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Impacts of active satellite sensors' low-level cloud detection limitations on cloud radiative forcing in the Arctic

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Supplement:

- Table S1: Monthly mean surface broadband albedo during the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept
Year	1997	1997	1997	1998	1998	1998	1998	1998	1998	1998	1998	1998
Starting Julian Day	274	305	335	366	397	425	456	486	517	547	578	609
Ending Julian Day	304	334	365	396	424	455	485	516	546	577	608	638
Mean Albedo	0.85	N/A	N/A	N/A	0.85	0.84	0.85	0.85	0.76	0.55	0.69	0.84

- *Table S2: Mean cloud amount from surface observations, CALIPSO, CloudSat, combined CALIPSO and CloudSat (CC), cloud amount difference of CALIPSO and surface, CloudSat and surface, and combined CALIPSO and CloudSat (CC) and surface based on data from the Surface Heat Budget of the Arctic Ocean (SHEBA). Values are shown for all other layers between 149.5 m and 2050.0 m, every 5 layers between 2050.0 m and 4050.0 m, and every 10 layers between 4050.0 m and 12050.0 m. These values are the same as those shown in Figure 8.*

Height (m)	Surface (%)	CALIPSO (%)	CloudSat (%)	CC (%)	CALIPSO – Surface	CloudSat - Surface	CC - Surface
149.5	59.7	28.9	0.0	28.9	-30.7	-59.7	-30.7
275.5	57.9	29.6	0.0	29.6	-28.3	-57.9	-28.3
401.5	51.6	27.7	0.0	27.7	-23.9	-51.6	-23.9
527.5	42.8	22.7	0.0	22.7	-20.2	-42.8	-20.2
653.5	39.0	21.2	1.8	22.8	-17.8	-37.2	-16.2
779.5	37.1	20.5	13.1	27.6	-16.6	-24.0	-9.5
905.5	31.9	17.2	21.2	27.7	-14.7	-10.7	-4.2
1050.0	30.4	16.9	23.0	27.6	-13.4	-7.4	-2.7
1250.0	25.6	14.1	20.2	23.5	-11.5	-5.4	-2.1
1450.0	24.2	13.5	19.4	22.4	-10.7	-4.8	-1.8
1650.0	24.1	13.8	19.3	22.5	-10.3	-4.8	-1.6
1850.0	23.3	13.8	18.8	22.0	-9.5	-4.5	-1.3
2050.0	22.4	13.6	18.2	21.1	-8.9	-4.2	-1.3
2550.0	21.4	14.2	18.1	20.8	-7.2	-3.3	-0.7
3050.0	21.5	16.0	17.2	20.5	-5.0	-3.9	-0.6
3550.0	20.8	17.0	16.9	20.5	-3.8	-4.0	-0.4

4050.0	20.2	17.6	16.2	20.0	-2.6	-4.0	-0.2
5050.0	18.9	17.8	15.1	18.9	-1.1	-3.8	-0.0
6050.0	16.9	16.7	12.6	16.9	-0.2	-4.2	-0.0
7050.0	12.5	12.5	8.3	12.5	-0.0	-4.3	-0.0
8050.0	7.9	7.9	4.7	7.9	-0.0	-3.2	0.0
9050.0	3.2	3.2	1.5	3.2	-0.0	-1.7	0.0
10050.0	0.7	0.7	0.3	0.7	0.0	-0.4	0.0
11050.0	0.1	0.1	0.0	0.1	0.0	-0.0	0.0
12050.0	0.0	0.0	0.0	0.0	0.0	-0.0	0.0

- *Table S3: Mean cloud amount from surface observations, CALIPSO, CloudSat, and combined CALIPSO and CloudSat (CC) for ice clouds, liquid clouds, and mixed phase clouds.*

