Improved Lake Model for CLM 4

Zack Subin
Bill Riley
Celine Bonfils

Land Model Working Group Meeting, NCAR
2/8/10

Work Funded by DOE and Lawrence Berkeley National Lab

Outline

- Motivation
- Deficiencies in CLM 3.5 / CLM 4 Lake Model
- Schematic of New Lake Model
- Comparison to Site Data
- Offline North America Flux Anomalies
- Feedbacks to Global Climate in CLM-CAM 4

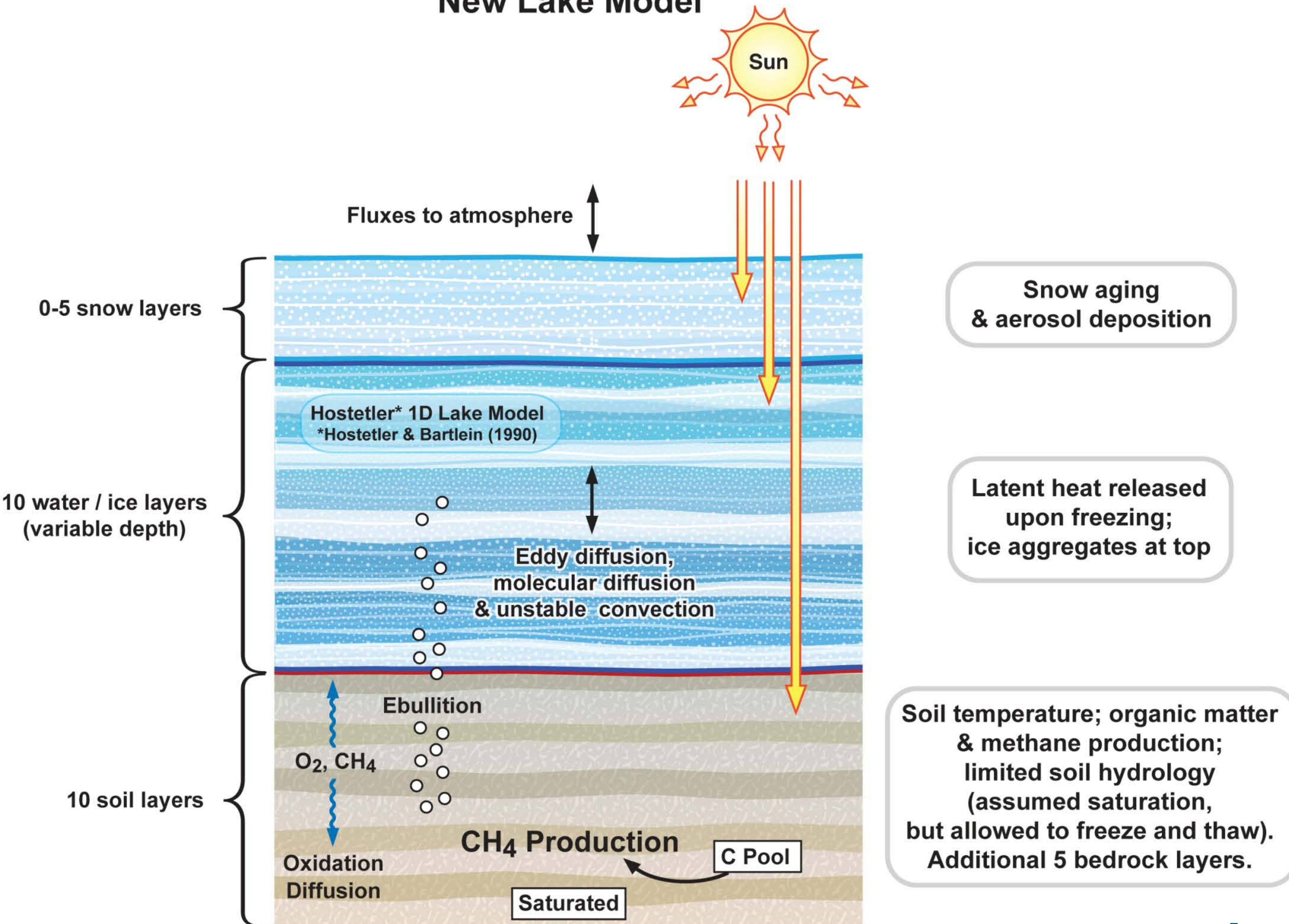
Motivation: Thermokarst Lakes

- Modeling with IMPACTS Arctic Boreal Abrupt Climate Change Group
- Deepened by thaw subsidence, with expansion mediated by wind, waves, and gravity-induced erosion
- Expanding lakes often have an unfrozen volume of soil (talik) below them
- Taliks can undergo extensive organic decomposition, releasing CO_2 and CH_4
- Lakes increase thawing rates in their surroundings

Deficiencies in CLM 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; no soil layers beneath lake
- No convection beneath frozen lake surfaces
- 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



New Lake Physics

- Each lake layer has an ice fraction that is used in calculating thermal properties
- Phase change done similarly to that done in soil layers: first do heat diffusion ignoring phase change, and correct for phase change
- Lake skin has eddy diffusion and convective mixing with top lake layer
- Heat diffusion solved using Crank-Nicholson / Tridiagonal solution over full 20-30 layers of snow, lake, & soil (with option for extra 15 lake layers)

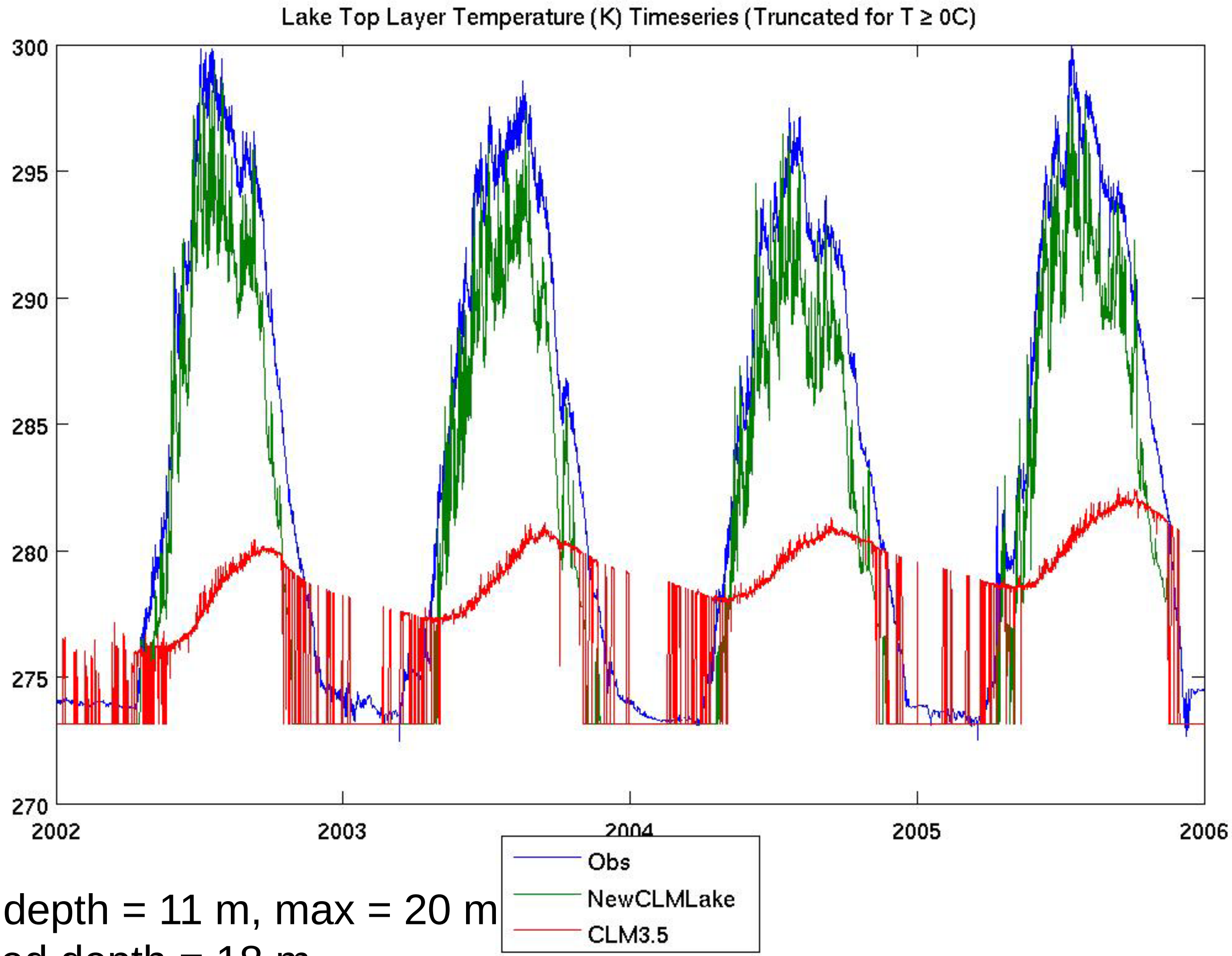
New Lake Physics (cont'd)

- Full CLM 4 snow capabilities over lakes
  - Temperature, water & ice content, & thickness for up to 5 layers
  - Snow compaction, aging, partial transmissivity, & aerosol deposition
- Radiation is allowed to reach top soil layer for unfrozen lakes
- Energy balance check includes effects of phase change & convection on heat capacity
- Extinction coefficient depends on depth (based on empirical regression), and top layer absorption fraction based on incoming NIR
- Gridcell lake depth optionally defined in surface data

Evaluation

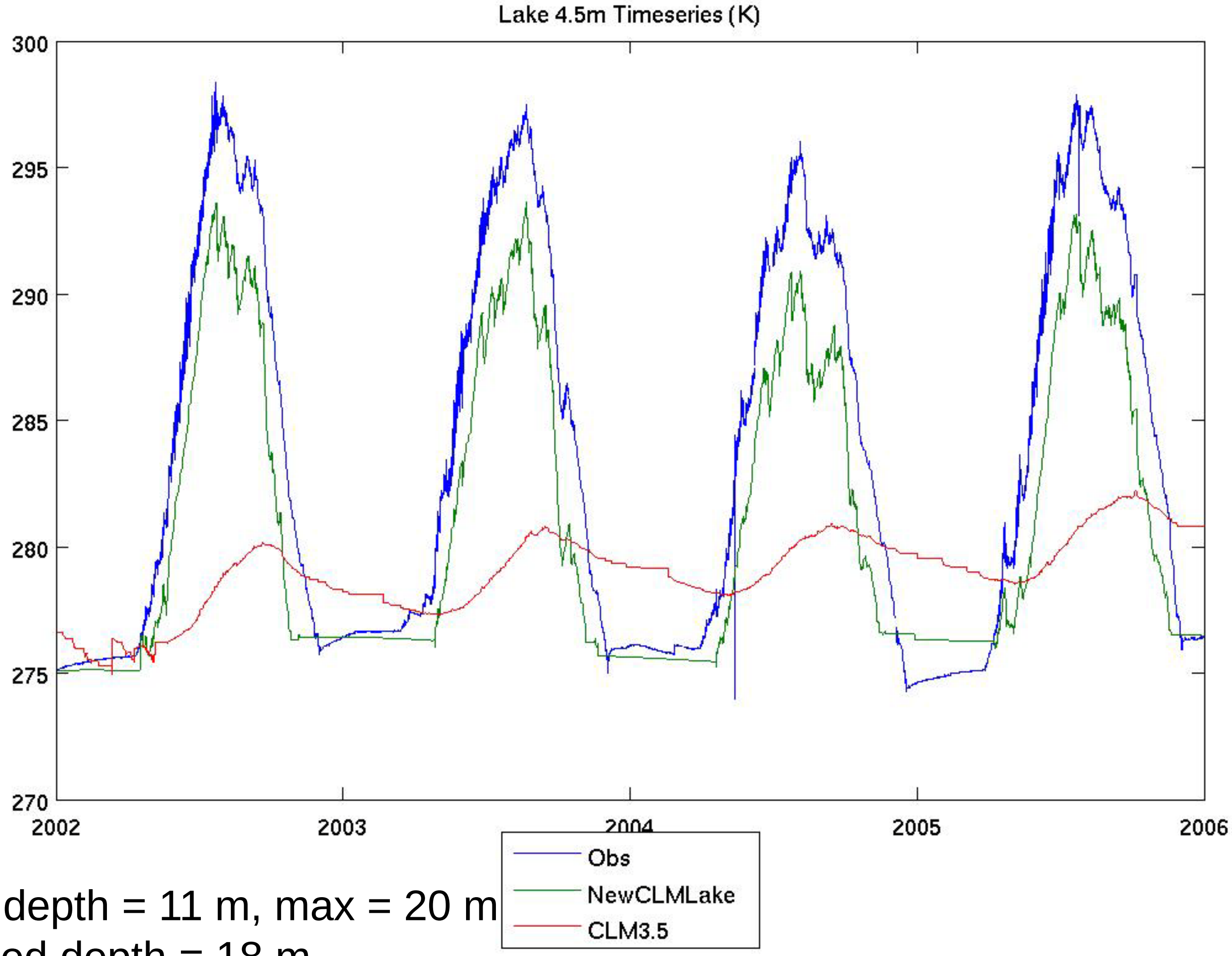
- 4 year hourly lake water temperature and meteorological forcing record for Sparkling Lake, WI
- ~10 other lakes of varying depths & climate zones tested with NCEP gridscale forcing
- New model (but not old) captures vertical and seasonal patterns, and agrees with surface temperature to $\pm 3^{0}$C
- Insufficient bottom mixing for very deep lakes consistent with other Hostetler Lakes
- Summer stratification for shallow lakes dependent on lake optics, which vary widely in real lakes

