An Improved Lake Model in CESM1, with Climate Sensitivity to Lake Distribution

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Introduction

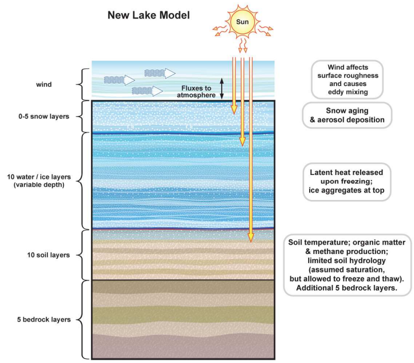
- **Lakes have different physical properties than their surroundings:**
  - Albedo
  - Heat conductance
  - Heat capacity
  - Surface roughness
- **Lakes can interact with climate change:**
  - Altered mixing and ice regimes
  - Changing lake area
  - Increasing methane emissions associated with expanding thermokarst lakes
- **Most GCMs have a highly simplified treatment of lakes:**
  - Simplifications that over-estimate or under-estimate mixing
  - Insufficient lake area / no subgrid lake tile
  - May be lacking phase change, snow insulation, or sediment models

New Lake Model

New Lake Model in CESM1 / CLM4

We improved the lake model in CLM4 and added components critical for modeling shallow high-latitude lakes and the methane fluxes from soil beneath them:

- Correcting errors in surface flux and eddy diffusivity calculations
- Integrating CLM4's extensive snow model with the lake model
- Adding a prognostic phase change scheme within the lake
- Integrating CLM4's soil thermal model to model sediment, soil, and bedrock beneath the lake
- Allowing lakes to have variable depth
- Improving characterization of surface properties, including surface roughness
- Coupling to a methane biogeochemical model in the sediment
- Allowing excess ice to be initialized in a soil layer, affecting thermal properties



Model Evaluation

Site tests compared to observations and old lake model.

We tested the new model at 13 lakes of diverse climates, geometries, and optical characteristics, including 3 small temperate / Boreal lakes with meteorological forcing observations. No site tuning was done; lake specific data were the depth and optical extinction coefficient.

Whereas the existing CLM4 lake model suffers from 10-25 ºC cold biases in the summer and winter due to excessive mixing, incorrect surface fluxes, and the absence of phase change or snow insulation, the new lake model captures vertical and temporal patterns in lake water temperature.

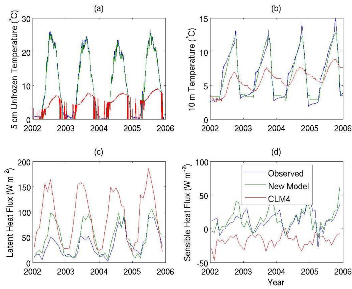


Figure 1: Sparkling Lake (WI) Water Temperature & Heat Fluxes. Forced with 2002-2005 2 m meteorological observations.

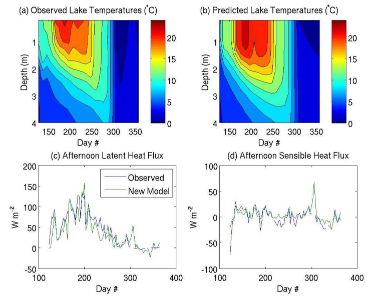


Figure 2: Valkea-Kotinen (Finland) Water Temperature & Heat Fluxes. Forced with 2006 1.5 m meteorological observations.

Effect of Lake Area on Boreal Climate

Changes in seasonal energy fluxes, surface temperature, and geopotential height are caused by increasing the lake area in CLM4 from 0.7 M km^2 to a more realistic 2.9 M km^2.

Both runs use a new global lake depth dataset (Kourzeneva et al., 2010).

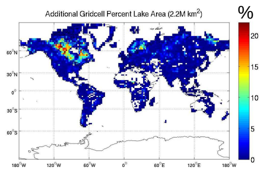


Figure 3: Missing lake area in CLM4 compared to Lehner & Doll (2004)

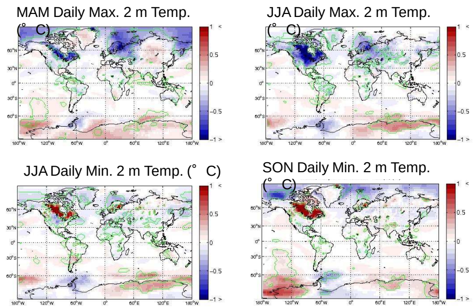


Figure 3: CAM-CLM4, 200 years, Slab Ocean, Differences between 2.9 M km^2 lake area and CLM4 default 0.7 M km^2 lake area. Green contours encircle regions statistically significant at the gridcell level.

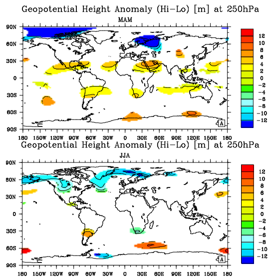


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Figure 4: CAM-CLM4, 200 years, Slab Ocean, Differences between 2.9 M km^2 lake area and CLM4 default 0.7 M km^2 lake area: **250 hPa Geopotential Height (m) Significant Differences**

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Model Sensitivity

- We tested the **sensitivity** of **surface fluxes** to model processes and parameters.
- Large changes in monthly fluxes (up to 30 W m^{-2}) occurred when eliminating **snow insulation** or **phase change**, and when varying lake **opacity**, **depth**, **melting ice albedo**, and mixing strength.

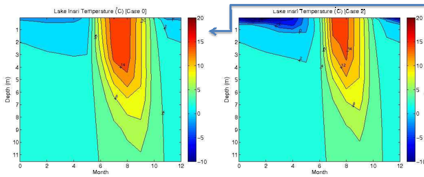

Figure 6

Conclusions

- **The new lake model in CESM1 has much better agreement with observations**, causing lakes to be much warmer in the fall and winter, colder in the spring, and more stratified in the summer with much lower diurnal variation in 2 m air temperature, with much lower latent heat fluxes and much higher sensible heat fluxes.
- **The cumulative effect of distributed small lakes in northern Canada** not resolved by many GCM datasets **causes seasonal temperature changes in North America and Scandinavia**, and may perturb atmospheric circulation.

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