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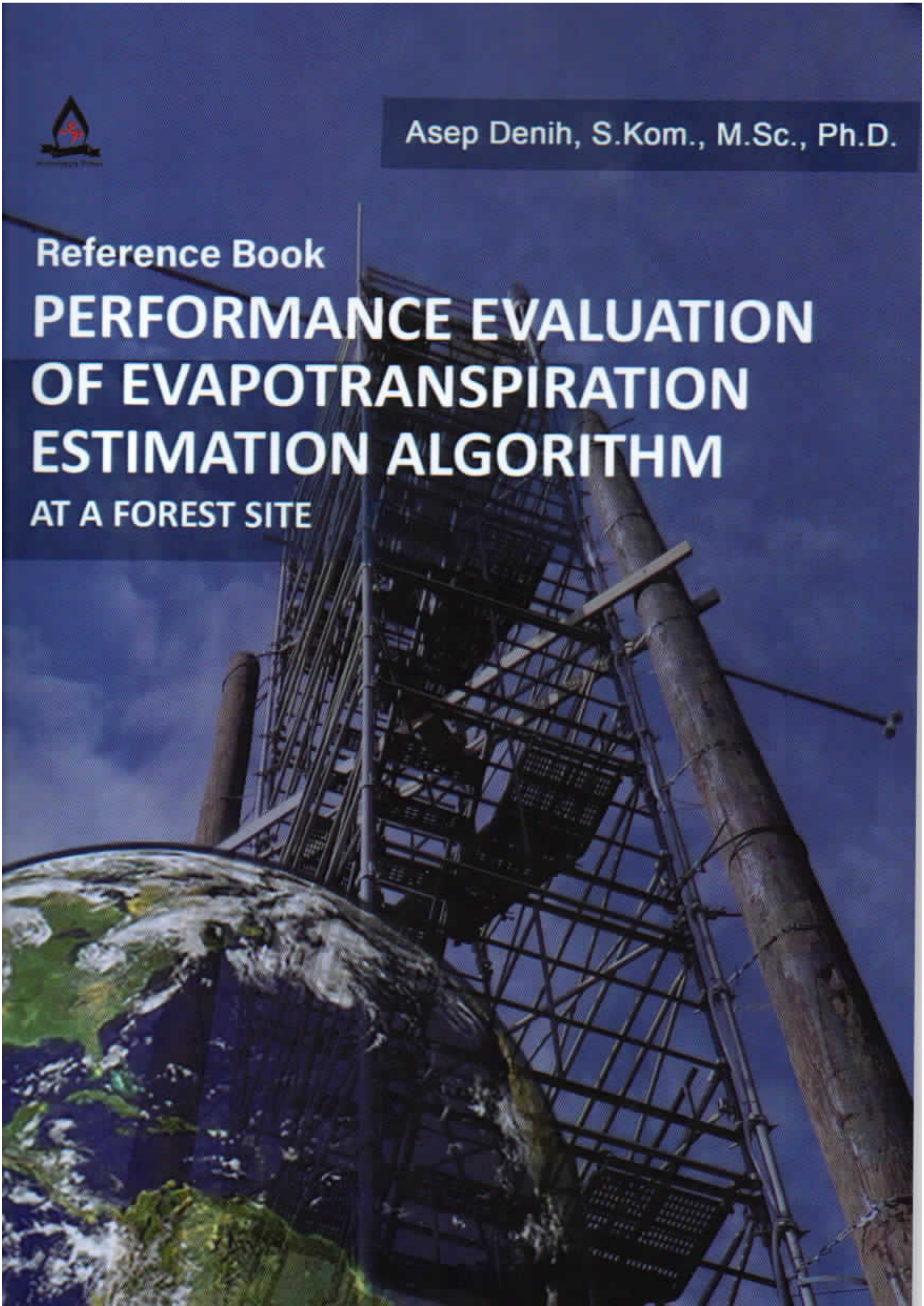
Reference Book

PERFORMANCE EVALUATION OF EVAPOTRANSPIRATION ESTIMATION ALGORITHM

AT A FOREST SITE



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PREFACE

During writing this book, the author supported by many kind and helpful people. The research data of this book processed at the Laboratory of Environmental Informatics, Program Study of Environmentally Harmonized Technology & Science, Department of Environment & Resource Sciences, Faculty of Interdisciplinary Graduate School of Agriculture & Engineering, University of Miyazaki, Japan.

