Simulating hydrodynamics and ice cover in Lake Erie using an unstructured grid model

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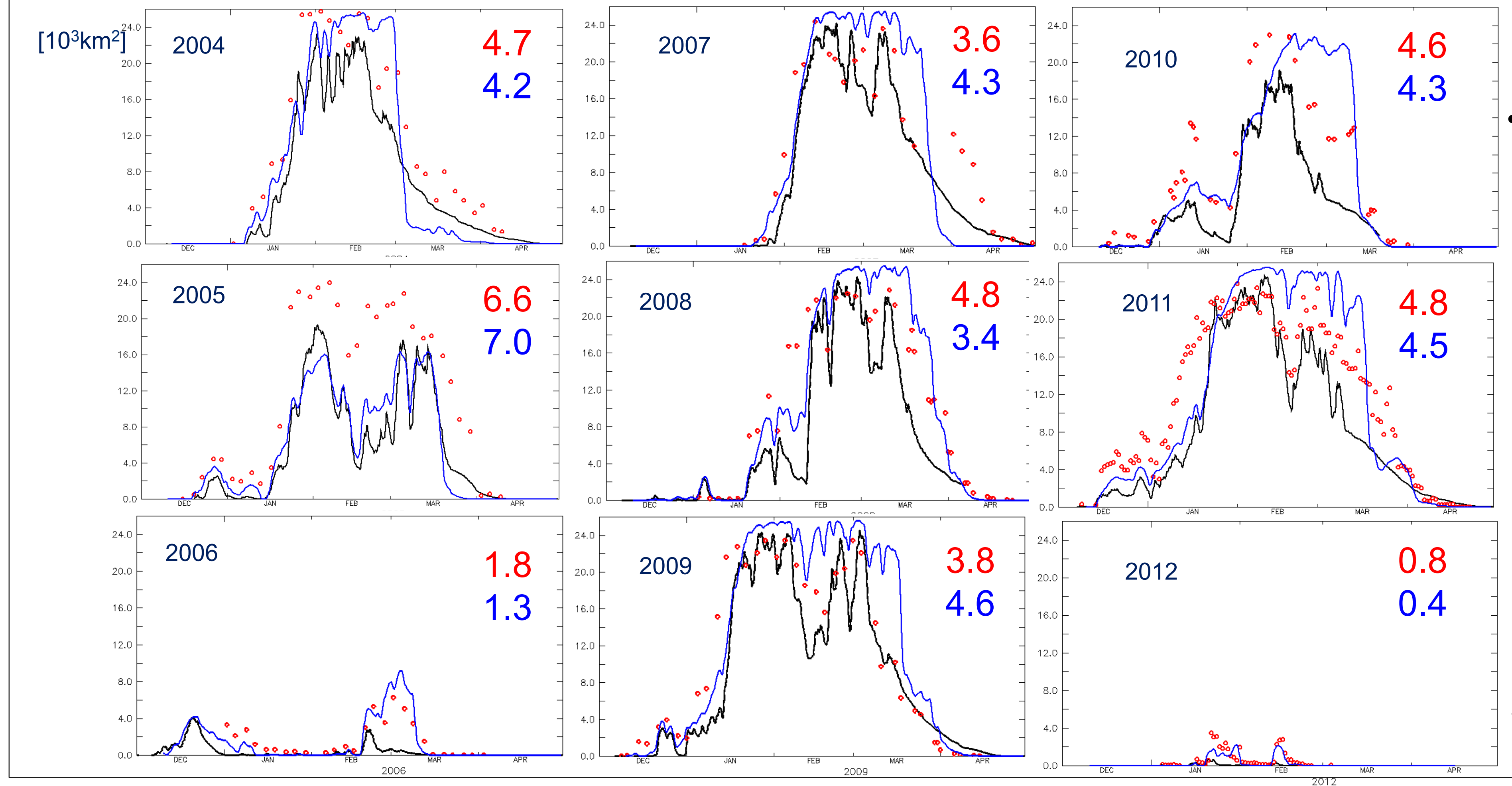
Introduction

