Supporting Information for "Sea ice production in the 2016 and 2017 Maud Rise polynyas"

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Introduction

This document provides 2 supplementary texts, 2 supplementary tables and 8 supplementary figures, referred to in the main text as Text S1-S2, Table S1-S2 and Figures S1-S8.

Text S1. Other two methods to estimate sea ice volume change In Section 5, we compare our sea ice production to that obtained from two other methods for sea ice volume changes, notably to confirm the robustness of our results. The first of these two methods, the Lebedev Freezing Degree Days, developed by ? (?), characterizes sea ice thickness growth as a function of the surrounding air conditions. This method is described in ? (?) as: $hi = 1.33\ FDD^{0.58}$, where hi is the sea ice thickness and FDD the freezing degree days determined as: $FDD = \int_0^t (T_w - T_s)dt$, where t is the number of consecutive days below freezing, T_w the freezing temperature of seawater, and T_s the 2 m air temperature. This method empirically accumulates the sea ice growth based on how long and by how much the surface temperature is below freezing and has already been used to examine the sea ice growth within the Greenland polynyas (?, ?). As explained in Section 2, we use the daily 2 m air temperature from JRA55 to integrate the ice growth.

The last method to estimate sea ice volume changes uses the apparent sea ice thickness from SMOS-SMAP. However, due to its low confidences and considerable uncertainties (?, ?), the SMOS-SMAP ice thickness over the polynya region can not be taken as the actual sea ice thickness. Instead, ? (?) suggests taking them as "apparent sea ice thickness". For clarity, we will label the ice volume changes from these two auxiliary methods as apparent "sea ice change". For both, the apparent sea ice volume change is computed as the differences in ice volume between two successive days: $V_{\text{apparent}}(t) = \sum V(hi(t+1), 1-\text{SIC}(t+1)) - \sum V(hi(t), 1-\text{SIC}(t))$, where $hi(t+1)$ ($\text{SIC}(t+1)$) and $hi(t)$ ($\text{SIC}(t)$) are the sea ice thickness (concentration) within the polynyas from two successive days. In Section 5, the apparent sea ice changes from FDD and from SMOS-SMAP methods are referred to as "FDD" and "SMOS-SMAP", respectively.

Text S2. Dynamic sea ice volume change within the 2017 Maud Rise polynya

As introduced in Section 5, the dynamic sea ice changes are included in the form of horizontal advection. Schematically, the dynamic sea ice volume changes (ΔV_D) within the polynya are calculated within the grey shading grid cells in Fig. **??**a, where light and dark purple lines are the polynya extent in the first and second day, respectively. Briefly, the dynamical evolution of ice volume, V_D, is governed by:

$$\frac{\partial V_D}{\partial t} = \nabla \cdot (\vec{U} A_{\mathrm{SIC}} hi) \tag{1}$$

where $\vec{U}$ is ice motion from NSIDC product, A_{SIC} is the sea ice cover area, and hi is the sea ice thickness of each grid cell from SMOS-SMAP product. If we assume that A_{SIC} and hi are unchanged in the two successive days, i.e. that the polynya only changes shape, then over one day, we obtain:

$$\Delta V_D = A_{\mathrm{SIC}} hi \int_t^{t+1} \vec{U}\, dt \tag{2}$$

Here, $\int_t^{t+1} \vec{U}\, dt$ decides whether the grid cell advects sea ice into (positive: ice volume gain) or out of (negative: ice volume loss) the polynya, as well as the normal distance between one-day drifting geolocation and the geolocation of the centre of mass within the polynya. Hence, $A_{\mathrm{SIC}} \int_t^{t+1} \vec{U}\, dt$ provide the area changes when sea ice advects across the boundary of polynya. Fig. **??**b indicates how one 2017 Maud Rise polynya event develops on Oct-4 (light blue) and Oct-5 (dark blue) and the new sea ice location (small orange dots) after Oct-4 ice drifting. Therefore, the orange shading circles are the active or critical grid cells that dominate the sea ice volume changes within the Oct-5 Maud Rise polynya. In total, this 2017 Maud Rise polynya event is tracked from Sep-13 until

Oct-31, and for each day, the sea ice volume dynamic changes are calculated based on Eq. **??** and then accumulated during the whole 49 days.