	Ice clouds (%)				Liquid clouds (%)				Mixed phase clouds			
Height (m)	Surface	CALIPSO	CloudSat	CC	Surface	CALIPSO	Cloudsat	CC	Surface	CALIPSO	CloudSat	CC
149.5	37.7	21.0	0.0	21.0	9.9	2.2	0.0	2.2	12.1	5.7	0.0	5.7
275.5	31.8	17.9	0.0	17.9	11.8	4.4	0.0	4.4	14.3	7.3	0.0	7.3
401.5	27.2	15.2	0.0	15.2	12.1	6.2	0.0	6.2	12.3	6.3	0.0	6.3
527.5	24.0	13.2	0.0	13.2	9.4	4.7	0.0	4.7	9.5	4.7	0.0	4.7
653.5	22.1	12.4	1.4	13.6	8.5	4.7	0.0	4.7	8.4	4.1	0.4	4.5
779.5	20.7	11.8	7.9	16.0	8.6	4.9	0.9	5.4	7.9	3.8	4.3	6.2
905.5	18.8	10.8	11.9	16.2	6.8	3.3	3.7	5.5	6.3	3.1	5.7	5.9
1050.0	18.1	10.6	13.1	16.2	6.2	3.2	4.2	5.5	6.1	3.1	5.7	5.9
1250.0	16.8	10.2	12.6	15.3	3.9	1.7	3.0	3.4	4.9	2.2	4.7	4.7
1450.0	16.1	10.0	12.5	14.9	3.8	1.6	2.8	3.3	4.3	2.0	4.1	4.2
1650.0	16.0	10.2	12.6	15.0	4.3	1.9	3.1	3.8	3.8	1.7	3.7	3.8
1850.0	15.9	10.5	12.6	15.0	3.9	1.8	2.8	3.5	3.6	1.5	3.5	3.5
2050.0	16.1	11.0	12.7	15.2	2.9	1.2	2.1	2.5	3.4	1.3	3.3	3.4
2550.0	15.1	11.5	12.4	14.7	2.9	1.1	2.3	2.6	3.5	1.6	3.4	3.5
3050.0	16.4	13.4	13.0	16.0	1.8	0.9	1.3	1.6	2.9	1.7	2.8	2.8
3550.0	16.9	14.7	13.4	16.7	1.4	0.7	1.0	1.3	2.5	1.6	2.5	2.5
4050.0	17.0	15.6	13.3	16.9	0.9	0.5	0.7	0.9	2.3	1.5	2.2	2.3
5050.0	17.1	16.4	13.5	17.1	0.9	0.6	0.7	0.9	1.3	1.0	1.3	1.3
6050.0	16.0	15.8	11.8	16.0	0.2	0.1	0.1	0.2	0.8	0.7	0.7	0.8
7050.0	12.1	12.1	7.9	12.1	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4
8050.0	7.8	7.8	4.6	7.8	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
9050.0	3.2	3.2	1.5	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10050.0	0.7	0.7	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11050.0	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12050.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

- Table S4: Monthly mean cloud radiative forcing (CRF) at the surface for longwave (LW), shortwave (SW), and the combined LW and SW (all) with the clouds from the surface observations collected during the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment and the differences between the CRF with clouds in the surface observations only identified from combined CloudSat and CALIPSO, CALIPSO, or CloudSat and the CRF from the clouds from the surface observations.

	All clouds from surface observations with hourly data			(CloudSat+calipso)-clouds from surface with hourly data			(CloudSat+calipso)-clouds from surface with per 15 minutes data			All clouds from surface observations with per 15 minutes data		
	LW	SW	all	LW	SW	all	LW	SW	all	LW	SW	all
Oct	32.7	-0.1	32.6	-1.0	0.0	-1.0	-1.0	0.0	-1.0	32.1	-0.1	32.0
Nov	34.2	0.0	34.2	-0.2	0.0	-0.2	-0.1	0.0	-0.1	34.0	0.0	34.0
Dec	21.0	0.0	21.0	0.2	0.0	0.2	0.1	0.0	0.1	20.5	0.0	20.5
Jan	22.0	0.0	22.0	0.3	0.0	0.3	0.3	0.0	0.3	21.8	0.0	21.8
Feb	20.5	-0.2	20.3	0.2	0.0	0.2	0.4	0.0	0.4	20.2	-0.2	19.9
Mar	34.6	-4.2	30.4	0.1	0.3	0.4	-0.1	0.2	0.2	34.8	-4.3	30.5
Aprl	42.5	-12.6	29.9	-0.9	0.6	-0.3	-0.8	0.6	-0.2	42.7	-12.7	30.0
May	43.3	-22.3	21.1	-3.0	2.9	-0.1	-3.1	2.9	-0.2	43.9	-22.6	21.4
Jun	44.4	-34.5	10.0	-2.5	3.6	1.1	-2.6	3.2	0.6	45.0	-34.5	10.5
Jul	43.9	-61.0	-17.1	-3.4	6.1	2.7	-3.0	5.5	2.4	44.0	-61.0	-16.9
Aug	59.8	-33.9	25.9	-2.8	4.0	1.2	-3.4	3.9	0.5	59.8	-33.4	26.4
Sept	63.2	-8.2	55.0	-3.0	0.4	-2.6	-2.9	0.4	-2.5	63.0	-8.2	54.9

- Table S5: Monthly mean cloud radiative forcing (CRF) at the top of atmosphere for longwave (LW), shortwave (SW), and the combined LW and SW (all) with the clouds from the surface observations collected during the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment and the differences between the CRF with clouds in the surface observations only identified from the CALIPSO and the CRF from the clouds from the surface observations. The CALIPSO cloud detection thresholds are 4, 5, and 6. This sentivity estimation is based on profiles with 1-hour interval.

