How Clouds Affect The Vertical Structure Of Radiative Heating Rates: A Multi-model Evaluation Using A-train Observations

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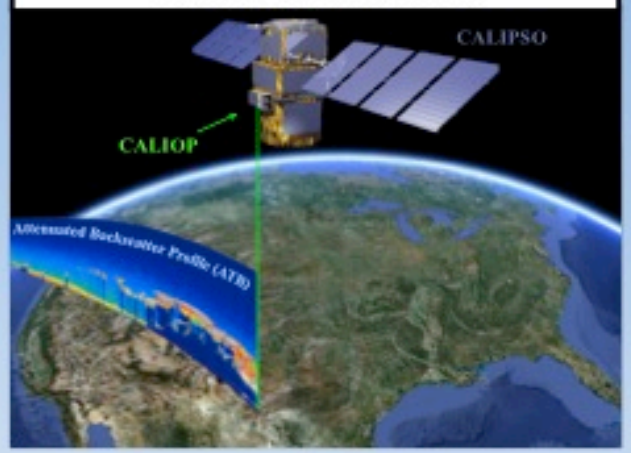
The GCM-Oriented CALIPSO Cloud Product (CALIPSO-GOCCP)

Obs: CALIPSO



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GOCCP Algorithm

(*Cesana and Chepfer*, 2013 JGR)

=

CALIPSO-GOCCP

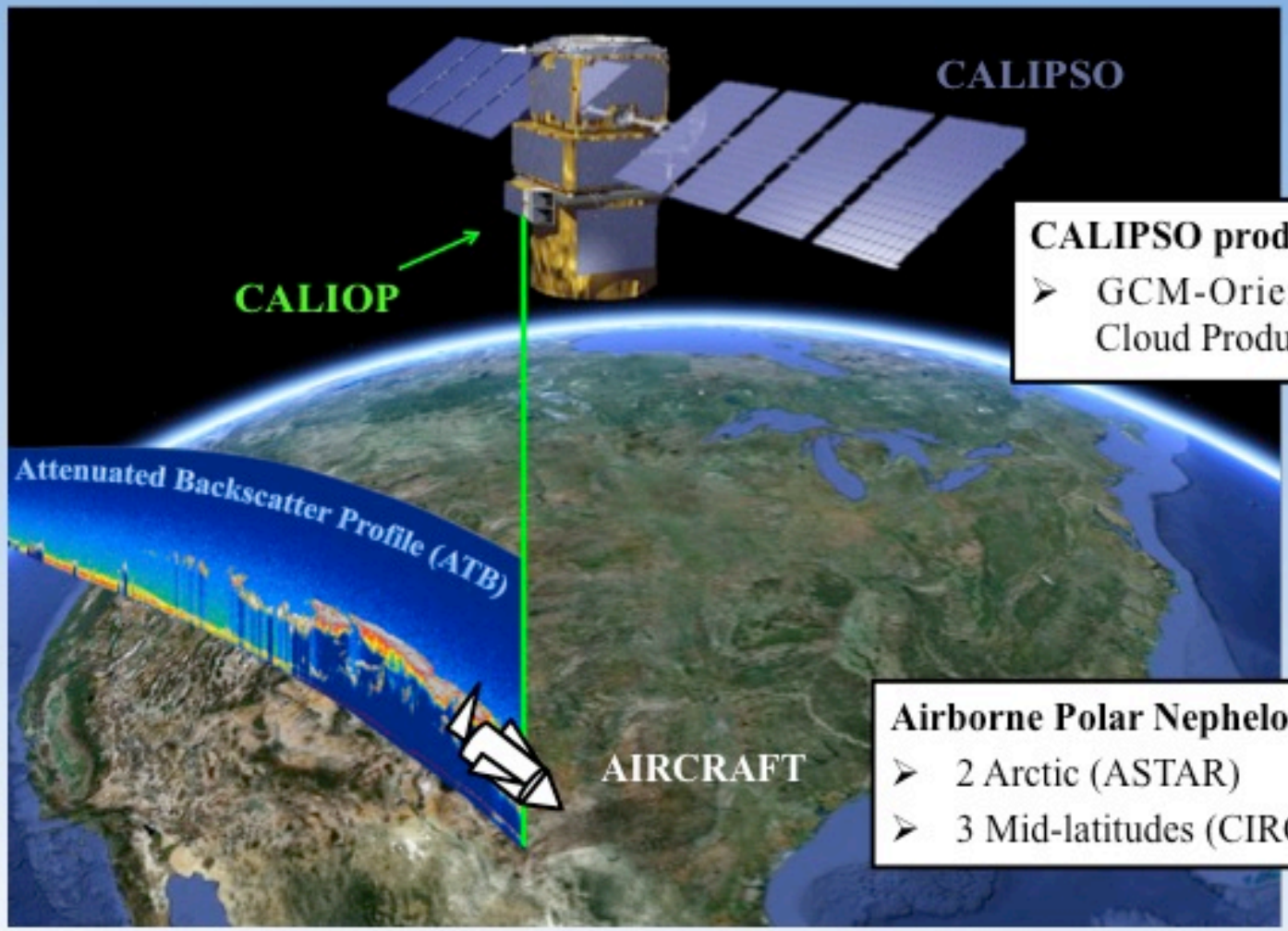
- Thin cirrus and shallow cumulus clouds
- High vertical resolution and multi-layer detections (Δz=30/60m) every 330m
- **Cloud phase independent of temperature**
- Available over continents and reflective surfaces
- More than 7 years of observations (June 2006)
- Colocated with other A-Train sensors

- GOCCP is designed for Model Evaluation
- GOCCP is built from the CALIPSO ATB lidar profiles (level 1)
- The cloud detection is based on Scattering Ratio (SR) profiles each 330meters (SR>5)
- Vertical resolution is 480m

➔GOCCP is designed for model evaluation and uses a vertical resolution and detection thresholds consistent with models

CALIPSO-GOCCP Validation

Using co-located in-situ airborne measurements



CALIPSO product:

- GCM-Oriented CALIPSO Cloud Product

Airborne Polar Nephelometer

- 2 Arctic (ASTAR)
- 3 Mid-latitudes (CIRCLE-2)

Cesana G., H. Chepfer, D. Winker, H. Okamoto et al.: Using In-situ Measurements To Evaluate Three Cloud Phase Products Derived From CALIPSO, *JGR,* in press.

CALIPSO-GOCCP Validation

Using co-located in-situ airborne measurements

Cloud Detection

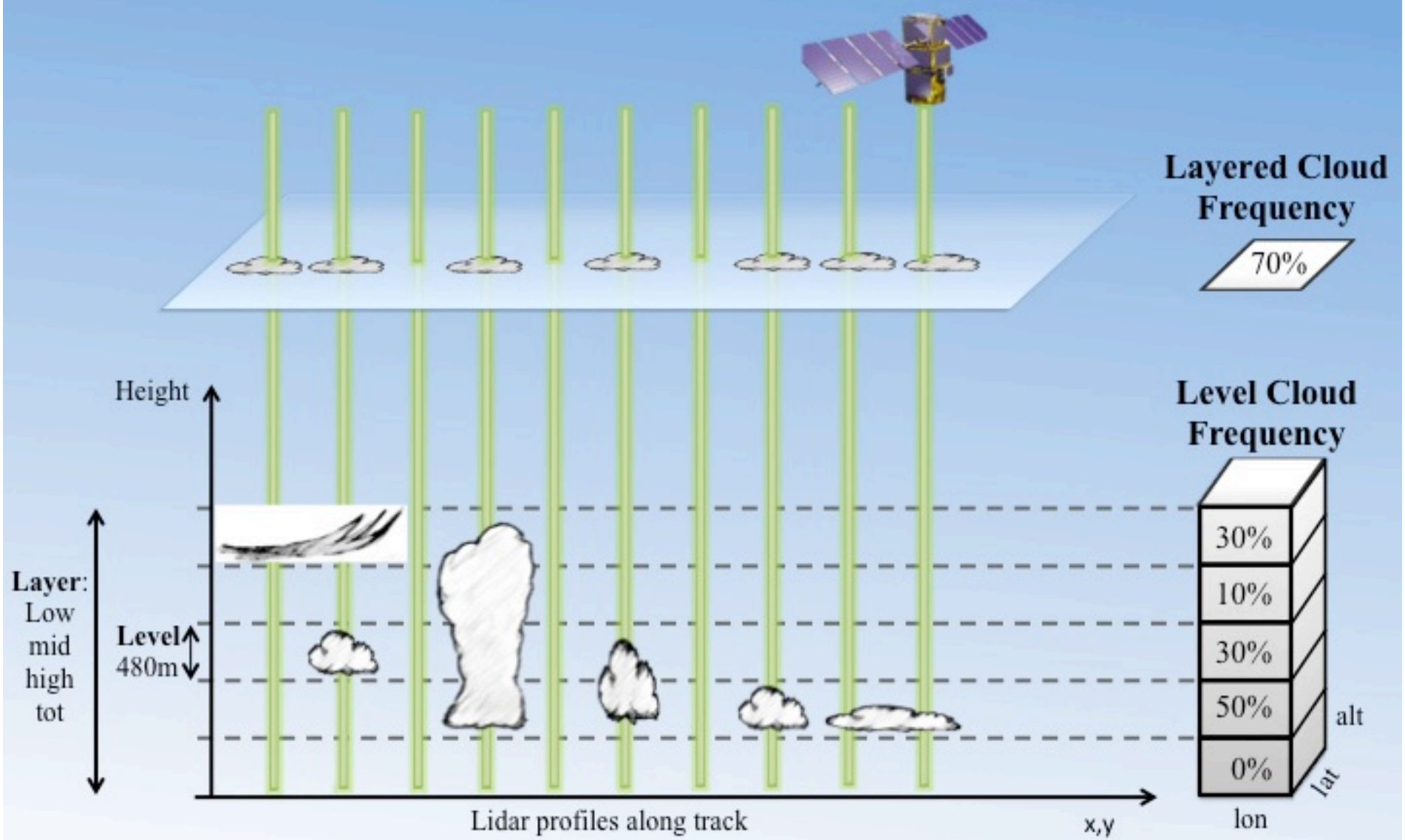
- Mid-Latitude High Clouds from 81% to 96% of agreement with in-situ.
- Arctic BL clouds ~ 70% (Underestimate of low-level clouds because of lidar attenuation).

Cloud Phase Determination

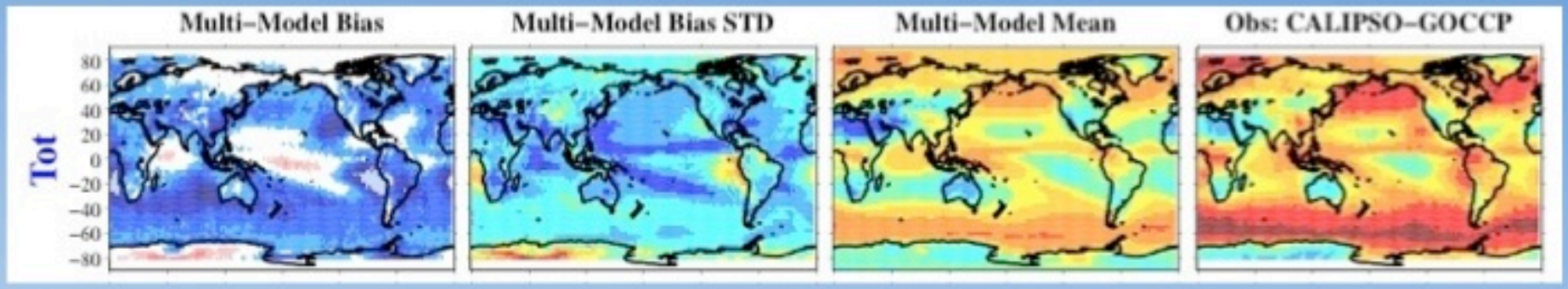
- Mid-Latitude High Clouds > 97%
- Arctic BL clouds ~ 70% (Most of the remaining differences are due to lidar attenuation and the difference in vertical resolution between the aircraft and satellite).

Cesana G., H. Chepfer, D. Winker, H. Okamoto et al.: Using In-situ Measurements To Evaluate Three Cloud Phase Products Derived From CALIPSO, *JGR,* in press.

