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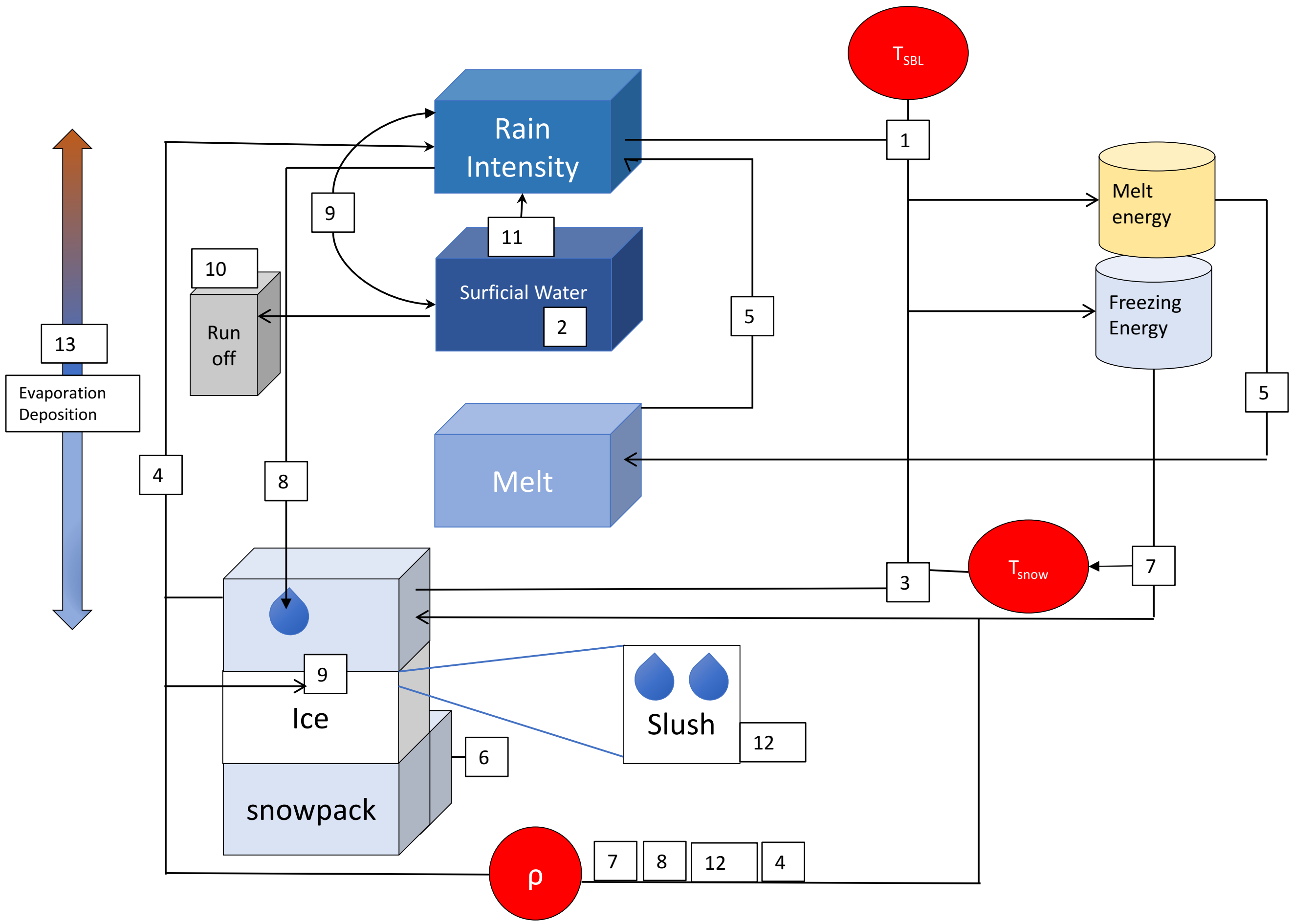
# Melting over the northeast Antarctic Peninsula (1999–2009): evaluation of a high-resolution regional climate model

**Rajashree Tri Datta et al.**

*Correspondence to:* Rajashree Tri Datta (tri.datta@gmail.com)



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


(a)

| Step | Effect on Variables |
|---|---|
| **1) Energy from Rain**<br>Energy <- RI * Cw * $T_{exc}$ * t | Energy + or - |
| **2) Surficial Water Exists?** (a function of $T_{exc}$) | |
| **3) Energy from Snow**<br>Energy <- ρ * Cs * $T_{exc}$ * ds | Energy + or - |
| **4) Water from snowpack**<br>RI <- ρ*ds * (soil humidity) ρ reduced by soil humidity | Rain Intensity +<br>density - |
| **5) MELT (when Energy is positive)**<br>melted snow <- Energy / (Lf * ρ)<br>ds -> melted snow -> RI | Energy -<br>snow depth -<br>Rain Intensity + |
| **6) Alter the snow history based on whether melting is occurring**<br>faceted crystals? Liquid water with no faceted crystals?<br>Liquid water with faceted crystals before? | |
| **7) FREEZE (when Energy is negative)**<br>Energy / (Lf * ρ) <- frozen water <- RI<br>Tsnow -> Energy / (ρ * ds * Cs )<br>ρ increased by the addition of frozen water | Temperature -<br>Rain Intensity -<br>Energy +<br>Density + |
| **8) Water saturation in snow**<br>an irreducible portion of the snowpack must contain water.<br>RI -> irreducible water in snowpack (constant * pore volume * ds * density(water)<br>irreducible water in snowpack -> ρ<br>*** | Rain Intensity -<br>Density + |

| Step | Effect on Variables |
|---|---|
| **9) Pore hole close off / superimposed ice**<br>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.<br>Pore close off -> RI converted to surficial water<br>No pore close off -> RI remains in RI<br>*** | Surficial Water, Rain Intensity + / - |
| **10) Surficial water runoff**<br>Final Energy reduced by Energy from rain (Step 1)<br>A decay function determines the portion of surficial water converted to runoff<br>Reference: Zuo and Oerlemans, 1996<br>*** | Surficial water -<br>Runoff + |
| **11) Conversion back to rain**<br>Where no superimposed ice occurs (Step 9 above), surficial water is added back into RI (rain intensity) | Rain Intensity +<br>Surficial water - |
| **12) Slush**<br>Where surficial water exists (step 2), the highest snow/ice layer will fill the pore volume with water from surficial water, adding to density<br>slush + <- surficial water slush -> ρ +<br>*** | Surficial water -<br>density + |
| **13) Add/Subtract Deposition/Sublimation**<br>Snowpack either +/ -<br>DepOrSubl= t * LHF / (Lx * ρ) <- -> ds added to the snowpack<br>Energy of vapor calculated<br>EnVp = (Cs * $T_{exc}$-Lf * (1-soil humidity) ) / (1 + (DepOrSubl / ds))<br>and used to alter humidity of soil/snow<br>Hum = 1 + (EnVp – Texc * Cs) / Lf<br>as well as the temperature<br>$T_{exc}$ = (EnVp + Lf*(1-Hum) )/ Cs | Soil/Ice Humidity +/-<br>Temp +/-<br>snowpack +/- |

