

Developing a new lake model in CCSM4



Zack Subin

Bill Riley

Celine Bonfils

Breckenridge

6/29/10

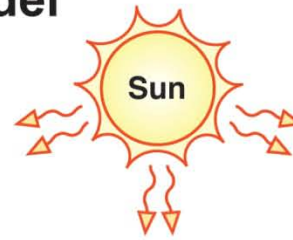
Work Funded by DOE and Lawrence Berkeley
National Lab



Deficiencies in CCSM 3.5 / 4 Lakes

- Problems with surface energy budget and mixing
 - Error in partitioning fluxes
 - Only molecular conductivity between lake skin & top lake layer
 - Error in eddy diffusion calculation
- Simple bulk snow scheme with no thermal insulation; no soil layers beneath lake
- Fixed 50 m depth & optical properties for all lake columns
- No phase change physics: no change in thermal properties or exchange of latent heat for freezing or melting

New Lake Model



Fluxes to atmosphere



0-5 snow layers

Snow aging
& aerosol deposition

Hostetler* 1D Lake Model
*Hostetler & Bartlein (1990)

10 water / ice layers
(variable depth)

Eddy diffusion,
molecular diffusion
& unstable convection

Latent heat released
upon freezing;
ice aggregates at top

10 soil layers

Ebullition

O₂, CH₄

Oxidation
Diffusion

CH₄ Production

C Pool

Saturated

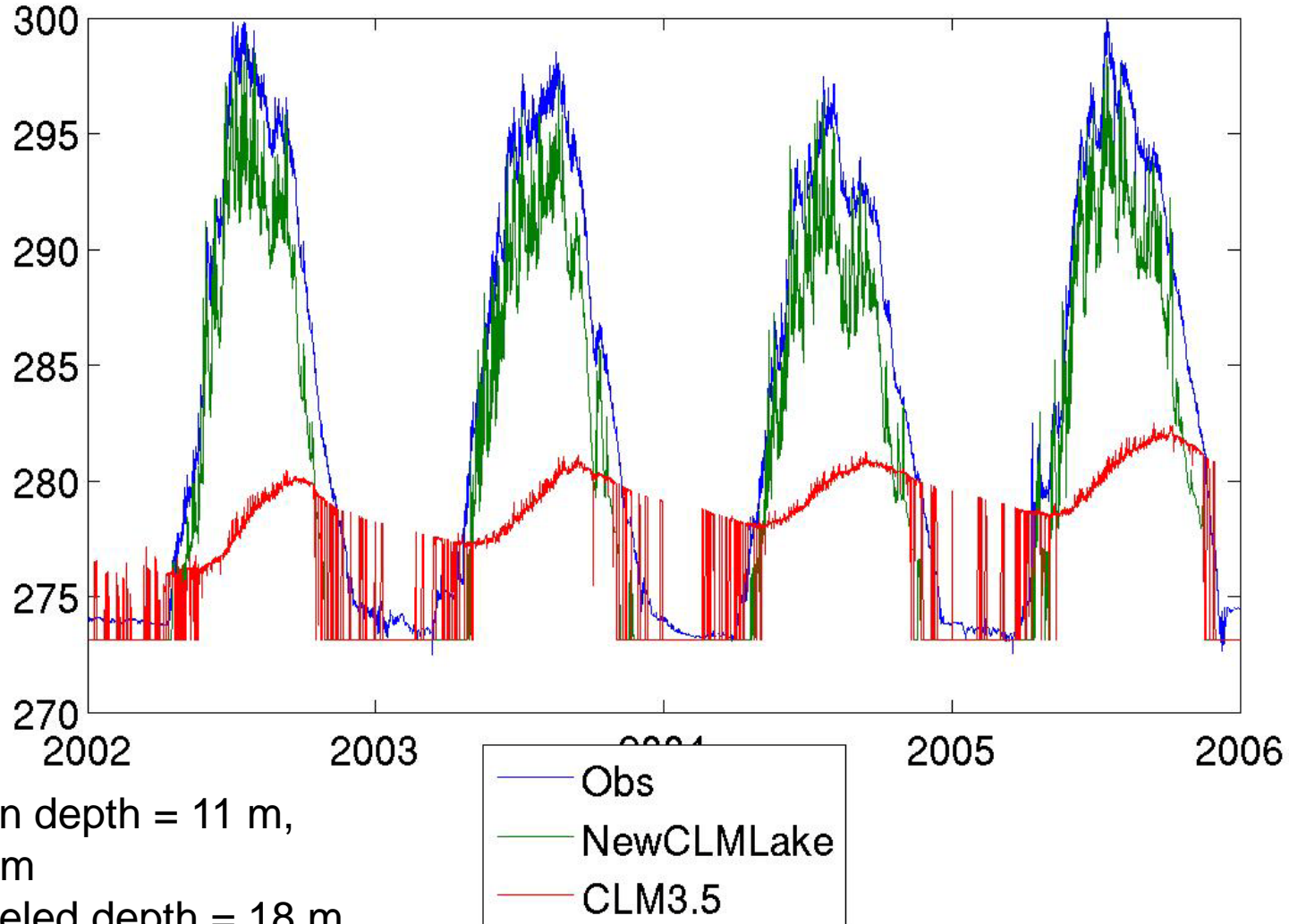
Soil temperature; organic matter
& methane production;
limited soil hydrology
(assumed saturation,
but allowed to freeze and thaw).
Additional 5 bedrock layers.

New Lake Physics

- Ice fraction in each lake layer
- Phase change solved similarly to soil layers
- Lake skin has eddy diffusion and convective mixing with top lake layer
- Heat diffusion includes snow, lake, & soil
- Full CLM 4 snow capabilities over lakes
- Variable lake depth & optics

Sparkling Lake @ 5 cm

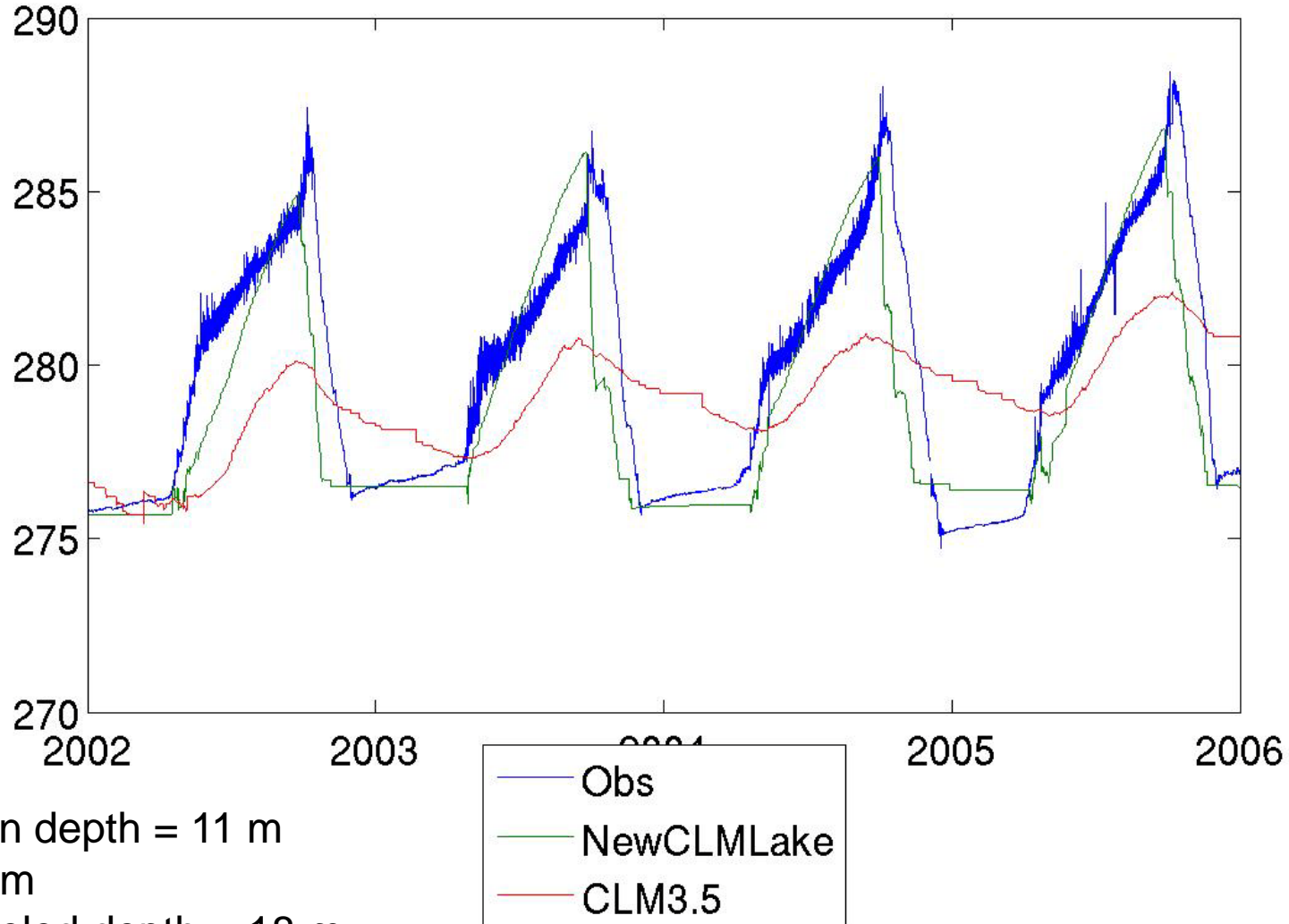
Lake Top Layer Temperature (K) Timeseries (Truncated for $T \geq 0\text{C}$)