	All clouds from surface observations	CALIPSO-clouds from surface, with	CALIPSO-clouds from surface, with	CALIPSO-clouds from surface, with

				cloud detection threshold of 4			cloud detection threshold of 5			cloud detection threshold of 6		
	LW	SW	all	LW	SW	all	LW	SW	all	LW	SW	all
Oct	32.7	-0.1	32.6	-4.8	0.0	-4.8	-2.1	0.0	-2.1	-1.3	0.0	-1.3
Nov	34.2	0.0	34.2	-3.7	0.0	-3.7	-2.4	0.0	-2.4	-1.4	0.0	-1.4
Dec	21.0	0.0	21.0	-0.4	0.0	-0.4	-0.2	0.0	-0.2	0.0	0.0	0.0
Jan	22.0	0.0	22.0	-0.3	0.0	-0.3	0.1	0.0	0.1	0.3	0.0	0.3
Feb	20.5	-0.2	20.3	-0.9	0.0	-0.8	-0.4	0.0	-0.4	-0.2	0.0	-0.2
Mar	34.6	-4.2	30.4	-3.8	0.7	-3.1	-2.4	0.5	-1.8	-1.4	0.5	-1.0
Aprl	42.5	-12.6	29.9	-4.4	2.0	-2.4	-3.1	1.6	-1.5	-2.4	1.3	-1.1
May	43.3	-22.3	21.1	-7.0	5.7	-1.3	-5.0	4.4	-0.6	-3.6	3.4	-0.2
Jun	44.4	-34.5	10.0	-12.3	12.4	0.2	-9.1	10.0	0.9	-6.9	8.0	1.2
Jul	43.9	-61.0	-17.1	-12.4	21.6	9.2	-9.1	17.6	8.6	-6.7	14.7	8.0
Aug	59.8	-33.9	25.9	-14.4	11.7	-2.7	-10.0	9.4	-0.7	-7.6	7.9	0.3
Sept	63.2	-8.2	55.0	-19.3	3.1	-16.2	-15.0	2.6	-12.4	-11.3	2.1	-9.2

- Table S6: Monthly mean cloud radiative forcing (CRF) at the surface for longwave (LW), shortwave (SW), and the combined LW and SW (all) with the clouds from the surface observations collected during the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment and the differences between the CRF with clouds in the surface observations only identified from combined CloudSat and the CRF from the clouds from the surface observations. The CloudSat's thresholds are threshold -10, threshold -15, and threshold-20. This sentivity estimation is based on profiles with 1-hour interval.

	All clouds from surface observations			CloudSat-clouds from surface, with threshold - 10			CloudSat-clouds from surface, with threshold - 15			CloudSat-clouds from surface, with threshold - 20		
	LW	SW	all	LW	SW	all	LW	SW	all	LW	SW	all
Oct	32.7	-0.1	32.6	-14.6	0.1	-14.6	-14.2	0.1	-14.1	-2.1	0.0	-2.1
Nov	34.2	0.0	34.2	-9.5	0.0	-9.5	-9.0	0.0	-9.0	-2.4	0.0	-2.4
Dec	21.0	0.0	21.0	-2.9	0.0	-2.9	-2.7	0.0	-2.7	-0.2	0.0	-0.2
Jan	22.0	0.0	22.0	-9.3	0.0	-9.3	-9.1	0.0	-9.1	0.1	0.0	0.1
Feb	20.5	-0.2	20.3	-3.2	0.0	-3.1	-3.1	0.0	-3.1	-0.4	0.0	-0.4
Mar	34.6	-4.2	30.4	-8.3	1.2	-7.1	-8.0	1.2	-6.8	-2.4	0.5	-1.8
Aprl	42.5	-12.6	29.9	-16.1	4.9	-11.1	-15.9	4.9	-11.0	-3.1	1.6	-1.5
May	43.3	-22.3	21.1	-23.5	12.0	-11.5	-22.6	11.5	-11.1	-5.0	4.4	-0.6
Jun	44.4	-34.5	10.0	-16.8	11.5	-5.4	-16.4	11.1	-5.3	-9.1	10.0	0.9
Jul	43.9	-61.0	-17.1	-15.9	19.2	3.3	-15.7	19.0	3.3	-9.1	17.6	8.6

