Representation of melt ponds for Global Circulation Models

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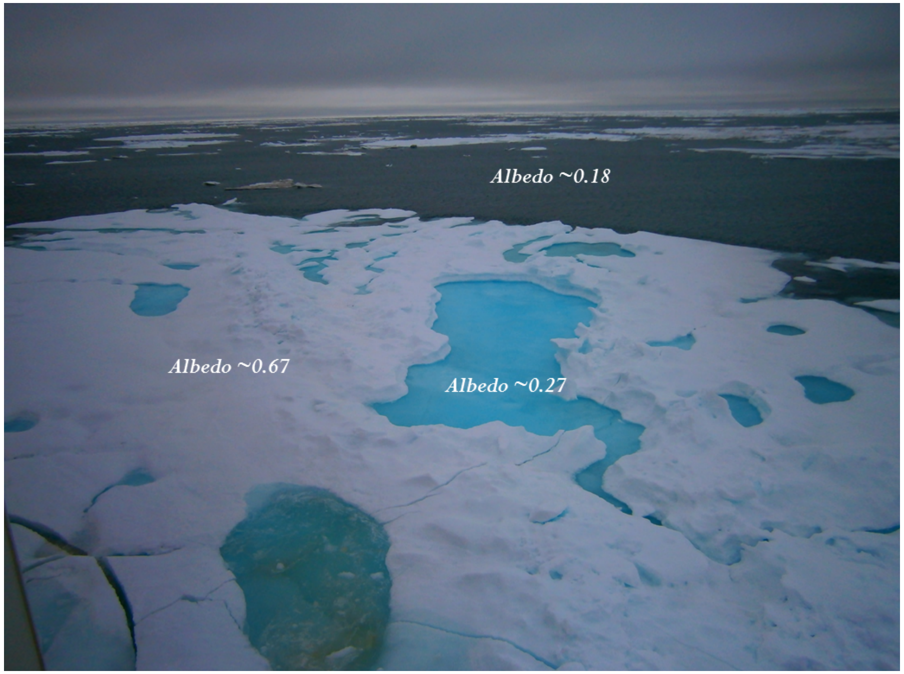
J. Sterlin, T. Fichefet, F. Massonnet, O. Lecomte, M; Vancoppenolle

UCLouvain / Earth and Life Institute, ELIC, Louvain-la-Neuve, Belgium

Melt ponds and the Arctic climate

Melt ponds

pools of freshwater on sea ice
appear in the Arctic during summer months
30 to 50% of area on flat ice
Ice and snow melts + precipitation



Melt ponds on Arctic sea ice.
Credit: I. Sudakov

Effect on the Arctic climate:

Ice-Albedo Feedback
Pond albedo is lower than the snow or ice
More ponds → lower albedo → more melts

Freshwater redirection
Re-stratification of the ocean surface layer
Refreezing of pond melt waters

Neutral Drag coefficients
Edges of the ponds contribute to the form drag, in the same manner as floe edges, leads, and ridges on the ice surface

=> there is a need of including the effects of melt ponds in sea ice models

Melt pond schemes and GCM

Lüthje et al. (2006)
Mathematical model solved by finite difference method

Pedersen et al. (2009)
Polynomial fit of results from Lüthje et al. (2006)

SHEBA

Holland et al. (2012)
Linear fit of depth against melt pond area fraction from SHEBA

Zhang et al. (2018)
Increased water capacity on thicker ice

Flocco and Feltham (2007)
Ice Thickness Distribution to infer the ice surface topography

Flocco et al. (2010, 2012)
Further refined and adaptation to CICE

Schröder et al. (2014)
Melt pond fraction and September minimum

Lecomte et al. (2015)
Implementation in LIM3 + blowing snow

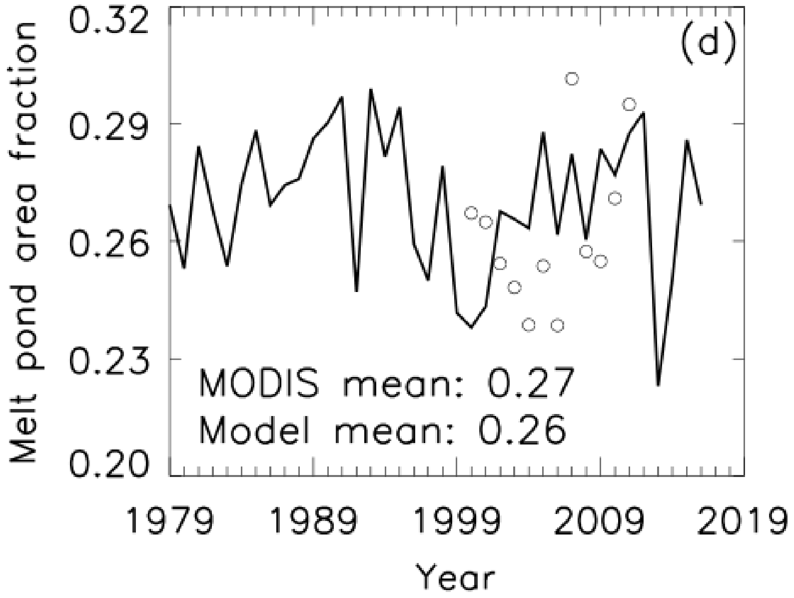
Hunke et al. (2013)
Level ice based definition

