Cloud Radiative Forcing at the ARM Climate Research Facility:
Part 1. Technique and Validation.
Part 2. The Vertical Redistribution of Radiant Energy By Clouds

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- In this paper, we describe a data analysis technique that attempts to reduce the raw ARM data into a meaningful description of the atmospheric physical state.

Characterization of the physical properties of the vertical column for cloud radiative effect studies requires knowledge of

1. Thermal and water vapor profile
2. Cloud occurrence
3. Cloud microphysical properties
4. Cloud radiative properties
5. Solar and IR up and downwelling fluxes

Furthermore, accomplishing this characterization over long periods of time requires that estimation of these 5 items be accomplished operationally.

Toward Continuous Cloud Microphysics:

The Easy Part: Profiles with only liquid water and/or cirrus can be addressed using existing retrieval algorithms.

The Hard Part: Because the MWR observes the total liquid water path, the challenge is to treat profiles that contain supercooled clouds/mixed phase volumes along with perhaps cloud volumes that are warm (T>273K).

Approach to supercooled/mixed phase liquid:

Use a parameterization of the liquid water content (LWC) profile (Kiehl et al, 1998) and the MMCR cloud occurrence profile to provide a *normalized* distribution of LWC. From this normalized profile and the MWR LWP define a *supercooled* LWP and a *warm* LWP.

For the warm layer, goto easy part.

For Supercooled liquid: Distribute the supercooled LWP vertically using the normalized parameterization of LWC and the MMCR cloud occurrence.

Important: The layer then is guaranteed to have the *observed* LWP distributed vertically in the column.

Approach to non-cirrus ice phase:

Assume the radar reflectivity and Doppler velocity record information only about the ice phase.

We require a relationship that provides the IWC in such layers.

March 2000 IOP: the Citation was instrumented with the CVI and PMS probes.

We use data from deep altostratus and mixed phase layers to define a regression relationship relating the radar reflectivity and the Doppler velocity calculated from the PMS size distributions to the observed condensed water:

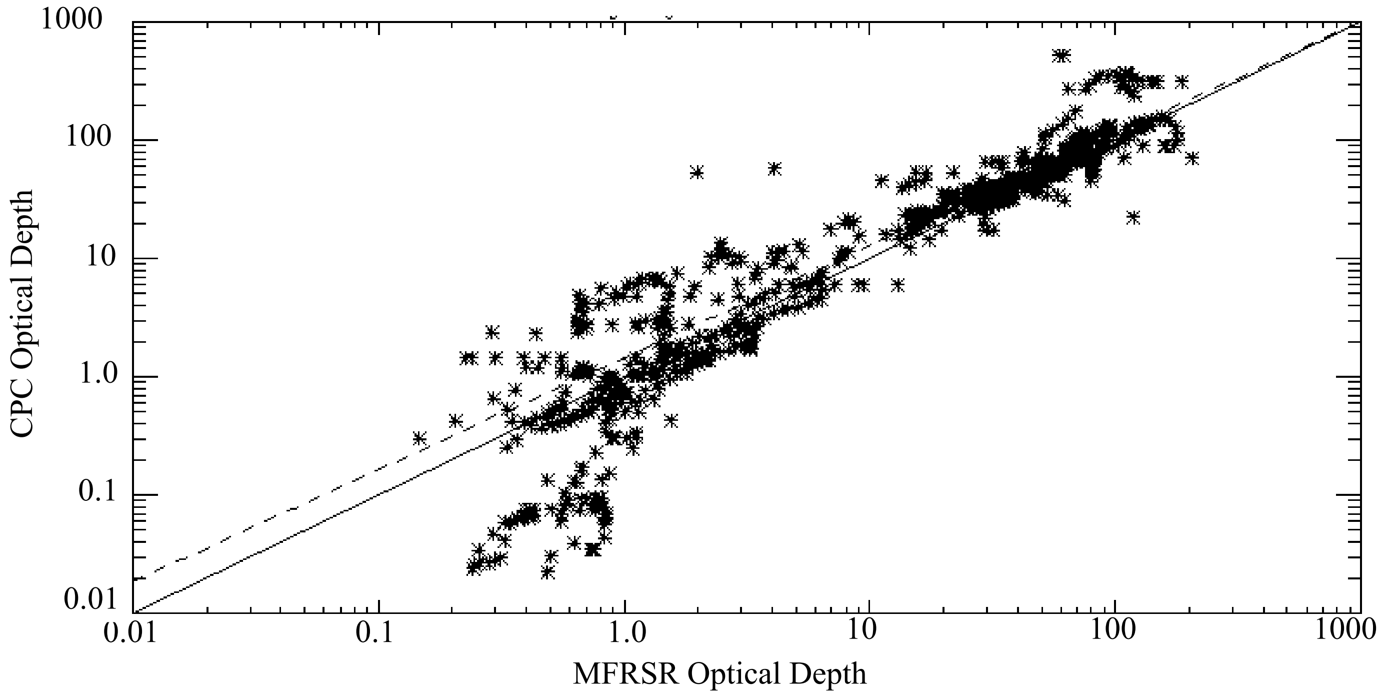
$$IWC = a + bF_1\left(Z_e, V_d\right) + cF_2\left(T\right)$$

