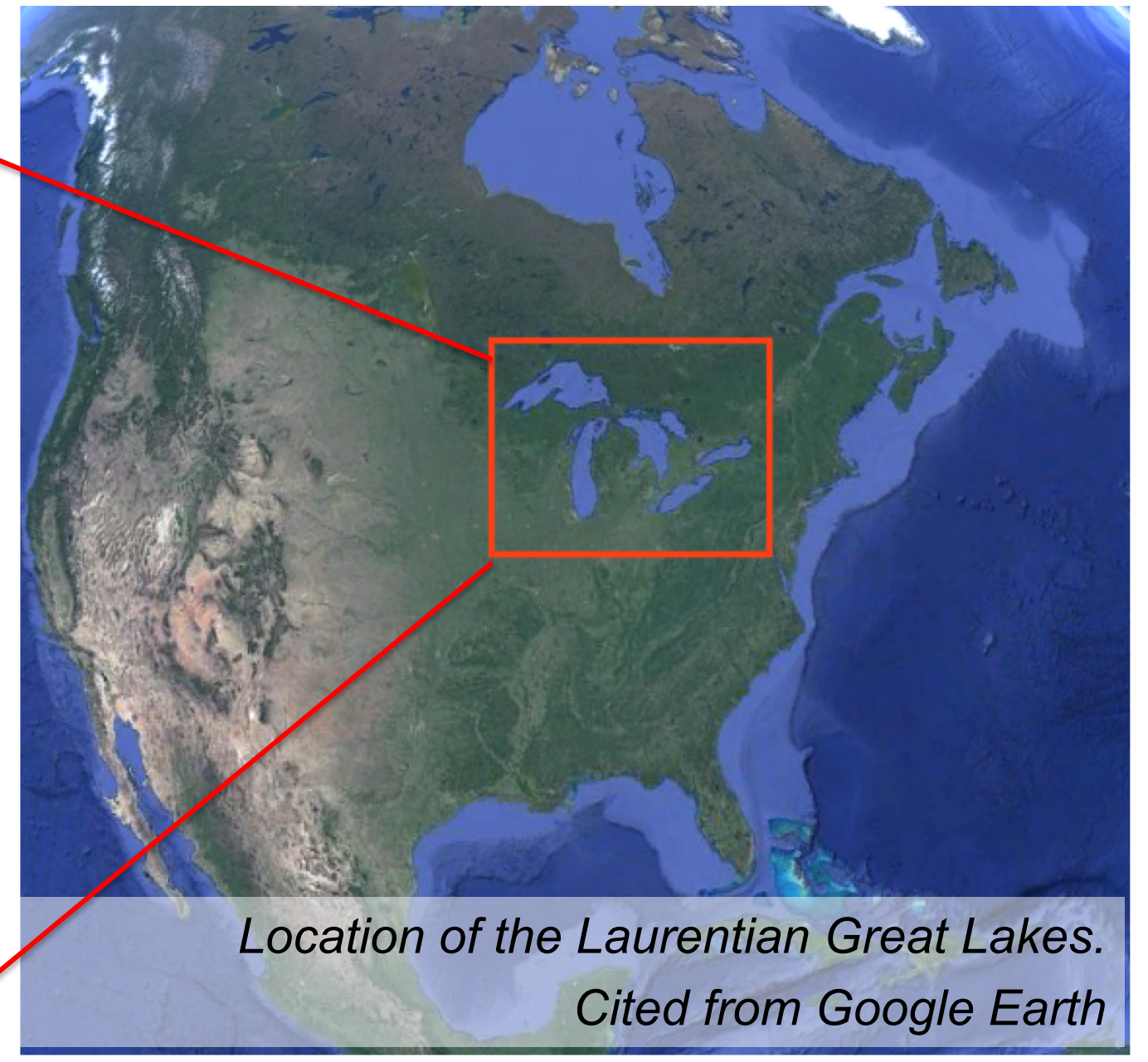
Impacts of Heat from Precipitation on Ice Cover in Large Lakes

Ayumi Fujisaki-Manome[1,2], Eric J. Anderson[3], James A. Kessler[1], Gregory Lang[3], Jia Wang[3], Philip Chu[3], and Andrew Gronewold[3]
[1]*University of Michigan, Cooperative Institute for Great Lakes Research,* [2]*University of Michigan, Climate & Space Sciences and Engineering Department,*
[3]*NOAA Great Lakes Environmental Research Laboratory*

Introduction

Heat from precipitation to lakes, oceans, and ice cover has been often overlooked yet can play a significant role in the energy budget. However, it is often neglected or lies buried in complex model systems. In the Great Lakes, the world largest freshwater system, the quantification of this process is relatively important among many other detail processes in numerical models because 1. the temperature gradient between the water surface and the wet-bulb temperature of the air above, which is approximately the temperature of rain droplets/snow flakes, can be large, 2. winter-spring precipitation often falls as snow, which cools the lake surface by absorbing latent heat due to melting. In addition, snowfall generally increase bulk albedo of the lake ice surface. This study evaluates the impacts of precipitation to water temperature and ice cover on the Great Lakes using the time series analyses and the three-dimensional ice-hydrodynamic model.