Sparkling Lake @ 5 cm



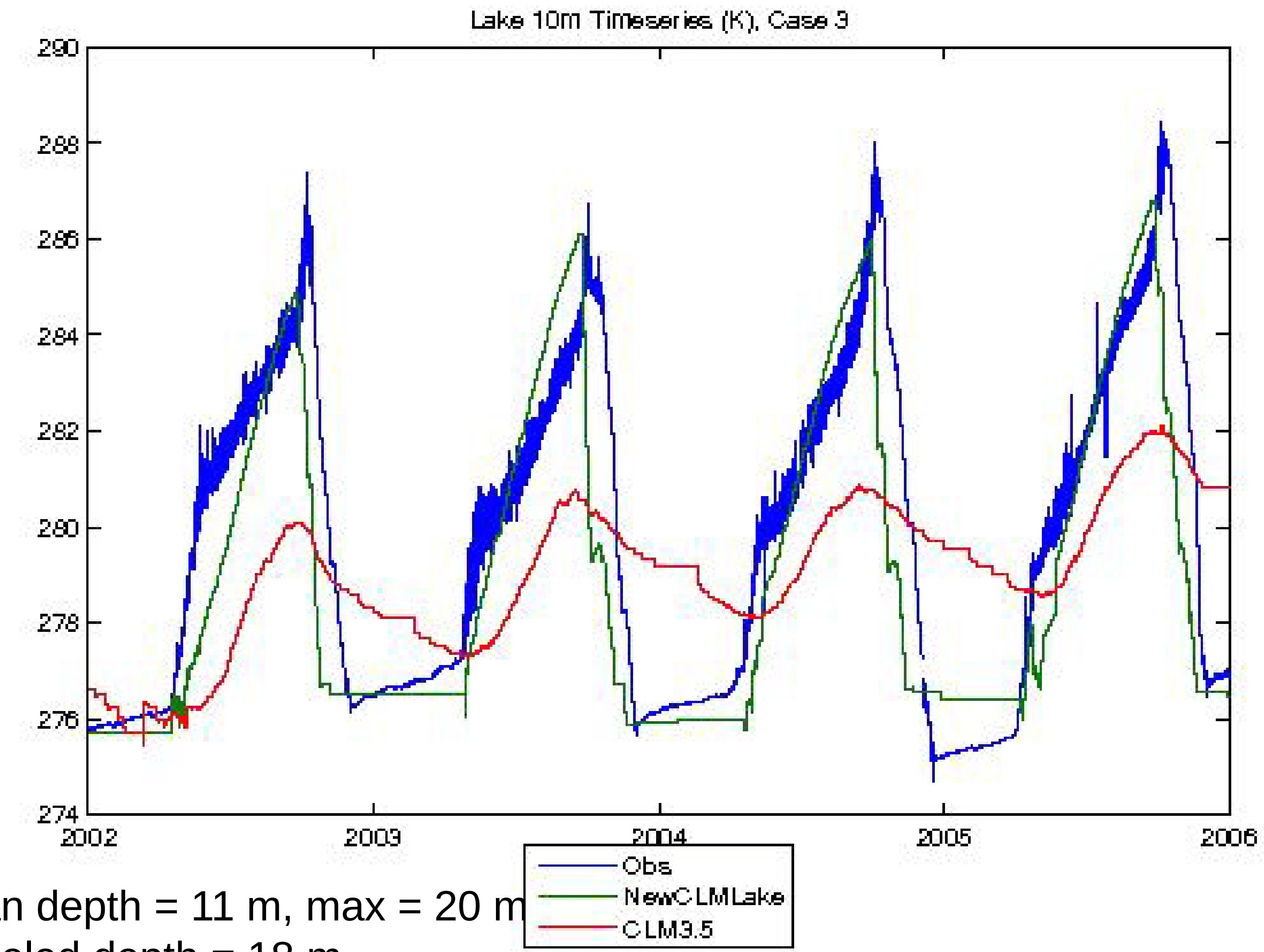
Lake mean depth = 11 m, max = 20 m
Lake modeled depth = 18 m
Temp. probe depth = 18 m

Sparkling Lake @ 4.5m



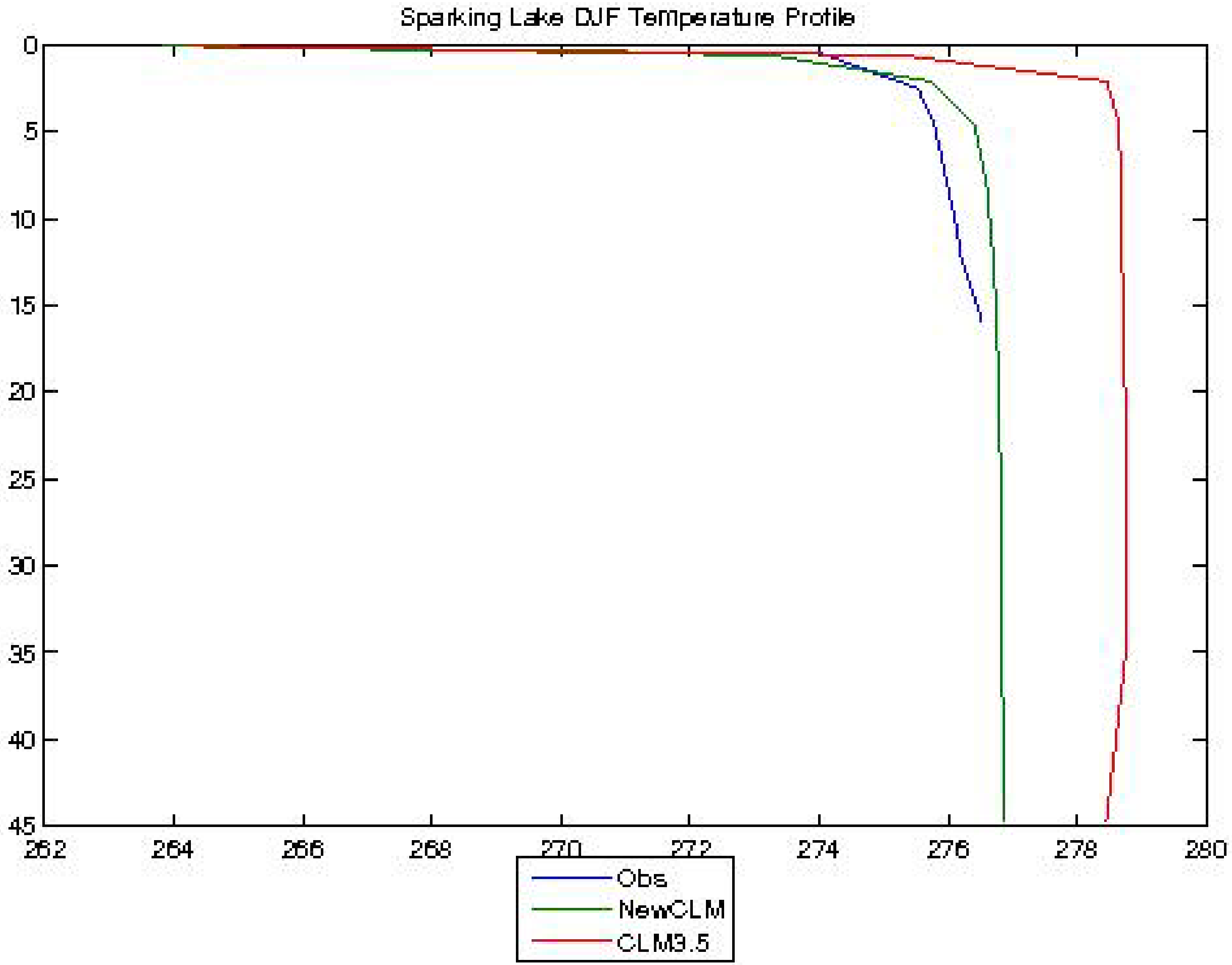
Lake mean depth = 11 m, max = 20 m
Lake modeled depth = 18 m
Temp. probe depth = 18 m

Sparkling Lake @ 10m

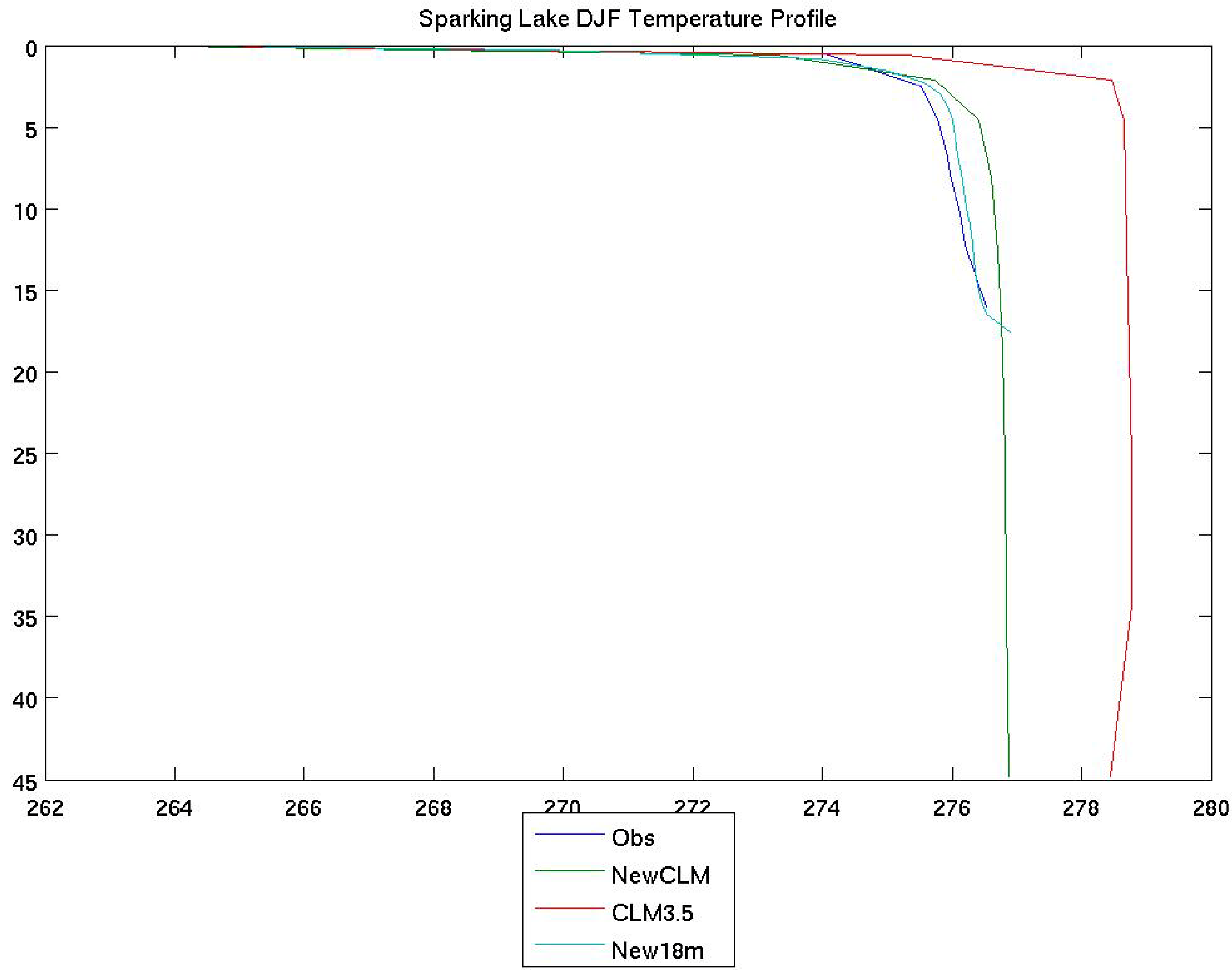


Lake mean depth = 11 m, max = 20 m
Lake modeled depth = 18 m
Temp. probe depth = 18 m

