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# A Comparison of Simple Snowmelt Models for the Ane River Basin

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**Synopsis**

The objective of the present work was to develop and compare simple snowmelt model formulations using data from the Ane River Basin. The model comparison was done using winter 2001-2002 data from the Surumi station, located in the Ane River Basin, Northeast part of Lake Biwa. A temperature-index and a enhanced temperature-index (including income shortwave radiation) models were applied to the data considering different time resolutions. The results show that the empirically derived base model using hourly time steps had a good agreement with the data. Apparently, using hourly data to go to a finer resolution of 10 minutes data could be used without so much error arising from the simulation. The Enhanced Temperature-index compared to the other models showed little to no improvement.

**Keywords**: Snowmelt, Temperature-index model, Ane River Basin, Lake Biwa Basin

## 1. Introduction

Lake Biwa is the largest freshwater body in Japan and it has been studied by many scientists due to its importance for the regional water resources. Lake Biwa has experienced many environmental problems such as loss of species habitat and changes in water quality (Kumagai et al., 2003). Different catchments characterized by different land use and climatic conditions play an important role in Lake Biwa circulation and water quality. Different patterns of nutrients are found due to seasonal cultivation of paddy fields for example (Tanaka et al., 2009). Also, it is believed that in the winter water from snowmelt have different pattern of intrusion in the lake and carry high concentration of dissolved oxygen (Kumagai and Fushimi, 1995; Kitazawa and Kumagai, 2005).

The largest basin that contributes to Lake Biwa is the Ane River Basin. This basin is located in the northern part of Lake Biwa where there is significant snowfall in the winter. Therefore, it is important that we estimate how much and when runoff from snowmelt is being produced in this area. Snowmelt might influence the water quality (e.g. DO concentration in the hypolimnion of the lake) as well as the water quantity (e.g. flood problems due to snowmelt and rain during spring). Besides that, the proper estimation of the snowmelt is necessary for analyzing different climate change scenarios.

Usually two approaches are used for snowmelt estimation: energy balance models and temperature index models. The advantage of the former one is that it calculates melt as a residual of the heat balance equation; however, they are more complex to be implemented and usually need more meteorological data. The latter is easy to be implemented and uses data that are usually widely available, such as air temperature; its shortcoming is the dependence on the empirical relationship which is usually site specific and difficult to transfer to different locations. Japanese researchers

(Suizu, 2005; Totsuka et al., 2004) have developed models for the estimation of distributed snow water equivalent (SWE) and snowmelt. Kazama et al. (2008) successfully applied a distributed temperature index method for simulating snow cover in Japan using remote sensing information. However, the lack of ground truth data, such as SWE, and the resolution and time lag in the dates between image acquisitions sometimes might limit the simulations. The objective of the present work was to develop and compare simple snowmelt model formulations using data from the Ane River Basin. This type of simple temperature index point studies might be helpful for further implementation of spatially distributed models or for validation of their accuracy.

## 2. Study Area

The Ane River Basin is located in the Northeast region of Shiga Prefecture (Fig. 1) and it is the largest contributing basin to Lake Biwa. It belongs to the Japan Sea climatic region, there is snowfall in the winter and snowmelt during spring is a big part of total river discharge. The average temperature is 14.5 °C and precipitation around 2000 mm per year. The Surumi meteorological station is located in the town of Yogo in the north part of the Ane River Basin, 35.57 N 136.22 E, at an elevation of 214 m.