The unstructured-grid framework has advantage in local grid refinement and representing complicated coastlines in the Laurentian Great Lakes. In the context of the regional climate model development and the next generation operational Great Lakes Coastal Forecasting System at CILER and GLERL, we configured an unstructured grid Finite-Volume Coastal Ocean Model (FVCOM) to Lake Erie to simulate seasonal ice cover and hydrodynamics. The model is coupled with an unstructured-grid, finite-volume version of the Los Alamos Sea Ice Model (UG-CICE, Gao et al., 2011). The simulation results are validated in comparison with the satellite and in-situ observations, as well as the previous modeling results based on the Princeton Ocean Model coupled with an ice model (ICEPOM, Fujisaki-Manome et al. 2013). The sensitivity study of ice mechanical deformation parameters is conducted to identify adequate values for the freshwater application. We also tested the original 2-time-step Euler forward scheme in time integration by the central difference (i.e., leapfrog) scheme to assure a neutrally inertial stability.

Ice extents

- Both models are successful to reproduce annual maxima and to underestimate the sharp development of ice extent in January.
- RMSEs are similar between the two models.
- ICEPOM tend to simulate too fast ice melting in spring, while FVCOM-Ice simulates decline of ice extent closer to the observation.



- Suppressing over-land/over-water correction in the ice period slightly improved the ice extent simulation.

Fig. Time series of ice extent. Dots: Observation (Great Lakes Ice Atlas. Black line: FVCOM-Ice results. Blue: ICEPOM results. Digits in the upper right are the root mean square error values (RMSE)

Model

- Atmospheric forcing: Interpolated meteorology based on the observations from the National Data Buoy Center and the Coastal Marine Automated Network. Over-land/over-water correction was applied (Croley, 1989).
- Sensitivity study:
  - Tunable parameters in ice mechanical deformation
  - Over-land/over-water correction to the interpolated meteorology was suppressed linearly with areal ice fraction.

The ice thickness distribution of ridges (Lipscomb et al. 2007)

$$g_R(h) \propto \exp[-(h - H_{\min})/\lambda]$$

$$\lambda = \mu h_n^{1/2}$$ μ: tunable parameter [m$^{1/2}$]

Ice strength P (Lipscomb et al. 2007)

$$P = C_f\, C_p\, \beta \sum_{n=1}^{N_C} \left[-a_{Pn}\, h_n^2 + \frac{a_{Pn}}{k_n} \left(H_{\min}^2 + 2H_{\min}\lambda + 2\lambda^2 \right) \right]$$

C_f: empirical parameter

Hydrodynamics

Governing equations	Primitive equations
Resolution	200m-3km (horizontal), 21 layers (σ coordinate)
turbulence model	Mellor and Yamada 2.5-level Closure Model (vertical) Smagorinsky (horizontal)
atmospheric forcing	Interpolated observations. Hourly.
Time integration schemes	Euler forward (internal mode) +modified Runge-Kutta (external mode) Central difference

Ice physics

	UG-CICE	ICEPOM
Rheology	Elastic-Viscous-Plastic	
Thickness distribution	Multi categories	Single category
Ridging	Yes	No
Albedo	Function of surface temperature and thickness	Constant 0.7 (0.5 when melting)
Thermodynamics	Multi layer (4 layers)	0 layer

Ice thickness distribution

- Wide spectrum in the observed ice thickness (5-100 cm) is captured by the multi-category ice thickness distribution model with the ridge parameterization in FVCOM-Ice, while the single category model in ICEPOM produced a narrow peak in ~20 cm.
- Models captured the observed ice thickness, but in the eastern basin (downwind), they tend to overestimate ice thickness.

