Supplement of
Clouds damp the impacts of Polar sea ice loss

Authors: Ramdane Alkama[1*], Alessandro Cescatti[1], Patrick C. Taylor[2], Lorea Garcia-San Martin[1], Herve Douville[3], Gregory Duveiller[1], Giovanni Forzieri[1] and Didier Swingedouw[4]

Affiliation:

[1] European Commission, Joint Research Centre, Via E. Fermi, 2749, I-21027 Ispra (VA), Italy

[2] NASA Langley Research Center, Hampton, Virginia

[3] Centre National de Recherches Meteorologiques, Meteo-France/CNRS, Toulouse, France

[4] EPOC, Universite Bordeaux 1, Allée Geoffroy Saint-Hilaire, Pessac 33615, France

***Correspondence to:** Ramdane Alkama (ram.alkama@hotmail.fr)

1. Estimation of the part of SWcre due to albedo change and the part that is induced by the change in cloud cover/thickness

SWcre at the surface for the year yi (Eq. 11) and year yi+1 (Eq. 12) is function of surface albedo α, SWdown under clear sky conditions ($SW\downarrow_{clr}$) and SWdown under total sky conditions ($SW\downarrow_{tot}$).

$$SWcre_{yi} = (1-\alpha_{yi})(SW\downarrow_{tot,yi} - SW\downarrow_{clr,yi}) \quad (11)$$

$$SWcre_{yi+1} = (1-\alpha_{yi+1})(SW\downarrow_{tot,yi+1} - SW\downarrow_{clr,yi+1}) \quad (12)$$

Using the first-order Taylor series expansion to (11) yields

$$\Delta SWcre_{yi+1-yi} =$$

$$(-\Delta\alpha_{yi+1-yi})(SW\downarrow_{tot,yi} - SW\downarrow_{clr,yi}) + (1-\alpha_{yi})\Delta_{yi+1-yi}(SW\downarrow_{tot} - SW\downarrow_{clr}) \quad (13)$$

Where

$$\Delta_{yi+1-yi}(SW\downarrow_{tot} - SW\downarrow_{clr}) = (SW\downarrow_{tot,yi+1} - SW\downarrow_{clr,yi+1}) - (SW\downarrow_{tot,yi} - SW\downarrow_{clr,yi}) \quad (14)$$

Separating the terms yields,

$$\Delta SWcre_{ALB} = (-\Delta\alpha_{yi+1-yi})(SW\downarrow_{tot,yi} - SW\downarrow_{clr,yi}) \quad (15)$$

Where $\Delta SWcre_{ALB}$ is the part of SWcre change that is induced by the change in surface albedo.

$$\Delta SWcre_{cloud} = (1-\alpha_{yi})\Delta_{yi+1-yi}(SW\downarrow_{tot} - SW\downarrow_{clr}) \quad (16)$$

Where $\Delta SWcre_{cloud}$ is the part of SWcre change that is induced by the change in cloud cover and cloud optical.

$$\Delta SWcre_{yi+1-yi} = \Delta SWcre_{ALB} + \Delta SWcre_{cloud} \quad (17).$$

The above equations are used in figure 6 and S5.

2. Estimation of the local variation in SW, LW and NET energy flux, and cloud cover and cloud optical depth from the changes in sea ice concentration

To explain figure 4, 5, 6, S5 and S6 in detail, the methodology is schematized in Figure S7 and is based on the following steps. We use here SW as an example, but it can be applied in the same way to other variables.

1) For a given area, the ΔSW_i values are summarized in a schematized plot (Figure S7a) where each cell *i* shows the average ΔSW_i observed for all possible combination of sea ice concentration in the two consecutive observation years (year yi and yi+1 from time period 2001-2016) reported on the X and Y axis, respectively. For the sake of clarity in Figure S7 the X and Y axes report sea ice concentration by interval of 10%, while in Figure 4, 5, 6, S5 and S6 the axes are discretized with 2% bins.

