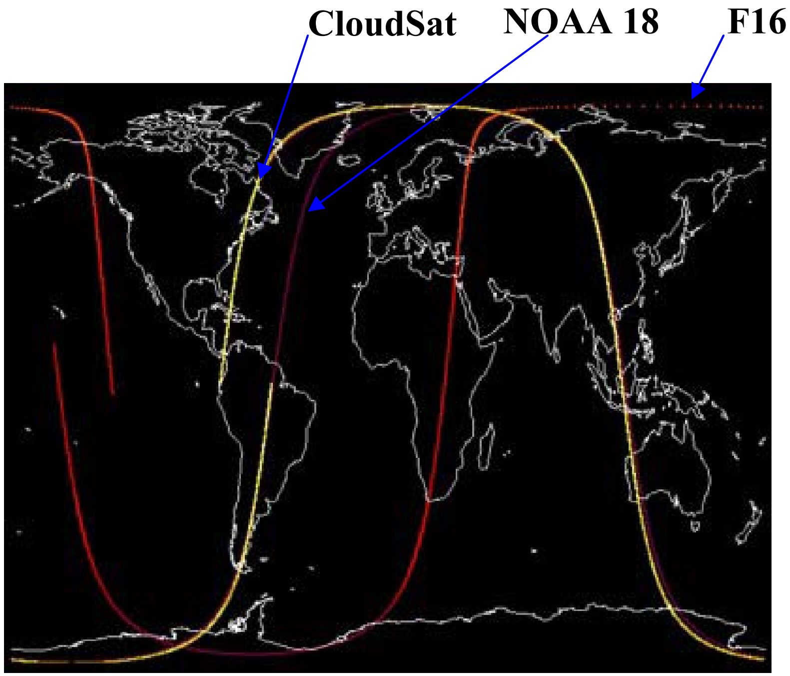


CloudSat and NOAA 18 Orbit Data Matching

Using the simultaneous nadir overpass (SNO) method to match the polar-orbiting satellite radiometers.

- Predict SNOs using satellite orbit perturbation models with appropriate two-line-elements.
- Acquire satellite observation data at the SNOs.
- Perform pixel-by -pixel match of the data from satellite pairs, with minimized navigation errors.

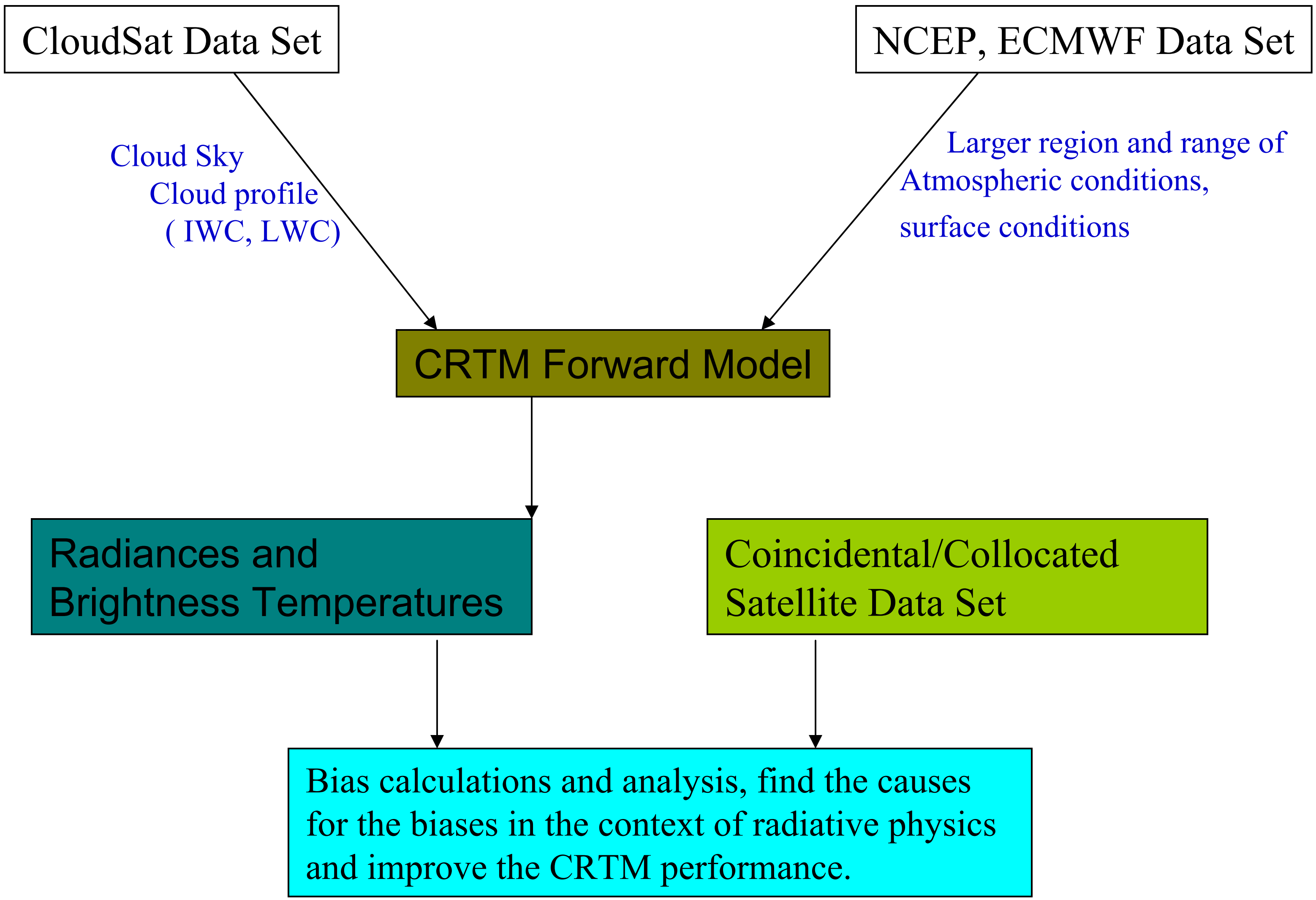




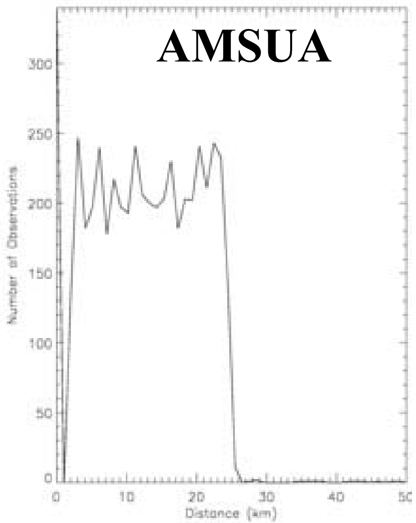
CloudSat and NOAA 18 Orbit Data Matching

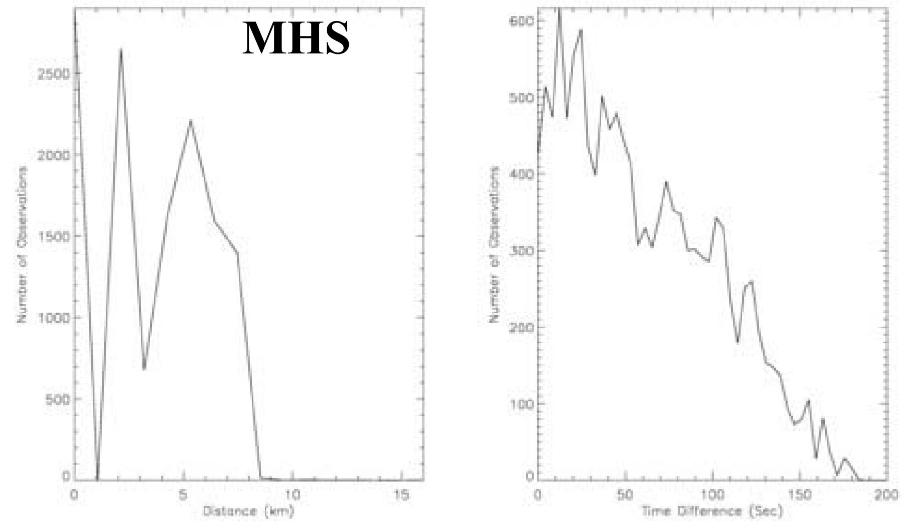
- The strict requirements for coincidence based on SNOs largely limit the data quantities with few points in several days.
- We loose the requirements by increasing the time difference within ~2 minutes and distance within ~50km for AMSUA (~16km for MHS, ~4km for AVHRR/3), the collocated data increased tremendously.
- Apply this method to CloudSat and NOAA-18 on the period of 07/07/06-08/16/06 (nadir-viewing position), 10/01/06-11/04/06, and 01/01/07-02/01/07. Total 31 orbit data meeting the requirements.
- For validation of the Cloud absorption/scattering model purpose, we only choose the match up points within latitude ranges of -50 to 50 and over ocean to reduce the surface emissivity effects on the simulated radiances/brightness temperatures.