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

Sparkling Lake @ 10m

Lake 10m Timeseries (K)



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

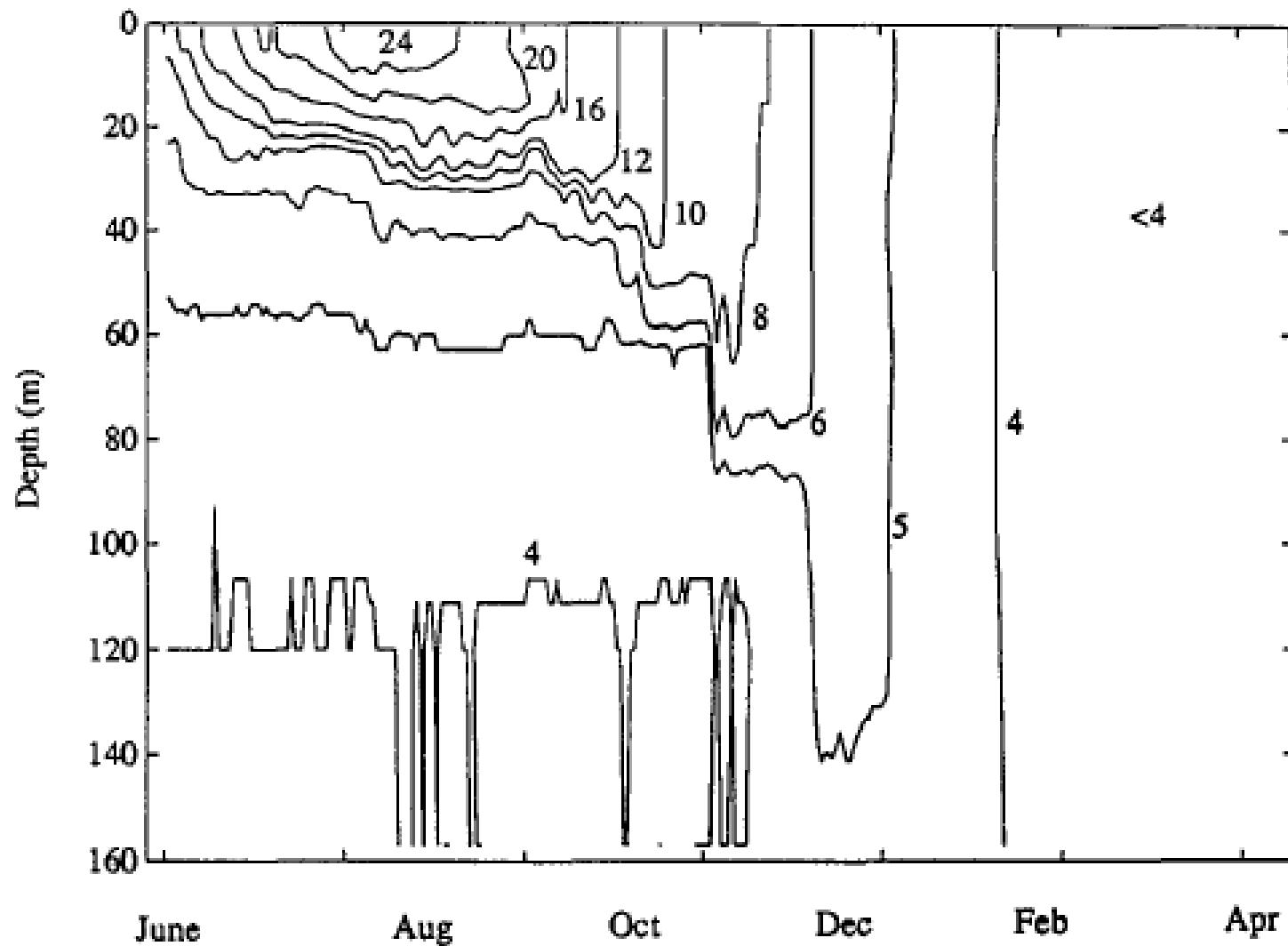
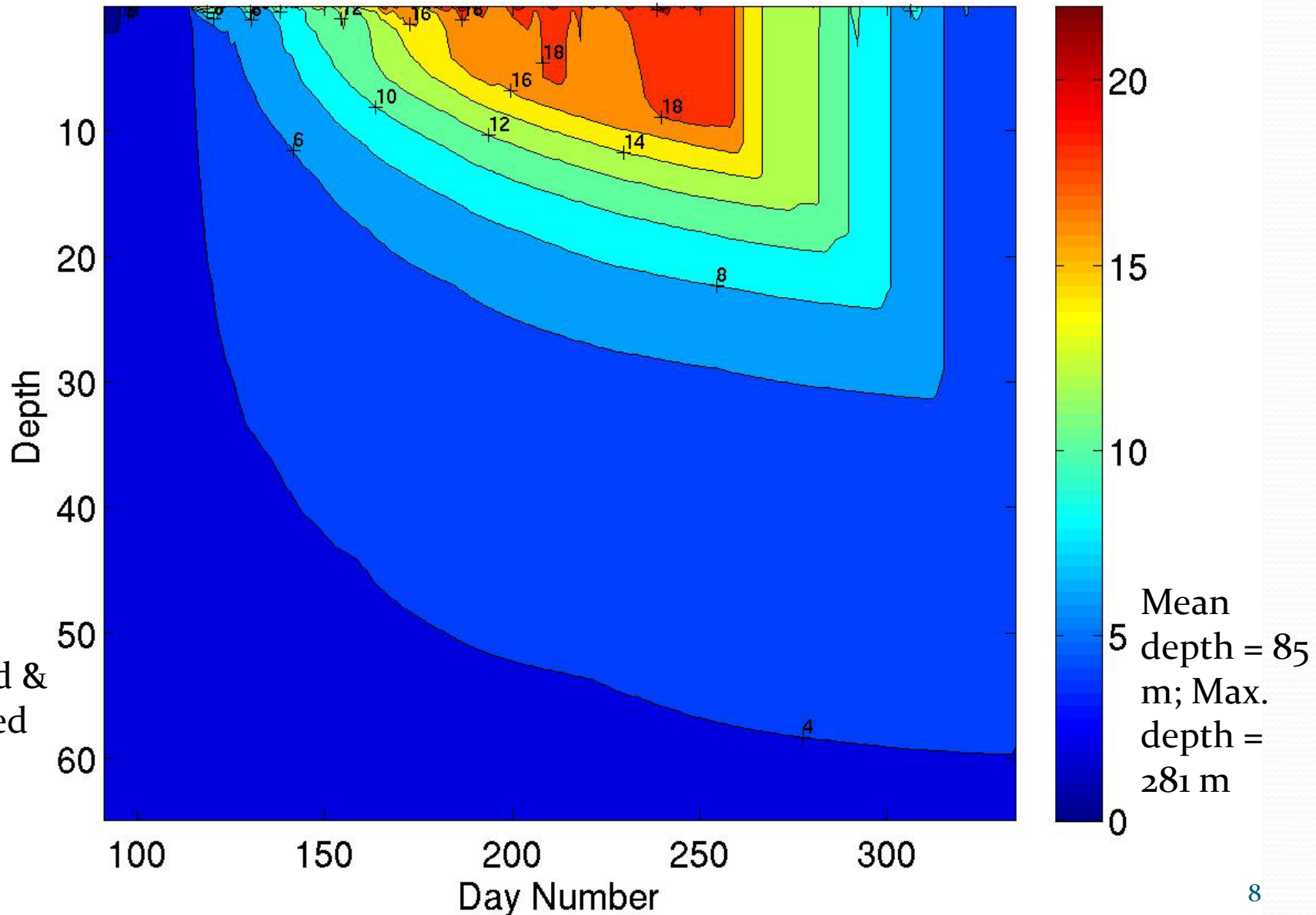


Fig. 2. Temperature contours for the offshore waters of Lake Michigan from 7 June 1990 through 18 April 1991. Contours were generated from daily averaged data.