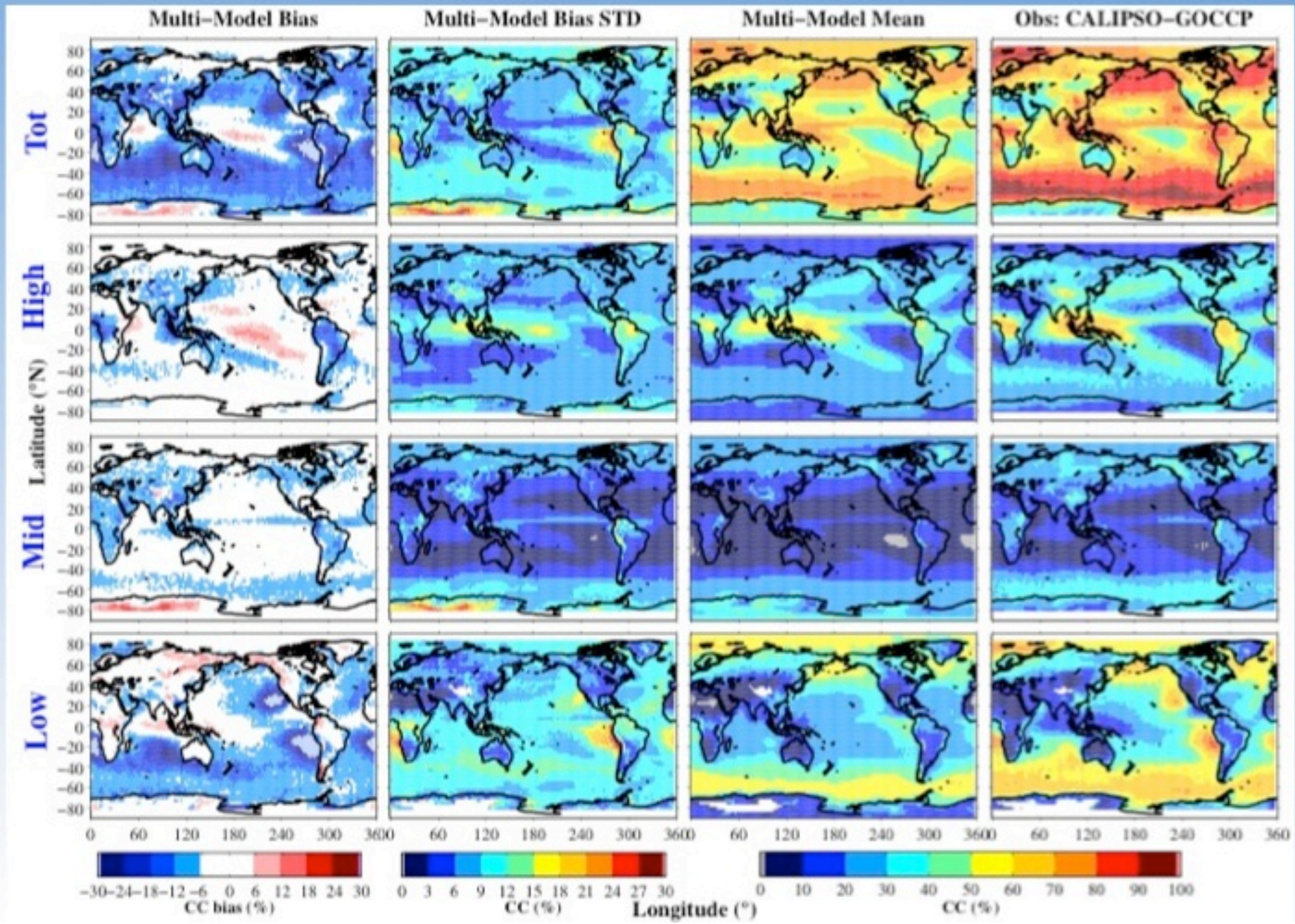
Definition of the Cloud Frequency



1. Layered Cloud Fraction



1. Layered Cloud Fraction



2. Layered Cloud Fraction Scores

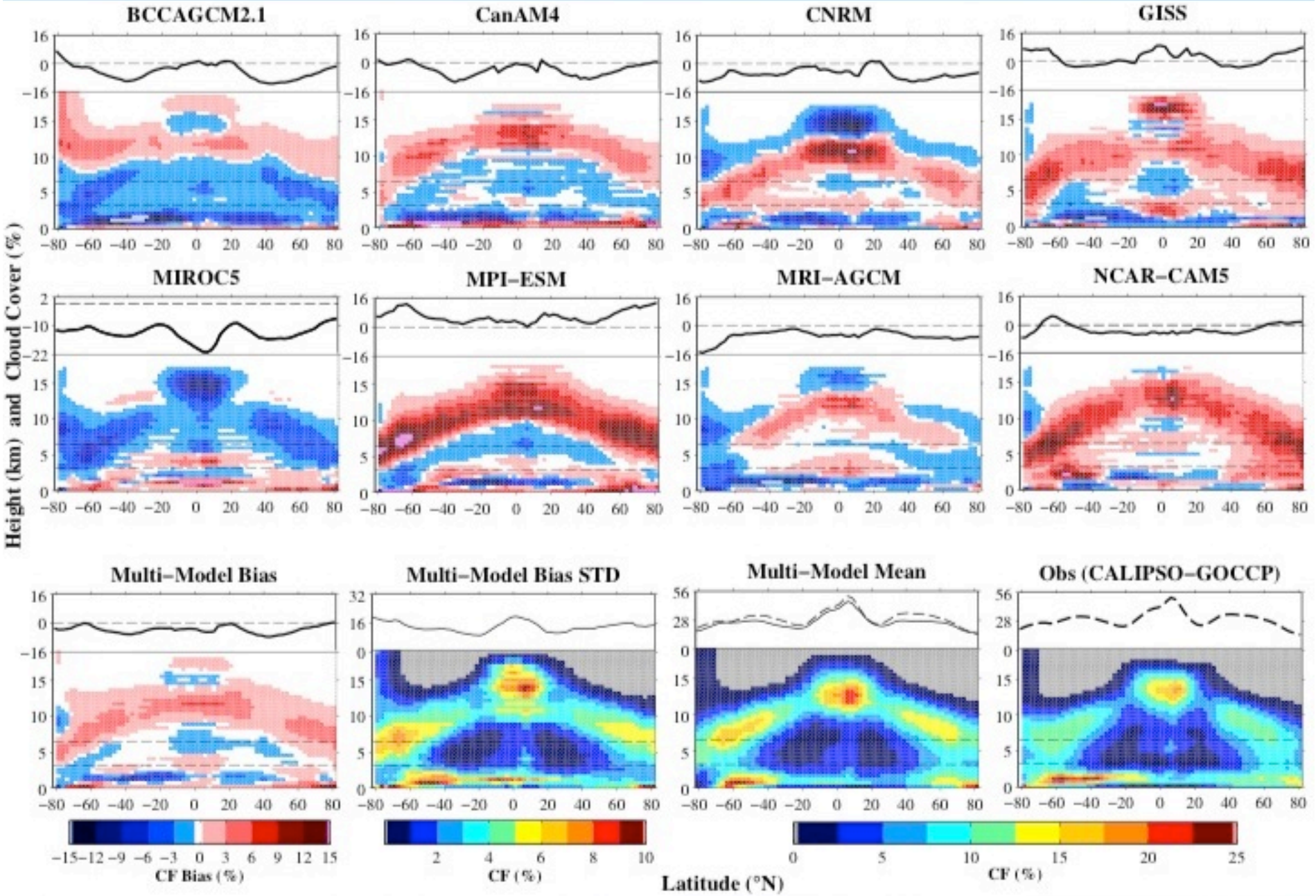
Positive bias
Negative bias

all	Low			Mid			High			Total		
Model	**tot**	**oc**	**land**	**tot**	**oc**	**land**	**tot**	**oc**	**land**	**tot**	**oc**	**land**
'NCAR-CAM5'	-5	-4.8	-0.3	-2.2	-0.7	-1.5	-3.5	-2	-1.5	-9.8	-7	-2.8
'GISS'	-8.3	-9.6	1.3	-2.8	-2.5	-0.3	1.4	1.7	-0.3	-9.5	-9.5	0
'CanCM4'	-3.4	-3.7	0.4	-6.7	-4.7	-2.1	-4.6	-1.8	-2.8	-7	-4.6	-2.4
'MPI-ESM'	-6.8	-5.9	-1	-5.3	-4.2	-1.1	4.7	3.7	1	-5.5	-4.7	-0.8
'MRI-AGCM'	-14.7	-12.5	-2.2	-4.6	-2.1	-2.5	-5.3	-2.8	-2.5	-16.8	-12.3	-4.5
'CNRM'	-12.7	-10.5	-2.2	-3.2	-0.9	-2.3	-5.5	-2.6	-2.8	-16.8	-11.7	-5.1
'MIROC5'	2.7	2.6	0.1	-7.5	-4.6	-2.8	-17.1	-11.4	-5.6	-12.7	-7.4	-5.3
BCCAGCM2.1'	-13.5	-12.8	-0.7	-11.6	-7.4	-4.2	-4.7	-2.2	-2.4	-19.3	-15	-4.3
'GFDL'	-5	-5.5	0.5	-2.4	-1.6	-0.9	0.7	1.3	-0.6	-3.8	-3.3	-0.5
'IPSL-CM5B'	-11.1	-9	-2.1	-7.4	-4.6	-2.8	-6	-2.6	-3.4	-14.3	-9.3	-5
'HadGEM2-A'	-10.8	-9.1	-1.8	-5.5	-3.2	-2.3	-7	-3.9	-3.1	-14.3	-10	-4.3
'EC-EARTH'	-15.5	-13.9	-1.7	-8.9	-5.4	-3.5	-7.4	-4.7	-2.7	-21.2	-16.2	-5
MultiModel	**-9**	**-8.1**	**-0.8**	**-5.7**	**-3.5**	**-2.2**	**-4.5**	**-2.3**	**-2.2**	**-12.6**	**-9.3**	**-3.3**
Obs	**37.7**	**31.4**	**6.3**	**18.2**	**11.4**	**6.8**	**32.1**	**22.2**	**9.9**	**67.3**	**50.4**	**16.9**

2. Layered Cloud Fraction Scores

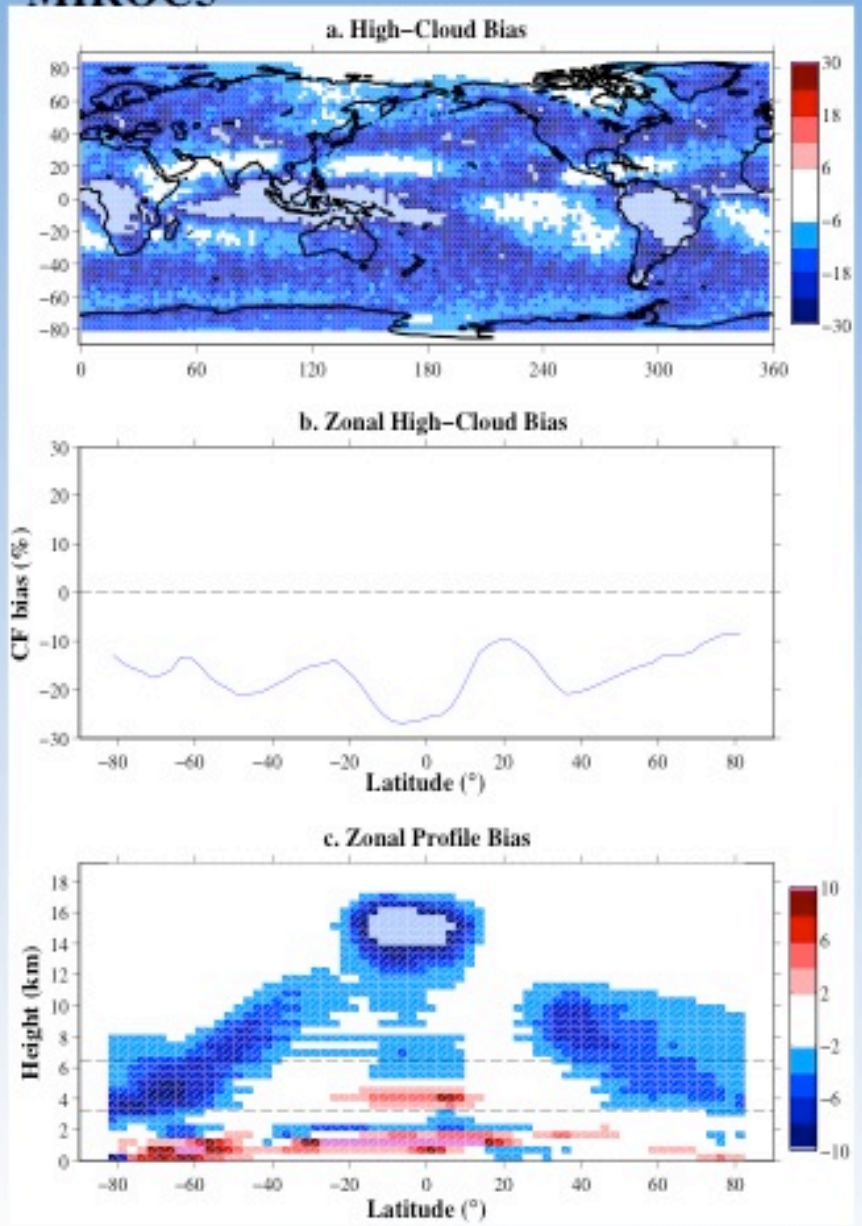
		Low			Mid			High			Total		
	Model	tot	oc	land	tot	oc	land	tot	oc	land	tot	oc	land
DJF	'NCAR-CAM5'	-3.8	-3.9	0.2	-1.9	-1	-0.9	-4.8	-3	-1.8	-9.5	-7	-2.6
	'GISS'	-6.8	-8.9	2.1	-2.7	-2.8	0.1	1.5	1.1	0.3	-8	-9.1	1.2
	'CanCM4'	-3	-3.5	0.5	-6.4	-4.8	-1.6	-5.5	-2.9	-2.6	-7	-5	-2
	'MPI-ESM'	-6.2	-5.3	-0.9	-4.8	-4.4	-0.4	3.4	2.5	0.9	-5.7	-5	-0.7
	'MRI-AGCM'	-13.8	-11.8	-2	-4.5	-2.5	-2	-7	-4.2	-2.8	-17	-12.7	-4.3
	'CNRM'	-11.3	-9.9	-1.4	-3	-1.3	-1.7	-6.6	-3.6	-3	-16.1	-11.8	-4.3
	'MIROC5'	2.9	2.6	0.3	-7.9	-5.1	-2.9	-17.9	-12.2	-5.7	-13.1	-8	-5.2
	BCCAGCM2.1'	-12.2	-12.3	0.2	-11.8	-7.8	-4	-5.4	-2.9	-2.6	-18.4	-14.9	-3.5
	'GFDL'	-3.8	-5	1.2	-2	-1.8	-0.2	-0.8	-0.1	-0.8	-3.7	-3.9	0.2
	'IPSL-CM5B'	-10.3	-8.4	-1.9	-7.3	-5	-2.2	-7.1	-4.2	-2.9	-14	-9.9	-4.1
	'HadGEM2-A'	-10.5	-9	-1.5	-5.3	-3.6	-1.7	-8.1	-5	-3.1	-14.3	-10.7	-3.6
	'CCSM4'	-15.7	-13.8	-1.8	-9	-5.7	-3.3	-8.3	-5.3	-3	-21.8	-16.6	-5.3
	MultiModel	**-8.2**	**-7.7**	**-0.5**	**-5.6**	**-3.8**	**-1.8**	**-5.6**	**-3.4**	**-2.2**	**-12.4**	**-9.6**	**-2.9**
	Obs	**37.8**	**31.3**	**6.5**	**18.5**	**11.7**	**6.8**	**32.6**	**22.6**	**9.9**	**67.6**	**50.5**	**17.1**
JJA	'NCAR-CAM5'	-5.8	-5.3	-0.5	-2.9	-0.4	-2.5	-3.1	-1.4	-1.7	-10.4	-7.1	-3.3
	'GISS'	-9.5	-10.3	0.8	-3.5	-2.5	-1	0.9	2	-1.2	-11.2	-10	-1.1
	'CanCM4'	-2.2	-2.9	0.8	-7.6	-4.7	-2.9	-4.7	-1.7	-3	-6.7	-4	-2.7
	'MPI-ESM'	-6.8	-5.8	-0.9	-5.8	-4	-1.8	4.7	4.3	0.4	-5.8	-4.3	-1.4
	'MRI-AGCM'	-14.9	-12.6	-2.2	-5.3	-2	-3.3	-4.5	-1.9	-2.7	-16.9	-11.8	-5.1
	'CNRM'	-13.9	-11.1	-2.8	-3.9	-0.7	-3.2	-4.6	-1.7	-2.9	-17.8	-11.7	-6.1
	'MIROC5'	2.9	3.2	-0.2	-7.3	-4.5	-2.8	-16.7	-11	-5.8	-12.3	-6.6	-5.7
	BCCAGCM2.1'	-13.9	-12.4	-1.5	-11.9	-7.3	-4.5	-4.1	-1.9	-2.2	-19.6	-14.6	-5
	'GFDL'	-6.3	-6.1	-0.2	-3.6	-1.7	-1.9	1.1	1.9	-0.8	-5.2	-3.6	-1.6
	'IPSL-CM5B'	-11.9	-9.1	-2.7	-8.4	-4.7	-3.7	-5.9	-1.7	-4.2	-15.7	-9	-6.7
	'HadGEM2-A'	-10.3	-8.3	-1.9	-6.3	-3.2	-3.1	-6.7	-3.2	-3.5	-14.1	-8.9	-5.2
	'CCSM4'	-14.7	-13.3	-1.4	-8.9	-5.1	-3.8	-6.6	-4.2	-2.3	-20.2	-15.5	-4.6
	MultiModel	**-9.2**	**-8.1**	**-1.1**	**-6.3**	**-3.4**	**-2.9**	**-4.2**	**-1.7**	**-2.5**	**-13**	**-9**	**-4.1**
	Obs	**38**	**32**	**6**	**18.2**	**11.3**	**6.9**	**31.8**	**21.8**	**10**	**67.4**	**50.7**	**16.7**

