Developing a new lake model in CESM

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Outline

- Deficiencies in current CESM Lake Model
- Schematic of New Lake Model
- Comparison to Site Data & Old Lake Model
- Uncoupled Lake Water & Surface Flux Sensitivities
- Sensitivity of CCSM4 Year 2000 Climate to Global Lake Area

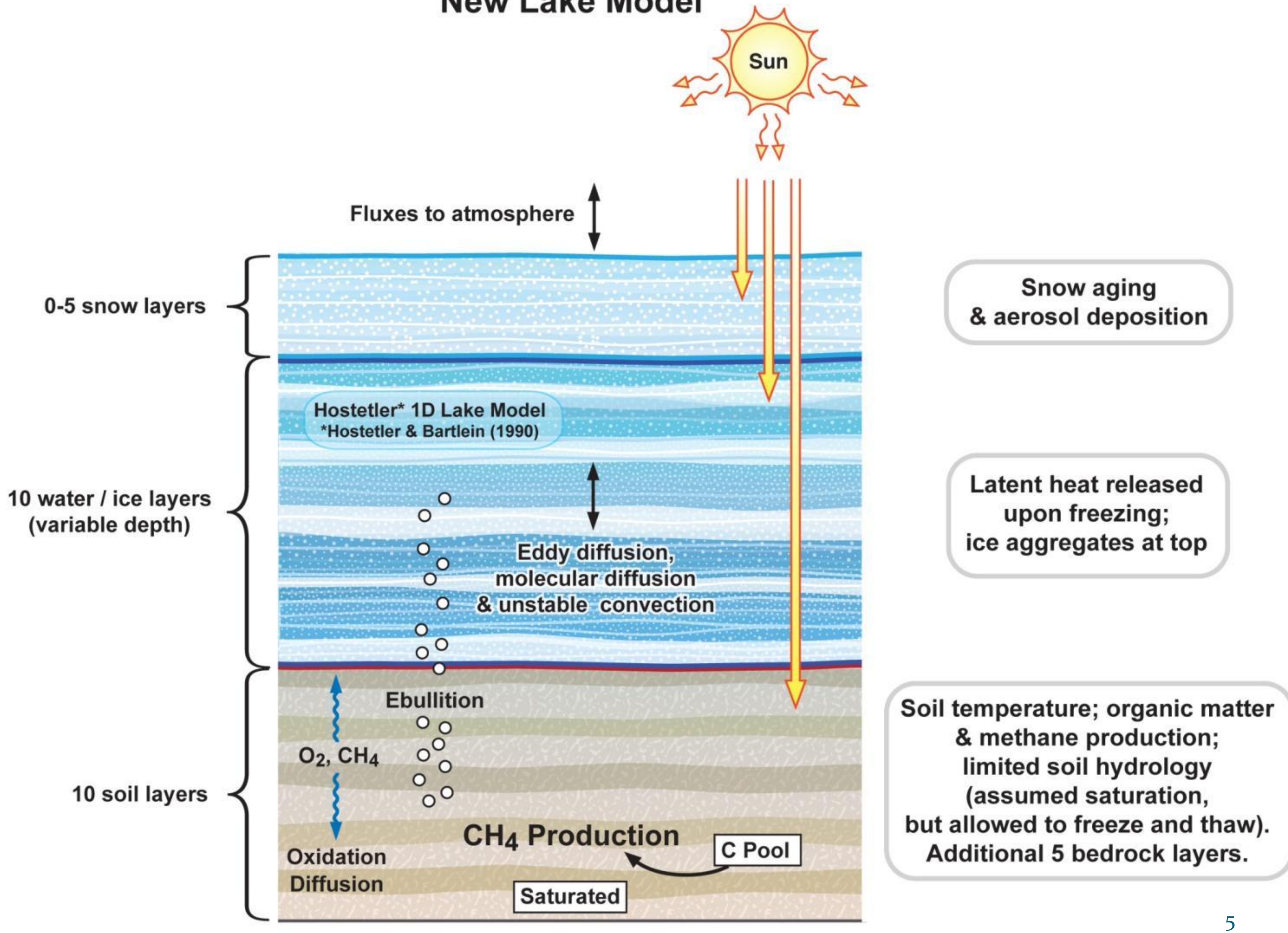
Motivation & Research Background

- DOE-funded: Investigation of the Magnitudes and Probabilities of Abrupt Climate TransitionS (IMPACTS)
- Our group focuses on Boreal / Arctic Terrestrial Ecosystems
  - How will wetlands, permafrost, thermokarst, and vegetation respond to and feed back to climate change?

Deficiencies in CCSM3.5 / CESM1 Lakes

- Problems with surface energy budget and mixing
  - Error in surface flux / ground temperature calculation
  - Only molecular conductance between lake surface & top lake layer
  - Error in eddy diffusion calculation
- Simple bulk snow scheme with no thermal insulation; no soil / sediment layers beneath lake
- Fixed 50 m depth & optical properties for all lake columns
- No phase change physics

New Lake Model



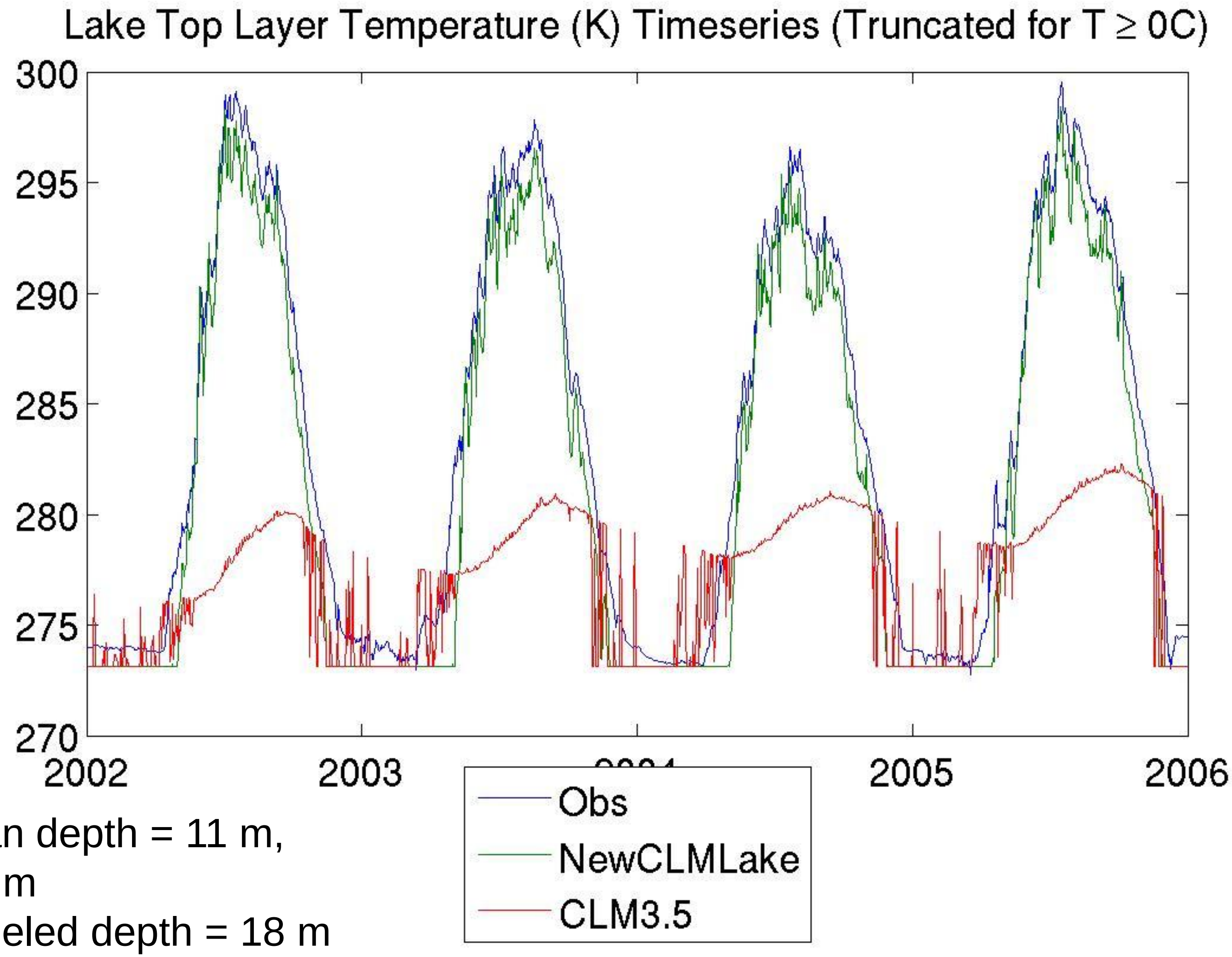
Modifications to Hostetler Lake Model

- Each lake layer is a free combination of ice and liquid.
  - For global climate simulations, ice convects to the top, but "puddling" can be allowed.
  - Vertical diffusion solved via Crank-Nicholson, then adjusted for phase change
  - Fixed virtual depth simplifies numerics
- Surface absorption = near IR fraction (> 700 nm)
- Regression (Hakanson 1995) ties opacity to depth