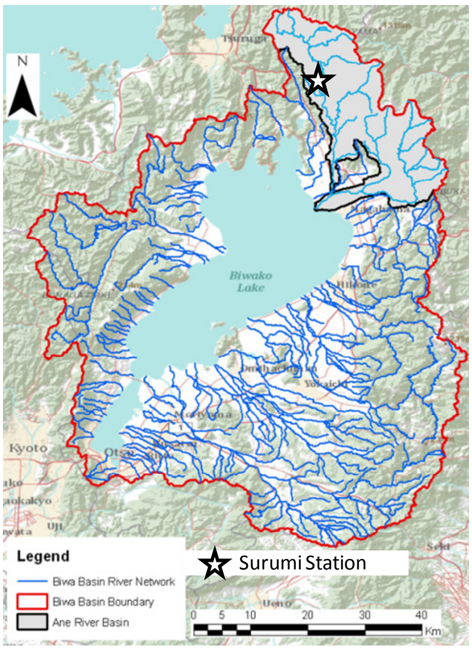


Fig. 1 Sketch of Lake Biwa Basin and the location of the Meteorological station in the Ane River Basin.

## 3. Meteorological and Snow Data

The meteorological data was obtained from the Surumi station (Fig. 2). The data used in this research was from 1st of December 2001 to 31st of March 2010. Precipitation, temperature, and solar radiation were measured automatically every 10 min. Data used in this study with different resolution (hourly and daily) were simply aggregated from the finest resolution one (10 minutes). The precipitation was measured using a rain gauge with a 0.5mm resolution. During this period, there were 16 measurements of snow depth and weight for the estimation of SWE.

Fig. 2 Surumi station. Right: meteorological equipment and rain gauge. Left: equipment for SWE measurement.

## 4. Snowmelt Models

### 4.1 Snow accumulation

The separation of precipitation into snow (Ps) and rain was made using an empirical relationship (Iwaki et al., 2009) Eq. (1). That is the first step for the snow accumulation

$$\begin{cases} P_s = P \cdot \dfrac{a}{100} & a = -17.63\ T + 86.61\ \ (-0.8 \le T \le 4.9) \\ P_s = P_s & a = 100\ \ (T < -0.8) \\ P_s = 0 & a = 0\ \ (T > 4.9) \end{cases} \quad (1)$$

$P$ is the precipitation (mm), $P_s$ the snow (mm), $T$ the ground air temperature (°C) and a (%) is the probability of occurrence of solid precipitation. The relation between $a$ and $T$ (°C) was derived by using data obtained from meteorological observations carried out in the city of Hikone, which is located in the eastern part of Shiga Prefecture. During this observations the temperatures ranged from -0.75 °C to 5.75 °C. The snow accumulation is then calculated using a simple mass balance equation:

$$\frac{d}{dt}SWE = P_s - M \qquad (2)$$

where *SWE* is the snow water equivalent (mm) and *M* the total snow melt.

**4.2 Snowmelt calculation**

Three different approaches for simulating snowmelt were adopted. One based on a previously developed and tested degree-hour method for the Surumi site (Iwaki et al., 2009). The temperature factor of the previous model was used to linearly estimate the temperature factor of two other time resolutions (10 minute and daily). The other methods were the temperature- index method and an enhanced temperature-index method, both calibrated considering different time resolution (10 minutes, hourly and daily).

**(1) General formulation**

The basic temperature-index method is calculated according to the commonly used (Hock, 2003) equation:

$$M = \begin{cases} TF * T & T > T_0 \\ 0 & T \le T_0 \end{cases} \qquad (3)$$

where $M$ is the melt (mm $[T]^{-1}$), TF is the temperature factor (mm $[T]^{-1}$ °C$^{-1}$), $T$ is the mean temperature (°C) for the time step in consideration and $T_0$ is the threshold temperature above which melt occurs (°C).

**(2) Base model**

The base model for comparison in this study was the degree-hour of Eq. (4) (Iwaki et al., 2009).

$$M = \begin{cases} TF_h * T & T > T_0 \\ 0 & T \le T_0 \end{cases} \qquad (4)$$

In this case the $TF_h$ is the hourly temperature factor which is set equal to 0.23 (mm h$^{-1}$ °C$^{-1}$) for the base model. It was calculated as the average between the value obtained by regression and the heat balance method using the aggregated 10 minute resolution data to hourly time steps.

