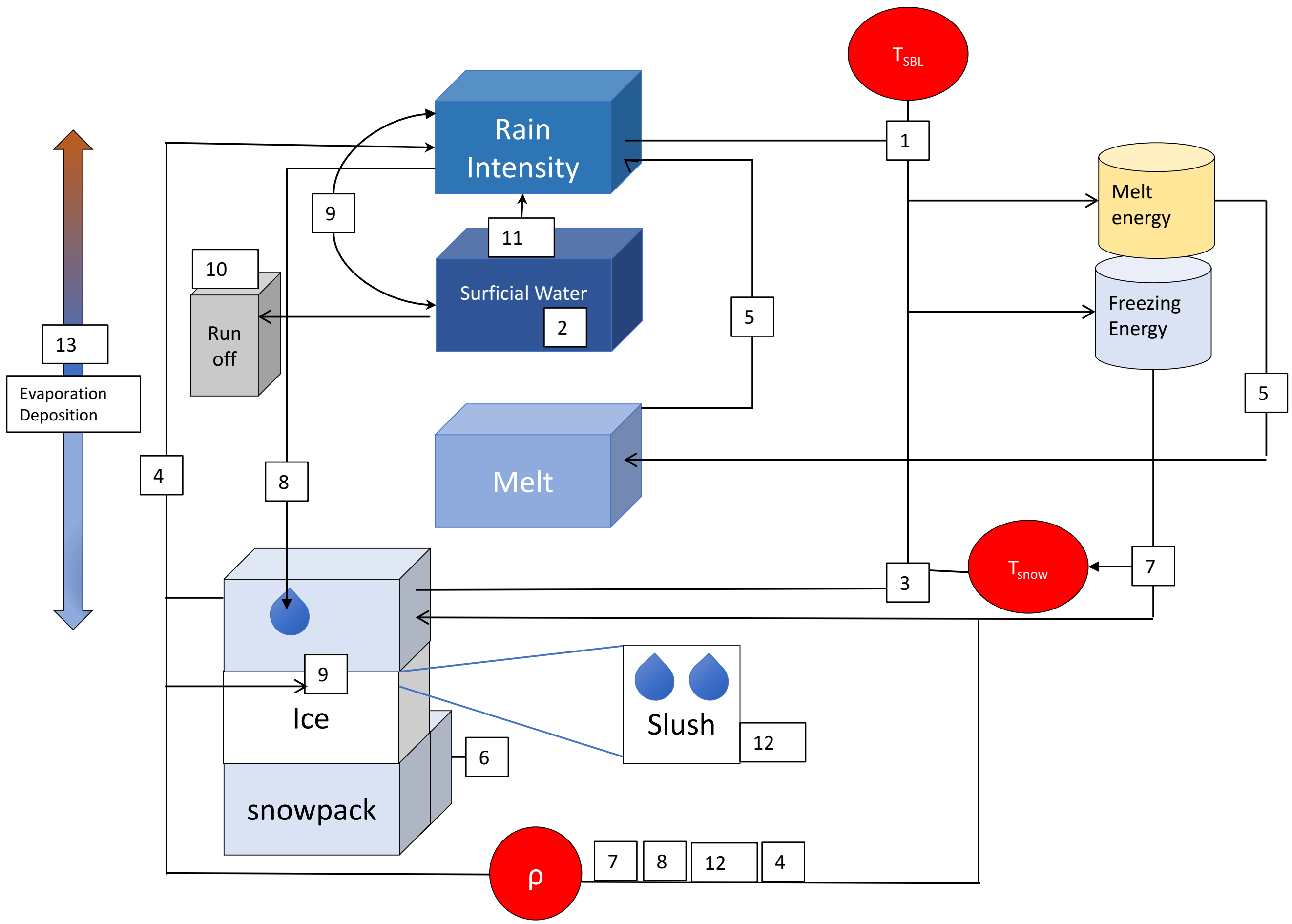
1
2



Rain Intensity
Surficial Water
Melt
Run off
Ice
snowpack
Slush
Evaporation Deposition
Melt energy
Freezing Energy
T_{SBL}
T_{snow}
ρ
1
2
3
4
5
5
6
7
7
8
8
9
9
10
11
12
12
13
4

(a)

Step | **Effect on Variables**

1) Energy from Rain — Energy + or -

Energy <- RI * Cw * T_{exc} * t

2) Surficial Water Exists? (a function of T_{exc})

3) Energy from Snow — Energy + or -

Energy <- ρ * Cs * T_{exc} * ds

4) Water from snowpack — Rain Intensity +, density -

RI <- ρ*ds * (soil humidity)   ρ reduced by soil humidity

5) MELT (when Energy is positive) — Energy -, snow depth -, Rain Intensity +

melted snow <- Energy / (Lf * ρ)

ds -> melted snow -> RI

6) Alter the snow history based on whether melting is occurring

faceted crystals? Liquid water with no faceted crystals?

Liquid water with faceted crystals before?

7) FREEZE (when Energy is negative) — Temperature -, Rain Intensity -, Energy +, Density +

Energy / (Lf * ρ) <- frozen water <- RI

Tsnow -> Energy / (ρ * ds * Cs)

ρ increased by the addition of frozen water

8) Water saturation in snow — Rain Intensity -, Density +

an irreducible portion of the snowpack must contain water.

RI -> irreducible water in snowpack (constant * pore volume * ds * density(water)

irreducible water in snowpack -> ρ

***

Step | **Effect on Variables**

9) Pore hole close off / superimposed ice — Surficial Water, Rain Intensity + / -

Whether a pore hole closes off is determined as a function of density, density of ice and a constant value for pore hole close off density.