Table S1. Correlation matrix between our computed algorithm, denoted as F + O (JRA55), the fluxes directly from the four reanalyses, and F + O feeding in different reanalyses input for 2016 (left) and 2017 (right).

	F + O (JRA55)	JRA55	ERA5	CFSv2	MERRA2
F + O (JRA55)	1.00	[0.61,0.58]	[0.86,0.83]	[0.83,0.78]	[0.85,0.84]
JRA55	-	1.00	[0.76,0.72]	[0.84,0.78]	[0.83,0.82]
ERA5	-	-	1.00	[0.89,0.76]	[0.90,0.86]
CFSv2	-	-	-	1.00	[0.96,0.95]
MERRA2	-	-	-	-	1.00
F + O (ERA5)	[0.89,0.87]	-	[0.78,0.82]	-	-
F + O (CFSv2)	[0.83,0.85]	-	-	[0.85,0.86]	-
F + O (MERRA2)	[0.85,0.88]	-	-	-	[0.87,0.87]

Table S2. Relative changes in sea ice production (Units: %) for 2016 and 2017, for each mixed layer depth algorithm: $\Delta \mathrm{T} = 0.2°\mathrm{C}$ temperature threshold; $\Delta \frac{\partial \mathrm{T}}{\partial z} = 0.005^o\mathrm{C\ m^{-1}}$ temperature gradient; $\Delta \frac{\partial \sigma_\theta}{\partial z} = 0.0005\mathrm{kg\ m^{-4}}$ potential-density gradient; $\mathrm{T_{MLfit}} = \mathrm{T_{Thermfit}}$: temperature fit; $\sigma\theta_{\mathrm{MLfit}}$: potential-density fit; see ? (?). Then relative changes in sea ice production for each year when including the ice drift or ocean current errors, and for different freezing temperatures.

		2016	2017
$\Delta \mathrm{T}$		-7.88	-7.57
$\Delta \frac{\partial \mathrm{T}}{\partial z}$		5.89	5.63
$\Delta \frac{\partial \sigma_\theta}{\partial z}$		6.37	5.46
$\mathrm{T_{MLfit}} = \mathrm{T_{Thermfit}}$		-10.54	-39.10
$\sigma\theta_{\mathrm{MLfit}}$		-17.67	-16.26
± Ice drift error		-8.8∼1.33	-2.59∼1.69
± Ocean current error		-0.7∼1.33	-1.54∼2.03
	-2.0°C	-1.94	-4.32
Freezing temperature	-1.9°C	2.76	1.21
	-1.8°C	7.6	6.73