Evaluation

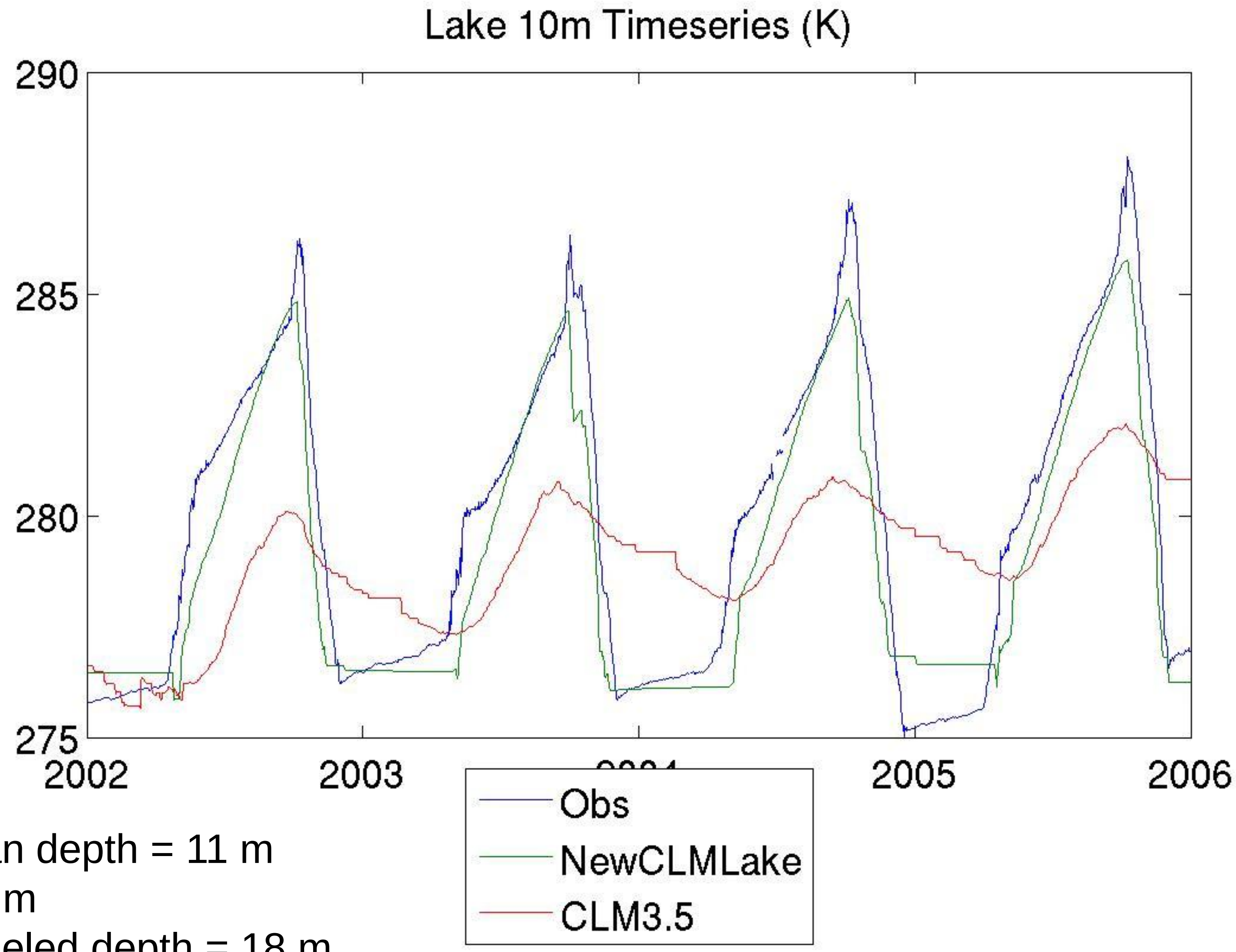
- Sparkling Lake, WI: water temperature & forcing data
- 12 other lakes: Qian 2006 NCEP reanalysis 2^0 forcing
- New model (but not old) captures vertical and seasonal patterns, with good surface temperature agreement
- Slightly insufficient bottom mixing for very deep lakes consistent with other Hostetler Lakes, but does not bias surface
- Summer stratification depends on lake optics, which vary widely in real lakes
- Decrease in roughness length (~1 cm → ~1 mm) improves simulation of surface temperature for small lakes

Sparkling Lake @ 5 cm



Lake mean depth = 11 m,
max = 20 m
Lake modeled depth = 18 m
Temp. probe depth = 18 m

Sparkling Lake @ 10m



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Lake Michigan Data (Climatic Change, 1993)

