Global and Regional Ice Cloud Properties Derived from CloudSat/CALIPSO 2C-ice, CERES MODIS, GOES and NEXRAD

Xiquan Dong, Baike Xi, Jingjing Tian, and Ryan Stanfield

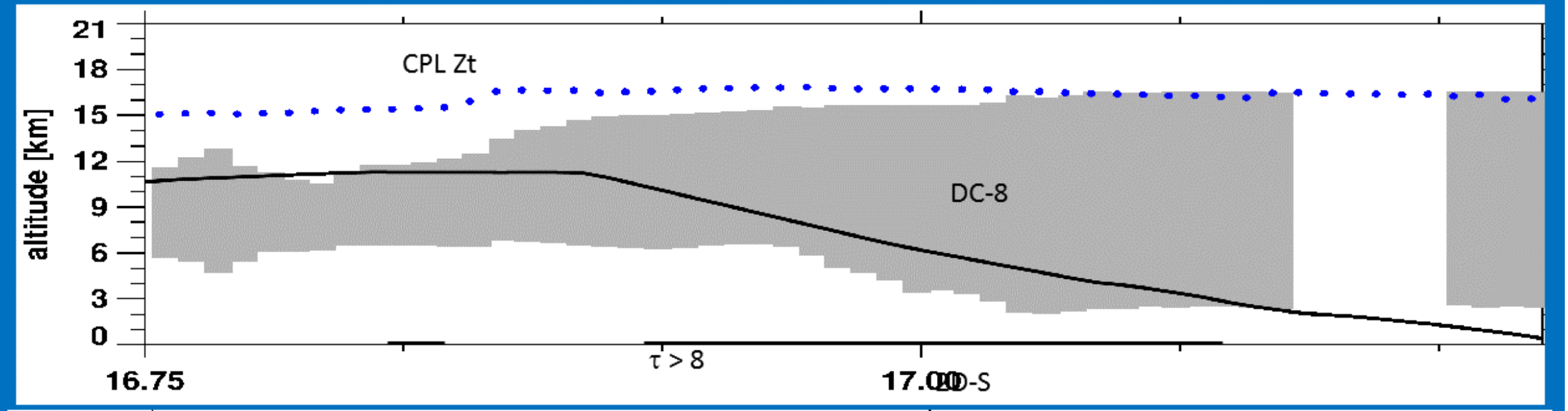
University of Arizona, Tucson

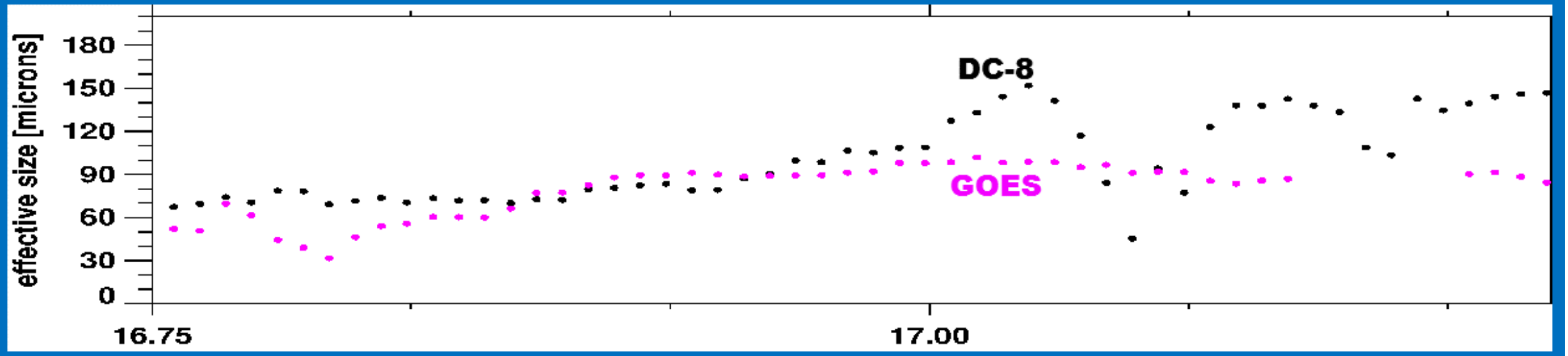
William L. Smith, Jr., Patrick Minnis, Sunny Sun-Mack and Mandy Khaiyer

NASA Langley Research Center, Hampton

Particle Size & Height Comparisons

13 September, Coordinated DC-8 & ER-2





What have been done since last CERES STM?

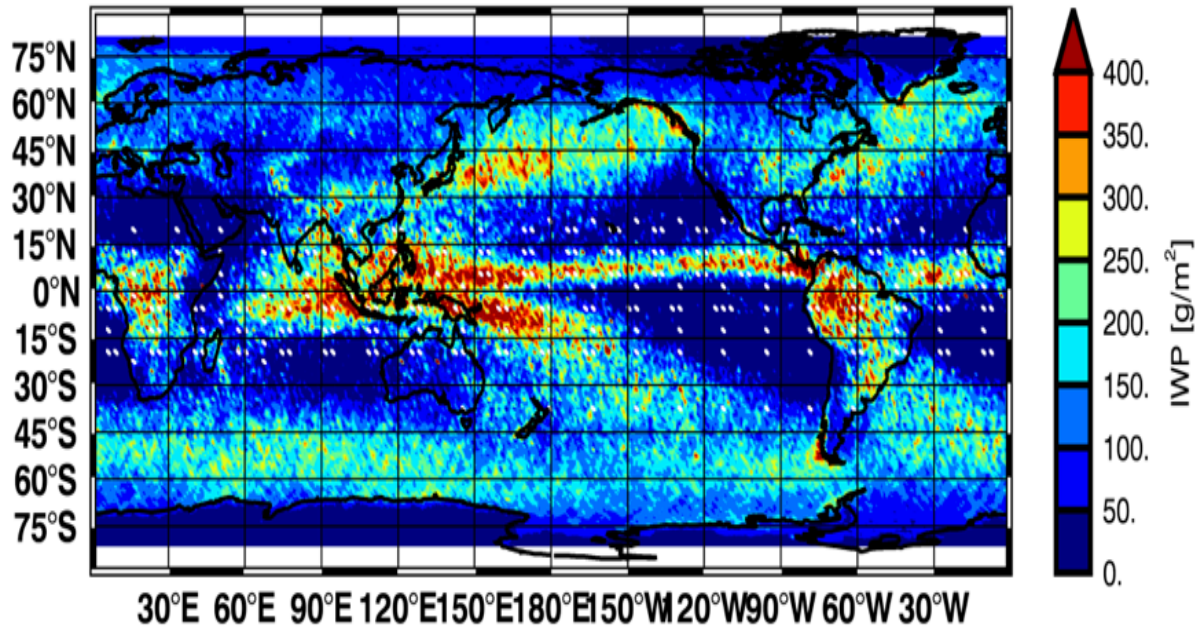
- Wu, P., **X. Dong**, B. Xi, Y. Liu, M. Thieman, and P. Minnis, 2017: Effects of environment forcing on marine boundary layer cloud-drizzle processes. *JGR*, 122, doi:10.1002/2016JD026326

- Tian, J., **X. Dong**, B. Xi, P. Minnis, W.L. Smith Jr., S. Sun-Mack, and M. Thieman, 2017: Comparisons of ice water path in Deep Convective Systems among CERES-MODIS, GOES, and Radar Retrievals. In preparation for *JGR* (finished the first draft).

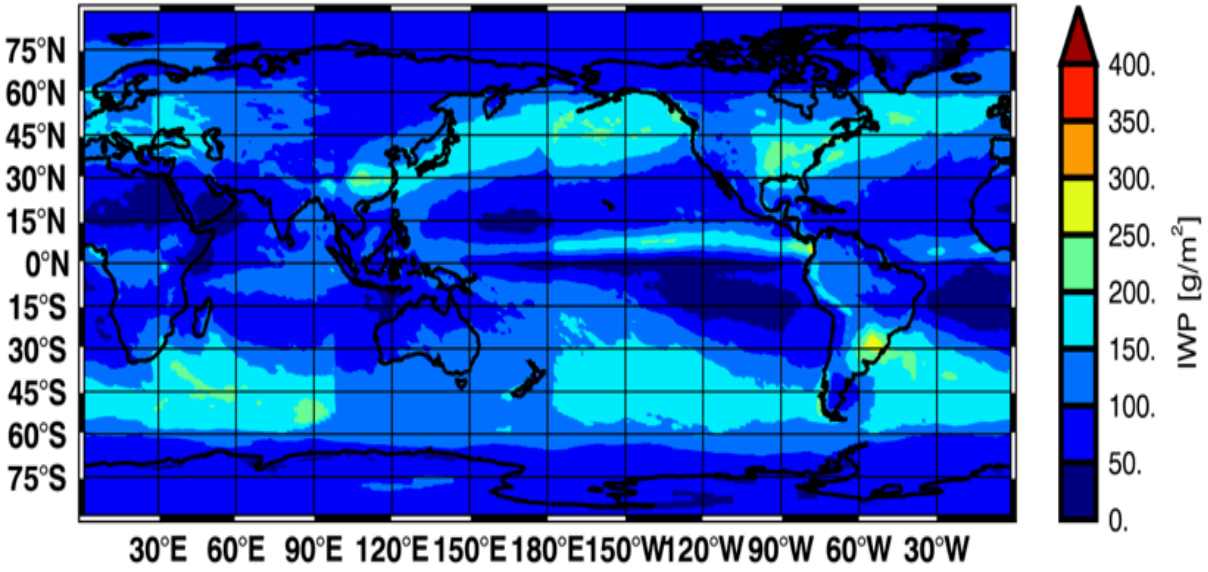
- McHardy, T., **X. Dong**, B. Xi, P. Minnis and M. Thieman, 2017: Comparison of Daytime low-level Cloud Properties derived from GOES and ARM SGP Measurements. In preparation for *JGR* (finished the first draft).