2) Because of the regular latitude/longitude grid used in the analysis, the area of the grid cells (a_m) varies with the latitude. The energy signal (ΔSW_i) is therefore computed as an area weighted average (Equation 7).

$$\Delta SW_i = \frac{\sum_{m=1}^{M} a_m \Delta SW_m}{\sum_{m=1}^{M} a_m} \qquad (7)$$

3) Calculation of the area weighted average (ΔSW_p) of the energy signal (ΔSW_i) of all (*N*) grid cells with the same fraction *X* of change in sea ice concentration (shown with the same colour in Figure S7, Equations 8, 9).

$$A_i = \sum_{m=1}^{M} a_m \qquad (8)$$

$$\Delta SW_p = \frac{\sum_{i=1}^{N} A_i \Delta SW_i}{\sum_{i=1}^{N} A_i} \qquad (9)$$

The average energy signals (ΔSW_p) per class of sea ice concentration change are finally reported in a scatterplot (Figure 4e; Figure S7 right panel) and used to estimate a regression line with zero intercept.

The slope *S* of this linear regression represents the local SW energy signal generated by the complete sea ice melting of a 1° grid cell. The weighted root mean square error "WRMSE" of the slope is estimated by Equation 10, where *p* represents one of the *NP* points in the scatterplot (Fig. 4e; Fig. S7 right panel) and X_p is the relative change in sea ice concentration in the range ±1 (equivalent to ±100% of sea ice cover change).

$$WRMSE = \sqrt{\frac{\sum_{p=1}^{NP} A_p \left(\Delta SW_p - S X_p\right)^2}{\sum_{p=1}^{NP} A_p}}, \quad \text{where} \quad A_p = \sum_{i=1}^{N} A_i \qquad (10)$$

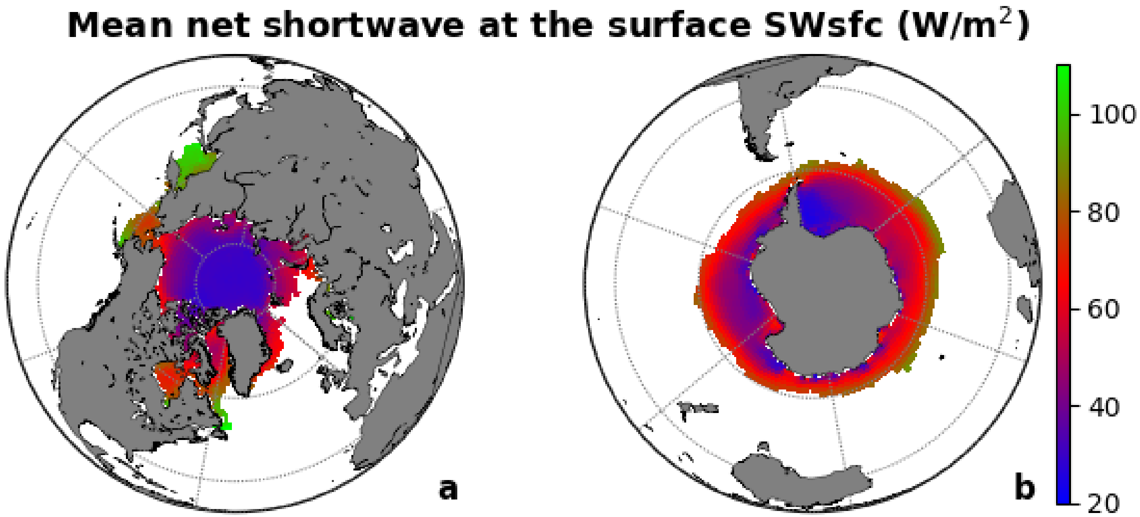

Figure S1 Mean (over 2001-2016) net radiation at the surface (NETsrf) over polar seas based on CERES data.

