Imperial Journal of Interdisciplinary Research (IJIR)
Vol-2, Issue-5, 2016
ISSN: 2454-1362, http://www.onlinejournal.in

Fresh Water Lake Model Application For Seasonal Variation Of Latent And Sensible Heat Fluxes From The Water Surface Of Rudrasagar Lake,Tripura

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Abstract: *This paper describes the seasonal variation of latent heat and sensible heat fluxes from the surfaces of lake Rudrasagar, Tripura using the fresh water lake model (FLaKe).Modeled output is very much helpful for predicting the vertical temperature structure and mixing in lakes of various depth .The model is also widely used in numerical weather prediction, climate modeling and also the model plays role of physical module in different aquatic ecosystem models. A parameterization scheme is required to develop to compute sensible and latent heat at the lake surface, which accounts for specific features of the surface air layer over lakes. Seasonal temperature map of lake water, mixed layer depth profile, water-sediment heat flux and change in surface fluxes of lake water may be obtained as model output.*

Introduction

There are numerous water resources in the Earth's hydrosphere but the availability of water suitable for human consumption is very much limited. Lakes are one of the most valuable water resources which have had a close relationship with human existence for centuries. Local, regional and even global climate may be greatly affected by the lakes through complex interactions of biophysical and biogeochemical processes [1].Various crucial factors are there that affects the climate variability of hydrologic processes. Out of these total heat flux from lake surface is very much important. Both water budget and energy budget of lake are influenced by latent heat and sensible heat fluxes from lake water which in turn is the characteristic of the lake itself. [2]. The phytoplankton biomass may be coupled to the net heat flux of lake.

The heat fluxes at any lake surface may be computed as $Q_{tot}=LW_{in}+LW_{out}+ LE+SE$, where LW_{in} represents incoming and outgoing long wave radiation respectively. LW_{in} depends on cloud cover. LW_{out} depends on surface water temperature, LE depends on the vapour pressure gradient between the lake and overlying water, temperature and wind speed. Whereas, SE depends up on air-water temperature difference and wind speed. Wind forcing and heat loss can both generate turbulence in the upper water column. By computing the turbulent velocity scales for both, one can comment that whether heat loss contributes to the mixing and whether wind or heat loss is dominating the mixing in the upper waters. According to the equation of Cozar et.al (2012) the latent and sensible heat fluxes are proportional to air density[3].The sensible heat flux due to conduction and convection process can be modeled in parallel to the latent heat flux and these two fluxes can be approximated by the ratio of temperature difference and water vapor pressure differences across the surface and a linear dependence on air pressure P_a ,called the Bowen ratio[4] The sensible and latent heat fluxes can be calculated from the measured values of air temperature, water surface temperature, relative humidity and wind speed above the lake water surface and these calculations are performed at a single point over short time intervals of 10 min by following the aerodynamic method [5].

2 Material and Method

Study area:

Tripura is a landlocked state of North-East India and in area it is the third smallest state of India. Geographically the actual study site Rudrasagar Lake

($23^{\circ}29'$ N and $90^{\circ}01'$ E) lies in the Melaghar Block under Sonamura Sub-Division in the West Tripura District and at a distance of about 50 km from the

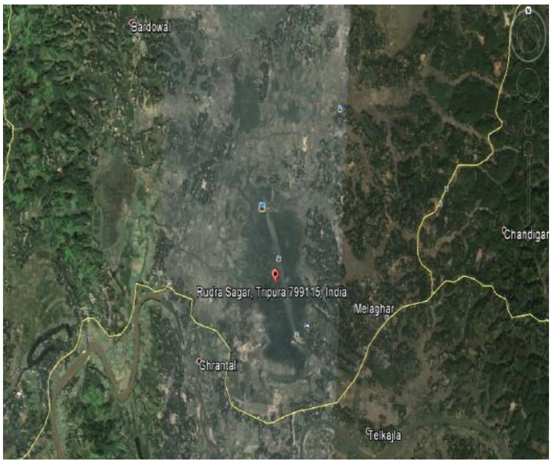

Fig 1: Satellite image of Rudrasagar wetland

State capital of Tripura. Rudrasagar Lake is a natural sedimentation reservoir and it has three sources of inflow and one outflow .Inflows are Noacherra, Durlavnaraya cherra and Kemtali cherra whereas Kachigang , the only connective channel which discharges water into the river Gomati acts as an outflow[6].