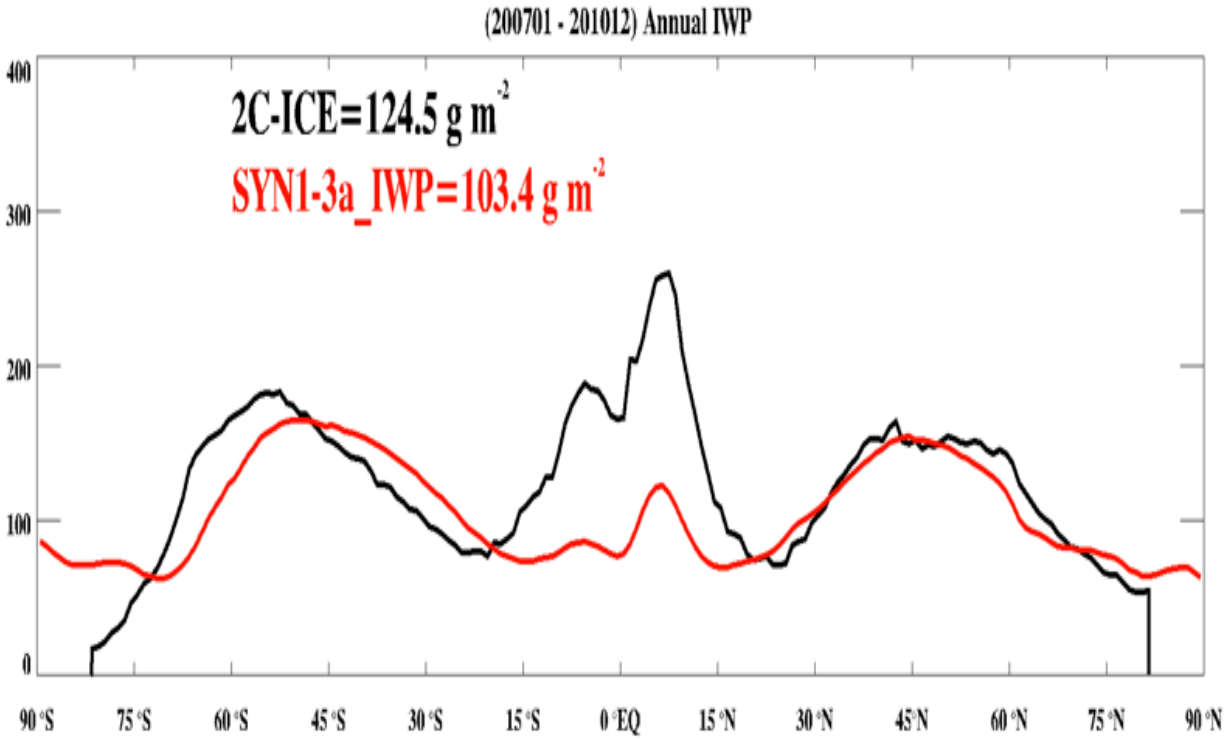
IWP Comparisons between 2C-ICE and SYN1 (2007-2010)

2C-ICE (200701 - 201012) Annual IWP [2C-ICE]



SYN1 (200701 - 201012) Annual IWP [SYN1]

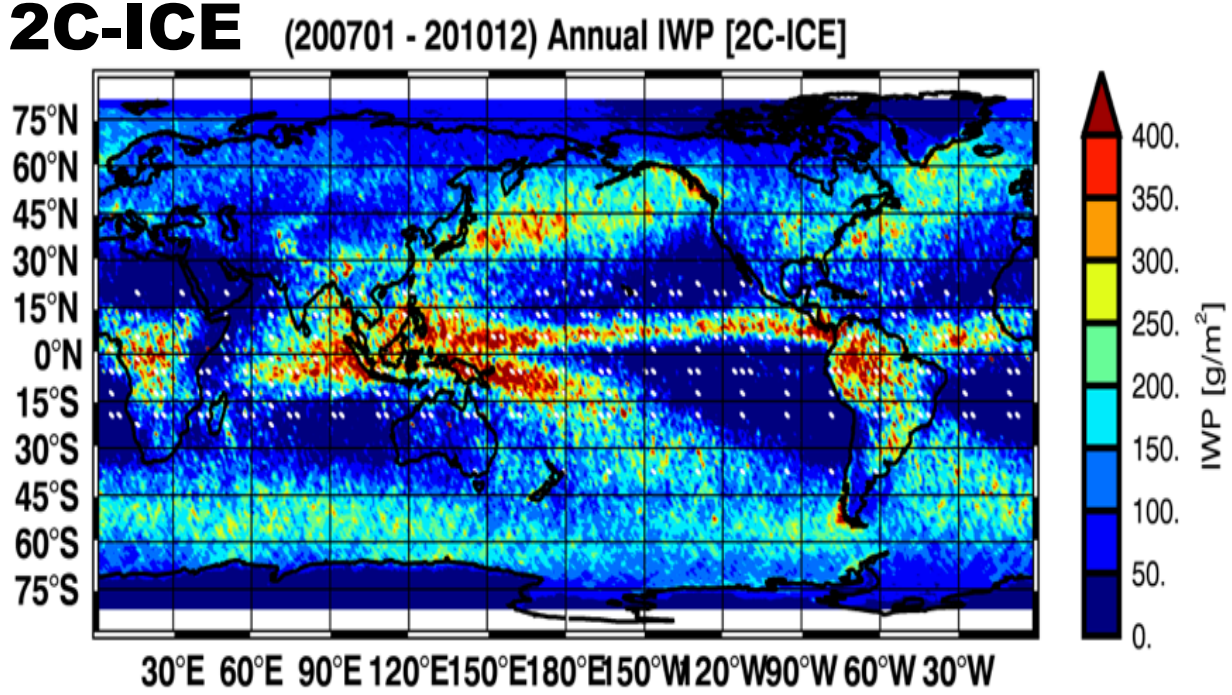




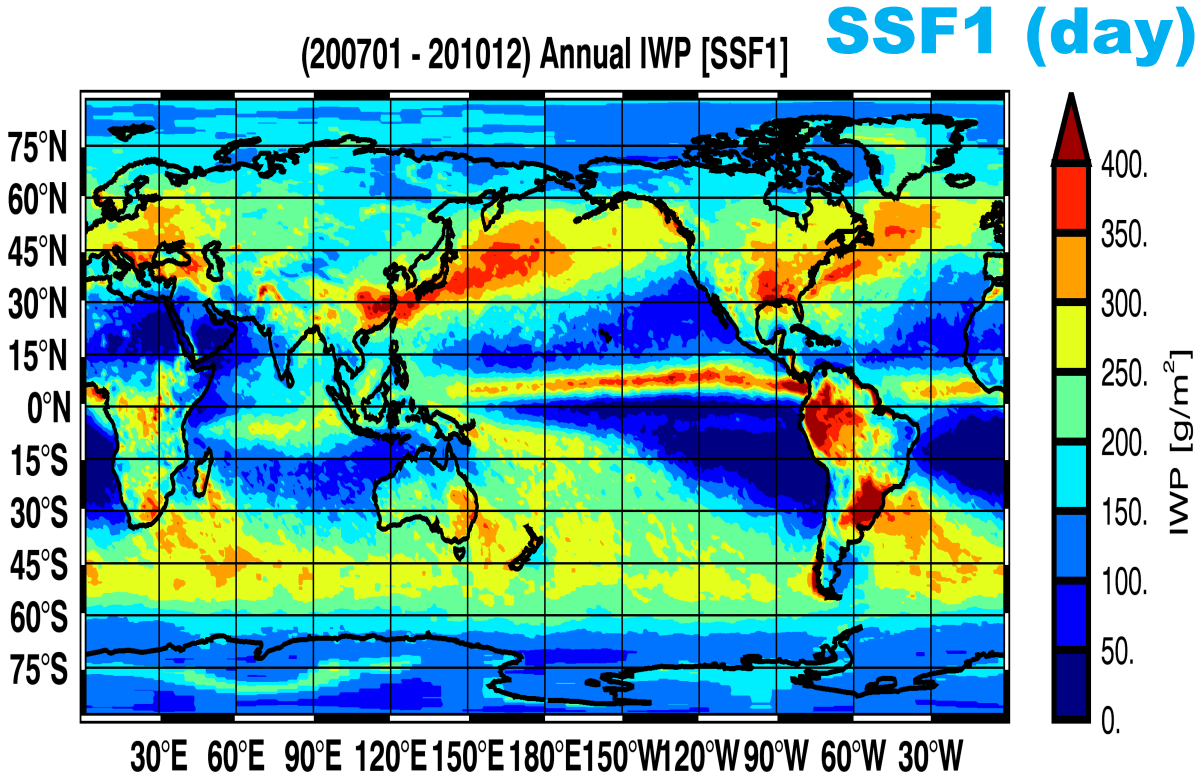
- **More consistent in Mid-latitudes.**
- **Large difference in Tropics (2C-ICE > SYN1).**
- **Night SYN1 IWPs have some limitations for larger IWPs.**
- **SYN1 also includes GOES retrievals**