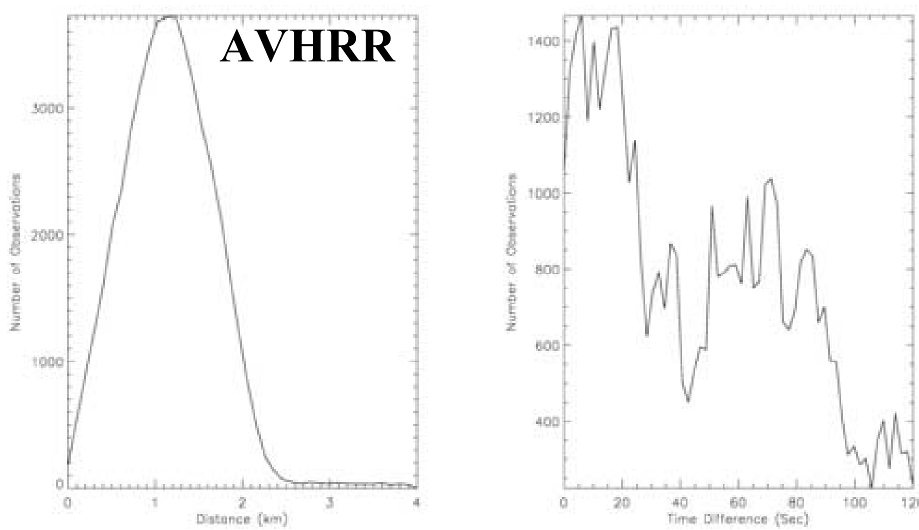
CRTM Validation



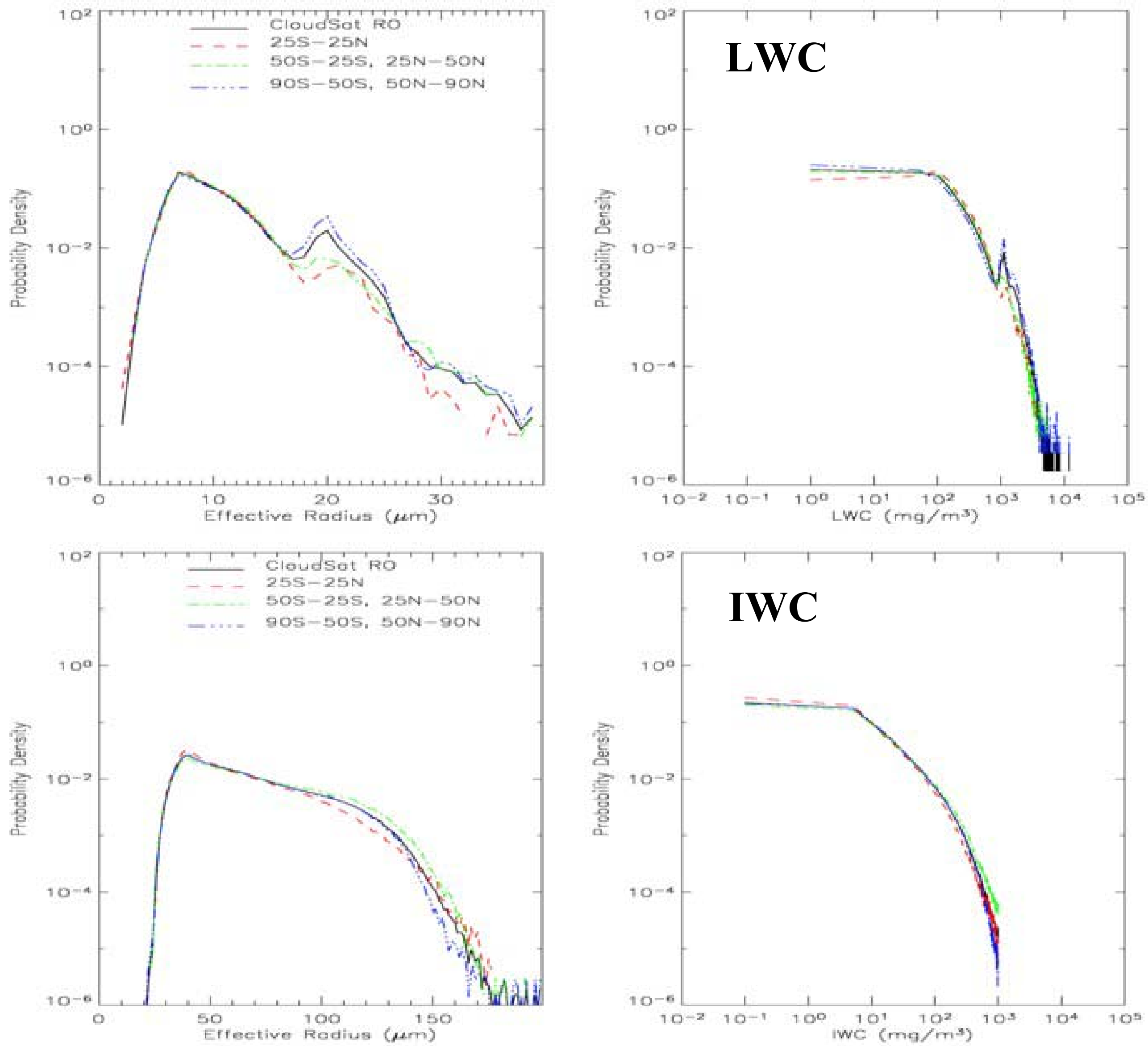
NOAA 18 and CloudSat match up time and distance difference distributions