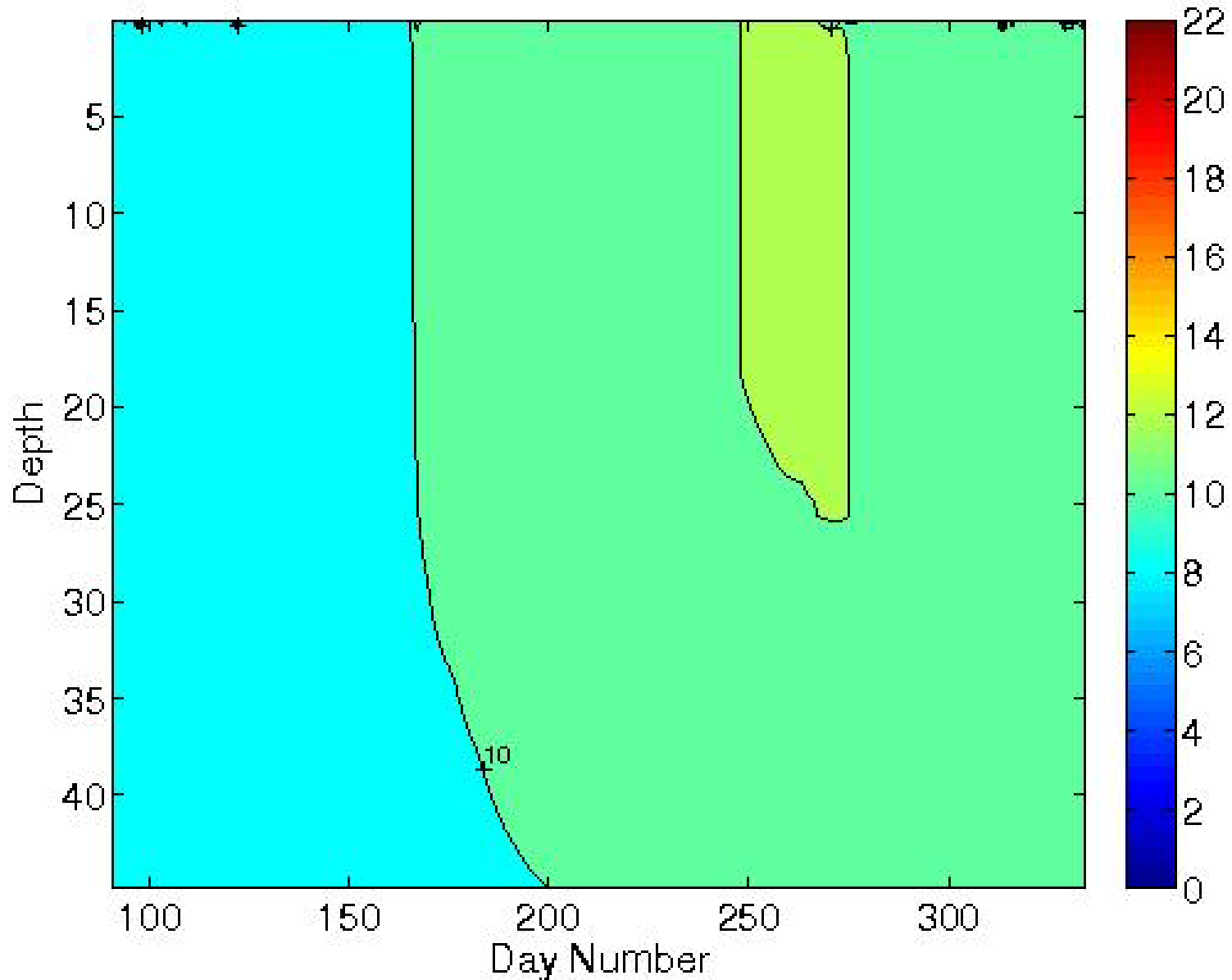
Lake Michigan, Apr-Nov 1990, New Lake Model