•*MODIS Imagery of Great Lakes ice conditions*



Location of the Laurentian Great Lakes. Cited from Google Earth

Method

Timeseries analysis

Sensible (H_{sp}) and latent (H_{lp}) heat fluxes from precipitation are calculated as below.

$$H_{sp} = \rho_w c_p P(T_s - T_{precip}), \qquad T_{precip} \sim T_{wetb}$$

$$H_{lp} = -L_f P$$

When $T_{wetb} < -2^{o}$C, precipitation is considered as snowfall.

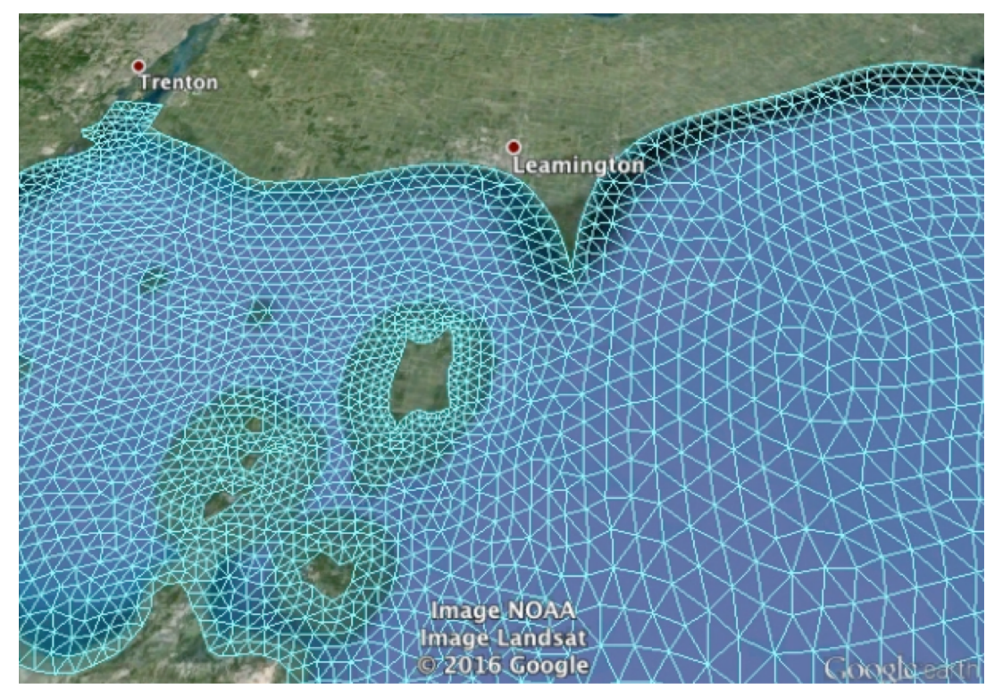
ρ_w	Density of water
c_p	Specific heat of water
P	Precipitation (rain or snow)
T_s	Water surface temperature
T_{wetb}	Wet-bulb temperature
T_{precip}	Temperature of rain/snow
L_f	Latent heat of snow melting

CaPA-MPE, the merged dataset using both the Canadian Precipitation Analysis and the Multi-sensor Precipitation Estimate (Gronewold et al. 2018), is used for precipitation.

From **Climate Forecast System (CFS) version 2**, the reanalysis and operational analysis datasets are used for surface air temperature and specific humidity (needed to calculate wet bulb temperature). **GLSEA**, the Great Lakes Surface Environmental Analysis is used for water surface temperature.

3-D ice-hydrodynamic model

The unstructured grid, Finite Volume Community Ocean Model (FVCOM, Chen et al., 2006) is used for hydrodynamic processes. The model is coupled with the unstructured grid version of the Los Alamos Sea Ice Model (Gao et al., 2011). These implementations of FVCOM are based on the Lake Erie Operational Forecast System and the Lake Michigan-Huron Operational Forecast System (Anderson et al., 2018).