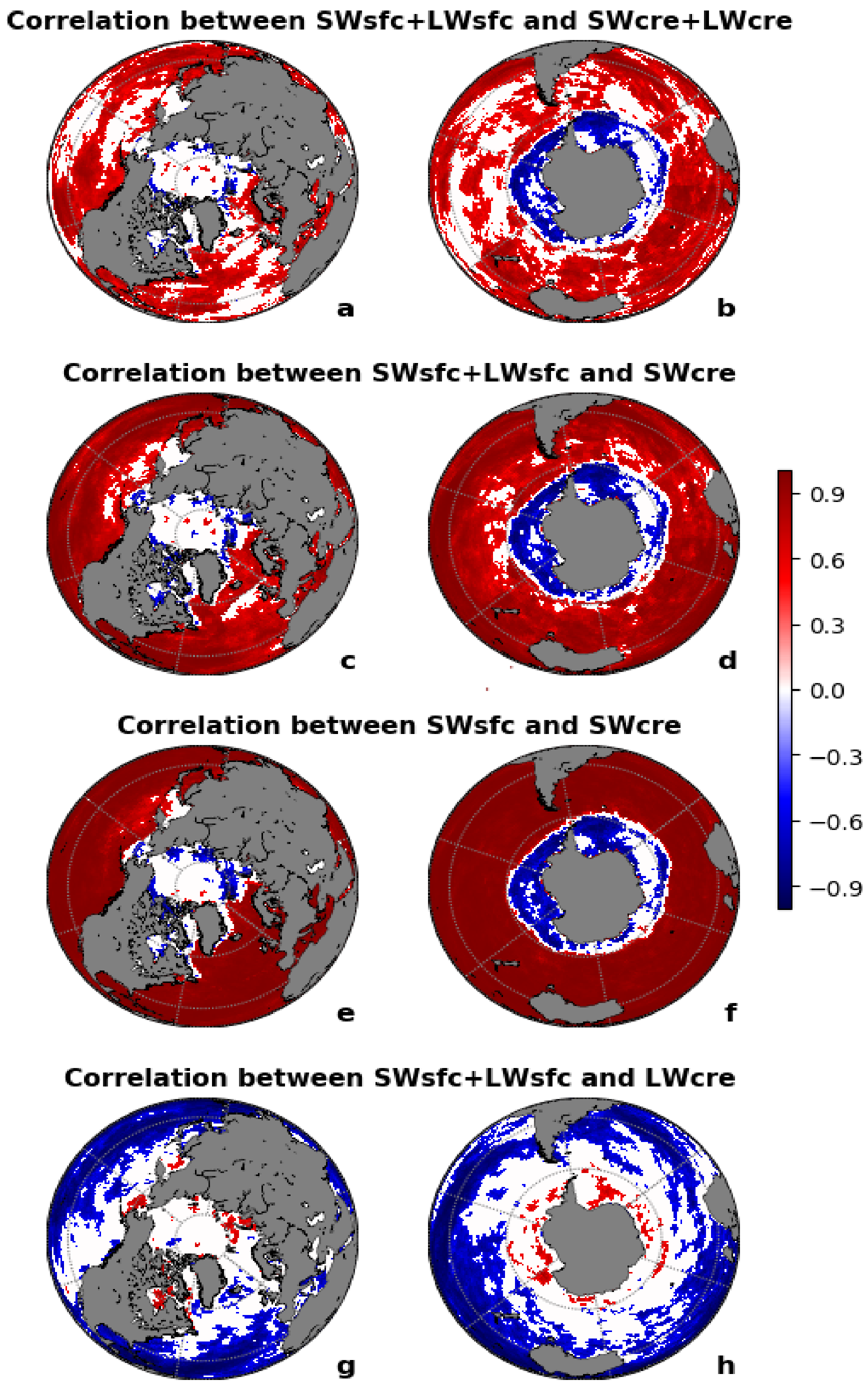

Figure S2 Same as figure 1 but only significant correlations are shown by blue and red colors. To test the significance of the observed correlations, we used the Pearson's correlation test of significance at level $\alpha = 0.05$ for 16-2=14 (16 years) degrees of freedom which correspond to the use of the critical values for Pearson r_0=0.497. This means that all correlation between -0.497 and 0.497 are not significant and set to white color.