The approach to assessing the efficiency and accuracy of an evapotranspiration estimation algorithm at a forest site in Western America is discussed in this reference book. The eddy covariance method is used to test the GCOM-C ET_{index} estimation algorithm.

The discussion on this book attempted to evaluate the performance of the GCOM-C ET_{index} estimation algorithm a lodgepole pine tree open forest in eastern Idaho, United States.

The presence of the energy balance closure problem in the eddy covariance method prevents a robust and quantitative evaluation of ET estimation, as seen in this reference book.

Thank you to all the people who contributed for the preparation of this reference book. Wish this reference book would be useful to the reader.

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GENERAL INTRODUCTION

Background

Understanding evapotranspiration (ET) availability with reasonable accuracy will make it useful for planning and managing water resources. Failure in ET estimation and accuracy will affect decision-making. ET from the land's surface is among the potential targets for estimation and observation. This study was conducted to provide a reasonably accurate ET estimation.

The eddy covariance method provides measurements of sensible heat and latent heat fluxes over an area and has been widely used in micrometeorology for over 30 y (Burba & Anderson, 2010). Some of the flux measurement dataset, measured globally by several researchers, has been available to the public, it is similar to AsiaFlux and AmeriFlux. Comparing the ET estimation results to latent heat flux measurements using the eddy covariance system has been the most popular method. Nevertheless, the contribution of recent studies regarding ET estimation and its accuracy using the eddy covariance method has still not achieved the expected results, there are difficulties in terms of accuracy to obtain an appropriate result. The energy imbalance problem and reductions in the accuracy of ground-measurement data have prevented an evaluation of the quantitative accuracy of ET estimation.

This book focused on evaluating the accuracy and performance of the Global Change Observation Mission satellite for Climate (GCOM-C) ET_{index} estimation algorithm. Two methods were used to assess the accuracy and performance of the algorithm model, in this book discussed on the eddy covariance method and the next book will discussed on scintillometer data measurement. The eddy covariance system has underestimated the ET because of an energy closure problem. There are some uncertainties and it fails to capture a portion of the energy flux. This study proposed that the GCOM-C ET_{index} estimation algorithm needs a simple linear adjustment to address the ET accuracy measured. To obtain the accuracy measurement of the actual ET estimation, a simple linear adjustment should be applied in the ET algorithm model. A novel approach technique in the ET estimation algorithm model for a forested area is presented in the next book.

Area of Research

The study area is in Island Park, which is situated near Idaho eastern border (Figure 1. Location of the study area) in western USA. The latitude and longitude for the heat transfer measurement location are approximately 44.5 ° N and 111.4 ° W, respectively, and the elevation is approximately 1950 m. Flux measurement was mainly conducted above the canopy in a reasonably homogeneous pine forest 50 y old and with an average maximum tree height of approximately 14–15 m (Figure 2. Photograph of the lodgepole pine forest). The vegetation of the understory was a combination of grasses and herbs of a moderate density. The flux measurement tower heights (Figure 3. Photograph of weather and flux observation tower) were, respectively, 24 m and 22 m for the north tower and south tower; the two towers were nearly 1.7 km apart.