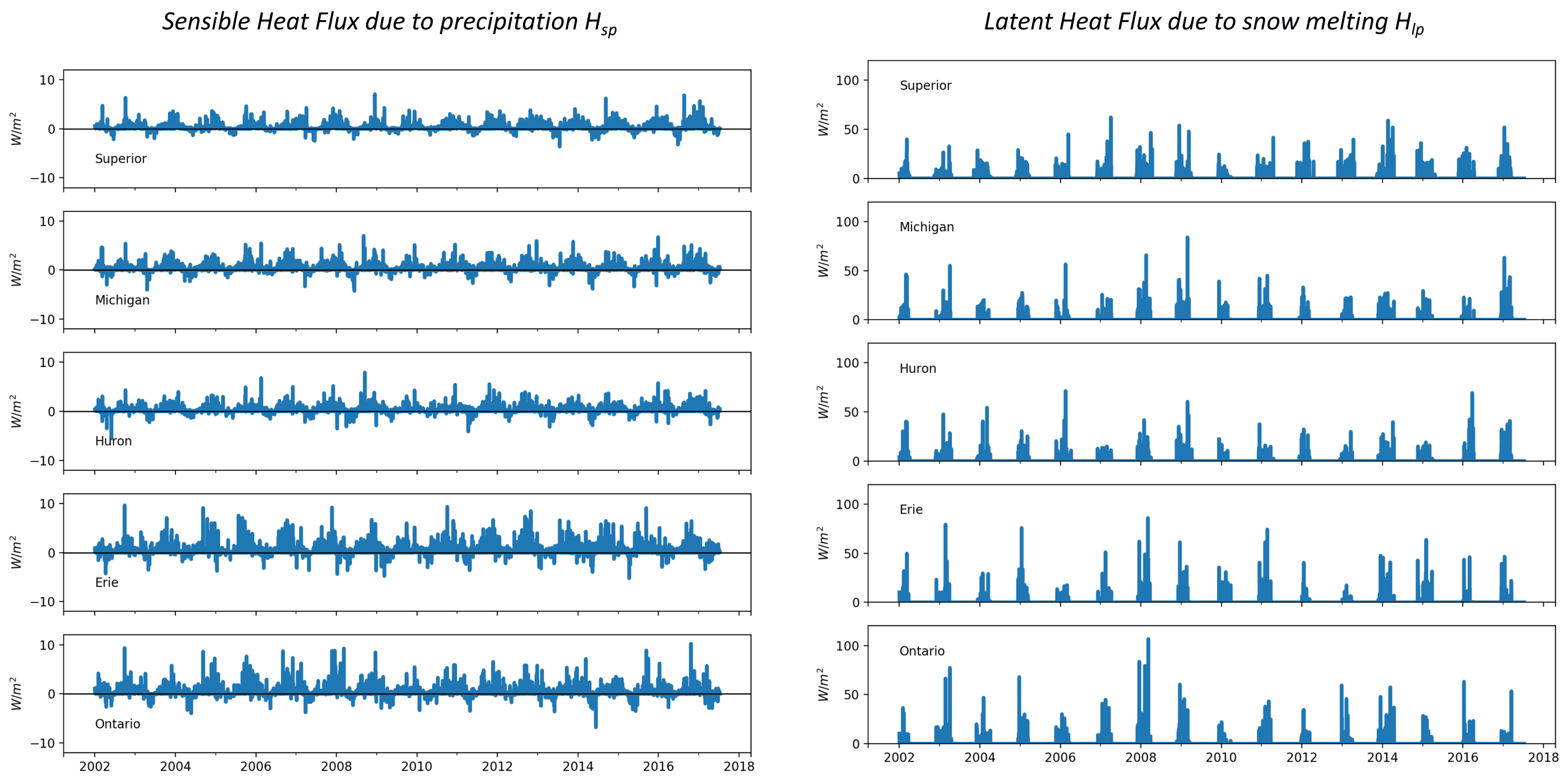


Unstructured-grid mesh

FVCOM+UG-CICE details

Governing equations	Primitive equations
Resolution	100 m-2.5 km (horizontal),
	21 layers (σ coordinate)
Turbulence Model	Mellor and Yamada 2.5-level Closure Model (vertical)
	Smagorinsky (horizontal)
Atmospheric Forcing	High Resolution Rapid Refresh (since 2015). Hourly.
Ice dynamics	Elastic-Viscous-Plastic rheology, five ice thickness categories, ice strength based on Hibler (1979)'s method
Ice thermodynamics	Vertical heat diffusion model with 4 layers. Albedo as a function of surface temperature and thickness, distinguished for four spectral bands
Simulation period and lake	2015 for Lakes Erie, Michigan and Huron