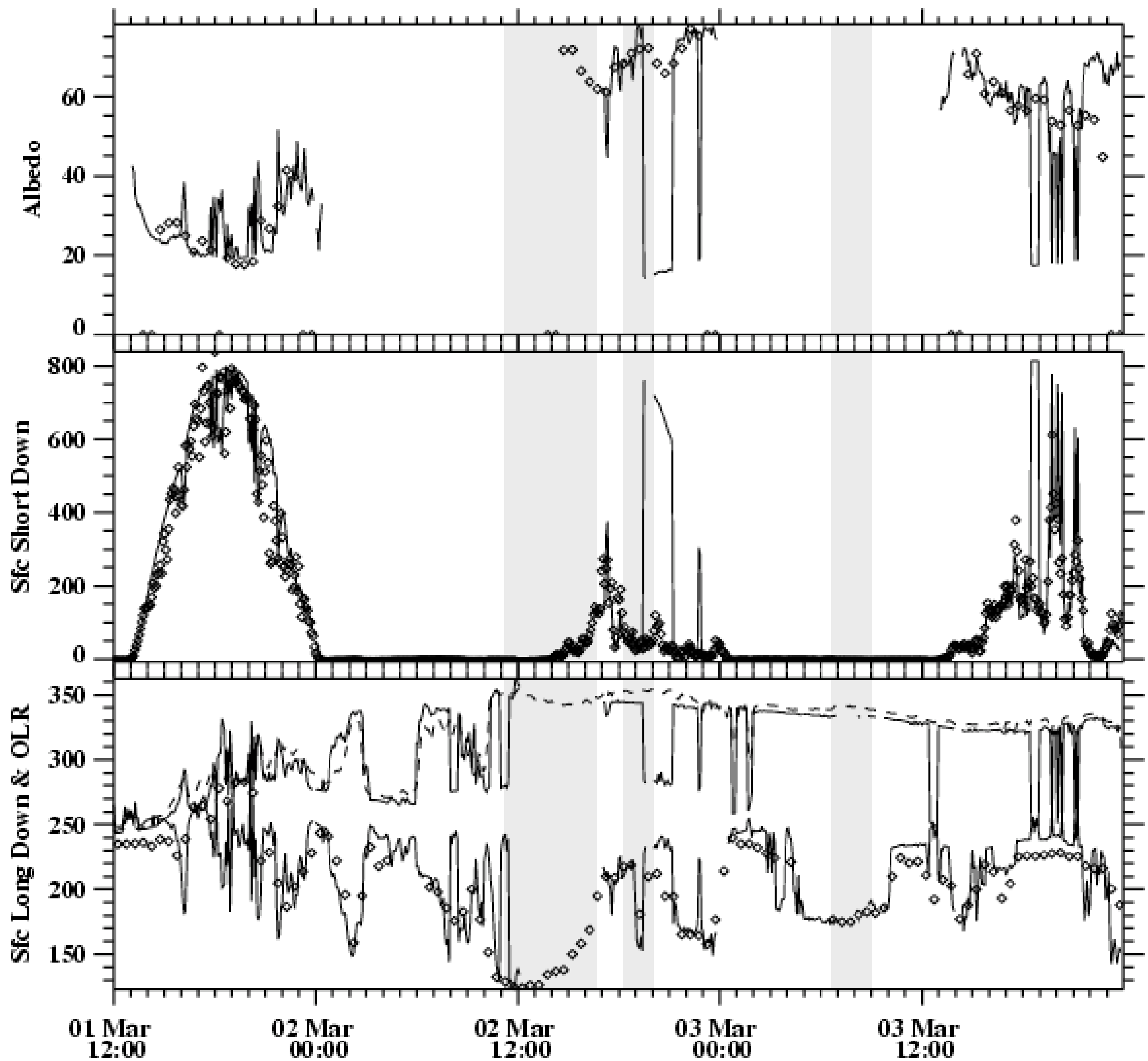
1560 5-second averages, the Bias in the fit is 0.2 mg/m3, the median fractional error is 0.33, and the normal deviation is 3.4 mg/m3.

