Modelling Sea Ice Thickness Evolution with Icepack during MOSAiC Expedition

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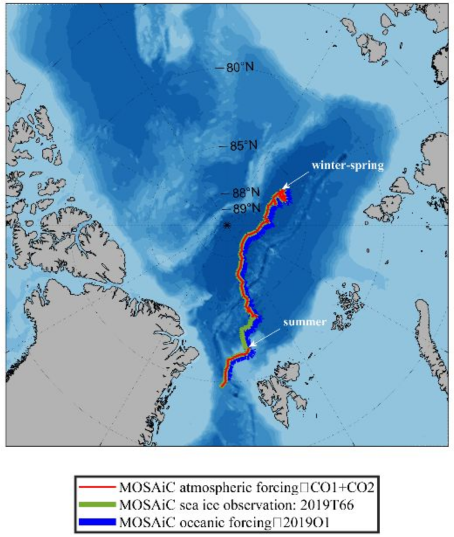
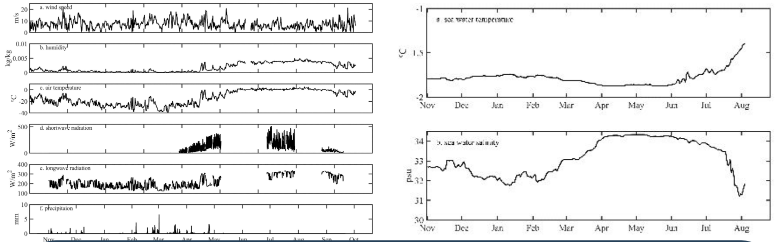
Thanks to: CICE Consortium

Simulation of Sea Ice Thickness Change During the MOSAiC Period

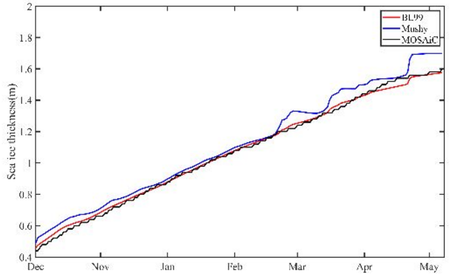
Presented at CICE Workshop 2024

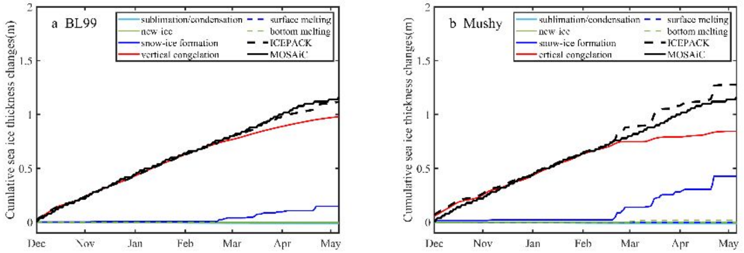




MOSAiC 2019/10–2020/09
BL99, Mushy Layer
CESM, LVL, TOPO

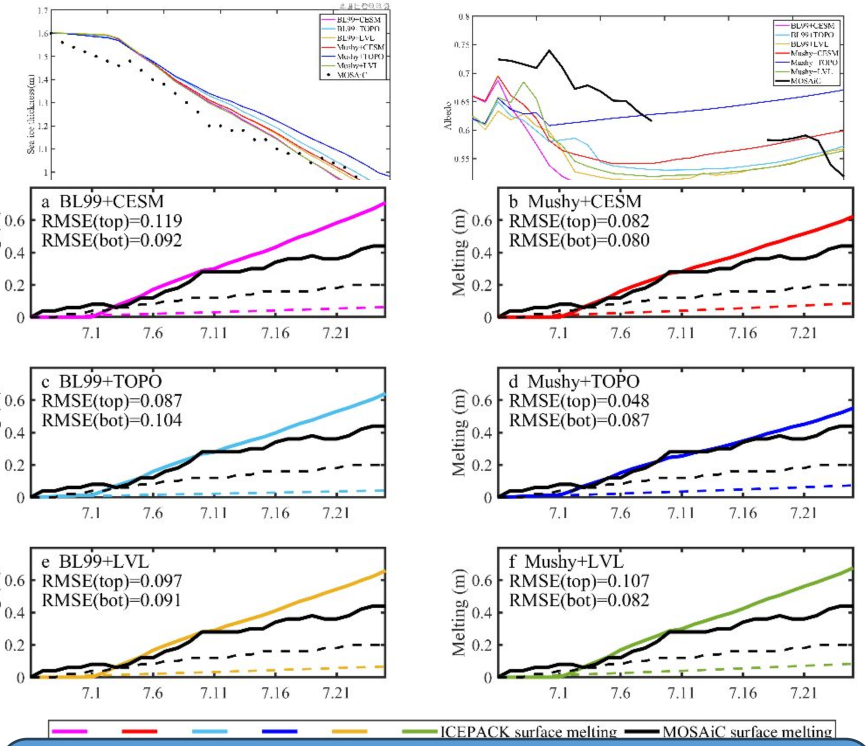
Nov 29—May 2020





The main reason of the error in sea ice thickness is due to excessive snow-sea ice conversion.