Sensible and latent heat from precipitation



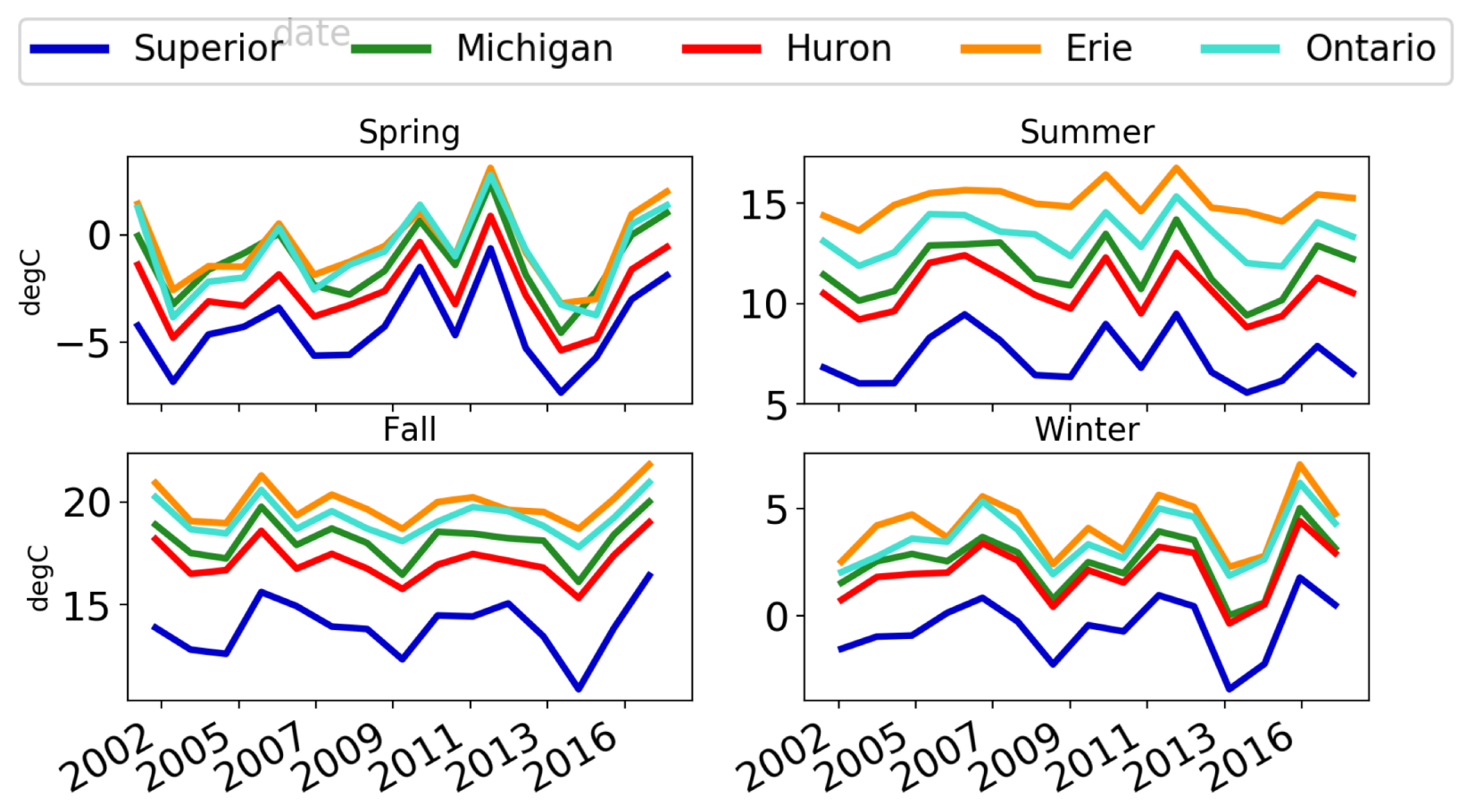
Daily over-lake sensible heat flux from precipitation (left) and latent heat flux from snowfall (right) from 2002 to 2017. Precipitation is from CaPA-MPE, surface meteorology is from CFS, and water surface temperature is from GLSEA. Positive values mean cooling of water.

H_{sp} was small, within ±10 W/m², but relatively large in fall-early winter in Lakes Erie and Ontario indicating additional cooling in these seasons. H_{lp} became non-zero only during November-April (snow season), and occasionally went above 50 W/m², which is comparable with turbulent heat fluxes. This indicates the significance of H_{sp}&H_{lp} in the energy budget.