Aug	59.8	-33.9	25.9	-22.0	13.7	-8.4	-20.9	13.0	-7.9	-10.0	9.4	-0.7
Sept	63.2	-8.2	55.0	-16.2	2.0	-14.2	-15.3	1..9	-13.5	-15.0	2.6	-12.4

- Table S7: Monthly mean cloud radiative forcing (CRF) at the surface for longwave (LW), shortwave (SW), and the combined LW and SW (all) with the clouds from the surface observations collected during the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment and the differences between the CRF with clouds in the surface observations only identified from combined CloudSat and CALIPSO with different thresholds and the CRF from the clouds from the surface observations. This sentivity estimation is based on profiles with 1-hour interval.

	All clouds from surface observations			(CloudSat+CALIPSO)-clouds from surface, CloudSat threshold of standard-15, and CALIPSO threshold of 5			(CloudSat+CALIPSO)-clouds from surface, CloudSat threshold of standard-20, and CALIPSO threshold of 6 (maximum detection)			(CloudSat+CALIPSO)-clouds from surface, CloudSat threshold of standard-10, and CALIPSO threshold of 4 (minimum detection)		
	LW	SW	all	LW	SW	all	LW	SW	all	LW	SW	all
Oct	32.7	-0.1	32.6	-1.0	0.0	-1.0	-0.6	0.0	-0.6	-1.8	0.0	-1.8
Nov	34.2	0.0	34.2	-0.2	0.0	-0.2	-0.1	0.0	-0.1	-0.7	0.0	-0.7
Dec	21.0	0.0	21.0	0.2	0.0	0.2	0.2	0.0	0.2	0.2	0.0	0.2
Jan	22.0	0.0	22.0	0.3	0.0	0.3	0.3	0.0	0.3	0.1	0.0	0.1
Feb	20.5	-0.2	20.3	0.2	0.0	0.2	0.1	0.0	0.1	0.3	0.0	0.4
Mar	34.6	-4.2	30.4	0.1	0.3	0.4	0.5	0.3	0.7	-0.2	0.3	0.1
Aprl	42.5	-12.6	29.9	-0.9	0.6	-0.3	-0.7	0.4	-0.2	-1.4	0.8	-0.6
May	43.3	-22.3	21.1	-3.0	2.9	-0.1	-2.0	2.1	0.1	-4.3	3.8	-0.5
Jun	44.4	-34.5	10.0	-2.5	3.6	1.1	-1.8	3.0	1.2	-4.1	4.7	0.7
Jul	43.9	-61.0	-17.1	-3.4	6.1	2.7	-2.4	4.9	2.5	-4.8	7.6	2.8
Aug	59.8	-33.9	25.9	-2.8	4.0	1.2	-1.7	3.3	1.6	-4.8	5.2	0.4
Sept	63.2	-8.2	55.0	-3.0	0.4	-2.6	-2.3	0.3	-2.0	-3.8	0.5	-3.3