Sampling details:

The sampling sites have been chosen considering the maximum water depth and less human intervention of lake water. The air temperature over the lake surface and also temperature of the bottom surface of lake have, however, been measured using multipurpose water quality analyzer devices. Stored data from memory cells of the devices has been transferred to the database of the computer. The water quality analyzer devices are usually calibrated before the field work in every sampling day following the laboratory methods [7]. The resolution of air temperature over lake surface measurement is 0.01^{0}c.Wind speed meter GEOS 11 has been used to measure the wind speed and humidity .The resolutions for wind measurement and relative humidity measurement by this instrument are 0.1 to 25.0 Beaufort and 0.1% rH respectively.

Theoretical Considerations

The model is based on the following quadratic equation of state for fresh water i.e

$$\boldsymbol{\rho}_w = \boldsymbol{\rho}_T[1-\frac{1}{2}a_T(\theta-\theta_T)^2]$$

where $\boldsymbol{\rho}_w$ is the water density $\boldsymbol{\rho}_T$ is the maximum density of fresh water at temperature θ_T =277.13 k which is taken as 1x 10^3 kg m^{-3} and a_T is empirical coefficient having value 1.6509x 10^{-5} K^{-2}.

A two-layer parametric representation of temperature profile has been adopted as described by Kitaigorodskii and Miropolsky 1970 .The mean temperature of water column is connected with the temperature of the upper mixed layer of depth h(t) and bottom temperature by the relation

$$\bar{\theta} = D^{-1}\int \theta dz$$ and

$$\bar{\theta} = \theta_s - C_\theta\left(1-\frac{h}{D}\right)(\theta_s-\theta_b)$$ where c_θ is the shape factor with respect to the temperature profile in the thermocline and is given by

$$c_\theta = \int_0^1 \phi_\theta(\zeta)\,d\zeta$$

The equation for the mean temperature of the water column considering z from 0 to D

$$D\frac{d\bar{\theta}}{dt} = \frac{1}{\rho_w c_w}\left[Q_s + I_s - Q_b - I(D)\right]$$

Where, C_w=4.2X10^3 $JKg^{-1}k^{-1}$ is the specific heat of water,Q_s and I_s are the values of the vertical heat flux Q and of the heat flux due to solar radiation respectively at the lake surface and Q_b is the heat flux through the lake bottom.

$$D\frac{d\bar{\theta}}{dt} = \frac{1}{\rho_w c_w}\left[Q_s + I_s - Q_b - I(D)\right]$$

The equation of heat budget of the mixed layer is given by

$$h\frac{d\theta_s}{dt} = \frac{1}{\rho_w c_w}\left[Q_s + I_s - Q_h - I(h)\right]$$

$$h\frac{d\theta_s}{dt} = \frac{1}{\rho_w c_w}\left[Q_s + I_s - Q_h - I(h)\right]$$

Where, Q_h is the heat flux at the bottom of the mixed layer.

The equilibrium mixed-layer depth h_e can be computed from

$$\left(\frac{fh_e}{c_{sn}u_s}\right)^2+\frac{h_e}{C_{ss}L}+\frac{h_e n}{c_{si}u_s}=1$$

where f=2ΩsinΦ is the coriolis parameter ,Ω is the angular velocity of the earth's rotation,Φ is the geographical latitude ,L is the Obukhov length,N is the bouncy frequency below the mixed layer and C_{sn}=0.5, C_{ss}=10 and C_{si} =20 are dimensionless constants.