IWP Comparisons between 2C-ICE and SSF1 (2007-2010)

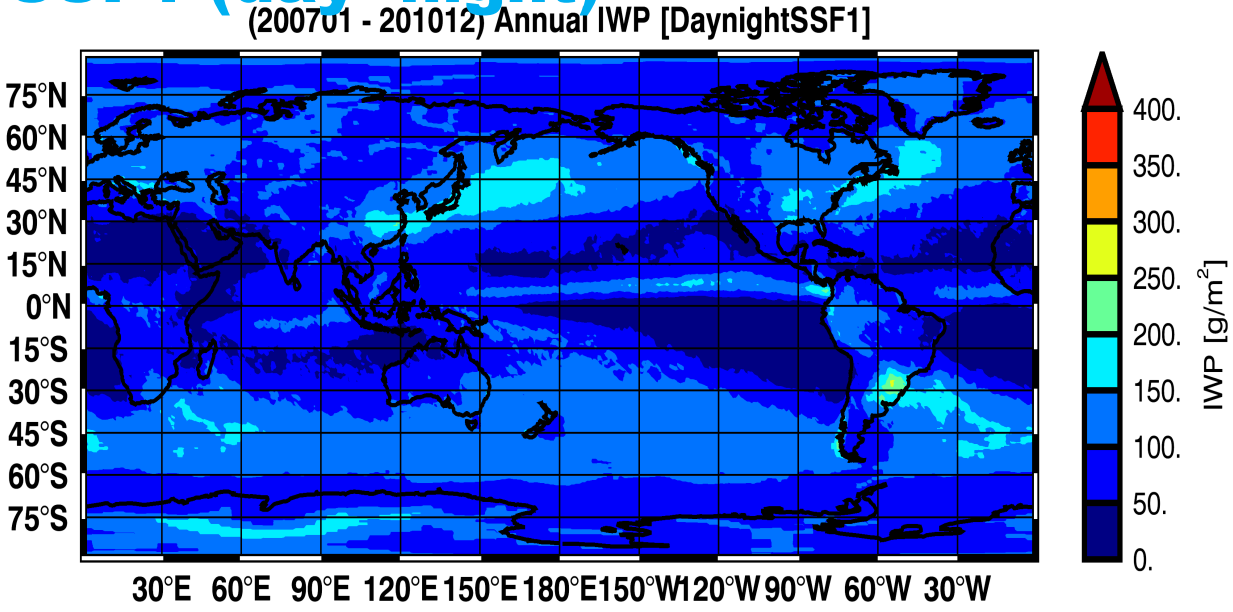
2C-ICE



SSF1 (day)

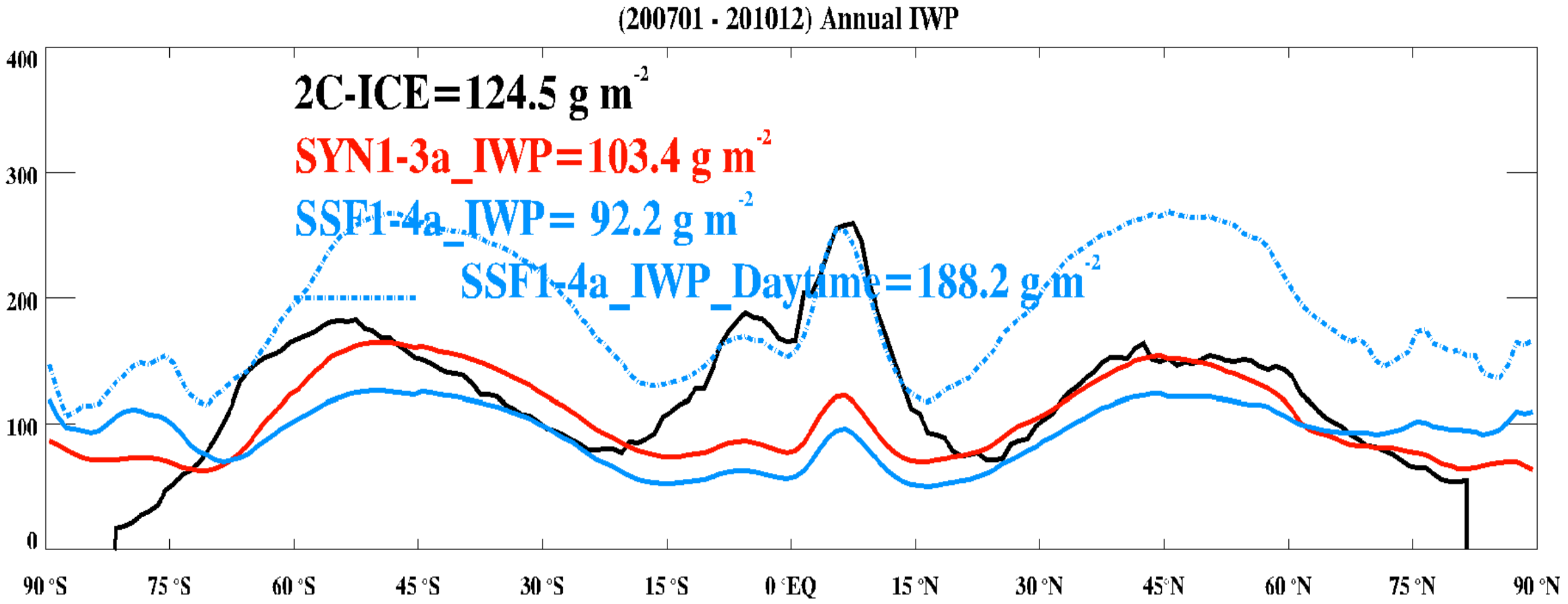


SSF1 (day+night)



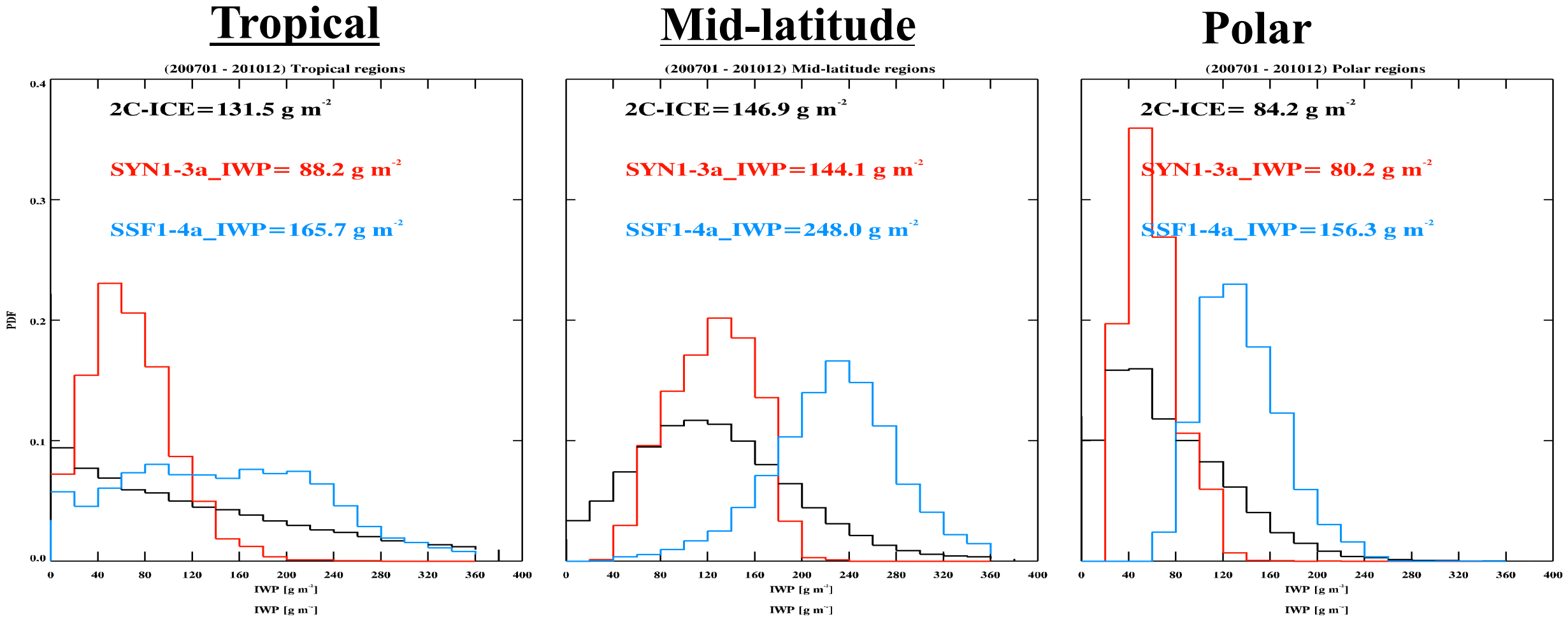
- **SSF1 (day+night) IWPs< 2C-ICE.**
- **SSF1 (day) IWPs agree with 2C-ICE in tropics but much larger at Mid-lat and Polar regions.**

IWPs from 2C-ICE, SSF (day and both) and SYN1 (2007-2010)



- **SSF1 (day+night) IWPs are similar to SYN1, but lower than SYN1 and 2C-ICE because of NO GOES retrievals (GOES IWPs > SSF IWPs)**
- **SSF (day only) IWPs agree with 2C-ICE in Tropics but much more in mid-lat and Polar regions.**

Regional PDFs of IWPs from 2C-ice, SYN1 and SSF1



- **Mean differences at Mid-lat and Polar regions are less than 5%.**
- **SYN1 and SSF1 IWPs have much narrower distributions than 2C-ICE, especially over tropical regions, did not retrieve large IWPs.**
- **Daytime SSF1 IWPs are much larger than 2C-ICE**

Possible reasons for IWP differences between 2C-ICE and SYN1/SSF1

2C-ICE

(1) Retrieving IWCs from T < 0 ^{o}C➔ Supercooled LWC existed. So 2C-ICE IWP may represent some LWC➔ Explaining 2C-ICE > SYN1/SSF1 IWPs.