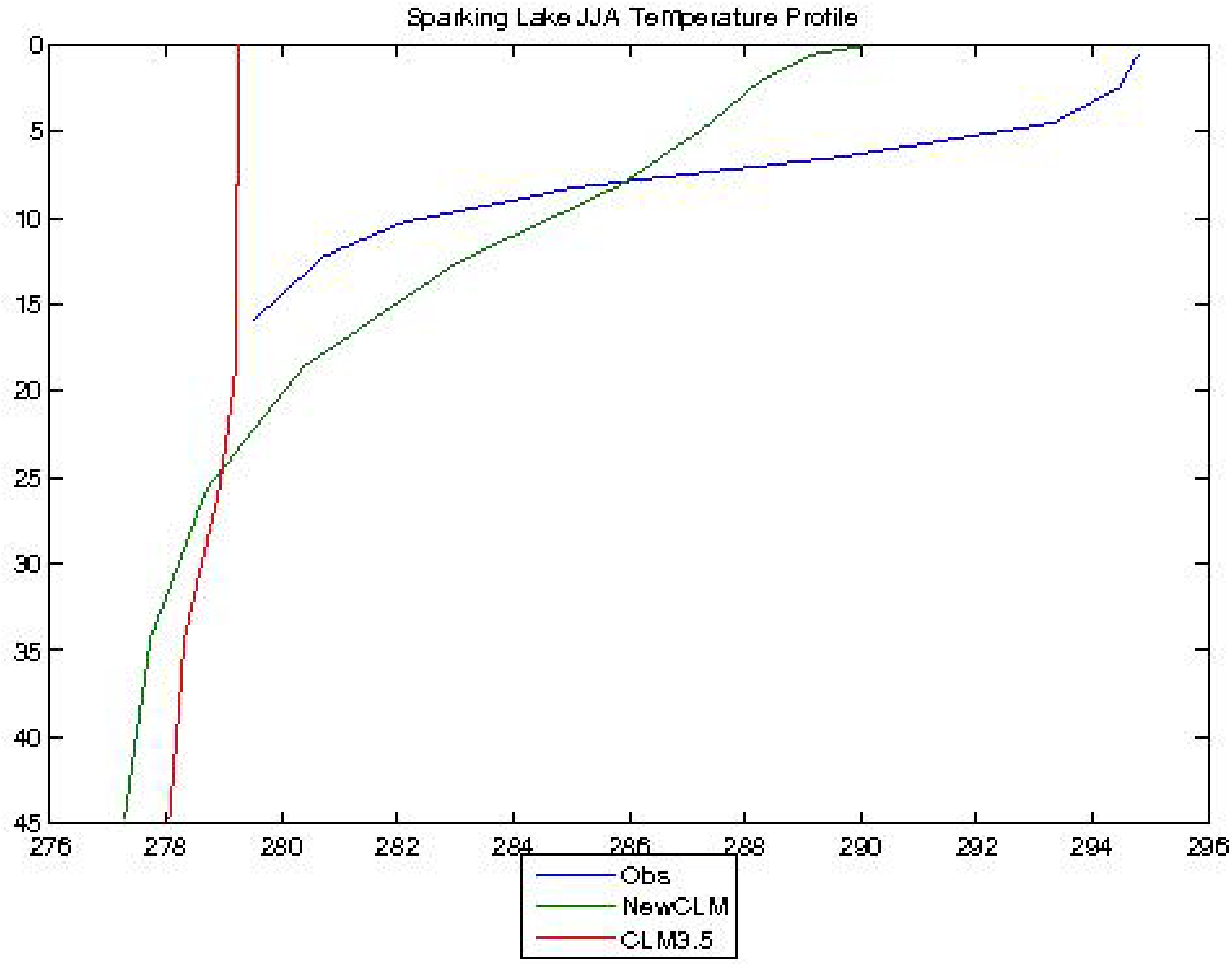
Sparkling Lake w/ 50m depth & original optics, DJF Profile



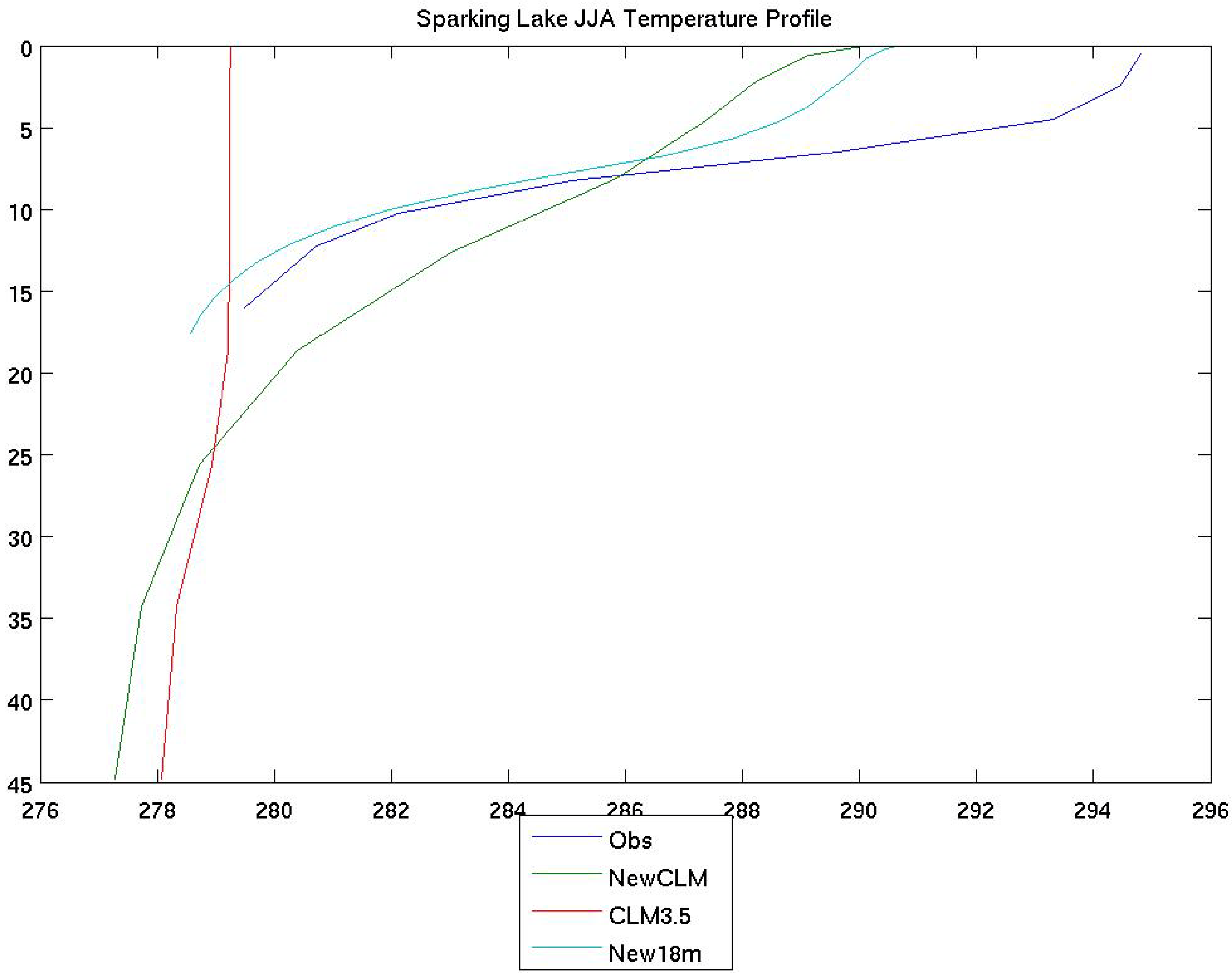
Sparkling Lake w/ 50m depth & original optics, DJF Profile



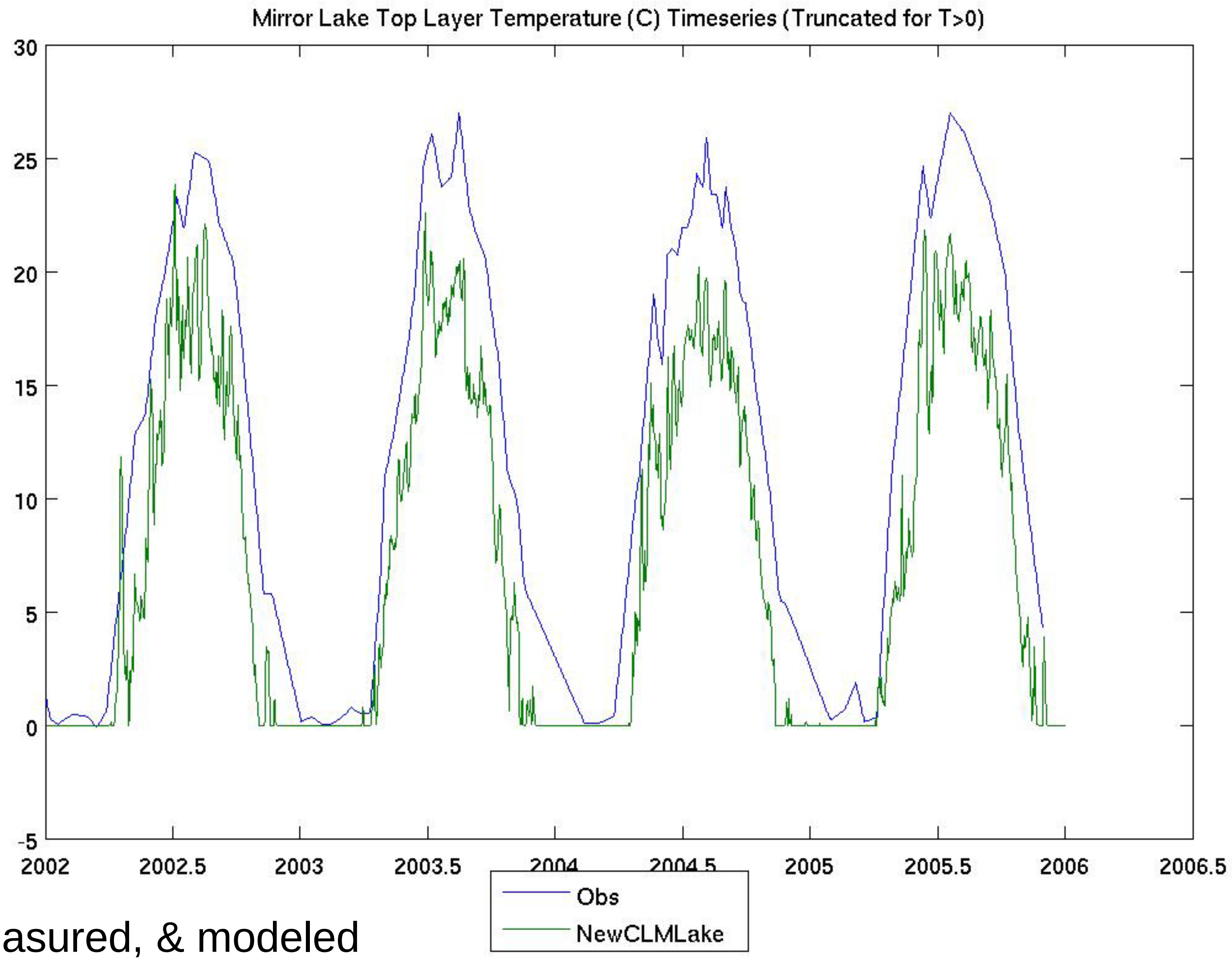
Sparkling Lake w/ 50m depth & original optics, JJA Profile



