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# What do we know about Indonesian tropical lakes? Insights from high frequency measurement

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**Abstract.** When measuring ecological variables in lakes, sampling frequency is critical in capturing an environmental pattern. Discrete sampling of traditional monitoring programs is likely to result in vital knowledge gaps in understanding any processes particularly those with fine temporal scale characteristics. The development of high frequency measurements offer a sophisticated range of information in recording any events in lakes at a finer time scale. We present physical indices of a tropical deep Lake Maninjau arrayed from OnLine Monitoring System (OLM). It is revealed that Lake Maninjau mostly has a diurnal thermal stratification pattern. The calculated lake stability (Schmidt stability), however, follows a seasonal pattern; low in December–January and around August, and high in May and September. Using a 3D numerical model simulation (ELCOM), we infer how wind and solar radiation intensity control lake's temperature profiles. In this review, we highlight the needs of high frequency measurement establishment in Indonesian tropical lakes to better understand the unique processes and to support the authorities' decision making in maximizing the provision of ecosystem services supplied by lakes and reservoirs.

## 1. Introduction

Lakes provide several number of ecosystem services of habitat for aquatic organisms, freshwater for all organisms, and for recreational purposes. Lakes are also known as sentinels of changes in climate and anthropogenic impacts [1]. With these vital functions and services, lakes have been assessed and monitored by the society around the globe to better understand how lakes behave in response to anthropogenic force and climate changes [2]. Hence, information gained from such monitoring program is aimed to support authorities in making adequate management decision. Over the years, traditional monitoring program, e.g.: the monthly observations, have been performed by lake managers. However, due to the discrete nature of that sampling program, a considerable gap of information related to short-lived, extreme events, and daily cycles may be undeniable. Therefore, the need for continuous monitoring, that is, type of monitoring program in continuously collecting data at high temporal scale is demanding.

In this paper, we present physical indices of Lake Maninjau, West Sumatra, Indonesia, arrayed from a continuous monitoring program which was initially installed to caution the lake manager on the possible of anoxic epilimnion. We are aiming to quantify variability in thermal stratification in a tropical deep lake using a high-frequency (10 minutes time interval) data set of vertical temperature profiles. In addition, we ran a 3D hydrodynamic model simulation (ELCOM) to capture the important factors that drives the temporal variability. Characterizing stratification structure of the lake is the first step towards understanding how hydrodynamics may force to influence lake-ecosystem dynamics especially biogeochemical cycling (e.g. anoxic epilimnion occurrence). Through this paper, we emphasize the importance of a sophisticated high frequency monitoring system in tropical deep lakes.

## 2. Methods

Lake Maninjau (0°19′S, 100°12′E) is a deep eutrophic system in the tropics that has a surface area of 99.5km2, a volume of 10.1km3, a mean depth of 105m and a maximum depth of 165m (Figure 1). Lake Maninjau has been included in the National Priority in Lake Restoration Program. The current trophic state of the lake is eutrophic with total nitrogen (TN) and total phosphorous (TP) concentration up to 1.4 mg $L^{-1}$ and 0.07 mg $L^{-1}$, respectively [3]. Anoxic epilimnion has been observed several times causing massive fish die off in floating cage aquaculture (Suryono, pers. Comm).

In late 2014 Research Centre for Limnology deployed a monitoring buoy; the On Line Monitoring System (OLM). The OLM buoy is equipped with a set of thermistor chain placed at 2 m intervals from 0.5m to 62m depth. All sensors are capturing data every ten minutes. However, due to occasional technical failures and system maintenance, gaps in time series data cannot be avoided. In addition to the thermistor line, meteorological sensors were also installed in the early February 2017.