(2) Uncertainties of 2C-ICE retrieved IWPs (~30%).

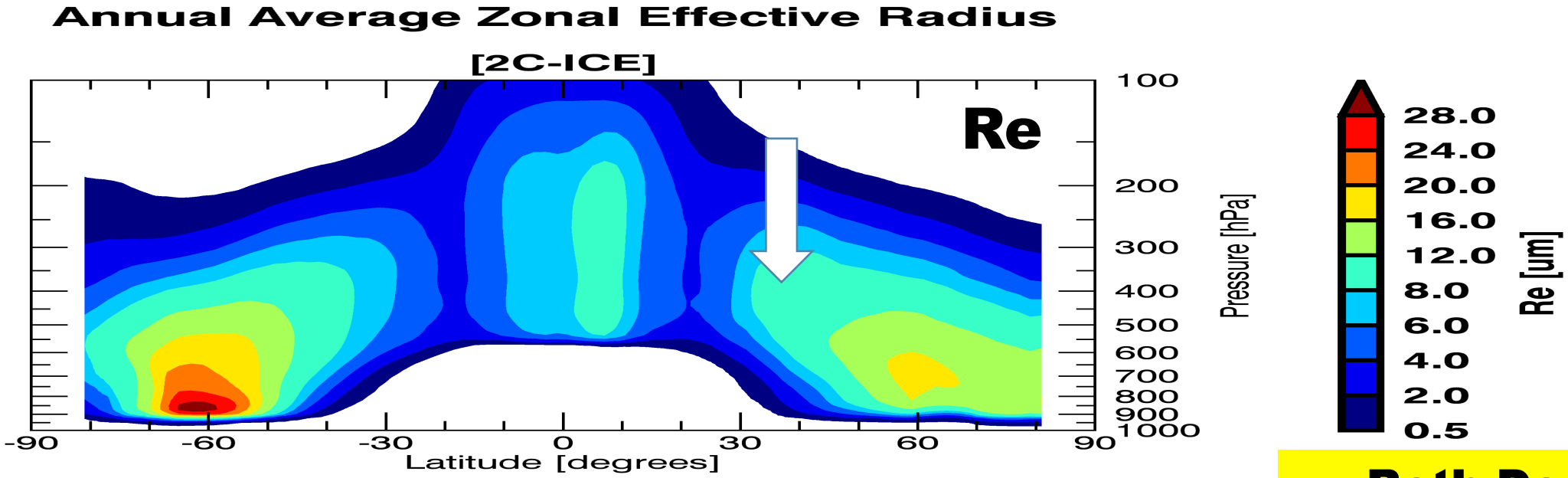
(3) Limited samples ➔ can not detect the diurnal cycle.

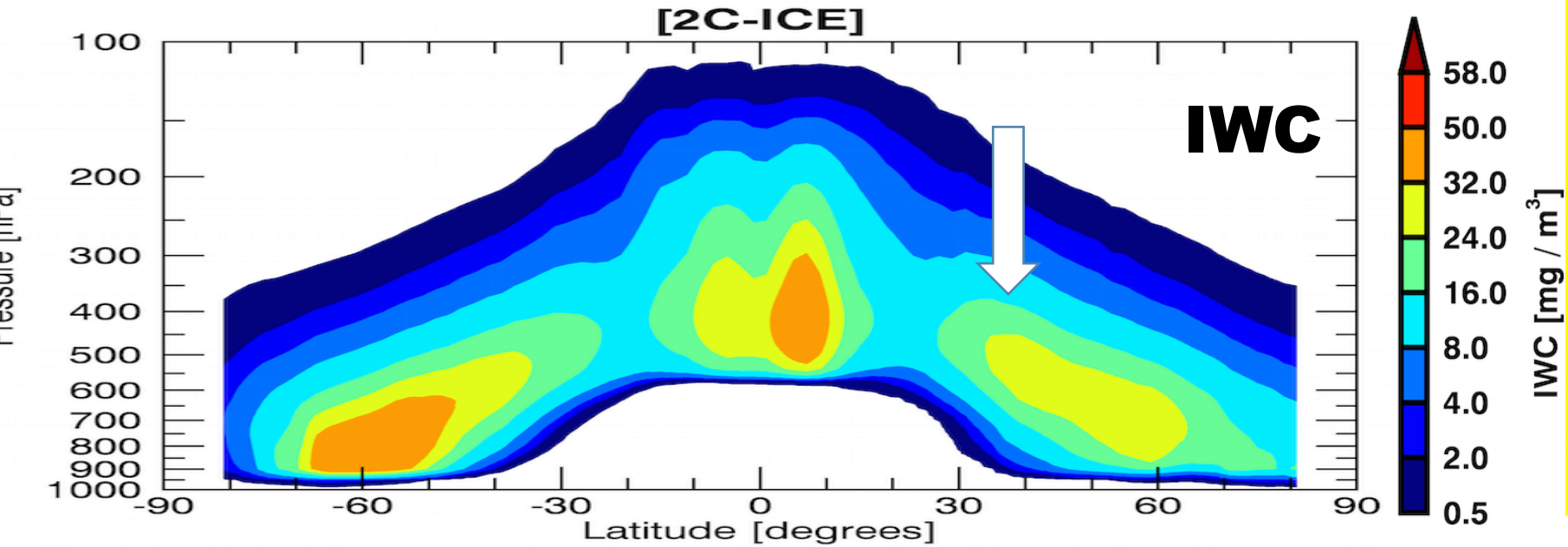
SYN1/SSF1

(1) Cloud optical depth (day) represents a full column, including both ice and liquid layers of a DCS➔ possible TWP, explaining SYN1/SSF1 IWPs > 2C-ICE.

(2) Retrieved De values represent near cloud top (lower than mean values) ➔ explaining SYN1/SSF IWPs < 2C-ICE

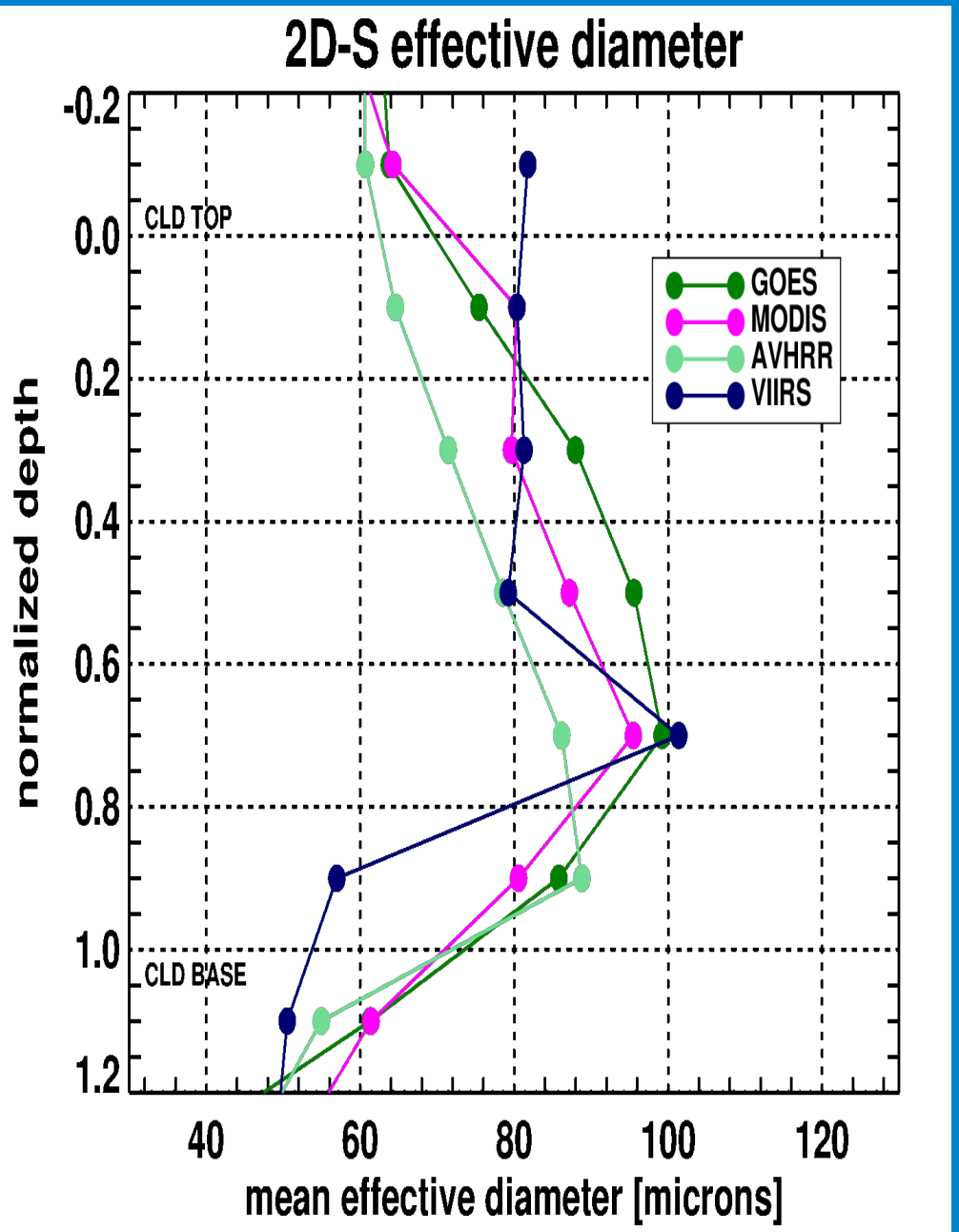
Vertical profiles of Re and IWC from 2C-ICE