Pore close off -> RI converted to surficial water

No pore close off -> RI remains in RI

***

10) Surficial water runoff — Surficial water -, Runoff +

Final Energy reduced by Energy from rain (Step 1)

A decay function determines the portion of surficial water converted to runoff

Reference: Zuo and Oerlemans, 1996

***

11) Conversion back to rain — Rain Intensity +, Surficial water -

Where no superimposed ice occurs (Step 9 above), surficial water is added back into RI (rain intensity)

12) Slush — Surficial water -, density +

Where surficial water exists (step 2), the highest snow/ice layer will fill the pore volume with water from surficial water, adding to density

slush + <- surficial water   slush -> ρ +

***

13) Add/Subtract Deposition/Sublimation — Soil/Ice Humidity +/-, Temp +/-, snowpack +/-

Snowpack either +/ -

DepOrSubl= t * LHF / (Lx * ρ) <- -> ds   added to the snowpack

Energy of vapor calculated

EnVp = (Cs * T_{exc}-Lf * (1-soil humidity)) / (1 + (DepOrSubl / ds))

and used to alter humidity of soil/snow

Hum = 1 + (EnVp – Texc * Cs) / Lf

as well as the temperature

T_{exc} = (EnVp + Lf*(1-Hum))/ Cs

*** denotes steps where tuning is possible or separate physics are calculated depending on the region

Variables			Constants:		
RI	Rain Intensity	kg m^{-2} s^{-1}	Cw	Heat Capacity of Water	$Jkg^{-1}K^{-1}$
T_{exc}	Temp above/below 0	C	Cs	Heat Capacity of snow	$Jkg^{-1}K^{-1}$
t	Time elapsed	s	Lf	Latent heat of fusion	Jkg^{-1}
ρ	density snow	kg m^{-3}	Lx	Latent Heat of Vap/Subl	Jkg^{-1}
ds	snow depth	m			
LHF	latent heat flux W m^{-2}				

(b)

Figure 1: Diagram (a) and description (b) of the physical processes within MAR's SISVAT (Soil Ice Vegetation Atmosphere Transfer Scheme) calculating meltwater production and meltwater percolation into the snowpack from the energy balance and the presence of water, using the density of the snowpack (ρ), temperature of the surface boundary layer (T_{SBL}) and temperature of the snow (T_{SNOW}).

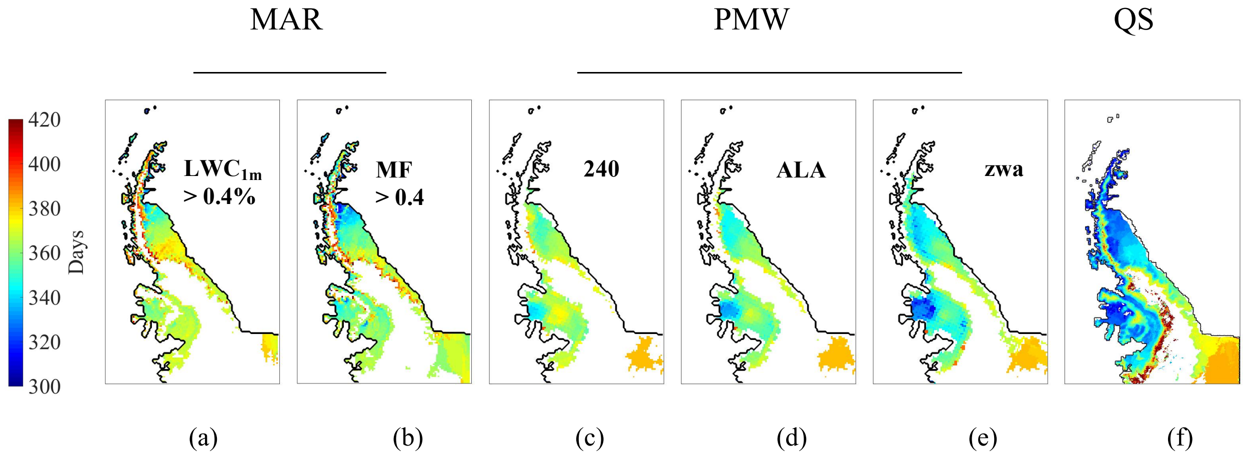


Figure 2: Average Melt Onset date from multiple sources (a) MAR, Liquid Water Content > 0.4% for three consecutive days. (b) MAR Total Melt Flux > 0.4 mmwe for 1 day or more. Satellite-based: (c) PMW 240 algorithm (d) PMW ALA (e) PMW Zwa (f) QuikSCAT. Day shown is the first day of a sustained three-day melt period for satellite estimates as well as LWC_{1m}, Date number is defined beginning in Jan 1st. of year1, such that 365 represents Dec 31st of year1. All averages are taken from the 2000-2009 period to retain consistency with the availability of QuikSCAT data.

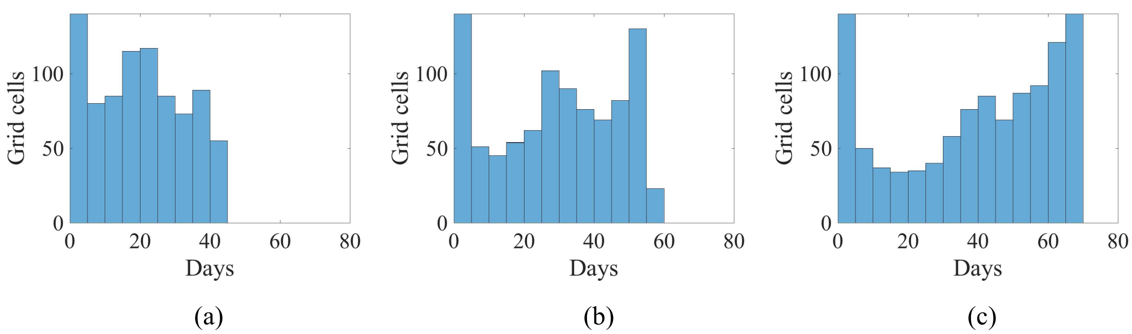


Figure 3: Number of 10km MAR grid cells from the NE basin (y axis) showing the avg number of total melt days (2001-2014) from three passive microwave algorithms: (a) PMW 240 (b) PMW ALA (c) PMW zwa