June-July 2020



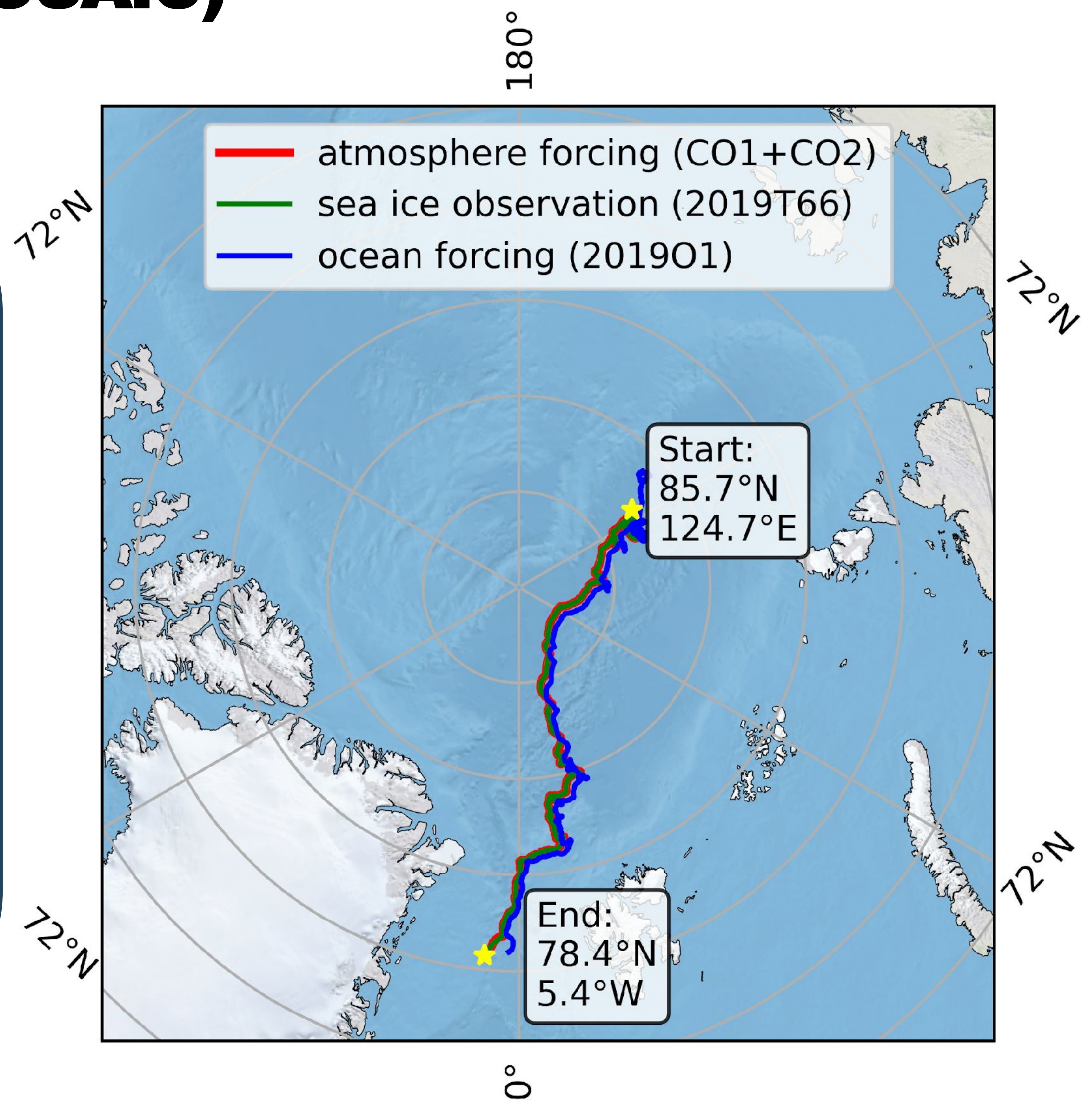
Model overestimated the surface melting and under estimated the bottom melting. The albedo simulated is also smaller

Lu Yang, Zhao Haibo, Zhao Jiawei, et al. Simulation error diagnosis of the seasonal evolution of sea ice thickness during MOSAiC in-situ observation[J]. Haiyang Xuebao, 2024, 46(6): 1–14, doi:10.12284/hyxb2024065

Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC)

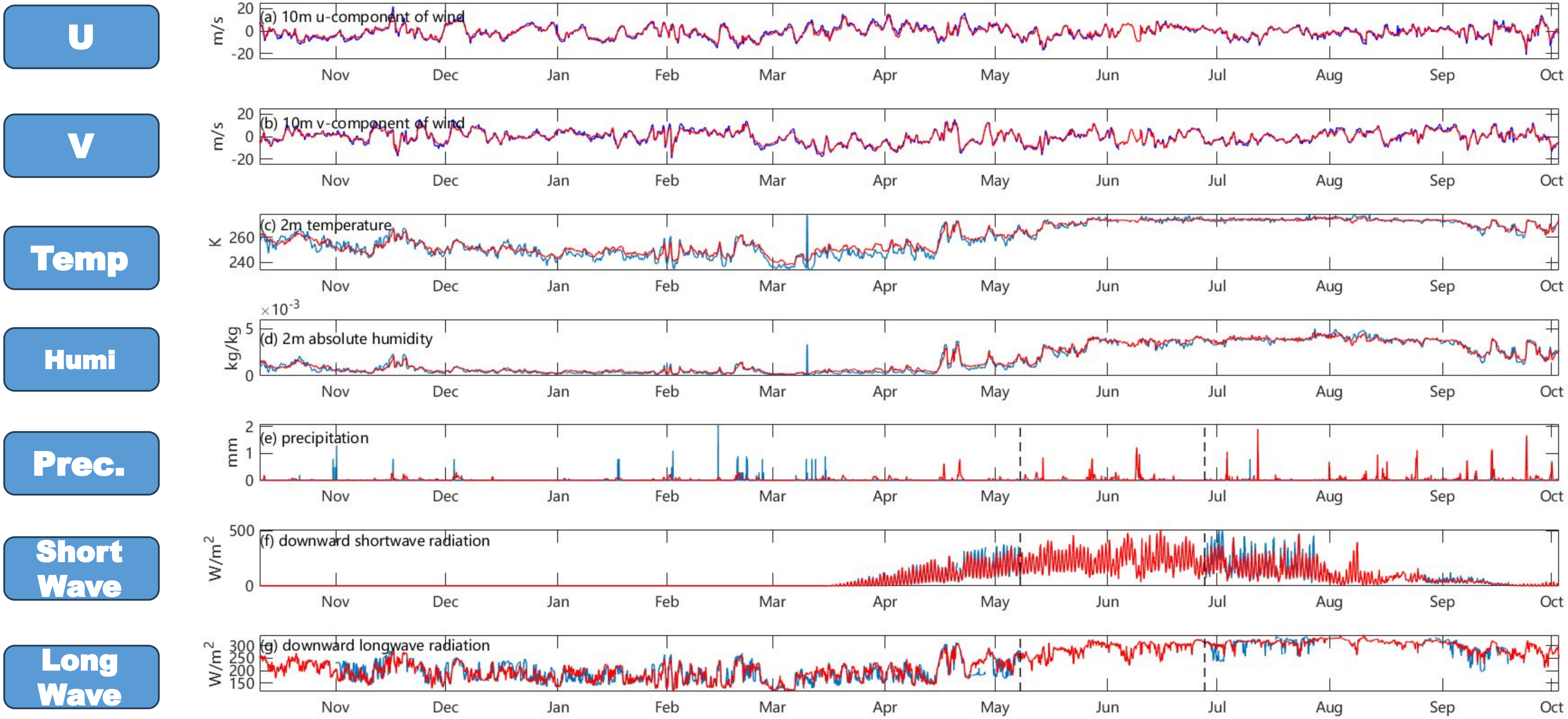
- **Sept. 2019----Oct. 2020**

- **Atmospheric Observation**
  CO1+CO2
- **Oceanic Observation**
  2019O1
- **Sea ice thickness Obs.**
  2019T66