Sparkling Lake w/ 50m depth & original optics, JJA Profile

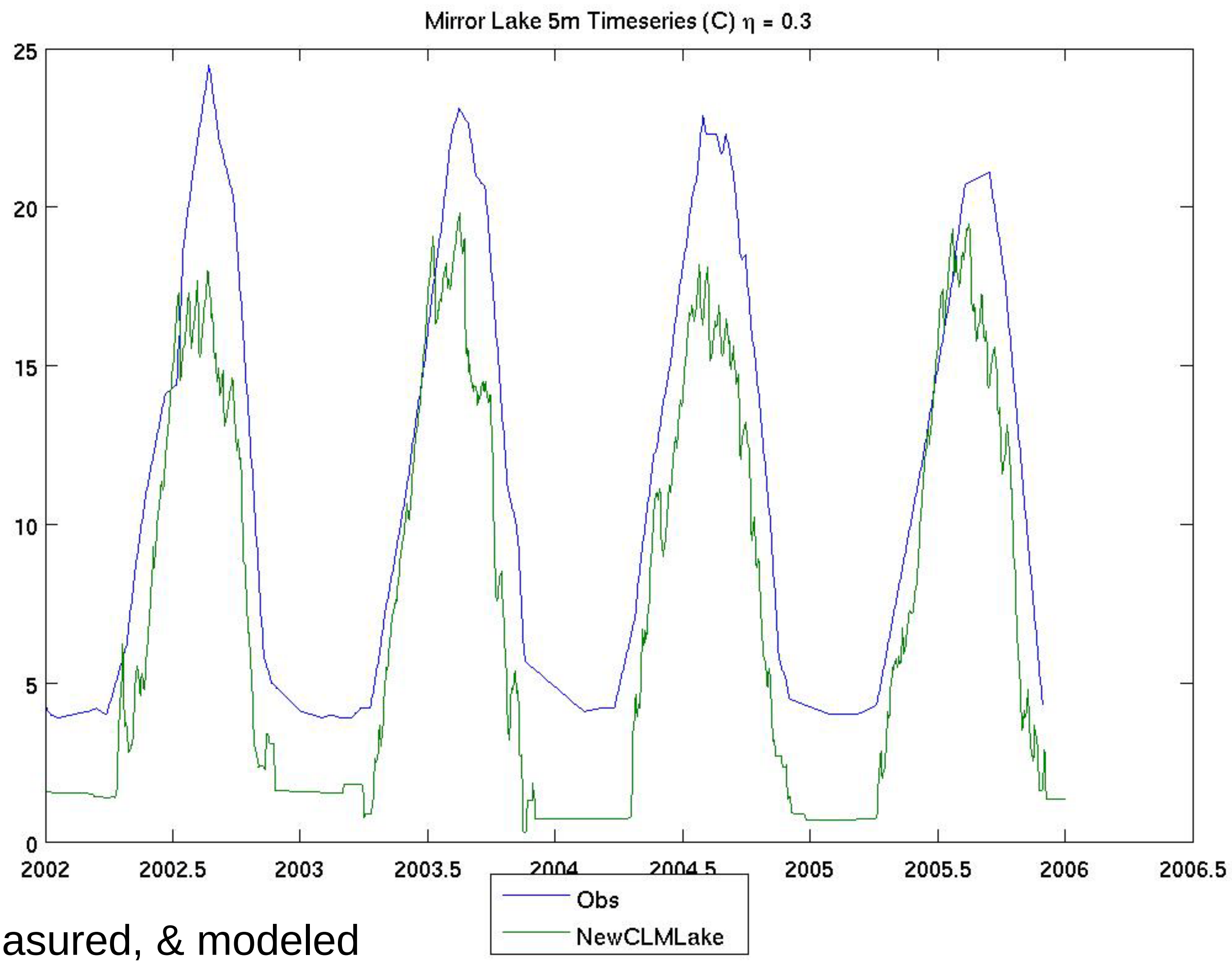


Mirror Lake (NH) @ 5 cm



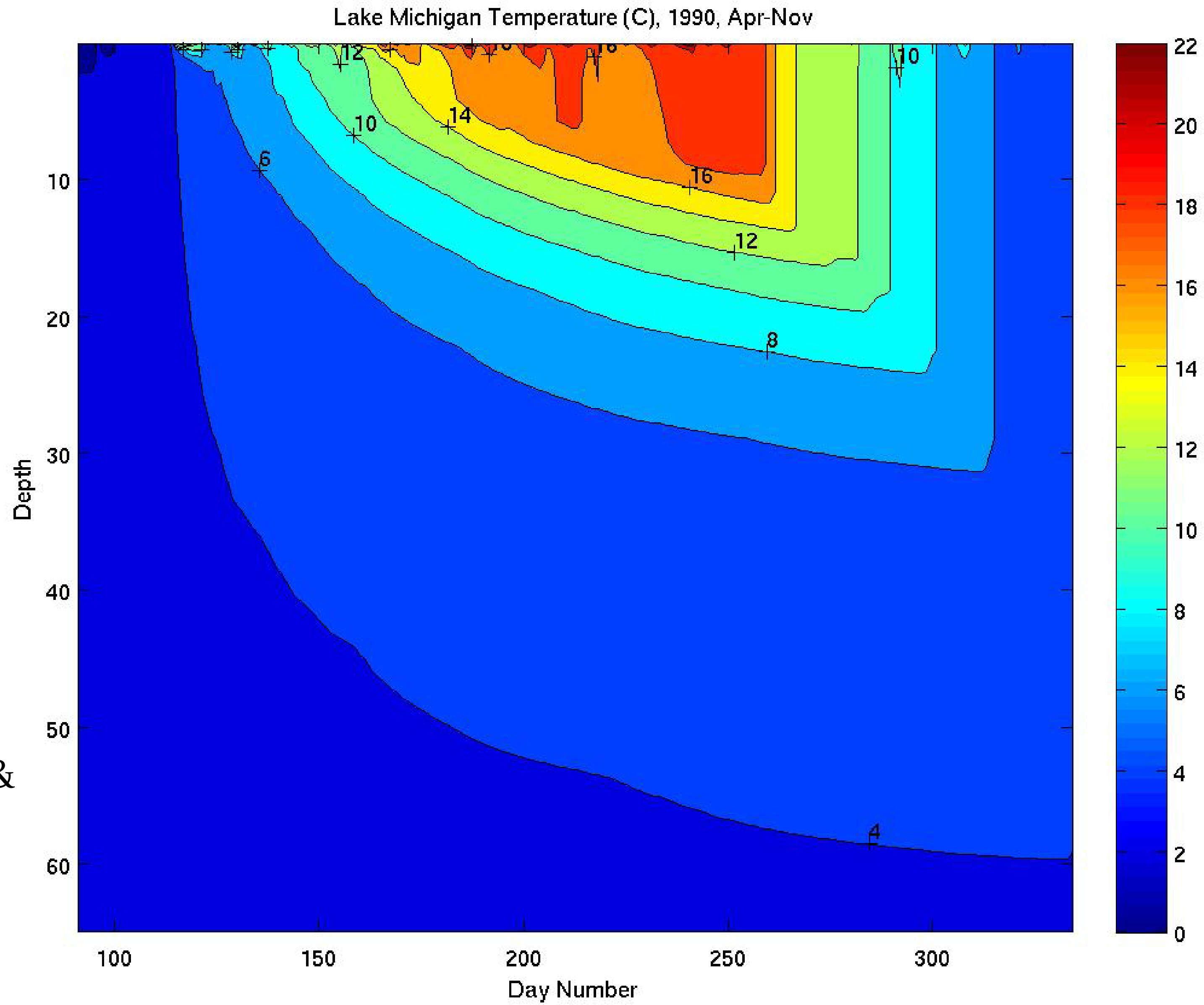
Max., measured, & modeled lake depth = 11 m

Mirror Lake (NH) @ 5 m



Max., measured, & modeled
lake depth = 11 m

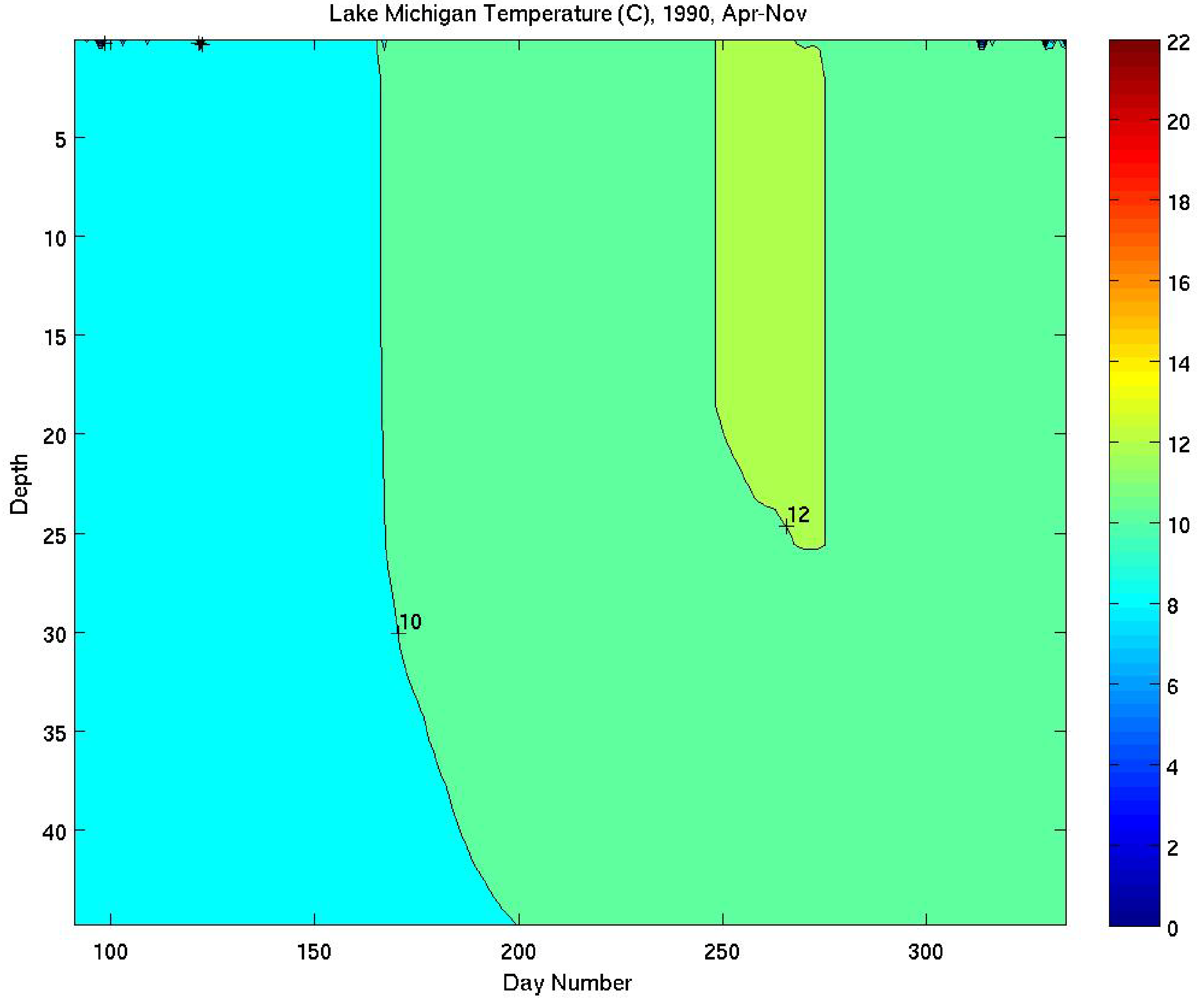
Lake Michigan, Apr-Nov 1990, New Lake Model



Modeled & measured depth = 160 m

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

Lake Michigan, Apr-Nov 1990, CLM 3.5



(Climatic Change, 1993)

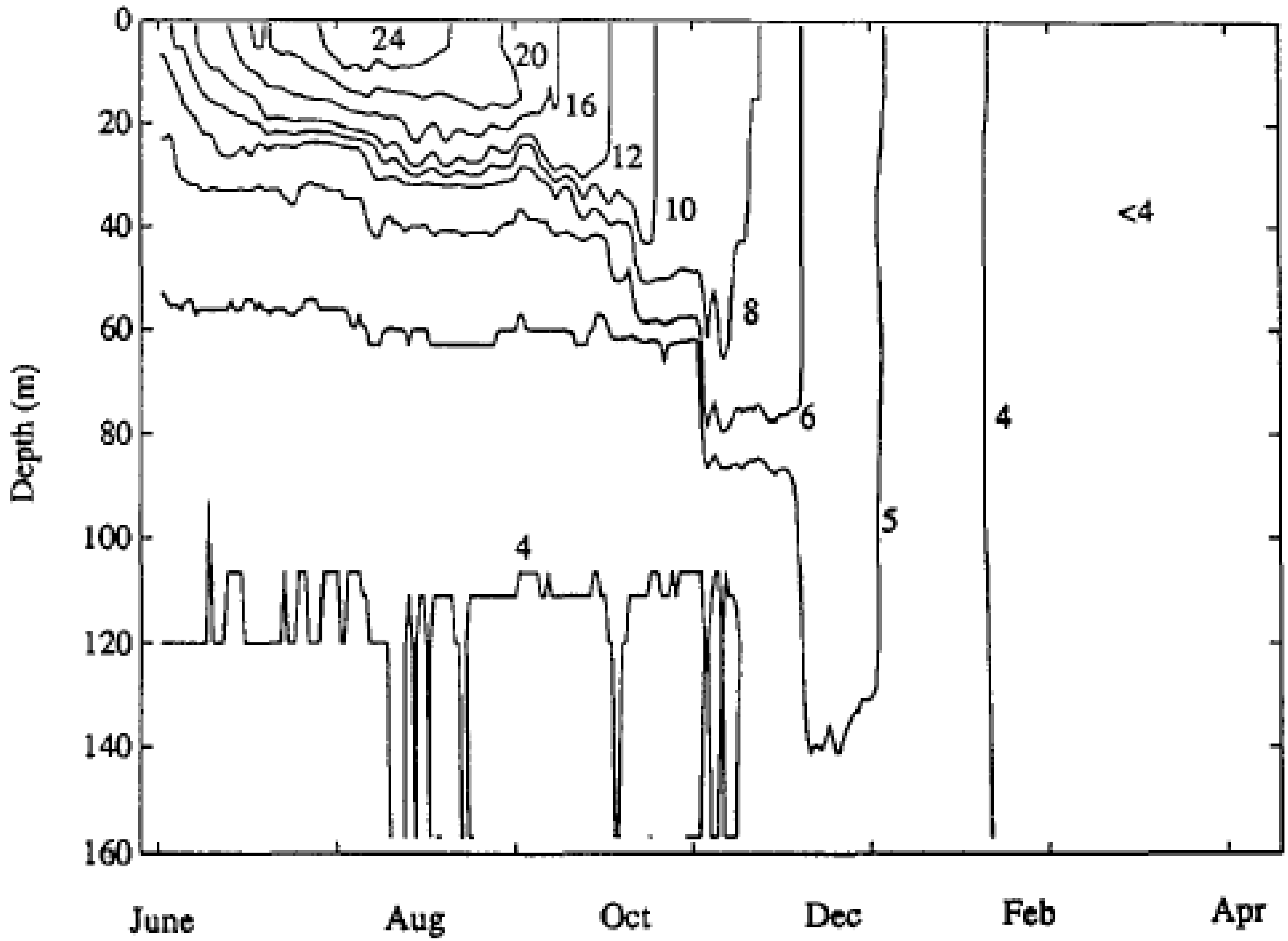
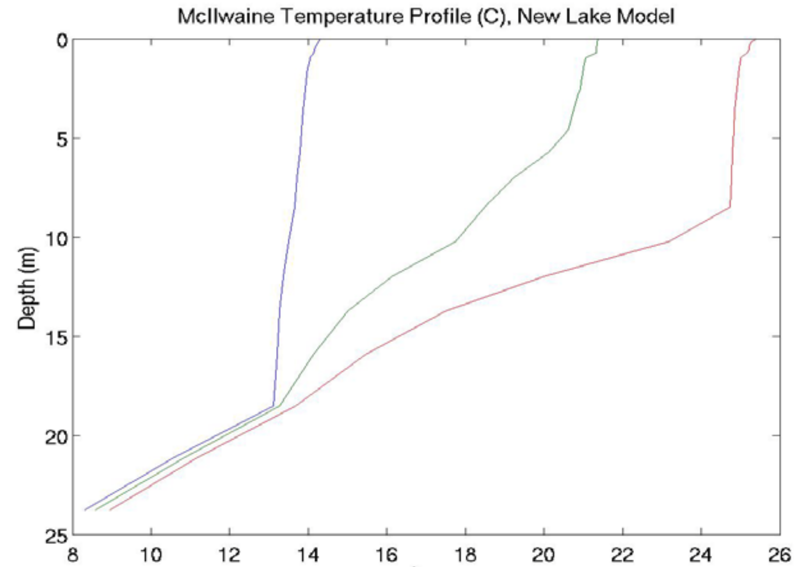
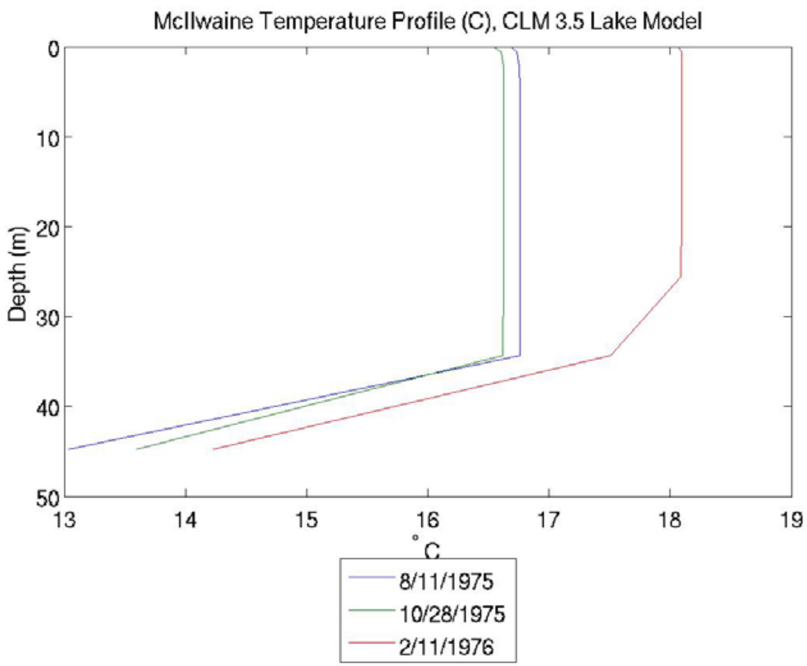