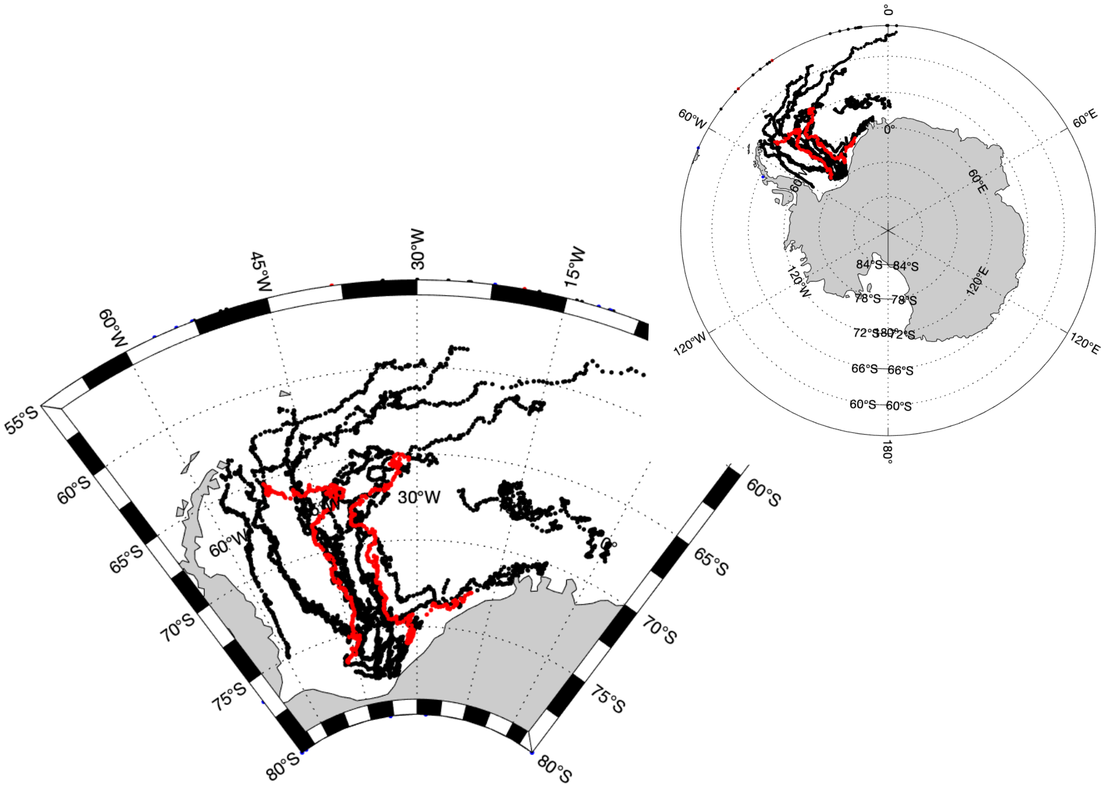

Figure S1. Location of the AWI snow buoys (black dots) and automatic weather station buoys (red dots) within the Weddell Sea.