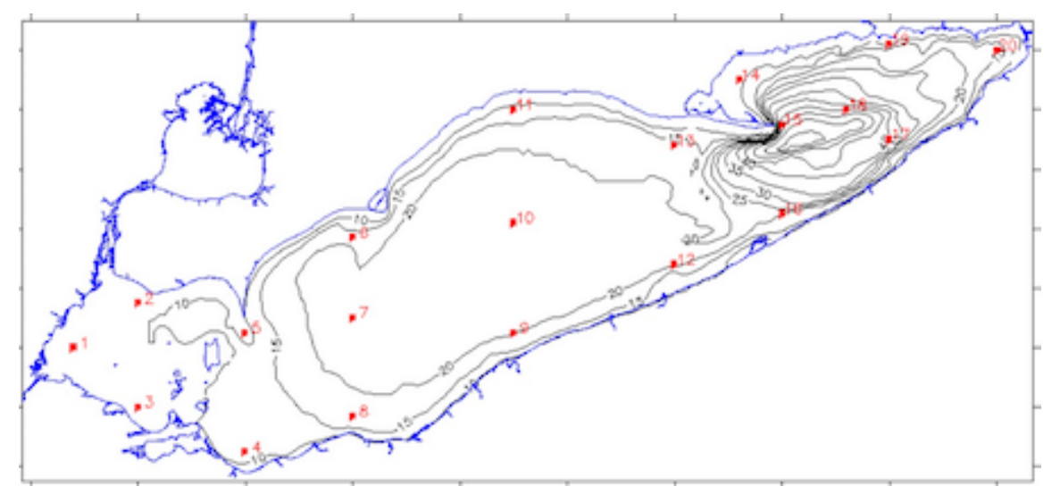


Fig. Ice thickness measurement sites. In-situ observations have been conducted by G. Leshkevich (GLERL) and U.S. Coast Guard since 2008.

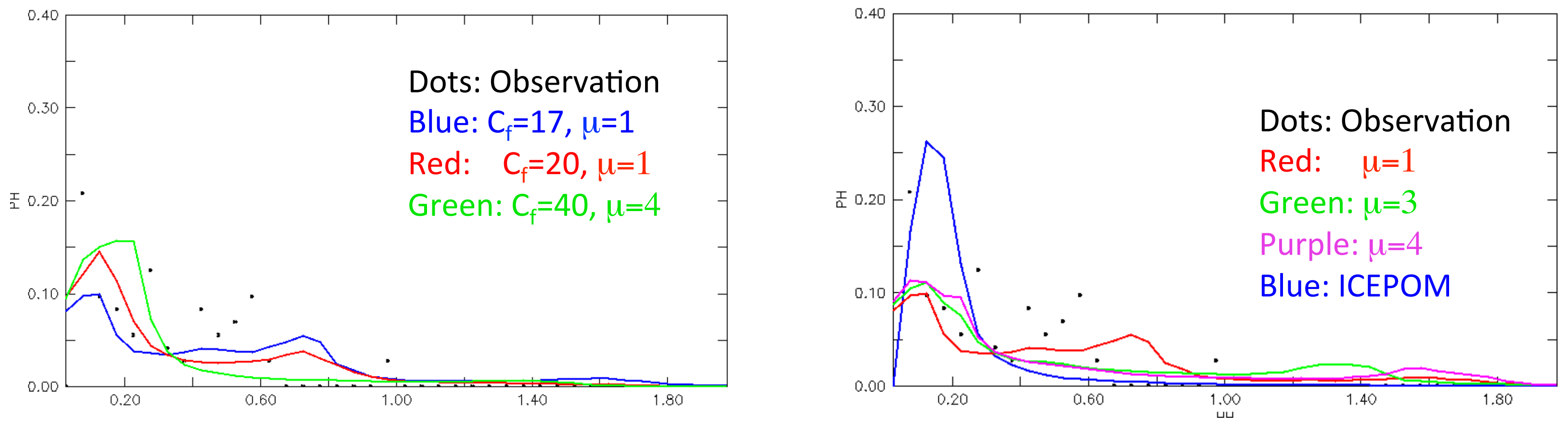


Fig. Probability density function of ice thickness. Modeled ice thickness are only from a stable ice period (February 20th – March 5th) for consistency with observations.