Lake Michigan Temperature (C), 1990, Apr-Nov



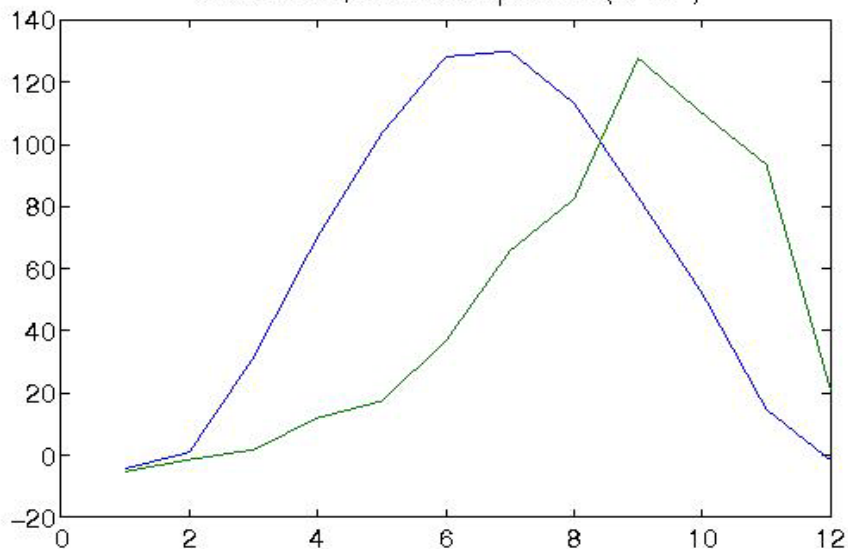
Lake Michigan, Apr-Nov 1990, CLM 3.5

Lake Michigan Temperature (C), 1990, Apr-Nov

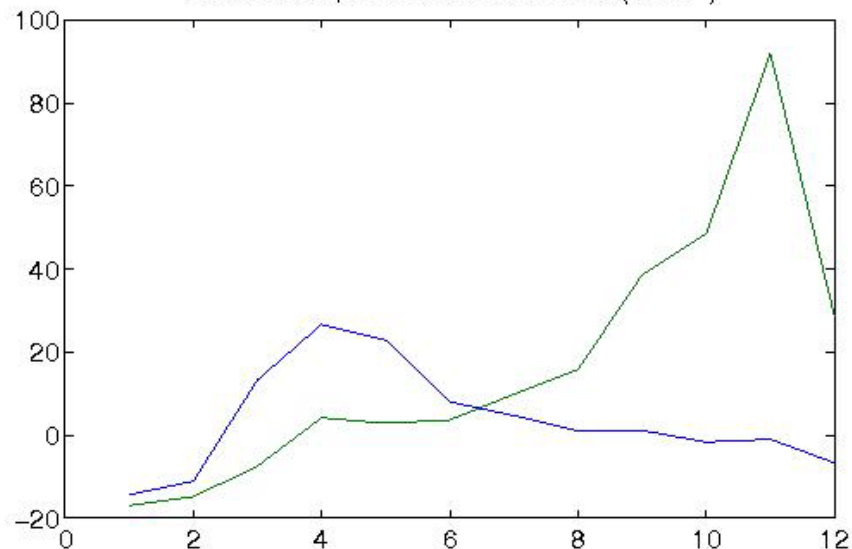


Uncoupled CLM 3.5, 24 yr, Great Lakes Fluxes

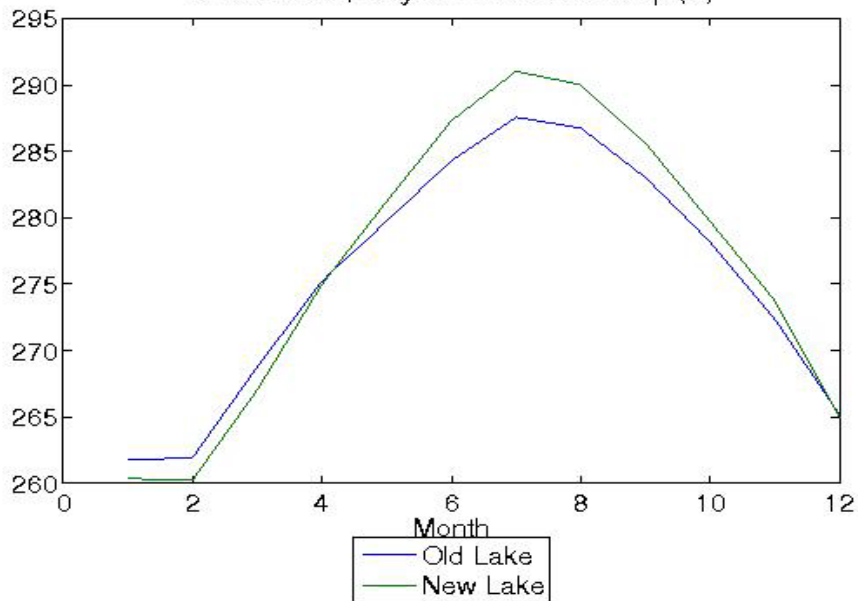
Great Lakes, Ground Evaporation ($W m^{-2}$)



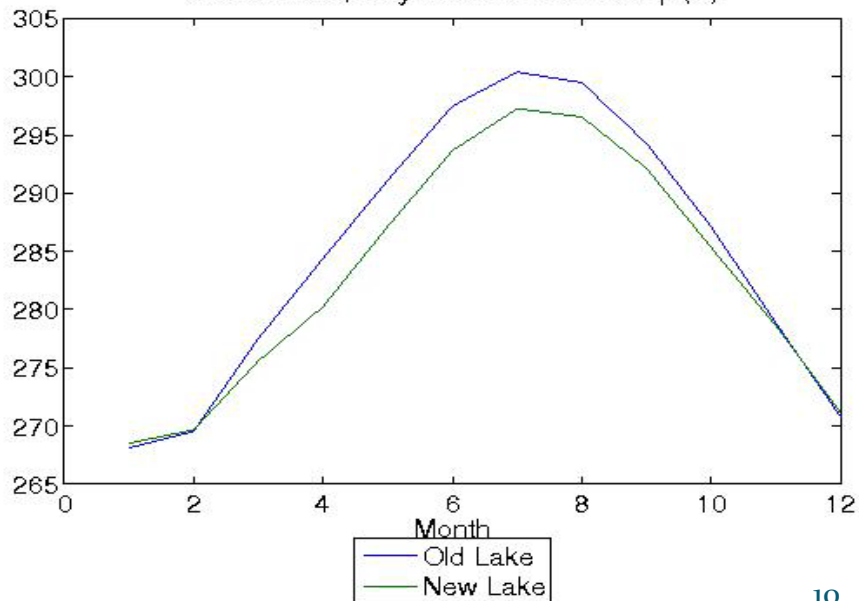
Great Lakes, Ground Sensible Heat ($W m^{-2}$)



Great Lakes, Daily Minimum 2 m Temp (K)



Great Lakes, Daily Maximum 2 m Temp (K)



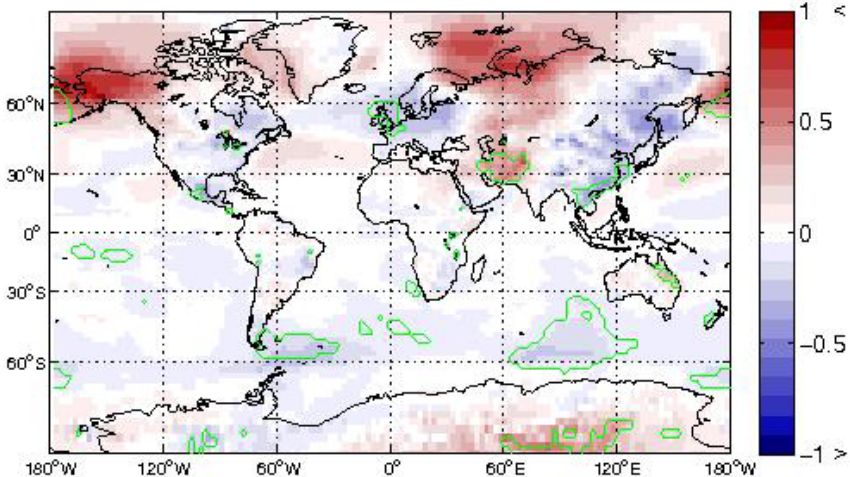
Effects of Lake Model on Year 2000 Climate in CCSM

- New – Old Lake Model in CLM-CAM 4 with slab ocean
- **New Lake Model with 0.7M km⁻² vs. 2.9M km⁻² Lake Area**

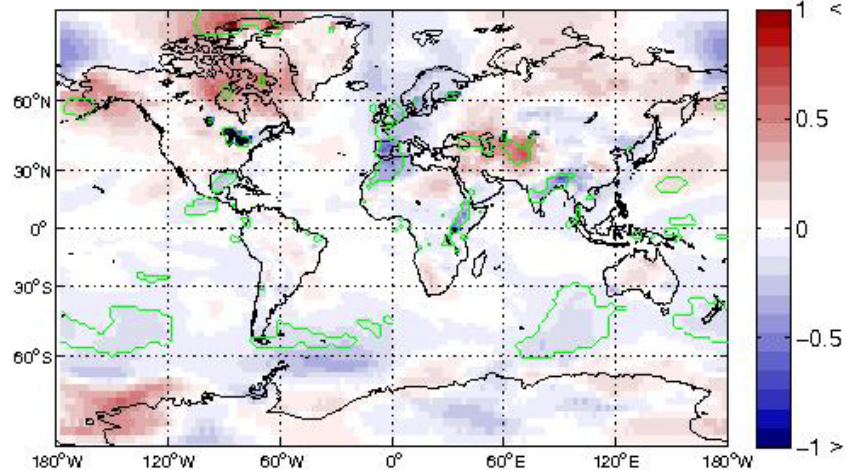
CAM-CLM4, 100 yr, New – Old Lake

Daily Max. Surf. Air Temp. (C)

DJF, Daily Max. Surf. Air Temp., (C)

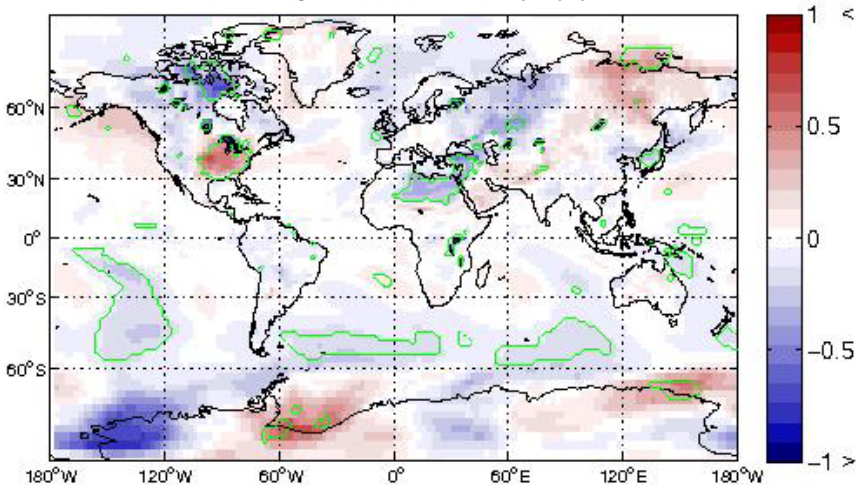


MAM, Daily Max. Surf. Air Temp., (C)