We quantified physical indices of the lake, i.e.: thermocline depth and Schmidt stability, on the hourly average scale. Thermocline depth (m) was defined as the greatest rate of density change with depth, arrayed from vertical temperature profile recorded by OLM. Schmidt stability (J $M^{-2}$), a measure of the resistance to physical mixing, was derived from the profile and lake bathymetric data. All physical indices computations (see theoretical basis given by [4]) were performed using *rLakeAnalyzer* software [5]. We bootstrapped the calculated thermocline and Schmidt stability at every 2 pm observation into a weekly and monthly scale to examine long-term and seasonal dynamics. The extracted median and 95% confidence interval of the bootstrapped data were then plotted to visualize seasonal pattern.

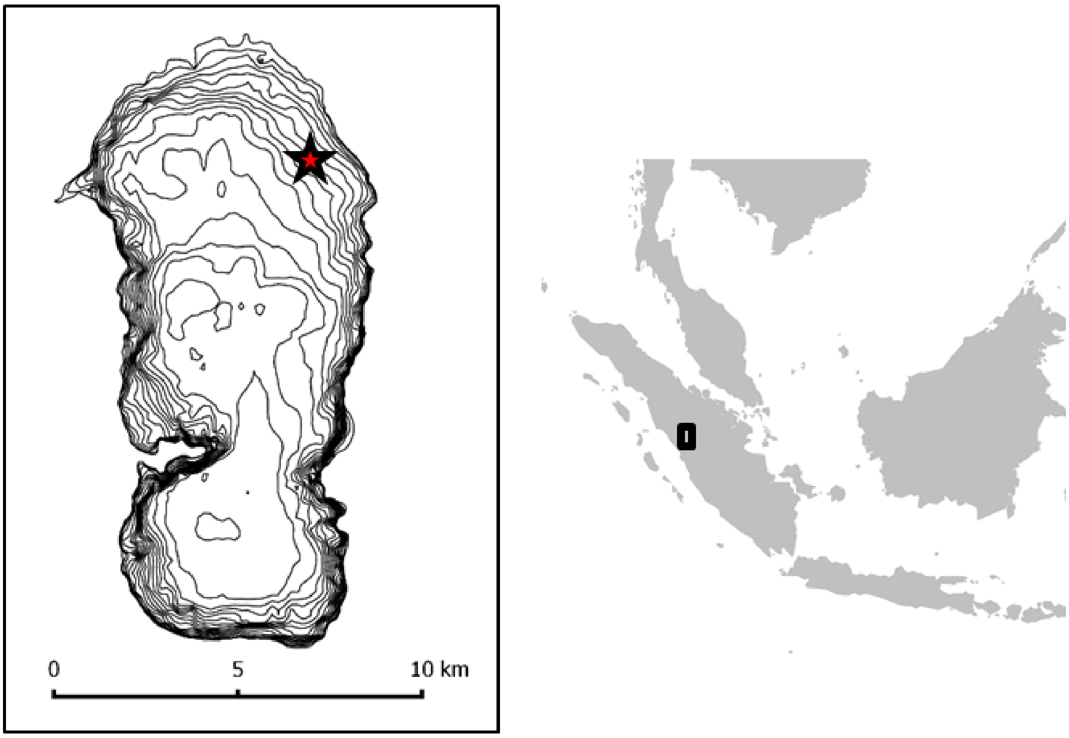


**Figure 1.** Lake Maninjau in Sumatra Island of Indonesia. Bathymetry map indicates isobaths of 10 m depth. The location of the OnLine Monitoring System (OLM) is shown by the red star. Source: GIS Lab. RC for Limnology-LIPI.