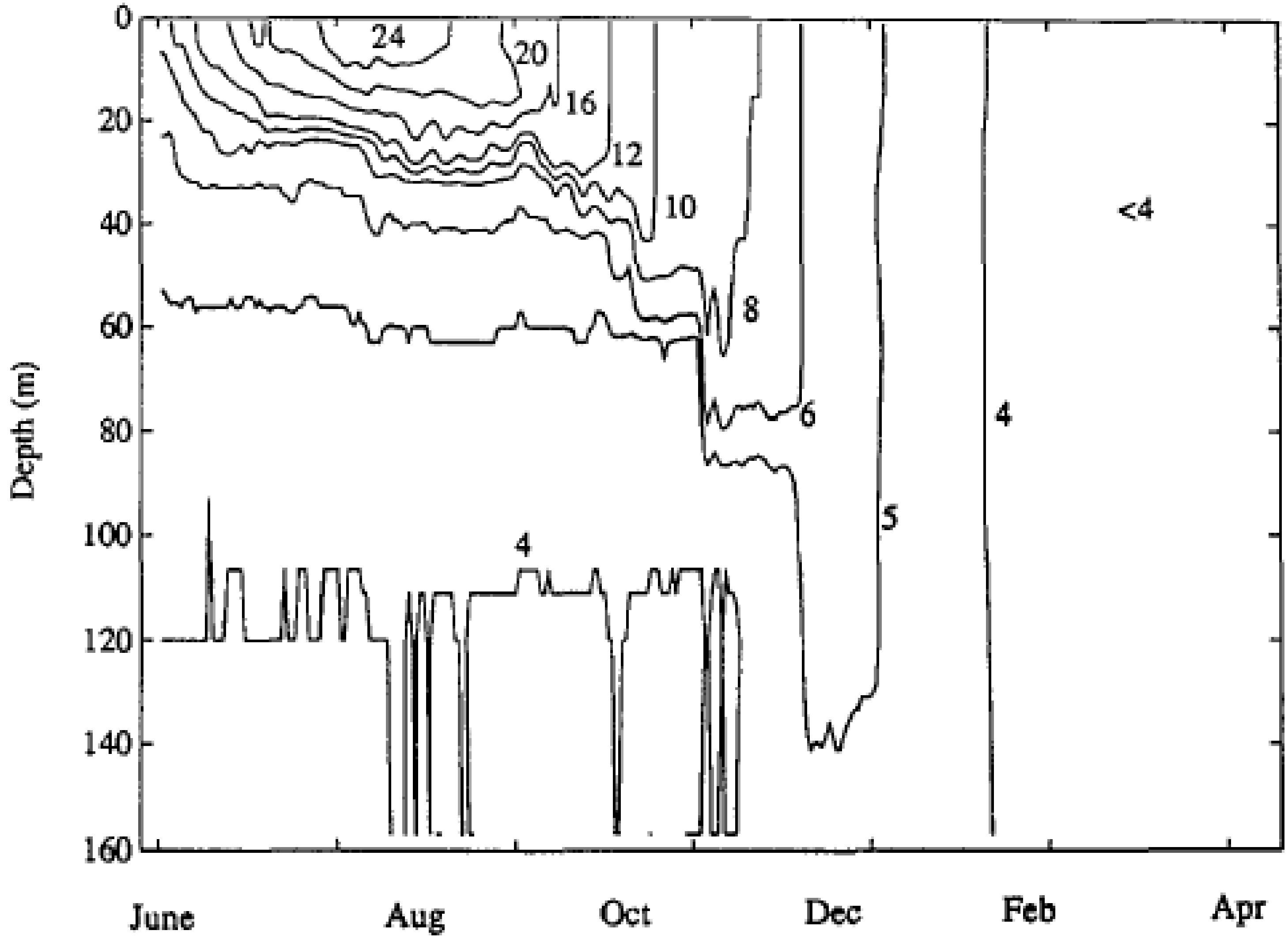
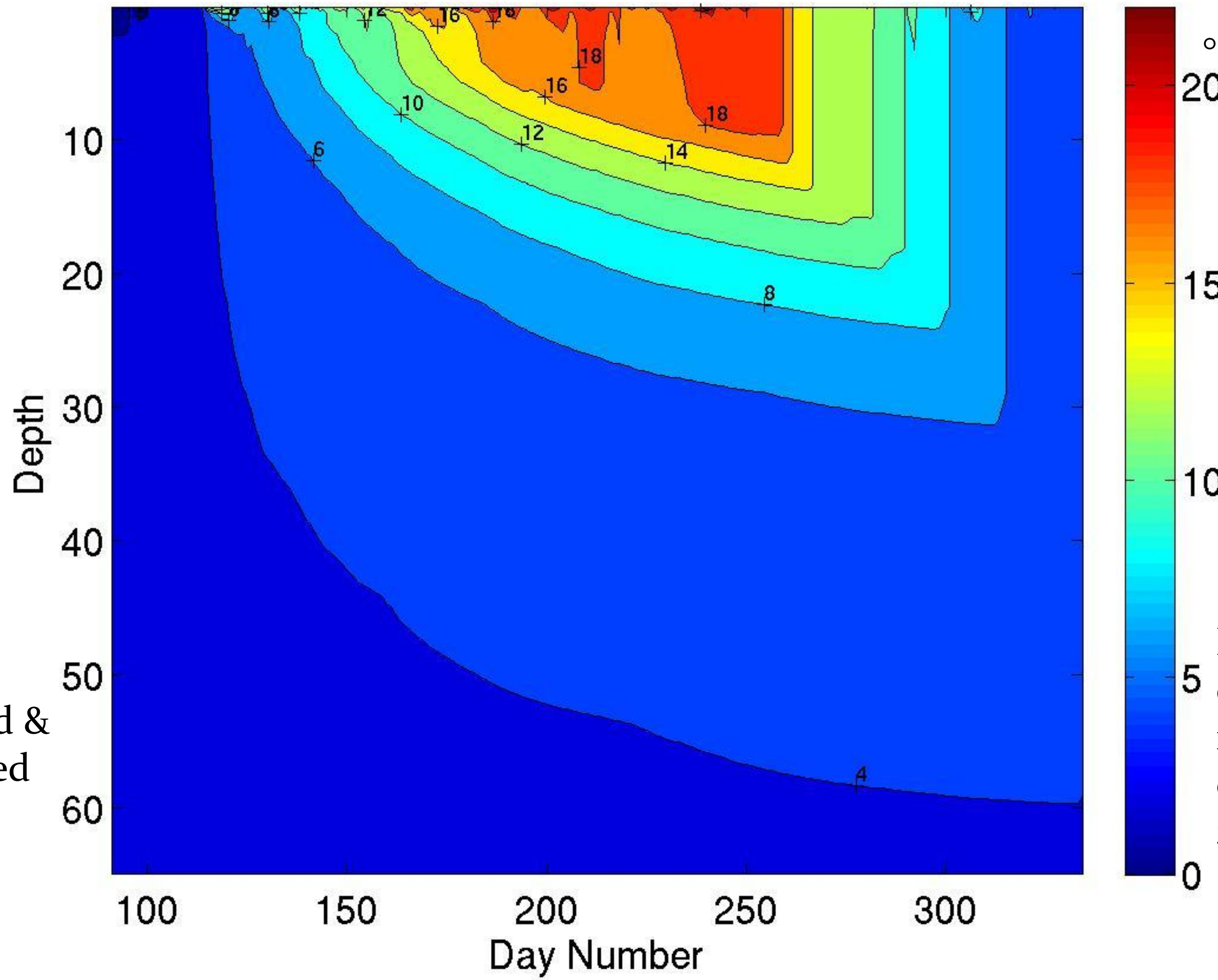


Fig. 2. Temperature contours for the offshore waters of Lake Michigan from 7 June 1990 through 18 April 1991. Contours were generated from daily averaged data.

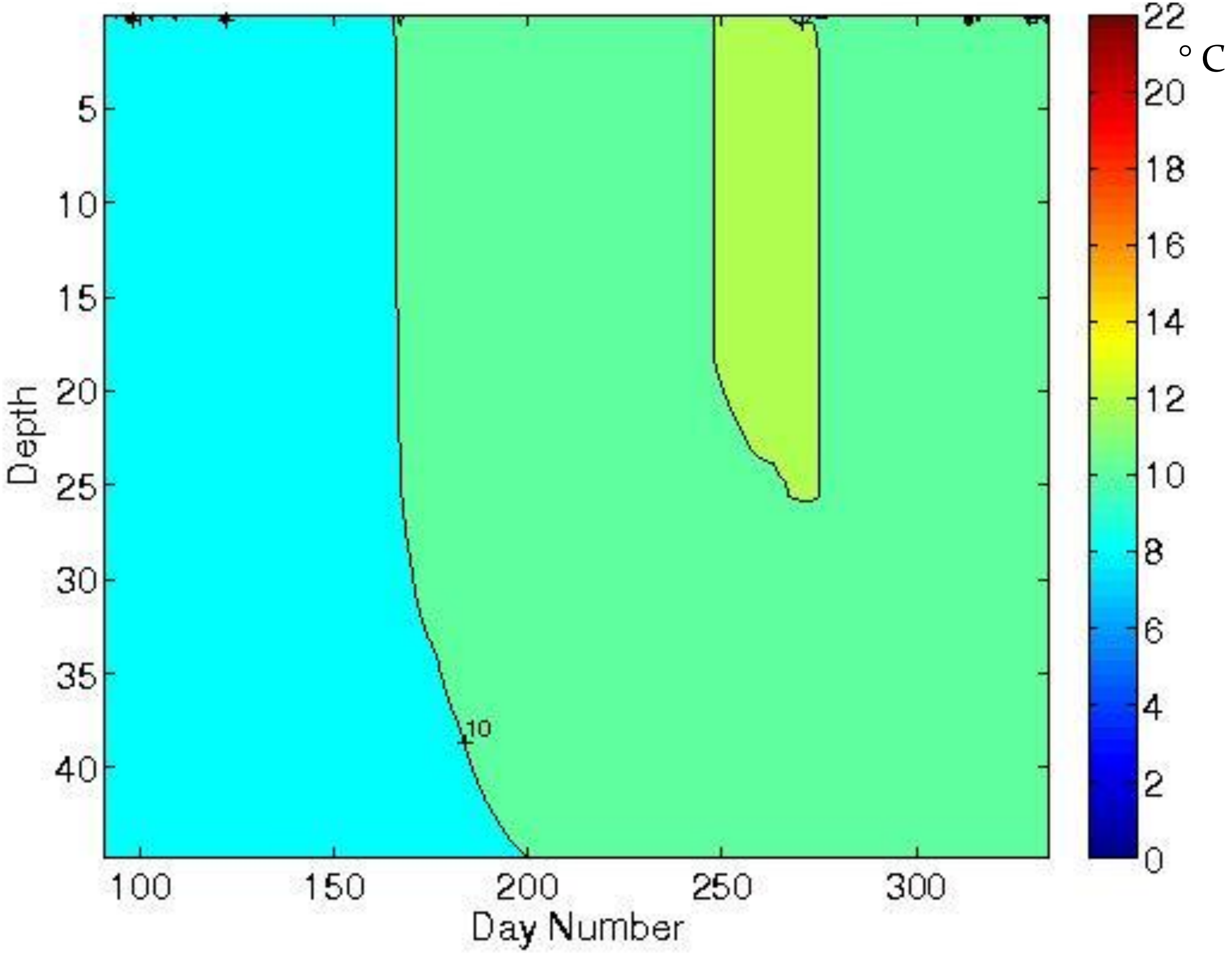
Lake Michigan, Apr-Nov 1990, New Lake Model