Region	**Avg. Annual Melt Days (2001-2014)** [Days]	**Elevation** [m]	**Avg coincident MAR Meltwater Production NDJF (2001 to 2014)** [mmWE/100km^2]
240 L	1 ≤ D < 10	833.70 ± 539.62	7.81
240 M	10 ≤ D < 30	72.37 ± 90.98	55.32
240 H	30 ≤= D	42.94 ± 17.78	95.09
ALA L	1 ≤ D < 15	1016.13±525.80	7.28
ALA M	15 ≤ D < 40	125.97±200.67	62.94
ALA H	40 ≤= D	56.92±56.69	128.72
zwa L	1 ≤ D < 20	1165.99±513.24	7.82
zwa M	20 ≤ D < 45	374.80±471.47	47.55
zwa H	45 ≤ D	101.73±173.27	126.19
CL Region		42.67±17.68	
PMW All	36.63 ± 4.01	39.15±17.87	96.15
$MF_{0.4}$	21.29±9.10	42.15±16.05	143.08
NL Region		594.12±601.20	
PMW All	7.74±8.90	86.72±137.87	41.24
$MF_{0.4}$	26.68±24.94	126.88±159.87	231.97

Table 1: Average statistics for regions of melt occurrence, restricted to the NE basin. The first 9 rows indicate regions where melt occurrence is determined by a PMW algorithm (i.e. 240) restricted by the number of days where melt occurrence (i.e. 240 L, where the number of avg annual melt days is between 1 and 10). CL and NL regions are described in text. Row indicating "PMW All"or "$MF_{0.4}$" in left column implies that corresponding statistics in columns 2-4 are calculated for where melt occurrence meets these conditions

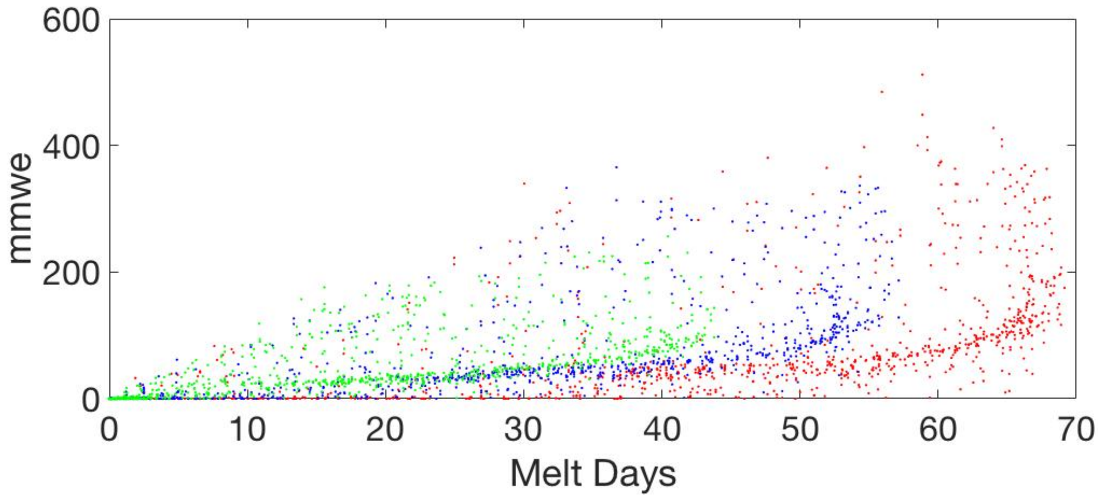


Figure 4: Avg Melt Days (2001-2014) from three passive microwave algorithms (described in text). Green shows PMW 240. Blue shows PMW ALA. Red shows PMW zwa.