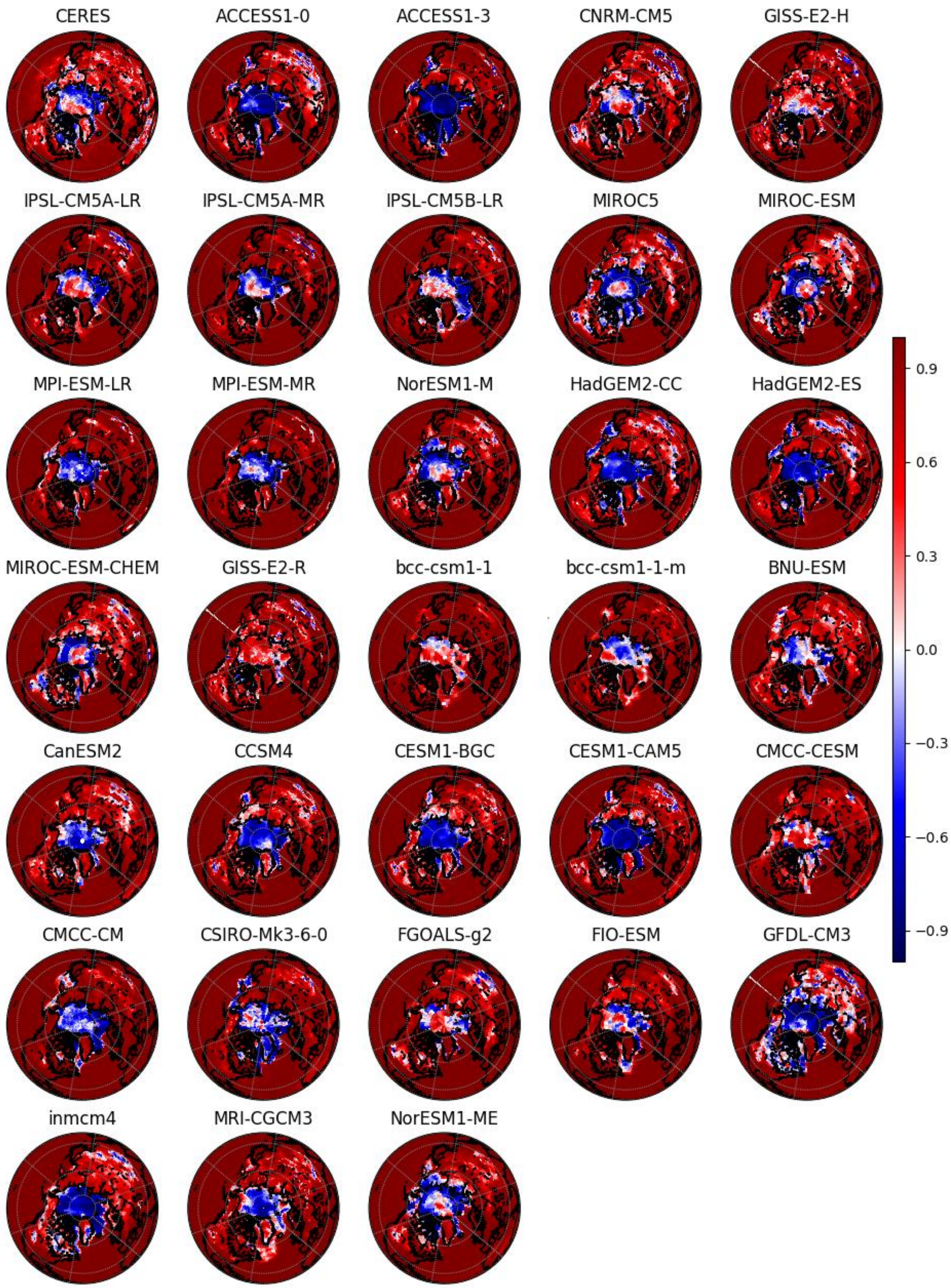

Figure S3 Correlation between SWcre and net solar radiation at the surface SWsfc shown by 32 CMIP5 earth system models and Satellites CERES over 2001-2016 over northern hemisphere.