Shupe et al. 2022; Rabe et al. 2022; Nicolaus et al. 2022; Webster et al. 2022

Comparison of MOSAiC Observation with ERA5



Radiation observation is missing from early May to late June, from late July to August of 2020

Comparison of MOSAiC Observation with ERA5

atmosphere variables	RMSE	correlation coefficient
10m u-component wind ($m\ s^{-1}$)	1.47	0.96
10m v-component wind ($m\ s^{-1}$)	1.43	0.97
10m wind ($m\ s^{-1}$)	1.62	0.94
2m temperature (K)	2.57	0.97
2m absolute humidity ($kg\ kg^{-1}$)	0.0024	0.99
snowfall/precipitation ($m\ h^{-1}$)	0.0022	0.03
downward shortwave radiation ($W\ m^{-2}$)	30.1	0.95
downward longwave radiation ($W\ m^{-2}$)	24.7	0.91

All the correlation coefficients are significant at 95% level except for snowfall/precipitation.

ERA5 and MOSAiC oceanic observation were used to force Icepack

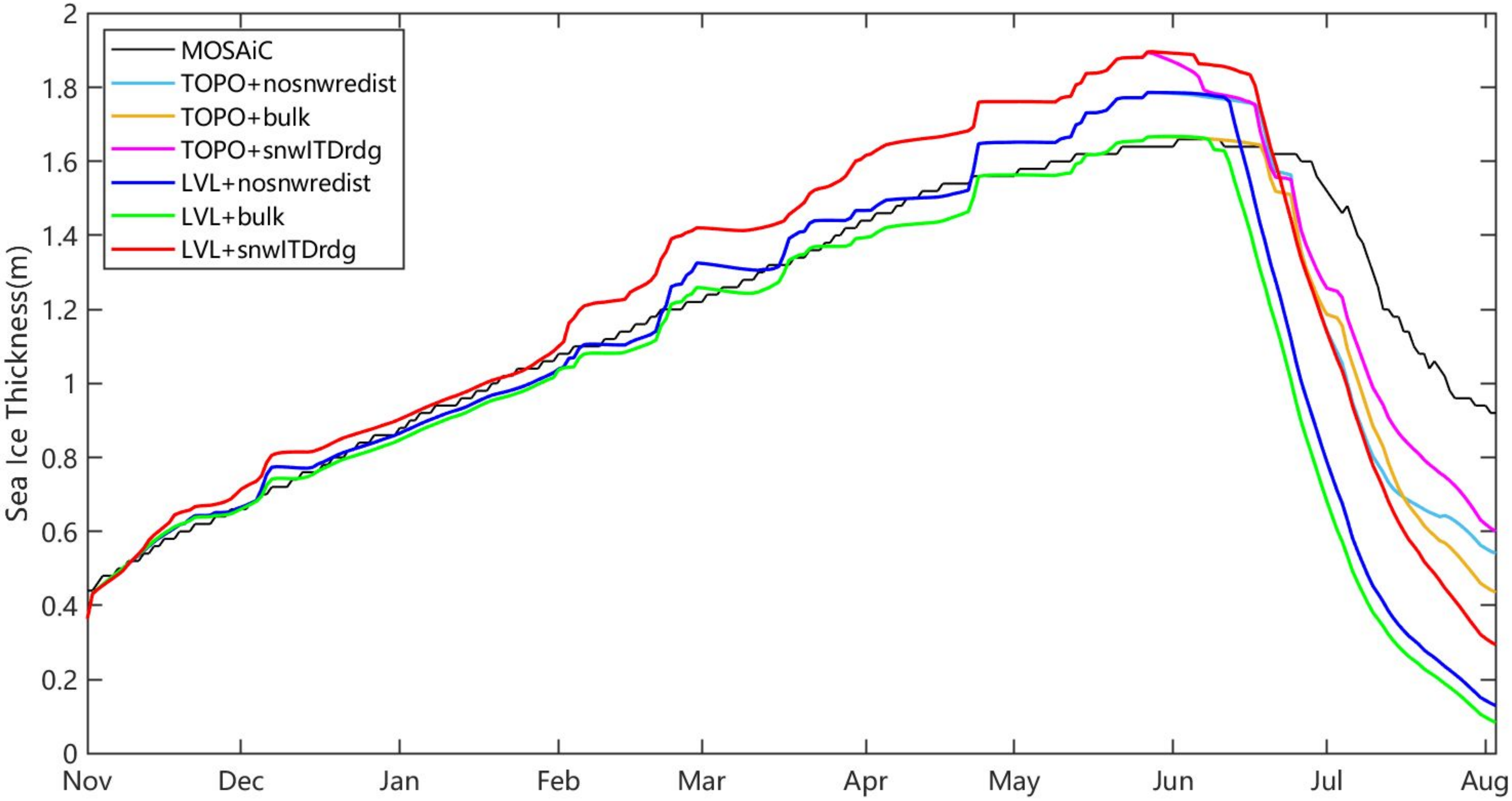
Using Icepack to reproduce Sea Ice Thickness evolution during MOSAiC

Icepack v1.4.1; Thermodynamic Scheme: Mushy layer
Initial Condition from Observation

Two melt pond schemes: TOPO (Flocco and Feltham 2007)
LVL (Hunke et al. 2002)
Three snow redistribution configurations: None
bulk (Sturn et al. 2002)
snwITDrage (Lecomte et al. 2015)