Modeled & measured depth = 160 m

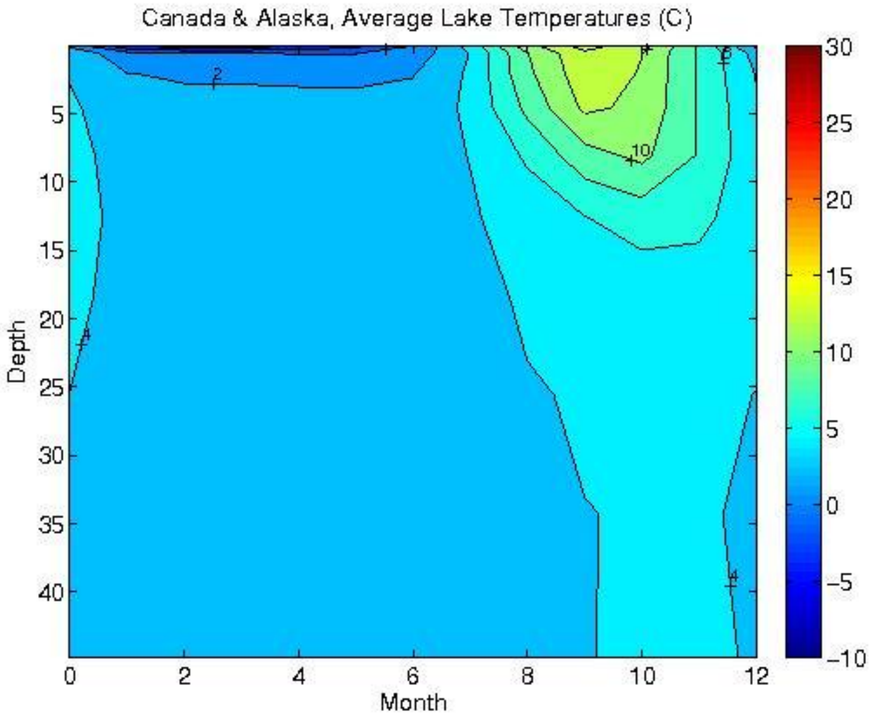
Mean depth = 85 m; Max. depth = 281 m

Lake Michigan, Apr-Nov 1990, CLM 3.5

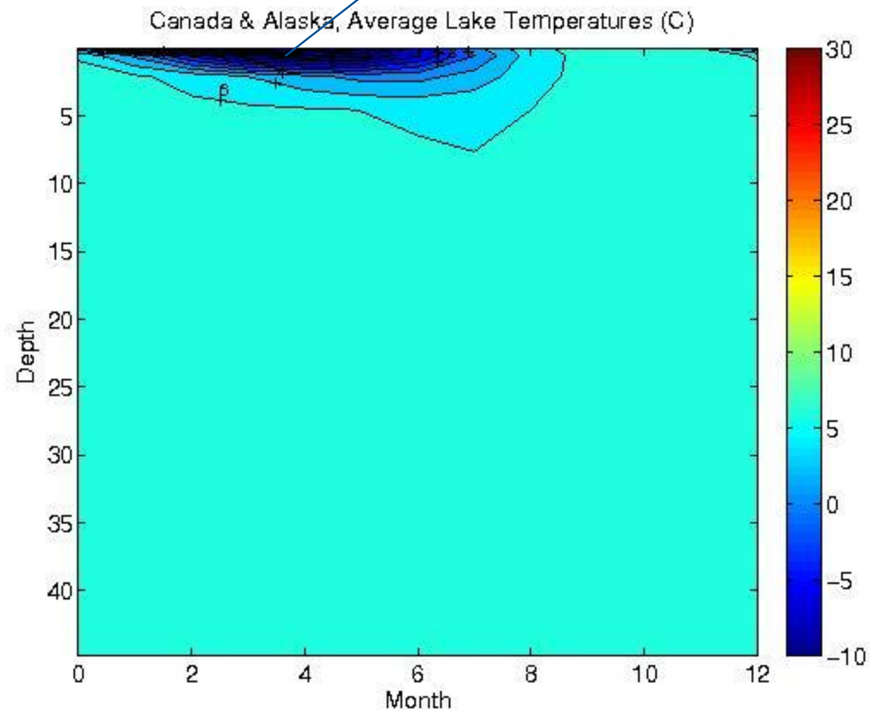


CAM-CLM4 Alaska + Canada Monthly Average Lake Water / Ice Temp.