*** 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 S1: 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 (TSBL) and temperature of the snow (TSNOW).**

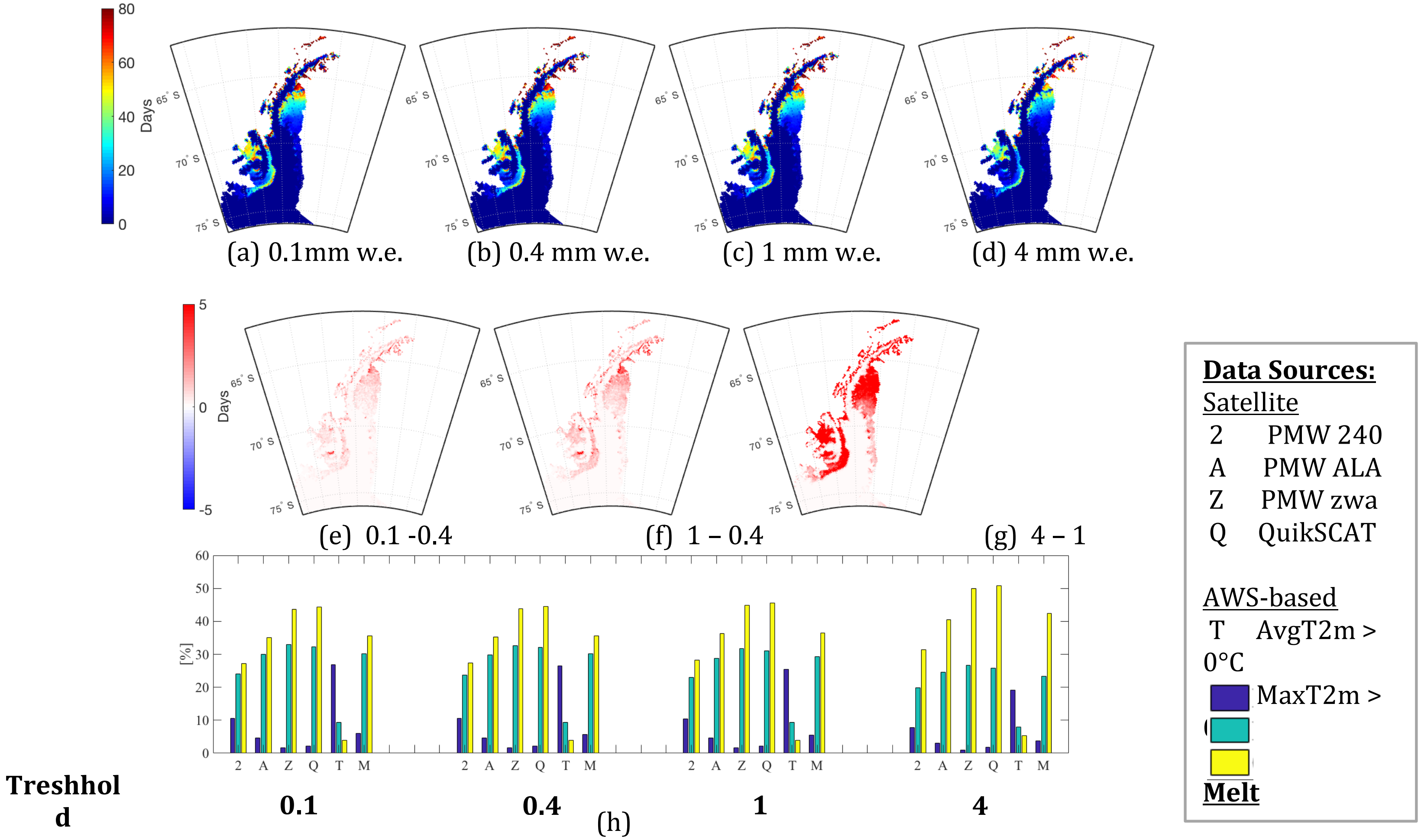



**Figure S2: Average MAR melt duration from 2000-2009 using different thresholds for total daily meltwater production to determine melt occurrence (1) 0.1 mm w.e. (b) 0.4 mm w.e. (c) 1 mm w.e. (d) 4 mm w.e. Major differences in average yearly melt duration between melt thresholds (e) 0.1 mm w.e. – 0.4 mm w.e. (f) 1 mm w.e. – 0.4 mm w.e. (g) 4 mm w.e. – 1 mm w.e.**

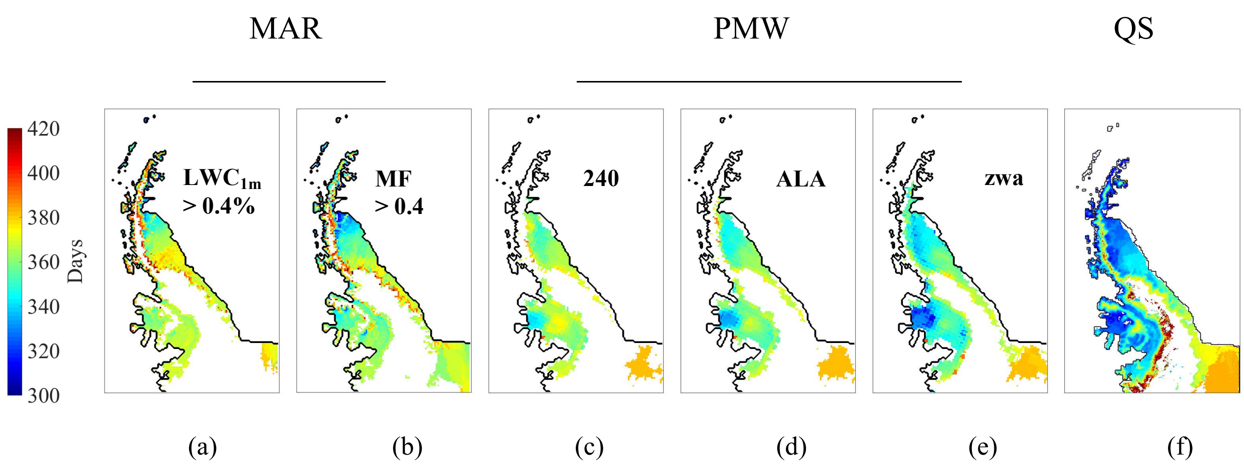



**Figure S3: Average Melt Onset date from multiple sources (a) MAR, Liquid Water Content > 0.4% for three consecutive days. (b) MAR Total Melt Flux > 0.4 mmwe for 1 day or more. Satellite-based: (c) PMW 240 algorithm (d) PMW ALA (e) PMW Zwa (f) QuikSCAT. Day shown is the first day of a sustained three-day melt period for satellite estimates as well as $LWC_{1m}$, Date number is defined beginning in Jan 1$^{st}$. of year1, such that 365 represents Dec 31$^{st}$ of year1. All averages are taken from the 2000-2009 period to retain consistency with the availability of QuikSCAT data.**