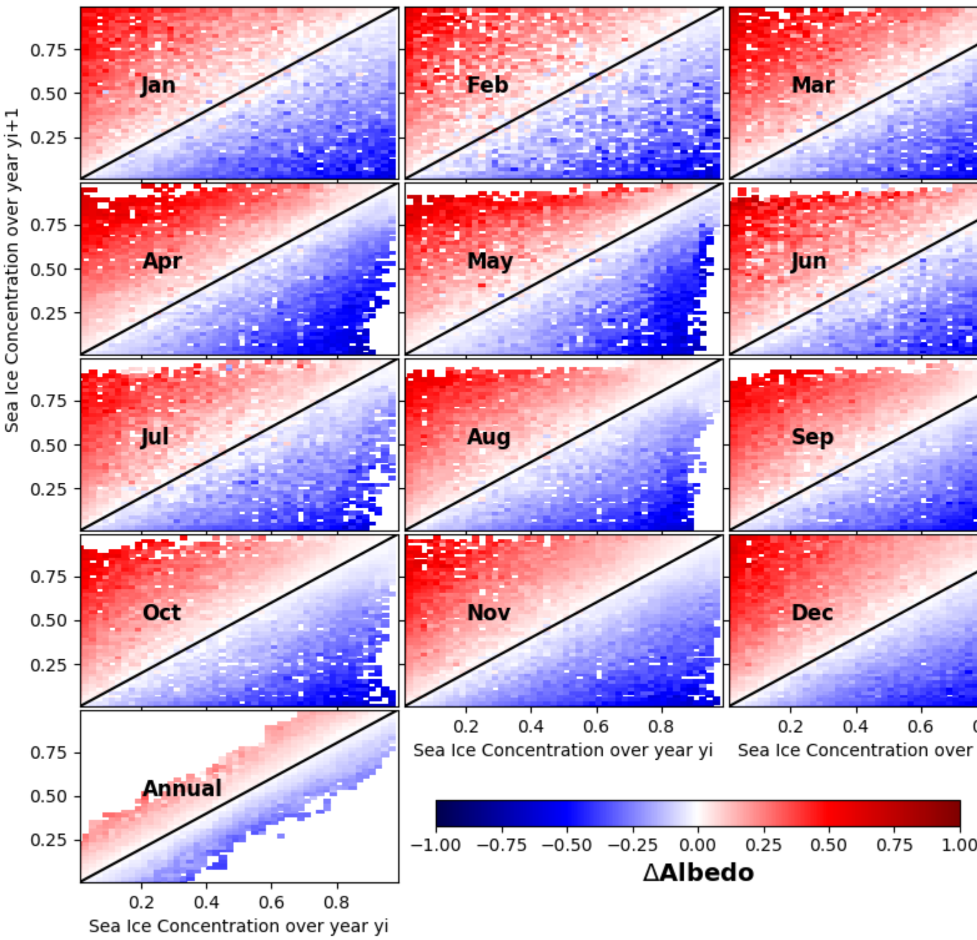

Figure S4 Monthly and annual albedo change between two consecutive years y_{i+1} and y_i over **Antarctic** sea as function of sea ice concentration SIC of the year y_{i+1} and y_i from 2001-2016 time period.