As low as -30 °C

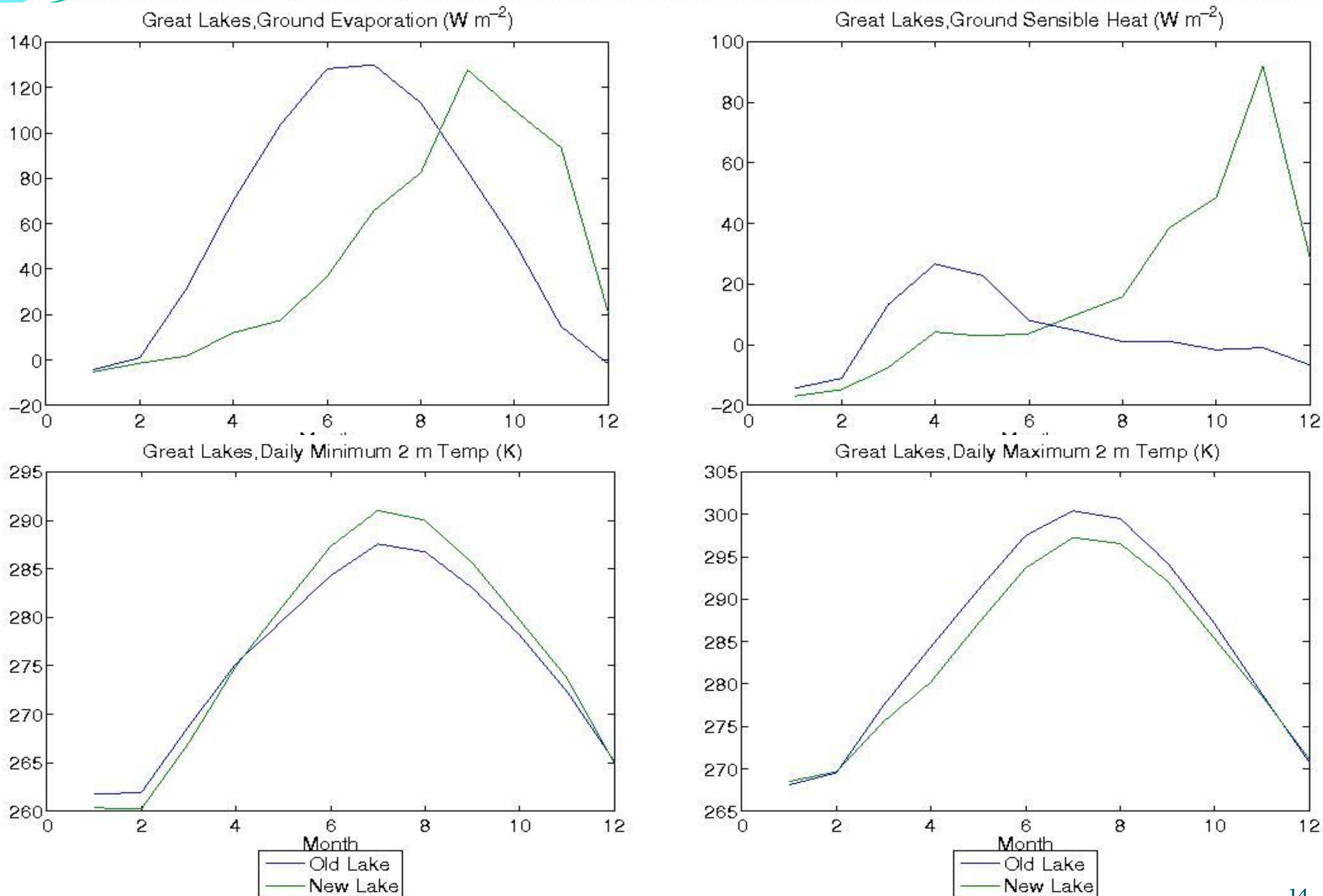


New Lakes



Old Lakes

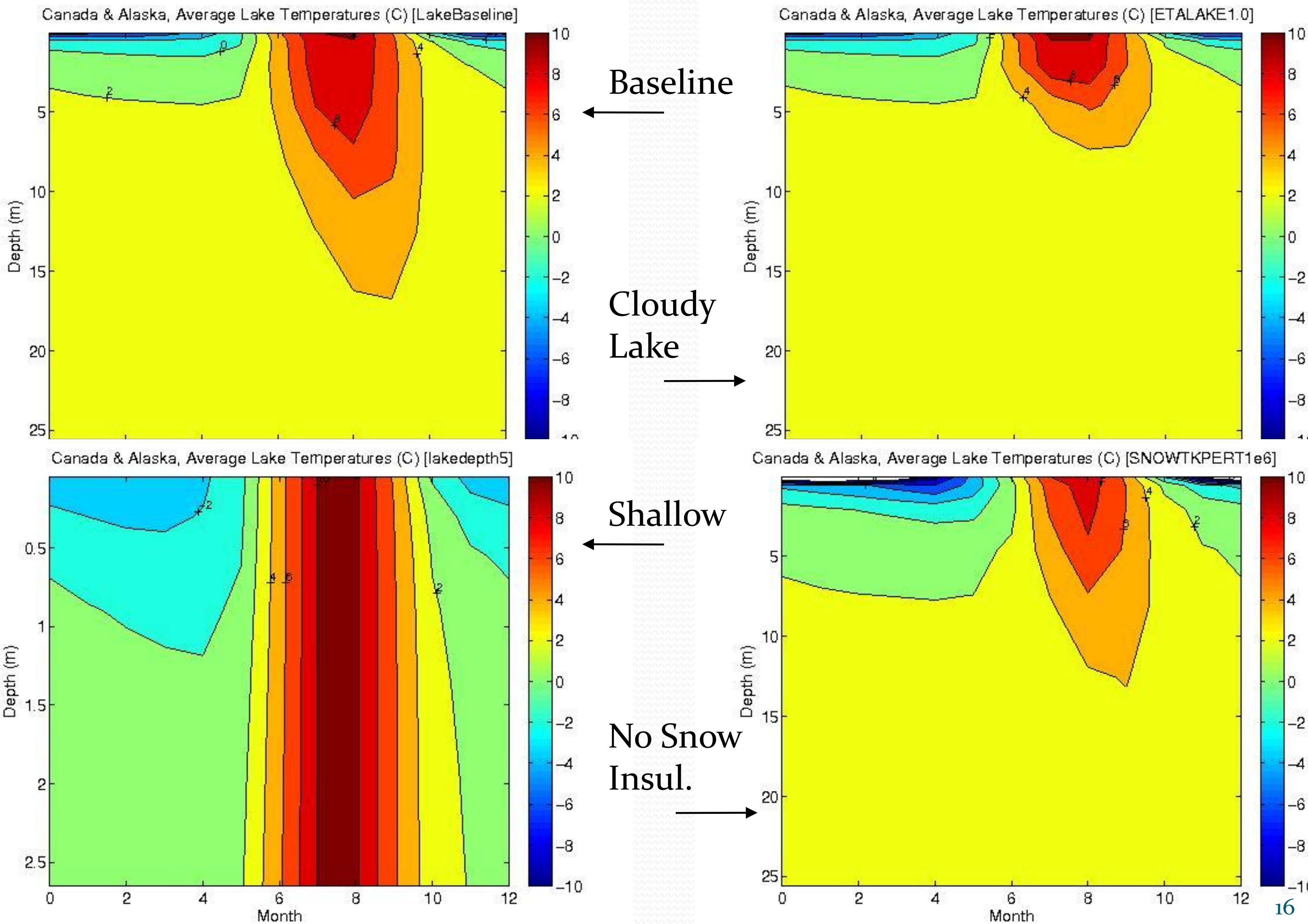
Uncoupled CLM 3.5, 24 yr, Great Lakes Fluxes



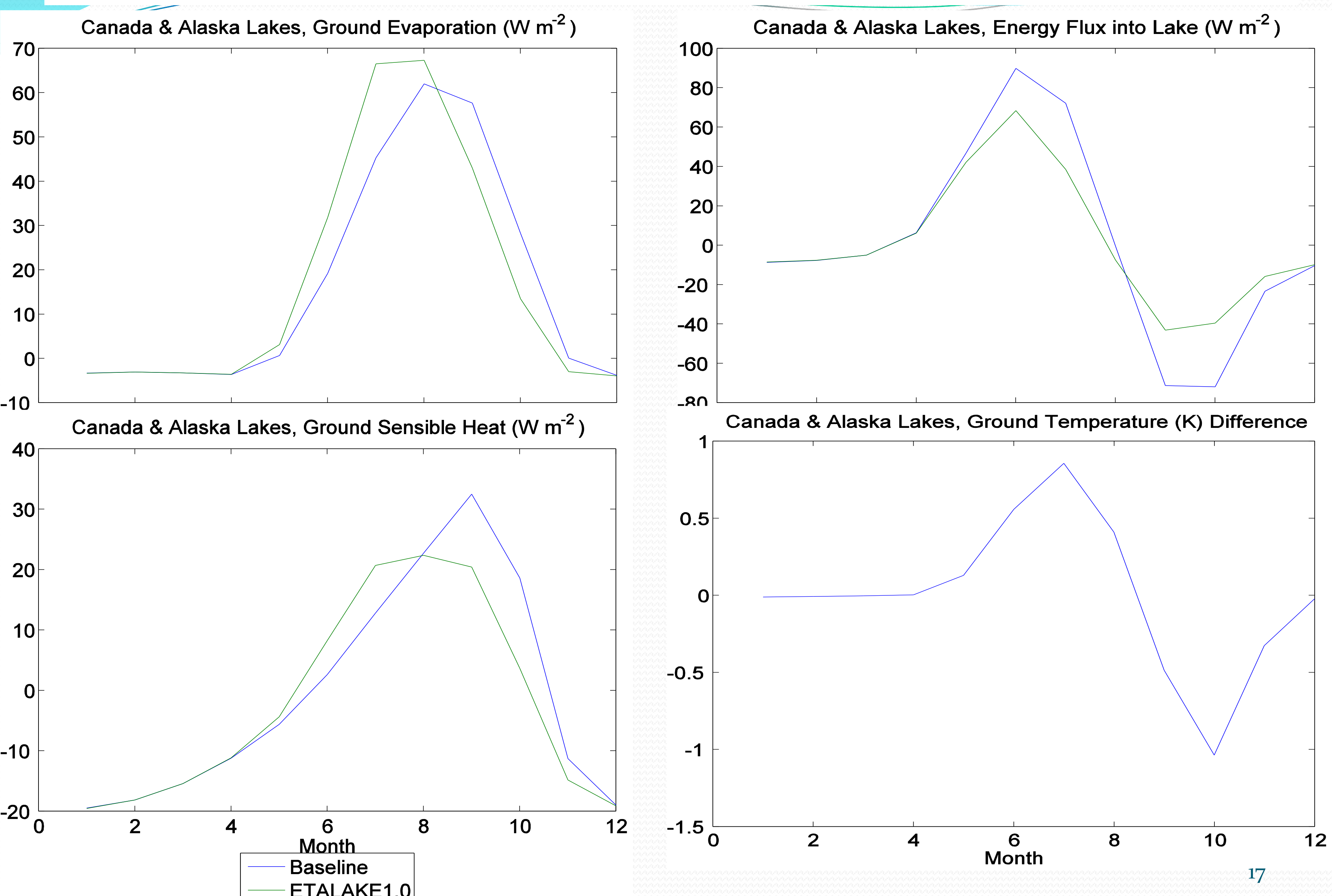
Lake Temp. and Surface Flux Sensitivity

- **Optical extinction coefficient**
- **Lake depth**
- **Roughness length**
- **Snow insulation**
- **Phase change with heat of fusion**
- Eddy mixing strength
- Albedo dependence on zenith angle
- Puddling on thick melting ice
- Enhanced molecular diffusion