Melt pond scheme	snow redistribution	Initial conditions			
		sea ice thickness	snow depth	pond fraction	pond depth
TOPO & LVL	none bulk snwITDrdg	0.44m	0.12m	0	0m

Sea Ice Thickness Evolution during MOSAiC



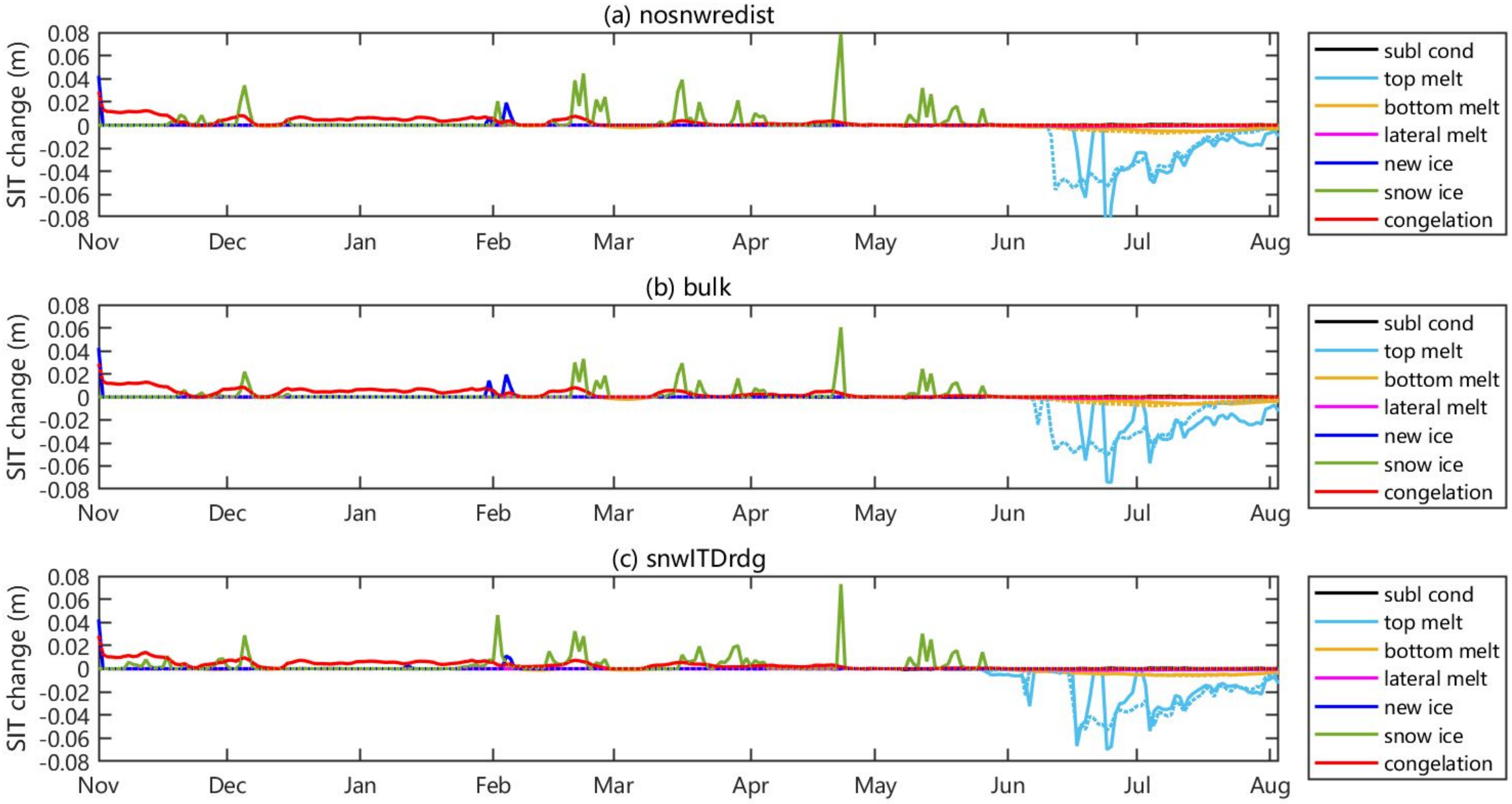
Bulk snow redistribution scheme improves the snow-ice conversation overestimation issue.
Not the snwITDrag