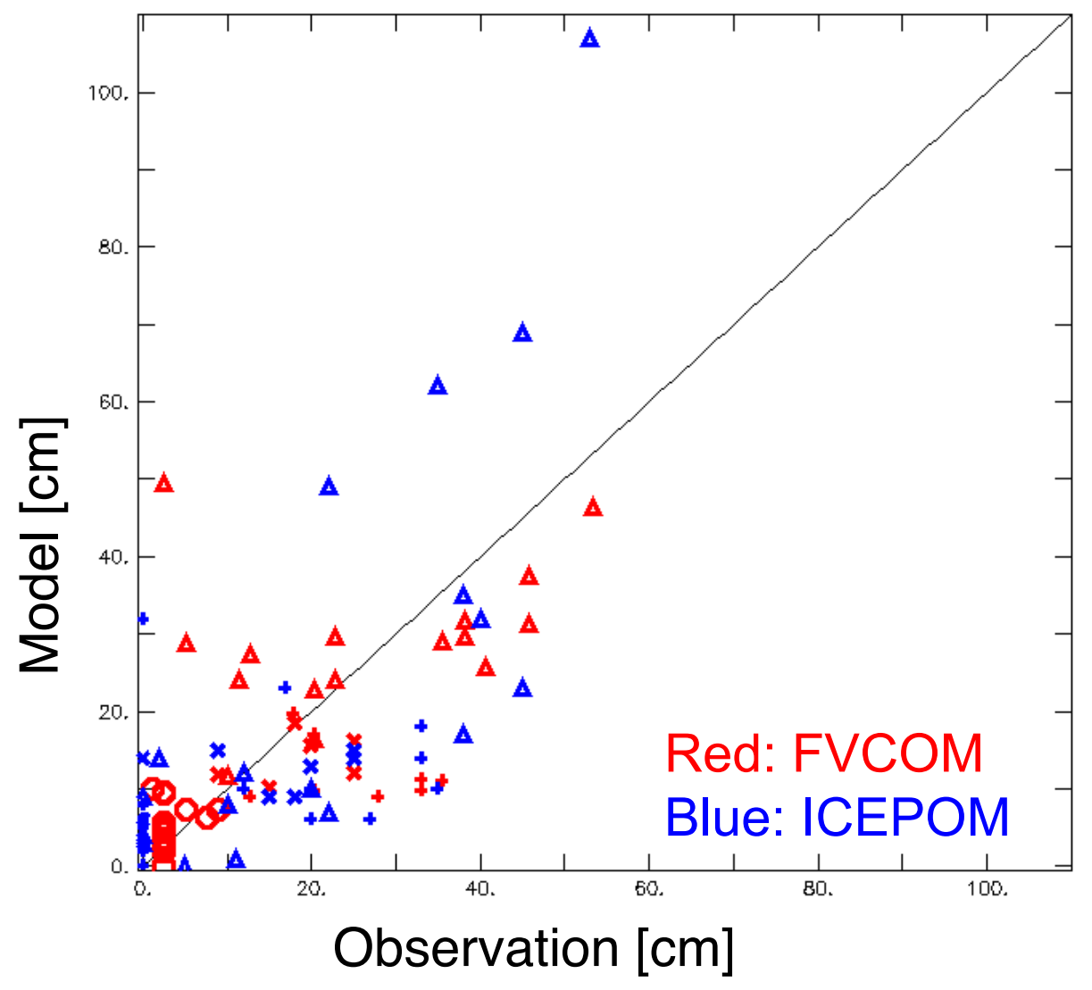


Fig. Ice thickness comparison

Thermal structure

- Winter thermal structure was better simulated by FVCOM-Ice than by ICEPOM.
- Diffuse thermocline in the model results was slightly improved by introducing the central difference time integration scheme.