Canada & Alaska Average Water Temp.



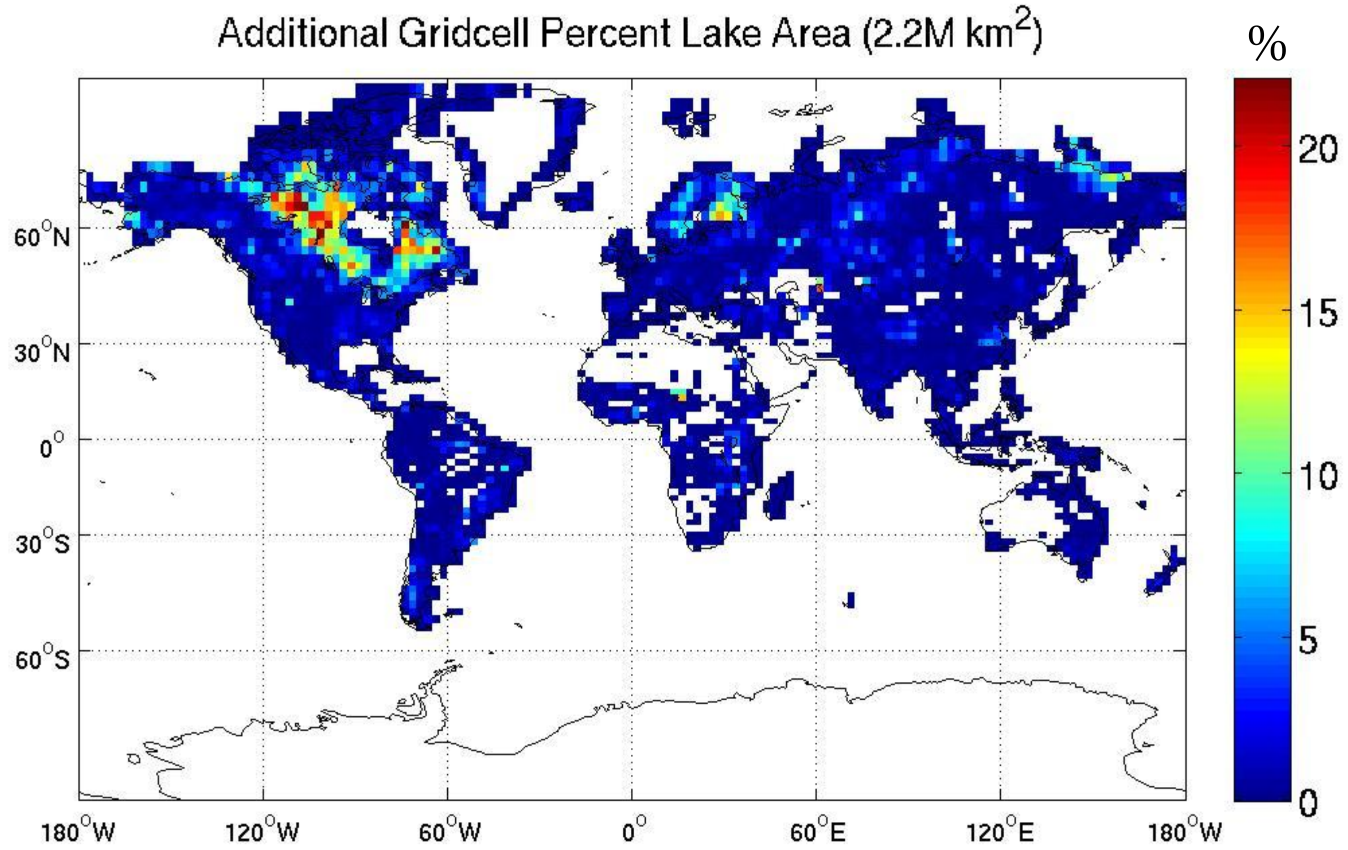
Extinction Coefficient: 0.2 m^{-1} → 1.0 m^{-1}



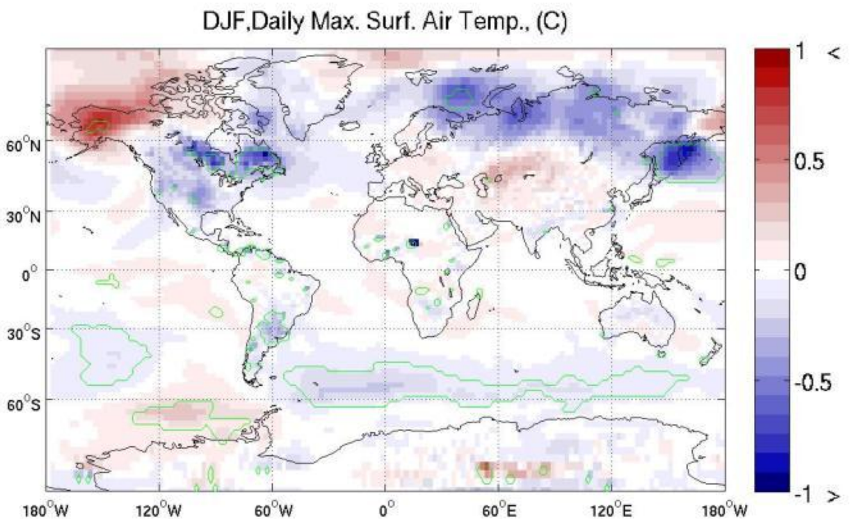
Effects of Lake Model on Year 2000 Climate in CCSM4 (with Slab Ocean)

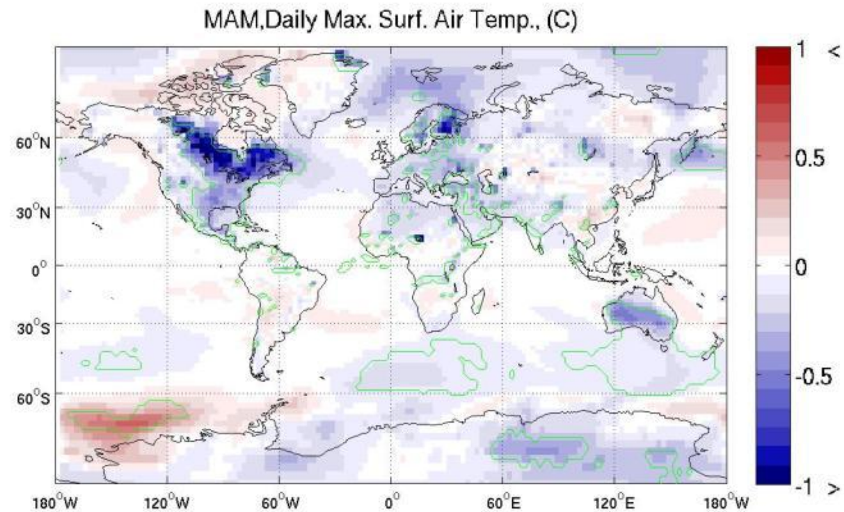
- **New Lake Model with 0.7M km^2 vs. 2.9M km^2 Lake Area**