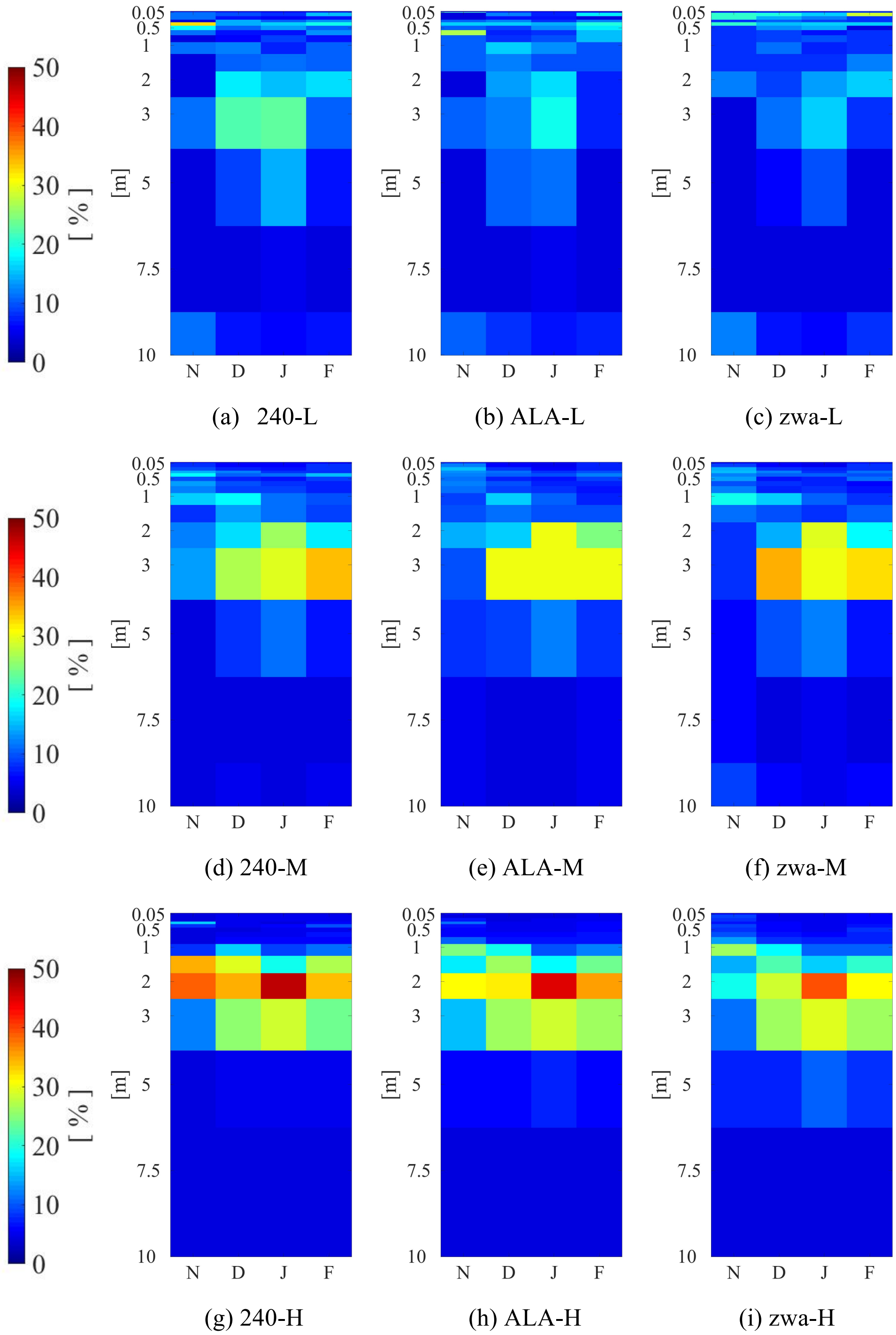


Figure 5: Maximum depth of MAR-modeled meltwater percolation (MAR) into the snowpack over the melt season. Colors indicate the percentage of grid cells where meltwater reaches the corresponding maximum depth (y axis) for the month (x axis), such that each column per month totals to 100%. Maximum percolation depth is determined by the maximum depth over the month where liquid water content in MAR is greater than 0.02 kg/kg. Grid cells for each column are restricted to the corresponding month during the 2001-2014 period which fulfill the conditions (a) 240-L (b) ALA-L (c) zwa-L (d)240-M (e) ALA-M (f) zwa-M (g) 240-H (h) ALA-H (i) zwa-H, as defined in table 1.

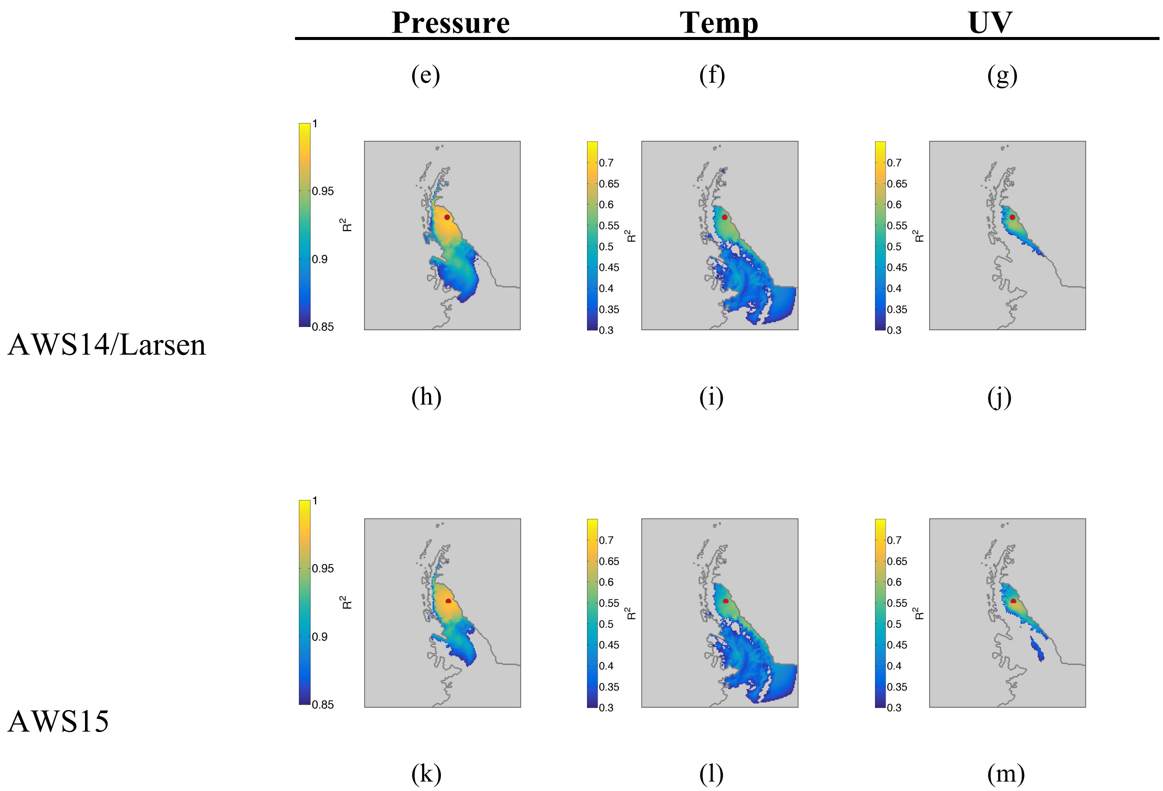


Figure 6: Left column is for surface pressure. Middle column for daily-averaged 2m air temperature, right column for 2m wind speed. Stations are as follows: Dismal Island (a)(b)(c) AWS 14/Larsen Ice Shelf, which are co-located in MAR (d)(e)(f) AWS 15