a	b	c
-1.52e-8	8.76e-8	2.28e-10

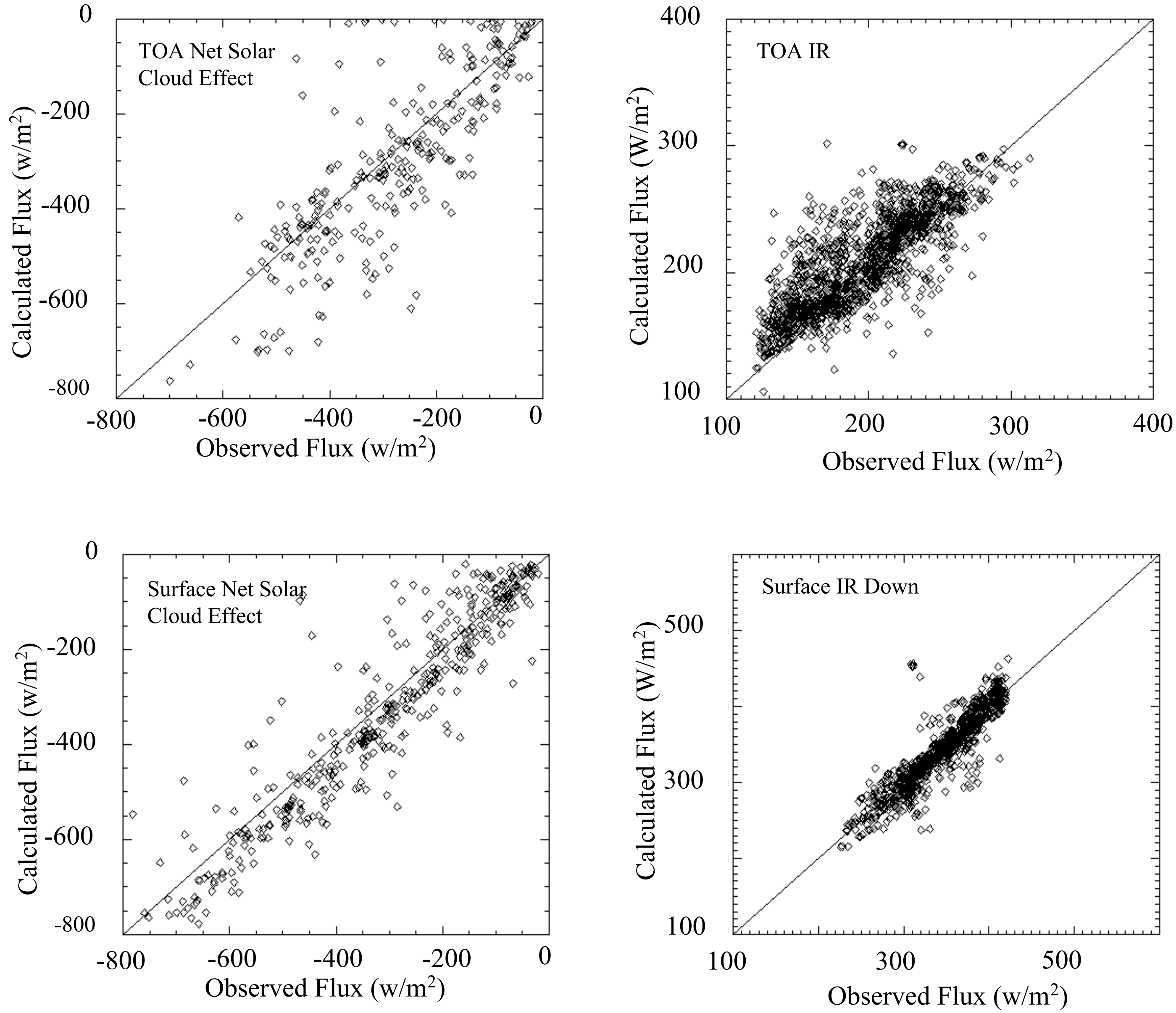
Validation:

Provided by radiative closure and comparison with independently derived optical depths





Albedo
Sfc Short Down
Sfc Long Down & OLR
01 Mar 12:00
02 Mar 00:00
02 Mar 12:00
03 Mar 00:00
03 Mar 12:00


TOA Net Solar
Cloud Effect
Calculated Flux (w/m2)
Observed Flux (w/m2)
0
-200
-400
-600
-800
-800
-600
-400
-200
0
TOA IR
Calculated Flux (W/m2)
Observed Flux (w/m2)
400
300
200
100
100
200
300
400
Surface Net Solar
Cloud Effect
Calculated Flux (w/m2)
Observed Flux (w/m2)
0
-200
-400
-600
-800
-800
-600
-400
-200
0
Surface IR Down
Calculated Flux (W/m2)
Observed Flux (w/m2)
500
300
100
100
300
500

		Median Fractional Difference	Fractional Offset	r	RMS Diff	Slope of Linear Fit	Normal Deviation
TOA	Solar Up	0.12	0.08	0.90	68	0.72	65
	LW Up	0.06	0.06	0.89	13	0.89	11
	Solar CRE	0.20	-0.05	0.81	107	0.60	74
SFC	Solar Down	0.13	0.01	0.8	0.17	0.67	0.10
	LW Down	0.02	-0.01	0.90	11.5	0.82	8.7
	Solar CRE	0.14	-0.05	0.84	76	0.84	38

Error in Cloud Radiative Effect (W/m2) and Cloud Radiative Forcing (K/day)