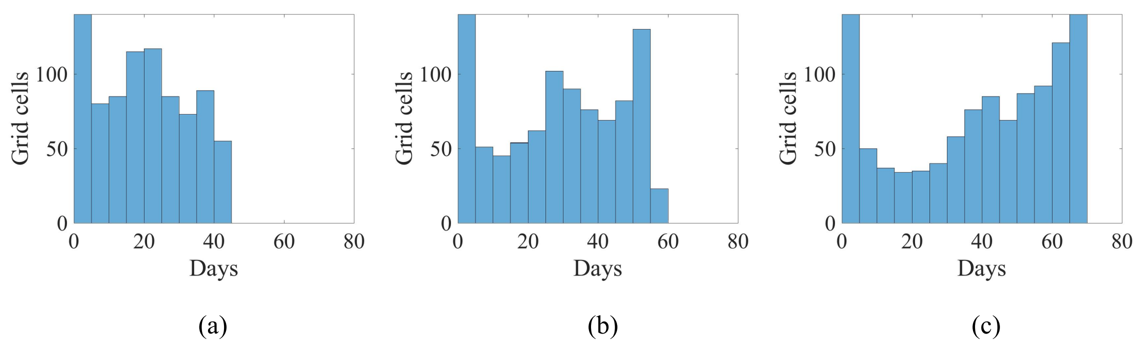



**Figure S4: Number of 10km MAR grid cells from the NE basin (y axis) showing the avg number of total melt days (2001-2014) from three passive microwave algorithms: (a) PMW 240 (b) PMW ALA (c) PMW zwa**

| **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 S1: 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**

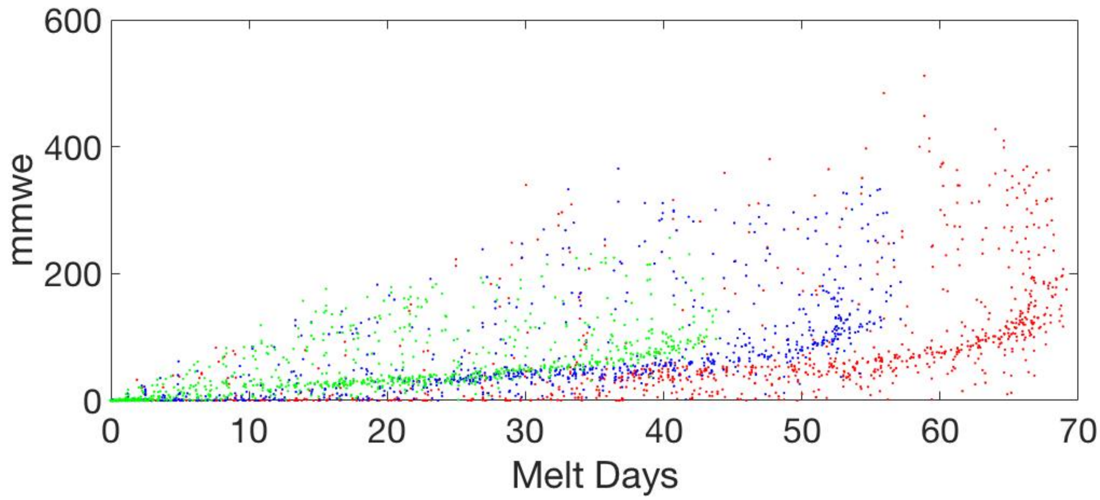



**Figure S5: Avg Melt Days (2001-2014) from three passive microwave algorithms (described in text). Green shows PMW 240. Blue shows PMW ALA. Red shows PMW zwa.**

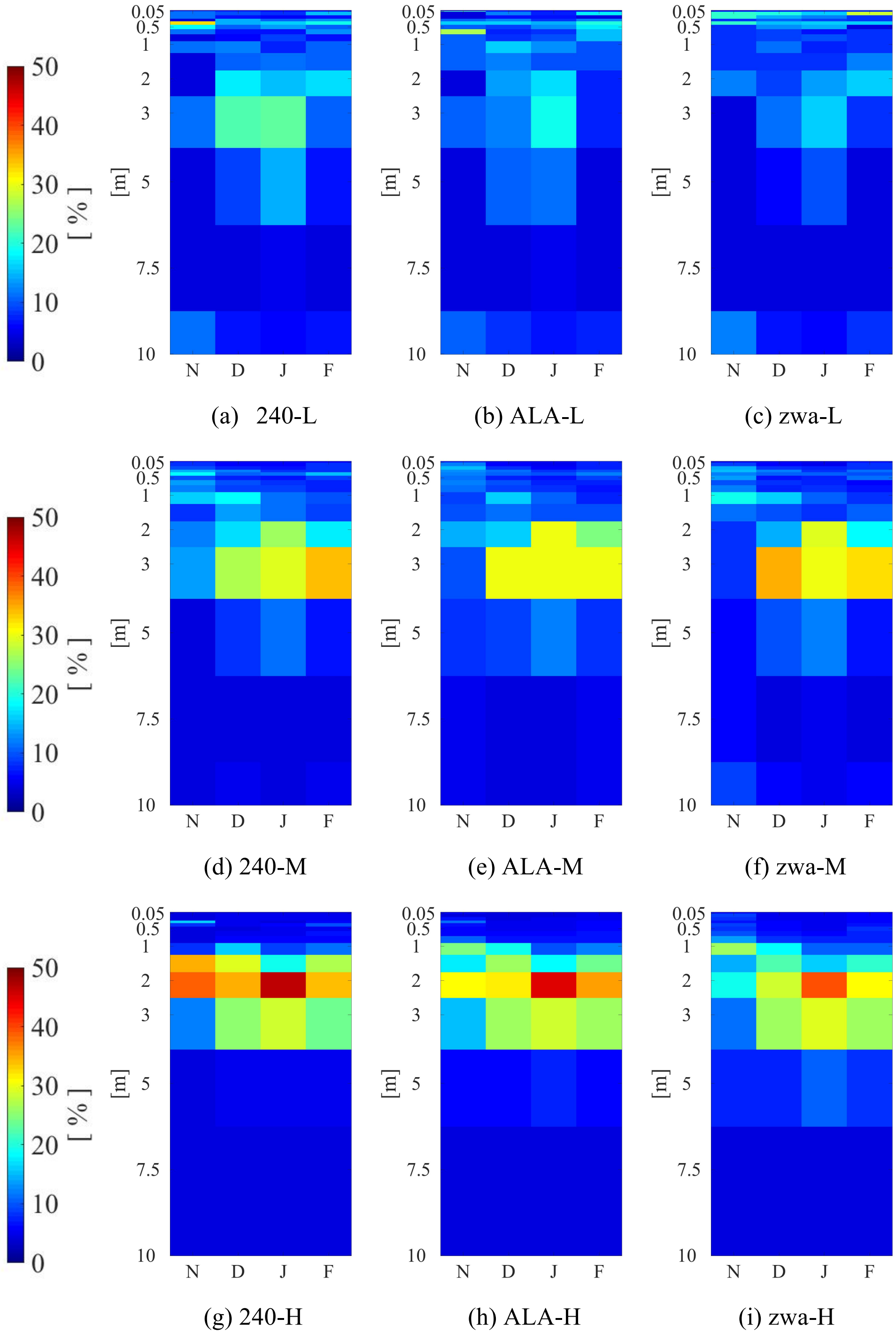



**Figure S6: Maximum depth of MAR-modeled meltwater percolation (MAR) into the snowpack over the melt season. Colors indicate the percentage of grid cells where meltwater reaches the corresponding maximum depth (y axis) for the month (x axis), such that each column per month totals to 100%. Maximum percolation 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.**