Explicit definition the melt ponds aspect ratio: from models or observations

Theoretical considerations to define the melt pond aspect ratio

Trends over the last decades

Zhang et al. (2018)

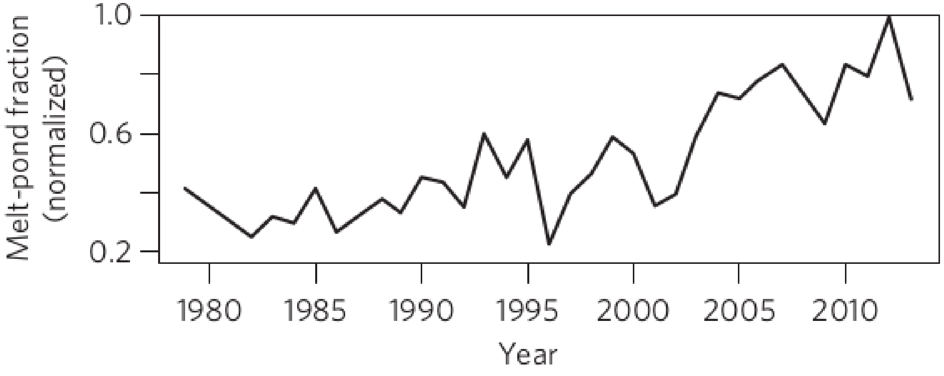


June-August mean melt pond area fraction, averaged over the Arctic Ocean

no trend in melt ponds area fraction

Model	MIZMAS (Ocean-ice)
Scheme:	CESM improved
Refreezing:	Exponential formulation
Surface forcing sets:	CFSR/CFSv2

Schröder et al. (2014)



Time series of normalized pond fraction (mean over the period from 25 June to 25 July)

positive trend in melt ponds area fraction

Model	CICE (stand-alone)
Scheme:	Topographic
Refreezing:	Ice lid formulation
Surface forcing set:	NCEP_Reanalysis-2

How can we explain the difference of trends?

1. definition of the aspect ratio

Explicit : Bounds the melt ponds to observations or model results
Time and spatial representativeness of the expressions

Non-Explicit : Avoid the use of the explicit definition of the aspect ratio
Flocco: melt ponds develop on the thinnest ice categories first

2. atmospheric surface boundary condition

The atmospheric surface condition determines the amount of surface melt
Differences in the atmospheric states may explain the two behaviors

3. refreezing of melt ponds

Zhang : refreezing formulation of Holland
melt ponds refreeze when surface air temperature is less than -2.00°C

Schroder: ice lid formulation of Flocco
a layer of ice forms on top the melt ponds below -0.15°C

Structure of the presentation

Melt ponds in GCM:

What we want

1) the conceptual difference of the aspect ratio definition in melt pond schemes;
2) the role of the refreezing of the melt ponds;
3) the impact of the uncertainties in the atmospheric forcing on the simulations.

What we have:

- CESM (Holland et al., 2012) + Topographic (Flocco et al. 2010, 2012) in LIM3
- Holland et al. (2012) refreezing mechanism in both schemes
  - → K: threshold to trigger the refreezing of the melt ponds
- DFS5.2 and JRA-55 reanalyzes to define the atmospheric surface state