3. Zonal Mean Cloud Profiles



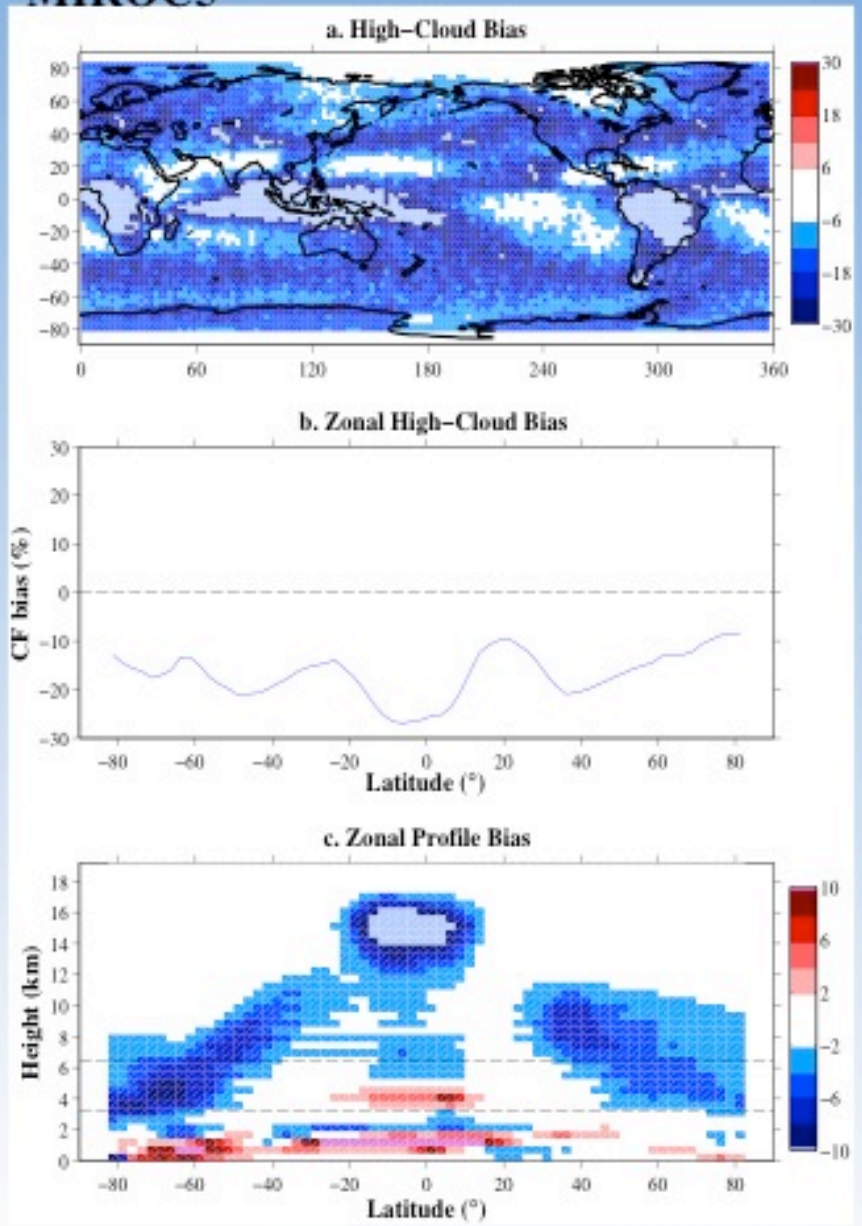
High-CF vs. Level CF bias

MIROC5

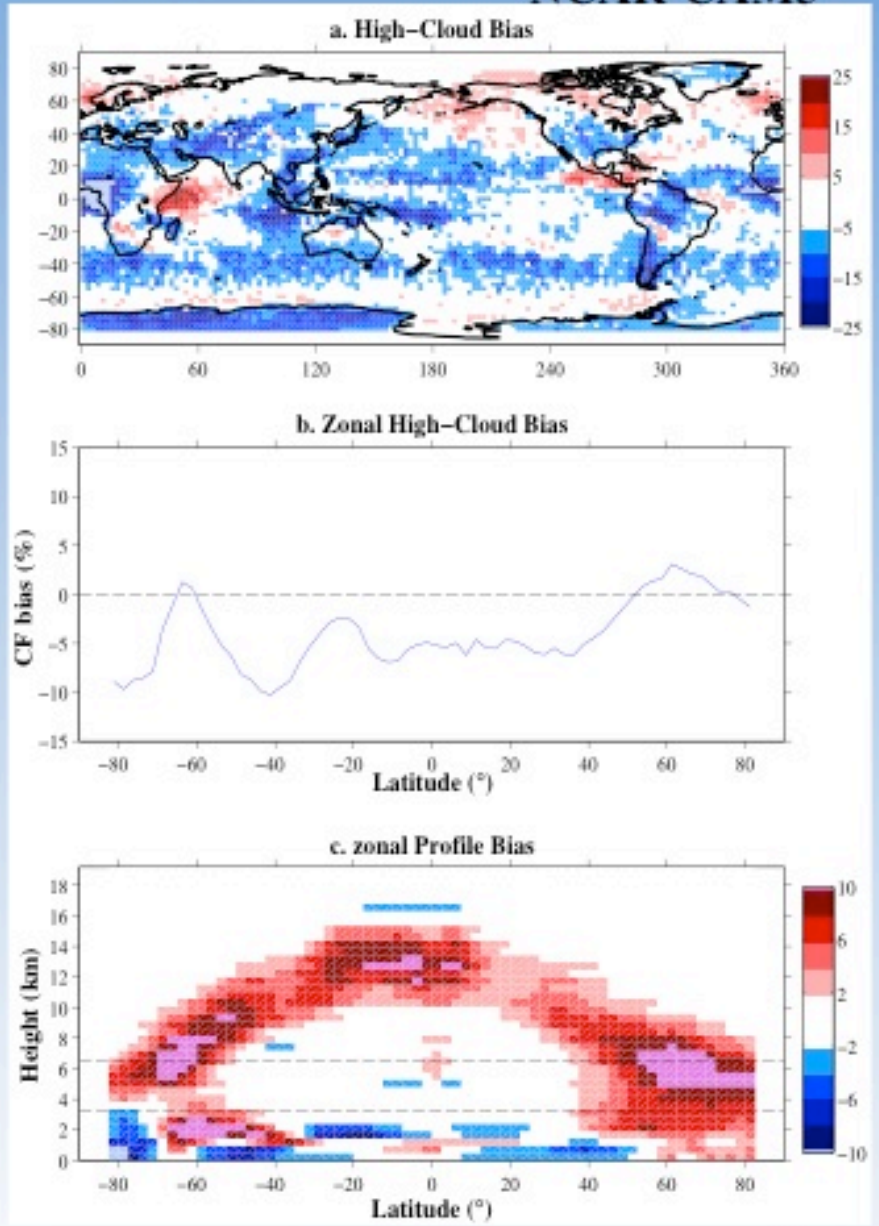


High-CF vs. Level CF bias

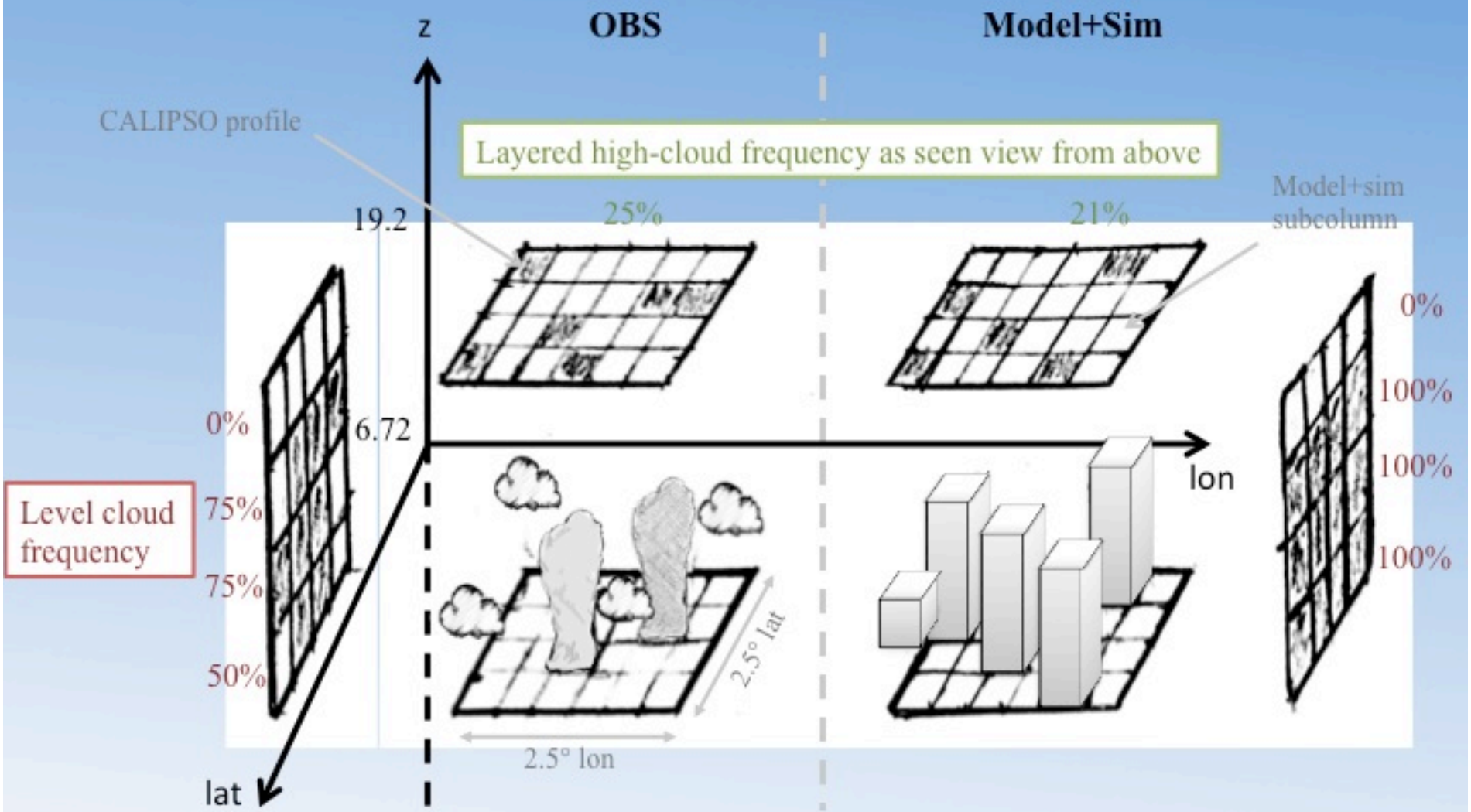
MIROC5



NCAR-CAM5

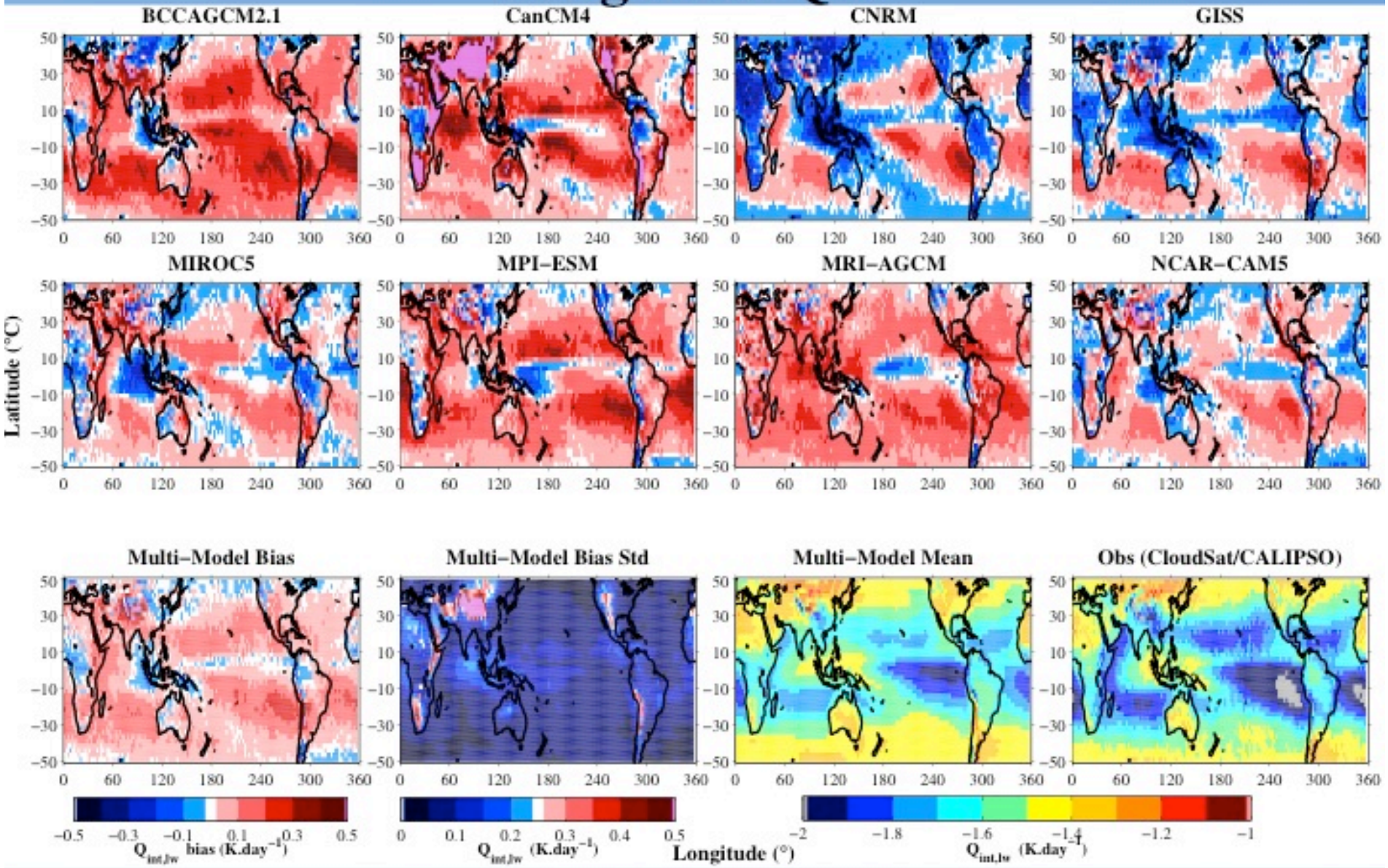


High Cloud Layer (6.72 to 19.2 km)



