Offline test of CLM4.0 lake model at lake Taihu

Bin Deng

06/09/2011
Outline

Introduction

Model

Results

PROGRAM Bin Micro
DO WHILE (it works)
...
...
END DO
END PROGRAM
Introduction (Taihu lake)

(Xiao et al., 2010)

- Inflow from W and SW
- Outlet at SE
- Spatial variation of water quality
- Warm polymictic lake (too shallow to develop thermal stratification)
- Large surface-to-volume ratio
- Different vertical structure from deep lakes
- High evaporation (pronounced local cooling)
- Sensitive to climate change (e.g., drought) and anthropogenic perturbations
Introduction (algae bloom)

Algae outbreak on Jun, 2007

- Pose a threat to water quality
- More than 6000 tons of algae removed with 2 months after the break

(Paerl et al., 2010)
In this study:

(1) Evaluate and adapt CLM4.0 lake model for Taihu;

(2) Couple CLM4.0 lake model into WRF to improve the weather prediction for Taihu region;
Model (schematic representation)

CLM4.0 lake model

Wind affects surface roughness and causes eddy mixing

Snow aging & aerosol deposition

Latent heat released upon freezing; ice aggregates at top

Saturated soil with freezing and thawing

(Subin et al., 2011)
(1) fetch, (2) surface albedo, (3) heat of vaporization, (4) top layer thermal properties

previous lake thermal properties

Model (component modules)

Climatological Inputs at $t_i$

Surface Module

Lake Module

Hydrology Module

Surface fluxes ($Q_H, Q_E, \tau, \ldots$) $T_{sfc}$ and $Q_g$

$t_{i-1}$

$t_i$
Module solver (based on surface layer heat budget):

\[ \beta (K_\downarrow - K_\uparrow) + L_\downarrow - L_\uparrow (T_{sfc}) - Q_H(T_{sfc}) - Q_E(T_{sfc}) - Q_g = 0 \]

\( \beta \): fraction of \( K^* \) absorbed in the lake surface layer (0.4~0.6)
\( Q_g \): heat flux as boundary condition for the top layer

\[ Q_g = \frac{\lambda (T_{sfc} - T_1)}{(\Delta z_1)/2} \]

\( \lambda = \lambda_m + \lambda_e \) (\( \lambda_e \sim 10^{2-3} \lambda_m \)): highly affects the module outcomes
Model (lake module)

**Module solver** (vertical heat diffusion):

\[
\frac{\partial T_i}{\partial t} = \frac{\partial}{\partial z} \left[ \left( K_m + K_{e,i} \right) \frac{\partial T_i}{\partial z} \right] + \frac{1}{c_{liq}} \frac{d\phi_i}{dz} \quad (i = 1, N_{lake} + N_{soil})
\]

\[
\begin{bmatrix}
    b_1 & c_1 & . & . & 0 \\
    a_2 & b_2 & c_2 & . & 0 \\
    0 & a_3 & b_3 & . & . \\
    . & . & . & c_{n-1} & . \\
    0 & . & . & a_n & b_n \\
\end{bmatrix} \begin{bmatrix}
    T_1 \\
    T_2 \\
    . \\
    . \\
    T_n \\
\end{bmatrix} = \begin{bmatrix}
    r_1 \\
    r_2 \\
    . \\
    . \\
    r_n \\
\end{bmatrix}
\]

\[a_i \sim f \left( T_{prev}, K_e \right)\]
\[b_i \sim f \left( T_{prev}, K_e \right)\]
\[c_i \sim f \left( T_{prev} \right)\]
\[r_i \sim f \left( T_{prev}, K_e, \phi \right)\]

\(\eta\) and \(K_e\) affect the heat redistribution within the lake.
Results (lake temperature measurements)

Aug 17, 2010

Aug 26, 2010

Cross correlation coefficient

Lag [hr]
Results (lake temperature measurements)

- Temperature overturn occurs on daily basis
- Isothermal lines tilt as a result of time lag
- Wind plays an important role in SEB of shallow lake
Results (lake parameters)

(1) CLM2.0 lake model
\[ \eta = 0.1 \, \text{m}^{-1} \]

(2) CLM4.0 lake model
\[ \eta = 1.1925D^{-0.424} \]

(0.89 for Taihu based on this formula)

Data source: Qin et al. (2007)
Results (lake parameters)

\( K_e \) (wind driven turbulence, enhanced diffusion due to unresolved 3D processes*)

\[ k_e \text{ [m}^2\text{ s}^{-1}] \]

\( k_{e\text{ mod}} @ z = 1\text{m} \)

\( k_{e\text{ obs}} @ z = 1\text{m} \)

\( k_e \text{ [m}^2\text{ s}^{-1}] \)

\( k_{e\text{ mod}} @ z=0.2\text{m} \)

\( k_{e\text{ obs}} @ z=0.2\text{m} \)

\( K_e \) deserves more attention
Model spin-up time (the time model takes to reach an equilibrium state) 

here the model is driven by repeating measurements from DOY 229
Results (CLM4.0 surface module outputs)

(parameter setting: $z_{0m}=z_{0h}=z_{0q}=0.01$ m, $\beta=0.4$, $\eta=0.89$ m$^{-1}$)
Results (CLM4.0 surface module outputs)

(parameter setting: $z_{0m}=z_{0h}=z_{0q}=0.001$ m, $\lambda=10\lambda_m$, $\beta=0.4$, $\eta=0.89$ m$^{-1}$)
Results (CLM4.0 lake module outputs)

(parameter setting: $z_{0m}=z_{0h}=z_{0q}=0.001$ m, $\lambda=10\lambda_m$, $\beta=0.4$, $\eta=0.89$ m$^{-1}$)

Soil layers are not properly scaled in above figure
Future work:

(1) Surface module needs:

- Site-specific roughness lengths for resistance estimation;
- Realistic estimates of $\lambda$ and $T_1$ to increase the coupling between climatological drivers and the lake;
- Longer testing period;

(2) Lake module needs:

- $K_e$ for the lake
- More work (particularly the tridiagonal matrix);