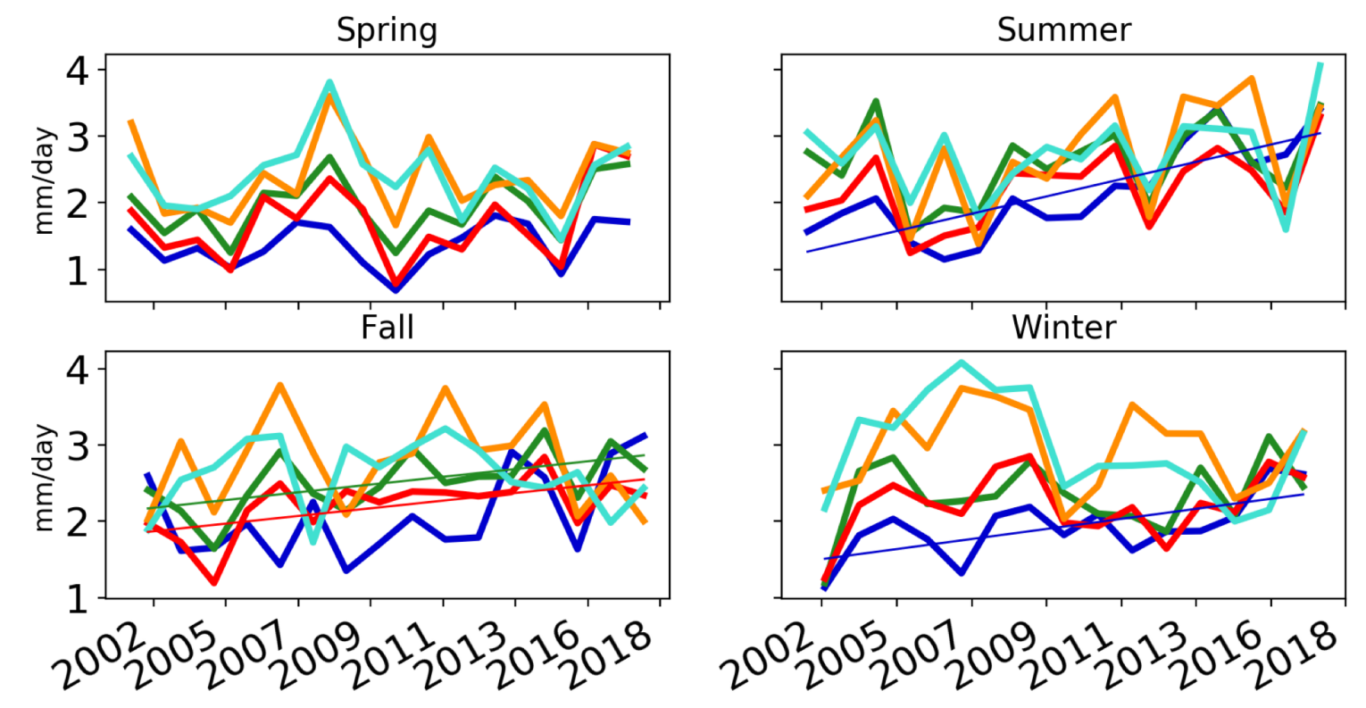
Trend in each season

Overall trends in over-lake precipitation during 2002-2017 were weak, with weak positive trends in Lake Superior for summer and winter, in Erie and Ontario for fall. There was no significant trend in 2m air temperature over the lakes. As a result, neither of H_{sp} or H_{lp} showed significant trend.

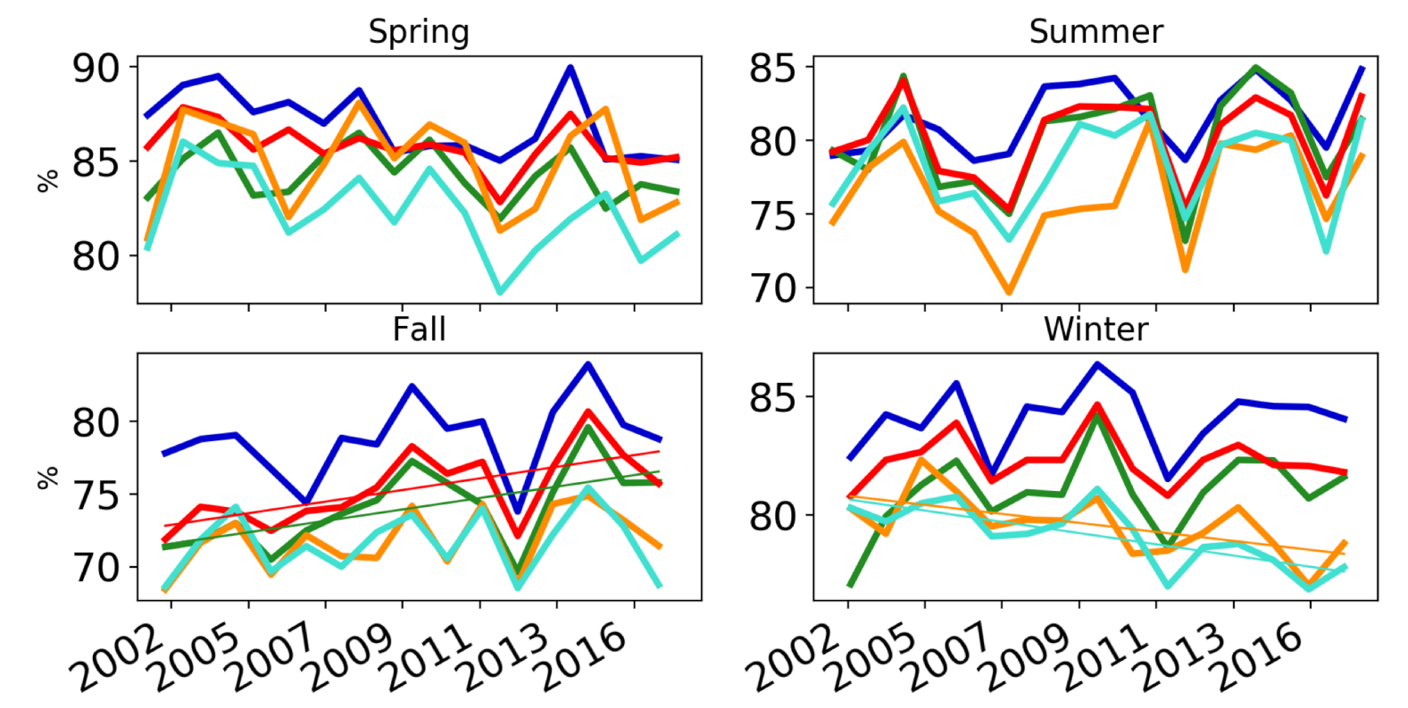
Figure. Seasonal mean of over-lake meteorology, H_{lp}, and H_{sp}. Seasons are defined as spring: March-May, summer: June-August, fall: September-November, winter: December-February. Linear regression lines are shown when the significance level is greater than 95%.