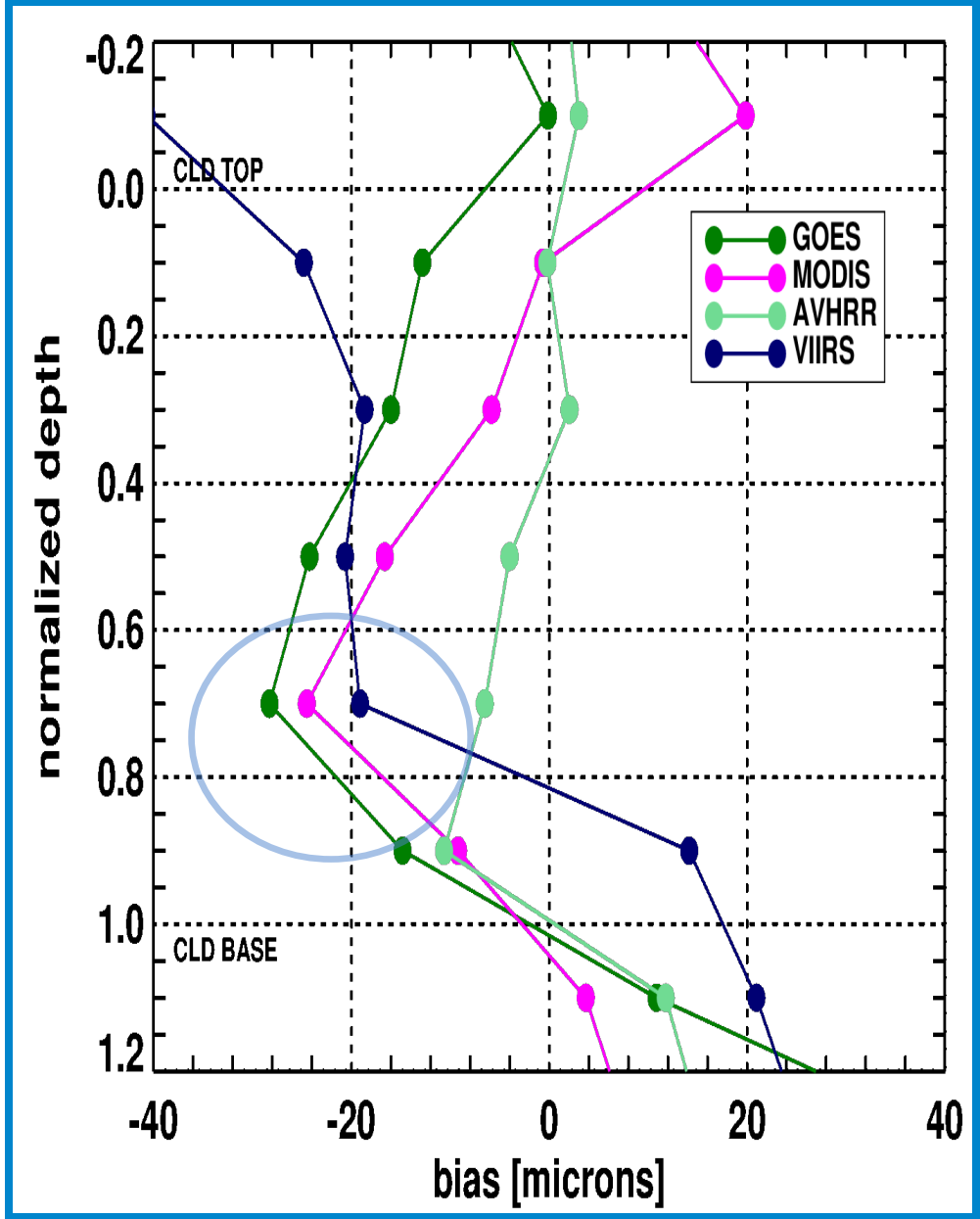




- **Both De and IWC increase from top to bottom.**
- **3.7-µm channel retrieved De values in SYN1/SSF1 represents cloud top → IWP less than grand truth.**

Ice Particle Size Comparisons: All SEAC^{4}RS Days





- **De(DC8) increases with depth from cloud top - decreases to bottom from 0.7 level.**
- **De(sat) smallest bias in top layer of cloud-**
- **De(sat) greatest bias at 0.7 level**
- **De(sat) based on 3.7 µm, low bias expected**

Summary of Part I (Global)

- **Global mean IWP from 2C-ICE (day+night) is 124.5 g m^{-2} during the period 2007-2010.**
- **Global means of IWPs from SYN1 (CM+GOES, Ed3) and SSF1 (CM, Ed4) for both day and night are 103.4 and 92.2 g m^{-2} with less variabilities.**
- **It also indicates that GOES retrieved IWPs are greater than MODIS ones (will also prove it in next section).**
- **SSF1 (day only) retrieved IWPs (188.2 g m^{-2}) are much larger than 2C-ICE (124.5 g m^{-2}), especially over mid-lats because it may represent TWP (IWP+LWP)**

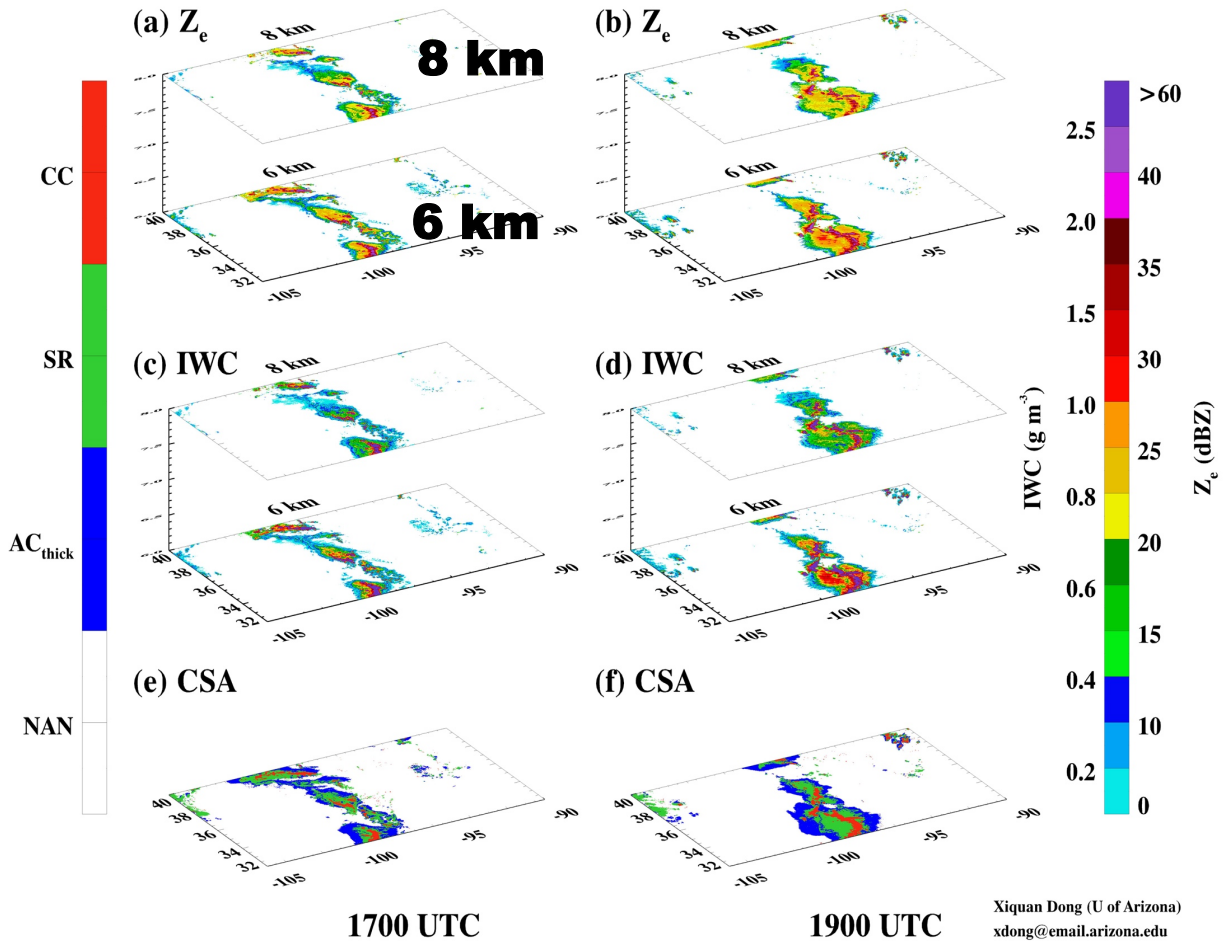
Therefore, we should do detailed IWP comparison for DCS over mid-lats.