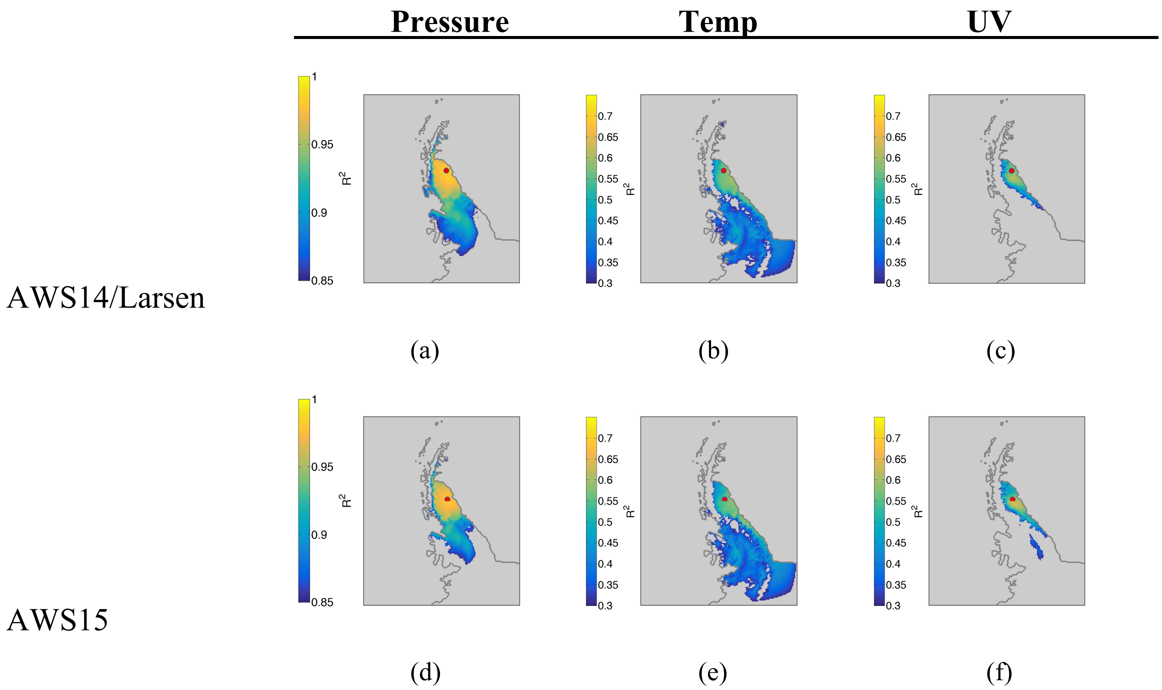



**Figure S7: Left column is for surface pressure. Middle column for daily-averaged 2m air temperature, right column for 2m wind speed. Stations are as follows: (a)(b)(c) AWS 14/Larsen Ice Shelf, which are co-located in MAR (d)(e)(f) AWS 15**

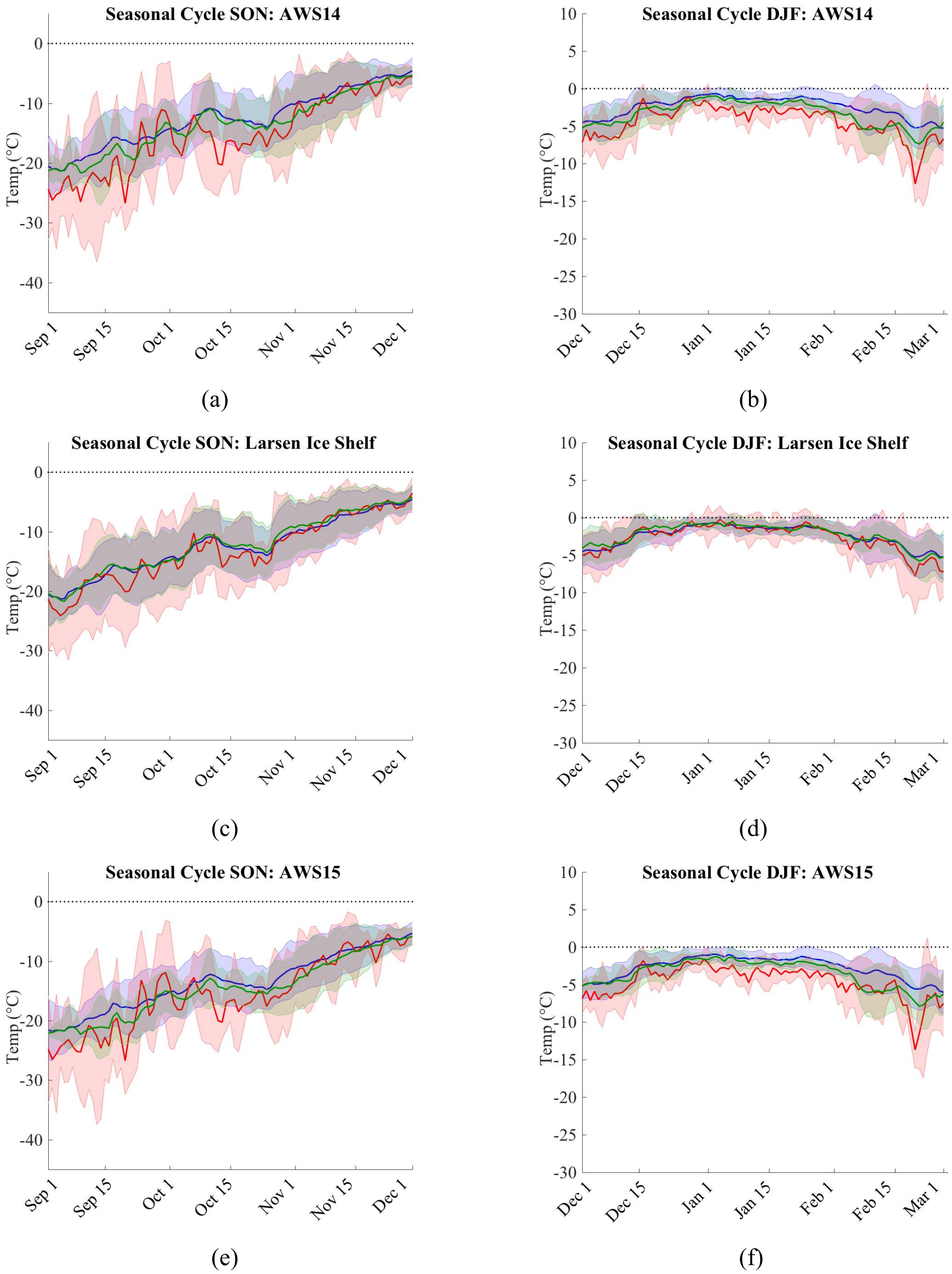



**Figure S8: Seasonal Avg Ts climatology for spring (SON) and summer(DJF) with envelope indicating one standard deviation, Red: computed for available data from AWS station, with quality control as described in section 2. Green: MAR daily-averaged T2m data restricted to AWS-data availability. Blue: MAR 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 S2: $R^2$ 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 S3: 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 S4: 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 | | |