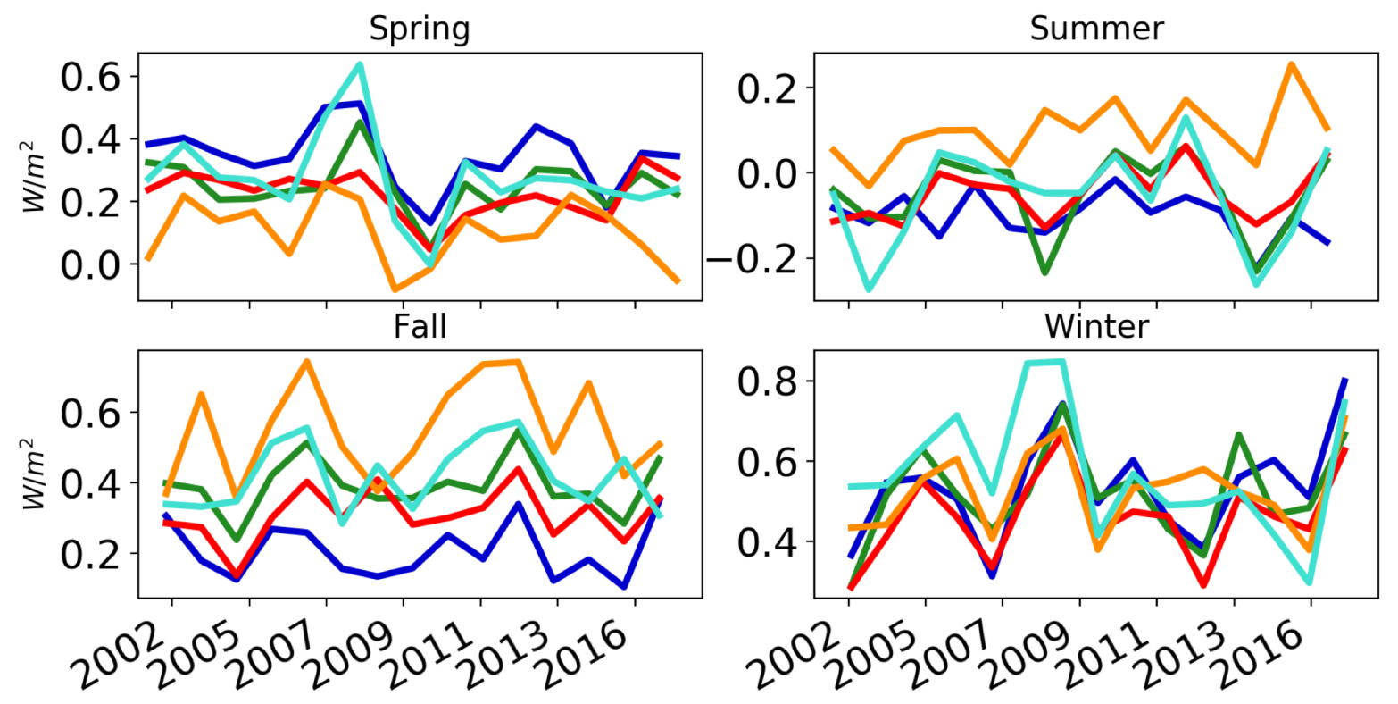
Seasonal mean of over-lake 2m air temperature.



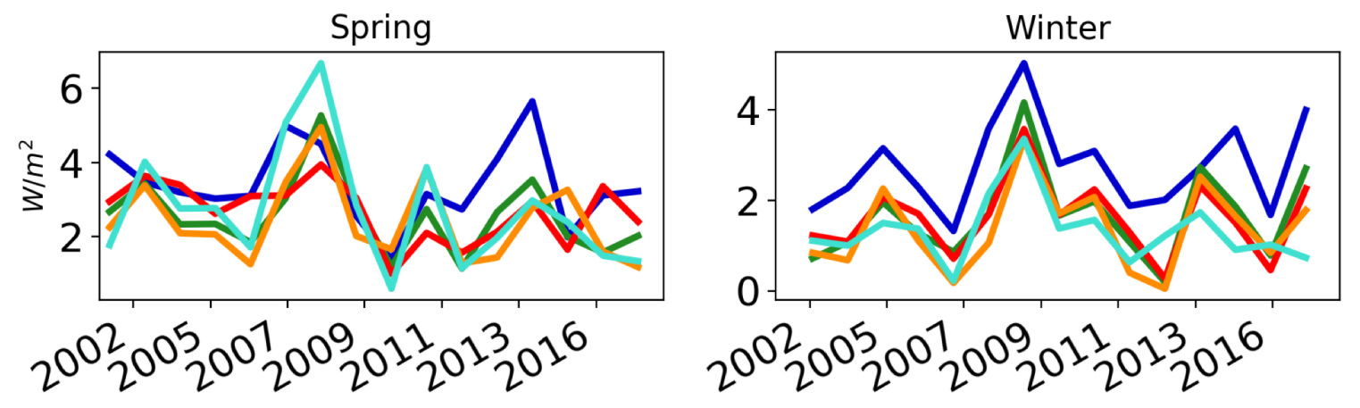
over-lake precipitation.



Seasonal mean of over-lake 2m air temperature.