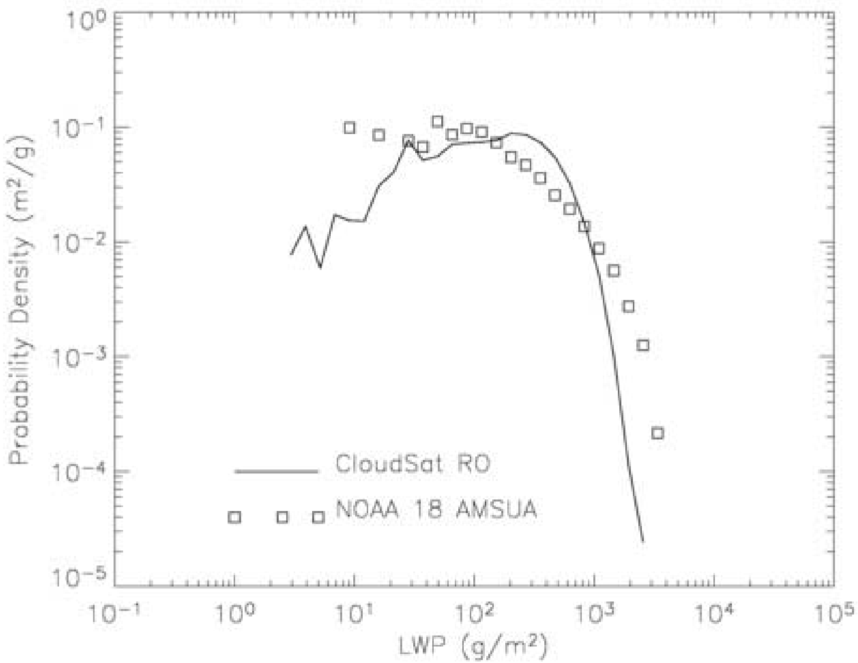


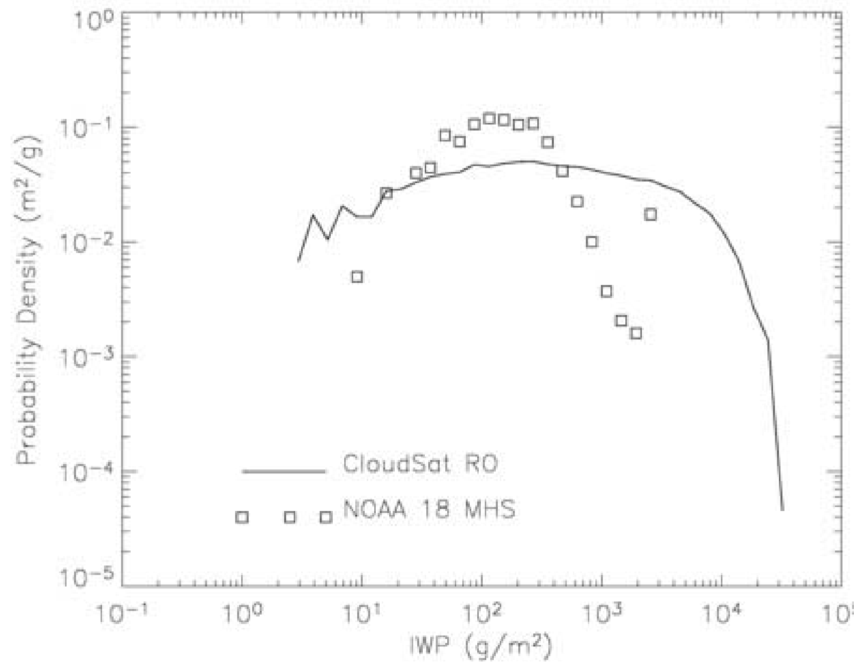


CloudSat LWC/IWC and Effective Radius



LWP/IWP Comparison between CloudSat and NOAA 18 AMSUA/MHS

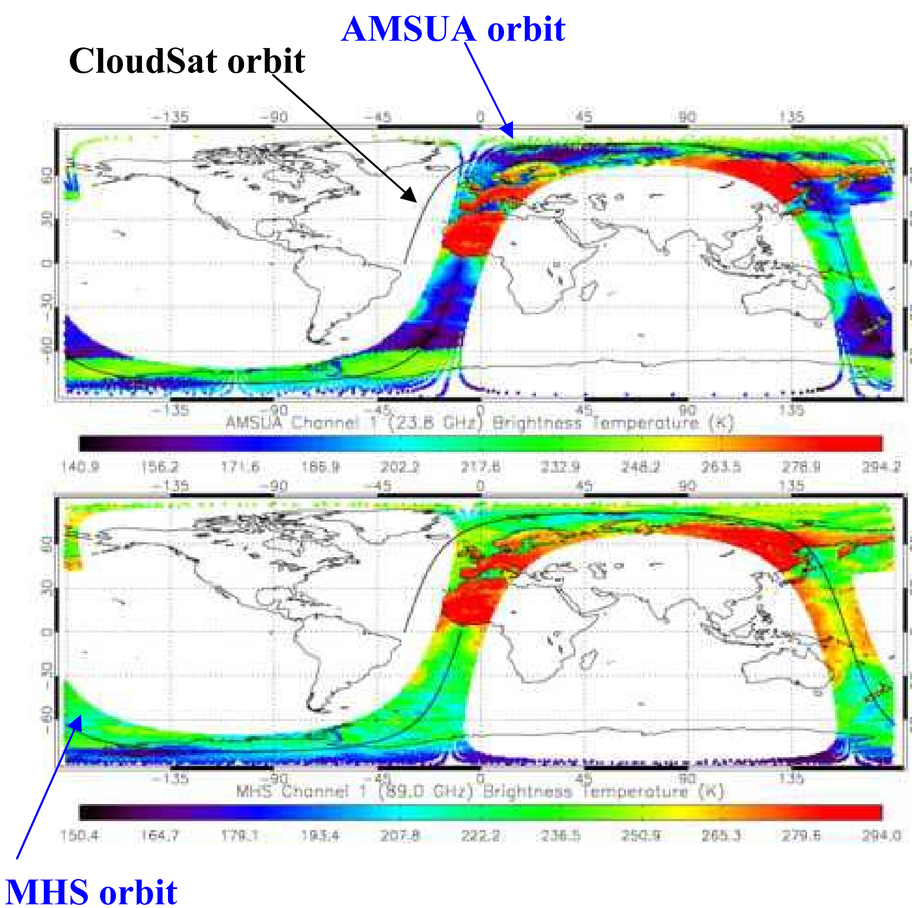


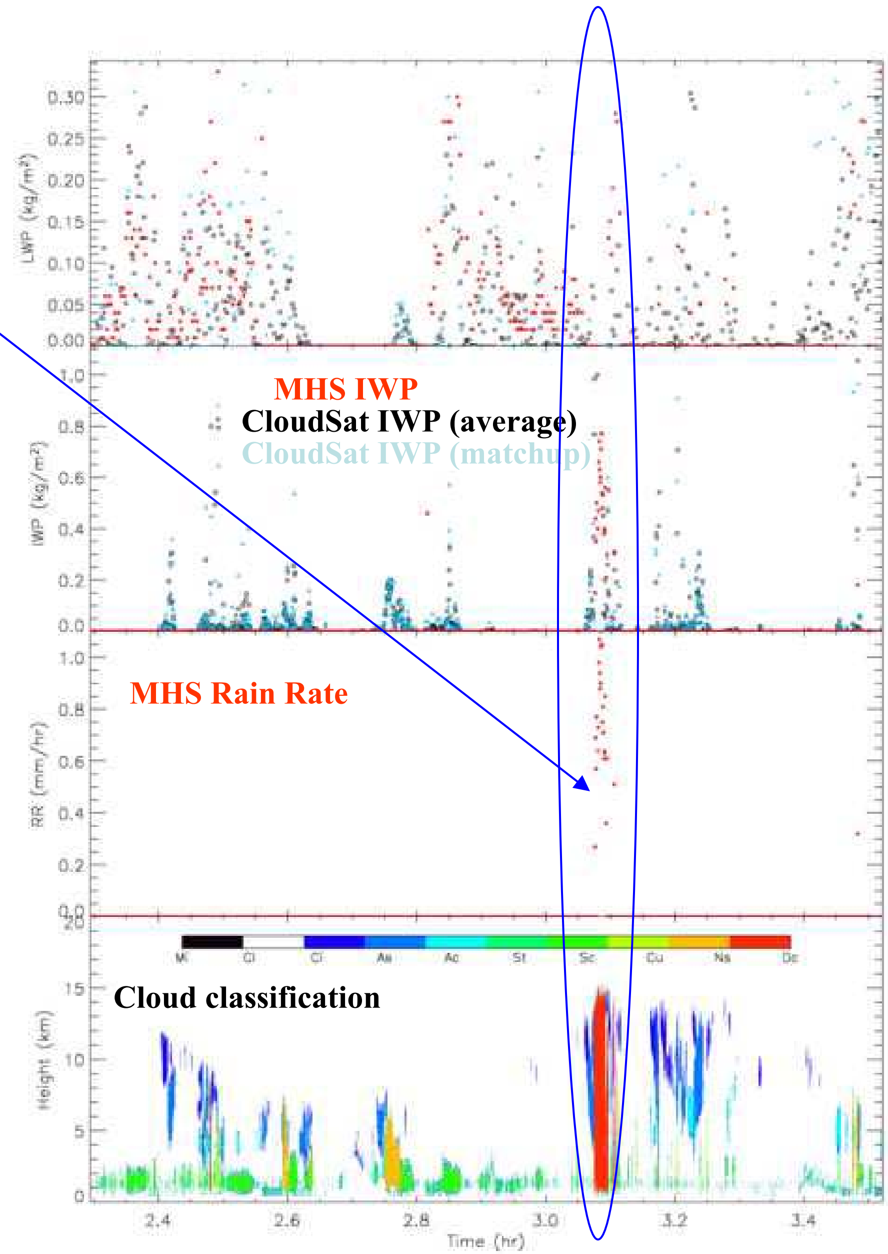


Case Study: Time series of IWP/LWP Comparison

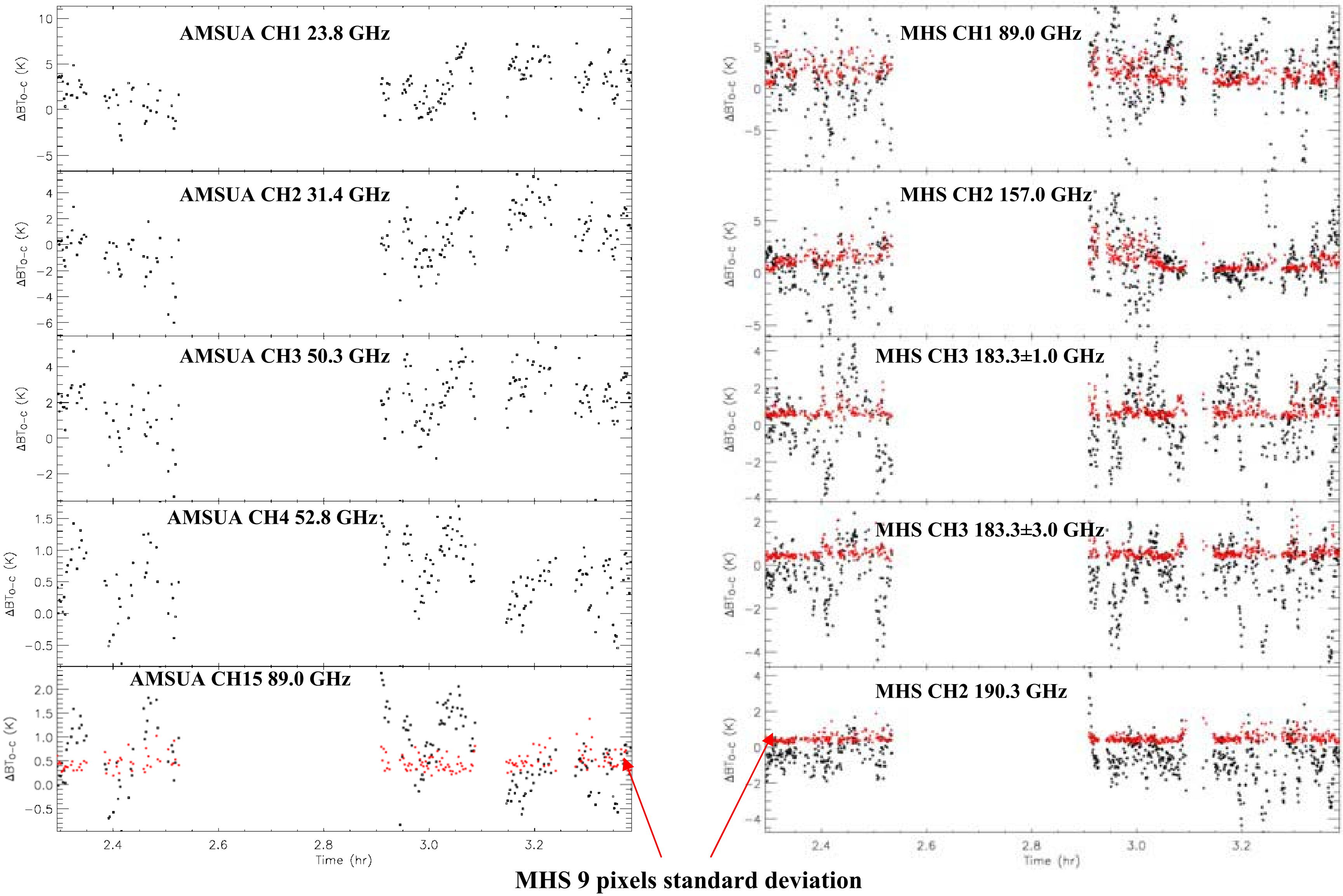
07/27/2006