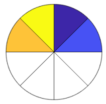
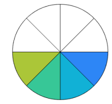
**Table S5: $R^2$ values between MAR and AWS data for daily-averaged 2m air temperature in Summer (DJF) for years shown**

| | 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 S6: Root Mean Squared Error between MAR and AWS data for daily-averaged 2m air temperature [°C] in Summer (DJF) for years shown**

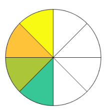
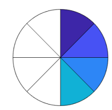
| | 01-02 | 02-03 | 03-04 | 04-05 | 05-06 | 06-07 | 07-08 | 08-09 | 09-10 | 10-11 | 11-12 | 12-13 | 13-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AWS14 | | | | | | | | | 0.98 | 1.00 | 1.61 | 0.32 | 1.30 |
| AWS15 | | | | | | | | | 1.06 | 0.81 | 1.60 | 0.32 | 1.11 |
| Larsen IS |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

**Table S7: Mean Error (MAR-AWS) for daily-averaged 2m air temperature [°C] in Summer (DJF) for years shown**

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

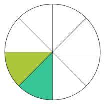
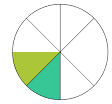
| | Pr. [%] | Mean Avg T2m [°C] | | Mean MaxT2m [°C] | | Temp Bias [°C] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MAR | AWS | MAR | AWS | AvgT2m | AvgT2m >0 | MaxT2m | MaxT2m >0 |
| ALL | 8 | -2.31 (±2.27) | -3.18 (±3.61) | -1.50 (±2.19) | 0.54 (±3.25) | 0.88 (±2.87) | -1.45 (±1.56) | -2.07 (±2.88) | -3.36 (±2.23) |
| MAR | 8 | -0.70 (±0.80) | -1.89 (±2.69) | -0.27 (±1.32) | 1.73 (±2.74) | 1.19 (±2.53) | -0.89 (±1.15) | -2.00 2.85(±) | -3.08 (±2.28) |
| PMWEx | 6 | -1.76 (±1.16) | -1.73 (±1.63) | -0.90 (±1.17) | 1.45 (±2.19) | -0.04 (±1.46) | -2.06 (±0.71) | -2.35 (±2.12) | -2.99 (±1.99) |
| QSEx | 6 | -1.91 (±1.18) | -2.04 (±2.21) | -0.97 (±1.29) | 1.25 (±2.38) | 0.12 (±2.03) | -2.81 (±1.60) | -2.28 (±2.39) | -3.15 (±2.15) |

**Table S8: Temp averages and biases, proportions where AWS-observed northerly winds are reported as southerly in MAR, as a percentage of all wind direction values for the condition. Conditions for ALL , PMWEx and QSEx (in text)**

 180-360° recorded by AWS 0-180° recorded by MAR 

| | Pr. [%] | Mean Avg T2m [°C] | | Mean MaxT2m [°C] | | Temp Bias [°C] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MAR | AWS | MAR | AWS | AvgT2m | AvgT2m >0 | MaxT2m | MaxT2m >0 |
| ALL | 10 | -2.25 (±2.24) | -3.35 (±3.44) | -1.50 (±2.16) | 0.35 (±3.96) | 1.09 (±2.32) | -1.52 (±1.41) | -1.88 (±3.24) | -3.76 (±2.68) |
| MAR | 10 | -0.64 (±0.74) | -1.40 (±1.84) | -0.16 (±1.33) | 2.12 (±2.86) | 0.76 (±1.75) | -1.07 (±1.05) | -2.24 (±2.63) | -3.19 (±2.19) |
| PMWEx | 8 | -1.92 (±0.99) | -1.88 (±1.95) | -1.23 (±1.24) | 0.86 (±3.82) | -0.04 (±1.60) | -2.60 (±1.10) | -2.09 (±3.29) | -3.86 (±2.95) |
| QSEx | 9 | -2.12 (±1.26) | -2.83 (±2.63) | -1.23 (±1.24) | 0.86 (±3.82) | 0.71 (±2.18) | -2.85 (±1.52) | -2.09 (±3.29) | -3.83 (±2.59) |

**Table S9: Temp averages and biases, proportions where AWS-observed westerly winds are reported as easterly in MAR, as a percentage of all wind direction values for the condition. Conditions for ALL , PMWEx and QSEx (in text)**

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

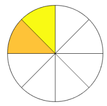
| | Pr. [%] | Mean Avg T2m [°C] | | Mean MaxT2m [°C] | | Temp Bias [°C] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MAR | AWS | MAR | AWS | AvgT2m | AvgT2m >0 | MaxT2m | MaxT2m >0 |
| ALL | 7 | -2.44 (±2.41) | -3.41 (±3.56) | -1.69 (±2.55) | -0.95 (±3.56) | 0.97 ( ±1.88) | -1.14 (±1.14) | -0.76 (±2.04) | -1.83 ( ±1.57) |
| MAR | 6 | -0.33 ( ±0.60) | -1.06 (±1.35) | 0.25 (±1.37) | 0.99 (±1.74) | 0.73 (±1.11) | -0.54 ( ±0.82) | -0.71 (±1.48) | -1.17 ( ±1.31) |
| PMWEx | 6 | -1.55 (±1.07) | -1.97 (±1.95) | -0.63 (±1.30) | 0.97 (±2.20) | 0.41 (±1.60) | -1.57 (±0.15) | -1.60 (±1.91) | -2.10 (±1.52) |
| QSEx | 7 | -2.01 (±1.30) | -2.50 (±2.18) | -1.10 (±1.48) | 0.22 (±2.50) | 0.49 (±1.58) | -2.23 (±0.76) | -1.33 (±2.07) | -2.33 (±1.59) |

**Table S10: Temp averages and biases, proportions where AWS-observed southesterly winds are preserved in MAR, as a percentage of all wind direction values for the condition. Conditions for ALL , PMWEx and QSEx (in text)**

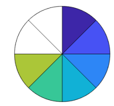
 180-270° recorded by AWS 90-180° recorded by MAR 

| | Pr. [%] | Mean Avg T2m [°C] | | Mean MaxT2m [°C] | | Temp Bias [°C] | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MAR | AWS | MAR | AWS | AvgT2m | AvgT2m >0 | MaxT2m | MaxT2m >0 |
| ALL | 4 | -2.13 (±1.77) | -3.12 (±3.14) | -1.71 (±1.69) | -1.01 (±3.39) | 0.99 ( ±2.01) | -1.27 (±0.59) | -0.74 (±2.51) | -2.81 (±1.42) |
| MAR | 4 | -0.77 ( ±0.40) | -1.27 (±1.20) | -0.54 (±0.56) | 1.35 (±1.98) | 0.49 (±1.30) | -1.21 (±0.57) | -1.84 (±2.22) | -2.92 (±1.59) |
| PMWEx | 3 | -1.69 (±0.62) | -1.87 (±1.95) | -1.27 (±0.73) | -0.32 (±1.62) | 0.18 (±1.48) | N/A | -0.95 (±1.26) | -1.98 (±0.56) |
| QSEx | 4 | -1.90 (±0.79) | -2.99 (±2.59) | -1.47 (±0.77) | -1.28 (±2.81) | 1.08 (±2.13) | N/A | -0.16 (±2.39) | -2.35 (±0.94) |