Diagnostics of SIT Change

None

Bulk

snwITDra
g



Solid line: TOPO scheme; Dotted line: LVL scheme

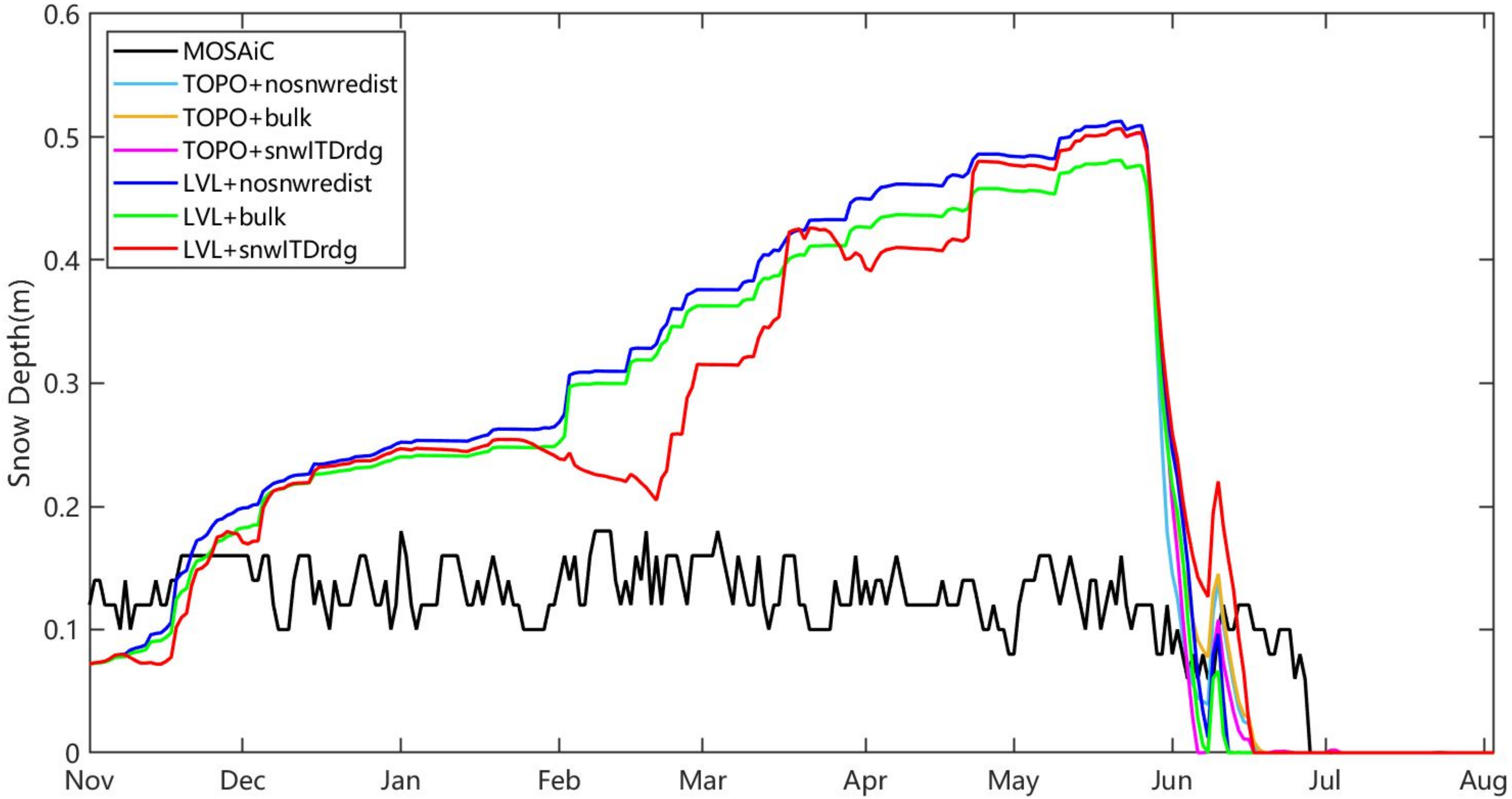
Diagnostics of SIT Change

Melt pond scheme	snwredist	subl cond	new ice	snow ice	congelation	top melt	bottom melt	lateral melt	RMSE
TOPO	none	-0.084	0.077	0.73	0.66	-1.29	-0.28	-0.062	0.16
TOPO	bulk	-0.075	0.086	0.48	0.77	-1.17	-0.26	-0.043	0.16
TOPO	snwITDrdg	-0.094	0.066	0.71	0.79	-1.26	-0.26	-0.067	0.16
LVL	none	-0.109	0.077	0.73	0.66	-1.46	-0.30	-0.052	0.31
LVL	bulk	-0.116	0.086	0.48	0.77	-1.49	-0.30	-0.048	0.33
LVL	snwITDrdg	-0.112	0.066	0.71	0.79	-1.50	-0.28	-0.053	0.23

During winter/spring time, snow ice conversion causes overestimation of SIT

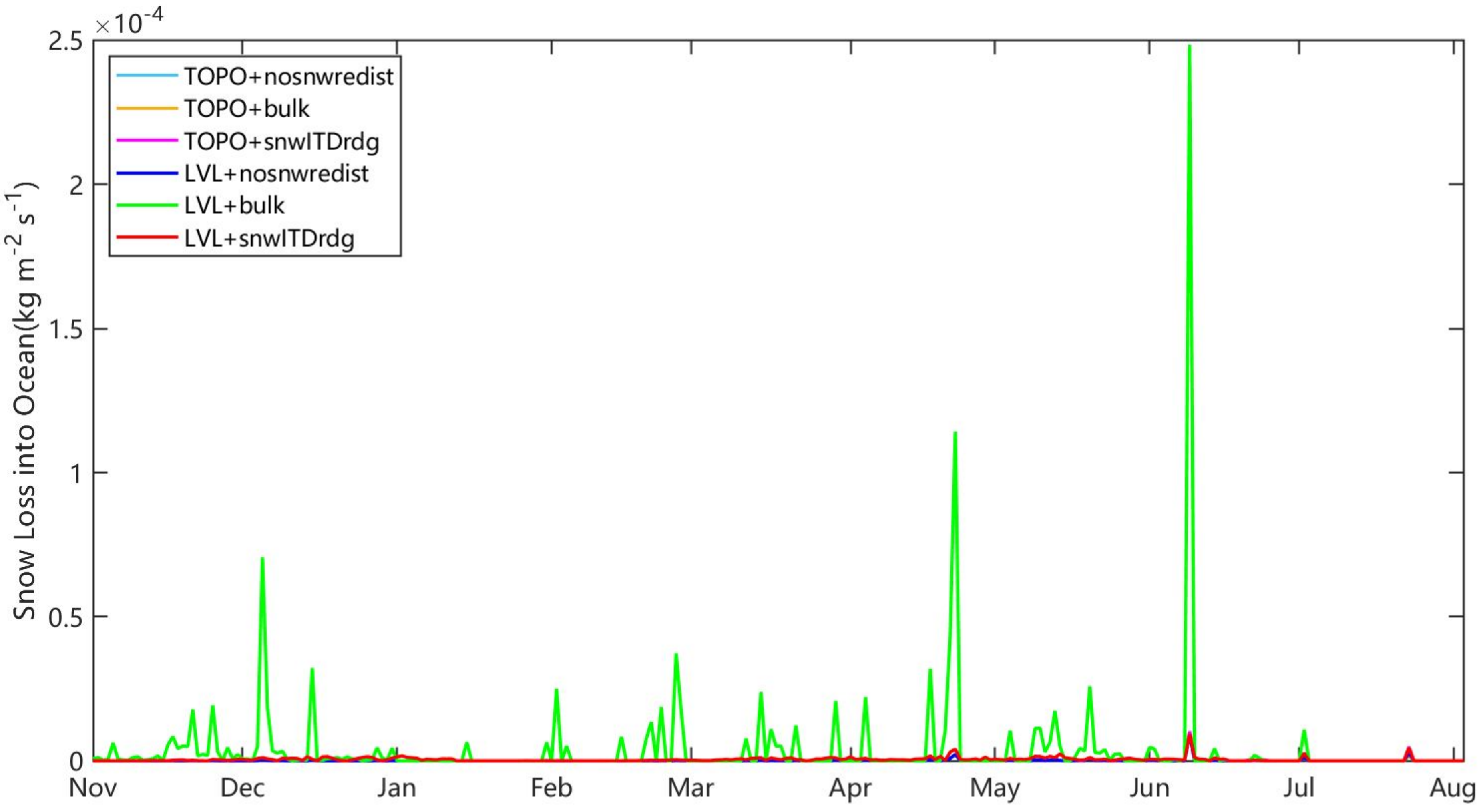
During summer time, excessive top melt causes underestimation of SIT