Fig. 2. Temperature contours for the offshore waters of Lake Michigan from 7 June 1990 through 18 April 1991. Contours were generated from daily averaged data.

Lake McIlwaine (Rhodesia), 1975-6





Robarts & Ward, Hydrobiologia 1978

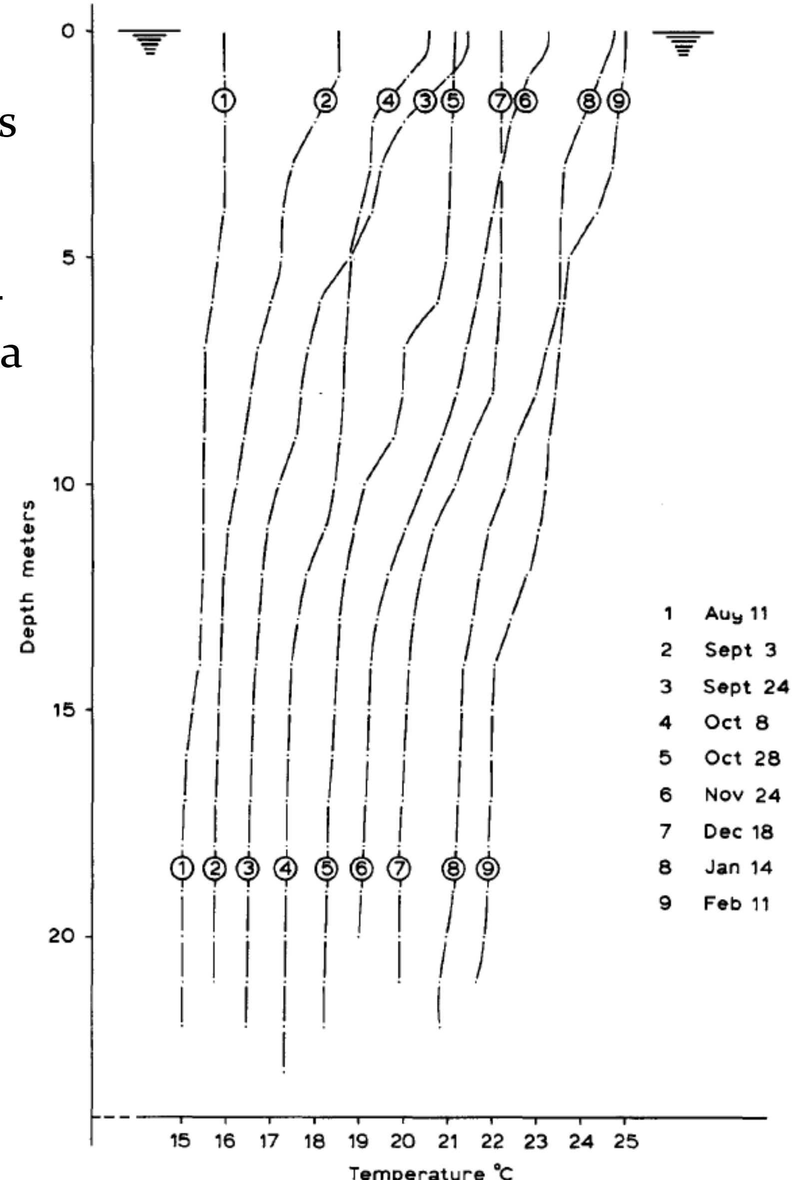
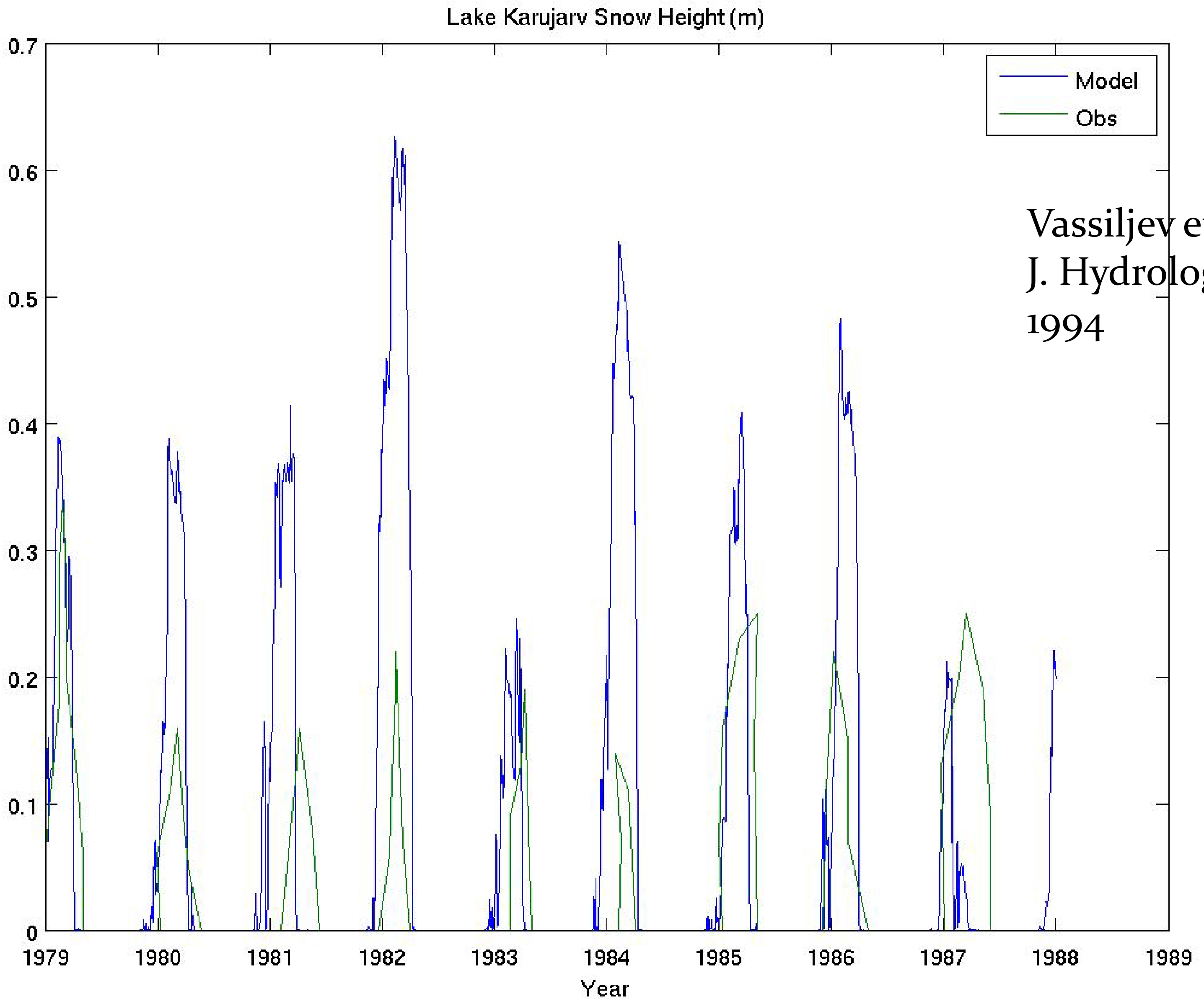


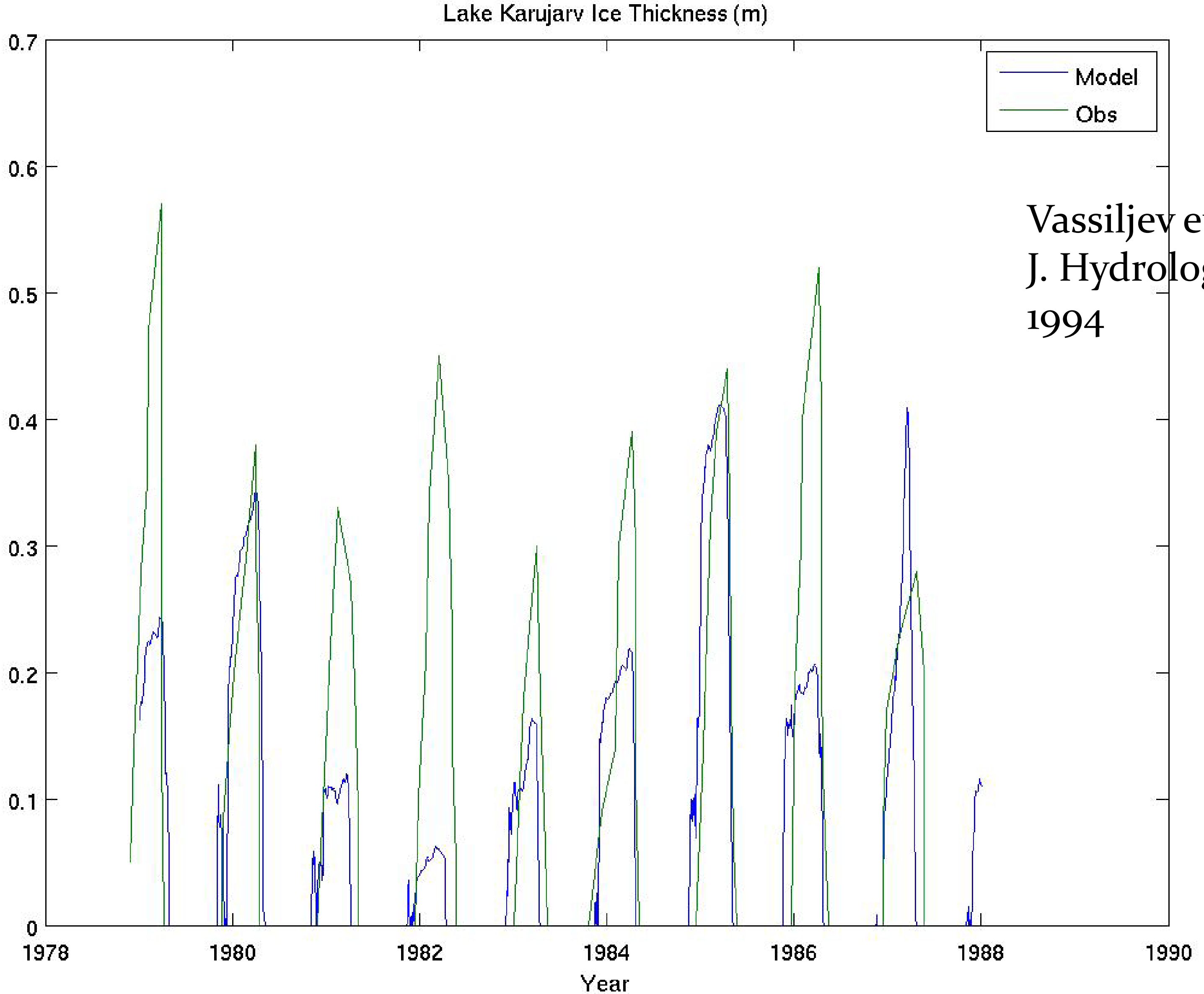
Fig. 2. Temperature profiles in Lake McIlwaine (1975/1976).