CloudSat retrieval failure in regions of high Z (precipitation)**,** due to the assumption of distributions of cloud particle without substantial numbers of larger precipitation particles.

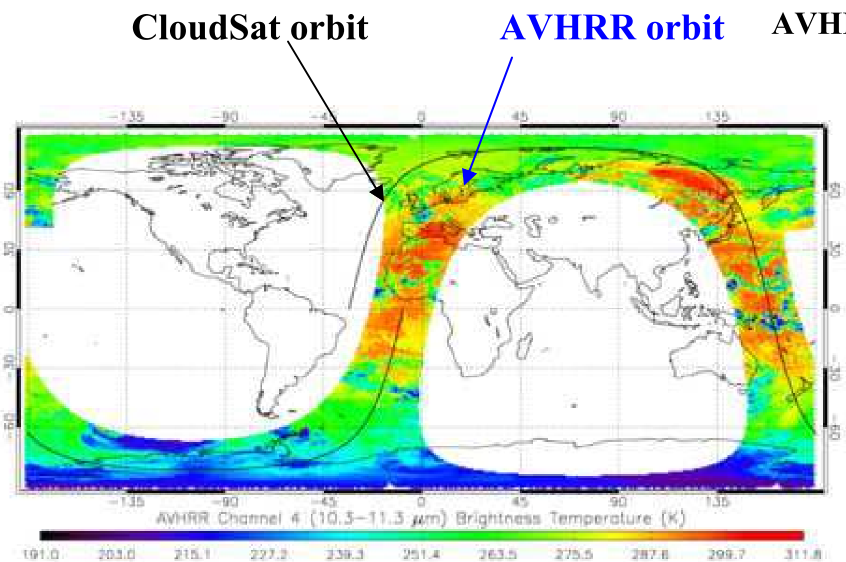


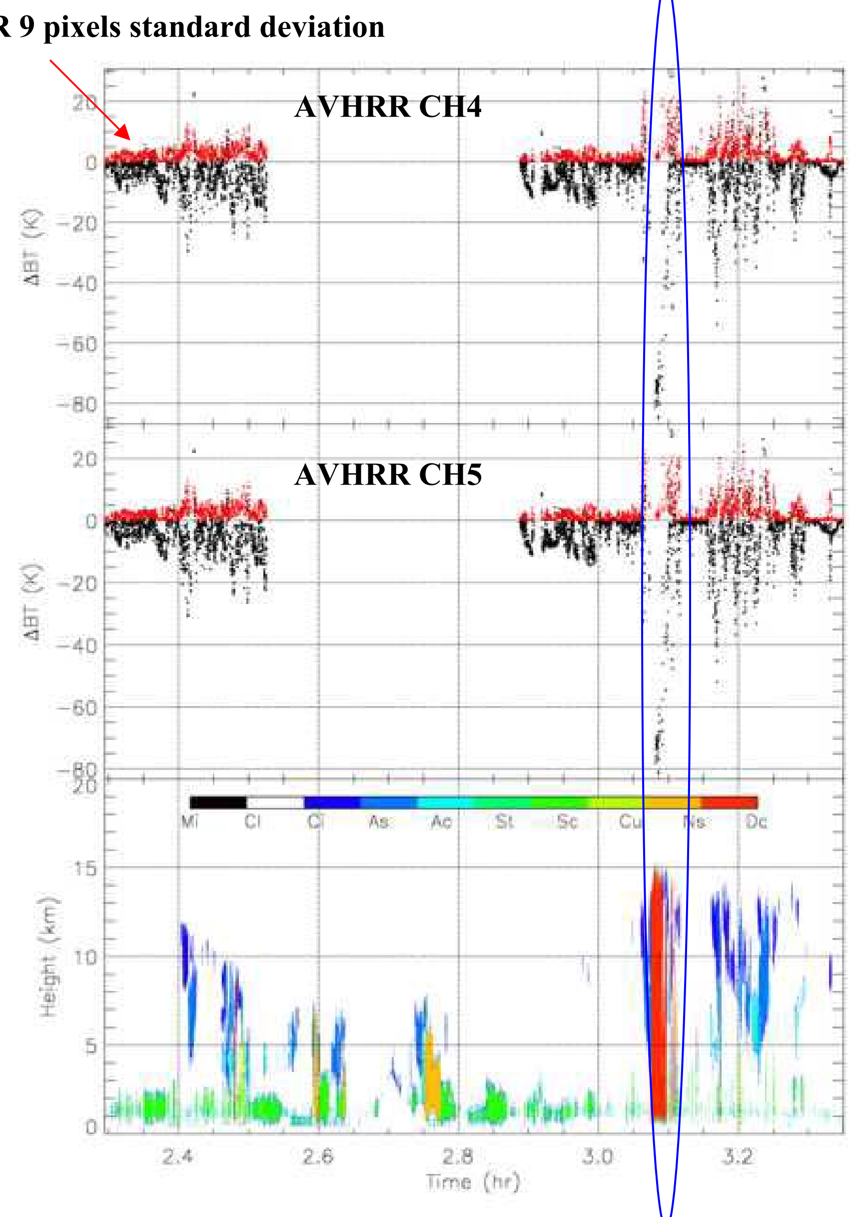


Time series of AMSUA, MHS observations versus CRTM simulations using CloudSat data (non-precipitating weather)