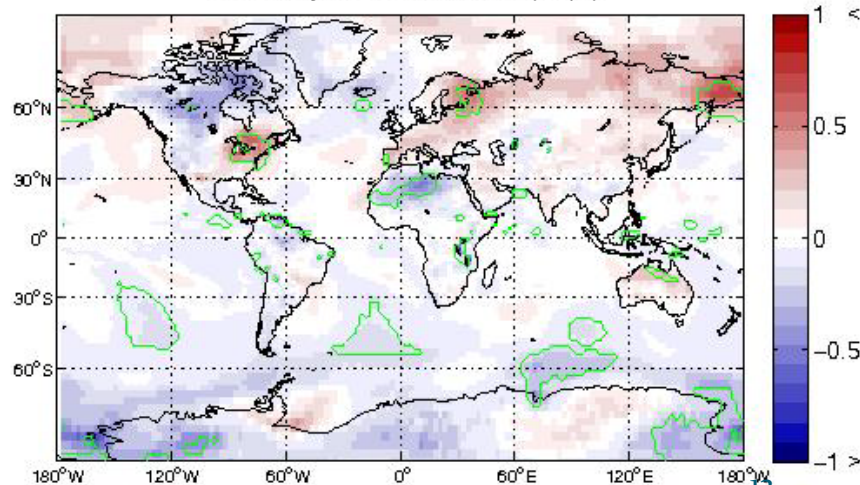


Green contours = significance at 5%

JJA, Daily Max. Surf. Air Temp., (C)



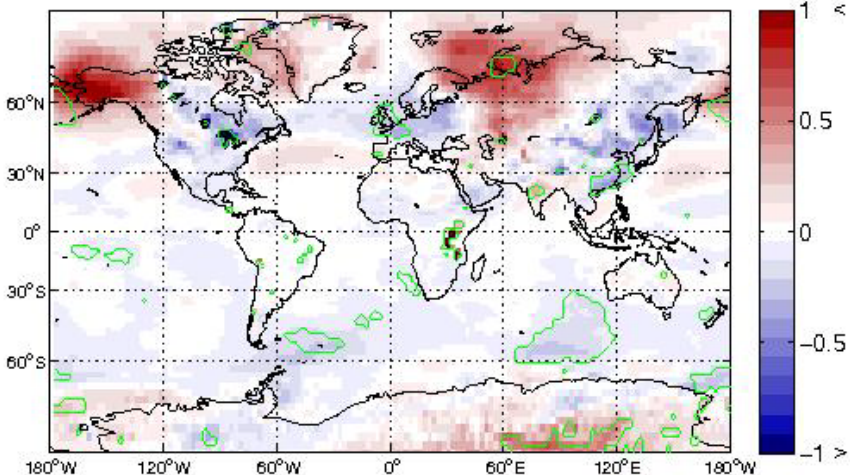
SON, Daily Max. Surf. Air Temp., (C)



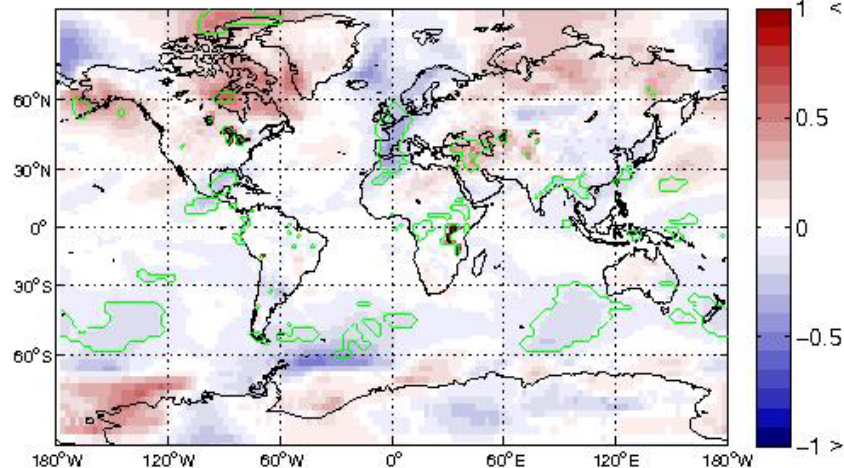
CAM-CLM4, 100 yr, New – Old Lake

Daily Min. Surf. Air Temp.(C)

DJF, Daily Min. Surf. Air Temp., (C)

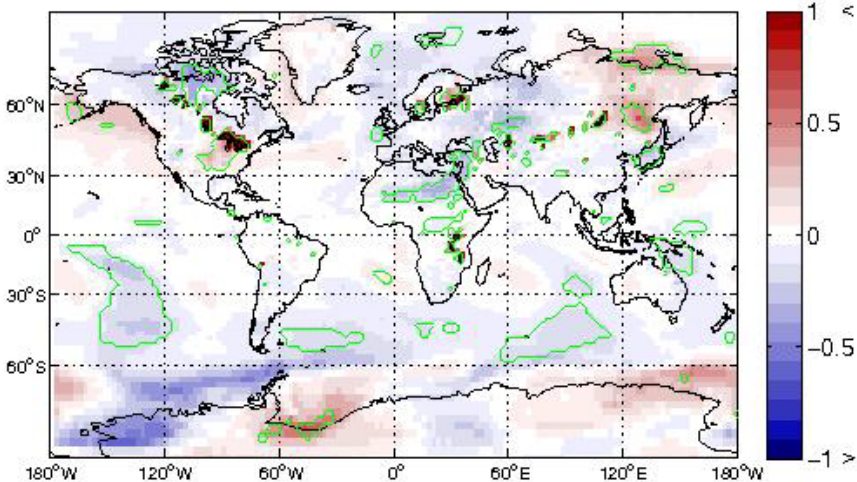


MAM, Daily Min. Surf. Air Temp., (C)

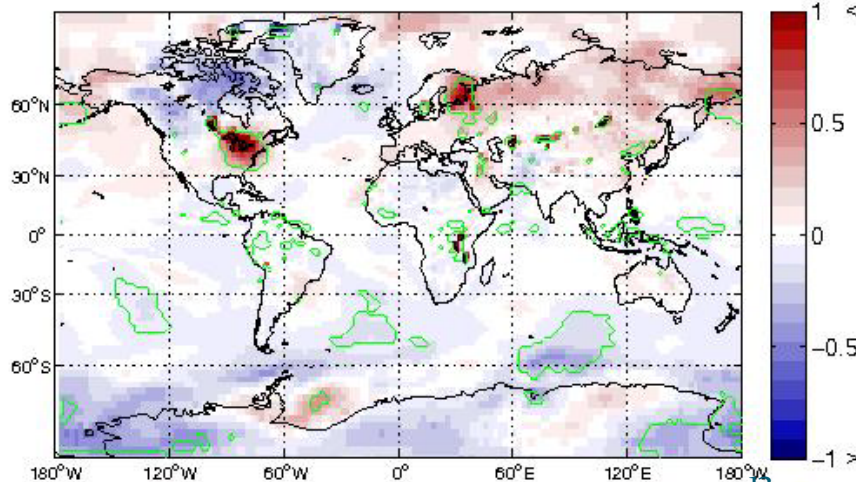


Green contours = significance at 5%

JJA, Daily Min. Surf. Air Temp., (C)