The exponential approximation of the decay law for the flux of solar radiation is given by

$$I=I_s\sum_{k=1}^{n}a_k\exp\left[-\gamma_k\left(z+h_i\right)\right],$$

where I_s is the surface value of the incident solar radiation heat flux multiplied by 1-α, αbeing the albedo of the water surface with respect to solar radiation,n is the number of wavelength bands,a_k are fractions of the total radiation flux for different wavelength bands, and γ_k are attenuation coefficients for different bands. The attenuation coefficients are taken as piece wise constant function of z.

Results and discussion

Geographical coordinates of lake, Mean lake depth and Water transparency are the major input parameters of the model. NCEP atmospheric forcing is taken as another input. Average depth of lake was found as 3.5 m and transparency was found as 2m (clear) in the year 2014. Seasonal variations of heat fluxes at the lake surface obtained as model output and have been displayed in fig.6 .Annual temperature cycle in time-depth coordinates of the lake water has been displayed in fig.2 .Fig.3 and fig.4 represent seasonal variation of surface and bottom temperature

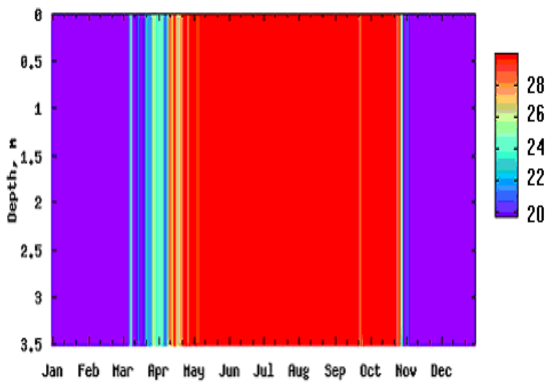

Fig 2: Annual temperature cycle in time-depth coordinates of the lake water in the year 2014

of lake water respectively as model output. It is clear from these two fig that lake surface temperature and bottom surface temperature almost follow the similar trend of seasonal variation. Seasonal variation of water temperature as model output shows its highest value both in surface and bottom of lake during the month of June which has a good agreement with the recorded temperature of lake surface of the field measurement data. The seasonal variations in latent heat flux and sensible heat flux are closely linked with local wind pattern. The wind induced vertical mixing on the other, tends to reduce the heat loss at the lake surface by reducing the surface temperature, which again depend not only on the wind speed, but also on the temperature structure of the water body. The nature of solar radiation is the most important