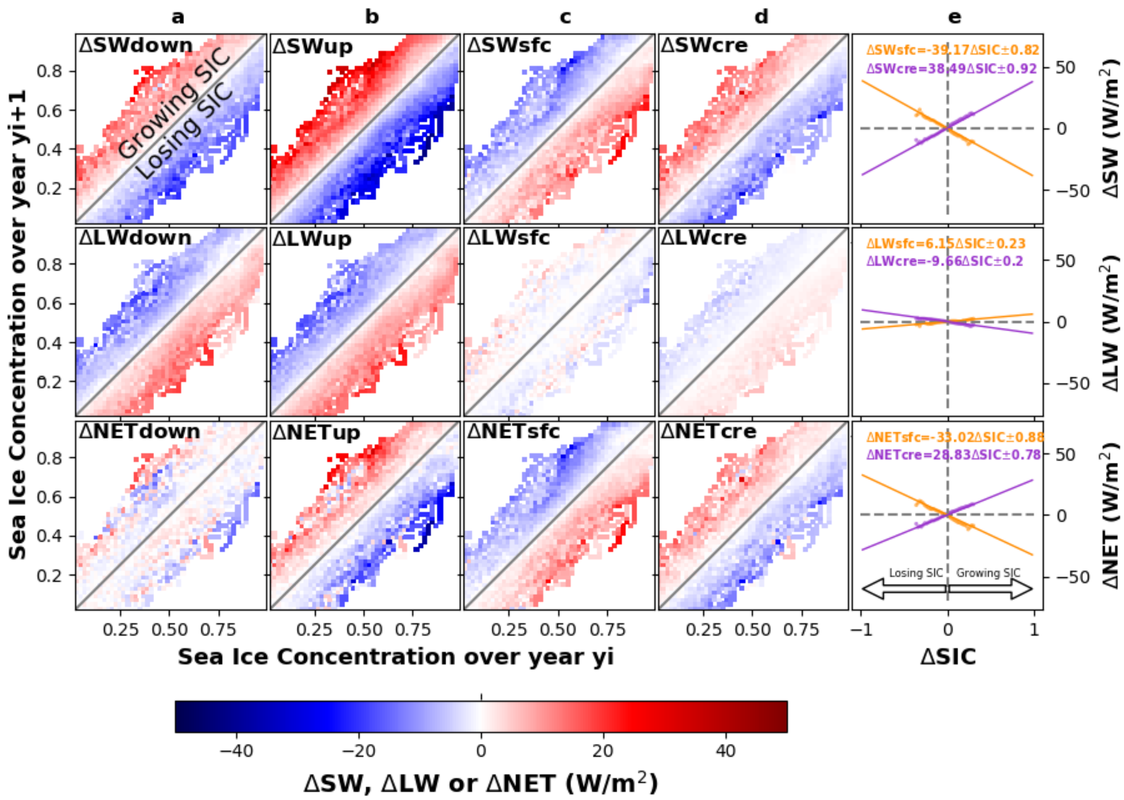

Figure S5 Annual changes in SW, LW and NET as function of SIC. Annual changes in SW (top), LW (middle) and NET (bottom) of radiative down (a), up (b), sfc=down-up (c) and cre (d) over Arctic sea as function of SIC change between two consecutive years y_{i+1} and y_i from 2001-2016 time period. The top triangles in (c top) refers to the increase (growing) in SIC while the blue color means a reduction (cooling) in SWsfc. Whereas, the top triangles in (d) refers to the increase in SIC while the red color means an increase (decreasing the cooling role of clouds) in SWcre. Each dot in column (e) represent the average of one parallel to the diagonal in (c) or (d).