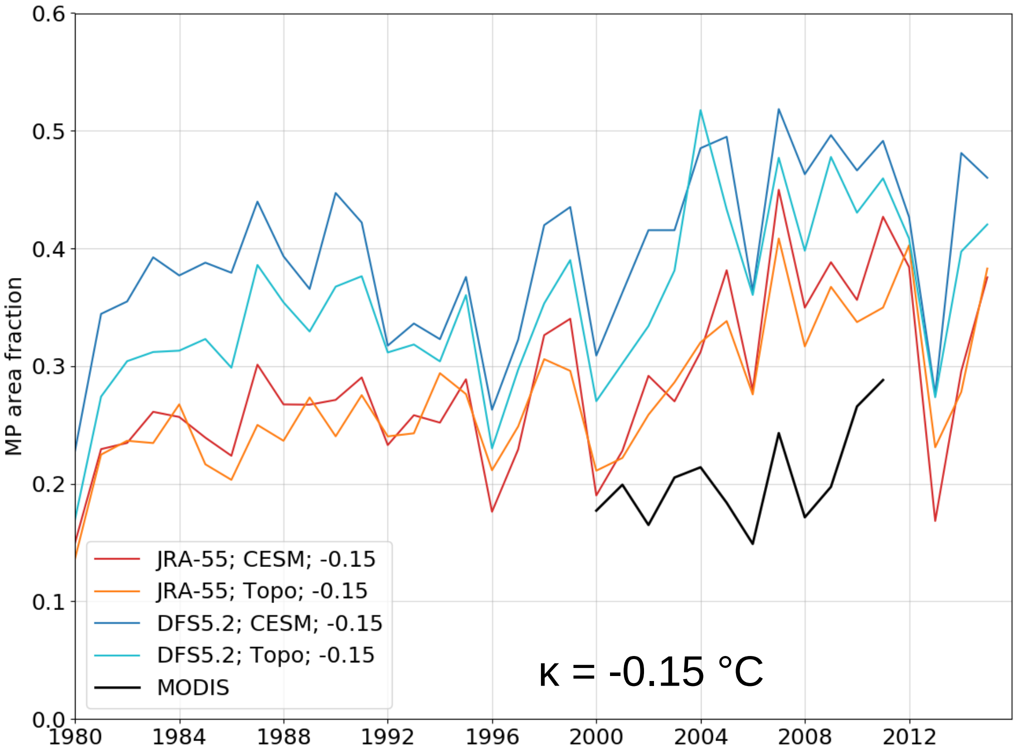
Method

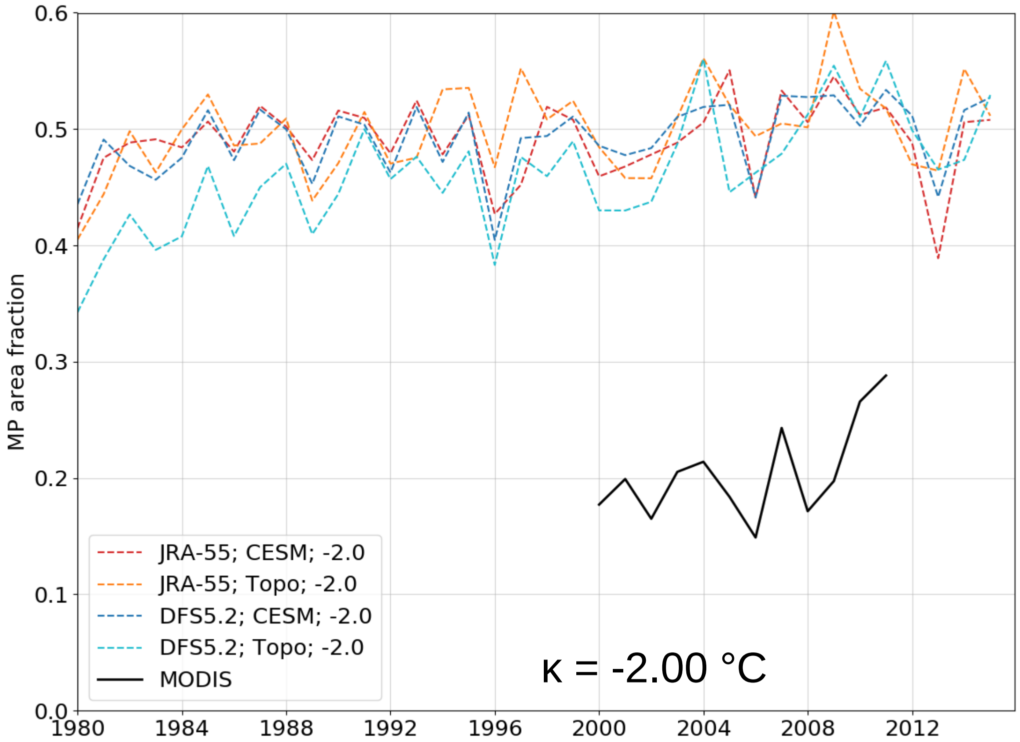
Run NEMO 3.6 + LIM3 on ORCA1 grid for 58 years, in combination with:
CESM or Topographic schemes; κ = -2.00°C or κ = -0.15°C ; JRA-55 or DFS5.2

Results & discussions

Impact on the representation of the melt ponds and the sea ice
Inclusion of melt ponds schemes in GCM

Trends in melt pond area fraction (of sea ice) in August





When κ = -0.15 °C:

positive trends in ponded ice area
larger variability
lower melt pond area fraction

When κ = -2.00 °C:

no trends in ponded ice area
lower variability
larger melt pond area fraction

=> The temperature threshold κ has a strong impact on the trends in melt pond area fraction