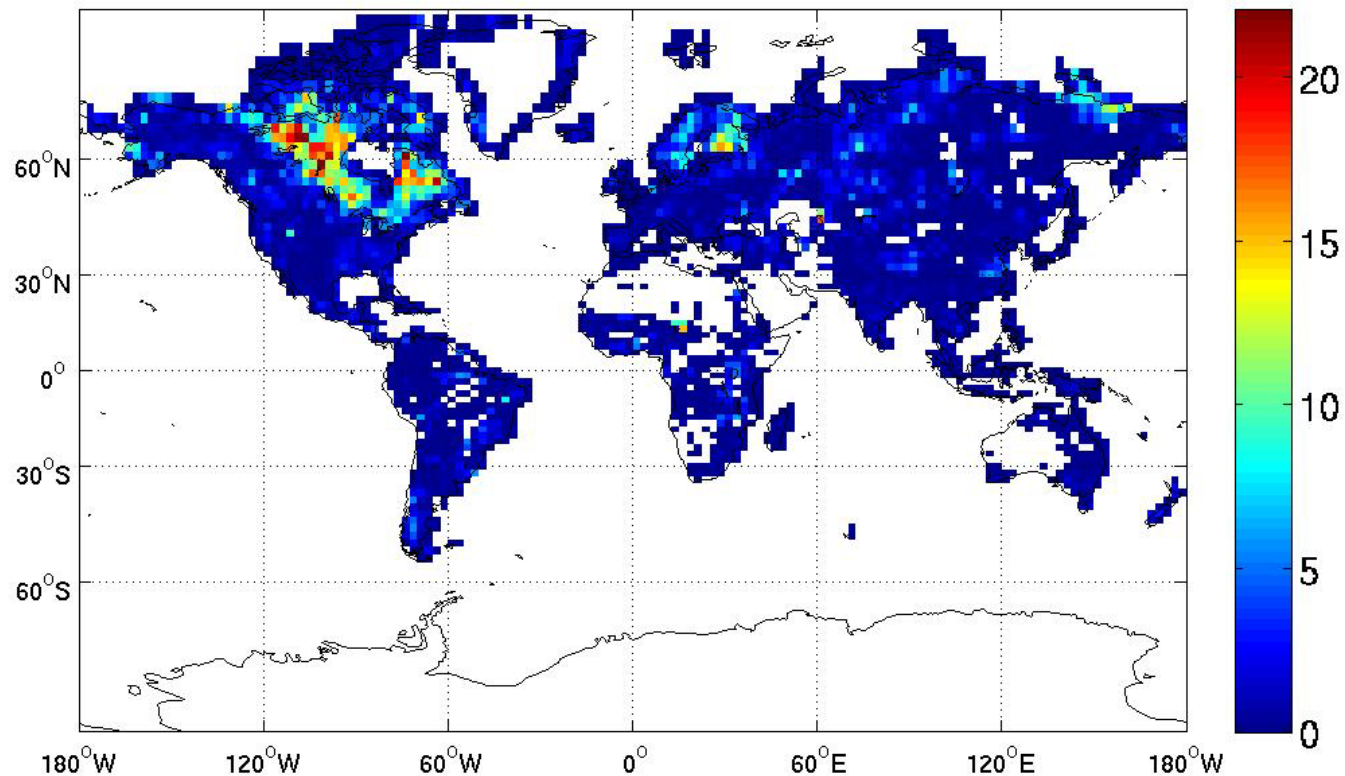


SON, Daily Min. Surf. Air Temp., (C)



Low Estimate of Missing (Small) Lake Area in CCSM 4 from GLWD

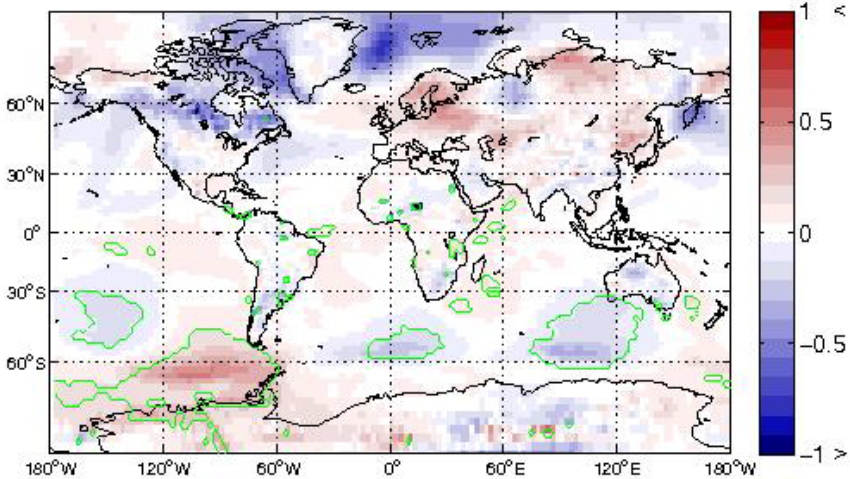
Additional Gridcell Percent Lake Area (2.2M km²)



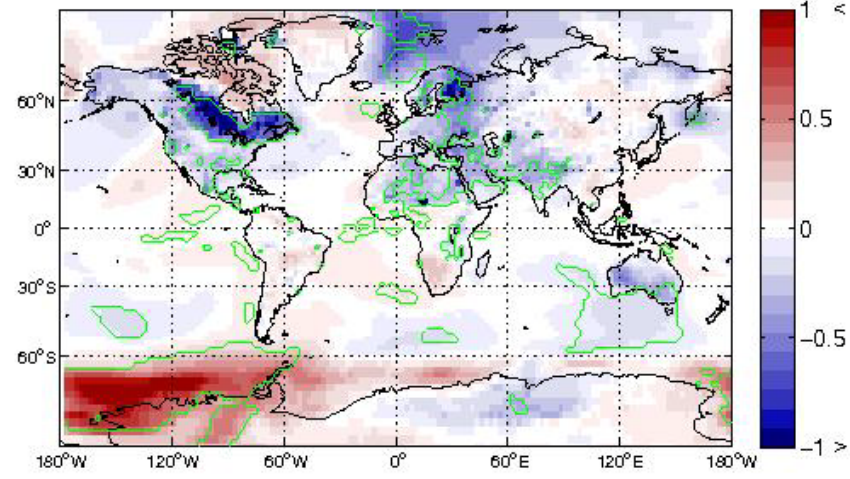
CAM-CLM4, 100 yr, High – Low Lake Area

Daily Max. Surf. Air Temp. (C)

DJF, Daily Max. Surf. Air Temp., (C)

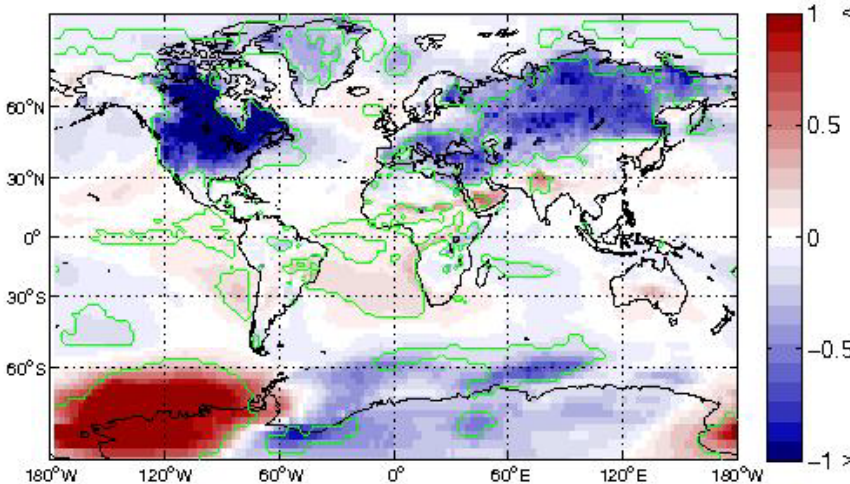


MAM, Daily Max. Surf. Air Temp., (C)

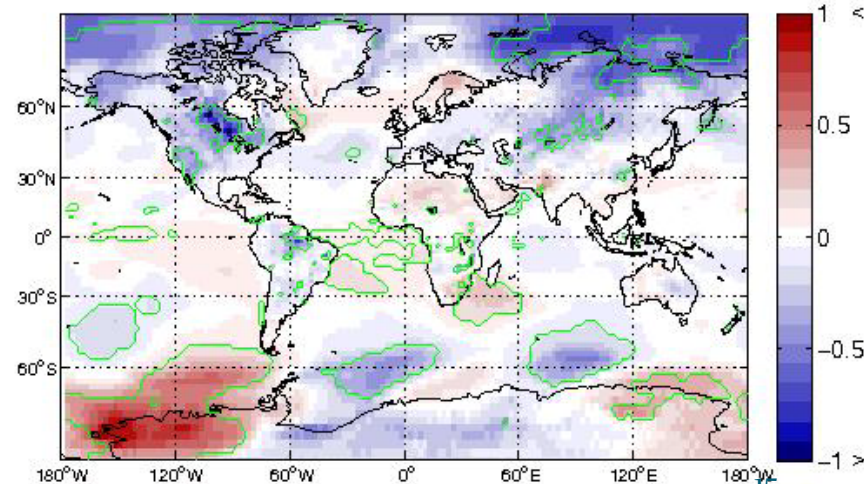


Green contours = significance at 5%

JJA, Daily Max. Surf. Air Temp., (C)