**(3) Enhanced temperature-index model**

Some changes that include shortwave radiation in the simple temperature-index model have been proposed and seem to have a positive effect in the calculations (Hock, 2003; Pellicciotti et al., 2005). We call the enhanced temperature- index model the formulation which we included the incoming shortwave radiation Eq.(5).

$$M = \begin{cases} TF * T + SRF * Rad & T > T_0 \\ 0 & T \le T_0 \end{cases} \qquad (5)$$

where SRF is the shortwave radiation factor (mm $[T]^{-1}$ W$^{-1}$) and Rad is the incoming shortwave radiation (W m$^{-2}$). It should be noticed that it differs from other formulations where usually shortwave radiation balance was used (Hock, 2003; Pellicciotti et al., 2005). For simplicity and lack of data, we decided to use only the incoming shortwave radiation.

**4.3 Calibration and sensitivity analysis**

For the calibration we gave each of the index factors a broad range of values selected from previous simulation trials (Table 1). We used a Monte Carlo simulation with uniform distribution to sample parameter values. For each different time resolution we ran it 10,000 times. The parameters which yielded minimum error values were selected as the optimum ones.

Table 1 Parameter ranges used for calibration.TIM is the Temperature-index method. E-TIM is the Enhanced Temperature-index method. *TF* is the temperature factor and *SRF* is the shortwave radiation factor.

| | Parameter Range | |
|---|---|---|
| | *TF* | *SRF* |
| TIM (daily) | 0.01 - 100 | - |
| TIM (hourly) | 0.001 - 10 | - |
| TIM (10 minutes) | 0.001 - 10 | - |
| E-TIM (daily) | 0.000001 - 4 | 0.000001 - 40 |
| E-TIM (hourly) | 0.000001 - 4 | 0.000001 - 5 |
| E-TIM (10 minutes) | 0.000001 - 4 | 0.000001 - 5 |

The error function chosen for the calibration and sensitivity analysis was the average relative error, calculated as follows:

$$Error = \frac{\sum_{t=1}^{N} \left| \frac{SWE_C(t) - SWE_O(t)}{SWE_O(t)} \right|}{N} \qquad (6)$$

where *Error* is the average relative error, $SWE_C$ is the snow water equivalent calculated for the time step *t*, $SWE_O$ is the observed snow water equivalent and *N* is the number of observations.

## 5. Results and Discussion

### 5.1 Base model

The base model run can be seen in Fig. 3. As expected, the best simulation was obtained with the hourly time resolution, since that was the one used to derive the $TF_h$ value. The temperature factor for the 10 minutes time step simulation was calculated by simply dividing the value of $TF_h$ by 6 (10min/60min). The temperature factor for the daily calculation was obtained by multiplying $TF_h$ by 24 (24h/1h). This would be the rational if we expected a uniform temperature distribution along the day. Since it is not uniform, this method underestimates the *TF* value for the daily simulation and over estimates the *TF* value for the 10 minutes resolution simulation (Fig. 3). However, the difference between the relative error of the hourly and the 10 minutes estimates is very few.

### 5.2 Calibration

The calibration of the Temperature-index method showed a quite significant reduction in the error of the simulations for all the time resolutions (Table 2). This was due to specific calibration for each one of them. Table 3 shows that in relation to the base model, the values of calibrated *TF* for the daily time step was about four times higher, for the 10 minutes one it was lower. It is interesting to see that the value of the calibrated temperature-factor for the daily series is about 20.79 (mm $d^{-1}$ $°C^{-1}$) and that in previous study (Kazama et al., 2008) it was found a value of 20 for Japan when using satellite images for the calibration.

The calibration of the Enhanced Temperature-index method only showed better performance in relation to the base model in the daily time step simulation. For the hourly and 10 minutes simulation, it actually had worse results than the other models.