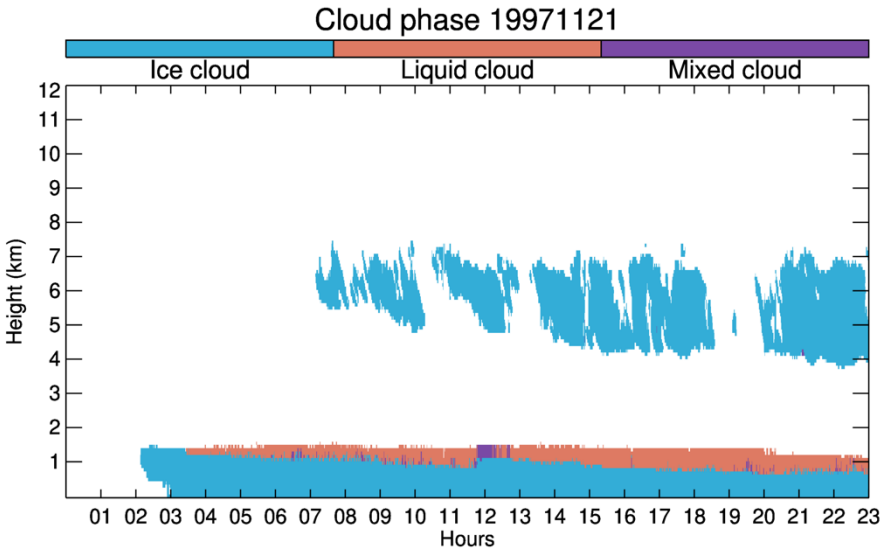

Figure S1: Cloud phase vertical profile on November 21 1997 collected in the Surface Heat Budget of the Arctic Ocean (SHEBA).

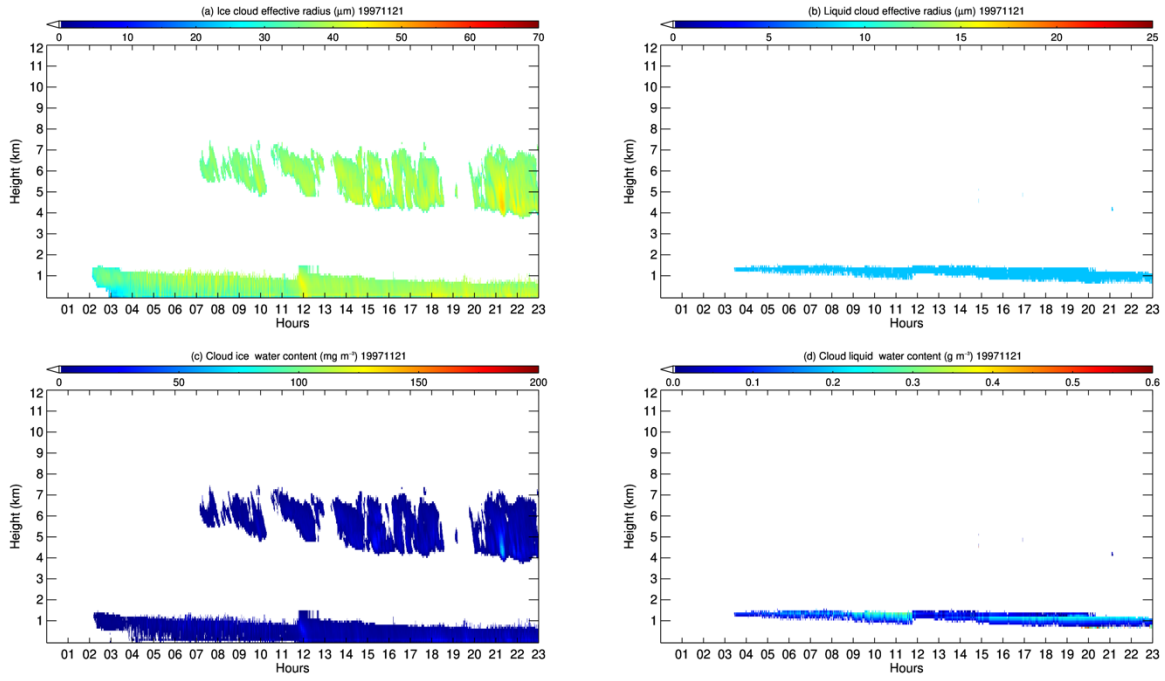

Figure S2: Cloud vertical profile on November 21 1997 collected in the Surface Heat Budget of the Arctic Ocean (SHEBA), including (a) ice cloud effective radius, (b) liquid cloud effective radius, (c) cloud ice water content, and (d) cloud liquid water content.