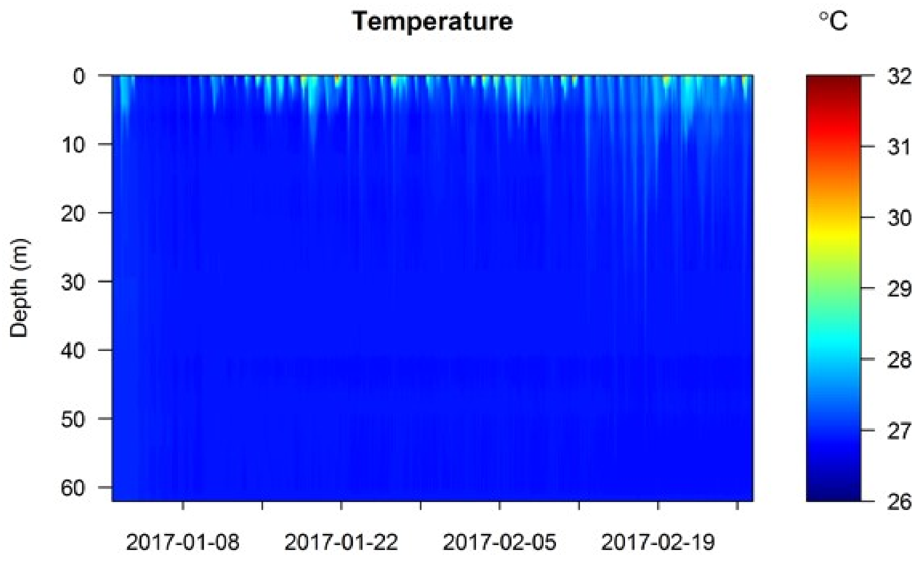


**Figure 2.** A Snapshot of water temperature of Lake Maninjau arrayed from the OnLine Monitoring System (OLM).

We employed a 3D hydrodynamic model (ELCOM: [6]) by feeding the model with the observed meteorological data, i.e. atmospheric pressure, air temperature, relative humidity, wind speed, solar radiation, wind direction and precipitation rate. The model was run over a period of 1 week from an initial condition given by the measured temperature profile. We simulated the scale of meteorological force in controlling thermal stratification in the lake.

## 3. Results

### *3.1. Diurnal stratification*

We revealed that the deep tropical Lake Maninjau has a diurnal thermal stratification cycle (Figure 2). Temperature difference between surface and bottom water is up to 3°C during the day while during the night thermal stratification is barely to happen. However, occasionally thermal stratification could not be developed. There was no temperature difference between surface and the deep water during that period.

### *3.2. Seasonal variation*

A strong seasonal pattern of physical indices was observed over a 2 years high frequency dataset (Figure 3). Thermocline depths during the peak of solar intensity (around 2 pm) were observed around 4 – 20m (figure 3A and 3B). The deepest thermocline depths were mostly observed around August and October. However, in mid to late of 2016, thermocline depth sink to a deeper layer (30 – 50m). The calculated Schmidt stability ranged from over 1500 to 4660 J $m^{-2}$ annually. The lowest stability mostly occurred around December to January, being highest in May and September (figure 3C and 3D). Stability also dropped in August to around 2500 J $m^{-2}$.

### *3.3. Forcing from meteorological factors*

ELCOM simulated that high wind condition is able to de-stratify surface layer (Figure 4A and 4B). At low wind condition, thermal stratification can be developed during the day. Weak stratification was also modelled to happen when solar radiation is low. Hence, it is likely that the occasional isotherm (e.g. early 2017: figure 2) is due to a strong wind event and insufficient solar radiation.