Time series of AVHRR observations versus CRTM simulations using CloudSat data (non-precipitating weather)

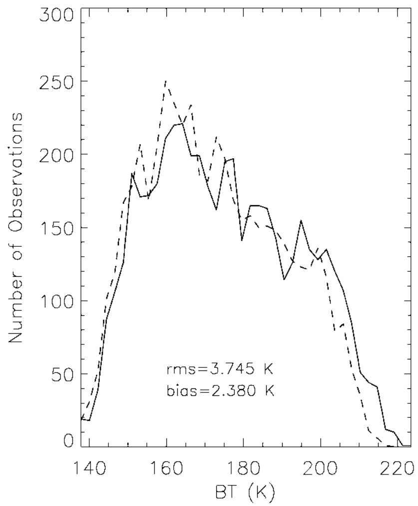




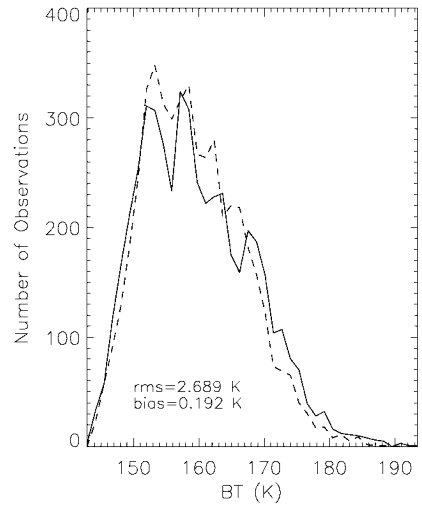
- Cirrus clouds have very high standard deviation, implying the high inhomogeneity in FOV.
- Higher STD accompanying with higher BT differences between observations and simulations.
- Infrared radiations have high sensitivity for ice clouds where CloudSat 94 GHz radar is not.
- CloudSat may miss thin cirrus cloud because of thick vertical resolution (240 meters).