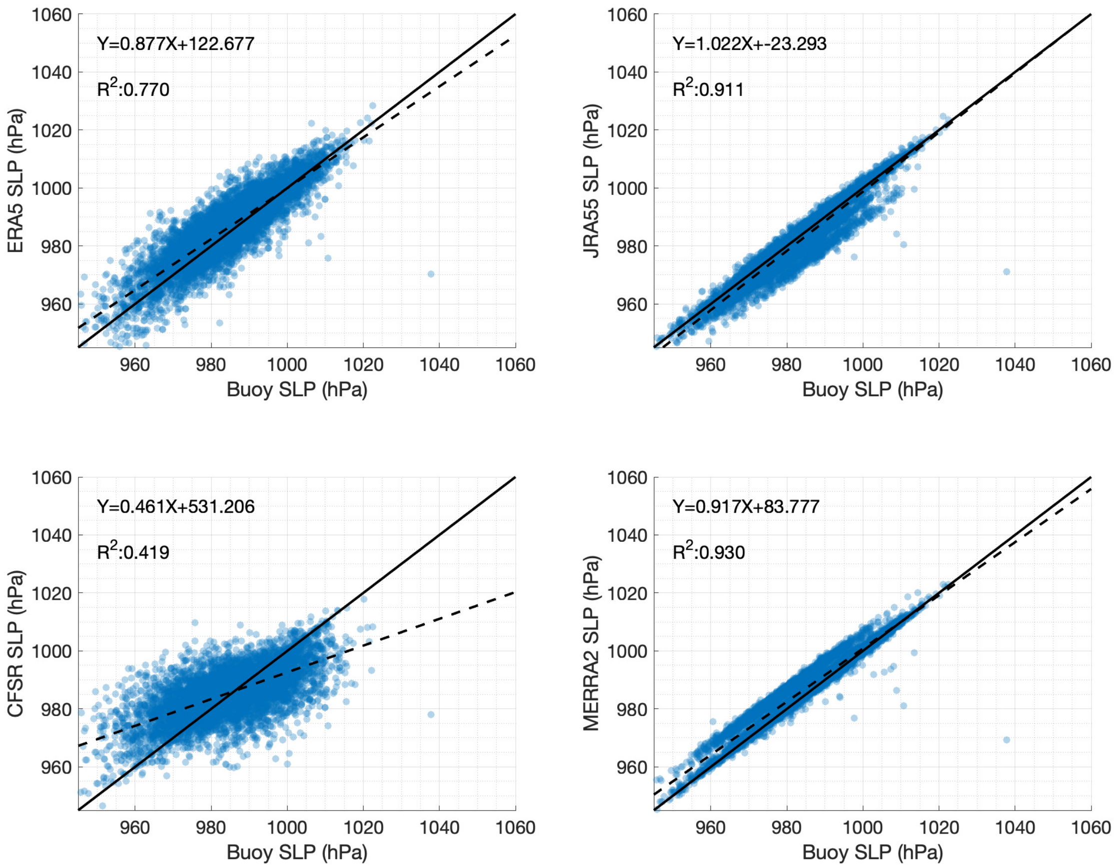

Figure S2. Sea level pressure (SLP) in austral winter (May to October) from the four different reanalyses (y-axis) validated against the AWI buoys (x-axis). Statistics are displayed for each in the top left corner of the panel (dashed black line is the corresponding fitting line). Solid line indicates perfect correspondence.

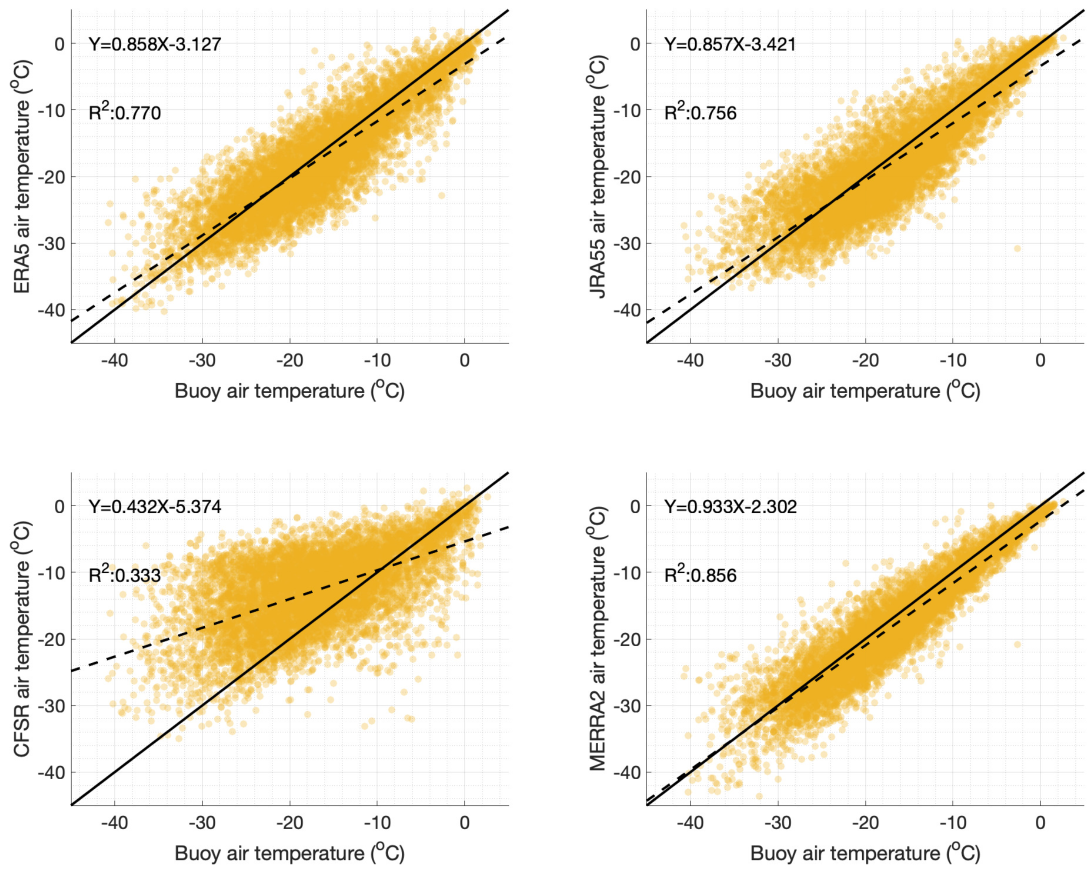

Figure S3. Same as Fig. S2 but for the 2 m air temperature.