	Hourly	Daily	Weekly	Monthly	Yearly
TOA Solar CRE (w m^{-2})	41	12	4.5	2.2	1.1
TOA IR CRE (w m^{-2})	9.2	2.7	1.0	0.50	0.25
Atm Solar CRE (w m^{-2})	42	16	4.6	2.3	1.2
Atm IR CRE (w m^{-2})	16	4.5	1.7	0.86	0.43
Sfc Solar CRE (w m^{-2})	18	5.2	2.0	0.98	0.49
Sfc IR CRE (w m^{-2})	13	3.7	1.4	0.69	0.35
Solar Heating Rate (K day^{-1})	23.4	6.8	2.6	1.3	1.1
IR Heating Rate (K day^{-1})	14.5	4.2	1.6	0.80	0.40

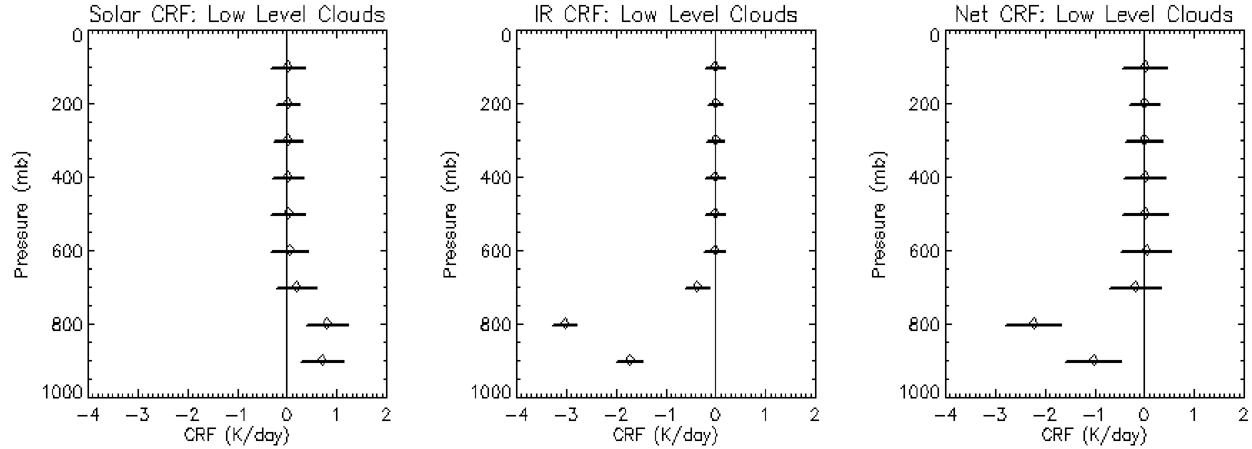
The CRF and CRE from Overcast Periods during the Year 2000 as a Function of Cloud Type

We define cloud types based on their base and top height and optical depth

Type	Definition	hours
Low Clouds	Tops < 3 km, _ > 0	218 (30%)
Deep Low	Bases < 3 km, Tops > 6.5 km, _ > 10	18 (3%)
Thin Mid	Bases > 3 km, Tops < 6.5 km , _ < 10	42 (6%)
Thick Mid	3 km < Base < 6.5 km, Top > 3 km, _ > 10	27 (4%)
Thin High	Base > 6.5 km, _ < 5	374 (51%)
Thick High	Base > 6.5 km, _ > 10	15 (2%)
High – Low	Low Clouds with High Clouds, all _	34 (5%)
All Overcast	No Specification as to type	977