Snow Thickness Evolution



Snow density change is not accounted for …

Snow Loss into the Ocean



Bulk scheme loses more snow to the ocean and reduces snow ice conversion

Radiation Comparison

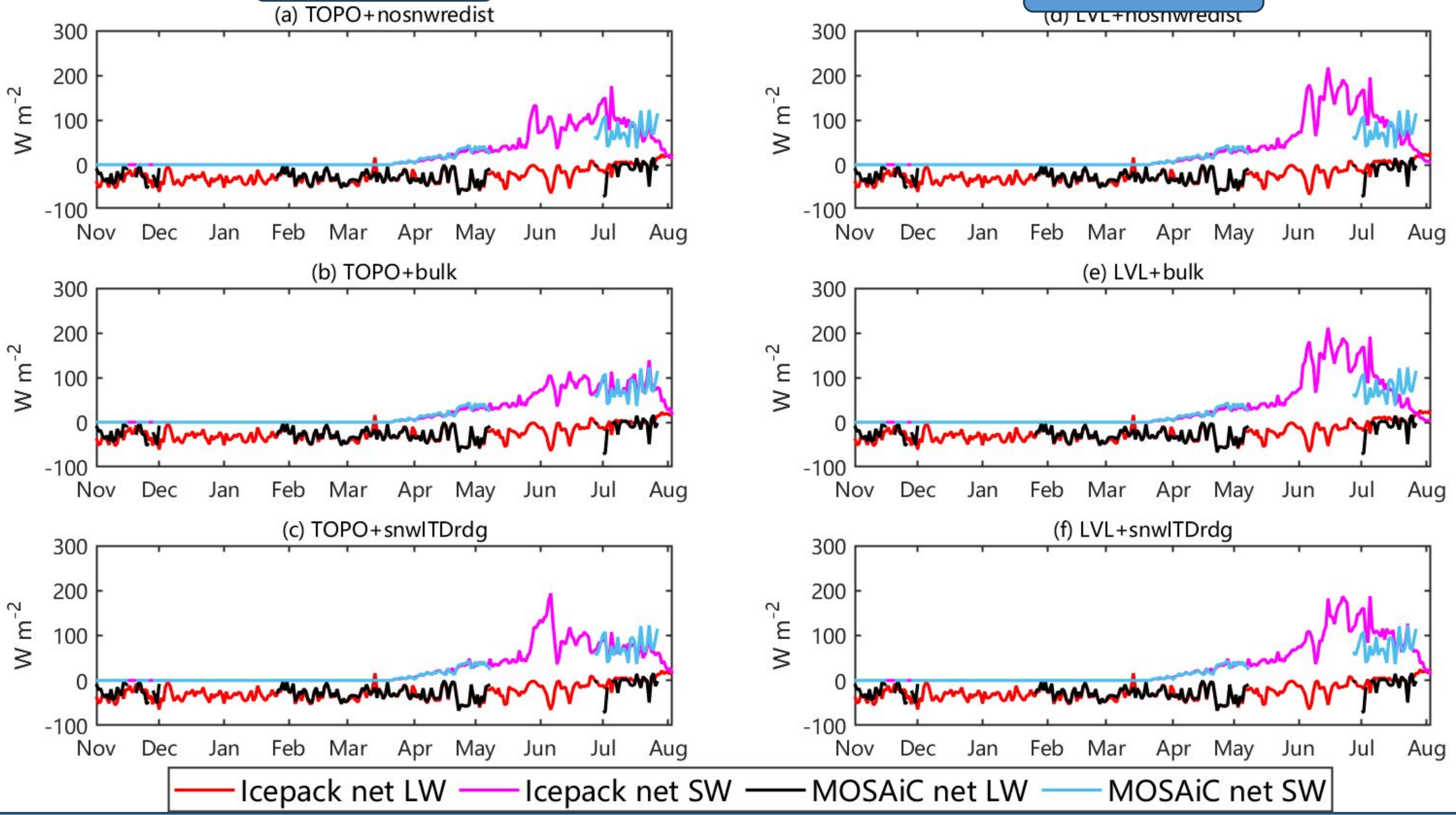
TOPO