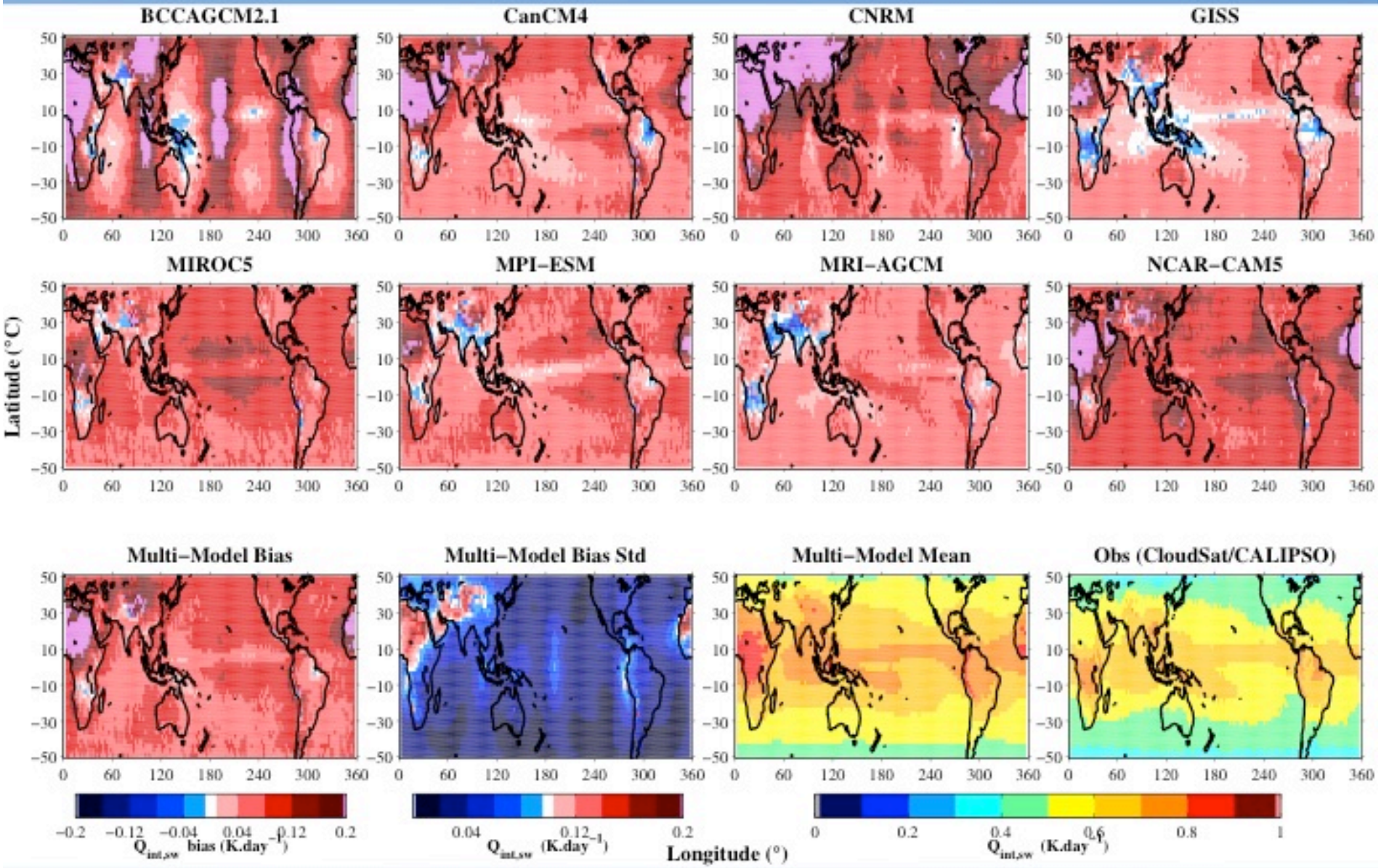
➔**The model tends to over-simulate the deep convective clouds or geometrically thick high-level cloud compared to observations** (too infrequent high-clouds but fill too many vertical levels)

Integrated Qlw



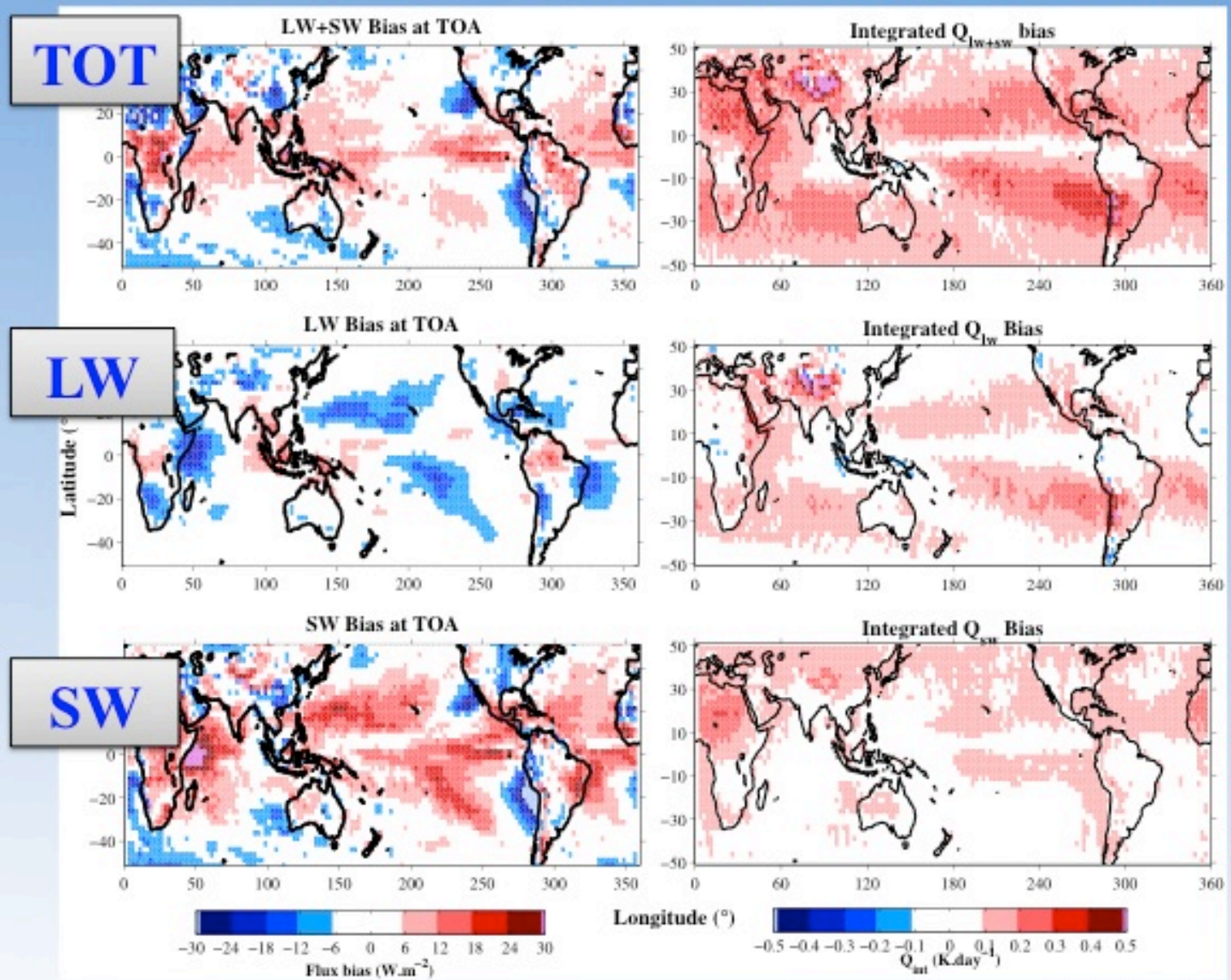
- Qlw,int bias is related to cloud cover bias but not correlated