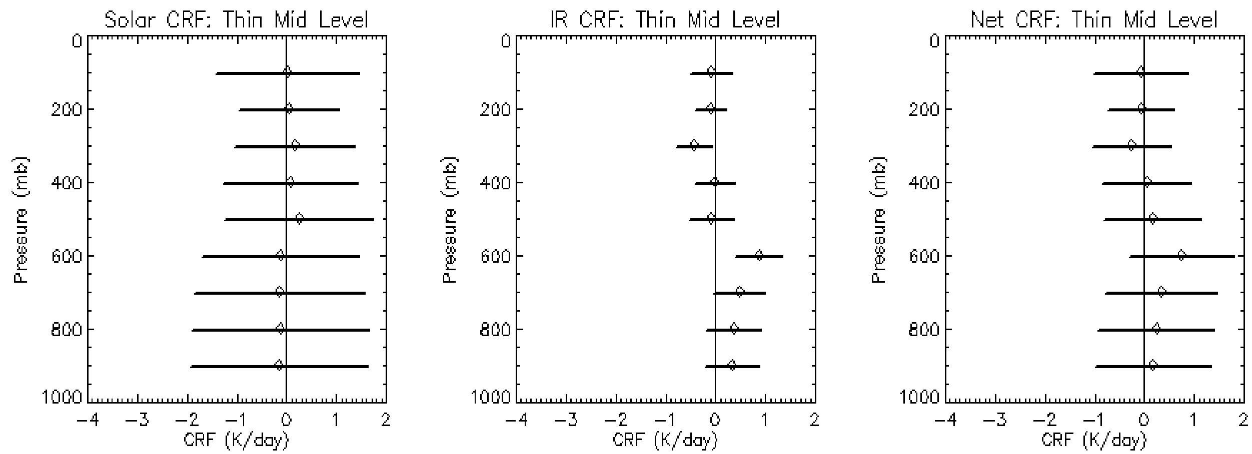
Low Level Clouds

Low Level	Solar	IR	Net
TOA	-130 (7)	+10 (3)	-120 (8)
ATM	+25 (8)	-63 (3)	-37 (9)
SFC	-156 (3)	+73 (2)	-83 (4)



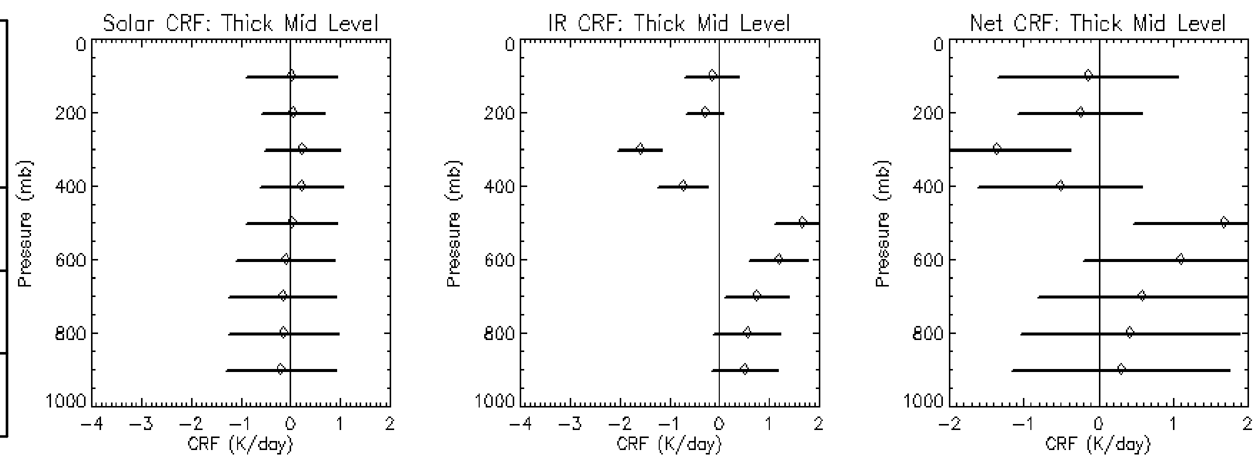
Thin Mid Level Clouds

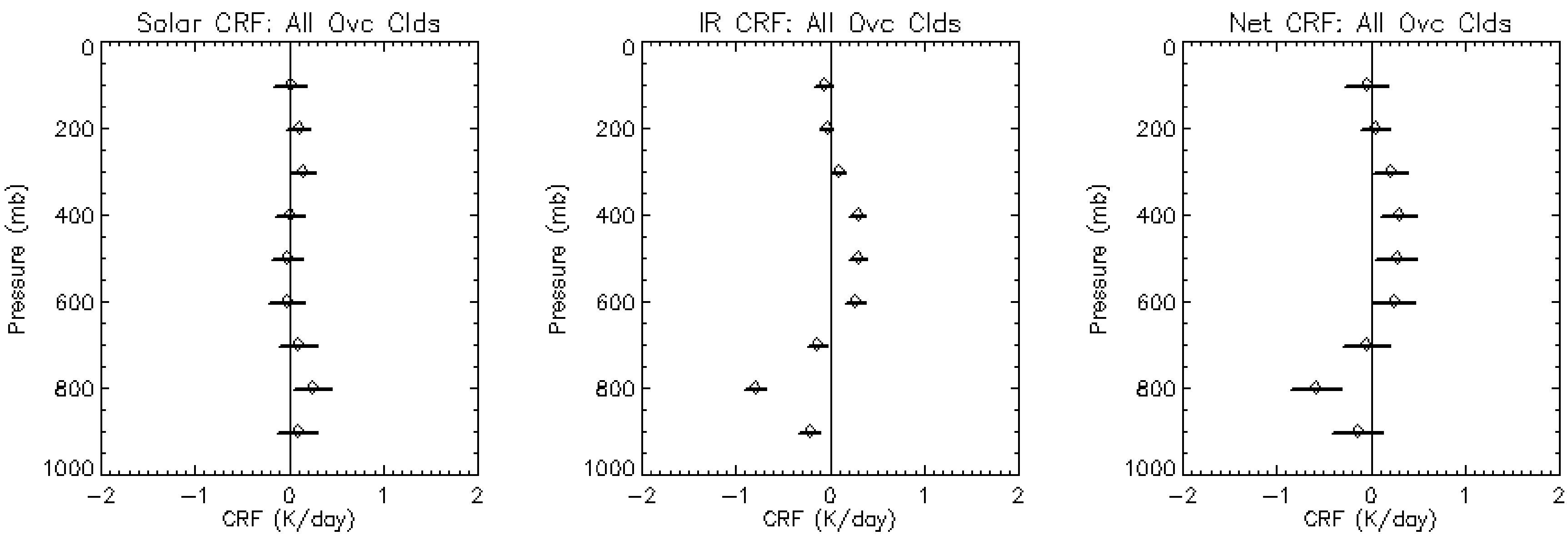
Thin Mid	Solar	IR	Net
TOA	-47 (12)	+46 (3)	-1 (14)
ATM	0 (14)	+17 (5)	+17 (16)
SFC	-47 (6)	+29 (4)	-17 (8)