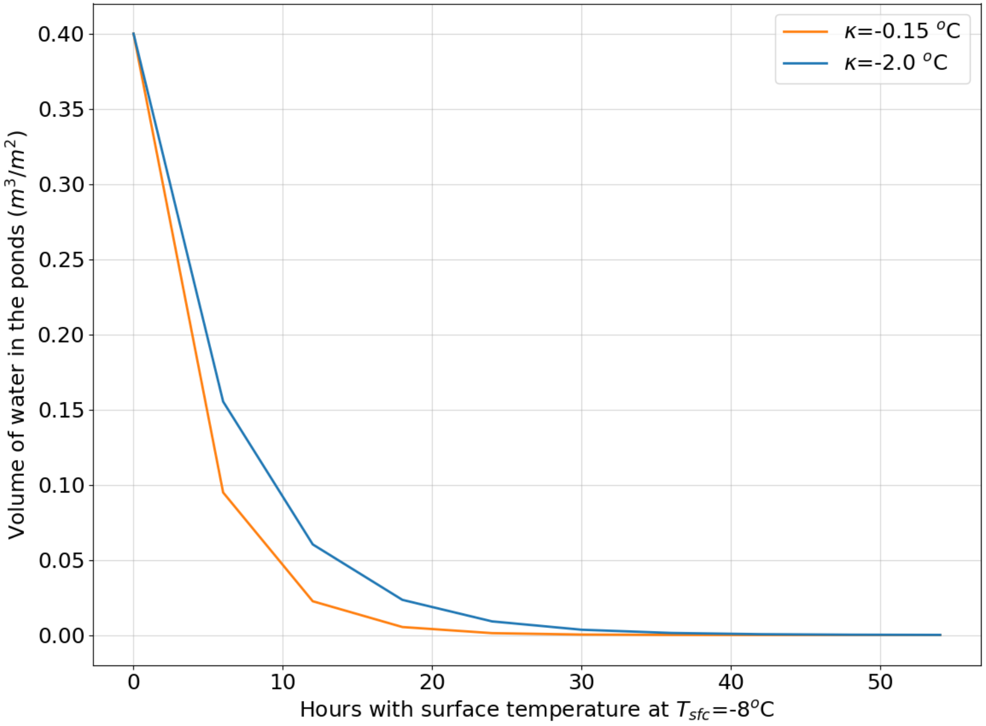
Holland refreezing melt pond mechanism

When T_{sfc} is lower than κ, the volume in the ponds decreases exponentially:

$$V_{pnd}^{t+1} = V_{pnd}^{t} \exp\left(-0.01\frac{T_{sfc} - \kappa}{\kappa}\right)$$

Where:

V_{pnd}^{t}	volume in the ponds at time step t
K	threshold temperature for refreezing
0.01	melt pond freezing rate