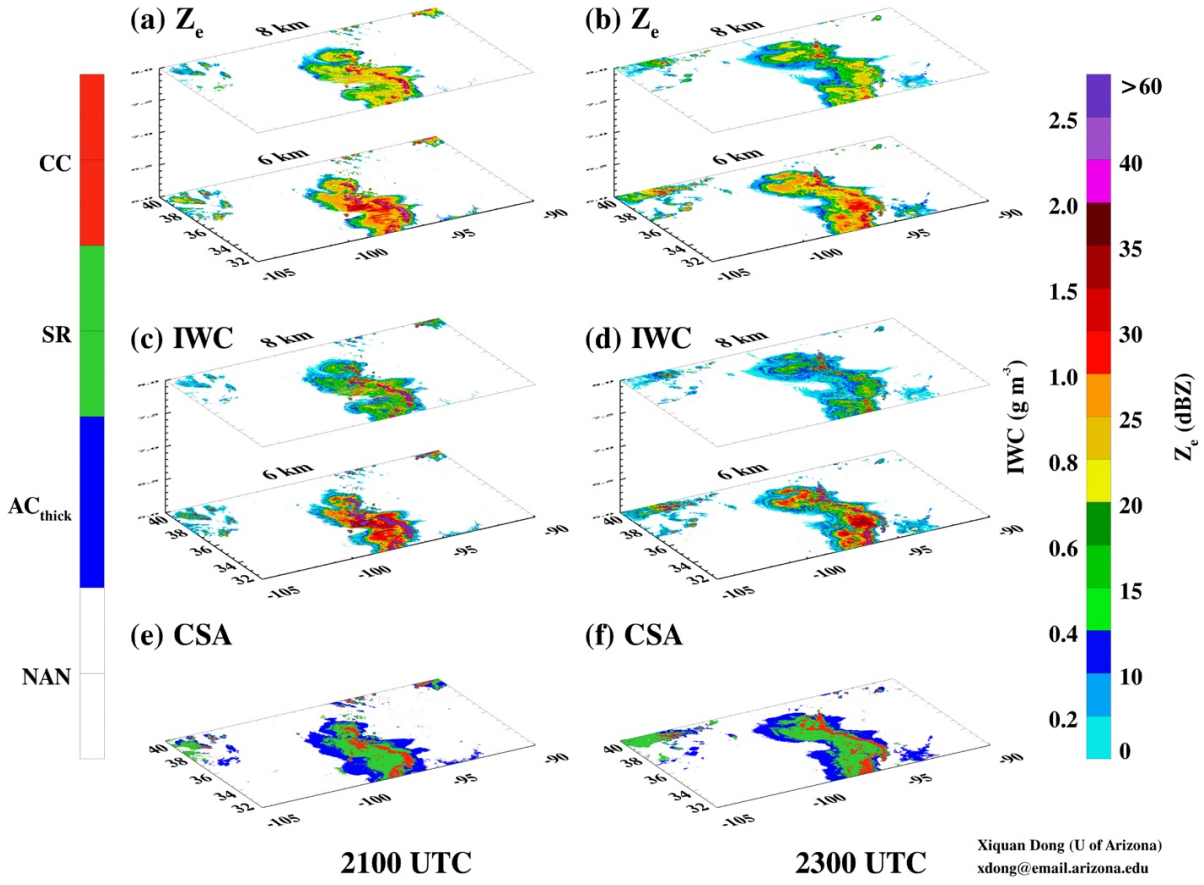
Comparisons of IWPs in *Deep Convective Systems* (DCSs) among Daytime CERES-MODIS, GOES, and Ground-Based Retrievals during MC3E (ARM SGP)

Tian, J., X. Dong, B. Xi, P. Minnis, W.L. Smith Jr., S. Sun-Mack, and M. Thieman, 2017: Comparisons of Ice water path in Deep Convective Systems among CERES-MODIS, GOES, and Radar Retrievals. In preparation for *JGR* (finished the first draft).

Newly retrieved DCS IWPs from NEXRAD reflectivity

and validated by aircraft in situ measurements [*Tian et al.*, 2016].





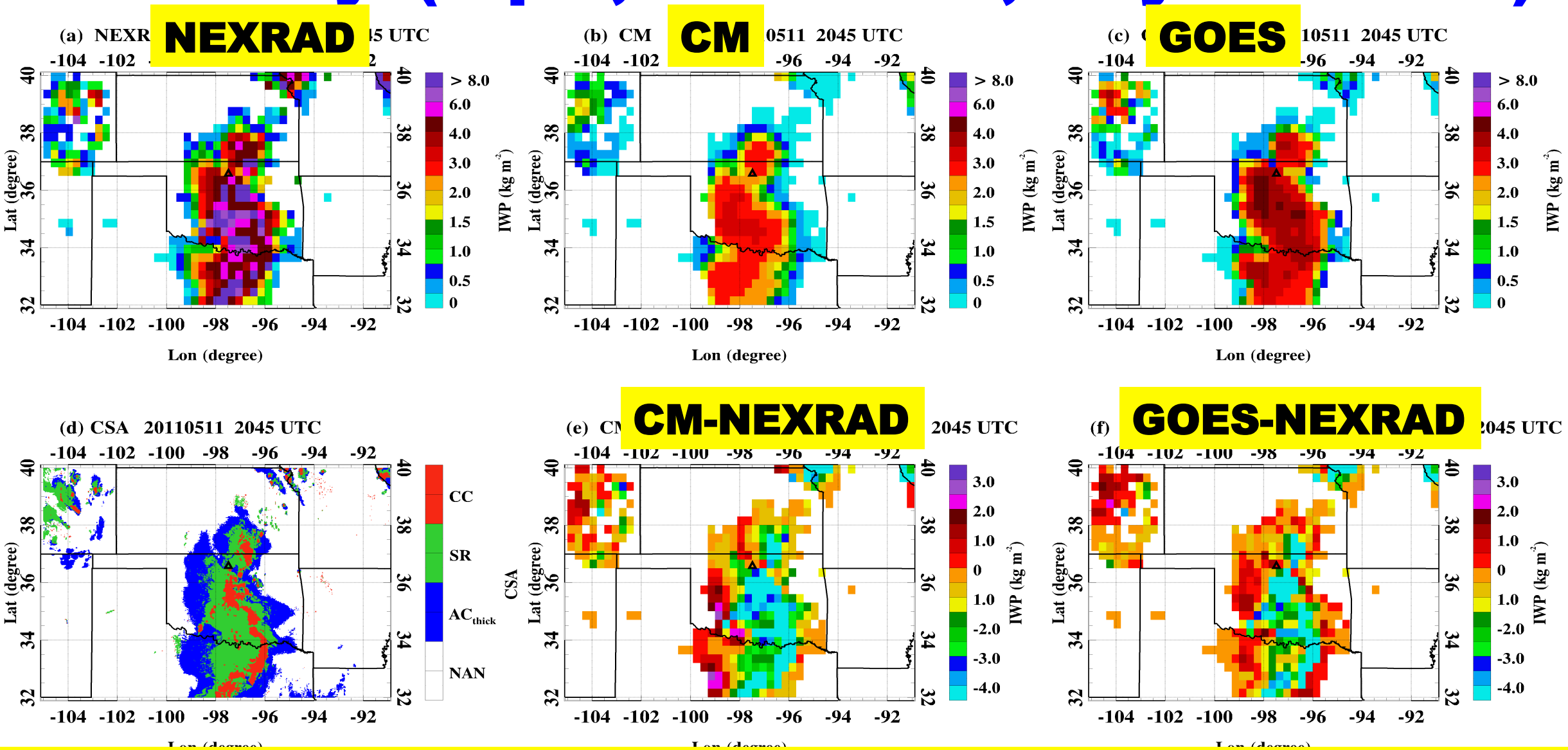
Time

Can provide routinely and continuously ground-based IWP retrievals (~30%)

Both day and night, 3D+time evolution.