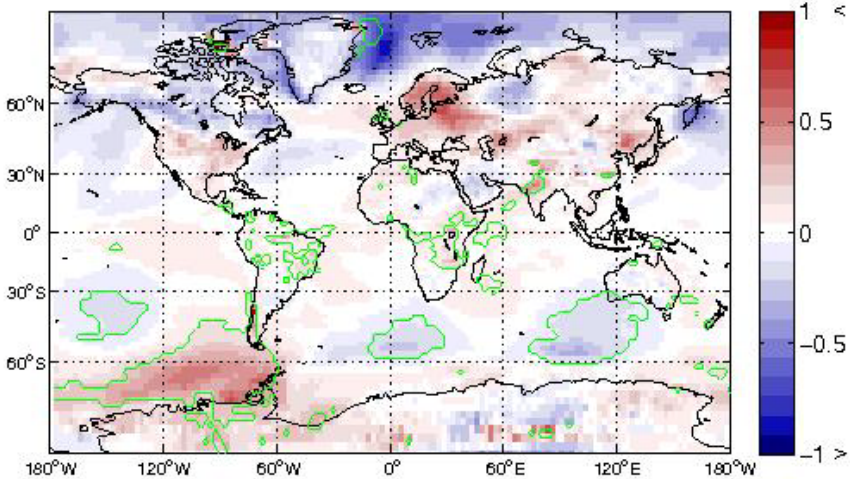
SON, Daily Max. Surf. Air Temp., (C)



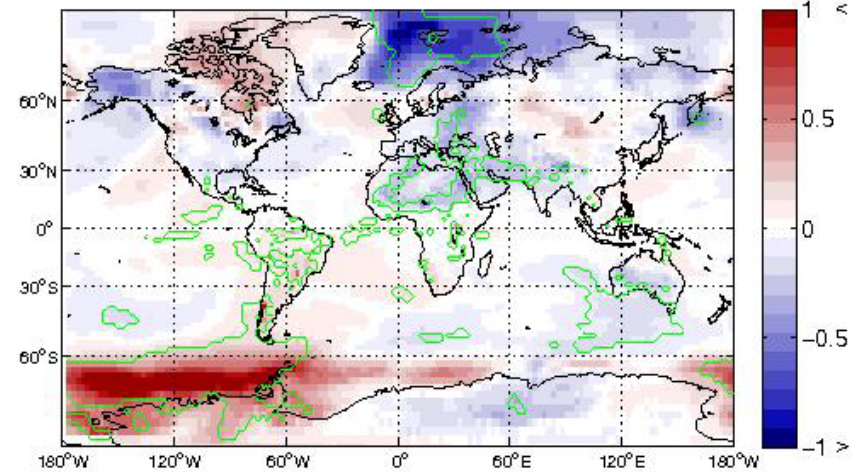
CAM-CLM4, 100 yr, High – Low Lake Area

Daily Min. Surf. Air Temp. (C)

DJF, Daily Min. Surf. Air Temp., (C)

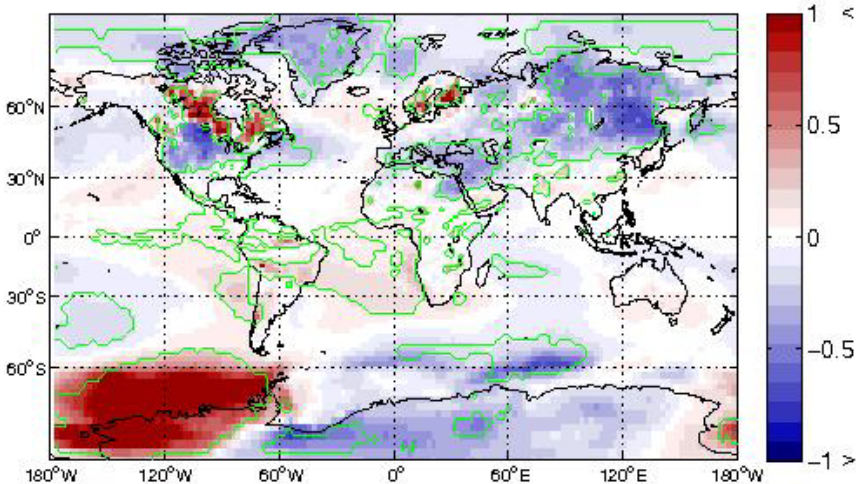


MAM, Daily Min. Surf. Air Temp., (C)

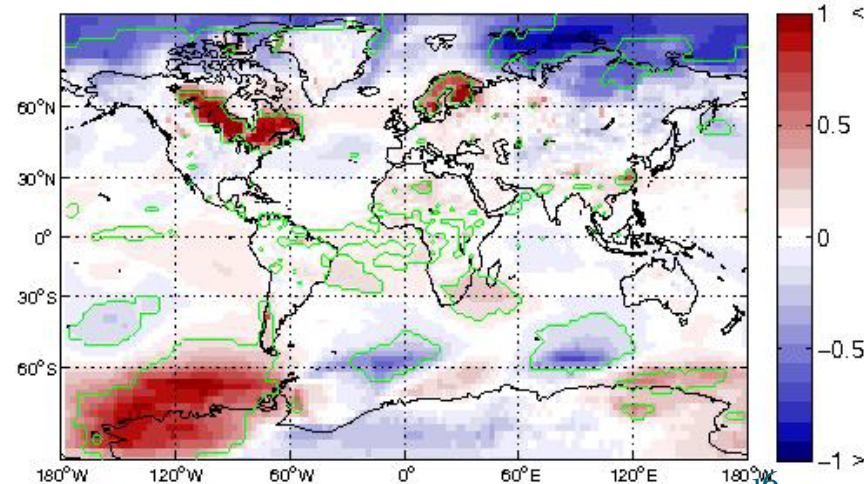


Green contours = significance at 5%

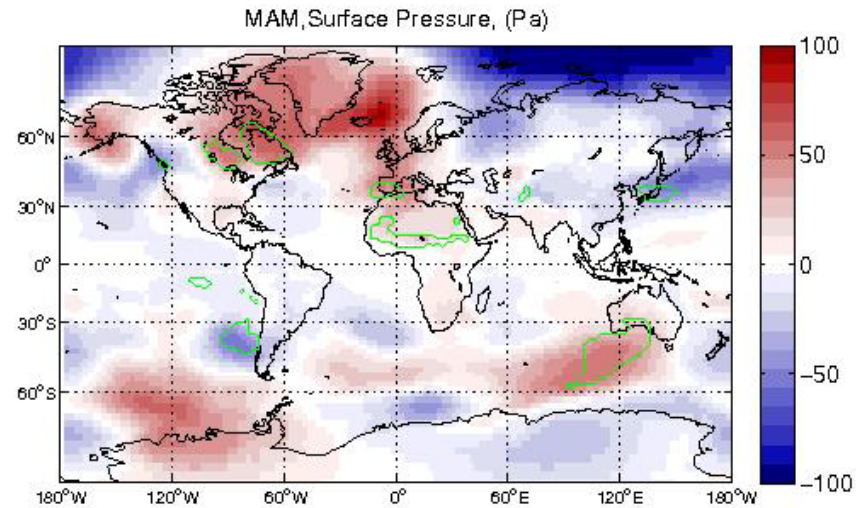
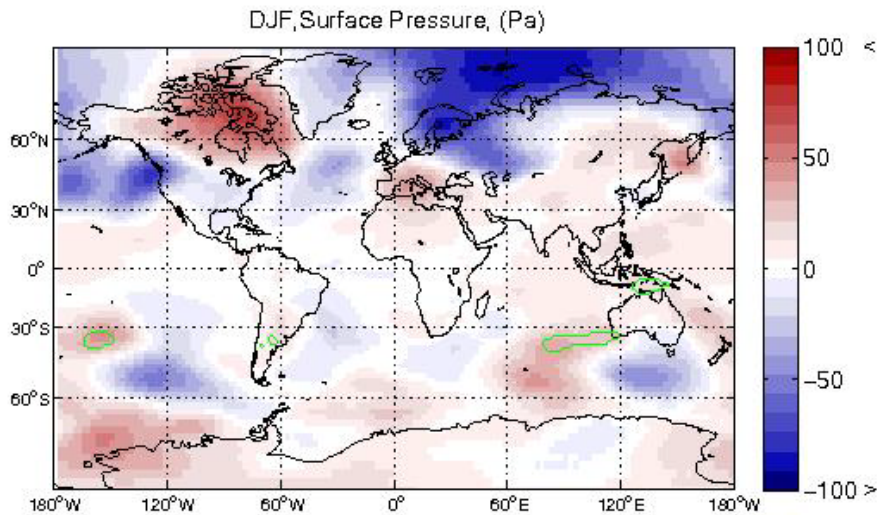
JJA, Daily Min. Surf. Air Temp., (C)



