

Sensitivity analysis of time integration methods for updating soil moisture in land surface model

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1. INTRODUCTION

Accurate prediction of soil moisture plays an important role in land surface model (LSM) for estimating water and energy balance. This study aims to investigate the impacts of different time integration methods using two sets of soil parameters adopted in two LSMs: SiBUC (Tanaka, 2005) and MRI-SiB (Hirai et al. 2007) on soil moisture estimation.

2. METHODOLOGY

In this study, numerical experiments were performed by SiBUC to investigate the impacts of different time integration methods on water budget and soil moisture estimation. The equations for soil moisture in SiBUC is calculated based on a simplified Richards equation for three soil layers. Two methods applied in this study are an explicit-midpoint (adopted in SiBUC) and a semi-implicit (implemented in MRI-SiB) (Tinumbang et al. 2021). The explicit method is calculated by evaluating the slope of the solution at the midpoint between the current and next time step. While the implicit method is applied to matric potential by linearizing soil moisture using a Taylor expansion. The sets of parameters were selected based on dominant soil parameters in the upper part of the Ping River Basin in Thailand, shown in Table 1. Soil-a is a set of parameters of clay-loam soil used in SiBUC, while soil-b is broadleaf-evergreen forest parameters in MRI-SiB. Hydraulic conductivity and matric potential in SiBUC are based on Clapp and Hornberger's relationship, shown in Fig. 1. One year simulation in 1991 with hourly time steps was performed using MRI-AGCM 3.2S output (Mizuta et al. 2012). However, only one-day results during an intense-rainfall event on August 15, 1991, were analyzed for the impact analysis.

3. RESULTS AND DISCUSSION

3.1 Comparison of water budget

Table 2. shows comparison of water budget for one-day on August 15, 1991, in one soil column for each soil type, using different time integration methods for updating the soil moisture. Most of the rainfall became runoff in this event, and only a small portion was evapotranspired. All simulation shows the runoff was generated mainly as surface runoff rather than subsurface runoff. The estimated amount of each runoff component was similar in the case of using soil- a. On the other hand, when soil-b was applied, simulation using the midpoint-explicit method showed a significantly higher surface runoff than that of the semi-implicit method. This was due to the difference in soil moisture estimation by each method, particularly of the surface soil layer.

3.2 Time series of soil moisture

Fig. 2 shows an hourly time series of rainfall, hydraulic conductivity, and soil moisture of the top layer estimated by each

Table 1 Soil parameter settings used in this study.

Parameters	Soil-a	Soil-b
Saturated hydraulic conductivity K_s ($m s^{-1}$)	1.44×10^{-6}	2×10^{-5}
Saturated matric potential ϕ_s (m)	-0.63	-0.086
B power	8.41	7.12
Thickness of 1 st , 2 nd , and 3 rd soil layer (m)	0.02, 2.53, 3.92	0.02, 1.48, 2

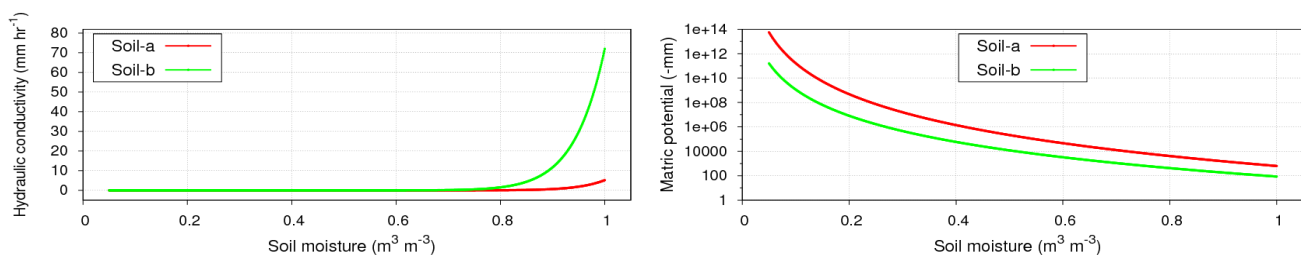


Fig. 1 Hydraulics property of each soil type following Clapp and Hornberger's relationship.

Keywords: land surface models, soil moisture, runoff, Richards equation, Ping River Basin

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Table 2 Comparison of water budget on August 15, 1991 event (unit: mm day⁻¹).