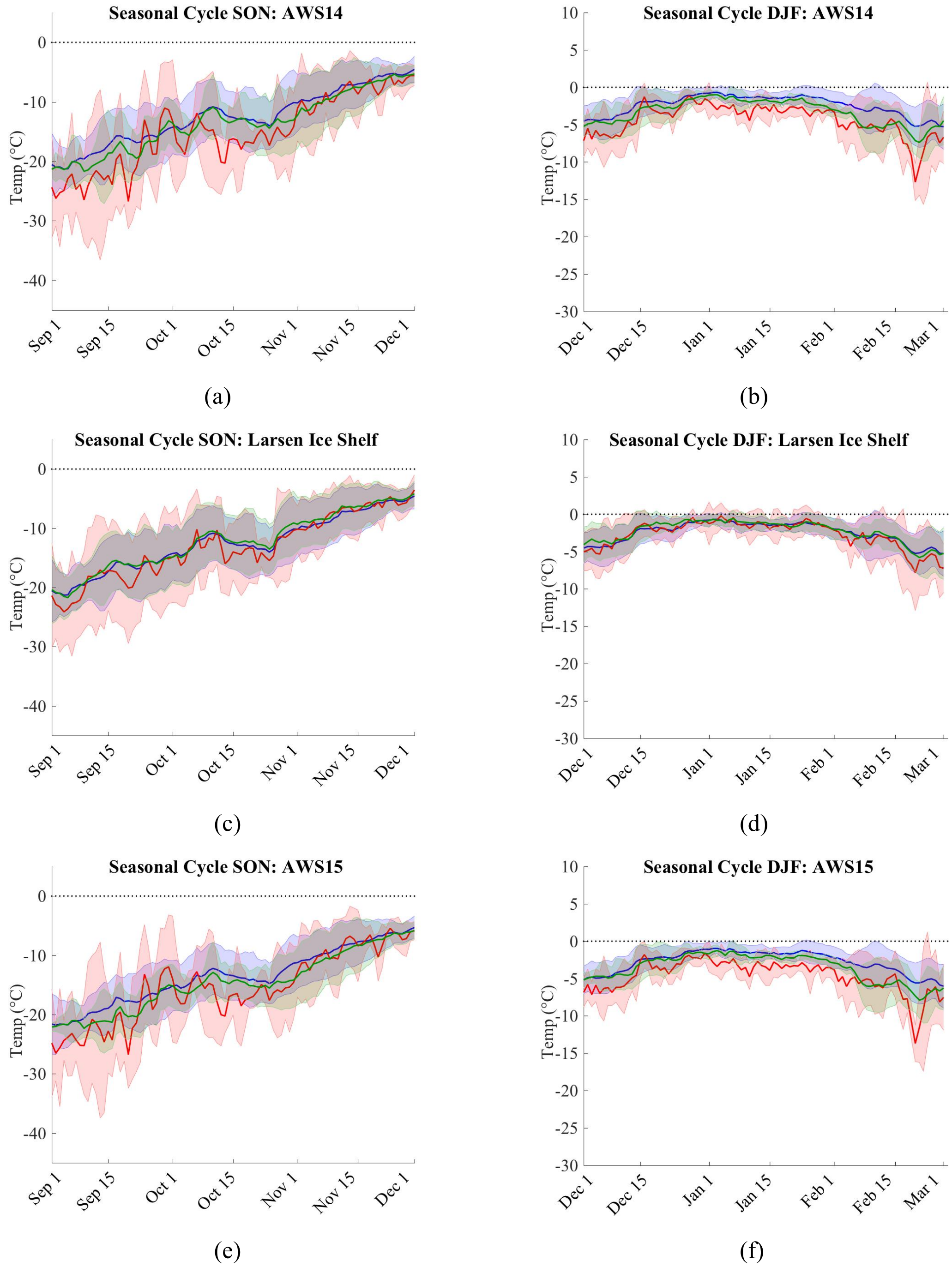


Figure 7: Seasonal Avg Ts climatology for spring (SON) and summer(DJF) with envelope indicating one standard deviation, Red: computed for available data from AWS station, with quality control as described in section 2. Green: MAR daily-averaged Ts data restricted to AWS-data availability. Blue: MAR daily-averaged T2m data for the full period (1999-2014). Data is shown for (a)(b) AWS 14 (c)(d) Larsen Ice Shelf (e)(f) AWS 15

	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
AWS14									0.98	0.98	0.98	0.99	0.97
AWS15									0.98	0.98		0.60	0.97
Larsen IS	0.99	0.98	0.98				0.98	0.98	0.98	0.98	0.98		

Table 2: R^2 values between MAR and AWS data for Surface Pressure in Summer (DJF) for years shown

	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
AWS14									2.36	1.71	2.36	2.4	2.48
AWS15									2.46	2.05		6.04	1.97
Larsen IS	1.14	1.71	2.01				2.07	2.25	2.25	1.77	2.19		

Table 3: Root Mean Squared Error between MAR and AWS data for Pressure [hPa] in Summer (DJF) for years *shown*

	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
AWS14									-2.10	-1.32	-2.04	-2.26	-2.17
AWS15									-2.21	-1.72		-0.84	-1.59
Larsen IS	-0.65	-1.21	-1.66				-1.59	-1.82	-1.95	-1.36	-1.83		