Lake Karujarv (Estonia) Snow Height, 1979-1989



Vassiljev et al.,
J. Hydrology,
1994

Lake Karujarv (Estonia) Ice Thickness, 1979-1989

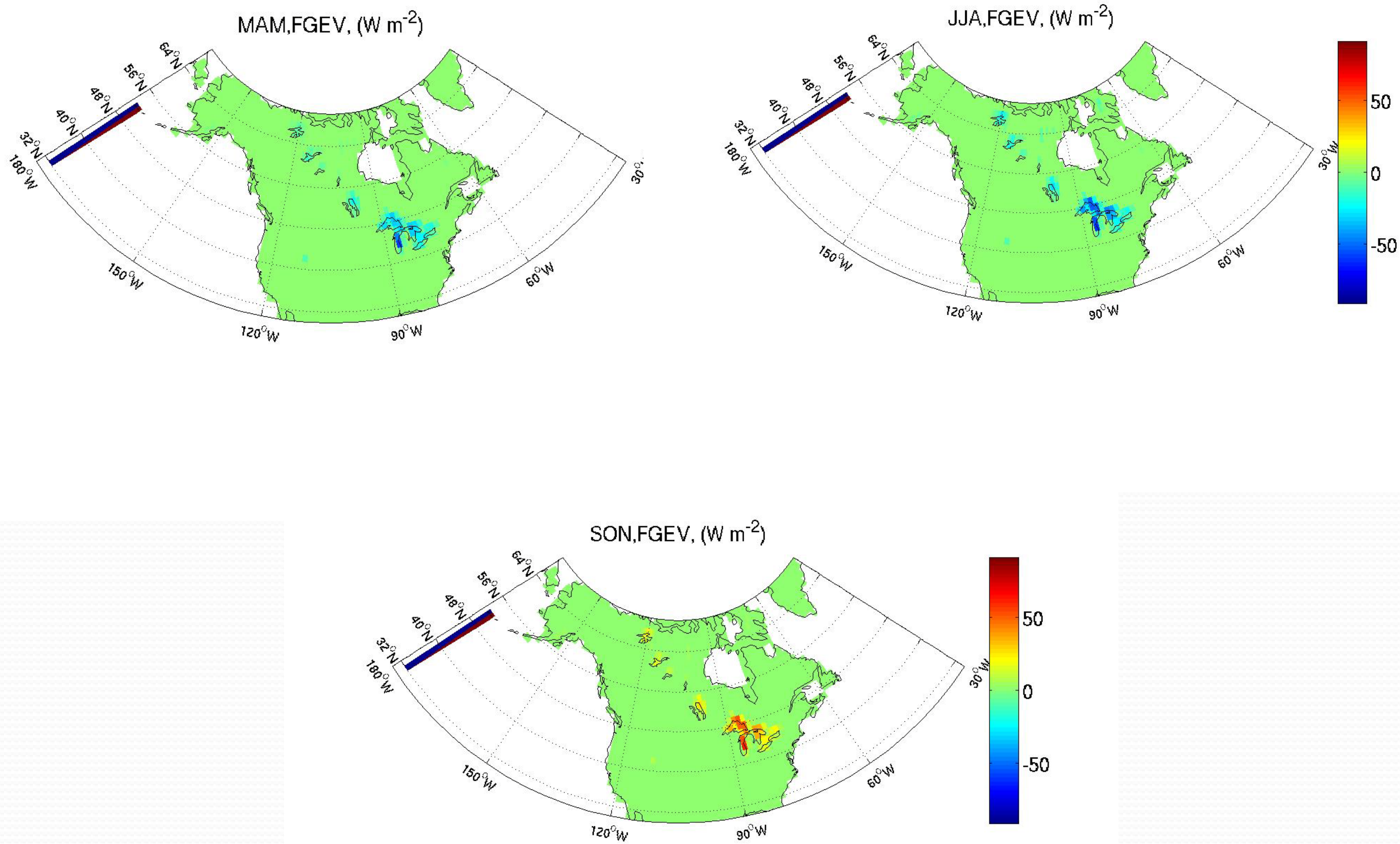


Vassiljev et al., J. Hydrology, 1994

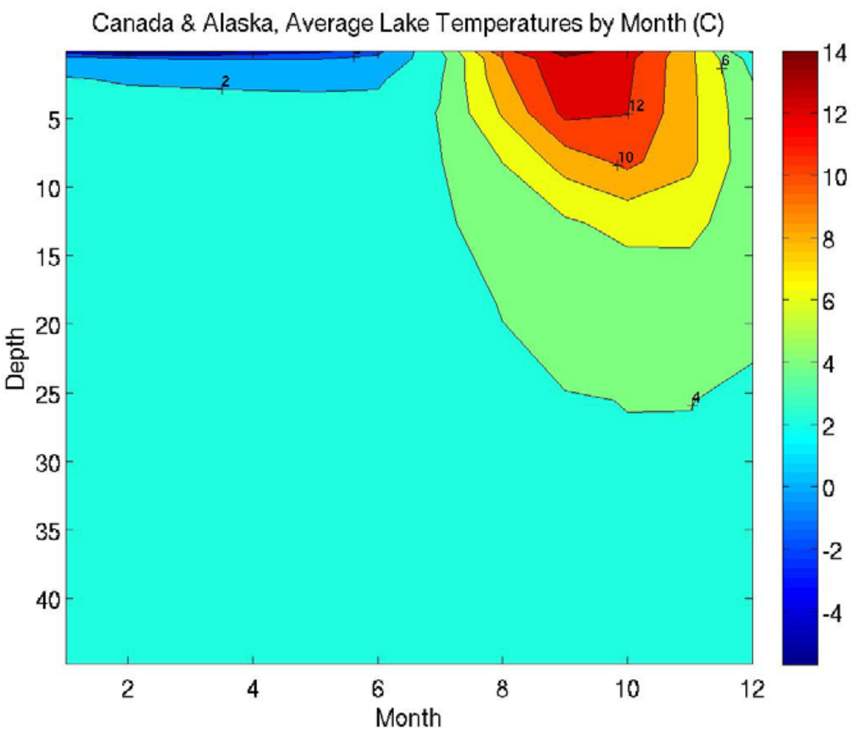
Feedbacks to Global Climate

- Forcing in offline CLM 3.5
- Response in CLM-CAM 4 with Fixed SSTs

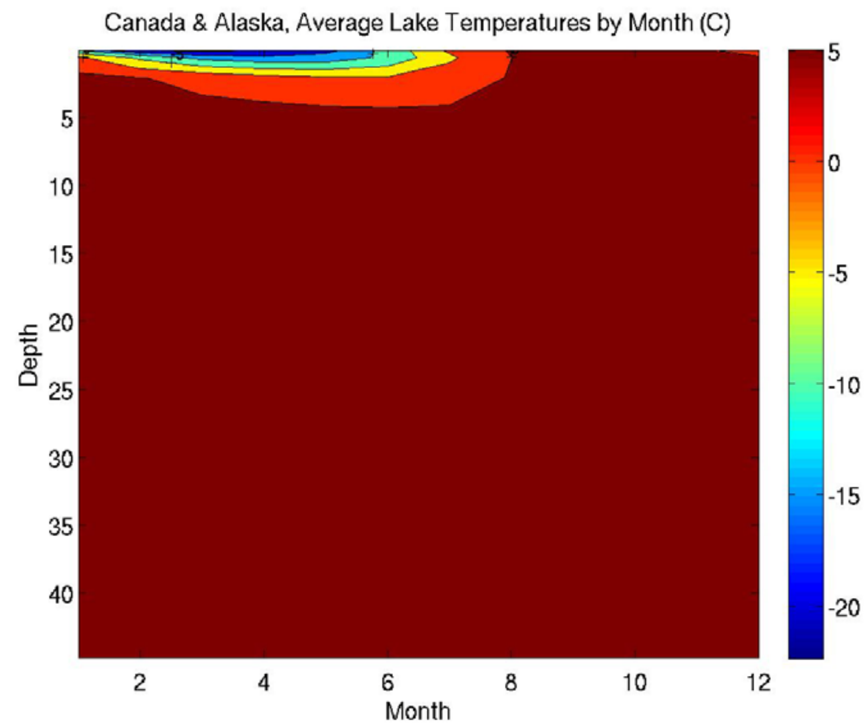
Offline Global CLM 3.5, 24 yr, New – Old Lake Spring, Summer, & Fall Ground Evaporation (W/m^2)



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

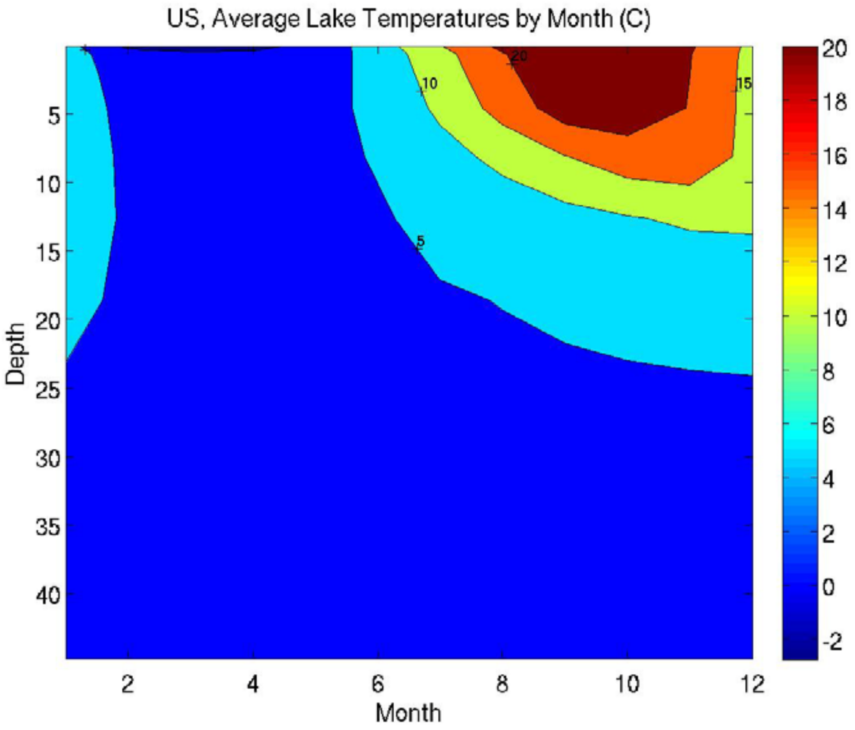


New Lakes

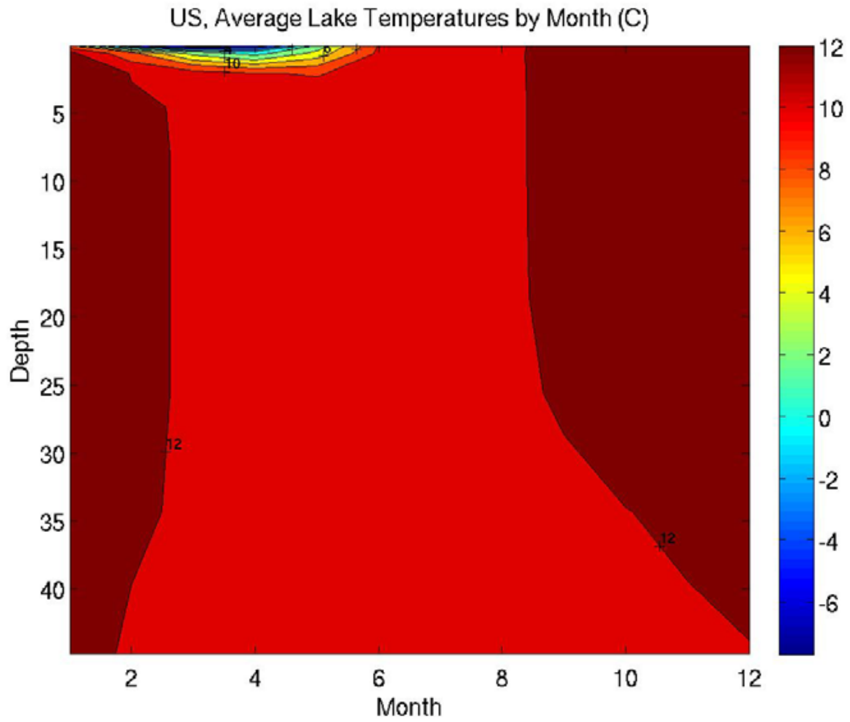


Old Lakes

CAM-CLM4 US Monthly Average Lake Water Temp.