Integrated Qsw



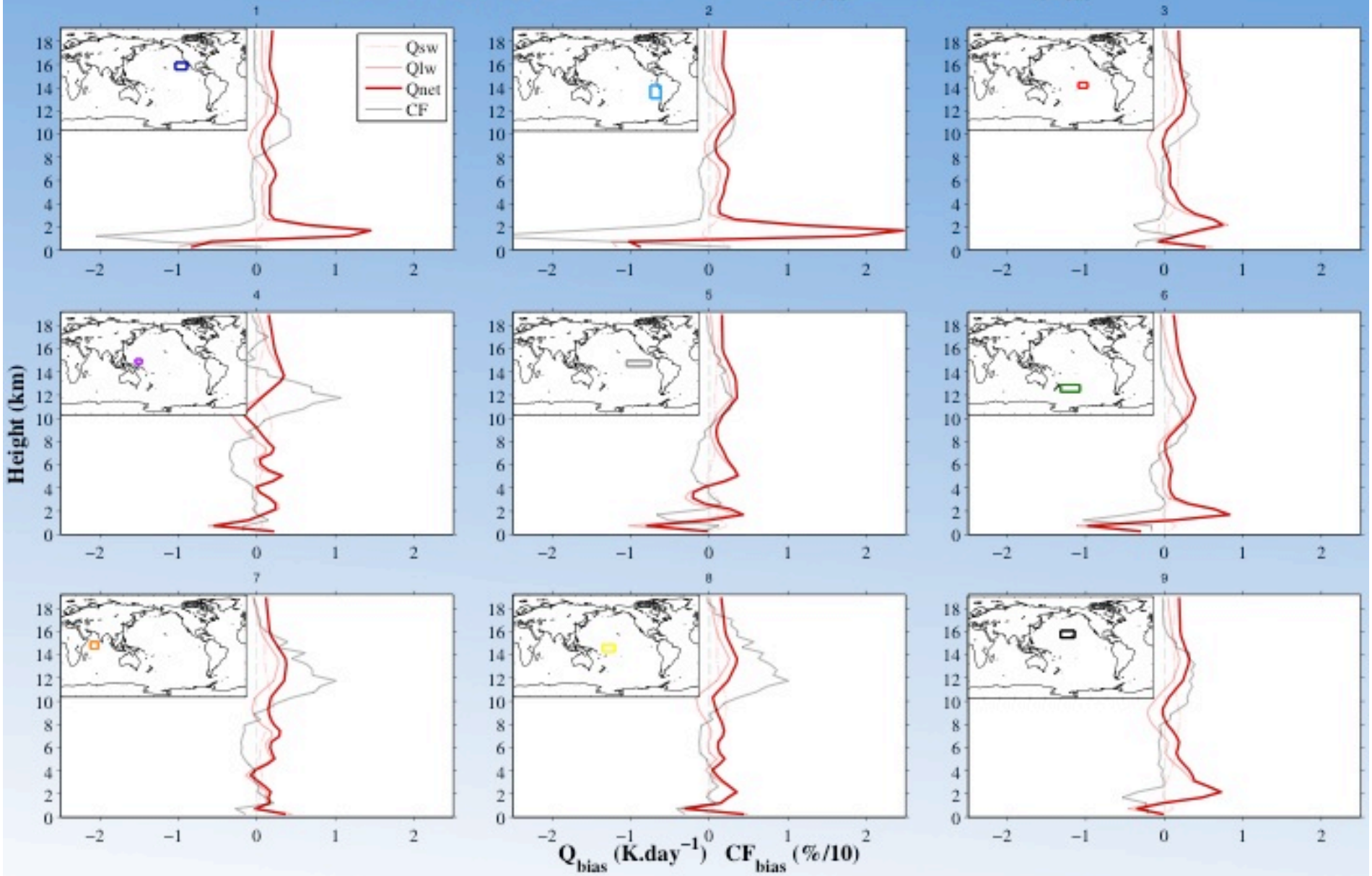
- Qsw bias is smaller and something is happening above reflective surfaces

TOA Radiation Bias vs. Q integrated Bias



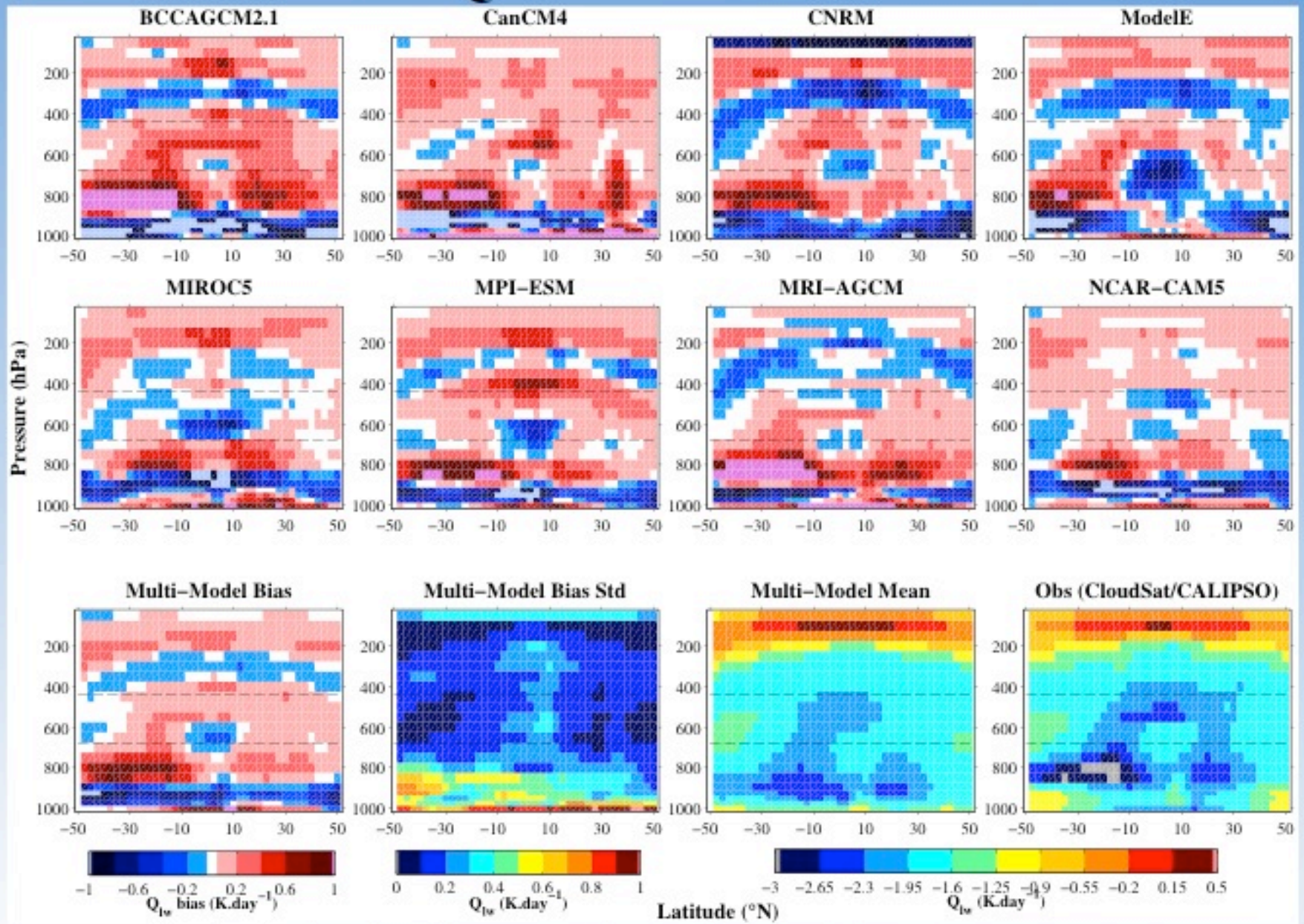
- No particular correlation between the TOA flux bias and the integrated Qbias

Case study profiles of Q_{bias} and CF_{bias}



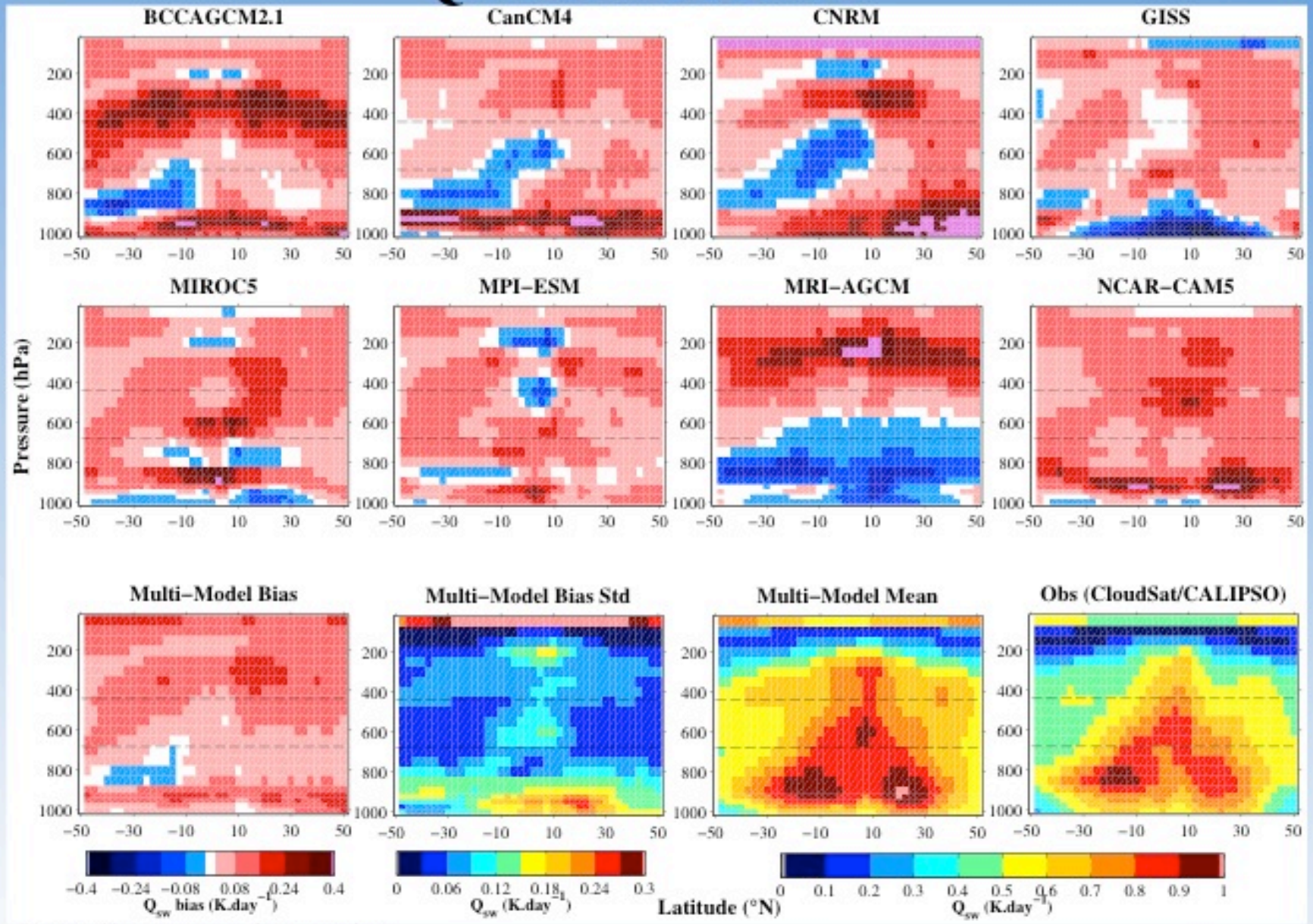
- Different response in Qbias depending on the type/height of cloud bias

Qlw zonal Profiles



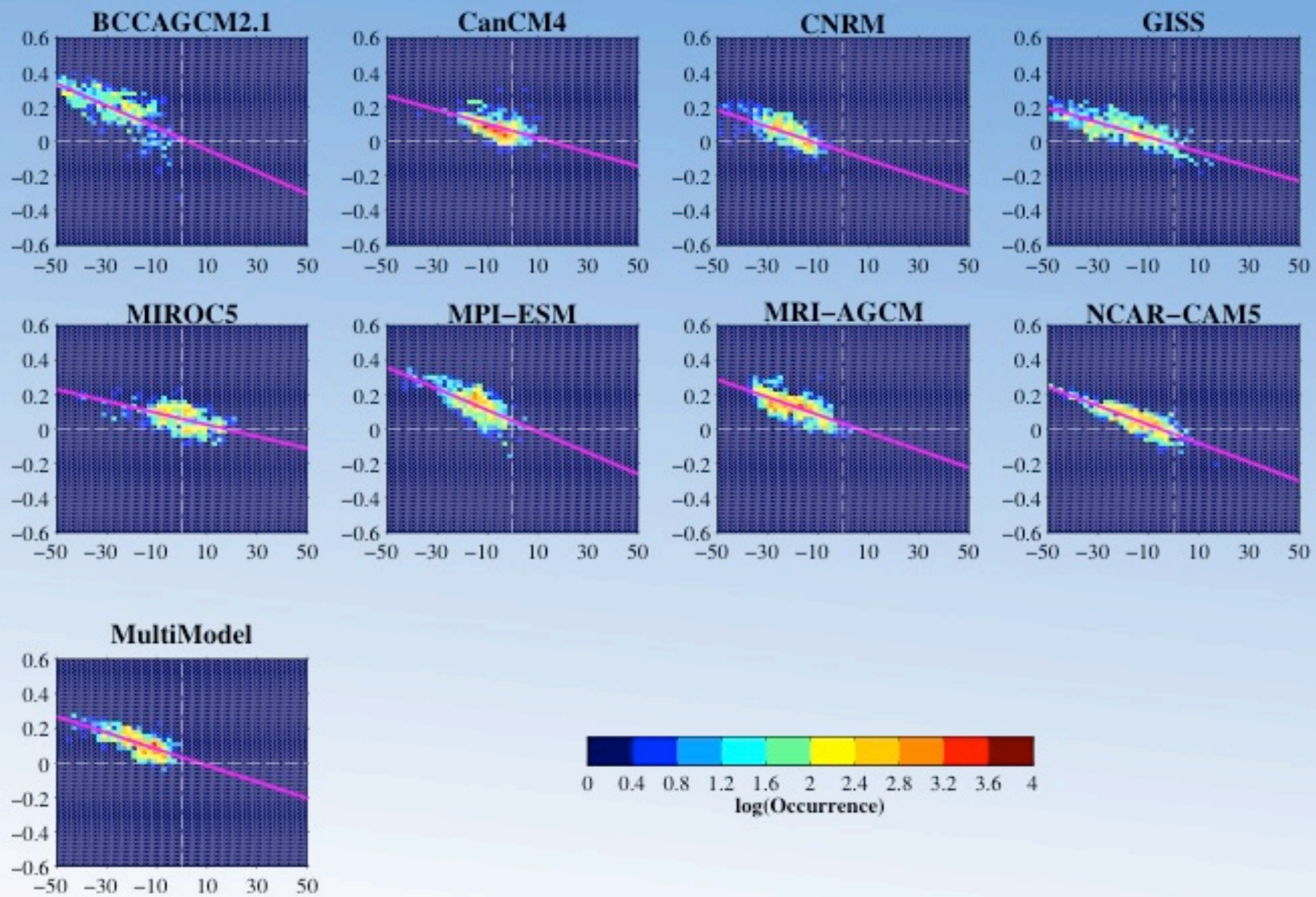
- Larger bias in the low-level layers than in the high-level layers