**Table S11: Temp averages and biases, proportions where AWS-observed southwesterly winds are reported as southeasterly in MAR, as a percentage of all wind direction values for the condition. Conditions for ALL , PMWEx and QSEx (in text)**



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



| | **Pr. [%]** | **Mean Avg T2m [°C]** | | **Mean MaxT2m [°C]** | | **Temp Bias [°C]** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | MAR | AWS | MAR | AWS | AvgT2m | AvgT2m >0 | MaxT2m | MaxT2m >0 |
| ALL | 3 | -2.74 (±3.11) | -3.78 (±4.45) | -1.19 (±3.08) | 2.46 (±4.54) | 1.04 ( ±3.35) | -1.71 (±2.08) | -3.72 (±4.15) | -4.98 (±3.61) |
| MAR | 3 | -0.61 (±1.34) | -2.01 (±4.10) | 0.40 (±2.38) | 3.31 (±4.19) | 1.40 (±3.72) | -0.82 (±1.41) | -2.91 (±3.77) | -4.04 (±3.08) |
| PMWEx | 3 | -2.51 (±1.69) | -2.43 (±2.24) | -0.76 (±1.68) | 4.60 (±4.20) | -0.08 (±1.92) | -2.89 (±1.68) | -5.36 (±3.80) | -5.57 (±3.80) |
| QSEx | 4 | -2.71 (±1.82) | -3.09 (±2.92) | -1.00 (±1.92) | 3.23 (±4.01) | 0.38 (±2.65) | -3.42 (±2.12) | -4.34 (±3.69) | -5.11 (±3.46) |

**Table S12: Temp averages and biases, proportions where AWS-observed southwesterly winds are reported as southeasterly in MAR, as a percentage of all wind direction values for the condition. Conditions for ALL, PMWEx and QSEx (in text)**

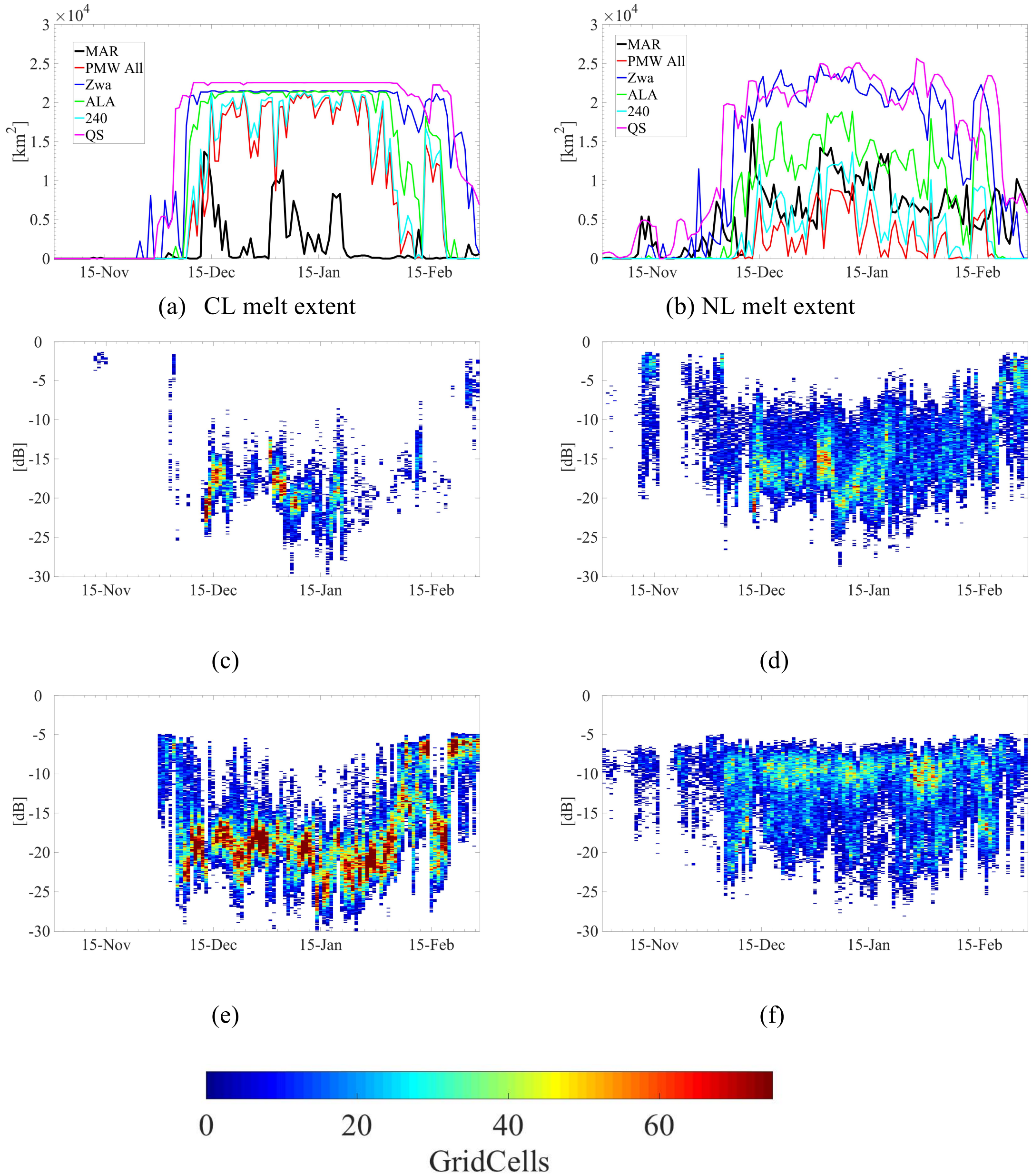



**Figure S9: Melt extent ( from satellite and MAR) and temperature (from AWS and MAR) over the 2001-2002 melt season., (a) CL region melt extent (b) NL region melt extent. Masks described in text and shown in inset of Fig.2. (c)(d) raw QuikSCAT backscatter for the number of QuikSCAT grid cells (~5 km$^2$) 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.**