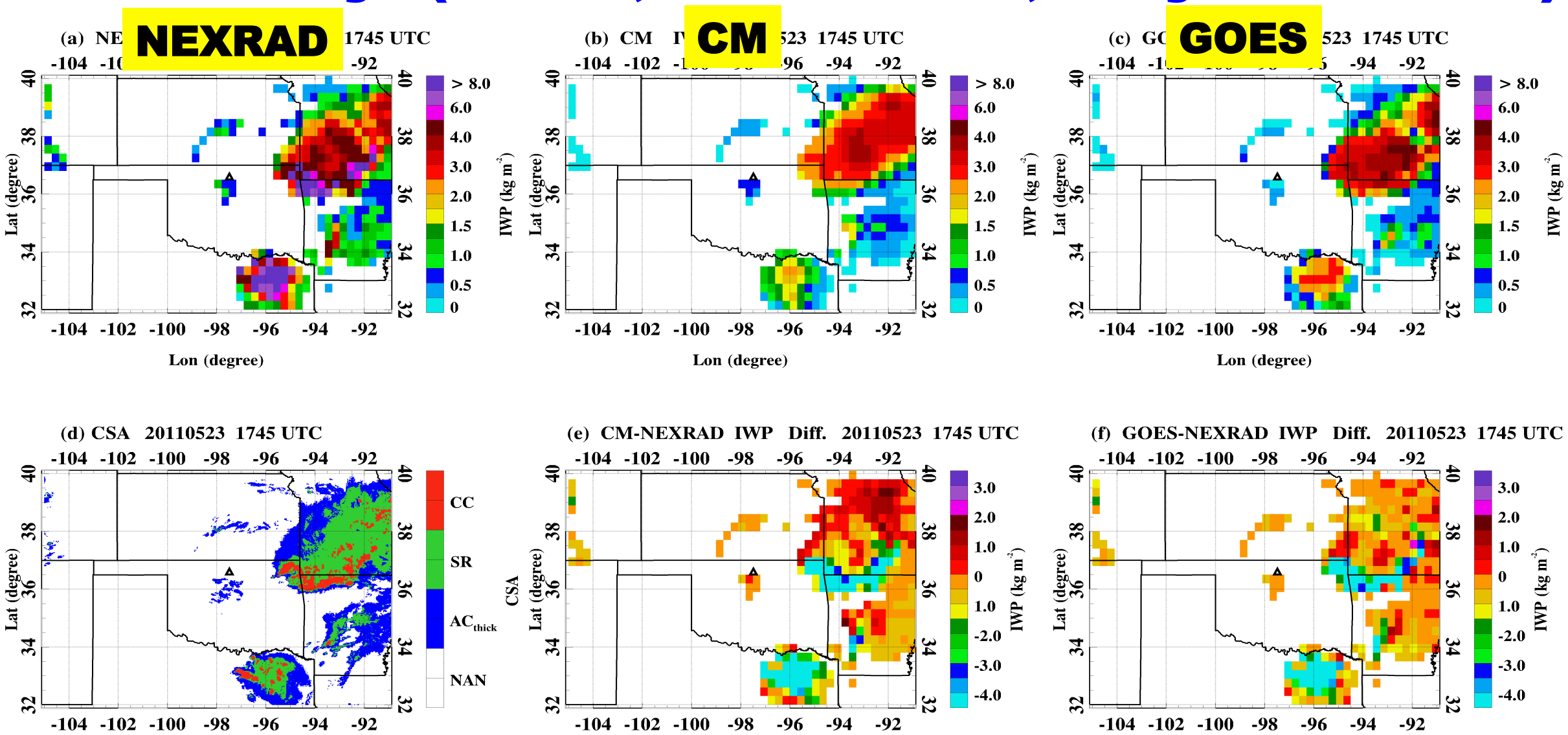
Case 5/11/2011

Case Study (Aqua, 20:45 UTC, May 11th 2011)



Both CM and GOES retrievals are close to NEXRAD retrievals over the AC$_{thick}$ regions of DCSs, but severely underestimate IWPs in SR and CC regions.

Case Study (Terra, 17:45 UTC, May 23th 2011)



The IWP comparison for TERRA is consistent to Aqua because Terra and Aqua use the same MODIS channels to derive cloud properties.

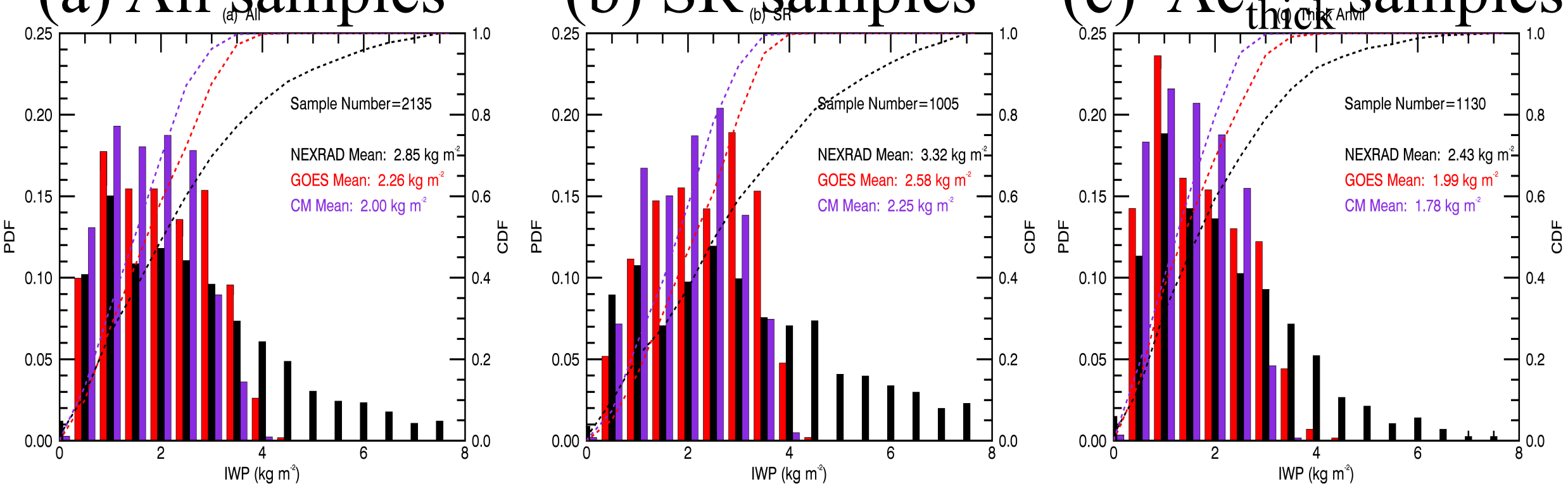
Statistical Results (NEXRAD=2.85 kg m^{-2}, CM and GOES)

Dataset	BIAS (kg m^{-2}) / (%)	σ_N	RMSE (kg m^{-2})	MSE_Corr (kg m^{-2}) / (%)	MSE_STD (kg m^{-2}) / (%)	MSE_BIAS (kg m^{-2}) / (%)
CM_All	-0.84 / -30%	0.48	1.72	1.47 / 50%	0.77 / 26%	0.71 / 24%
GOES_All	-0.58/ -21%	0.57	1.62	1.75 / 67%	0.54 / 20%	0.34 / 13%

- **The normalized standard deviation σ_N is ~0.5, the variation of satellite retrievals may be not large enough.**
- **The correlation term contributes MSE most (50%).**
- **Improving the correspondence of satellite retrievals to NEXRAD retrievals can decrease MSE most.**

Statistical Results (NEXRAD, CM and GOES, 2135 samples)

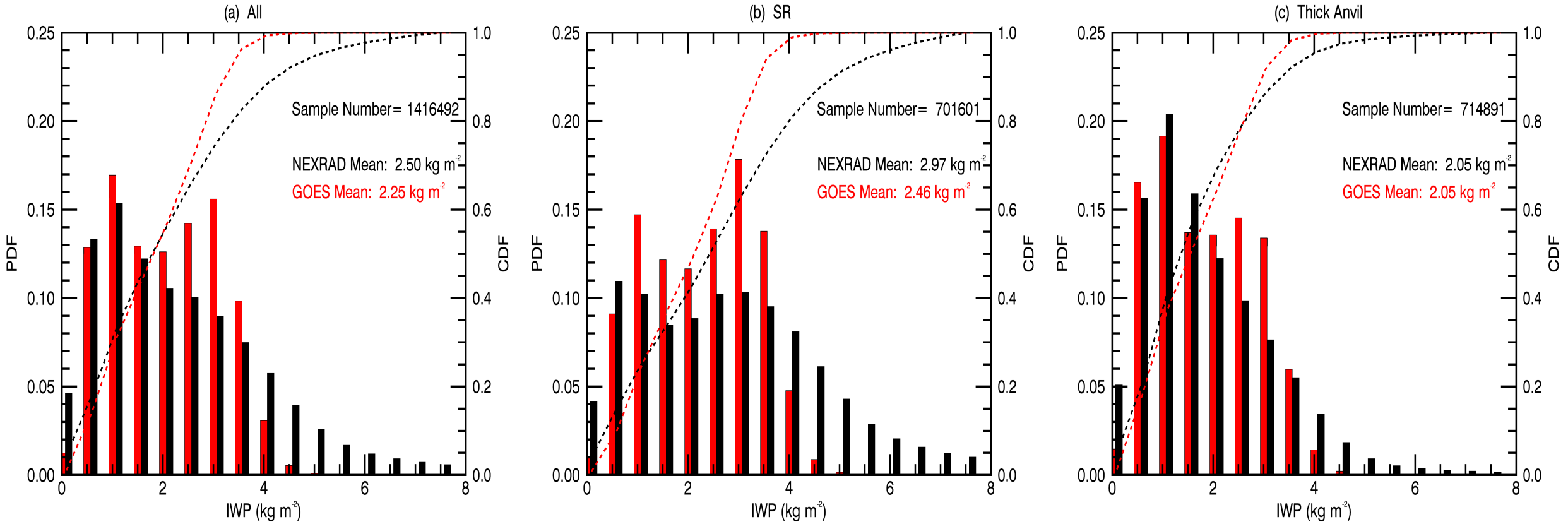
(a) All samples (b) SR samples (c) Ac_{thick} samples



(a) GOES and CM retrieved IWPs are 21% and 30% lower than NEXRAD. There are about 20% IWPs > 4 kg m^{-2} in NEXRAD, but NO GOES and CM IWPs > 4 kg m^{-2}.