Qsw zonal Profiles

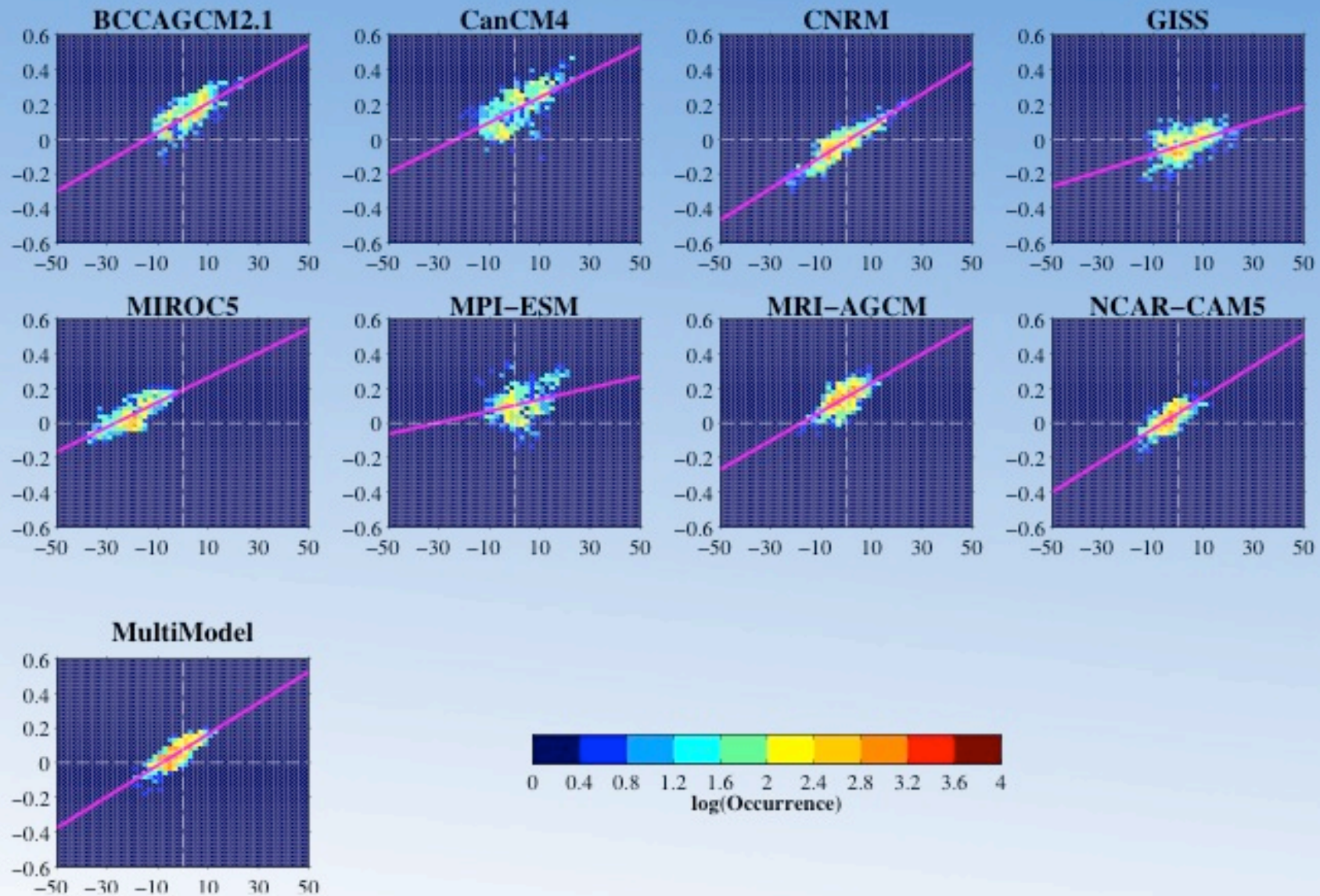


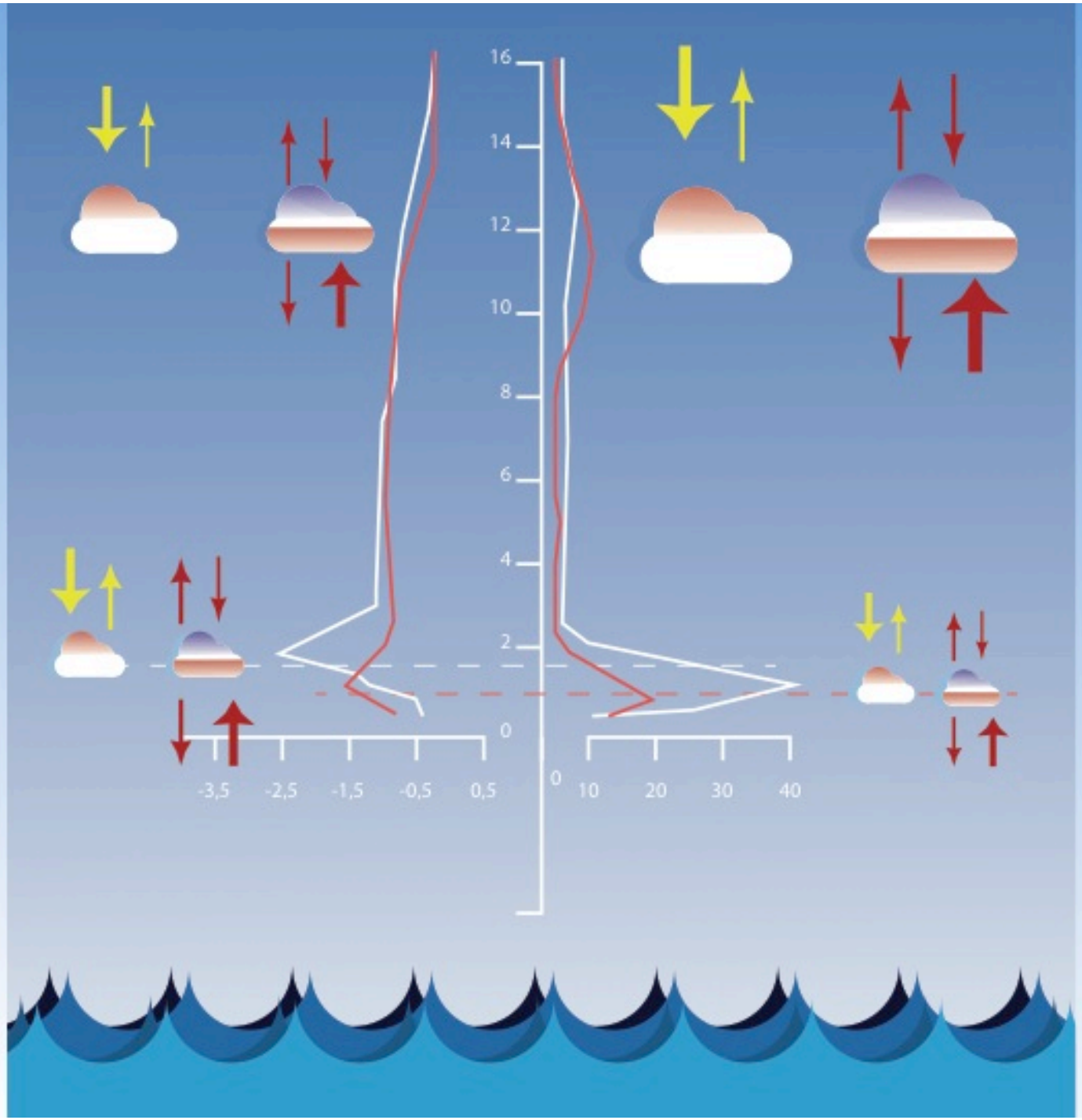
- Overall excess of warming.
- Lack of cloud generally correspond to lack of warming

Correlation High-Cld vs. $HR_{lw,int}$



Correlation Low-Cld vs. $HR_{lw,int}$




16
14
12
10
8
6
4
2
0
-3,5
-2,5
-1,5
-0,5
0,5
0
10
20
30
40

Summary

Using CALIPSO-GOCCP observations combined CALIPSO-CloudSat measurements, we assessed clouds and their impact on radiative heating rate profiles in several GCMs.

Backup Slides

Cloud Phase Profiles (Mask)

Mid-Latitudes High Clouds

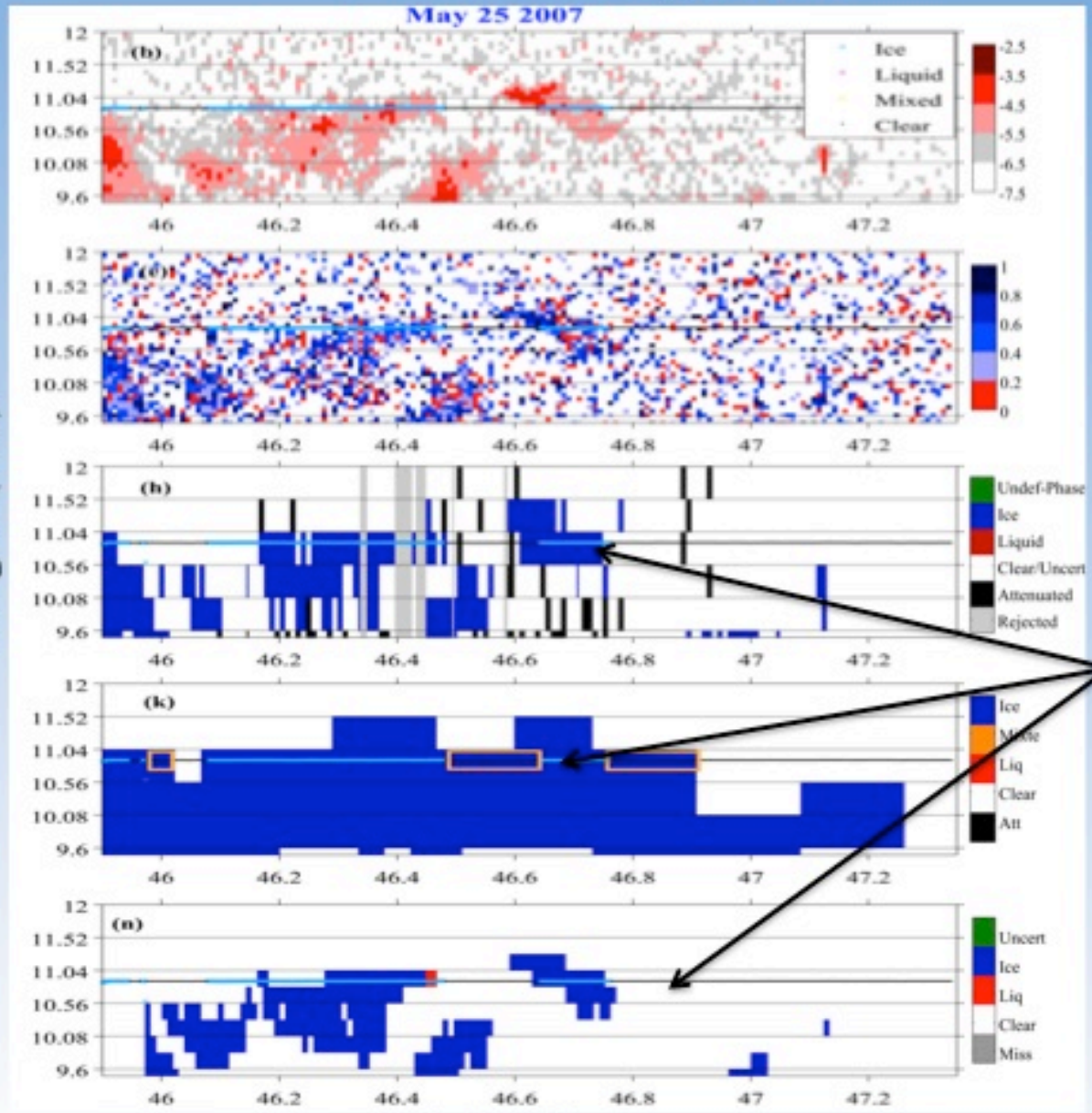
ATB

depol

GOCCP

ST

KU



Aircraft

➔ *Good agreement in cloud-detection*

➔ *Very good in cloud phase determination*

➔ *Horizontal averaging increases the disagreements*

Cloud Phase Profiles (Mask)