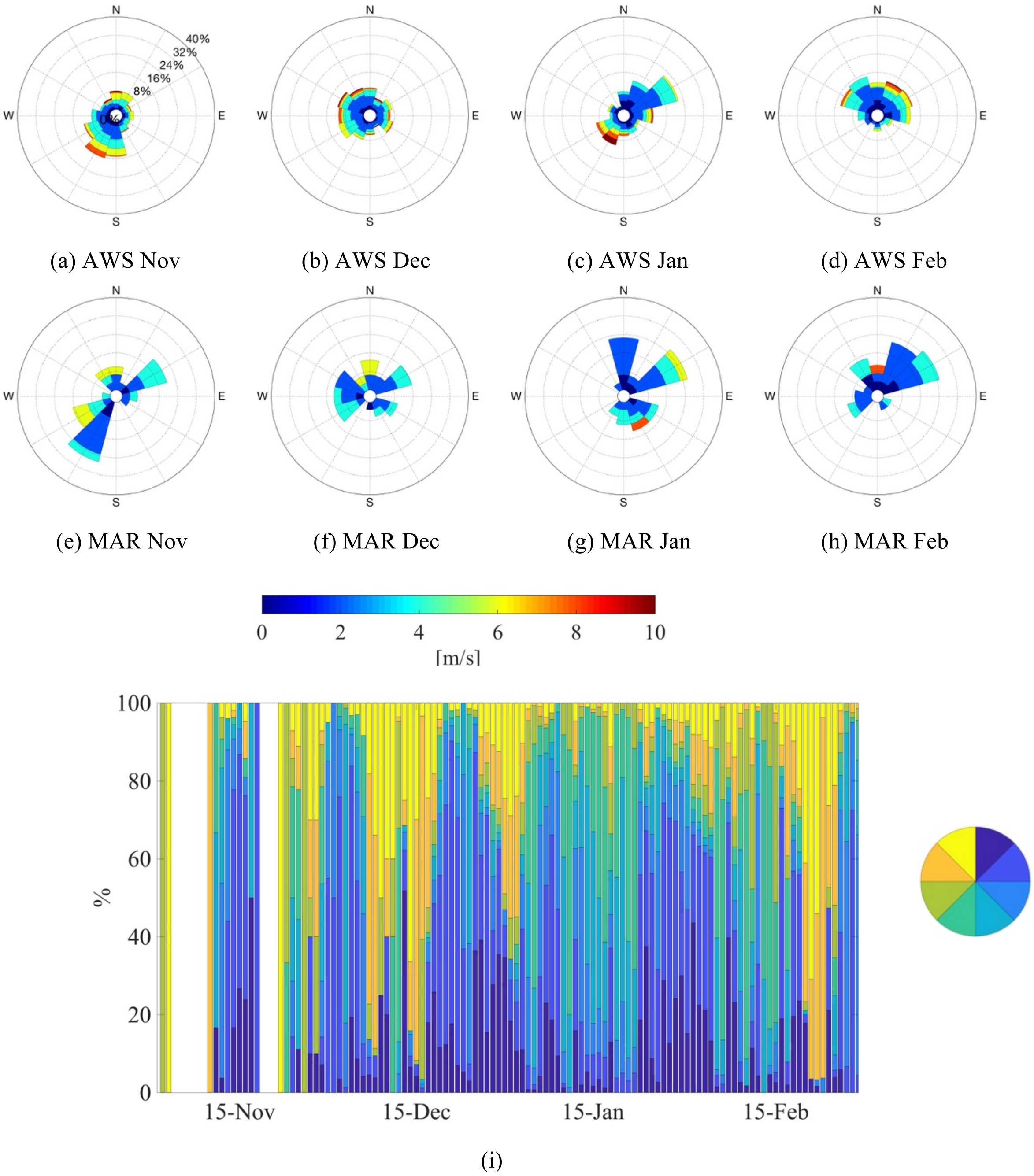



**Figure S10 : Wind roses shown for the Larsen IS AWS station in 2001-2002 for (a)Nov (b)Dec (c) Jan (d) Feb. Wind roses shown for the MAR grid cell co-located to the Larsen IS AWS station in 2001-2002 for (e) Nov (f)Dec (g) Jan (h) Feb.(i) Proportion of wind direction (directions shown in inset) for all grid cells where MAR melt occurs in the NL region over the melt season**