Histograms of the observed/simulated BTs for AMSUA/MHS

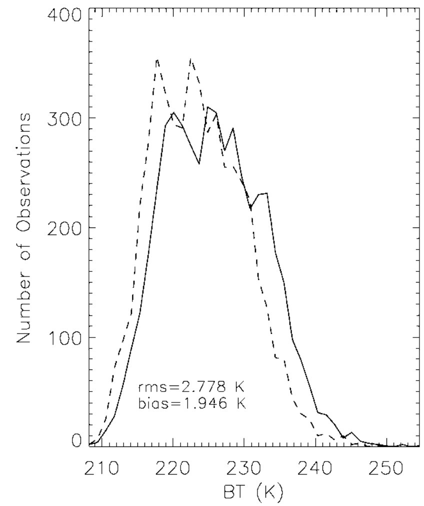
23.8 GHz



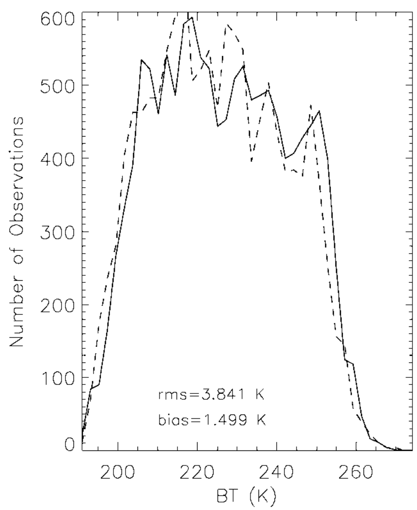
31.4 GHz



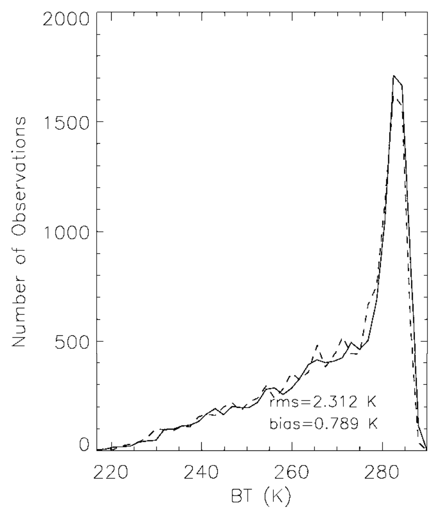
50.3 GHz



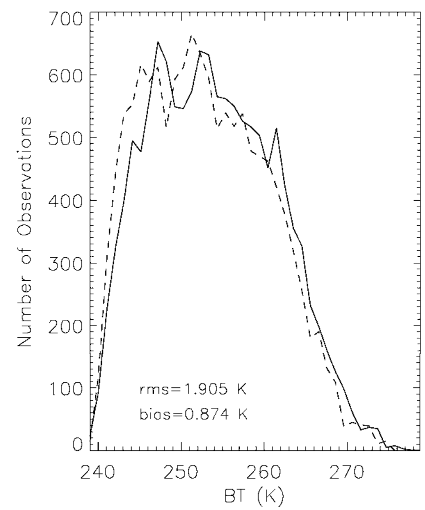
89.0 GHz



157.0 GHz

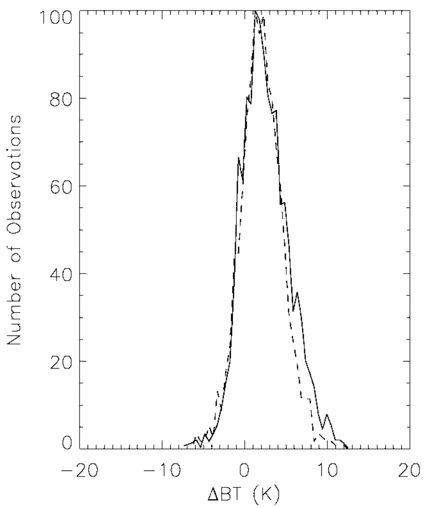


183.311 ± 1.0 GHz

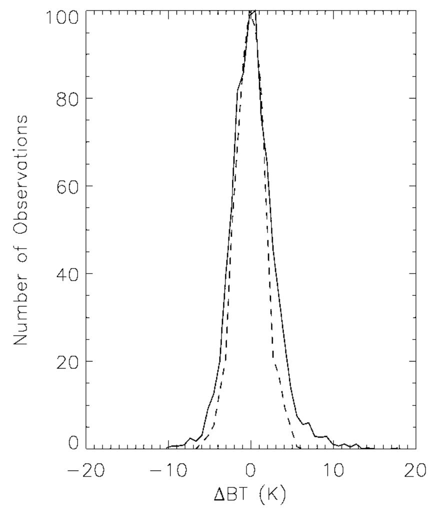


Histograms of the observed/simulated ΔBTs for AMSUA/MHS

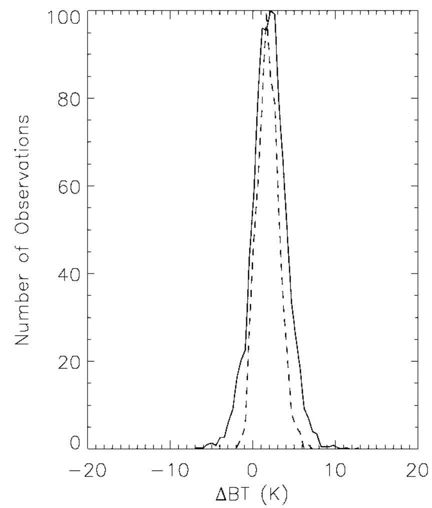
23.8 GHz



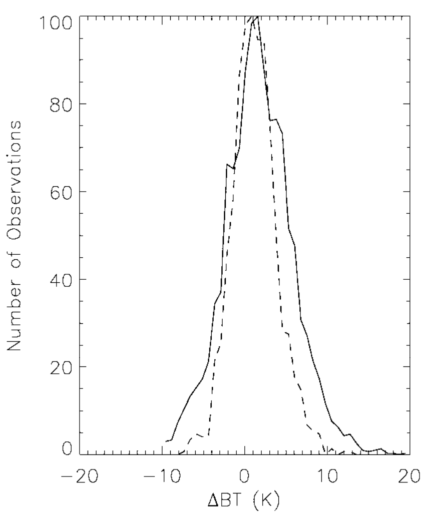