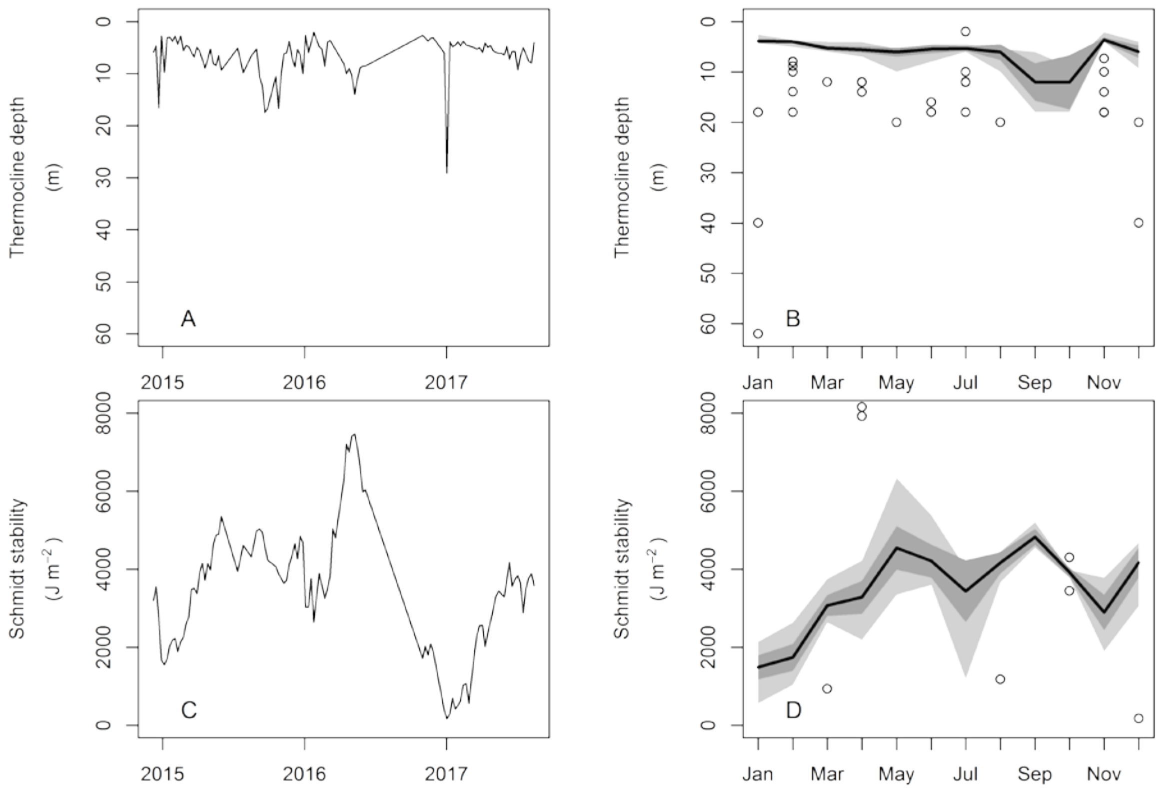


**Figure 3.** Seasonal pattern of physical indices in Lake Maninjau. Solid black lines indicate median, dark grey shadows indicate 95% confidence interval, light grey indicate 75% percentiles and open circles mean outliers.

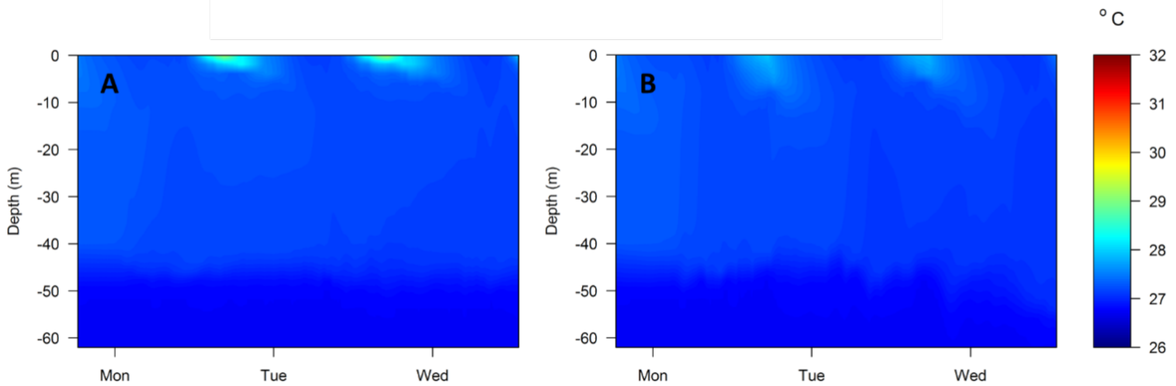


**Figure 4.** ELCOM simulation of Lake Maninjau at the OLM observation point under low wind and high solar intensity (A) and high wind and low solar radiation (B).