Mid-Latitudes High Clouds

Day	20070516			20070525			20070526			Comments
Product	GOCCP	ST	KU	GOCCP	ST	KU	GOCCP	ST	KU	
F'_{agree} (%)	**100**	**100**	**100**	**96.9**	**100**	**94.6**	**97.8**	**100**	**100**	(1) Very good agreement
$F'_{Aliq/Cliq}$	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	
$F'_{Aice/Cice}$	*100*	*100*	*100*	*96.9*	*100*	*94.6*	*97.8*	*100*	*100*	
$F'_{Amix/Cliq}$	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	
$F'_{Amix/Cice}$	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	
F'_{other} (%)	**0**	**0**	**0**	**3.1**	**0**	**5.4**	**2.2**	**0**	**0**	
$F'_{Aliq/Cice}$	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	
$F'_{Aice/Cliq}$	*0*	*0*	*0*	*0*	*0*	*5.4*	*2.2*	*0*	*0*	
$F'_{Aliq/Cun}$	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	
$F'_{Aice/Cun}$	*0*	*0*	*0*	*3.1*	*0*	*0*	*0*	*0*	*0*	
$F'_{Amix/Cun}$	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	

Cloud Phase Profiles (Mask)

Arctic Low Clouds

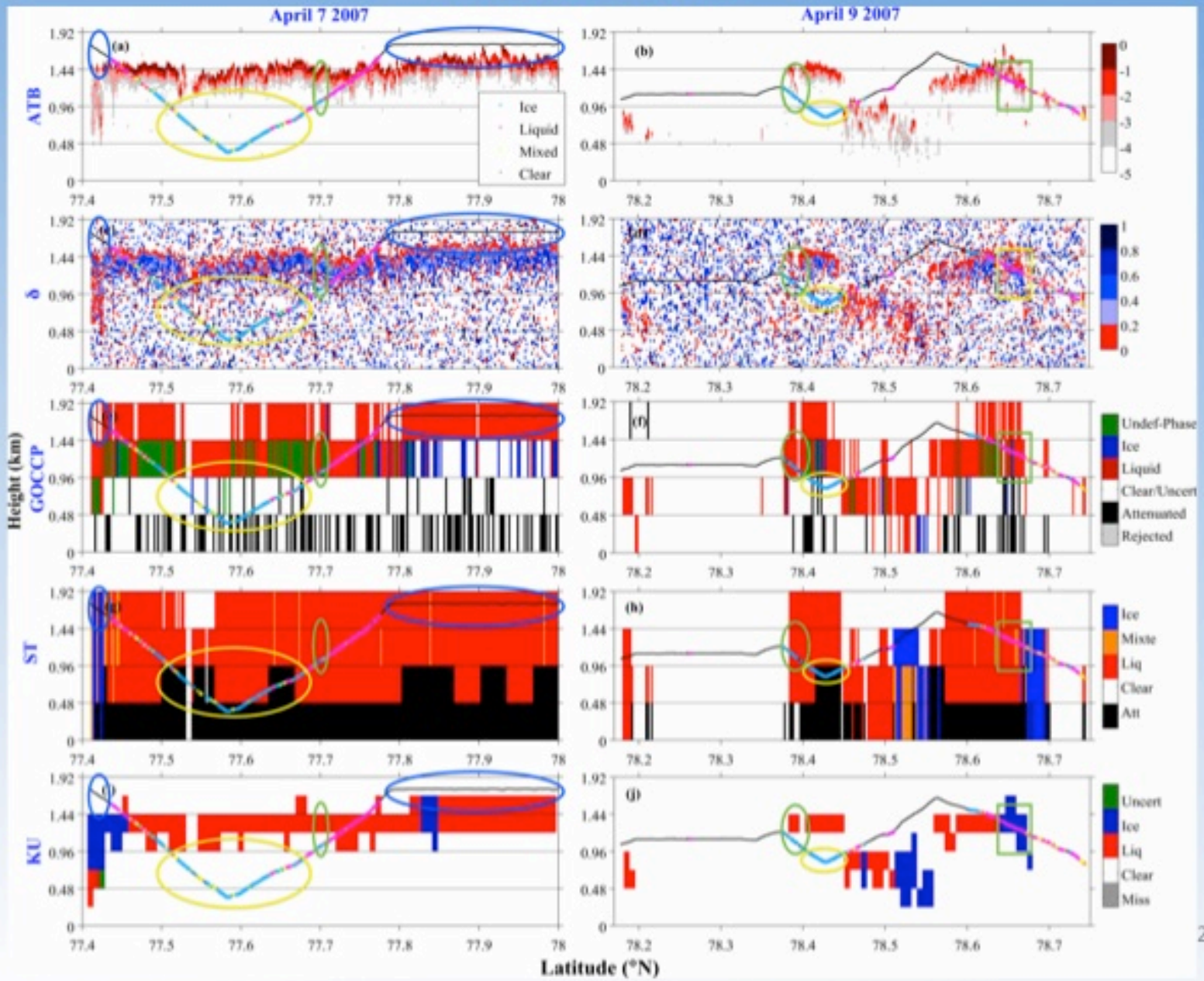
ATB

depol

GOCCP

ST

KU



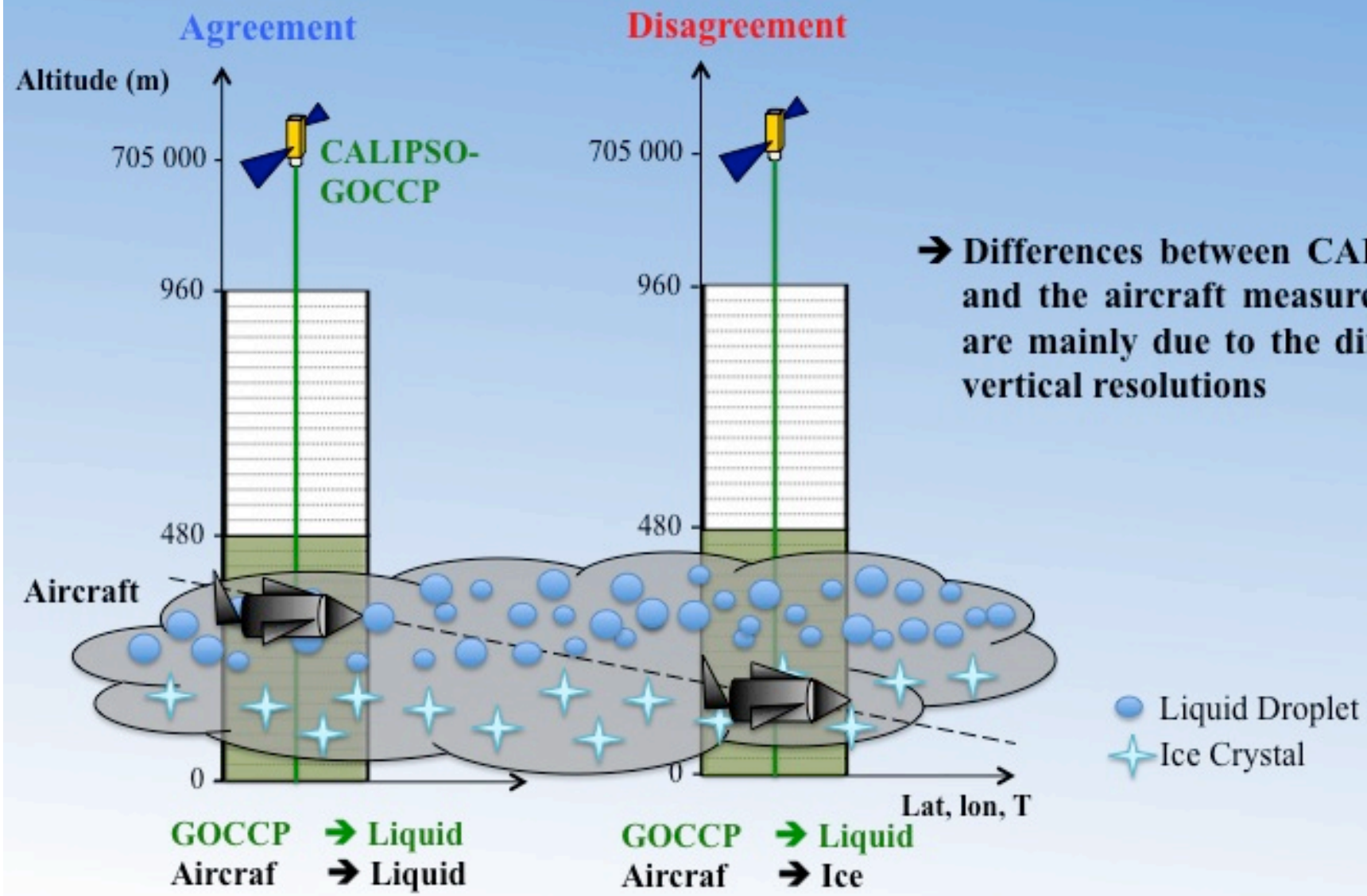
Cloud Phase Profiles (Mask)

Arctic Low Clouds

Day	20070407			20070409			Comments
Product	**GOCCP**	**ST**	**KU**	**GOCCP**	**ST**	**KU**	
F'_{agree} (%)	**52.2**	**74.7**	**79.8**	**56.1**	**51.5**	**37.5**	
$F'_{Aliq/Cliq}$	*43.9*	*60.2*	*62.4*	*46.9*	*38.8*	*32.5*	
$F'_{Aice/Cice}$	*1.9*	*0*	*0*	*0*	*0*	*0*	
$F'_{Amix/Cliq}$	*6.4*	*14.5*	*17.4*	*9.2*	*6.7*	*2.5*	(2) Clouds with Liquid at the top
$F'_{Amix/Cice}$	*0*	*0*	*0*	*0*	*6*	*2.5*	
F'_{other} (%)	**47.8**	**25.3**	**20.2**	**43.9**	**48.5**	**62.5**	
$F'_{Aliq/Cice}$	*0*	*0*	*6.2*	*3.1*	*14*	*56.7*	(3) Noisy measurements (SNR)
$F'_{Aice/Cliq}$	*5.2*	*20.4*	*14*	*28.1*	*26.1*	*5.8*	(4) Attenuation & vertical resolution
	(1)	*(4.2)*	*(3.4)*	*(11.8)*	*(10)*	*(3.3)*	(5) Sensitivity to g factor in aircraft
$F'_{Aliq/Cun}$	*17*	*4.9*	*0*	*11.4*	*7.7*	*0*	(6) Undef-phase in BL clouds to to noise in polarization channel
$F'_{Aice/Cun}$	*17.6*	*0*	*0*	*1.3*	*0*	*0*	
$F'_{Amix/Cun}$	*8*	*0*	*0*	*0*	*0.7*	*0*	

Differences (1/2) Due to Vertical Resolution

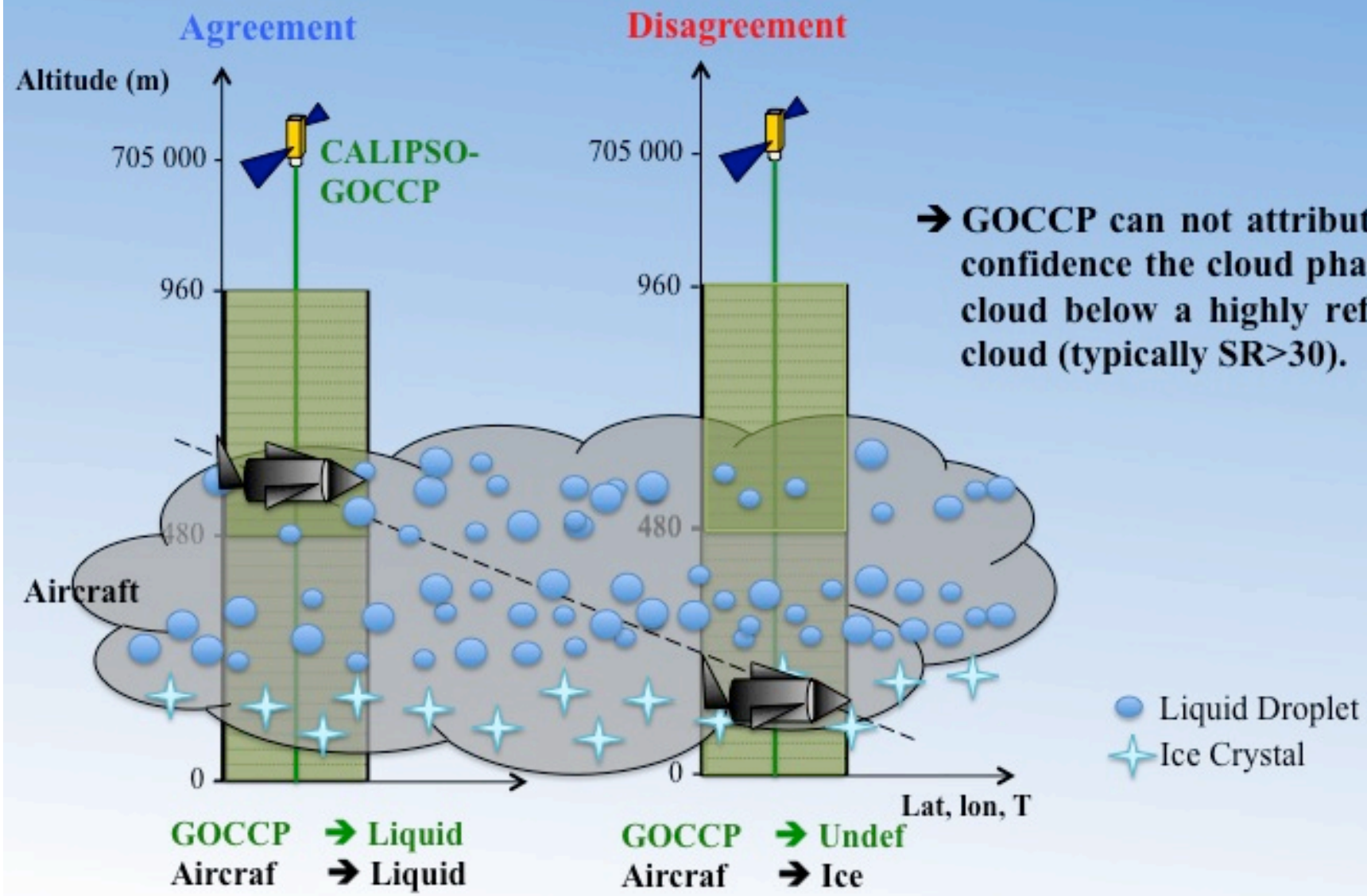
Arctic Boundary Layer Clouds



➔ Differences between CALIPSO and the aircraft measurements are mainly due to the different vertical resolutions

Differences (1/2) Due to Undef-Phase

Arctic Boundary Layer Clouds



➔ GOCCP can not attribute with confidence the cloud phase of a cloud below a highly reflective cloud (typically SR>30).