LVL

None

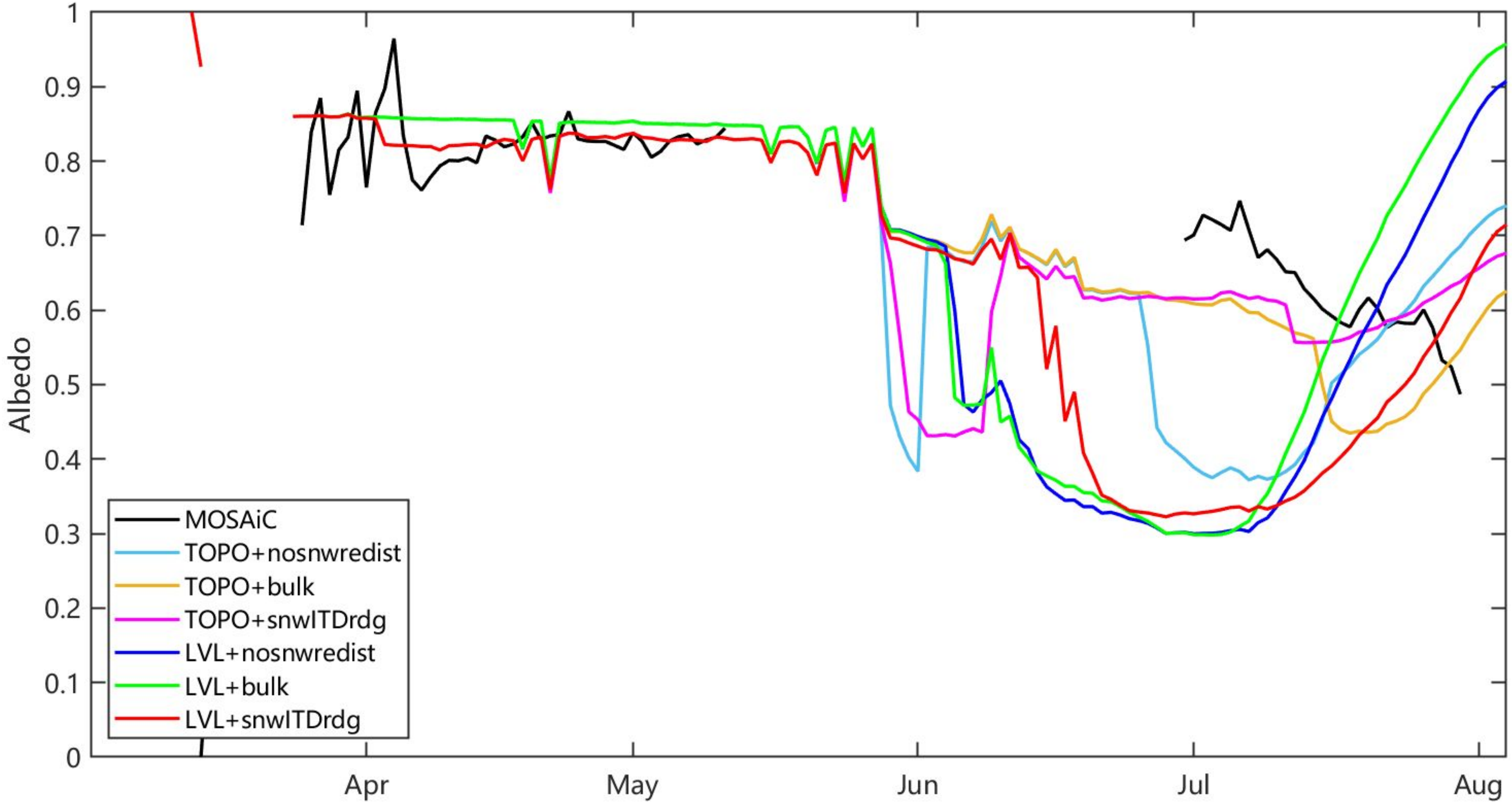
Bulk

snwITDrag



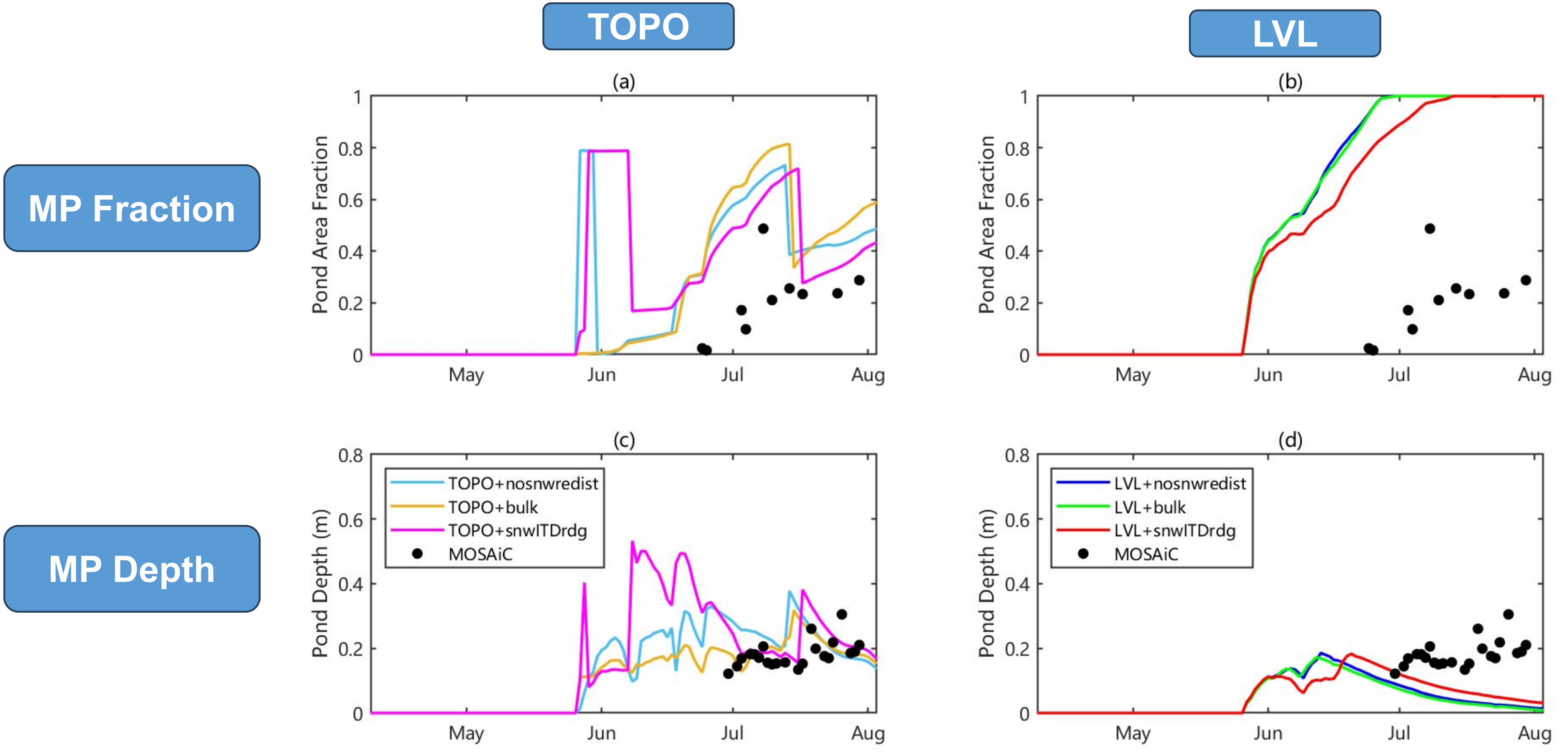
Both TOPO and LVL scheme cause overestimation of downward shortwave radiation
TOPO scheme seems agree better with observation