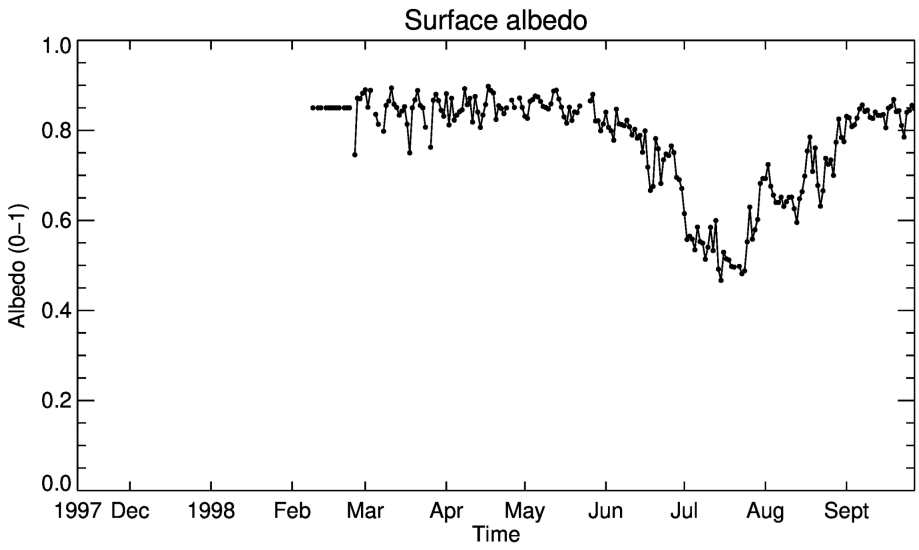

Figure S3: Annual cycle of the surface broadband albedo during the Surface Heat Budget of the Arctic Ocean (SHEBA) experiment.

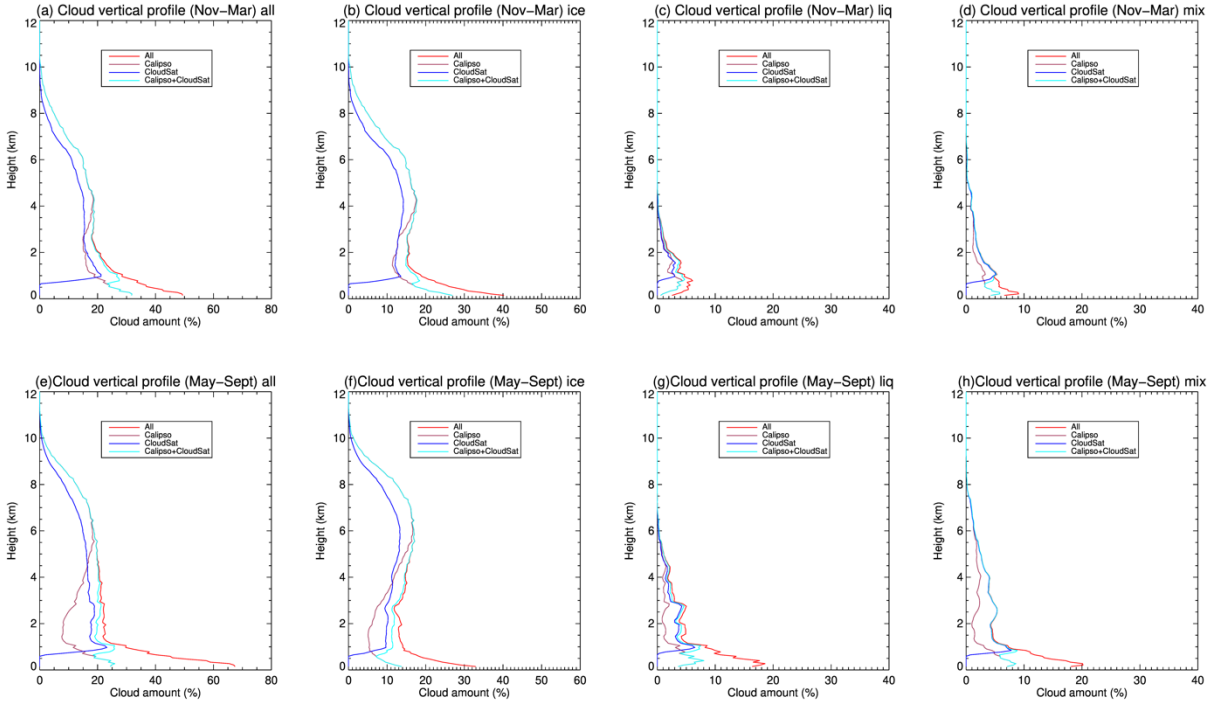

Figure S4: Mean cloud amount vertical distributions from surface observations during the Surface Heat Budget of the Arctic Ocean (SHEBA) and from estimated CloudSat, CALIPSO, and combined CloudSat and CALIPSO for (a) ice (b) liquid and (c) mix phase cloud from November to March, and for (d) ice (e) liquid and (f) mix phase cloud from May to September.