Table 4: Mean Error (MAR-AWS) for Pressure [hPa] in Summer (DJF) for years shown

	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
AWS14									0.68	0.41	0.71	0.39	0.59
AWS15									0.66	0.50	0.63	0.35	0.58
Larsen IS	0.36	0.27	0.56				0.57	0.67	0.70	0.44	0.71		

Table 5: R^2 values between MAR and AWS data for daily-averaged 2m air temperature in Summer (DJF) for years shown

	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
AWS14									1.91	2.19	2.56	2.60	2.47
AWS15									2.10	1.99	2.91	2.72	2.45
Larsen IS	1.39	2.20	3.37				1.82	2.36	1.62	1.81	2.34		

Table 6: Root Mean Squared Error between MAR and AWS data for daily-averaged 2m air temperature [°C] in Summer (DJF) for years shown

	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11	11-12	12-13	13-14
AWS14									0.98	1.00	1.61	0.32	1.30
AWS15									1.06	0.81	1.60	0.32	1.11
Larsen IS	-0.52	0.15	2.22				0.94	1.23	0.36	0.26	1.01		

Table 7 : Mean Error (MAR-AWS) for daily-averaged 2m air temperature [°C] in Summer (DJF) for years shown

 0-90° recorded by AWS 0-90° recorded by MAR 

	Pr. [%]	Mean Avg Ts [°C]		Mean MaxTs [°C]		Temp Bias [°C]			
		MAR	AWS	MAR	AWS	AvgTs	AvgTs>0	MaxTs	MaxTs>0
ALL	16.7	-1.59 (1.68)	-2.08 (2.90)	-0.94 (1.61)	2.36 (1.37)	0.48 (2.19)	-1.21 (1.04)	-1.99 (2.20)	-2.80 (1.60)
MAR	18.4	-0.45 (0.53)	-1.13 (1.32)	-0.06 (0.82)	2.91 (1.82)	0.69 (1.31)	-0.68 (0.74)	-2.40 (1.96)	-2.52 (1.62)
PMWEx	23.4	-1.58 (0.72)	-1.19 (1.26)	-0.89 (0.87)	1.58 (1.86)	-0.40 (1.20)	-1.67 (0.79)	-2.48 (1.68)	-3.09 (1.43)
QSEx	18.5	-1.89 (1.09)	-1.71 (1.79)	-1.09 (1.11)	1.16 (2.04)	-0.18 (1.43)	-1.90 (0.97)	-2.25 (1.81)	-2.99 (1.54)

Table 8: Temperature averages and biases and proportions of case 1 (AWS-observed northeasterly winds being preserved in MAR) as a percentage of all wind direction values for the condition. Conditions are for ALL (without regard to melt occurrence), MAR (when MAR reports melt from the $MF_{0.4}$ condition, PMWEx (when ALL PMW algorithms show melt, but MAR does not) and QSEx (when QuikSCAT ft3 show melt, but MAR does not)

 0-90° recorded by AWS 270-360° recorded by MAR 

	Pr. [%]	Mean Avg Ts [°C]		Mean MaxTs [°C]		Temp Bias [°C]			
		MAR	AWS	MAR	AWS	AvgTs	AvgTs>0	MaxTs	MaxTs>0
ALL	11.2	-1.25 (±1.57)	-2.04 (±2.72)	-0.05 (±1.76)	2.00 (±2.44)	0.79 (±1.79)	-1.20 (±1.03)	-2.06 (±1.88)	-2.38 (±1.79)
MAR	13	0.09 (±0.67)	-0.73 (±2.47)	1.15 (±1.29)	3.02 (±2.33)	0.82 (±2.18)	-1.13 (±1.07)	-1.87 (±2.05)	-2.10 (±1.97)
PMWEx	11.8	-0.57 (±1.12)	-1.23 (±2.49)	-0.41 (±1.13)	2.30 (±1.81)	0.44 (±2.08)	-1.50 (±0.84)	-2.70 (±1.73)	-2.86 (±1.53)
QSEx	12	-0.97 (±1.35)	-1.69 (±2.58)	-0.57 (±1.40)	1.83 (±1.98)	0.65 (±1.86)	-1.50 (±0.84)	-2.42 (±1.76)	-2.66 (±1.63)

Table 9: Temperature averages and biases and proportions of case 2 (AWS-observed northeasterly winds reported as northwesterly in MAR) as a percentage of all wind direction values for the condition. Conditions are for ALL (without regard to melt occurrence), MAR (when MAR reports melt from the $MF_{0.4}$ condition, PMWEx (when ALL PMW algorithms show melt, but MAR does not) and QSEx (when QuikSCAT ft3 show melt, but MAR does not)

 180-270° recorded by AWS 180-270° recorded by MAR 

	Pr. [%]	Mean Avg Ts [°C]		Mean MaxTs [°C]		Temp Bias [°C]			
		MAR	AWS	MAR	AWS	AvgTs	AvgTs>0	MaxTs	MaxTs>0
ALL	5.7	-1.36 (±1.77)	-1.71 (±1.82)	-0.25 (2.12)	1.38 (2.06)	0.36 (1.46)	-1.01 (1.20)	-1.63 (2.05)	-1.88 (1.89)
MAR	4.9	0.21 (±0.57)	-0.29 (±1.37)	1.27 (1.61)	1.89 (1.60)	0.49 (1.12)	-0.50 (0.82)	-0.63 (1.37)	-0.75 (1.39)
PMWEx	5.6	-0.48 (±1.15)	-0.96 (±1.50)	-0.01 (1.33)	2.03 (1.27)	0.44 (1.39)		-2.05 (1.89)	-2.05 (1.89)
QSEx	8	-1.12 (±1.39)	-1.58 (±1.73)	-0.60 (1.45)	1.35 (2.10)	0.44 (1.41)	-2.55 (0.80)	-1.96 (2.16)	-2.50 (1.86)