Cloud Detection Validation

Mid-Latitudes High Clouds

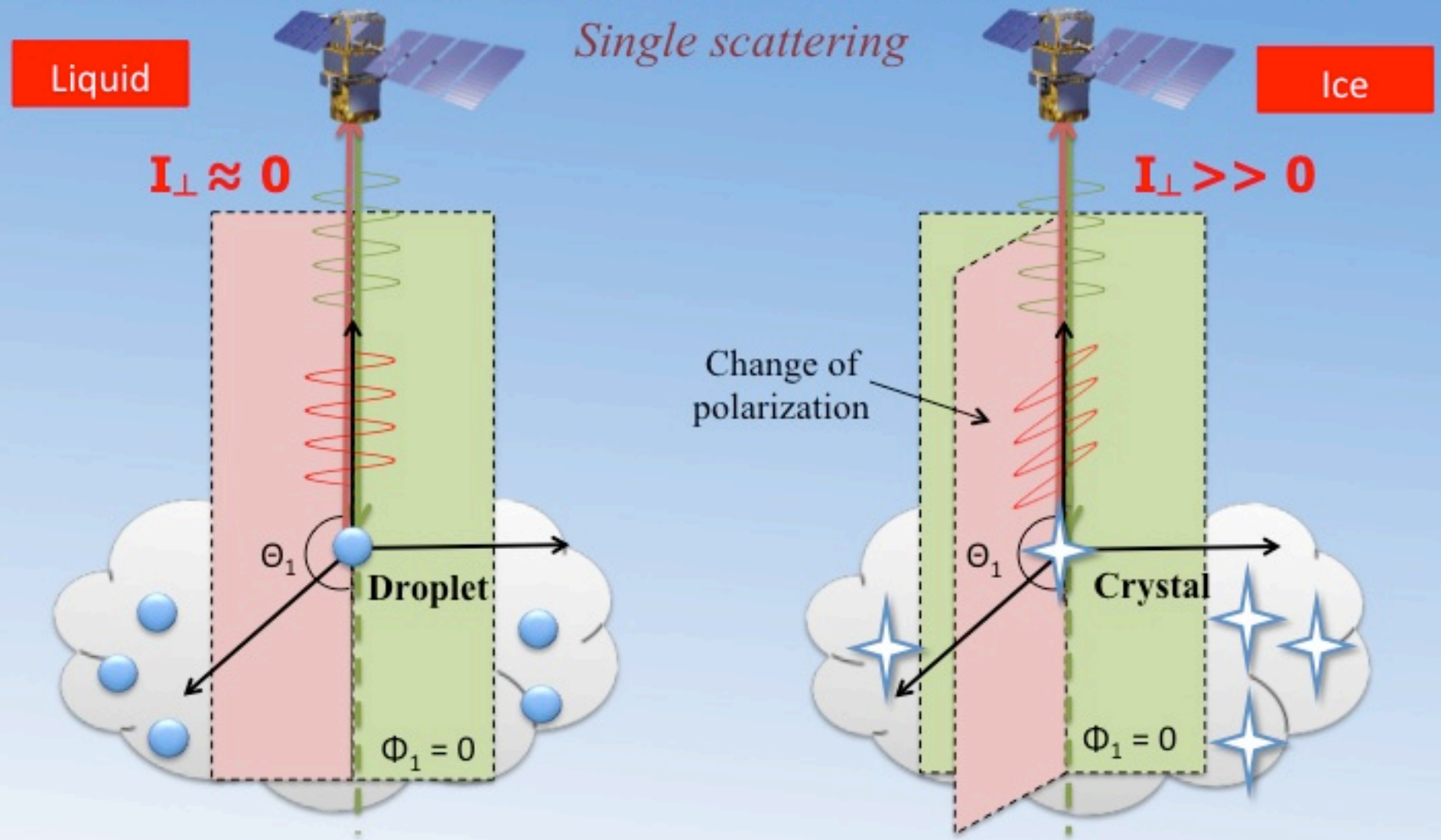
Day	20070516			20070525			20070526			
Product	**GOCCP**	**ST**	**KU**	**GOCCP**	**ST**	**KU**	**GOCCP**	**ST**	**KU**	
F_{agree} (%)	**95.8**	**89.6**	**97.6**	**87.3**	**76.4**	**84.5**	**80.9**	**81.2**	**84.1**	(1) Agreement (see Fig. 2)
$F_{Acloud/Ccloud}$	*85.9*	*84.6*	*84.1*	*38.2*	*47.3*	*23.4*	*62.7*	*77.7*	*63.4*	
$F_{Aclear/Cclear}$	*9.9*	*5*	*13.5*	*49.1*	*29.1*	*61.1*	*18.2*	*3.5*	*20.7*	
F_{other} (%)	**4.2**	**10.4**	**2.4**	**12.7**	**23.6**	**15.5**	**19.1**	**18.8**	**15.9**	(2) ST coarse horizontal resolution
$F_{Aclear/Ccloud}$	*4.2*	*10.4*	*1.7*	*2.5*	*23.6*	*0.9*	*1.9*	*18.8*	*1.8*	(3) Vertical resolution differences
$F_{Aclear/Cuncert}$	*0*	*0*	*0*	*0*	*0*	*0*	*1.5*	*0*	*0*	
$F_{Aclear/Catt}$	*0*	*0*	*0*	*1.7*	*0*	*0*	*1.3*	*0*	*0*	
$F_{Acloud/Cclear}$	*0*	*0*	*0.7*	*8.5*	*0*	*14.6*	*10.1*	*0*	*14.1*	
$F_{Acloud/Cuncert}$	*0*	*0*	*0*	*0*	*0*	*0*	*4.3*	*0*	*0*	
$F_{Acloud/Catt}$	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	

Cloud Detection Validation

Arctic Low Clouds

Day	20070407			20070409			
Product	**GOCCP**	**ST**	**KU**	**GOCCP**	**ST**	**KU**	
F_{agree} (%)	**30.6**	**26**	**59.4**	**69.9**	**67.5**	**65.1**	
$F_{Acloud/Ccloud}$	*26*	*25.8*	*14.8*	*19.3*	*25.3*	*10.2*	
$F_{Aclear/Cclear}$	*4.6*	*0.2*	*44.6*	*50.6*	*42.2*	*54.9*	
F_{other} (%)	**69.4**	**74**	**40.6**	**30.1**	**32.7**	**34.9**	
$F_{Aclear/Ccloud}$	*38.5*	*43.2*	*0.5*	*3.1*	*12.8*	*0*	(3) Vertical resolution differences
$F_{Aclear/Cuncert}$	*1.9*	*0*	*0*	*1.3*	*0*	*0*	(4) Definition of uncert in GOCCP
$F_{Aclear/Catt}$	*0*	*1.6*	*0*	*0*	*0*	*0*	
$F_{Acloud/Cclear}$	*21.8*	*1.4*	*40.1*	*20.7*	*11.7*	*34.9*	(5) Lidar attenuation
$F_{Acloud/Cuncert}$	*2.6*	*0*	*0*	*3.8*	*0*	*0*	
$F_{Acloud/Catt}$	*4.6*	*27.8*	*0*	*1.2*	*8.2*	*0*	(5) Lidar attenuation

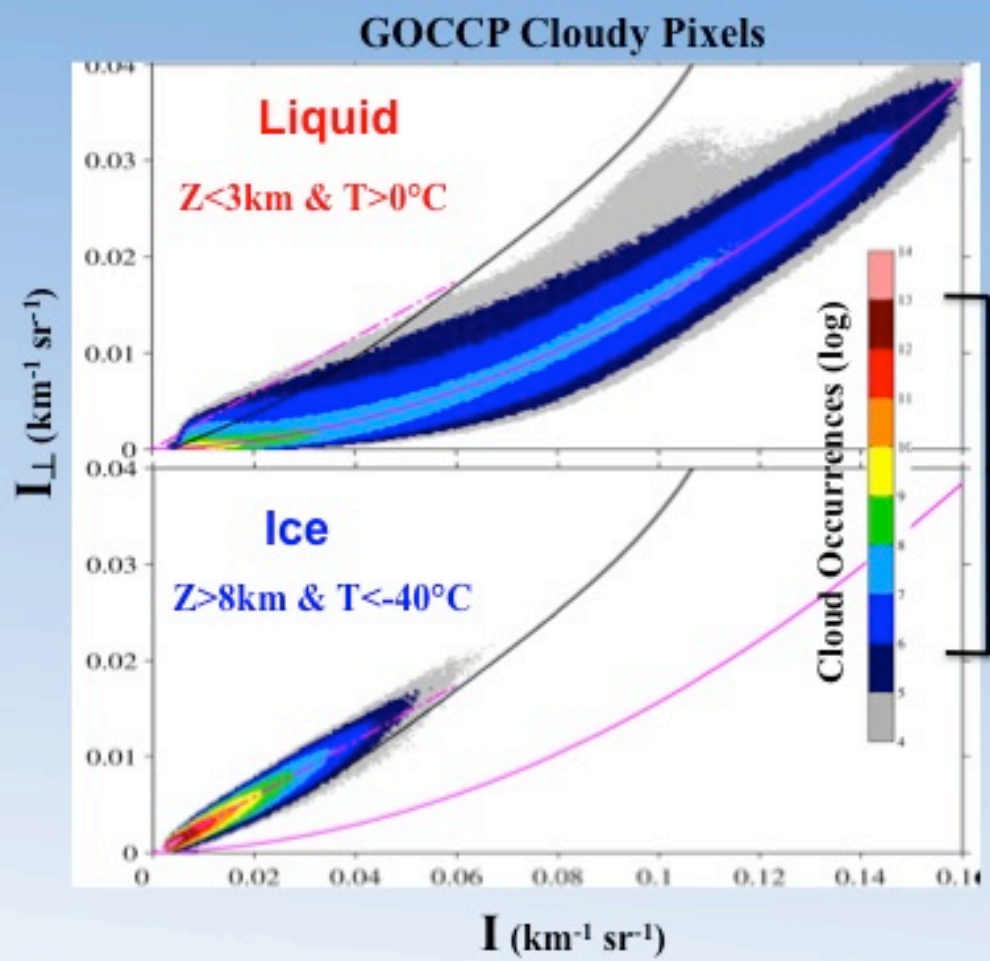
Obs: GOCCP Cloud Phase restitution 1/2

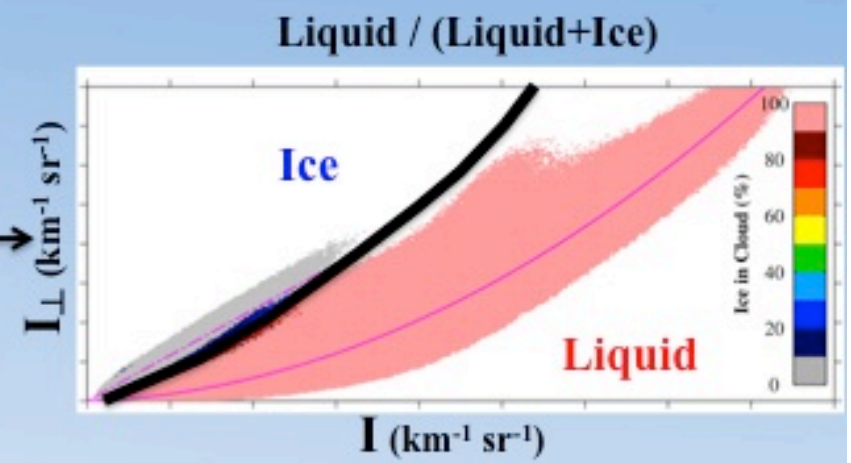


➔ **Liquid droplets (spherical) can be discriminated from ice crystals (non-spherical) thanks to the polarization change of the backscattered laser light ($I_\perp$).**

Obs: GOCCP Cloud Phase restitution 2/2

Cloud Phase diagram at global scale





➔ Discrimination curve

➔ A discrimination curve has been built to separate ice clouds from liquid clouds using the total intensity (I) and the perpendicular intensity ($I_\perp$) of the lidar signal.