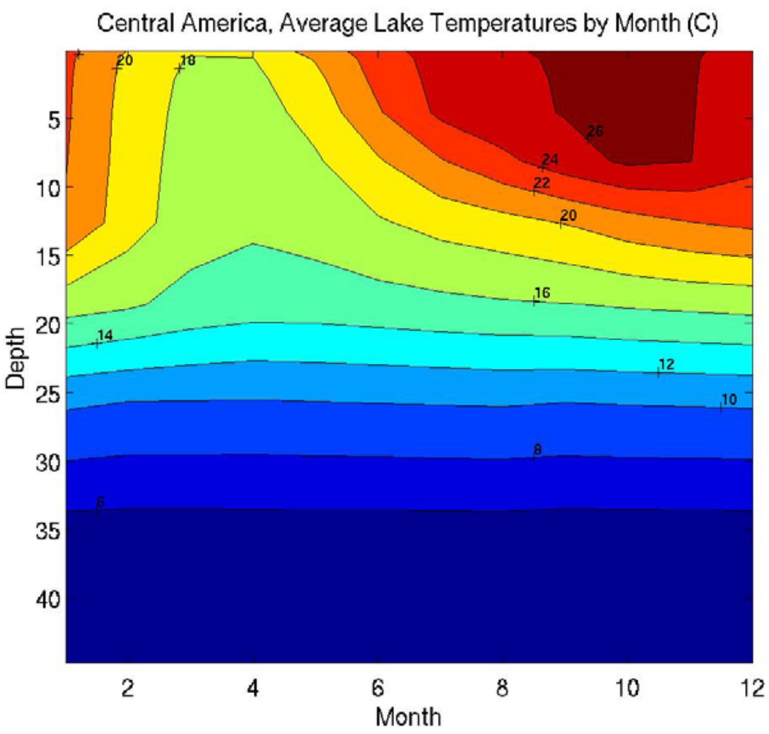


New Lakes

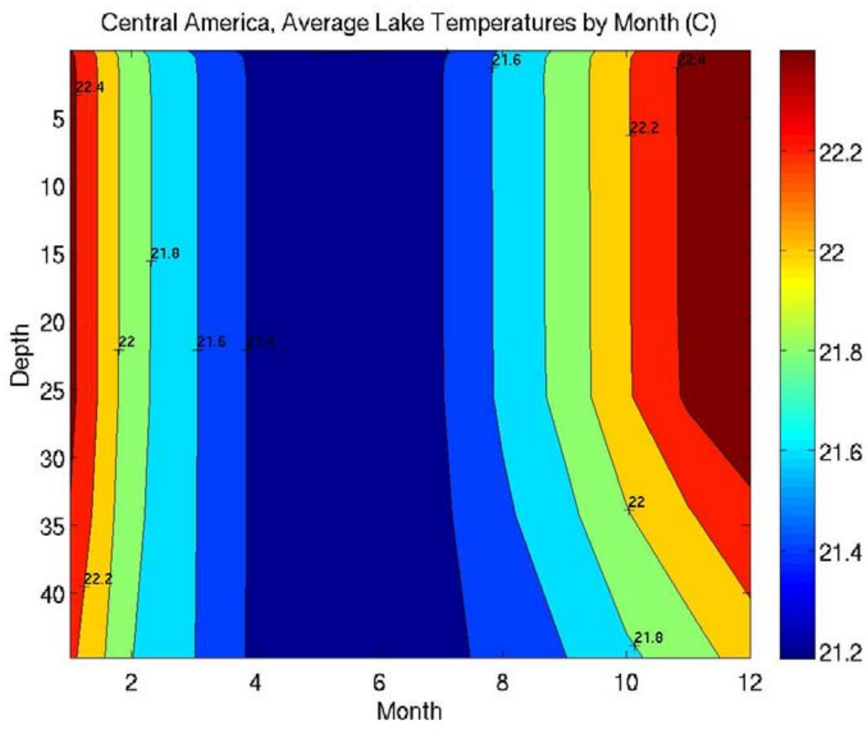


Old Lakes

CAM-CLM4 Central America Monthly Average Lake Water Temp.

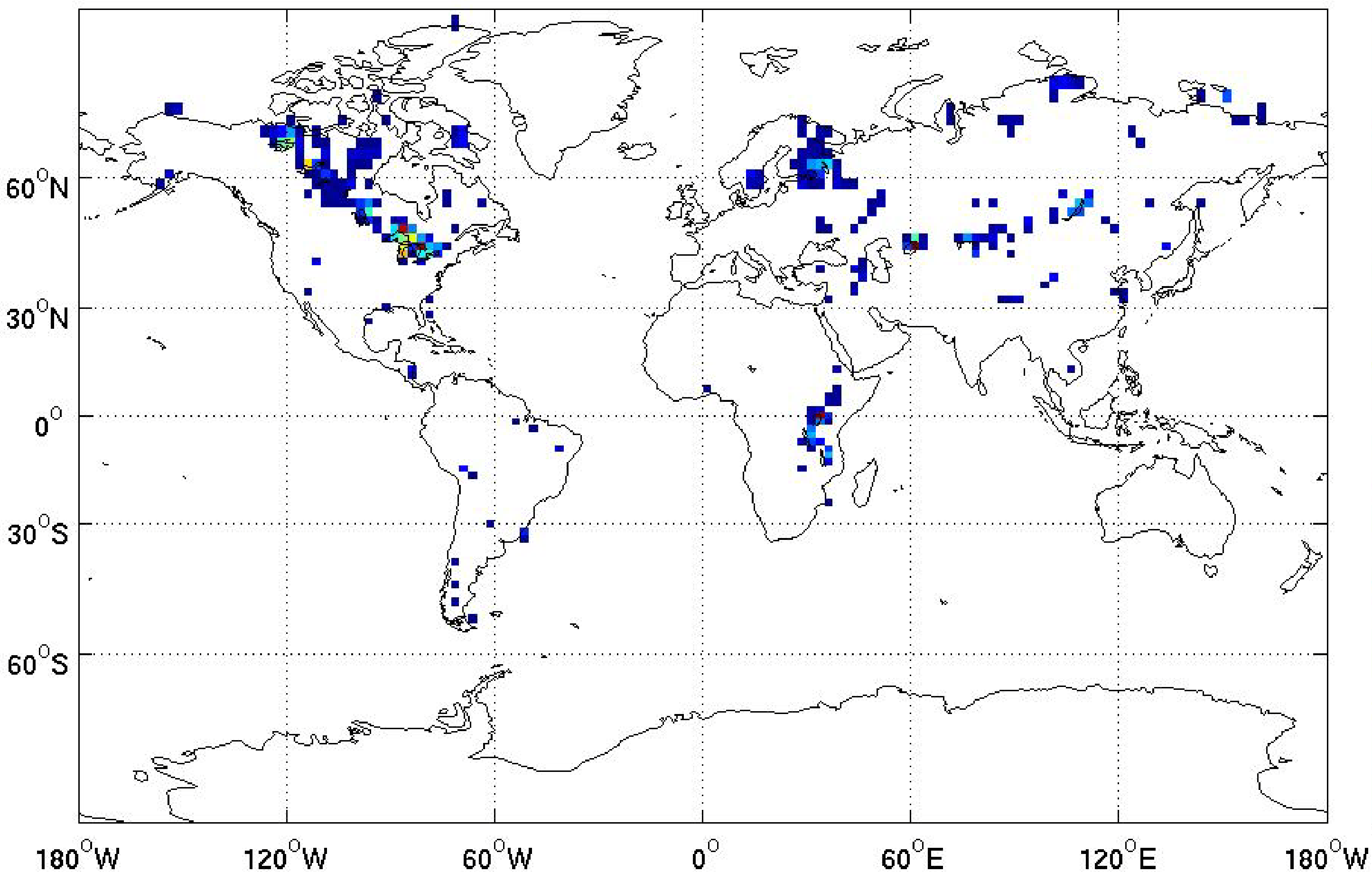


New Lakes

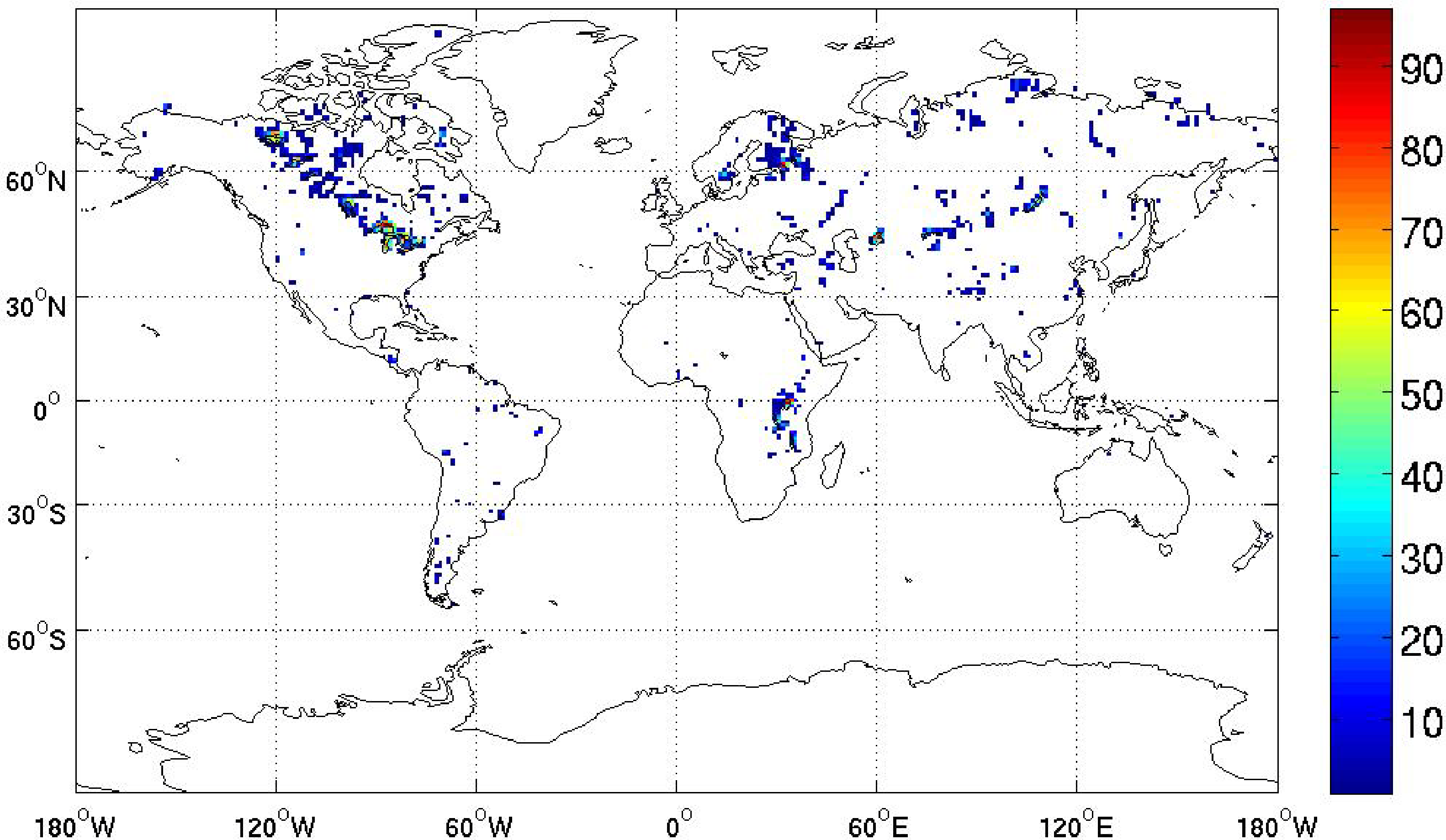


Old Lakes

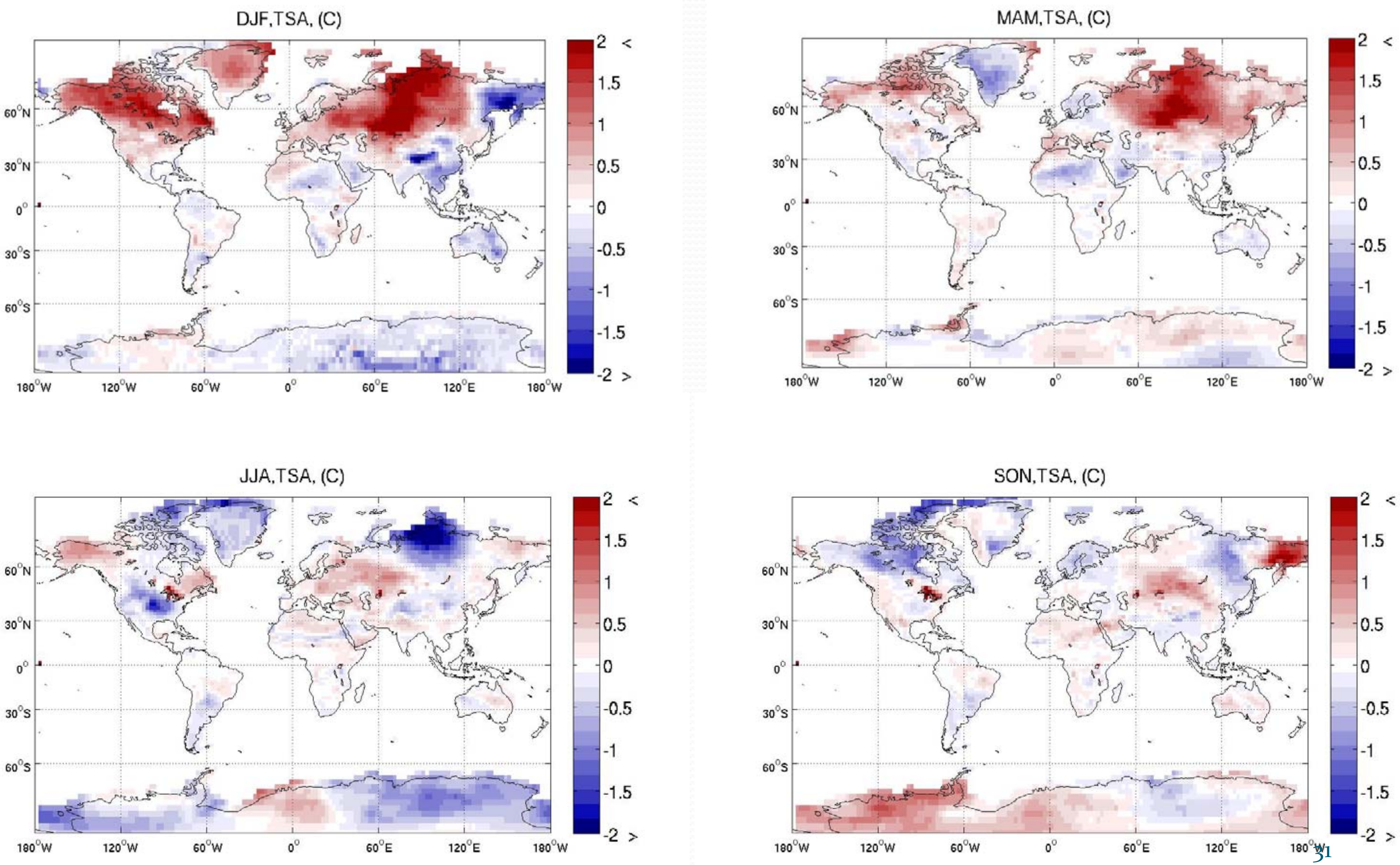
Gridcell Percent Lake Area $(1.9^0 \times 2.5^0)$