Low Estimate of Missing (Small) Lake Area in CCSM4 from GLWD

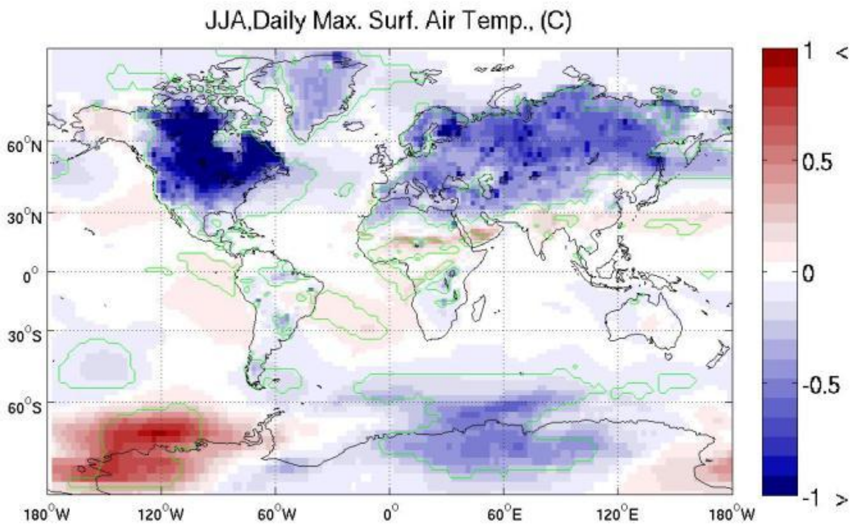


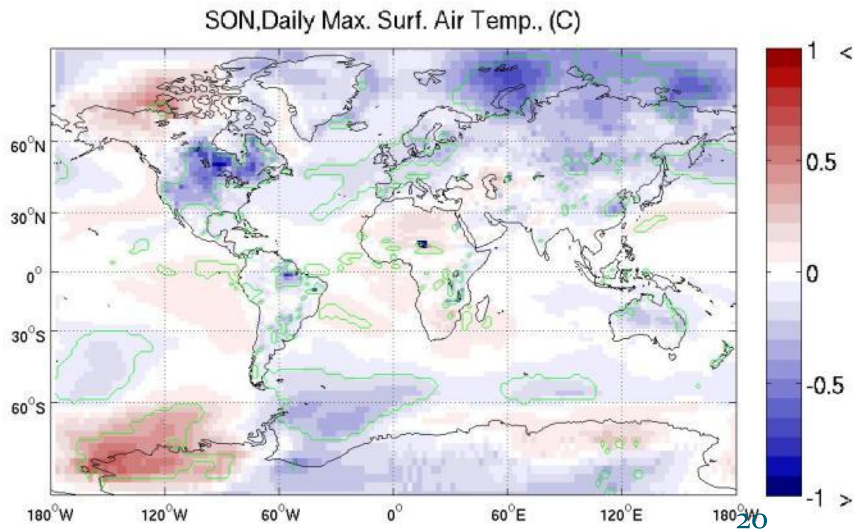
CAM-CLM4, 200 yr, High – Low Lake Area Daily Max. Surf. Air Temp. (C)



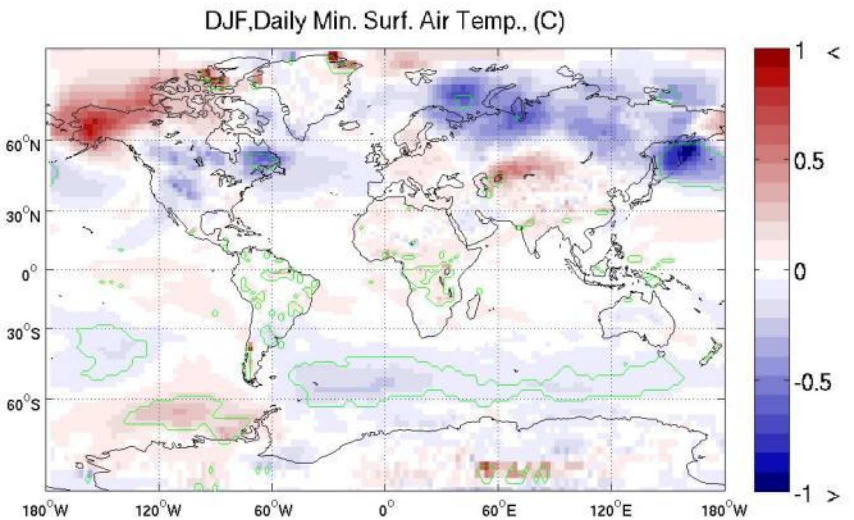


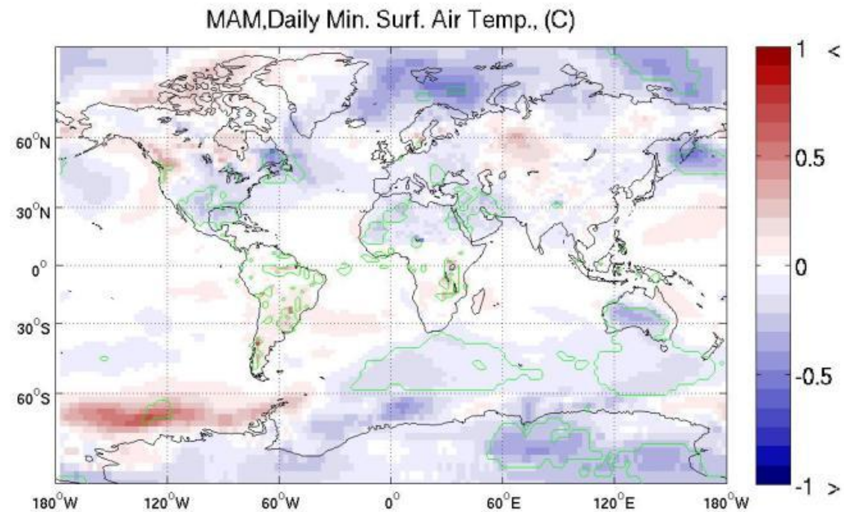
Green contours = significance at 5%





CAM-CLM4, 200 yr, High – Low Lake Area Daily Min. Surf. Air Temp. (C)