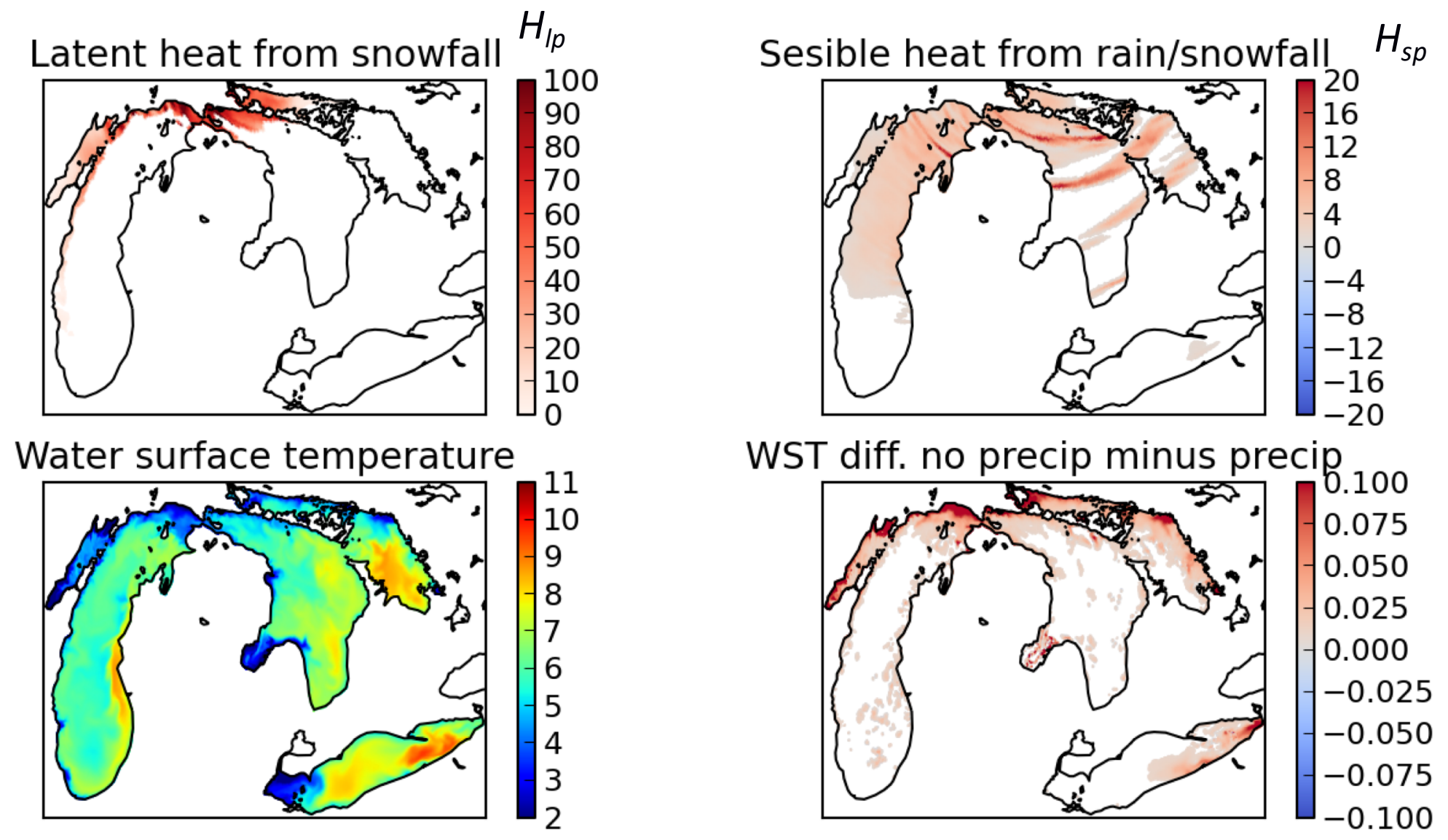
H_{sp}, sensible heat flux due to rain / snow.