## 4. Discussion

Lake hydrodynamics are known to control concentrations of nutrients, dissolved oxygen, gases and other biogeochemical properties in lakes. While in most temperate deep lakes, seasonal patterns are very obvious following its four season, i.e. summer stratification, autumn-winter-spring mixing [7], temporal variations in tropical lakes occur in daily scales, particularly in the epilimnion [8,9]. Although annual mixing is possible to happen in deep tropical lakes, it may occur only down to a shallow depth where the deeper layer of the lake is relatively stable [9]. In Lake Maninjau, this active mixed layer can be as deep as 50m (Figure 2A) hence a stable hypolimnetic water lays below that active layer.

It can be synthesized that there is a continuous shoaling of oxygenated upper layer in Indonesian deep lakes [10]. Their hypothesis was also related to the massive fish death in the floating cages as the anoxic bottom water moving upward to near surface due to a strong wind event. This is confirmed by our model simulation that a strong wind event and low insolation may destratify and mix the lake. It can also be also that: 1. Oxygen production from autotrophs were low due to low intensity of solar radiation, and 2. the diffused/mixed anoxic deep water to the surface may undergo oxidation (e.g. $NH_4$ to $NO_3$), hence reduces the availability of oxygen. However, to strengthen such argument, we should provide evidence resulted from biogeochemistry processes that involve oxygen dynamics in the lake.

As sentinels of climate change [1], deep tropical lakes may be of interest for most limnologist in that regard. Due to the warming climate, vertical mixing in the relatively shallow upper layer may slow down, hence increasing the persistence of the deep bottom water [8]. Thus, this may thicken the anoxic deep water to the upper layer as hypothesized by [10]. Further, the lake may also accumulate nutrients and greenhouse gases in which such condition may promote eutrophication and contribute to global warming if a mixing event occurs.

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**References**

[1] Adrian R, O'Reilly C, Zagarese H, Baines S, Hessen D, Keller W, Livingstone D et al. 2009 *Limnol. Oceanogr*.**54**, no. 6 (part2): 2283-2297
[2] Rose K, Weathers K, Hetherington A, and Hamilton D 2016 *INLAND WATERS*. **6**, no. 4: 476-482.
[3] Sulastri, Santoso A, and Nomosatriyo S 2016 *Proceedings of the 16th World Lake Conference*: 536-548.
[4] Read J, Hamilton D, Jones I, Muraoka K, Winslow L, Kroiss R, Wu C, and Gaiser E 2011 ***Environ Model Softw***. **26**, no. 11: 1325-1336.
[5] Winslow L, Read J, Woolway R, Brentrup J, Leach T, and Zwart J 2015 *rLakeAnalyzer: Package for the Analysis of Lake Physics*. *R package version 1.7.3*.
[6] Romero J, Antenucci J, Imberger J 2004. ***Ecol Modell***. **174**, no. 1: 143-160.
[7] Bruesewitz D, Carey C, Richardson D, and Weathers K 2015 *Limnol. Oceanogr***60**, 347–359. doi: 10.1002/lno.10014
[8] Verburg P, and Hecky R 2009. *Limnol. Oceanogr*. **54**, no. 6 (part2): 2418-2430.
[9] Katsev S, Crowe S, Mucci A, Sundby B, Nomosatryo S, Haffner D, and Fowle D 2010 *Limnol. Oceanogr*.**55**, no. 2: 763-776.
[10] Fukushima T, Matsushita B, Subehi L, Setiawan F, and Wibowo H. 2017 *Sci. Rep*. **7**:45320.