Table 10: Temperature averages and biases and proportions of case 1 (AWS-observed southwesterly winds being preserved in MAR) as a percentage of all wind direction values for the condition. Conditions are for ALL (without regard

to melt occurrence), MAR (when MAR reports melt from the $MF_{0.4}$ condition, PMWEx (when ALL PMW algorithms show melt, but MAR does not) and QSEx (when QuikSCAT ft3 show melt, but MAR does not)

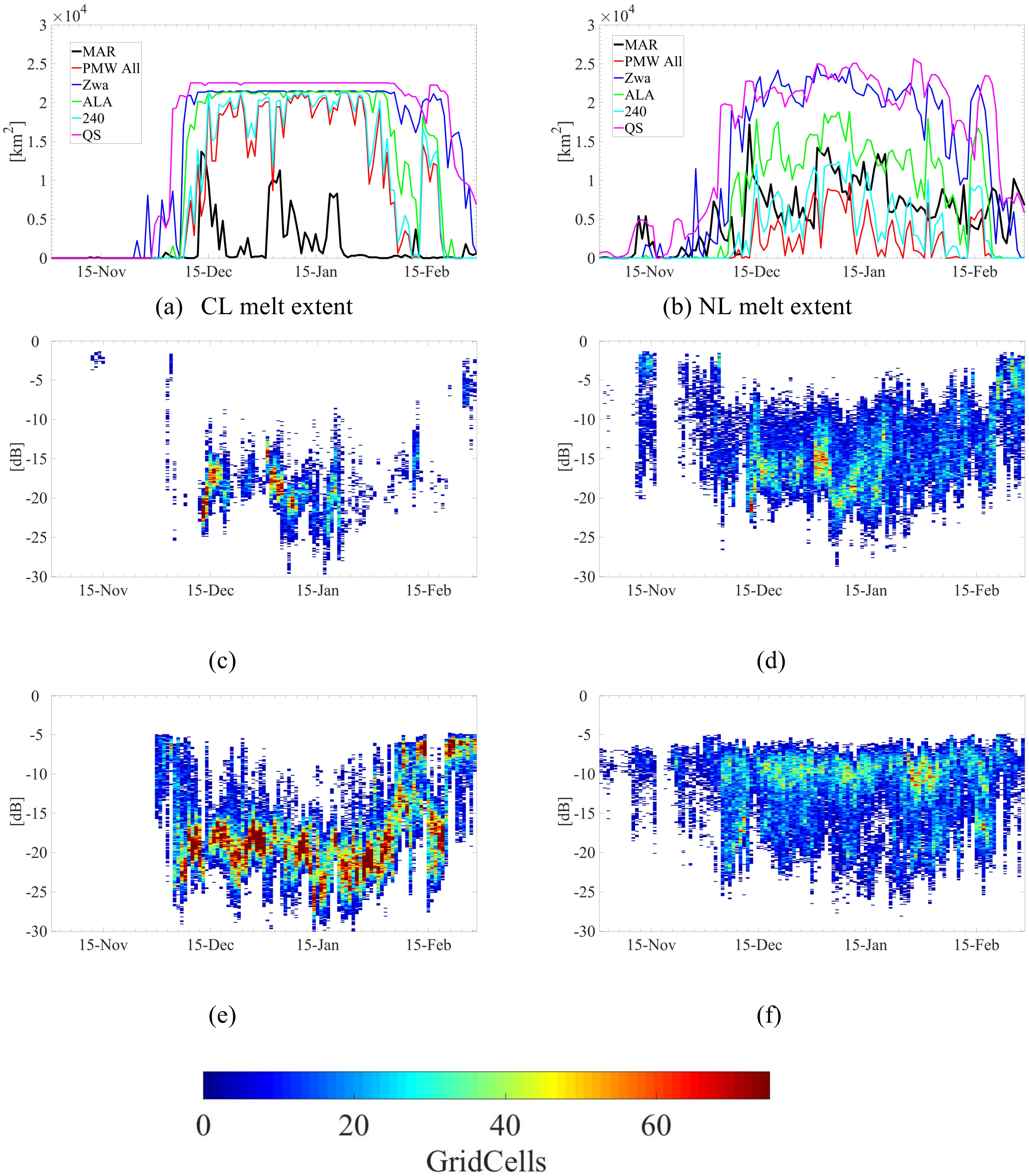


Figure 8: Melt extent (from satellite and MAR) and temperature (from AWS and MAR) over the 2001-2002 melt season., (a) CL region melt extent (b) NL region melt extent. Masks described in text and shown in inset of Fig.2. (c)(d) raw QuikSCAT backscatter for the number of QuikSCAT grid cells (~5 km^2) where both MAR and QuikSCAT ft3 detect melt (e)(f) raw QuikSCAT backscatter for the number of QuikSCAT grid cells where the QuikSCAT ft3 algorithm detects melt, but MAR does not.