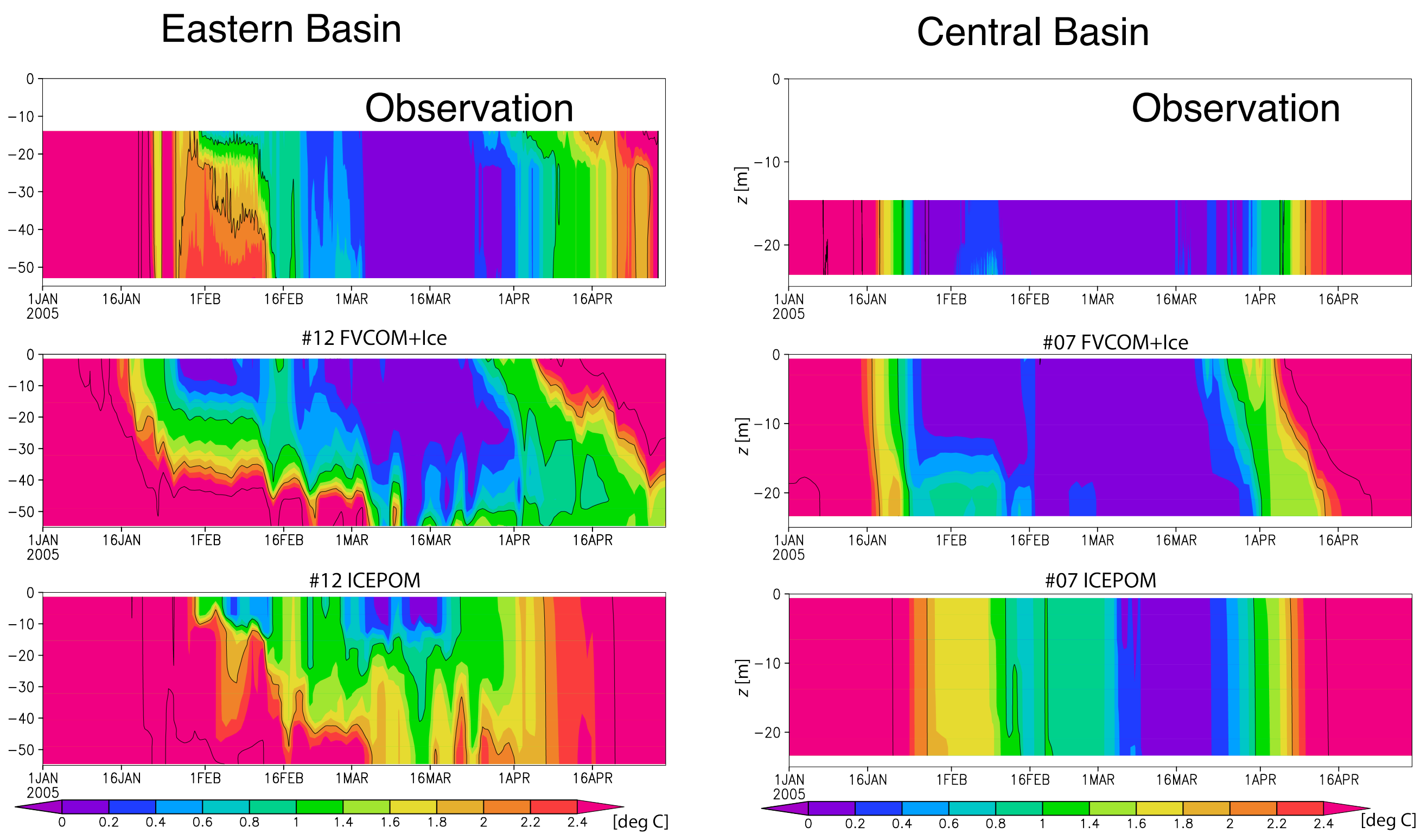


Fig. Water temperature profile. Top: Thermistor observations are in 2005 from International Field Year on Lake Erie (IFYLE). Middle: FVCOM-Ice. Bottom: ICEPOM.