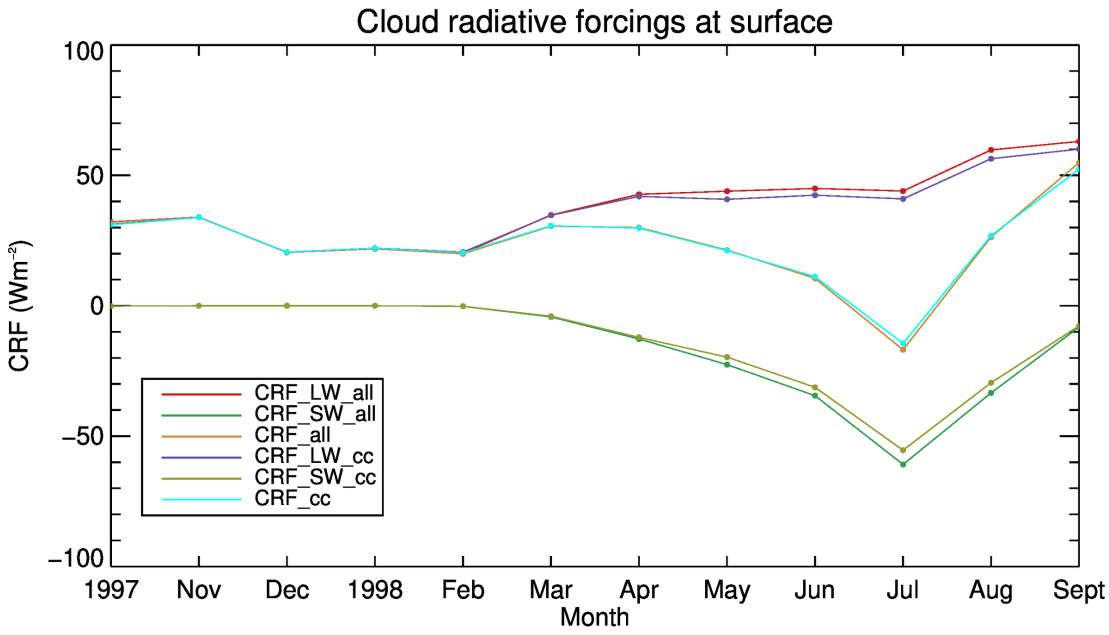

Figure S5: Monthly mean cloud radiative forcing (CRF) at surface for longwave (LW) and shortwave (SW) with cloud from surface observations collected during the Surface Heat Budget of the Arctic Ocean (SHEBA) (all) and with cloud from combined CloudSat and calipso (cc)..

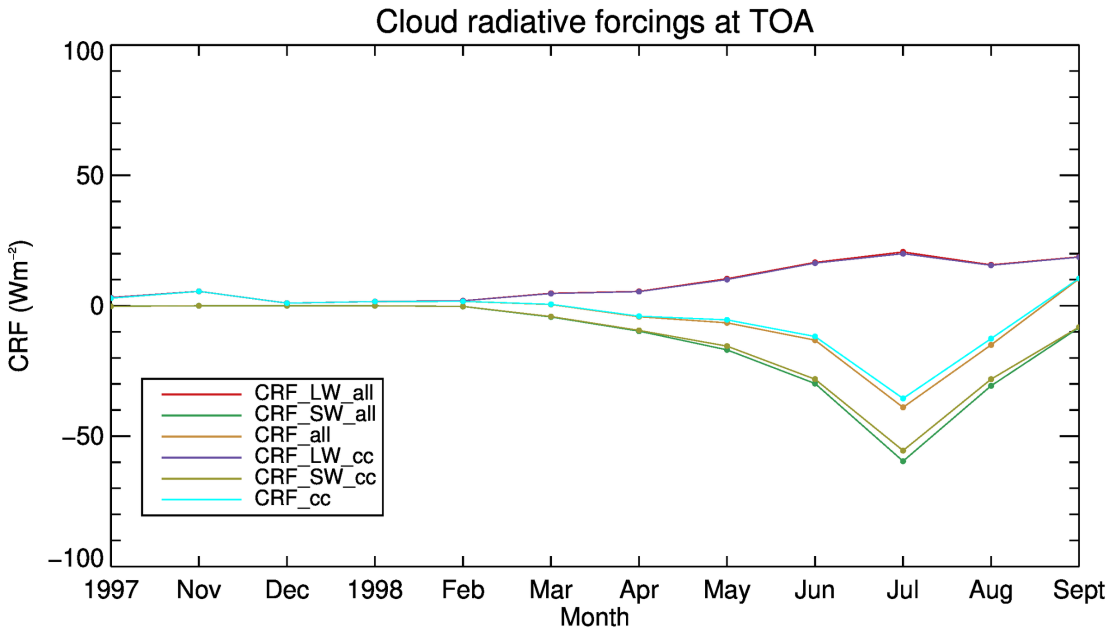

Figure S6: Same as Figure S5, but at the top of atmosphere (TOA).