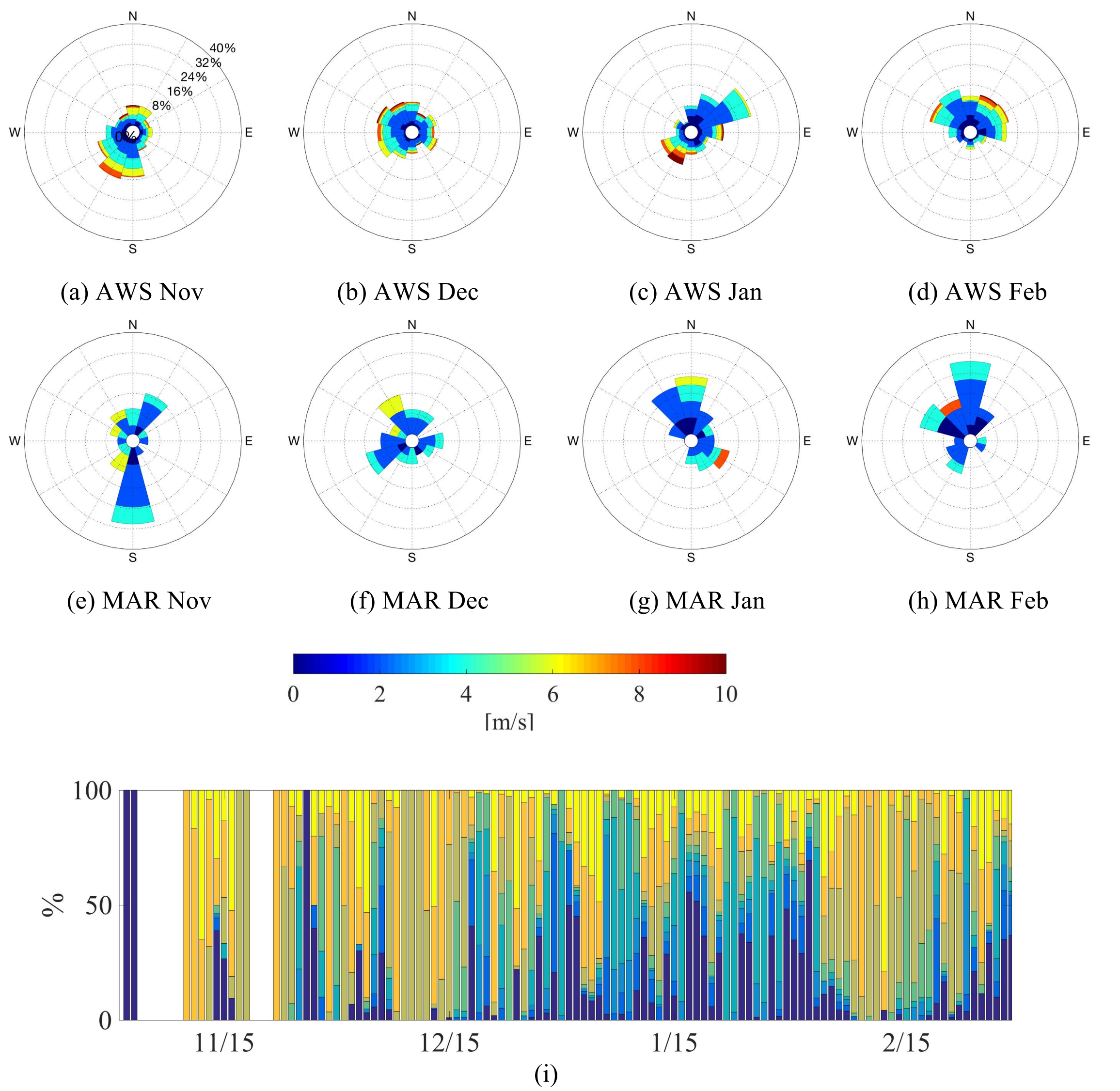


Figure 9 :Wind roses shown for the Larsen IS AWS station in 2001-2002 for (a)Nov (b)Dec (c) Jan (d) Feb. Wind roses shown for the MAR grid cell co-located to the Larsen IS AWS station in 2001-2002 for (e) Nov (f)Dec (g) Jan (h) Feb.(i) Proportion of wind direction (directions shown in inset) for all grid cells where MAR melt occurs in the NL region over the melt season

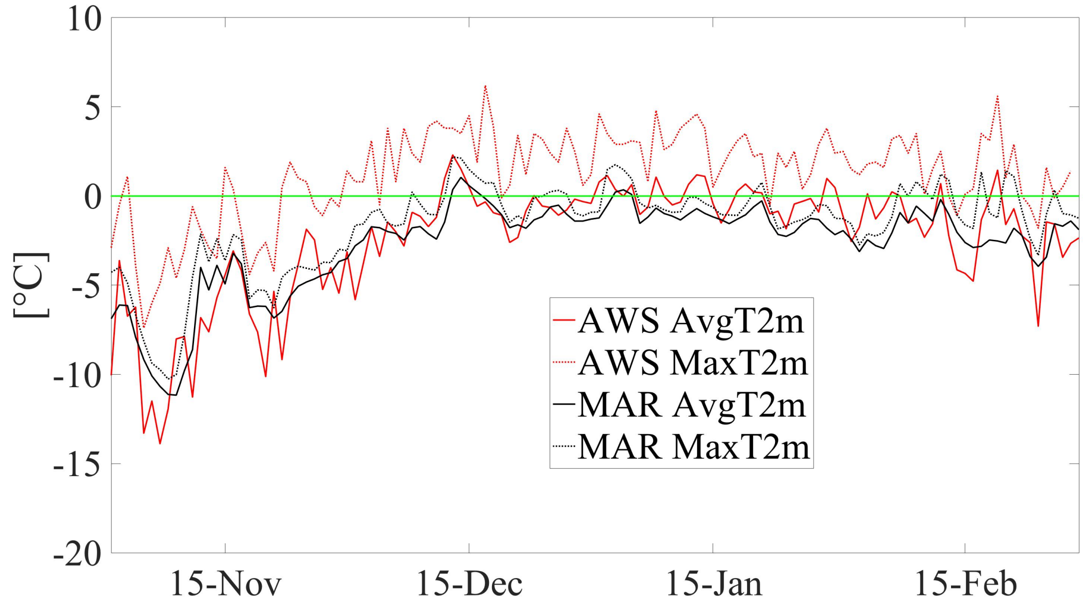


Figure 10: AWS and MAR AvgTs and MaxTs for the 2001-2002 season (Larsen Ice Shelf AWS station