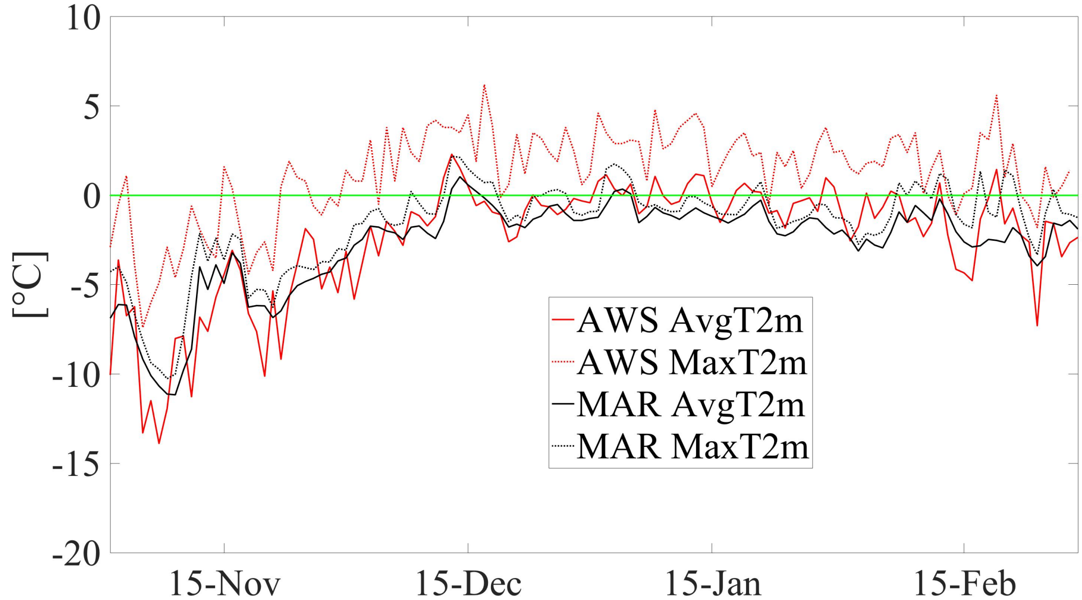



**Figure S11: AWS and MAR AvgTs and MaxTs for the 2001-2002 season (Larsen Ice Shelf AWS statio**

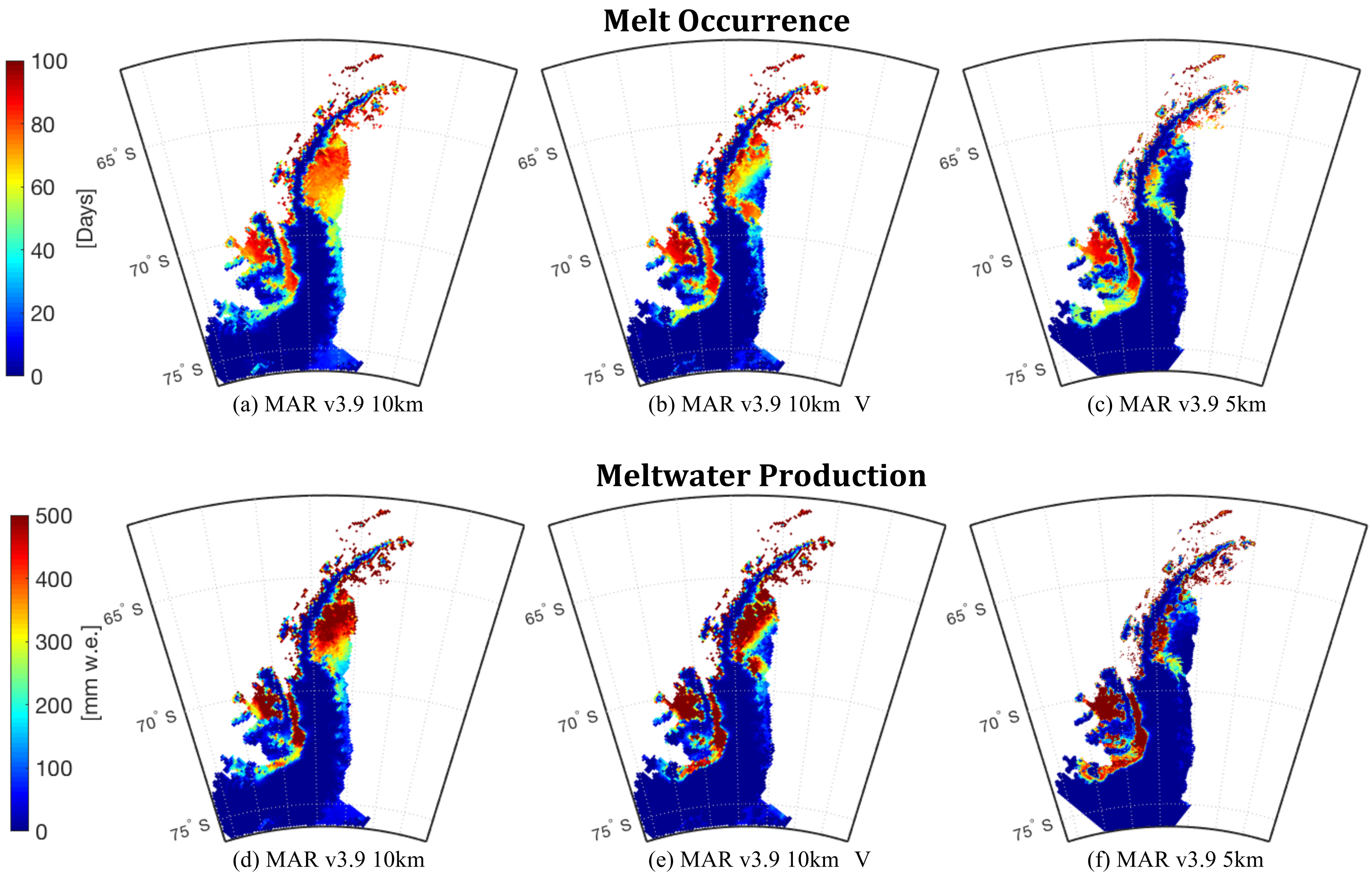
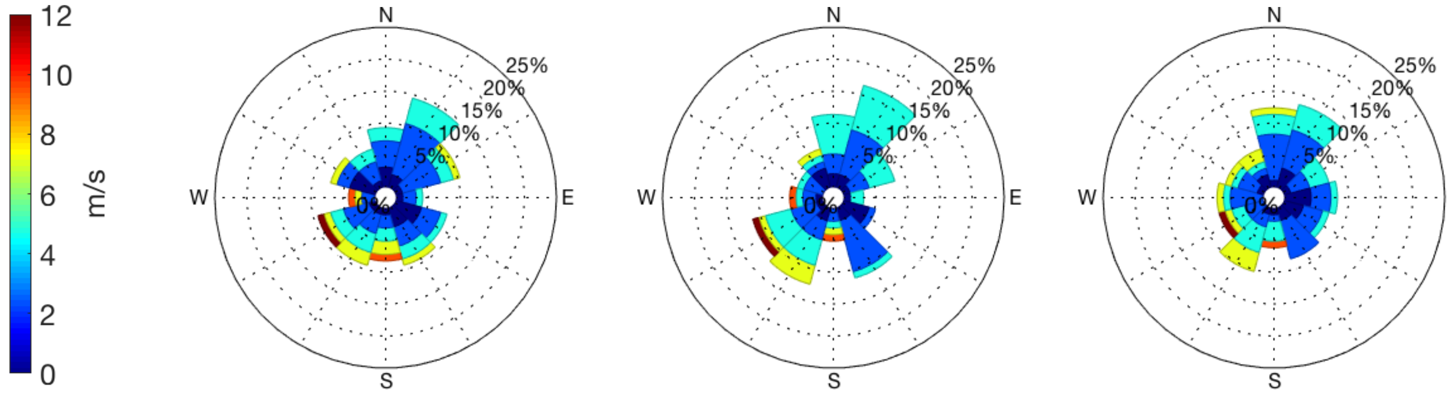
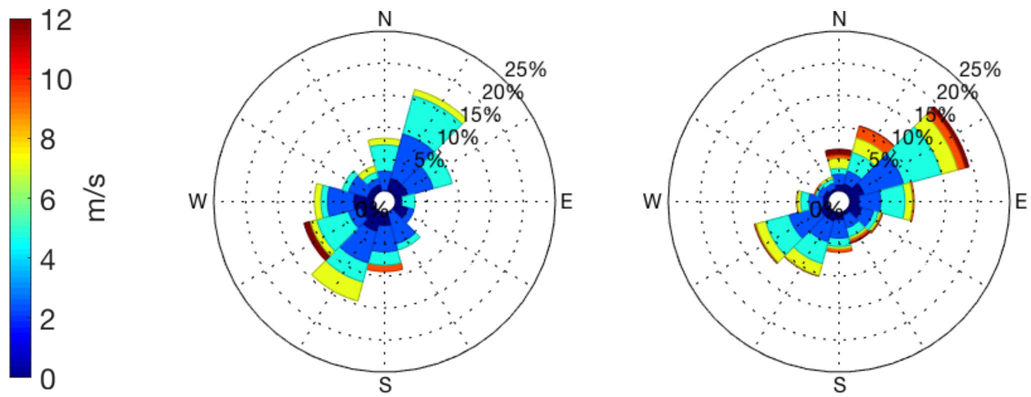



**Figure S12: Melt occurrence using the $MF_{0.4}$ criteria (a,b,c) and meltwater production (d,e,f) from Nov 1, 2004 – Feb 28, 2005 for MAR v3.9 at (a,d) 10km and 23 sigma layers (b,e) 10km and 32 sigma layers and (c,f) 5km horizontal spatial resolution and 23 sigma layers**




(a) MAR v3.9 5km (b) MAR v3.9 10km (c) MAR v3.9 10km V




(d) MAR v3.5.2 10km (e) AWS

**Figure S13: Wind roses at the Larsen IS AWS location (shown in Fig. 1) for Nov 1, 2004 – March 31, 2005 for MAR 3.9 at a 5km resolution, 23 sigma layers, daily values (a) 10 km and 23 sigma layers, daily values (b) 10km resolution and 32 sigma layers, daily values (c), MAR 3.5.2 at a 10km resolution and 23 sigma layers, daily values (d) and AWS at 3-hourly values (e). MAR values are calculated only when AWS data is available and AWS data reports no values between Dec 20, 2004 and February 12, 2005**