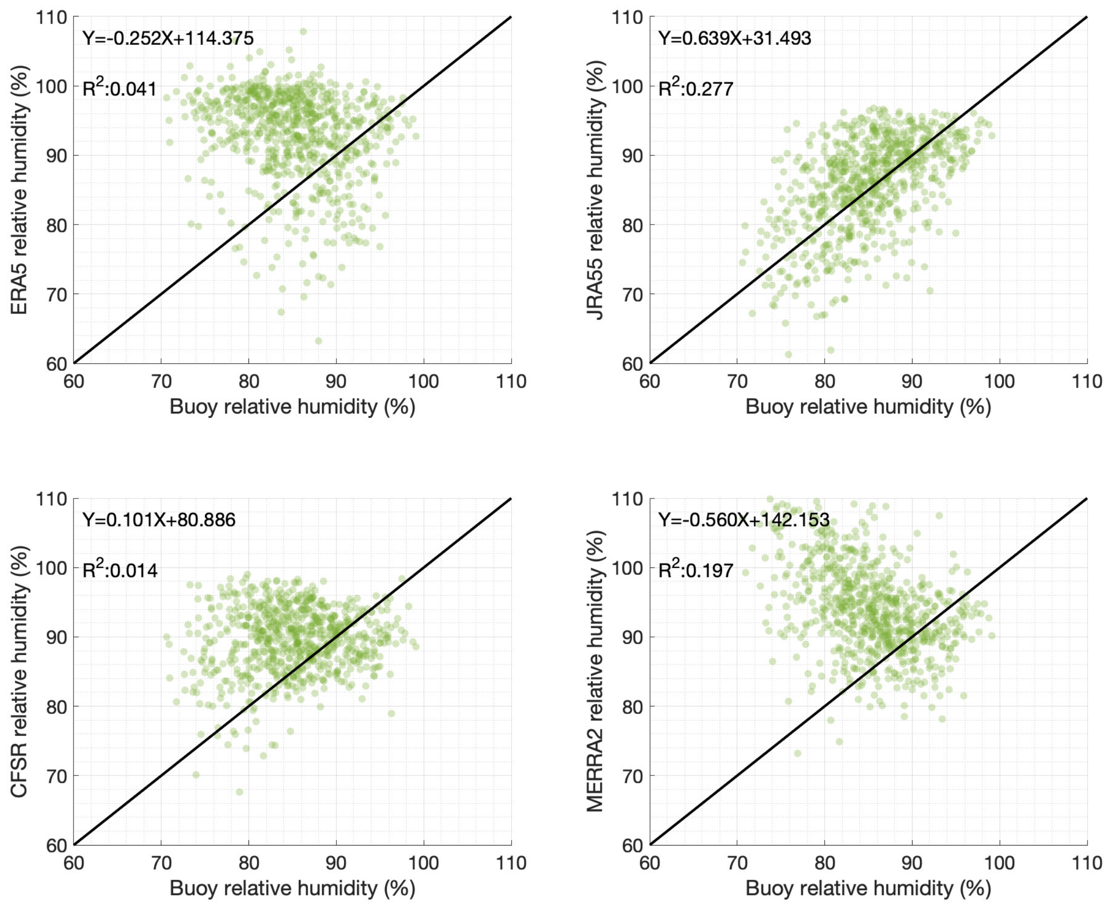

Figure S4. Same as Fig. S2 but for the relative humidity.