31.4 GHz



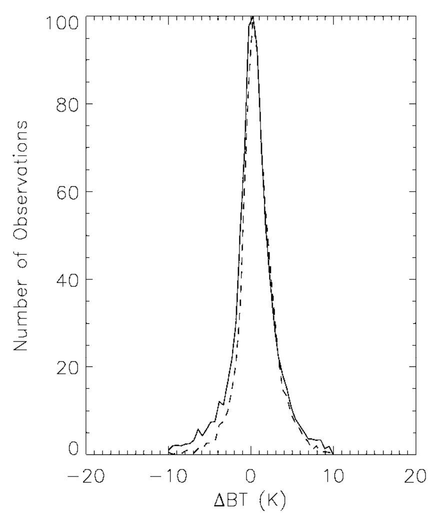
50.3 GHz



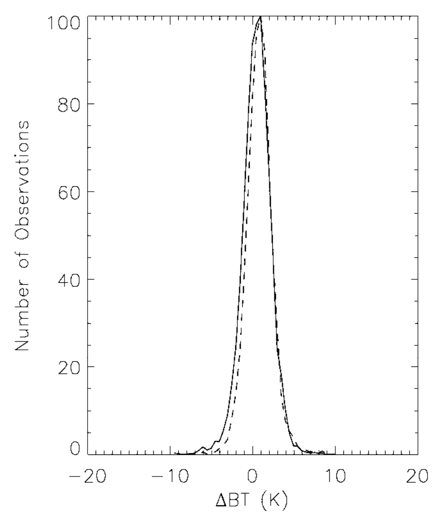
89.0 GHz



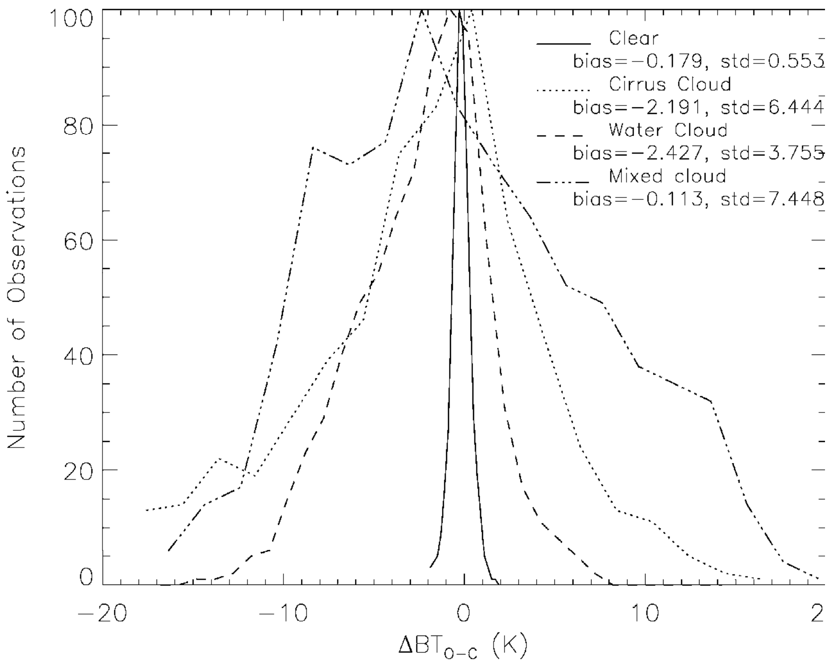
157.0 GHz



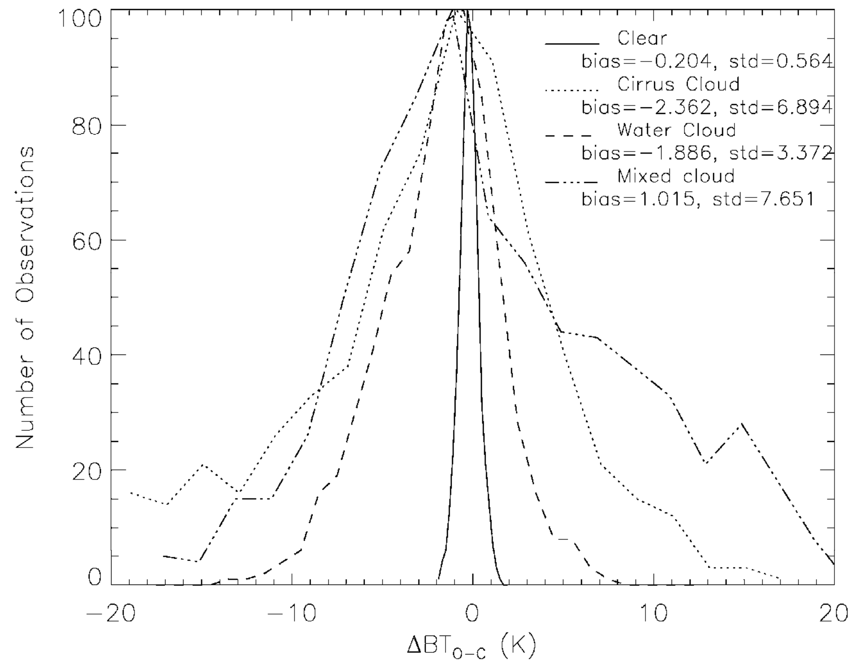
183.311 ± 1.0 GHz



Histograms of the observed/simulated ΔBTs for AVHRR

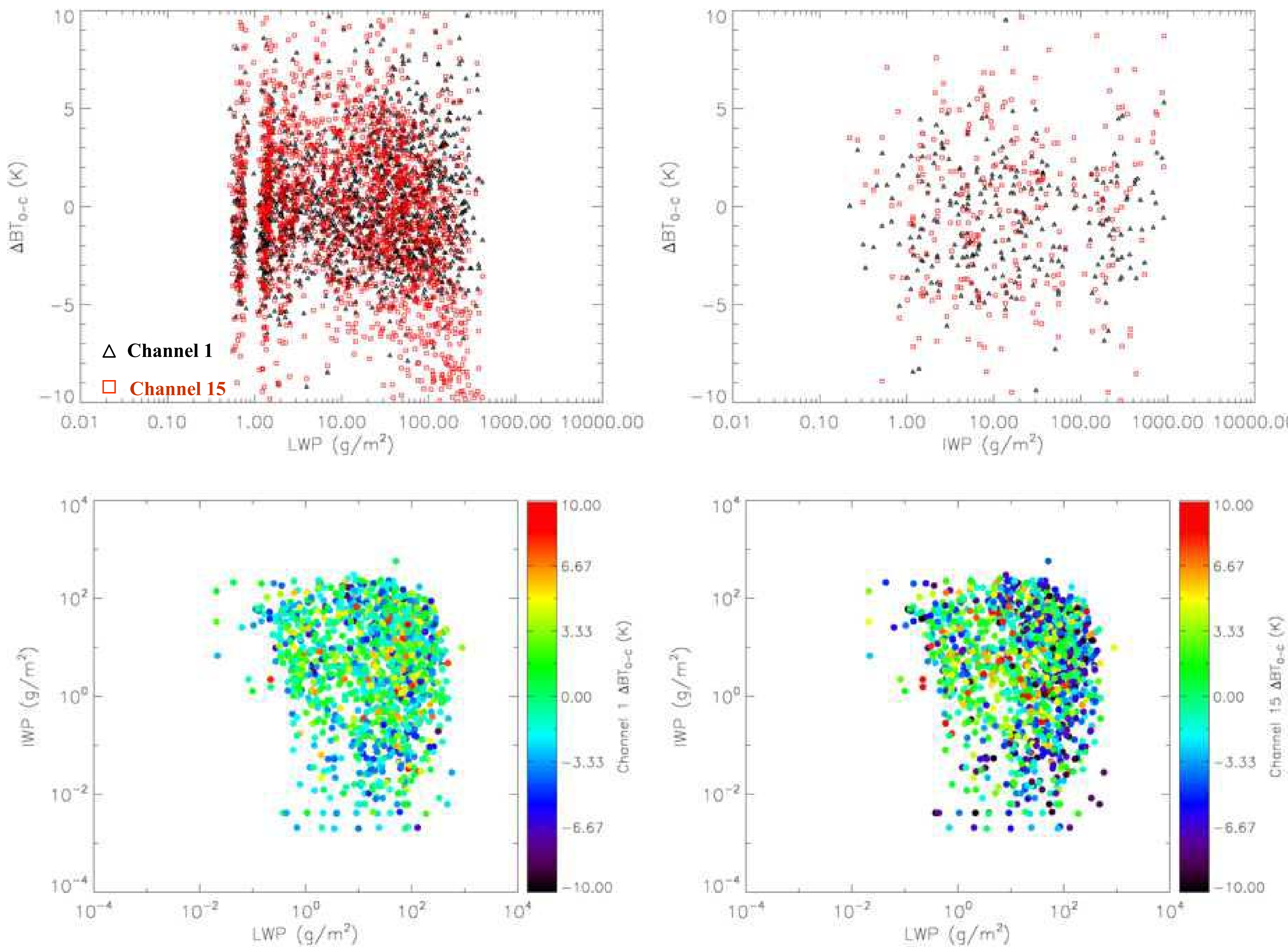


AVHRR CH4

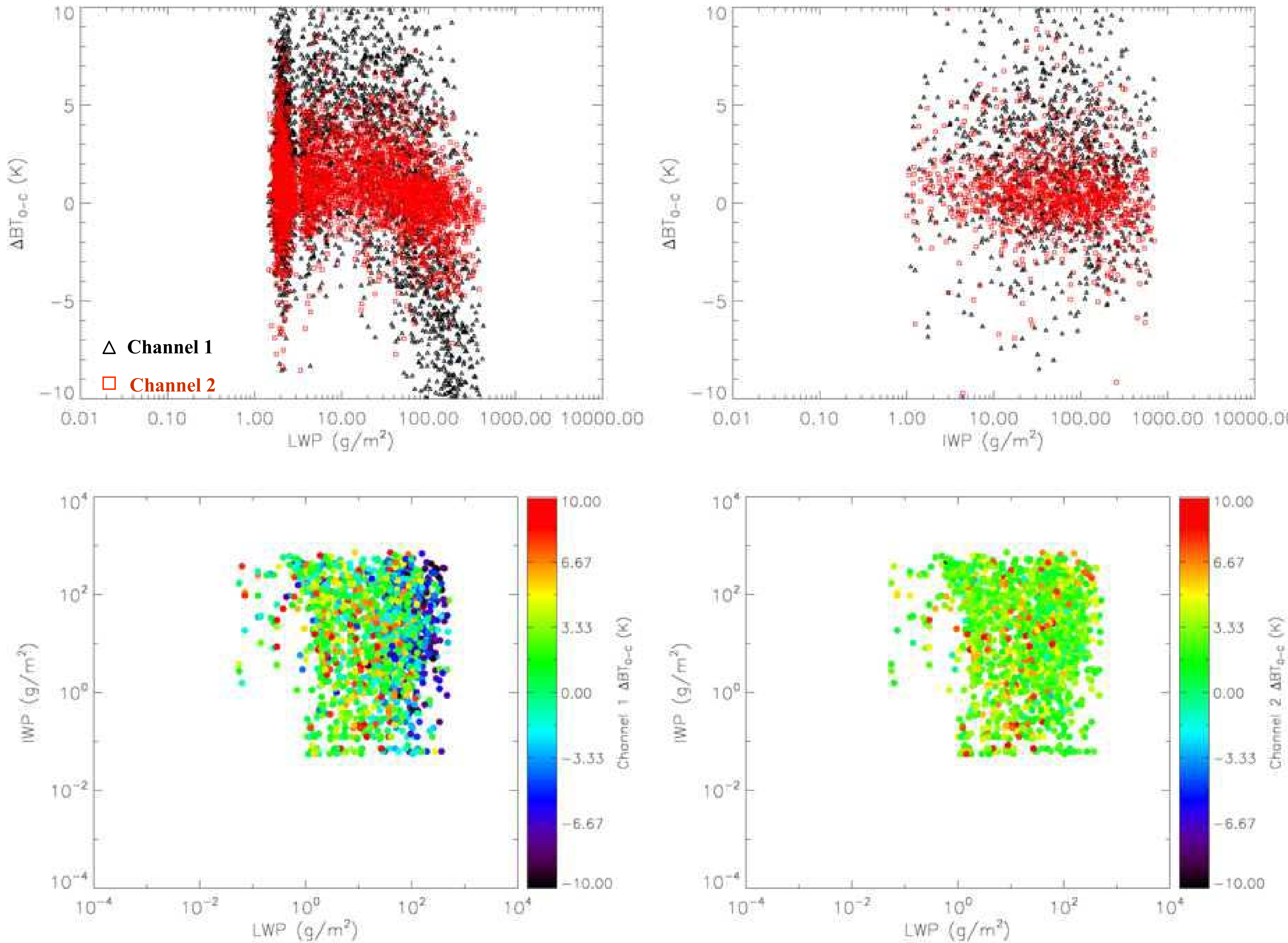


AVHRR CH5

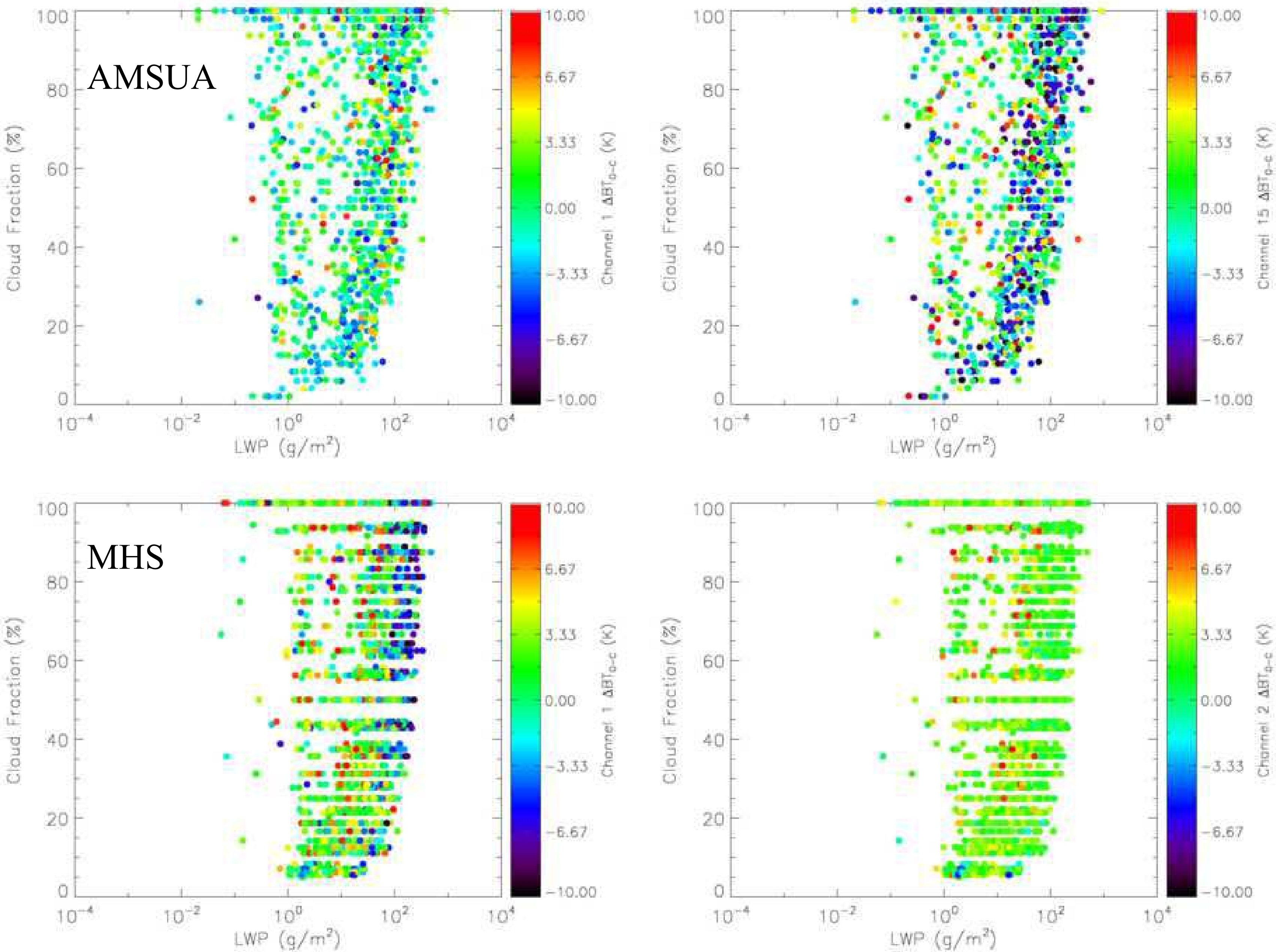
AMSUA biases over ocean V.S. LWP/IWP retrieved by CloudSat