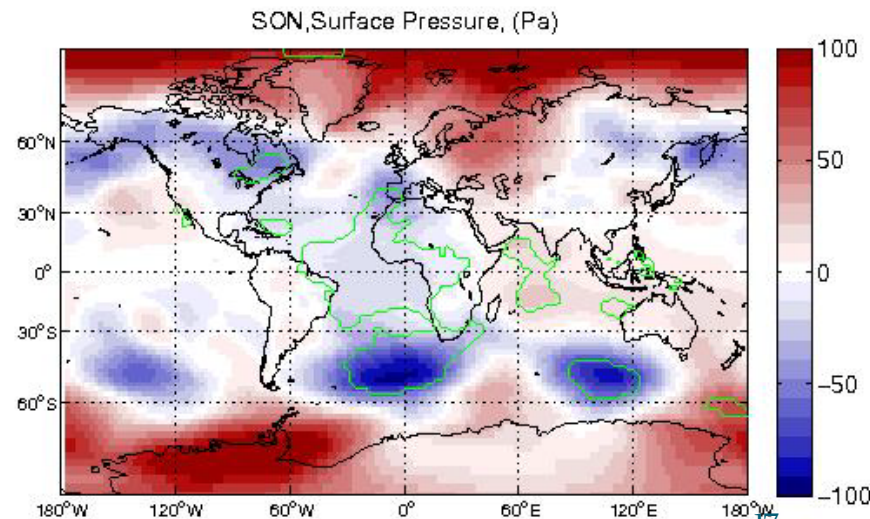
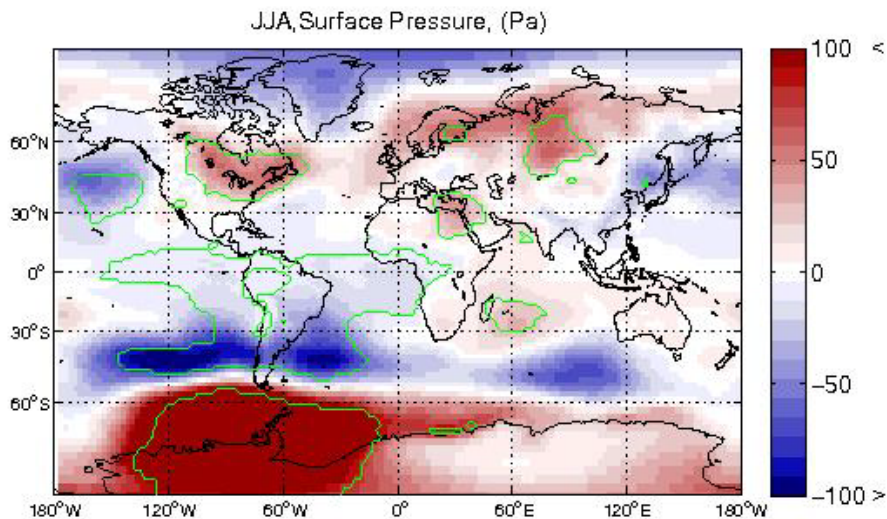
SON, Daily Min. Surf. Air Temp., (C)



CAM-CLM4, 100 yr, High – Low Lake Area Surface Pressure (Pa)



Green contours = significance at 5%



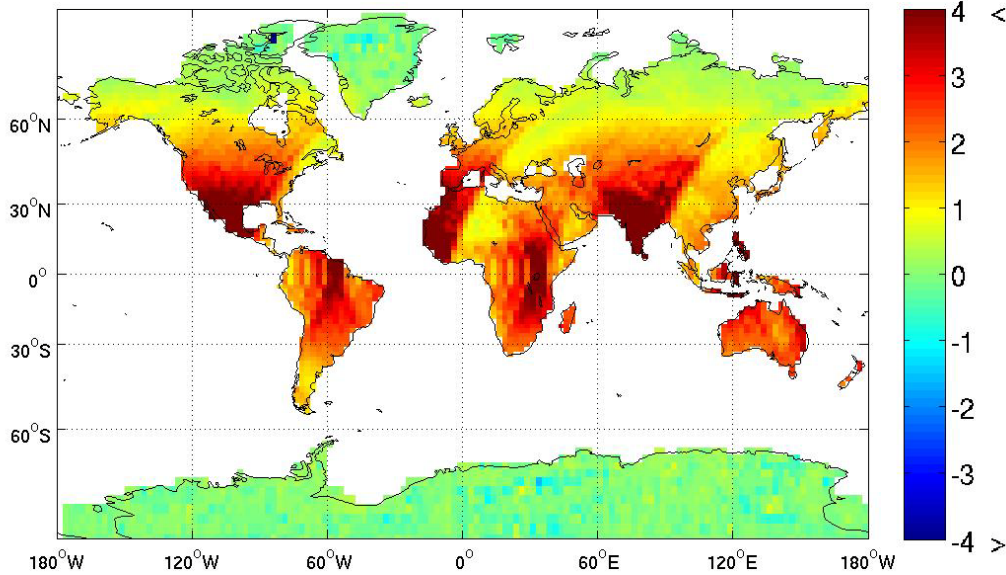
Conclusions

- A new CCSM 4 lake model substantially improves representation of lakes across climates and geometries.
- The new lake model changes offline gridcell surface fluxes by up to 100 W/m^2 .
- Surface fluxes are sensitive to lake optics and lake depth, which vary widely between real lakes.

Conclusions (cont'd)

- CCSM 4 may have regional (e.g. Great Lakes) biases because the current lake model is poor.
- CCSM 4 may have substantial biases in Canada and other regions with high lake area, because of insufficient lake area.
- The underestimation of lake area may influence the climate of remote locations (e.g. Southern Ocean).

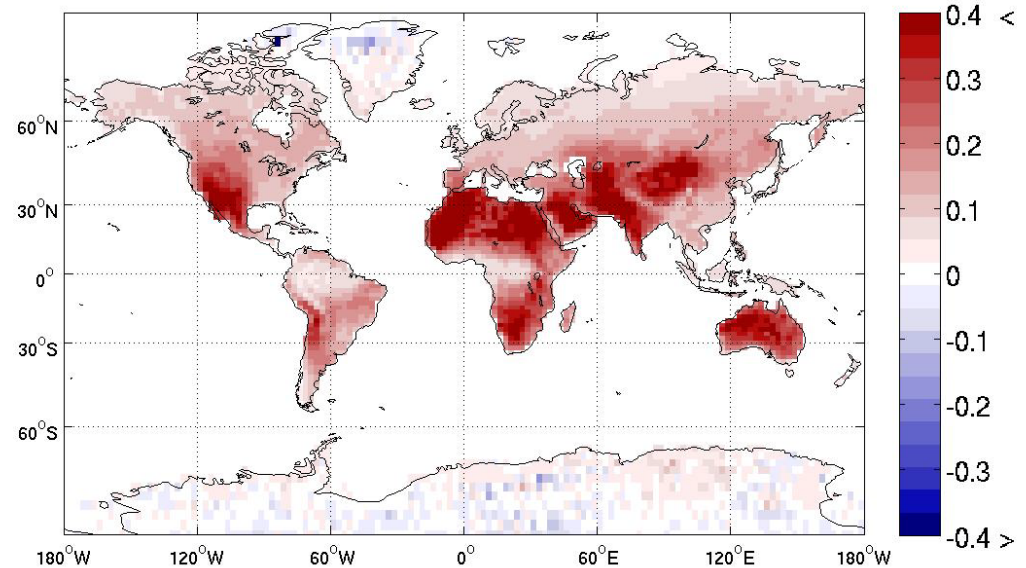
Absorbed Shortwave, 1800s dt - 600s dt, $W m^{-2}$, Truncated



Addendum: High CLM Timestep Sensitivity

Discretization error in
evaluation of zenith
angle?

Ground T, 1800s dt - 600s dt, C, Truncated



Acknowledgements

- Margaret Torn (LBNL / UC-Berkeley) and David Lawrence (NCAR)
- Andrey Martynov (UQAM)
- Funding from DOE & LBNL