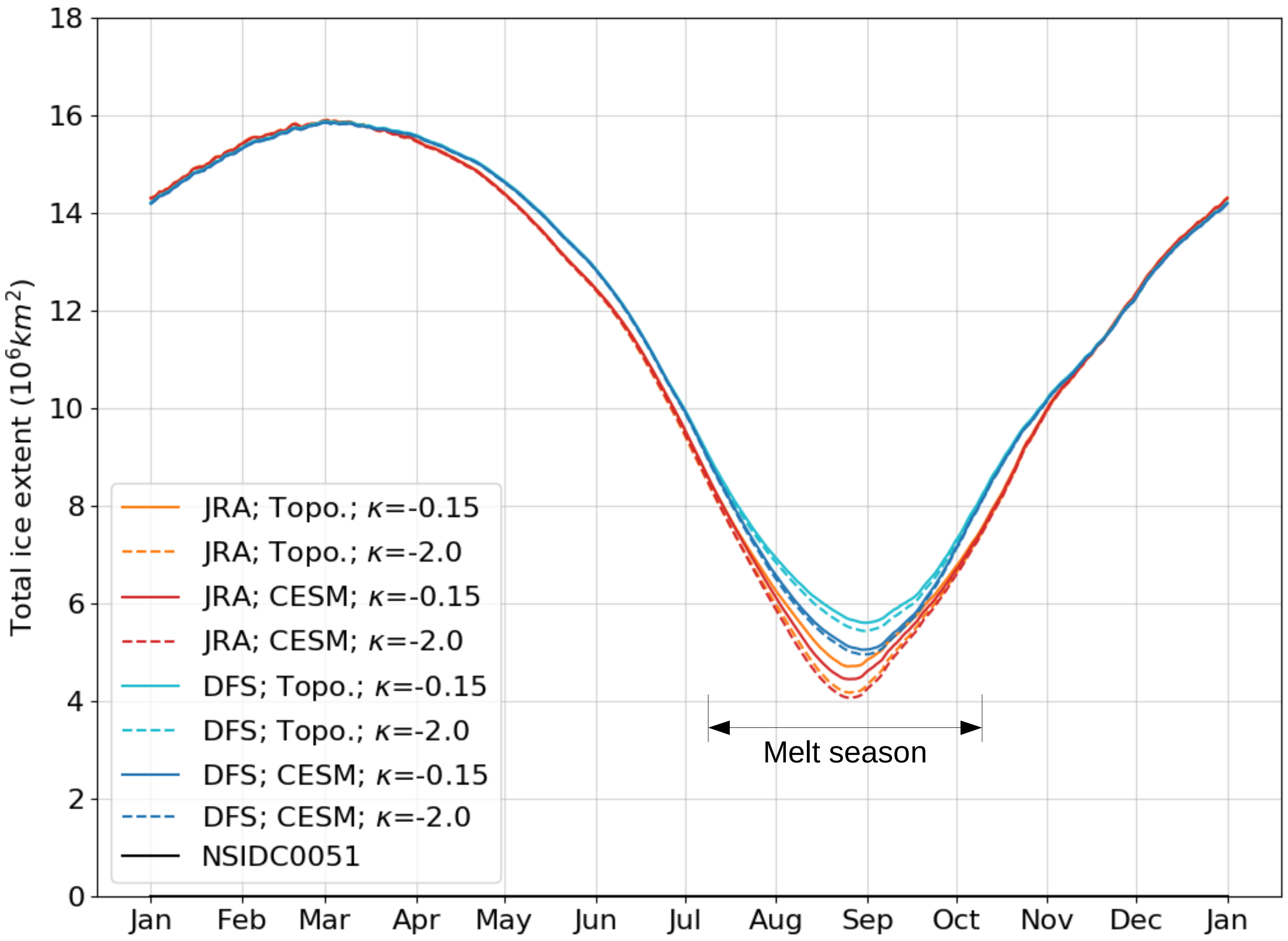


- The Refreezing is more efficient with -0.15 °C as threshold temperature

- There are more days with surface air temperature below -0.15 than -2.00°C
  - 7 to 15 days below -0.15°C in August in average
  - 1 to 5 days below -2.00°C

=> -2.00 °C delays strongly the refreezing of the melt ponds

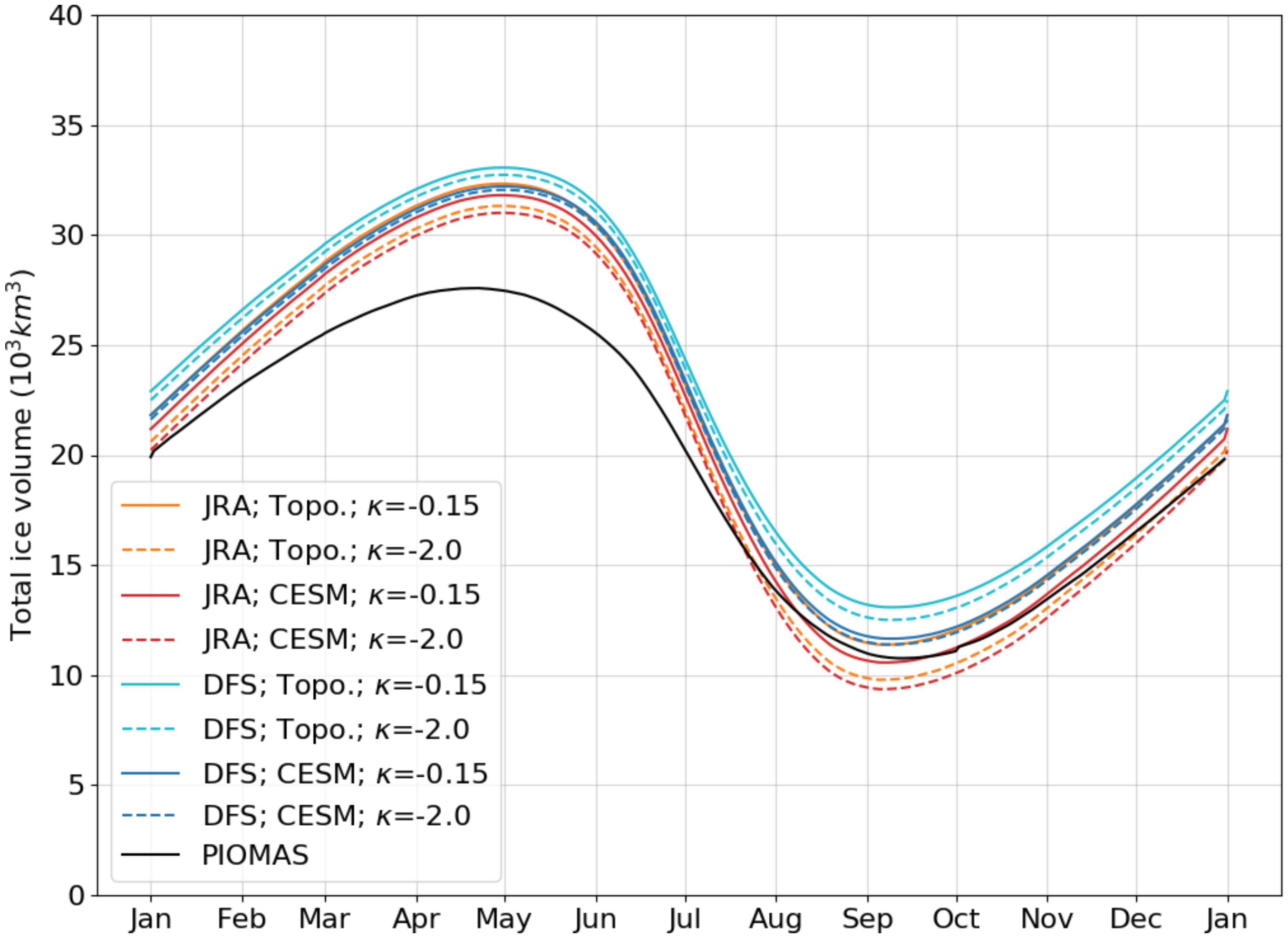
Impact on the Arctic sea ice



The effect of the ponds on the total sea ice extent is restricted to summer months.