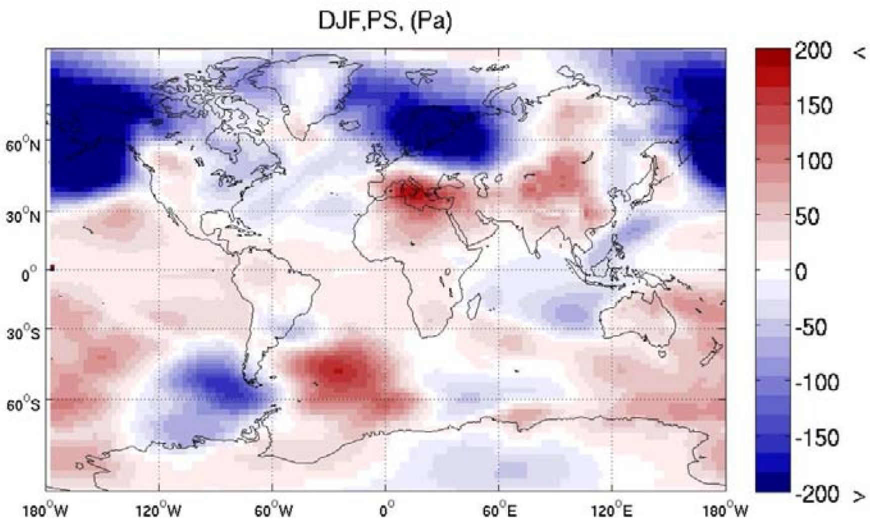
Gridcell Percent Lake Area (0.9^0 x 1.25 ^{0})

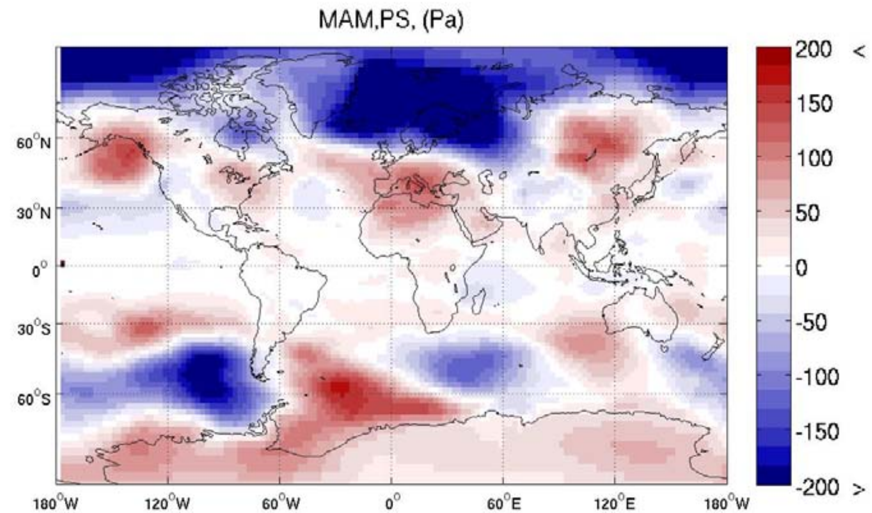


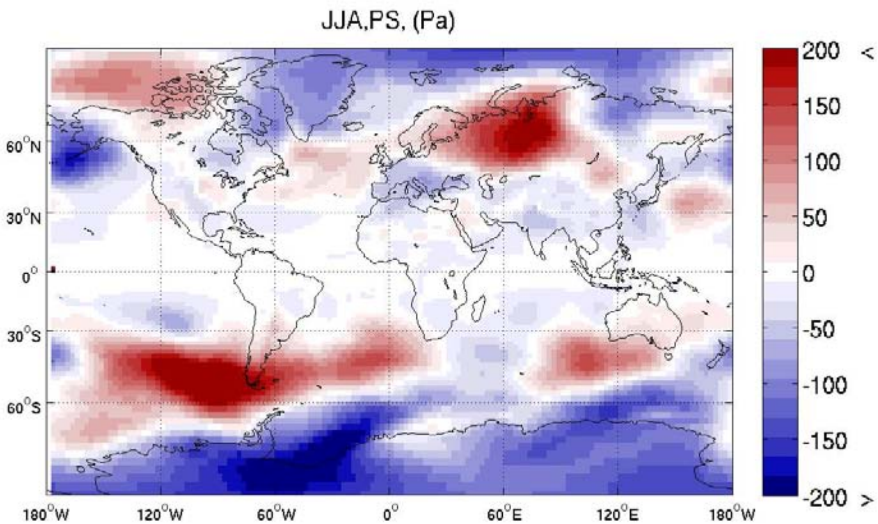
CAM-CLM4, 15 yr, New – Old Lake Land Surface Air Temperature (C)

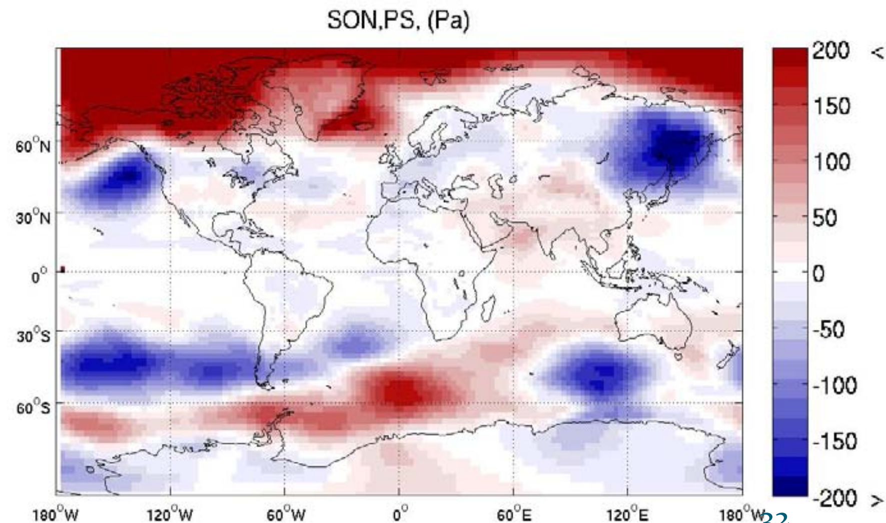


CAM-CLM4, 15 yr, New – Old Lake Surface Pressure (Pa)

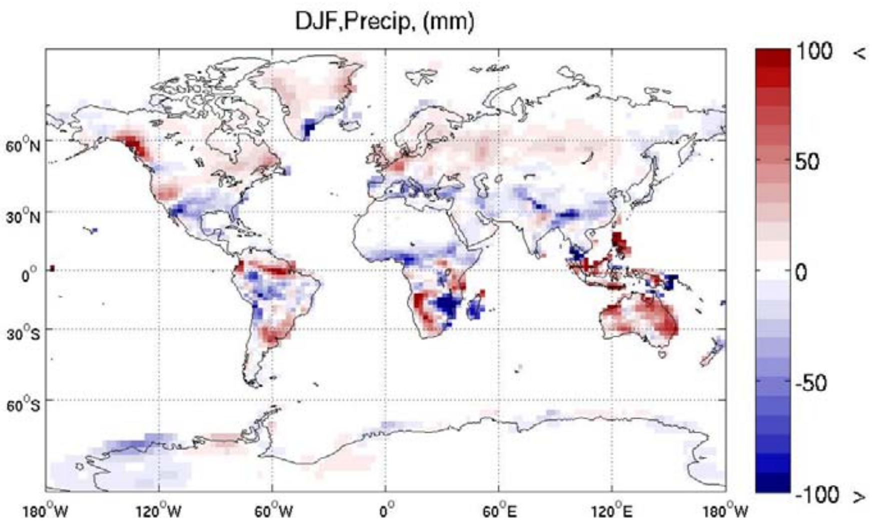


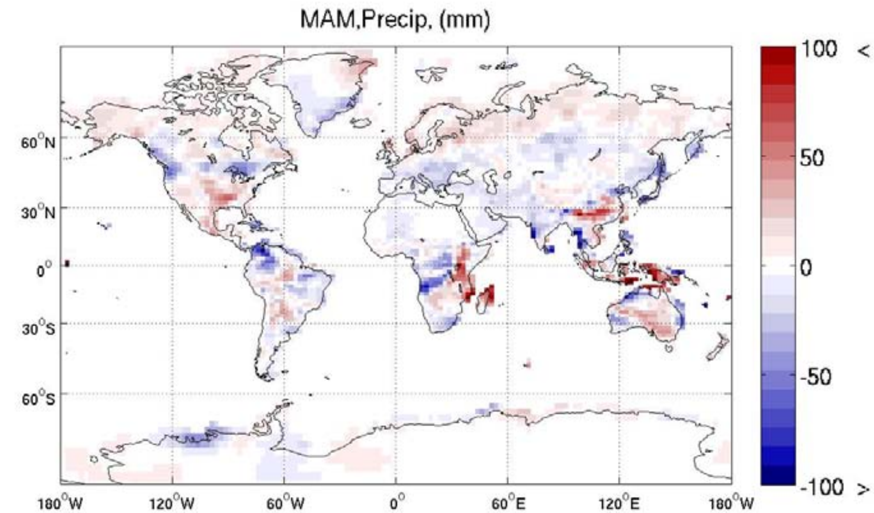


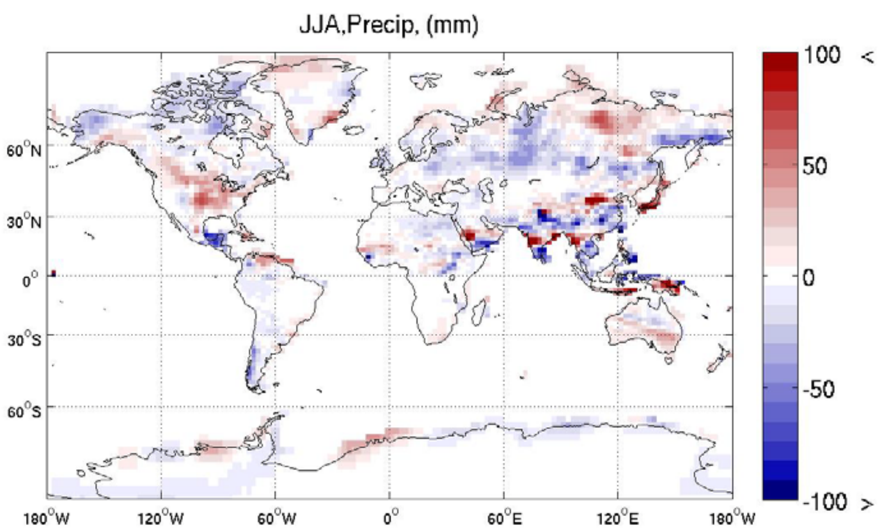


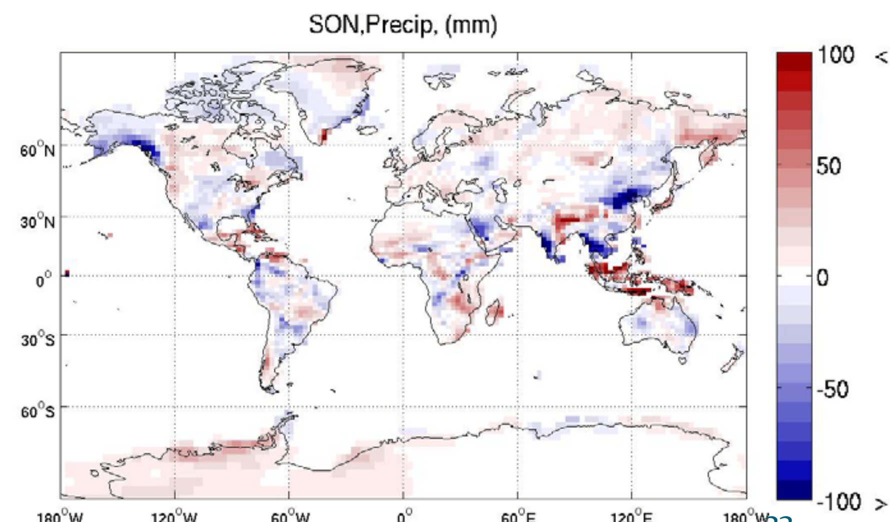


CAM-CLM4, 15 yr, New – Old Lake Land Precip. (mm/season)









Conclusions

- An updated lake model has been integrated into CLM 4 (currently sync'd with clm_3_6_54 and the developing methane code).
- The new lake model substantially improves representation 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.
- Preliminary CAM-coupled simulations suggest these local changes have the potential to alter global circulation of energy and water.
- CCSM 4 *may* have substantial biases in representing the spatial and seasonal patterns of global climate with the un-improved lake model.