Albedo Comparison



Both TOPO and LVL scheme may underestimate albedo
TOPO scheme has higher albedo until mid July

Melt Pond Comparison



Both TOPO and LVL tend to cause overestimation of melt pond fraction

Summary

- **Sea ice simulations were conducted using six combinations of two melt pond schemes (TOPO, LVL) and three snow redistribution configurations (none, bulk, snwITDrag).**
- **During winter/spring, Icepack can reproduce sea ice growth. Without snow redistribution scheme, Icepack simulates excessive snow ice formation and resulting in thicker sea ice than observation.**
- **During summer, Icepack underestimates the sea ice surface albedo, resulting in an underestimation of SIT at the end of simulation.**

Future Work

- **Snow density comparison (?)**

- **Estimation of parameters in melt pond and radiation schemes using adjoint method and its generalization**

Questions

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Developing Adjoint Model for Sea Ice Processes

Forward Model

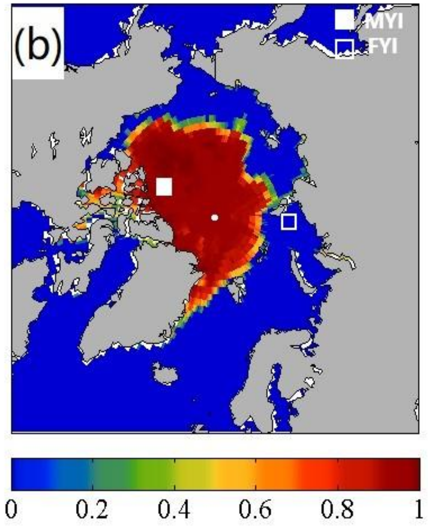
$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_L \end{bmatrix} = \begin{bmatrix} B_{11} & \cdots & B_{1M} \\ \vdots & \ddots & \vdots \\ B_{L1} & \cdots & B_{LM} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_M \end{bmatrix}$$

Tangent Linear Model

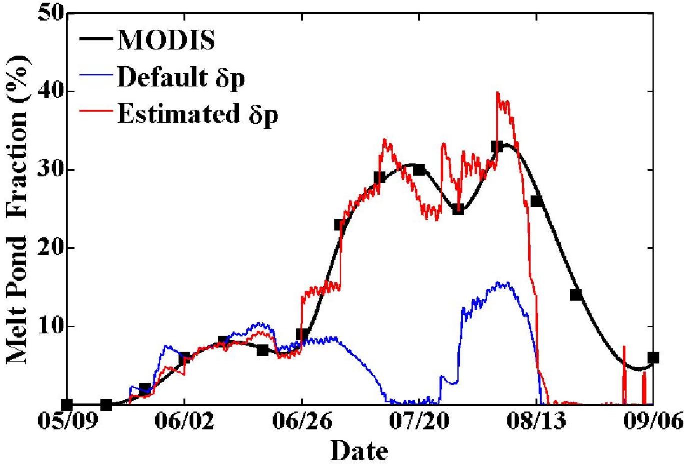
$$\begin{bmatrix} b'_1 \\ b'_2 \\ \vdots \\ b'_L \end{bmatrix} = \begin{bmatrix} \frac{\partial b_1}{\partial a_1} & \cdots & \frac{\partial b_1}{\partial a_M} \\ \vdots & \ddots & \vdots \\ \frac{\partial b_L}{\partial a_1} & \cdots & \frac{\partial b_L}{\partial a_M} \end{bmatrix} \begin{bmatrix} a'_1 \\ a'_2 \\ \vdots \\ a'_M \end{bmatrix}$$

Adjoint Model

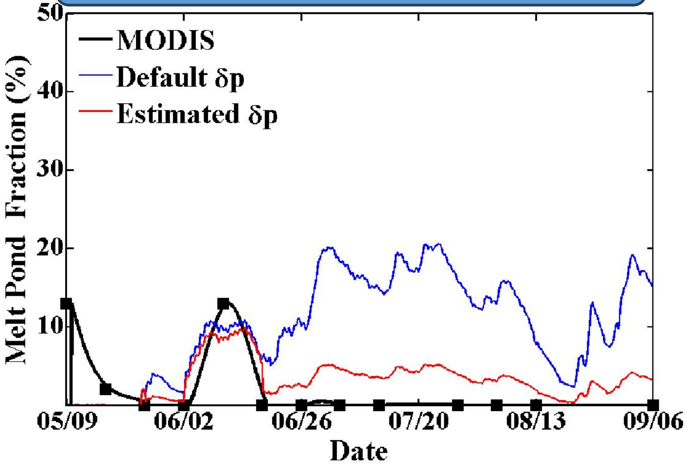
$$\begin{bmatrix} \frac{\partial J}{\partial a_1} \\ \frac{\partial J}{\partial a_2} \\ \vdots \\ \frac{\partial J}{\partial a_M} \end{bmatrix} = \begin{bmatrix} \frac{\partial b_1}{\partial a_1} & \cdots & \frac{\partial b_L}{\partial a_1} \\ \vdots & \ddots & \vdots \\ \frac{\partial b_1}{\partial a_M} & \cdots & \frac{\partial b_L}{\partial a_M} \end{bmatrix} \begin{bmatrix} \frac{\partial J}{\partial b_1} \\ \frac{\partial J}{\partial b_2} \\ \vdots \\ \frac{\partial J}{\partial b_L} \end{bmatrix}$$



Multi-year ice



One-year ice



Using adjoint model to optimize aspect ratio in CESM melt pond scheme to fit observed melt pond fraction

Lu, Y., X. Wang, J. Dong, 2021, Melt pond scheme parameter estimation using an adjoint model, Advances in Atmospheric Sciences, 38, 1525-1536 , Doi:10.1007/s00376-021-0305-x