- DFS5.2 > JRA-55
- K = -0.15°C > K = -2.00°C
- Topographic > CESM

Impact on the Arctic sea ice



The total sea ice volume is offset by a near constant amount between the simulations. The shape of the seasonal cycle is preserved.

- DFS5.2 > JRA-55
- K = -0.15°C > K = -2.00°C
- Topographic > CESM

Mean absolute difference between the simulations

The simulations are paired representations of the same climate system.

The differences between the simulations express the disagreement of the model on the climate state.

We can select paired simulations and express the difference between the simulations

$$D_s = \frac{1}{4} \sum_f \sum_\kappa \left\| X_{\{s=CESM\}} - X_{\{s=Topo\}} \right\|$$

$$D_f = \frac{1}{4} \sum_s \sum_\kappa \left\| X_{\{f=JRA\}} - X_{\{f=DFS\}} \right\|$$

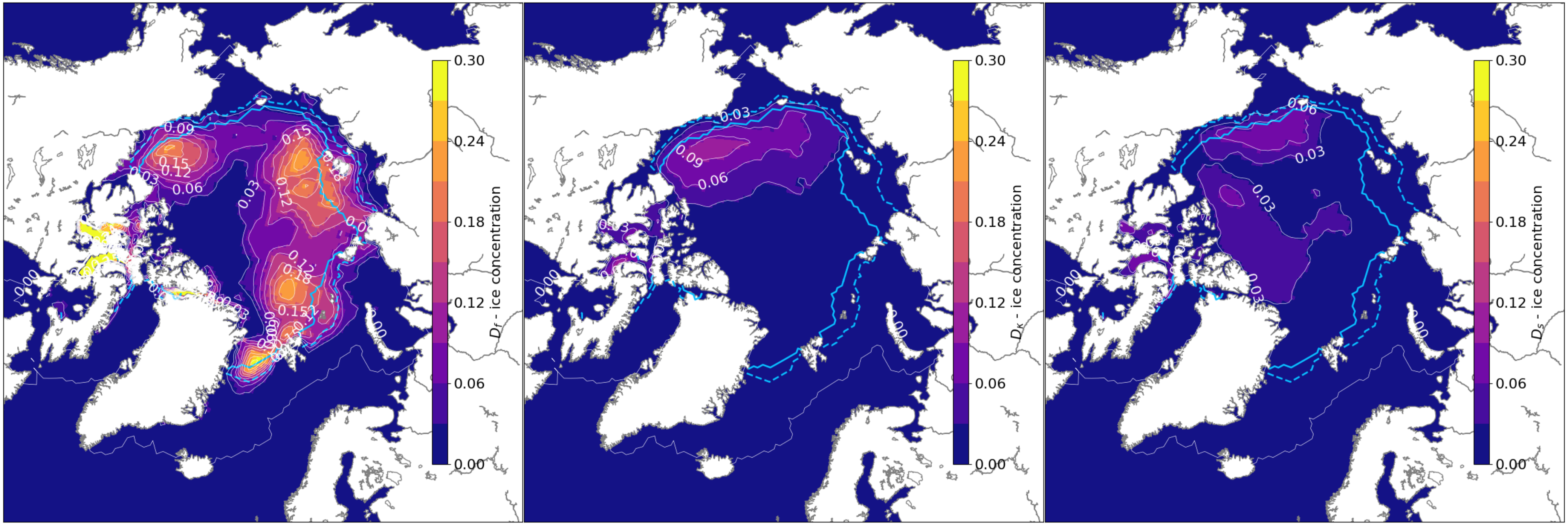
$$D_\kappa = \frac{1}{4} \sum_s \sum_f \left\| X_{\{\kappa=-0.15\}} - X_{\{\kappa=-2.00\}} \right\|$$

Where:

X is a variable of the model, such as the ice concentration, volume, etc
f is the forcing, either DFS or JRA
k is the refreezing temperature, -0.15°C or -2.00°C

Ds, Df, Dk are the mean absolute difference between the simulations.

