Update on New Lake Model for CLM

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Outline

• Model Recap
• Site Evaluation
• Parameter & Process Sensitivity
• Climate Sensitivity to Lake Distribution
Model Improvements

- Integrates CLM4 snow model
- Ice physics
- Underlying sediment
- Roughness lengths
- Enhanced mixing
- **3 bug fixes**
- Depth, opacity, & fetch can vary spatially
Roughness Lengths

• Waves move with wind!
• Mature waves $\rightarrow$ less momentum transfer
• CLM4 lake $z_0 = 10$ mm
• Literature: $z_0 \sim 0.1 - 1$ mm
• New model: $z_0 = f(u^*, \text{depth, fetch if avail.})$
Kossenblatter (Germany): old $z_0$ bias

(a) Surface Temperature

(b) 1 m Temperature

(c) Latent Heat Flux

(d) Sensible Heat Flux
Sparkling Lake (WI): CLM4 Comparison

(a) 5 cm Unfrozen Temperature

(b) 10 m Temperature

(c) Latent Heat Flux

(d) Sensible Heat Flux
Model Evaluation

- 13 lakes
  - Varying size, geometry, & climate
- Small lakes + forcing obs. → new model performs well
- Large lake simulation usually improved w/ increased mixing
- Snow, ice, & sediment OK but scarce data
- CLM4 model performs poorly
Great Slave Lake (Canada)

- Large, deep (90 m at measurements)
- Hostetler wind-driven eddy mixing
  ~100 times too weak
More mixing

- New lake model retains core Hostetler parameterization
- Mild enhanced diffusion from Fang & Stefan (1996) not enough
- 3D convection must be dominating
- More sophisticated turbulence models parameterize large lakes well, but over-predict mixing in small lakes…
- Hybrid approach needed?
Surface Flux Sensitivity

• 14 cases, processes & parameters
• **Key controls (seasonal 15 – 30 W m⁻²):**
  – Snow insulation
  – Phase change
  – Depth
  – Opacity (range of 0.05 to 7 m⁻¹ just for 13 lakes!)
  – Melting lake albedo
  – Mixing strength (if large range)
• For global simulations, errors in depth, mixing strength, & opacity are ~equally important.
Example: Opacity

- A turbid lake acts like a shallow lake.
- Remote sensing could constrain this.
CCSM 4 Sensitivity to Lake Area

- 2° CLM4: 0.7 million km² (Cogley 1991)
- 2° GLWD: 2.3 million km² (Lehner & Döll, 2004)
- Mostly missing in N. Canada

- Hi – Lo area experiments
  - 25 yr offline
  - 200 yr slab ocean
New Gridded Lake Depth Data

- First dataset
  - (Kourzenova et al., 2010)
- Interpolation to 2° is crude
Hi-Lo Canadian Flux Anomalies

The graph shows flux anomalies in W m⁻² over the months. The lines represent different types of heat flux:
- **Latent Heat**
- **Sensible Heat**
- **Subsurf. Enth. Stor.**
- **Upward Longwave**

The graph indicates variations in these fluxes throughout the year, with peaks and troughs corresponding to different months.
Hi-Lo Surf. Air Temp.

(a) MAM Daily Max.

(b) JJA Daily Max.

(c) JJA Daily Min.

(d) SON Daily Min.
JJA Diurnal Temp. Range

(a) Hi – Lo

(b) Hi – CRU

(c) Lo – CRU

(e) CLM4 – CRU
Atmospheric Response

- Lower atm. responds more to daytime SH
- Remote changes / modes of variability?
Future – Hi Area, 2 x CO₂
Conclusions

• **New lake model evaluated for 13 lakes**
  – CLM4 model evaluated for 4 lakes
  – New model: **large improvement in water temperature and surface fluxes**
  – Increased mixing improves results for large lakes; more work needed

• **14 surface flux sensitivity cases**
  – Snow & ice processes are important for climate.
  – Better data needed on **opacity, depth, melting albedo**
Conclusions, cont’d

• **Lake area is currently under-estimated.**
  – Correcting improves diurnal temp. range
  – Permafrost lake area changes likely much smaller in importance
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