Thick Mid Level Clouds

Thick Mid	Solar	IR	Net
TOA	-67 (16)	+71 (4)	+4 (18)
ATM	-1 (17)	+24 (6)	+23 (18)
SFC	-66 (7)	+47 (5)	-18 (9)



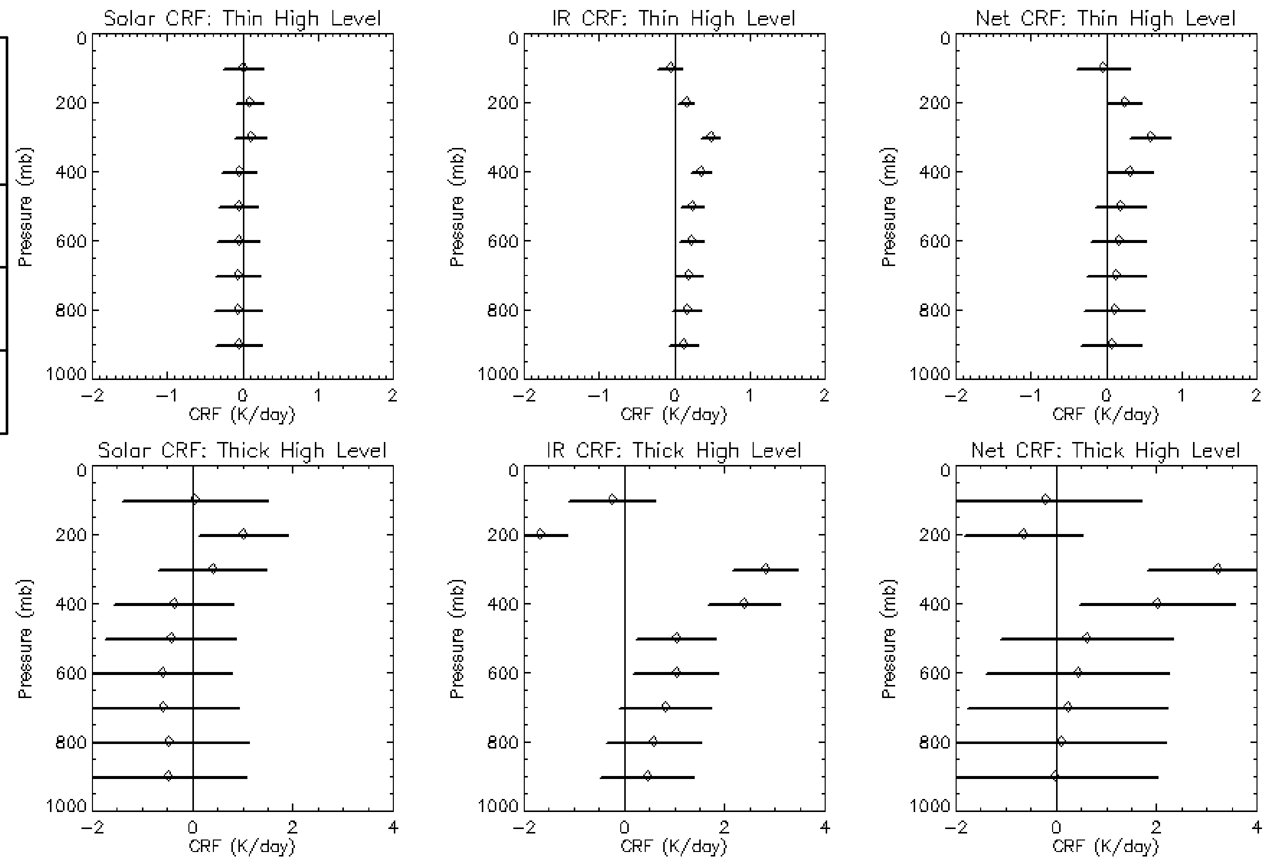


All Overcast Clouds

All Ovc	Solar	IR	Net
TOA	-56 (3)	+31 (1)	-25 (3)
ATM	+6 (3)	+1 (1)	+6 (3)
SFC	-62 (2)	+30 (1)	-32 (2)