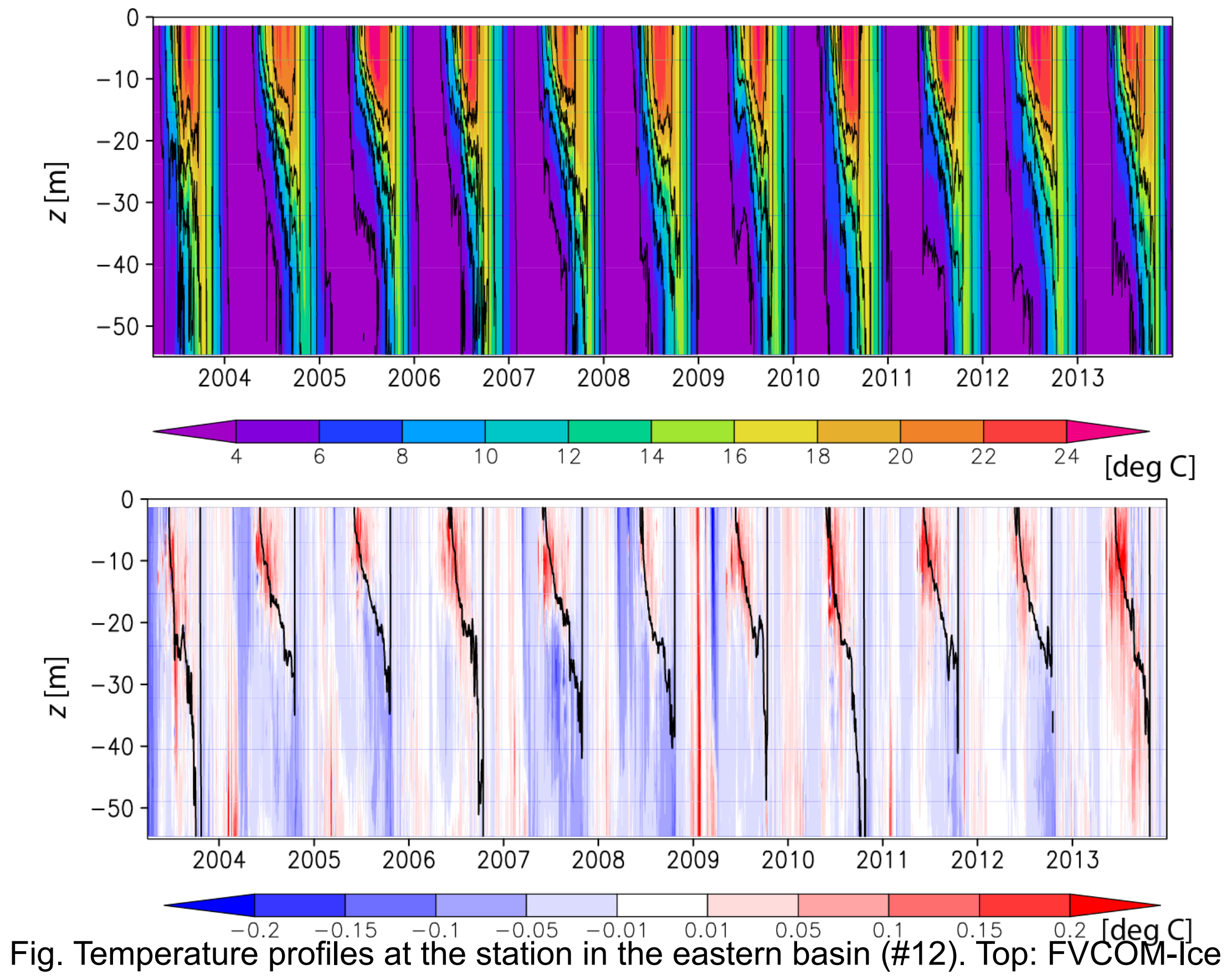


Fig. Temperature profiles at the station in the eastern basin (#12). Top: FVCOM-Ice results with the centered difference time integration scheme. Bottom: the difference between the centered difference and the default schemes, i.e. Euler forward scheme and the modified Runge-Kutta scheme.

Summary

- FVCOM coupled with UG-CICE (FVCOM-Ice) was configured and tested for a freshwater lake , Lake Erie.
- FVCOM-Ice performs similarly to ICEPOM, but outperforms in reproducing slow melting in spring and in reproducing the ice thickness distribution.
- The modeled thermocline, which was somewhat diffusive in comparison with the thermistor measurements, was slightly improved thermal structure by introducing the central difference time integration scheme.

References

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