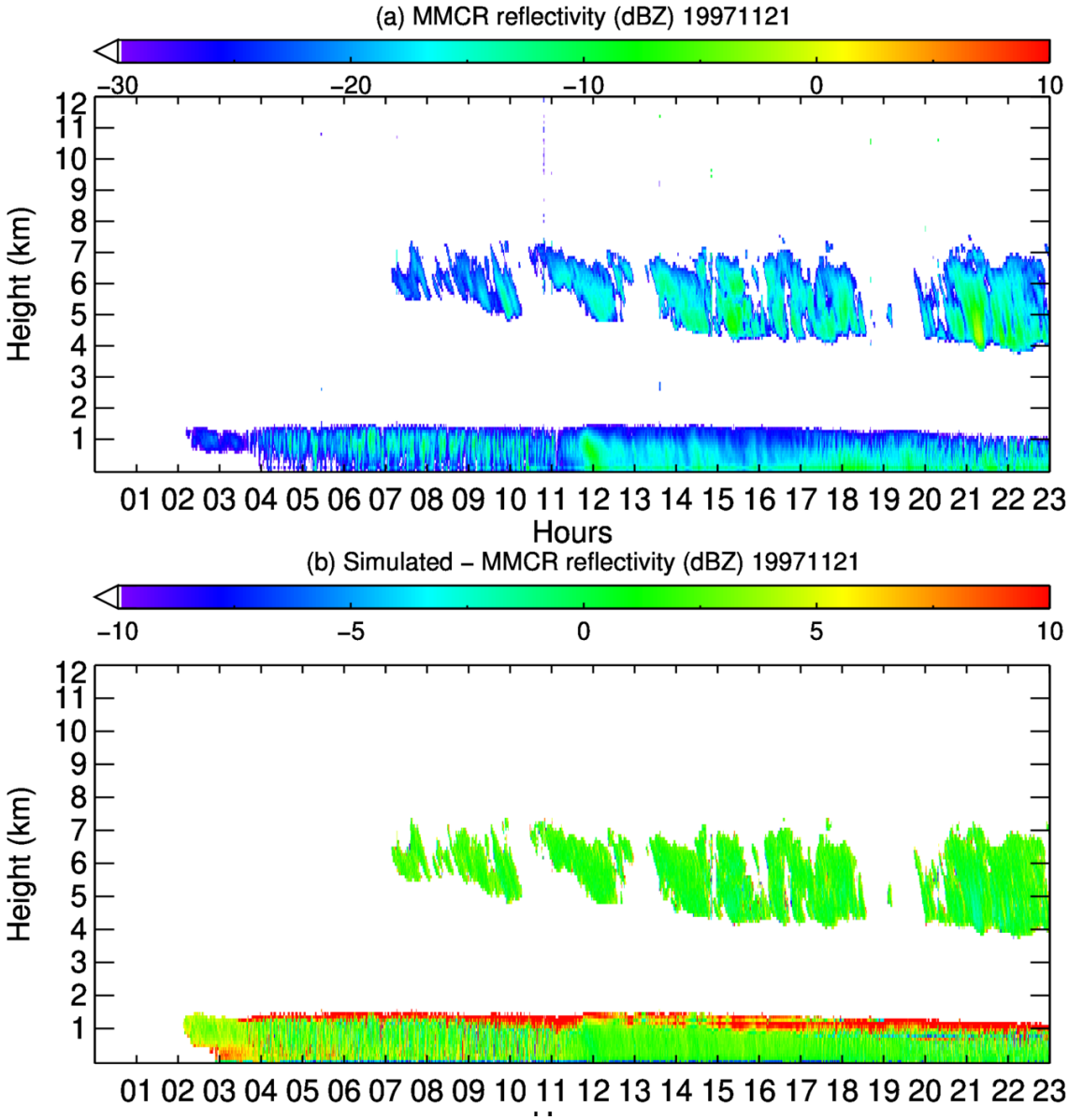

Figure S7: (a) Observed 35 GHz millimeter cloud radar (MMCR) reflectivity and (b) difference between the simulated and the observed MMCR reflectivity on November 21, 1997.