Mean absolute difference - ice concentration - August



D_forcing

D_freezing

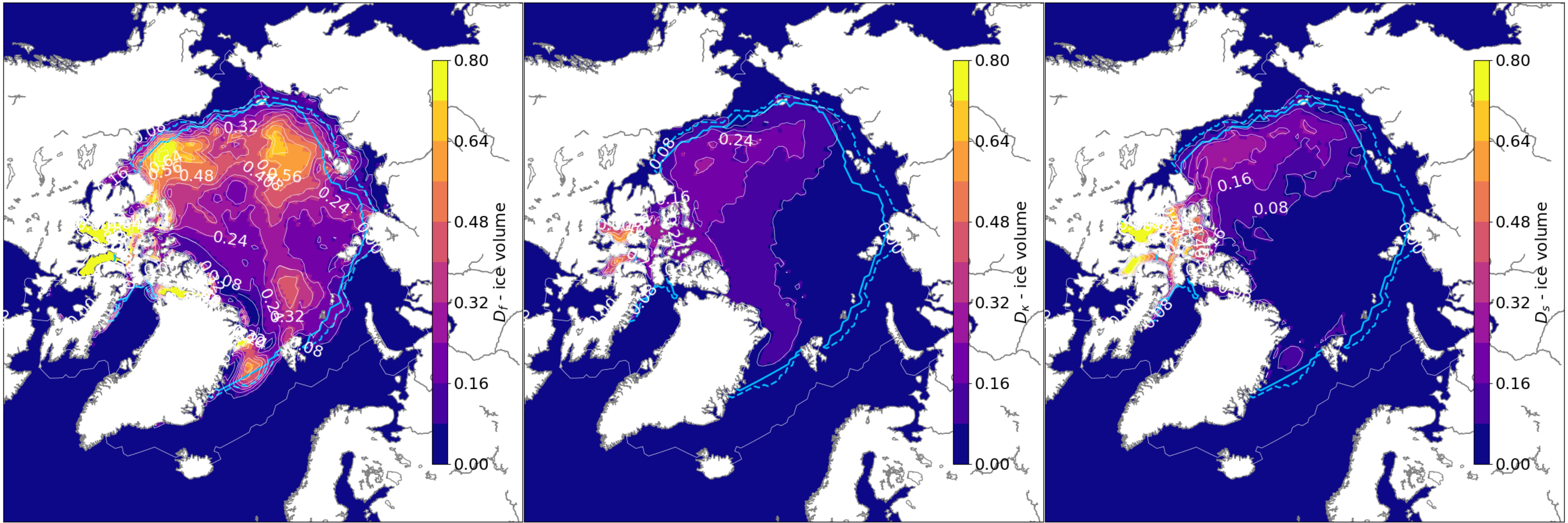
D_scheme

The atmospheric forcing method explains most of the differences in ice concentration between the simulations.

The choice of the refreezing temperature has an effect in August, in the Pacific sector of the Arctic: Beaufort, Chukchi, and East Siberian seas.

The melt pond schemes result in differences in August, in the central Arctic, an area not concerned by the uncertainties in the surface forcing. The schemes also have an effect in the Beaufort and Chukchi seas.

Mean absolute difference - ice volume - September



D_forcing D_freezing D_scheme

The uncertainties in the atmospheric states are the main driver of the differences in ice volume. However, the differences associated to kappa and the numerical schemes are non negligible.

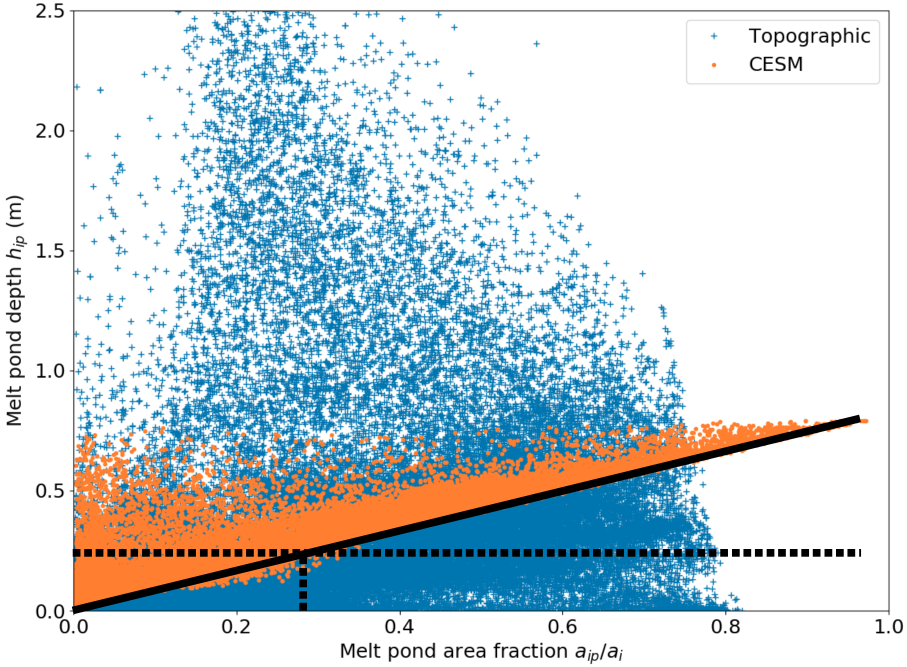
The numerical schemes give differences of the same order as the atmospheric uncertainties in the Chukchi sea and the Northwestern passages

Although smaller, the mean absolute difference is the most important along the northern coast of Greenland and the Arctic Archipelago

In winter, the differences between the simulations are less important and concentrate in the Arctic Archipelago.