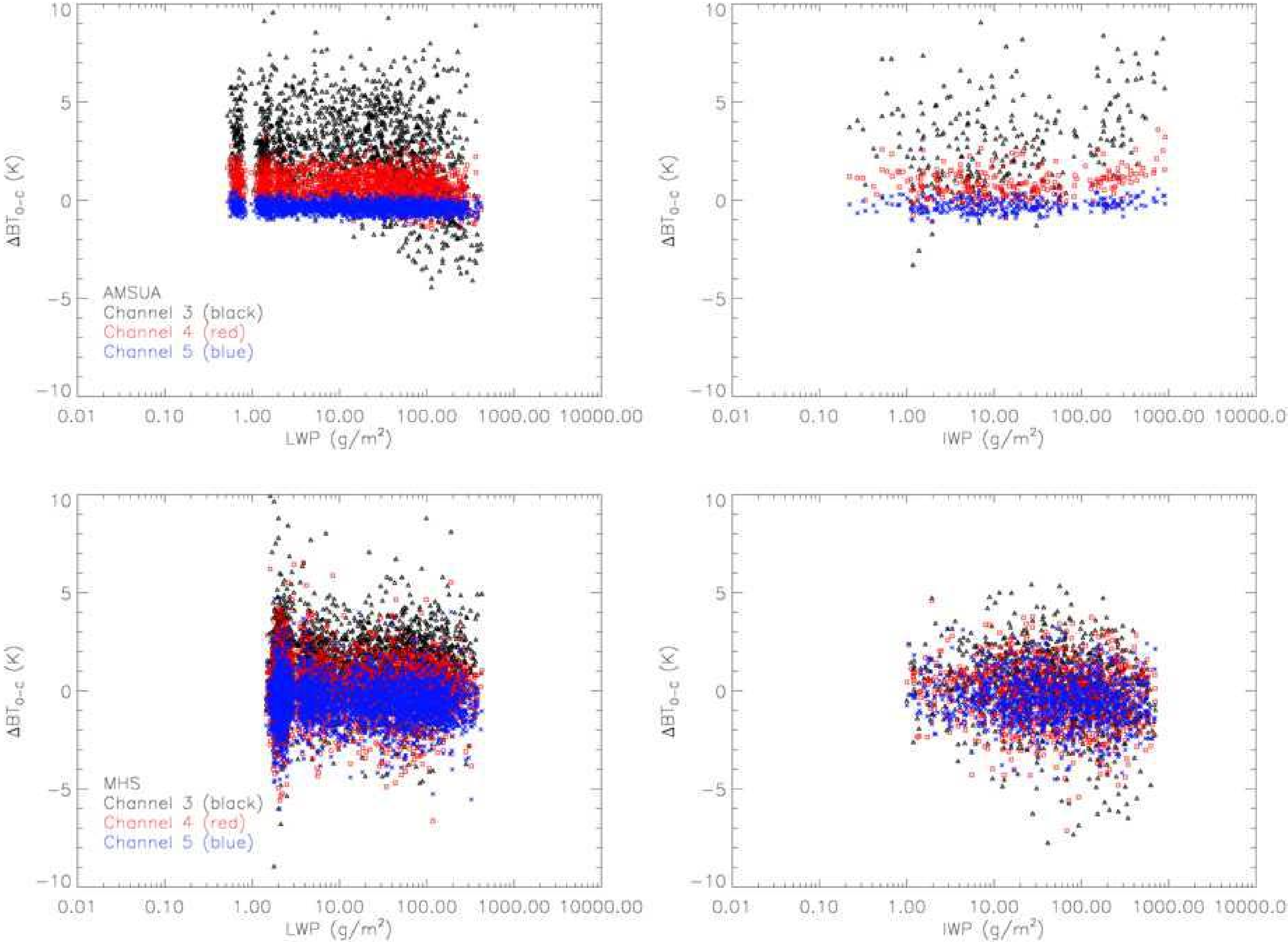
MHS biases over ocean V.S. LWP/IWP retrieved by CloudSat



Biases over ocean V.S. cloud fraction estimated from CloudSat



Biases Correction with LWP as a Predictor



Cloud inhomogeneity effects

AMSUA Channel	Frequency (GHz)	Clear Sky (1335) Matched Bias (K)	Clear Sky (1335) Matched Std (K)	Clear Sky (1335) Averaged Bias (K)	Clear Sky (1335) Averaged Std (K)	Cloudy Sky (3748) Matched Bias (K)	Cloudy Sky (3748) Matched Std (K)	Cloudy Sky (3748) Averaged Bias (K)	Cloudy Sky (3748) Averaged Std (K)
1	23.8	2.139	2.675	2.137	2.667	2.537	3.547	2.467	2.962
2	31.4	0.106	1.993	0.110	1.989	0.345	4.665	0.222	2.889
3	50.3	2.020	1.383	2.025	1.376	2.026	4.057	1.918	2.157
4	52.8	0.466	0.415	0.467	0.415	0.609	0.925	0.586	0.580
5	53.596±0.115	-0.407	0.248	-0.408	0.247	-0.326	0.293	-0.329	0.270
6	54.4	-1.368	0.205	-1.369	0.205	-1.304	0.251	-1.304	0.248
7	54.94	-2.169	0.338	-2.169	0.339	-2.059	0.408	-2.060	0.408
8	55.5	-1.124	0.394	-1.124	0.395	-1.012	0.485	-1.012	0.484
9	57.29	-0.823	0.478	-0.822	0.479	-0.780	0.495	-0.780	0.494
15	89.0	1.455	2.733	1.463	2.697	1.562	7.950	1.350	4.010

MHS Channel	Frequency (GHz)	Clear Sky (6924) Matched Bias (K)	Clear Sky (6924) Matched Std (K)	Clear Sky (6924) Averaged Bias (K)	Clear Sky (6924) Averaged Std (K)	Cloudy Sky (6179) Matched Bias (K)	Cloudy Sky (6179) Matched Std (K)	Cloudy Sky (6179) Averaged Bias (K)	Cloudy Sky (6179) Averaged Std (K)
1	89.0	1.818	2.995	1.818	2.995	1.383	6.047	1.420	4.029
2	157.0	0.869	2.100	0.866	2.098	0.786	2.975	0.702	2.250
3	183.311 ± 1.0	1.052	1.590	1.052	1.592	0.675	1.781	0.675	1.780
4	183.311 ± 3.0	0.070	1.247	0.070	1.248	-0.187	1.387	-0.185	1.385
5	190.311	-0.392	1.052	-0.393	1.053	-0.547	1.113	-0.542	1.098

Summary

- The coincidental/collocated satellite data set between CloudSat and NOAA 18 AMSUA, MHS, and AVHRR have been established.
- The comparisons between observations and simulations by using the collocated dataset allow for quantification of forward model biases under various cloudy conditions which is a very important step toward uses of cloudy radiances in data assimilation systems.
- Simulated BTs under non-precipitation, cloudy conditions are averaged in space to account for the cloud inhomogeneity within the sensors' fields of view. The simulated and observed BT fields, BT distributions, and BT difference distributions show good agreement for all microwave channels. Simulations under clear skies in general have low biases and standard deviation errors, and these errors are only marginally increased under cloudy conditions for microwave channels.
- For AVHRR channel 4 and channel 5, the biases and standard deviation errors are low and very accurate for clear and water cloud conditions. However, there are larger standard deviation errors under cirrus and mixed-phase cloud conditions for those channels.
- In this study, we have validated the CRTM modules (gaseous absorption model, cloud absorption and scattering model, and surface emissivity models over ocean) that generate optical properties of the atmosphere and surface, in the microwave and thermal infrared spectral region.

Future Work

- Continue the work on CRTM validations under cloudy environments, especially for precipitation weather conditions.
- Improve the infrared radiations simulations by using CloudSat/CALIPSO data for cirrus cloud.
- Validate the aersol absorption and scattering in CRTM model by using CALIPSO data.