Thin High Clouds

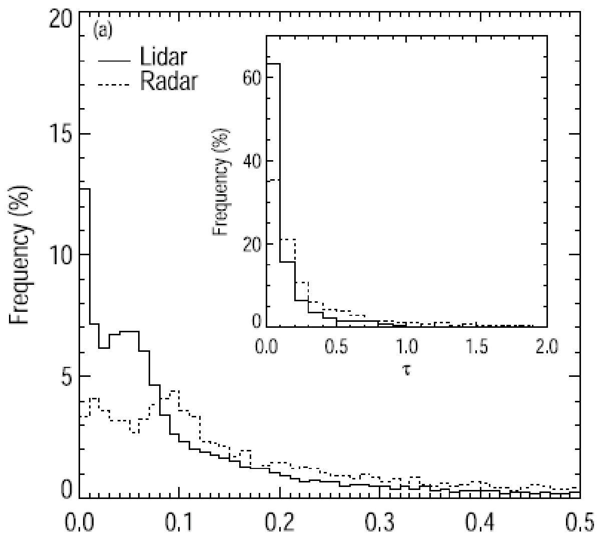
Thin High	Solar	IR	Net
TOA	-13 (2)	+29 (1)	+16 (2)
ATM	-1 (5)	+23 (2)	+21 (6)
SFC	-12 (2)	+6 (1)	-6 (2)

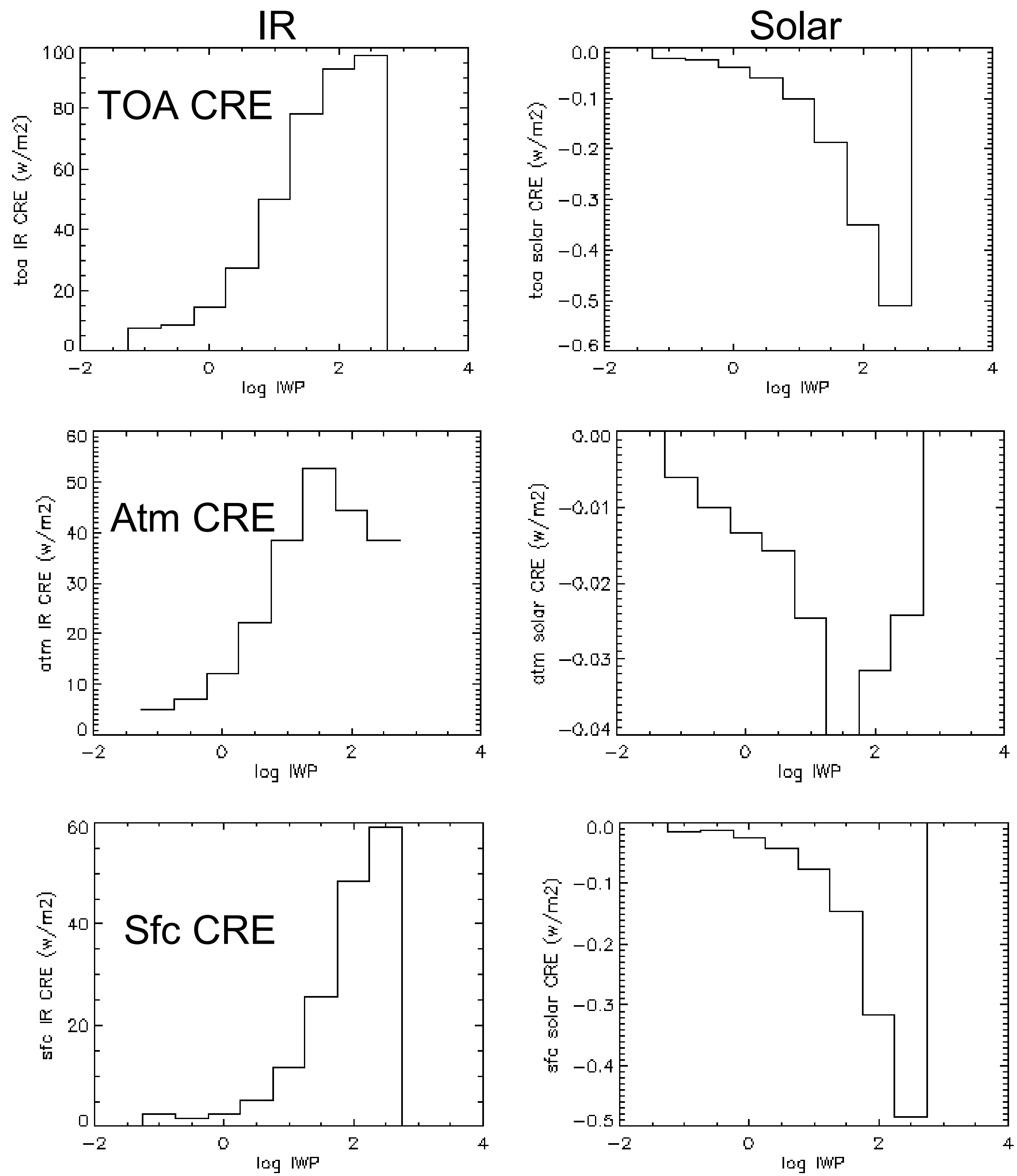


Thick High Clouds

Thick High	Solar	IR	Net
TOA	-138 (22)	+107 (6)	-30 (23)
ATM	-17 (25)	+87 (9)	+69 (27)
SFC	-119 (10)	+21 (7)	-99 (12)