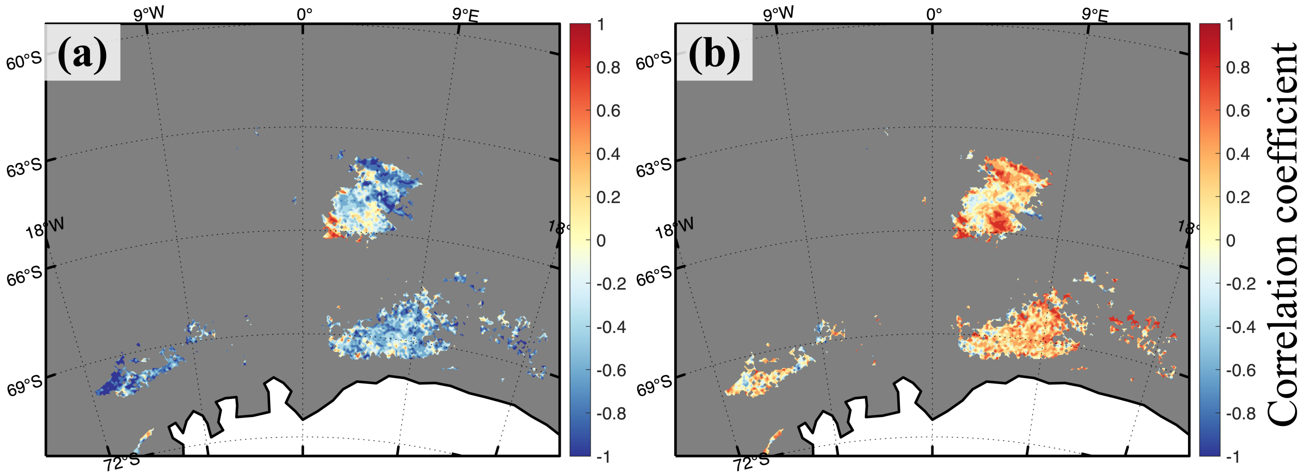

Figure S5. The correlation coefficient (a) between sea ice volume V_p and 2 m air temperature, and (b) between sea ice volume V_p and 10 m wind speed during the 2017 freezing seasons (May-Oct).

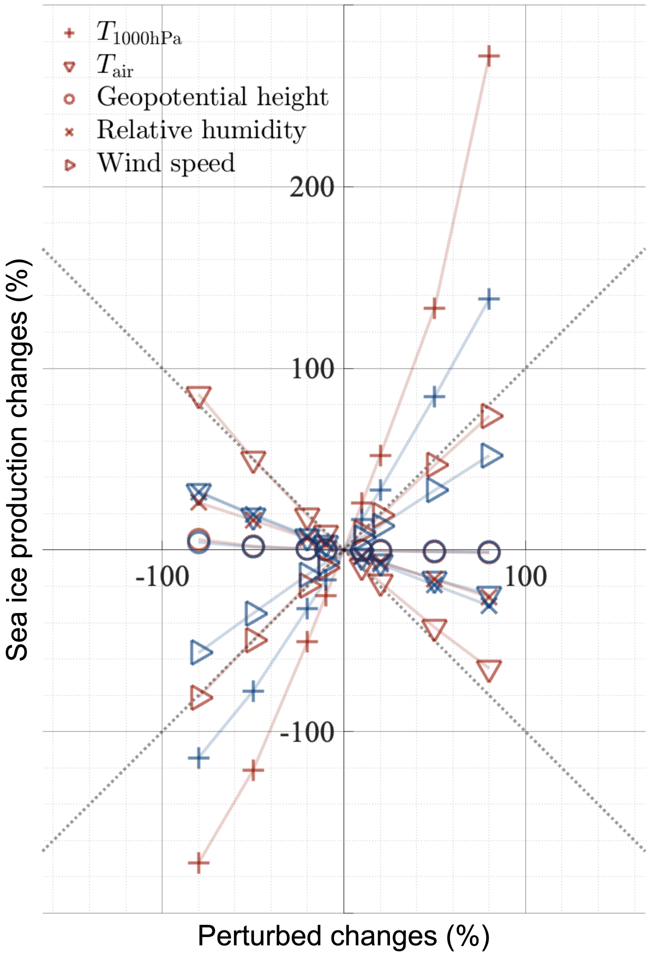

Figure S6. Sensitivities (relative change, Units: %) in accumulated May–October polynya sea ice production in 2016 (red) and 2017 (blue) to the five JRA55 atmospheric variable perturbations: 1000 hPa ($T_{1000hPa}$) and 2 m air (T_{air}) temperatures, geopotential height, relative humidity and wind speed, in eight scenarios (±10, ±20, ±50, ±80%). The black dotted lines are y=x and y=-x ($|\alpha|$=1).