Melt pond aspect ratio and albedo

Melt pond aspect ratio:



CESM scheme

- strongly bounded by the SHEBA relation
- Melt ponds can reach up to 100% of sea ice area

Topographic scheme

- wider range of melt pond depths and areas
- Most of the ponds are less than 0.5m deep, but can reach unphysical depth

Albedo of melt ponds

$$\alpha_{pnd}\left(h_{pnd}\right) = \alpha_{ice}^{dry} + (\alpha_{ice}^{dry} - \alpha_{pnd}^{ref})\exp\left(\frac{h_{pnd}}{\omega}\right)$$

The albedo of melt ponds quickly converges to a minimum as the water depth increases

A melt pond depth greater than 0.23 meter results in more than 99% of decrease in albedo

Surface type	Name	Value
Dry bare-ice albedo	α_{dry}^{ref}	0.72
Ponded ice albedo	α_{pnd}^{ref}	0.25
Characteristic depth	ω	0.05

=> CESM scheme is less sensitive to the melt pond depth than the topographic scheme

Conclusion

The temperature threshold K explains the difference of trends in melt pond area fraction

The atmospheric surface state is key to well represent the melt ponds in GCM

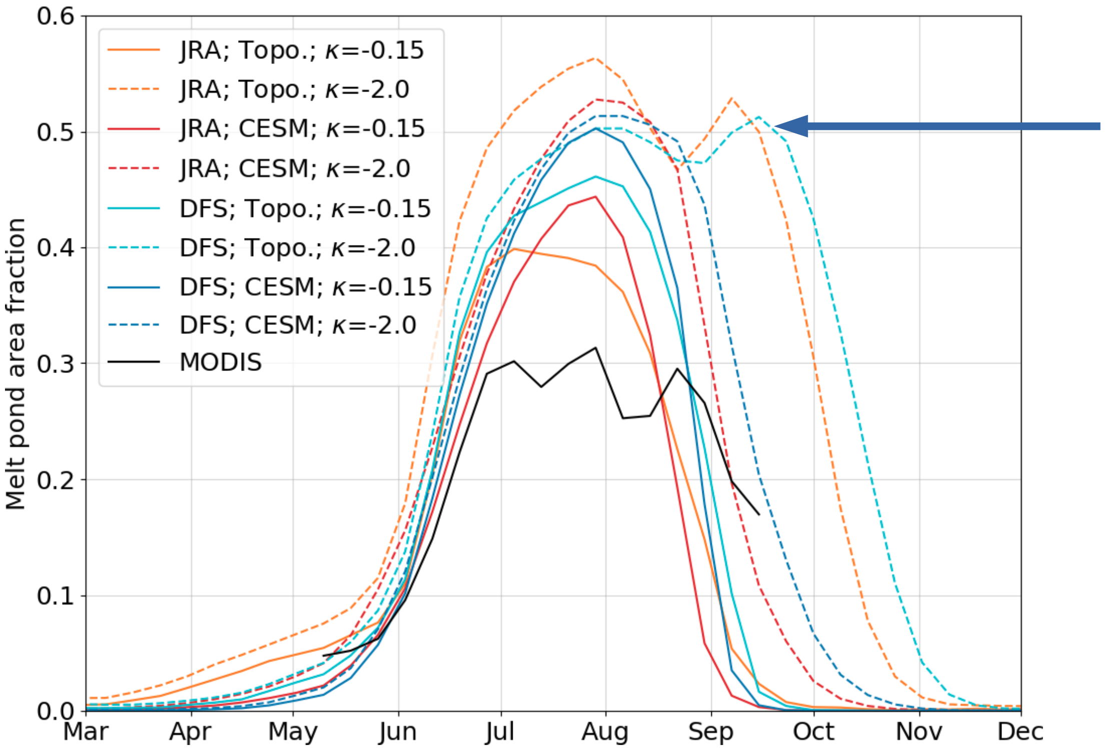
The differences between the simulations due to the scheme and the refreezing threshold are less important, in regard to the ice concentration and volume.

The albedo calculated from the CESM scheme is nearly independent to the melt pond depth → “ON/OFF” scheme

The topographic scheme gives a more realistic range of melt pond depths and areas

However, the CESM scheme can give similar effects on the global Arctic sea ice

Mean seasonal cycle in melt pond area fraction



Formation of sea ice
→flattening of the ITD

Topo. redistributes the melt water over the newly formed thin ice categories

=> shallow but extended melt ponds over the sea ice

κ = -0.15 °C:

The summer maximums show greater sensitivity to the reanalyzes and the schemes
The refreezing occurs in advance to MODIS and the simulations using -2.00 °C
CESM scheme gives larger ponded ice area than the topographic
DFS5.2 gives larger ponded ice area than JRA-55

κ = -2.00 °C:

Less differences between the simulations in July
When using the topographic scheme, second maximum in September
Differences between CESM and Topographic schemes unclear
DFS5.2 gives lower ponded ice area than JRA-55