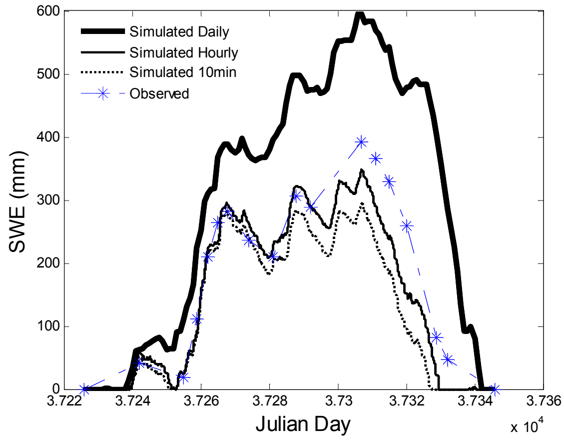


Fig. 3 Snow water equivalent (*SWE*) for the period of 1 December 2001 to 31 March 2002. Simulation were done using the base model. Simulated Hourly used hourly data, Simulated 10min used 10 minutes time steps and Simulated Daily used daily time steps.

Table 2 Error values obtained with the simulations. BM is the base model. TIM is the Temperature-index method. E-TIM is the Enhanced Temperature-index method.

| | *Error* | | *Error* | | *Error* |
|---|---|---|---|---|---|
| BM (daily) | 1.53 | BM (hourly) | 0.35 | BM (10 minutes) | 0.37 |
| TIM (daily) | 0.52 | TIM (hourly) | 0.26 | TIM (10 minutes) | 0.22 |
| E-TIM (daily) | 0.56 | E-TIM (hourly) | 0.52 | E-TIM (10 minutes) | 0.85 |

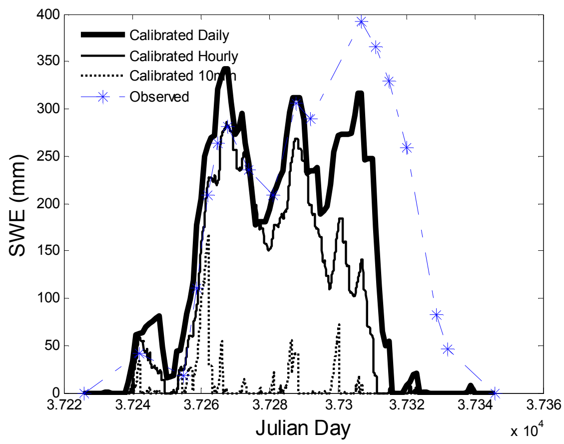


Fig. 4 Snow water equivalent (*SWE*) for the period of 1 December 2001 to 31 March 2002 calculated using the calibrated enhanced temperature-index method. Calibrated Hourly used hourly data.

### 5.3 Sensitivity analysis

A sensitivity analysis was carried out in order to identify the most suitable ranges of parameters that could be used for snowmelt simulation. This analysis is also useful to compare the different importance of the parameters in each model. Fig. 5

shows the sensitivity analysis for the Temperature-index method. We can distinguish that the simulations are much more sensitive when using higher temporal resolution (hourly and 10 minutes). The values of the temperature factor for the daily simulations can vary in a much wider range without changing so much the model performance.

The Enhanced Temperature-index model was more sensitive to the *SRF* in the daily and hourly time steps calculations (Fig. 6). For the 10 minutes calculations, the model became more sensitive to the *TF* parameter. This might be an indication of the greater importance of using radiation values for calculating snowmelt in daily time steps. However, this analysis is limited by our use of total incoming shortwave radiation and not net radiation information.

Table 3 Parameter values obtained with calibrations. BM is the base model. TIM is the Temperature-index method. E-TIM is the Enhanced Temperature-index method. *TF* is the temperature factor and *SRF* is the shortwave radiation factor.

| | Parameter | |
|---|---|---|
| | *TF* (mm day$^{-1}$ °C$^{-1}$) | *SRF* (mm day$^{-1}$ W$^{-1}$) |
| BM (daily) | 5.52 | - |
| TIM (daily) | 20.79 | - |
| E-TIM (daily) | 3.94 | 0.495 |
| | *TF* (mm h$^{-1}$ °C$^{-1}$) | *SRF* (mm h$^{-1}$ W$^{-1}$) |
| BM (hourly) | 0.23 | - |
| TIM (hourly) | 0.18 | - |
| E-TIM (hourly) | 0.15 | 0.01 |
| | *TF* (mm 10min$^{-1}$ °C$^{-1}$) | *SRF* (mm 10min$^{-1}$ W$^{-1}$) |
| BM (10 minutes) | 0.038 | - |
| TIM (10 minutes) | 0.027 | - |
| E-TIM (10 minutes) | 0.031 | 0.0396 |