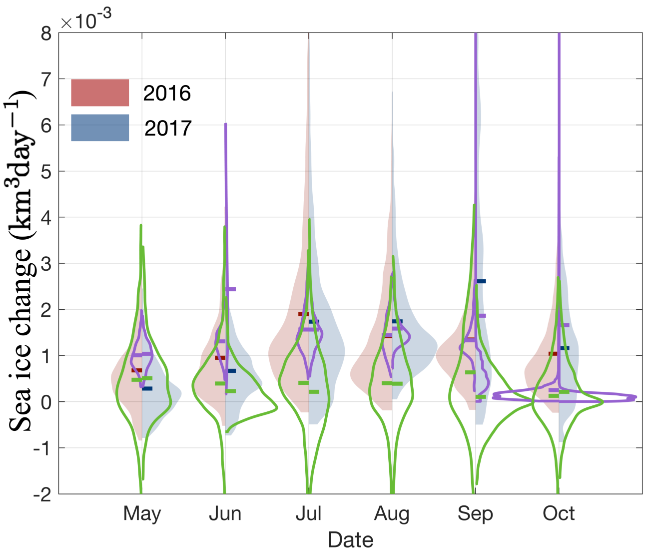

Figure S7. Distribution of monthly sea ice change (Units: km^3day^{-1}) from "FDD" (purple lines) and "SMOS-SMAP" (green lines), and from Eq. 8 (red and blue shading) within 2016 (left) and 2017 (right) polynyas. The short-solid horizontal lines are the monthly median production from each method.

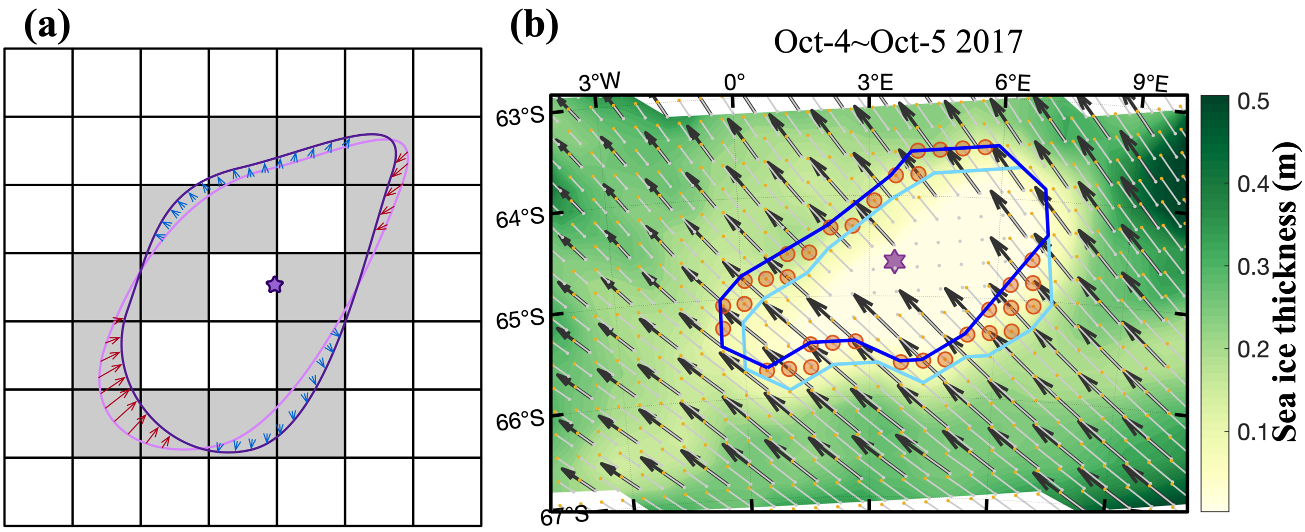

Figure S8. (a) Schematic for dynamic-induced ice changes within the polynya (light purple), showing the the import (red arrows) and export (blue arrows) of sea ice, and the extent of polynya in the next time step (dark purple). The purple stars are the centers of mass of the polynya and gray shading cells are the dynamic active area. (b) Sea ice thickness (contour shading; Units: m) from SMOS-SMAP, Maud Rise polynya extent in light (dark) blue line on Oct-4 2017 (Oct-5-2017), and sea ice drift (black vectors) from NSIDC on Oct-4 2017. The small grey (orange) dots are the sea ice location on Oct-4 2017 (Oct-5 2017) at each location of the entire region. The large orange circles in between the blue lines are the pixels where sea ice volume is changing due to dynamic drifting effects.