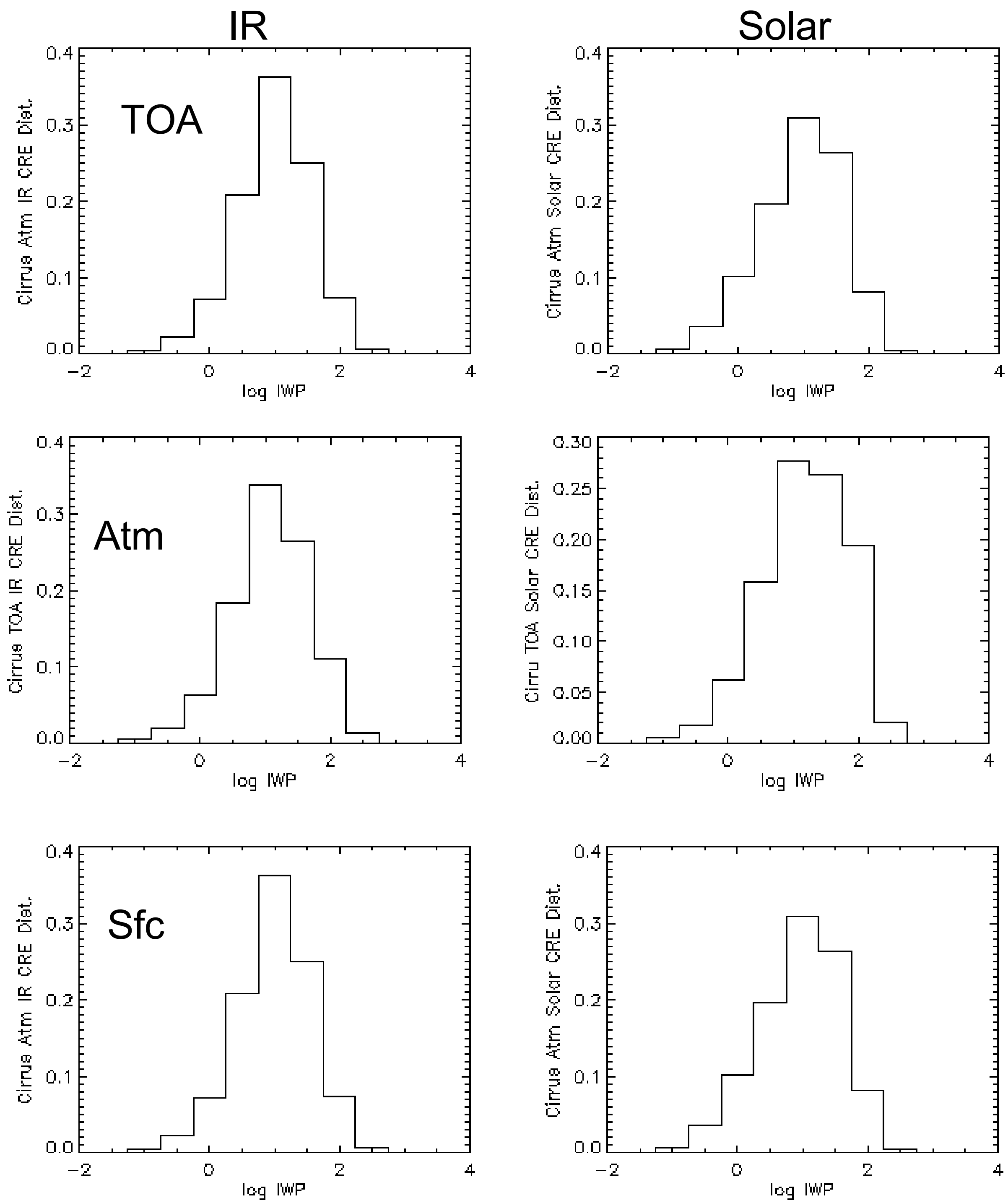
Cirrus Occurrence Frequency





What are radiatively important cirrus?

Convolve the Frequency of occurrence PDF with the radiative effect PDFs



The most radiatively important cirrus seem to be those in the 10 g/m2 range

Summary:

We are developing and implementing techniques to transfer the ARM ground-based data into physical descriptions of the atmospheric column

Enables characterization of the vertical distribution of CRF as a function of cloud type, large scale forcing, etc…