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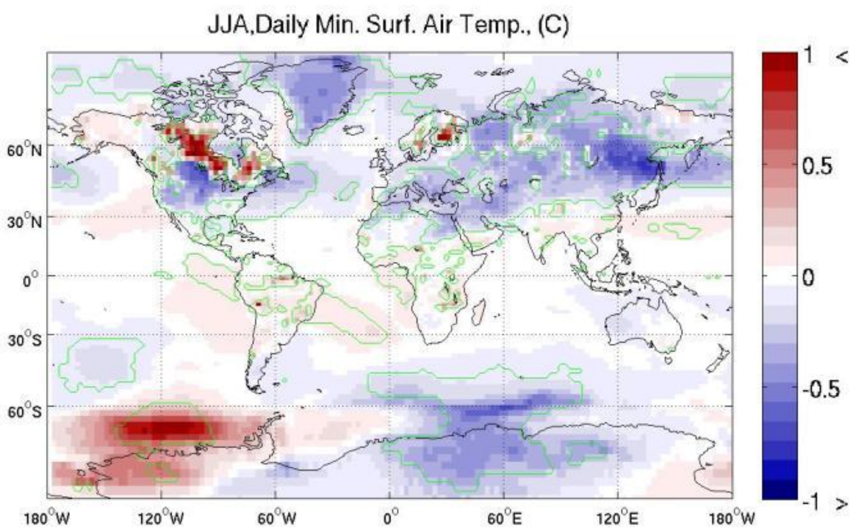
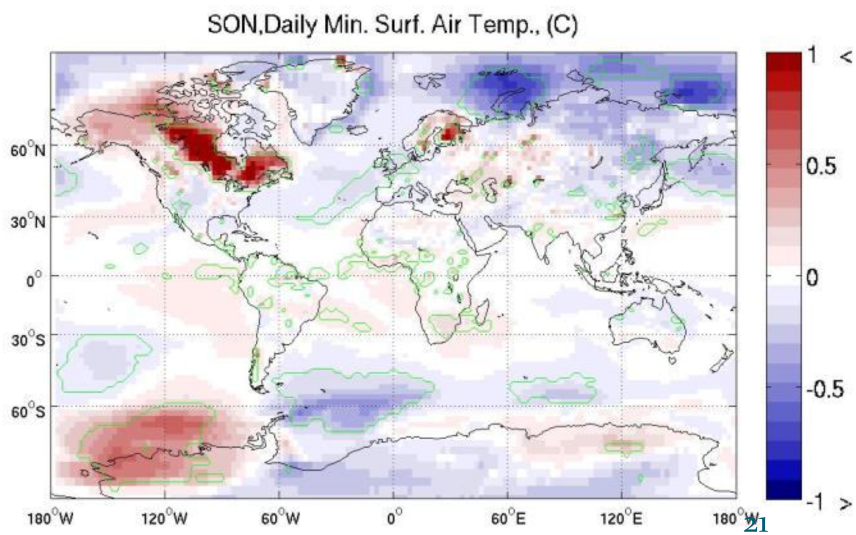
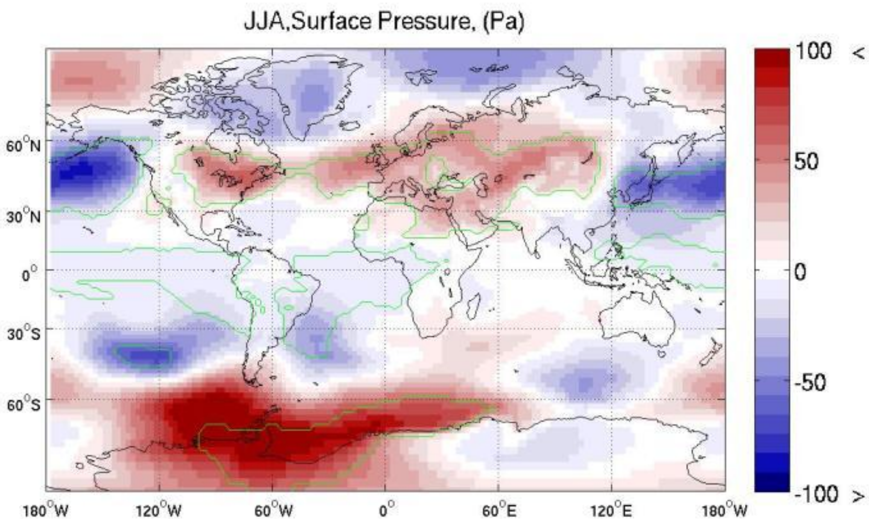
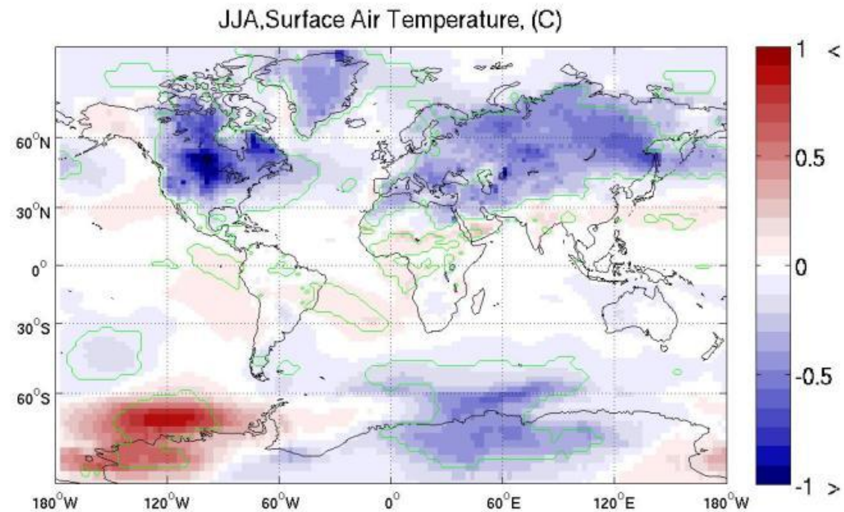


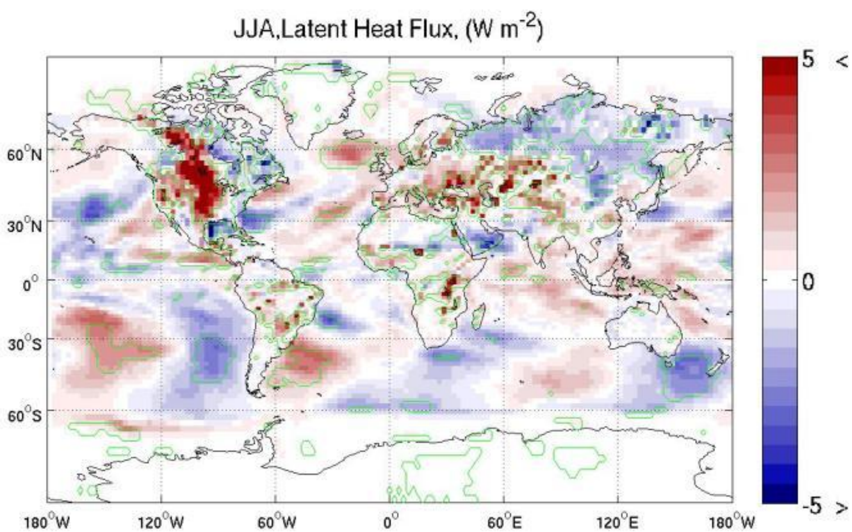


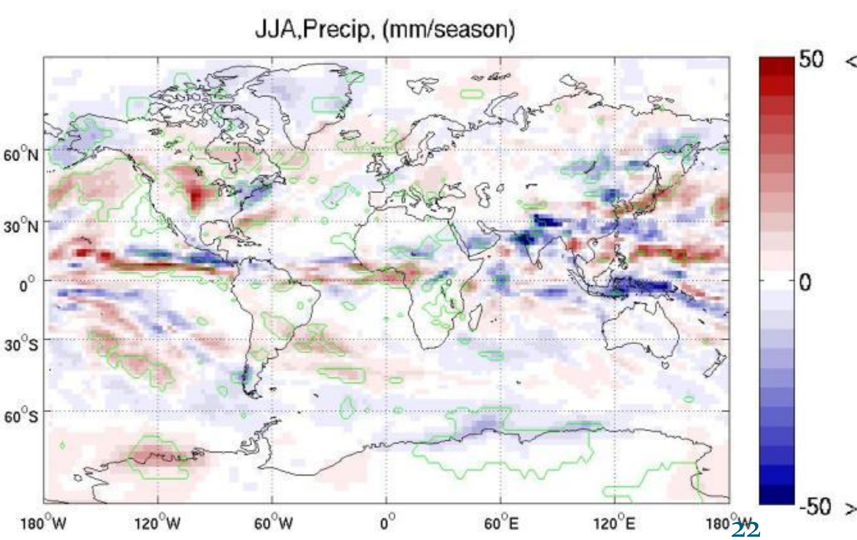
CAM-CLM4, 200 yr, High – Low Lake Area: JJA





Green contours = significance at 5%





Conclusions

- An updated lake model has been integrated into CCSM4 / CESM1.
- The new lake model substantially improves simulation of lakes across climates and geometries.
- In uncoupled CLM simulations, the new lake model changes gridcell surface fluxes by up to 100 W/m^2.
- The local climate is especially sensitive to lake optics and depth, which vary widely between lakes. Surface roughness is also important and should depend on lake shape and wind conditions.

Conclusions (cont'd)

- CESM1 may have regional (e.g. Great Lakes & Mississippi Valley) biases because the current lake model is poor.
- CESM1 and other climate models may have biases of ~1 K in Canada and the northern U.S., because of datasets that dramatically underestimate total lake area by excluding small lakes.
- The underestimation of lake area may influence the climate of remote locations (e.g. Southern Ocean, equatorial Pacific) by changing atmospheric transport of energy & moisture.

Acknowledgements

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