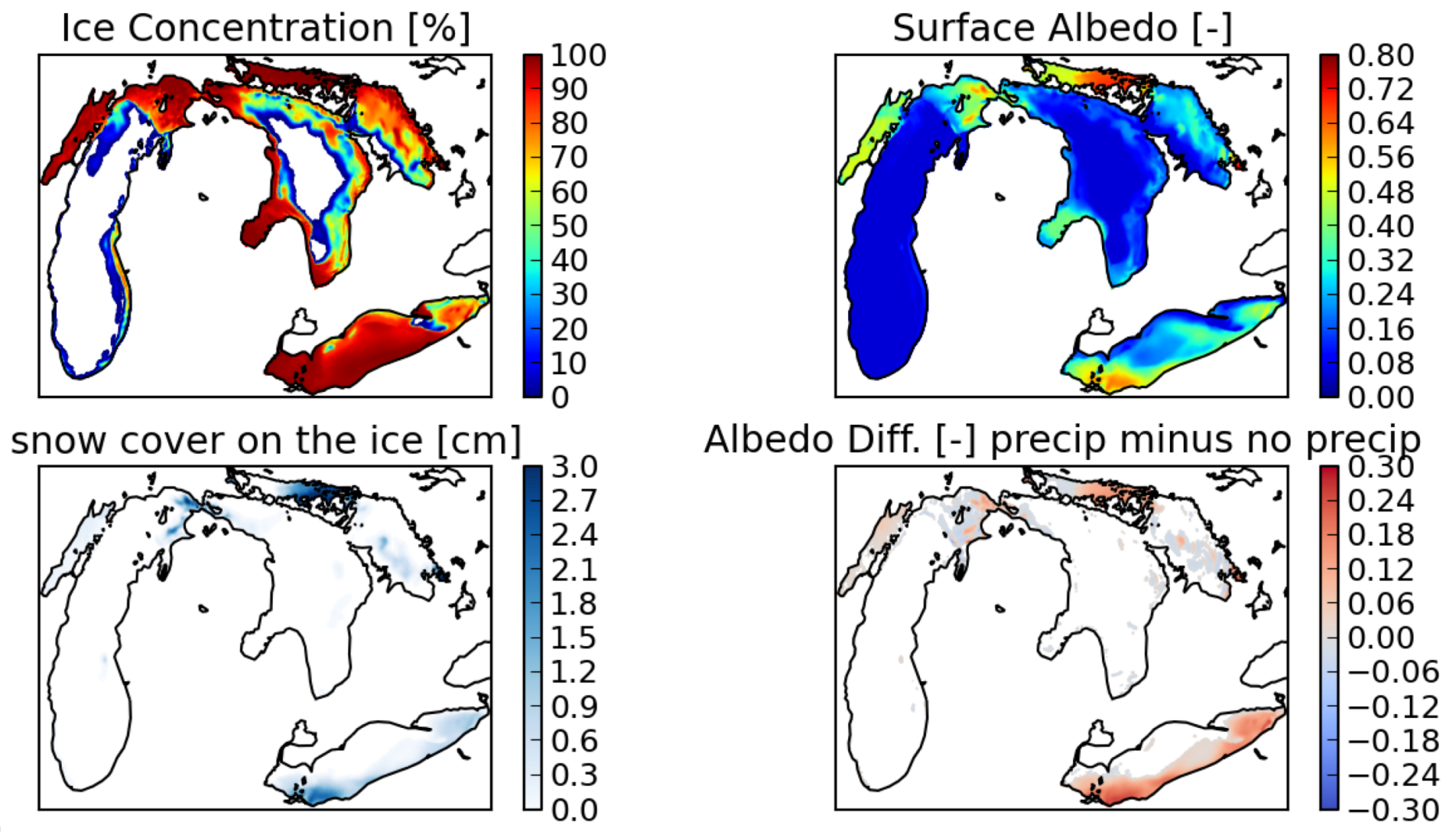
H_{lp}, latent heat flux due to snow fall. Only spring and winter are shown.

3-D ice-hydrodynamic simulation

Notable amounts of H_{sp} and H_{lp} were simulated during significant rainfall events and lake effects snow events. This resulted in some differences in water surface temperature simulations with and without precipitation, especially nearshore regions. Surface albedo was notably increased by inclusion of precipitation on the ice, as precipitation fell as snow when $T_{wetb} < -2$ ^{o}C. The larger albedo of snow cover contributed to the net increase of surface albedo .



H_{sp}, H_{lp}, water surface temperature simulated by FVCOM-Ice on November 25, 2014. Lower right panel shows the difference in water surface temperature between the simulation results without and with precipitation.



Ice Concentration, surface albedo, snow cover on the ice simulated by FVCOM-Ice on January 27, 2015. Lower right panel shows the difference in surface albedo between the simulation results with and without precipitation.

Summary and Future Work

Sensible (H_{sp}) and latent (H_{lp}) heat from precipitation can be significant in the Great Lakes. Snowfall over the ice notably increases surface albedo, altering the surface energy budget. It is logical that these should be included when models attempt to simulate accurate energy exchange between air, ice and water. This can be done at little computational expense yet can provide improved representation of the energy exchanges. Likewise, when coupling atmospheric and ice-lake models, it is important to take account of these processes in addition to exchanging conventional surface variables, such as water surface temperature.

A few snapshots from the 3-D ice-hydrodynamic model show they have notable impacts on the Great Lakes water temperature. More comprehensive assessment of precipitation impacts on the Great Lakes water temperature and ice cover is underway.

Funding Acknowledgements

- NOAA Oceans Joint Technology Transfer Initiative, "Implementation of the FVCOM-Ice model for the Great Lakes Operational Forecasting System (GLOFS)" 2018-2020.

References

- Anderson, E.J., Fujisaki-Manome, A., Kessler, J., Chu, P., Kelley, J.G.W., Chen, Y., Lang, G.A., Wang. J. (2018), Ice Forecasting in the Next-Generation Great Lakes Operational Forecast System (GLOFS), J. Mar. Sci. Eng., 6(4), 123.
- Chen, C., Beardsley, R.C., Cowles, G. (2006), An unstructured grid, finite volume coastal ocean model(FVCOM) system. *Oceanography*, 19, 78–89.
- Gao, G., Chen, C., Qi, J. and Beardsley, R. (2011), An unstructured-grid, finite-volume sea ice model: Development, validation, and application, J. Geophys. Res., 116, C00D04.
- Gronewold, A.D., Fortin, V., Caldwell, R. and Noel, J. (2018), Resolving Hydrometeorological Data Discontinuities along an International Border, Bull. Amer. Meteor. Soc., May 2018.
- Hibler, W.D. (1979), A dynamic thermodynamic sea ice model. J. Phys. Oceanogr., 9, pp. 817–846.