Soil type	Soil-a		Soil-b	
	Explicit-midpoint	Semi-implicit	Explicit-midpoint	Semi-implicit
Rainfall	173.60			
Evapotranspiration	0.70	0.71	0.57	0.56
Runoff	108.39	101.53	121.03	67.89
Surface runoff	108.36	101.50	111.71	53.53
Subsurface runoff	0.03	0.03	9.32	14.36
Change of soil moisture	64.51	71.43	51.80	105.15

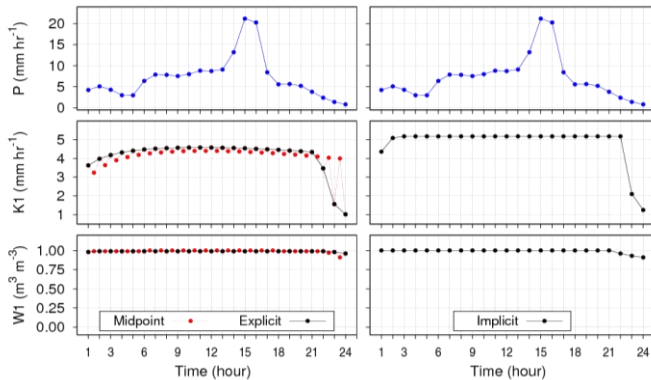


Fig. 2a Simulation by using soil-a.

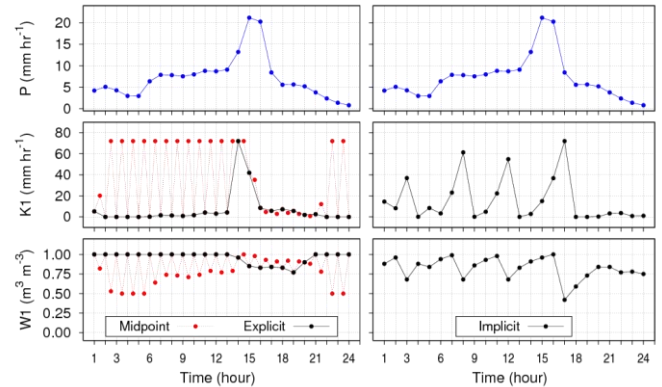


Fig. 2b Simulation by using soil-b.

Fig. 2 Top, middle, and bottom panels represent an hourly time series of rainfall from MRI-AGCM 3.2S (mm hr⁻¹), hydraulic conductivity (mm hr⁻¹), and soil moisture of surface soil layer (m³ m⁻³) on August 15, 1991, respectively. Left and right figures are simulated by midpoint-explicit and semi-implicit methods, respectively. Red and black lines represent midpoint and updated variables of each method for each time step.

method for each soil type. Hydraulic conductivity is one of the important variables affecting soil moisture as it is used for calculating infiltration rates. The higher the hydraulic conductivity, the more rainfall can be infiltrated, resulting in the soil moisture tending to be less saturated. It also affects the surface runoff generation because if the soil moisture of surface soil layers tends to be saturated, more surface runoff is calculated. Simulation using soil-a shows a similar estimation of soil moisture of the topsoil layer even though the the calculated hydraulic conductivity is slightly different between the two methods. As the estimated soil moisture tended to be saturated due to small hydraulic conductivity, the surface runoff was generated high. While simulation by soil-b shows a different estimation of soil moisture of the surface soil layer, which affects the surface runoff generation between the two methods. The two-steps calculation in the explicit-midpoint method seems to have some uncertainty when using soil-b was applied. On the other hand, the estimated soil moisture by the semi-implicit method demonstrated an oscillation. These results were due to the behaviour of hydraulic conductivity during saturated and unsaturated condition in this type of soil. Further analysis is required to determine which method is closer to reference soil moisture and to improve the numerical schemes in the land surface models.

4. CONCLUSIONS

This study performed four numerical experiments to investigate the impacts of different time integration methods: an explicit-midpoint and a semi-implicit method, on soil moisture using two sets of soil parameters (soil-a and soil-b), focusing on an intense-rainfall event. It was found that the water budget components were similar between the explicit and implicit methods in the case of soil-a. While, by using soil-b, the explicit method estimated significantly higher surface runoff than the implicit method. These results were due to the differences in soil moisture estimation, particularly of the surface soil layer between the two methods, caused by hydraulic conductivity behavior during saturated and unsaturated conditions. Future work should evaluate and propose improvement methods to enhance soil moisture accuracy in the LSMs.

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