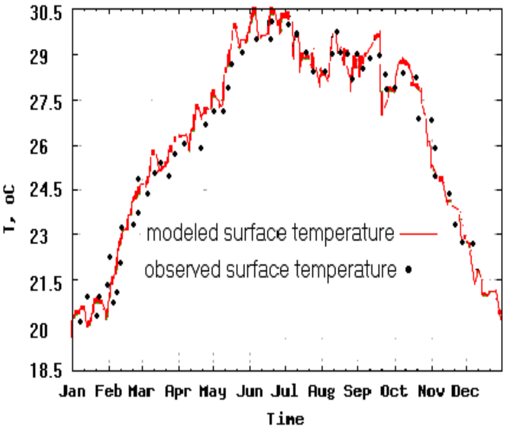

Fig3: Seasonal variation of lake surface temperature in the year 2014

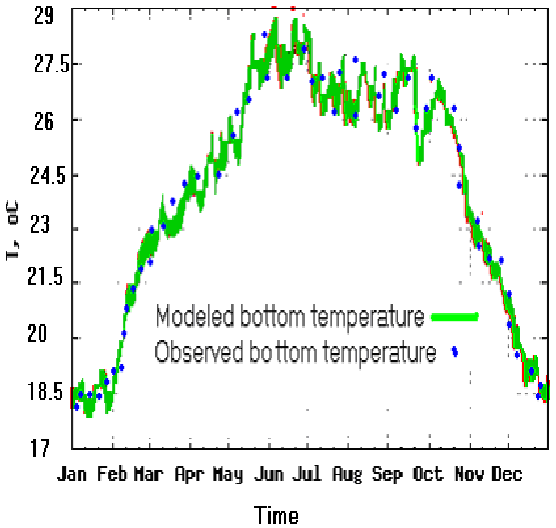

Fig 4: Seasonal variation of bottom temperature of lake in the year 2014

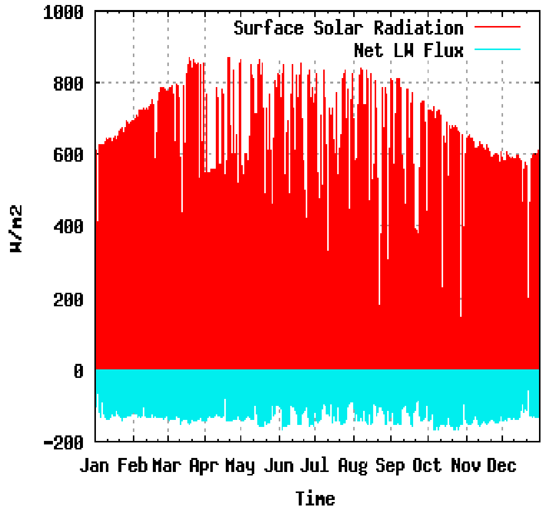

Fig 5: Seasonal variation of surface solar fluxes of lake Rudrasagar in the year 2014

aspect of the heat budget and its seasonal variation over the lake Rudrasagar has been displayed in fig 5 as a model output. The increase in heat flux in any lake can be related to strong long wave radiation. A very rough comparison with other fluxes in the heat balance equation indicates that the flux at the water-sediment interface can't be neglected.

In the overall heat budget of a lake, solar energy is the dominating factor. Solar energy may reach the bottom of a lake and the bottom water of the lake is also heated and cooled through heat transfer by the mixing and circulation patterns characteristic of lake

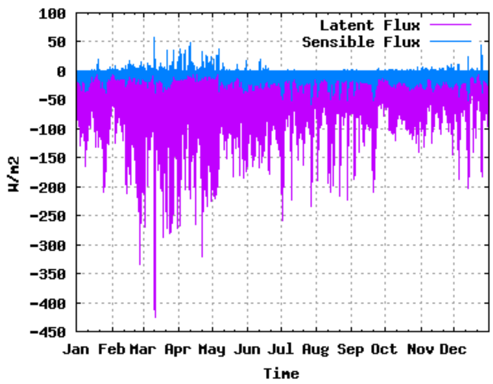

Fig 6: Seasonal variations of heat fluxes at the lake surface in the Year 2014

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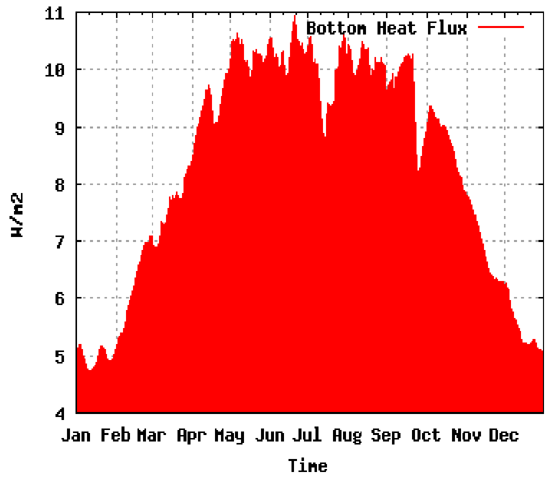

Fig 7: Seasonal cycle of heat flux at water-sediment interface

The heat budget of the sediments might be dependent on the amplitude of temperature variations of the overlying water.

Acknowledgements

The authors are very much grateful to the authorities of Rudrasagar lake for permitting and providing necessary facilities during field work. Also the authors gratefully acknowledge the Director of School of water Resource Engineering, Jadavpur University for his constant encouragement in this field. Financial support from University Grants Commission N.E.R.O, Govt. of .India, Guwahati is sincerely acknowledged.

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