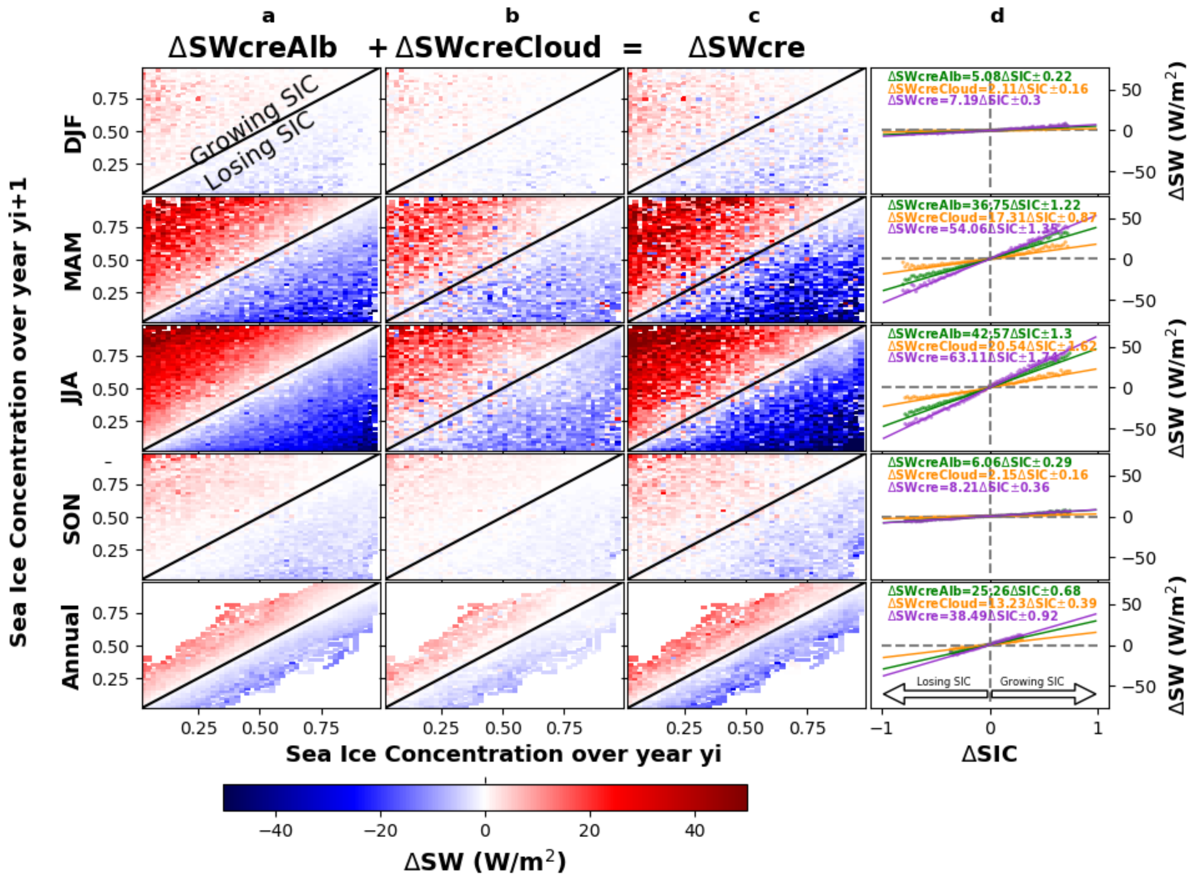

Figure S6 Seasonal and annual changes in SWcreAlb, SWcreCloud and SWcre over Arctic sea as function of SIC change between two consecutive years y_{i+1} and y_i from 2001-2016 time period. All the analysis are based on observations from satellites data.

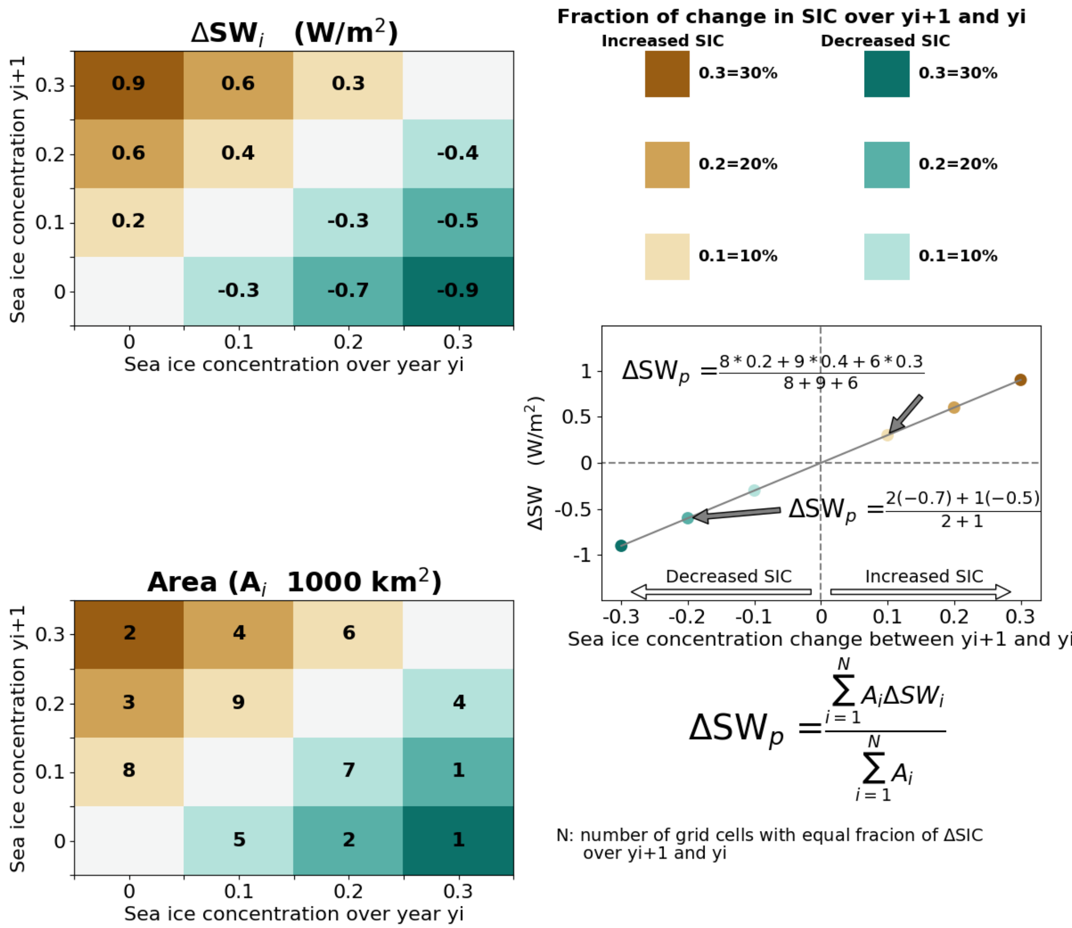

Figure S7 Schematic representation of the methodology used to estimate the energy flux sensitivity to changes in sea ice concentration as a linear regression between the percentage of sea ice concentration and the variation in energy flux (right panel) using SW energy flux data and sea ice concentration defined in the left panels.