(b) and (c): Satellite and NEXRAD CDFs are much closer to each other in AC_{thick} region than those for SR region.

Statistical Results from NEXRAD and GOES (1,416,492 Samples)



Dataset	BIAS (kg m^{-2}) / (%)
GOES_ALL	-0.25 / -10%
GOES_SR	-0.50 / -17%
GOES_AC	-0.00 / -0.12%

With much more samples,

- **GOES IWP ~ NEXRAD in AC_{thick} region**
- **GEOS IWP biase reduced from -21% to -10%**
- **No GOES IWPs> 4 kg m^{-2}**

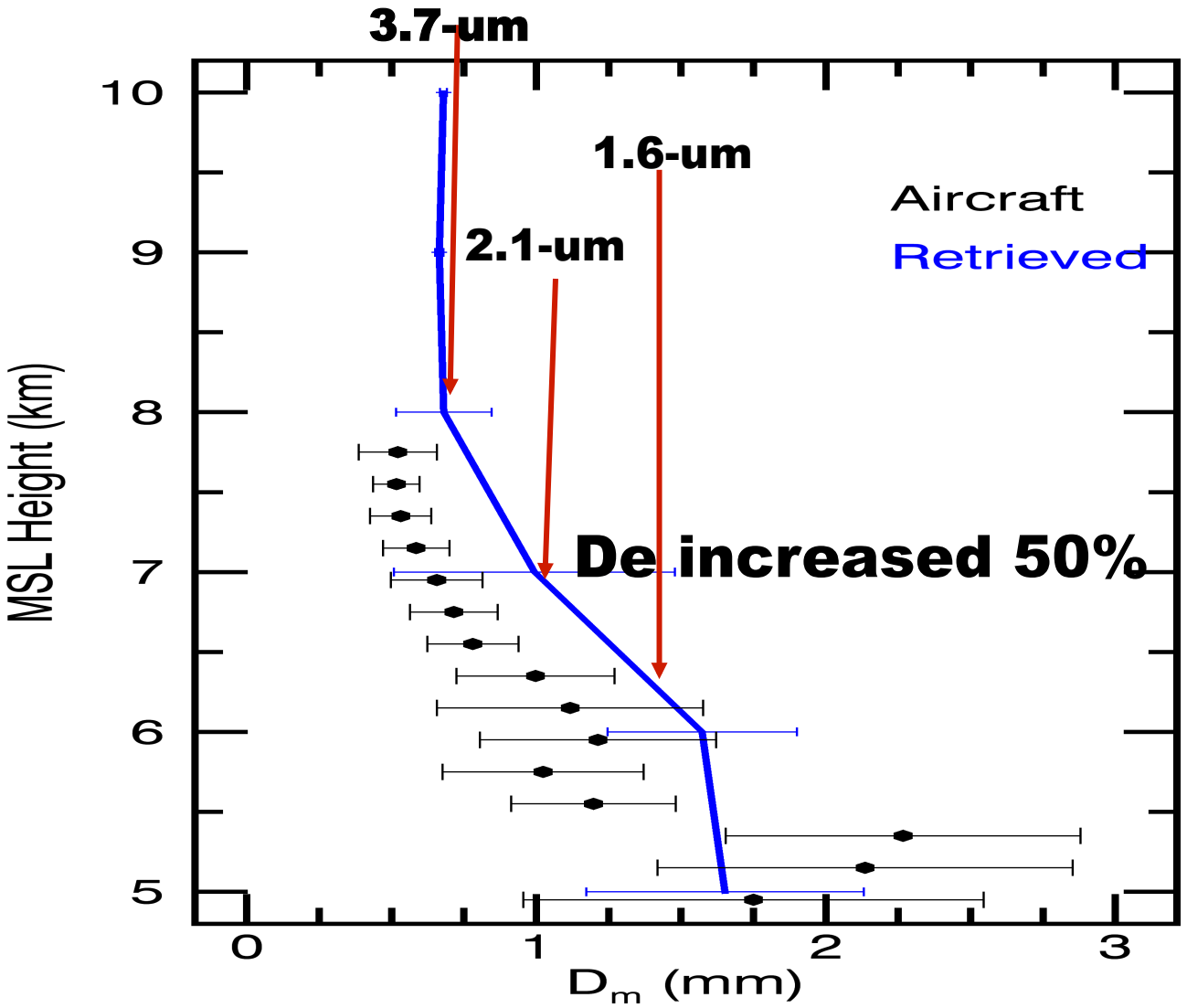
Suggestion for improving GOES and CM retrievals

Satellite

De Profile

With the increase of wavelength, less photons can penetrate deeper to cloud. Particle size retrieved using 3.9 (or 3.7) um channel may only represent the upper levels of optically thick clouds, underestimate particle size.

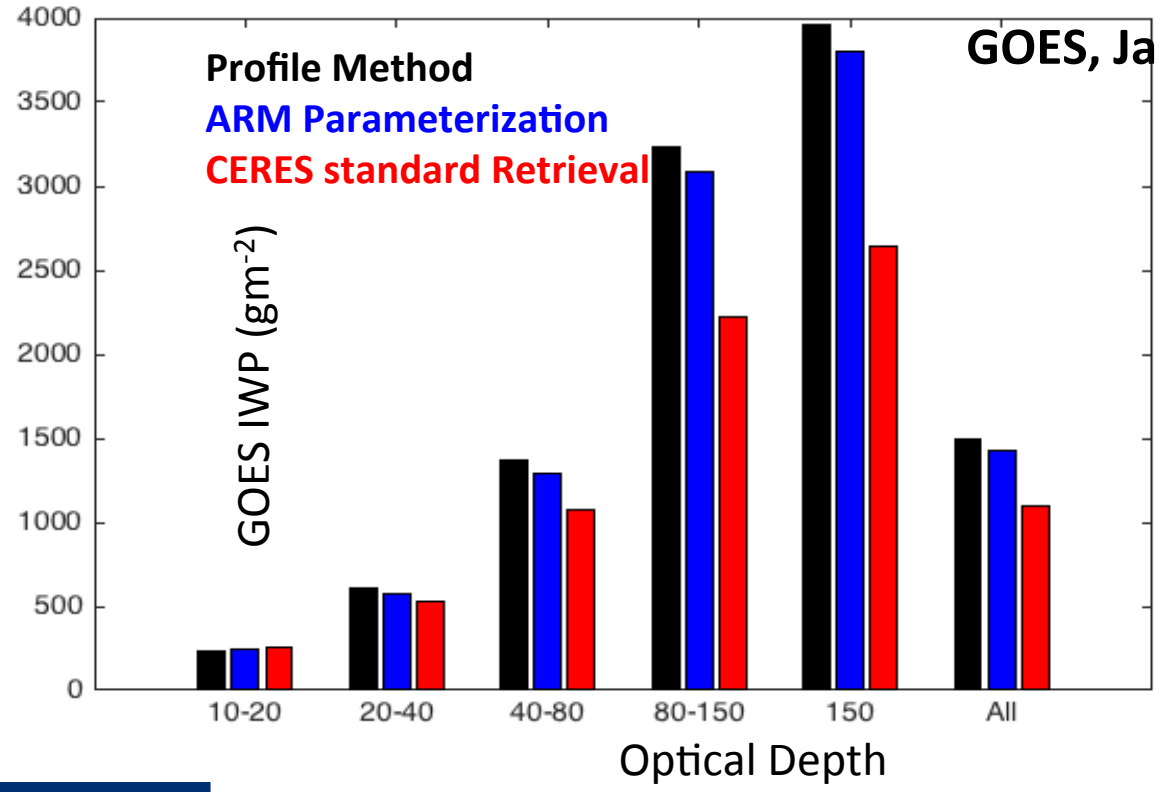
Suggestion: Using 2.1-um channel → increasing IWP with the current COD.



Passive Satellite Profiling Method

- Developed using C3M data
- Profiles constrained with MODIS/GOES COD, Cloud Heights
- Vertical structure information from active sensors. Phase partitioning from cloud model
- Validated with data from Cloudsat, CALIPSO, ARM and Aircraft observations
- Used to Test and Refine passive satellite IWP Parameterizations

Ref: Smith PhD Thesis, CERES STM (2014, 2016)



GOES, Jan-Mar, 2013 (Known icing conditions, Ice Phase tops)

BIAS (%) vs Profile Method

COD BIN	Profile method (IWP)	ARM Param	*Sat-CoRPS (VISST)	N
10-20	234	3%	11%	62515
20-40	604	-5%	-11%	74047
40-80	1368	-5%	-22%	47192
80-150	3228	-4%	-38%	25905
150	3960	-4%	-33%	42893
ALL	1494	-4%	-27%	252552

*SatCORPS (VISST) GOES – analogous to CERES-MODIS

- **Standard IWP method (e.g CERES CWG) underestimates IWP by up to 40%**

Summary of Part II (MC3E)

1) NEXRAD retrieved IWP, on average, is 2.85 kg m^{-2} during MC3E. GOES and CM retrieved IWPs are 21% and 30% lower than NEXRAD. GOES and CM IWPs are closer to NEXRAD IWPs in AC_{thick} region, but much lower in SR region.
2) There are about 20% of IWPs > 4 kg m^{-2} in NEXRAD, but NO GOES and CM IWPs > 4 kg m^{-2}.

Suggestion:

Using 2.1-um channel in CM to retrieve particle size instead of 3.7-um channel to get larger particle sizes for convective clouds (to get large IWPs)