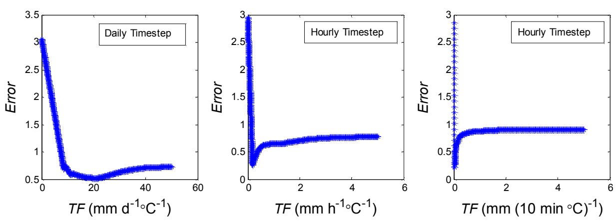


Fig. 5 Sensitivity of the temperature-index model to the temperature-factor (*TF*) considering different time scales. *Error* is the average relative error.

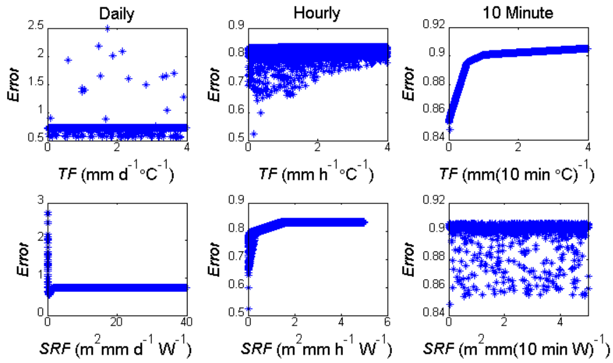


Fig. 6 Sensitivity of the enhanced temperature-index model to the temperature-factor (*TF*) value and to the shortwave radiation factor (*SRF*) considering different time scales. *Error* is the average relative error.

It is important also to take into account that this study used the *SWE* for the calibration. *SWE* is only a proxy value for snowmelt. Therefore, it is hard to judge if the radiation information was not very important for the improvement of the simulations. The comparison of this results with snowmelt data or to a energy balance model would be interesting for next studies and could shed some light on why the incoming shortwave radiation seemed to play a little role in the snowmelt results of the present study.

## 6. Conclusions

This study evaluated the use of simple model formulations for the simulation of the changes in SWE. The model comparison was done using winter 2001-2002 data from the Surumi station, located in the Ane River Basin, Northeast part of Lake Biwa. A temperature-index and an enhanced temperature- index model were applied to the data considering different time resolution.

The results show that the empirically derived base model using hourly time steps had a good agreement with the data. Apparently, using hourly data to go to a finer resolution of 10 minutes data could be used without so much error arising from the simulation. The Enhanced Temperature-index compared to the other models showed little to no improvement. When calibrated for the 10 minutes resolution, the model lost the sensitivity to the SRF parameter. This could be an indication that using radiation data is more important for daily calculations.

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## 姉川流域のための簡単な融雪モデルの比較


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### 要　旨

本研究の目的は，姉川流域より融雪期に取得した積雪および水文気象データを用いて簡易融雪モデルの構築を行なうことである。モデル結果は2001ー2002年における姉川流域摺墨観測点での観測データを用いて比較を行なった。温度指数(Temperature Index)モデルと短波放射を考慮した拡張温度指数(Enhanced Temperature-index Method)モデルをそれぞれ異なる時間ステップを考慮した上で計算を行なった。経験ベースのモデルにて１時間ステップの時間間隔でのシミュレーションが観測結果との最も良好な一致をみた。10分間隔の時間ステップを用いたシミュレーションはそれほど誤差の増加がなく用いることができる。拡張温度指数モデルと他のモデルを比較した結果は本検討においては著しい改善はみられなかった。



**キーワード**:融雪，拡張温度指数モデル，姉川流域，琵琶湖流域