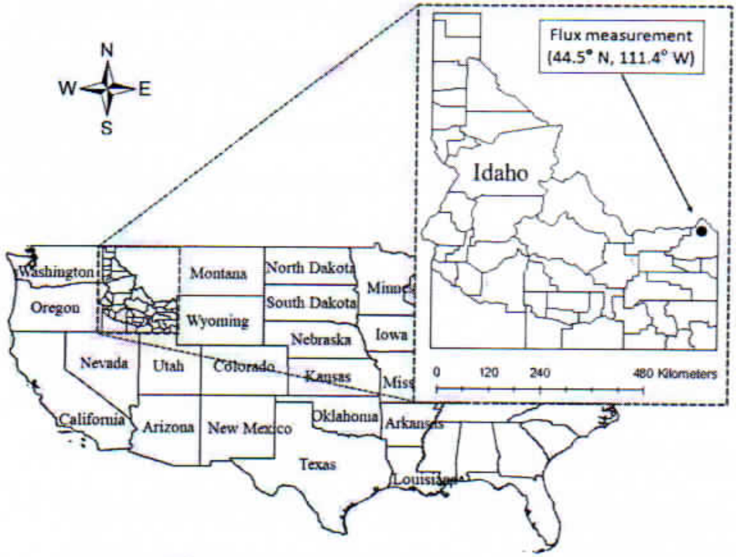

Figure 1. Location of the study area

Figure 2. Photograph of the lodgepole pine forest

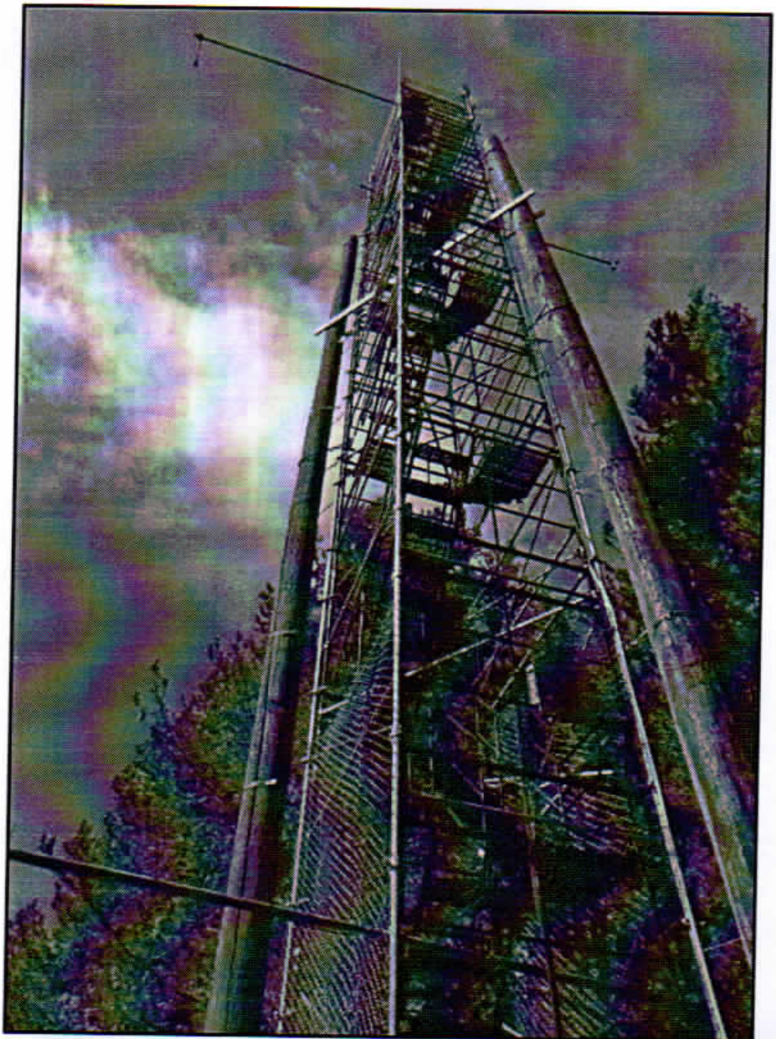

Figure 3. Photograph of weather & flux observation tower

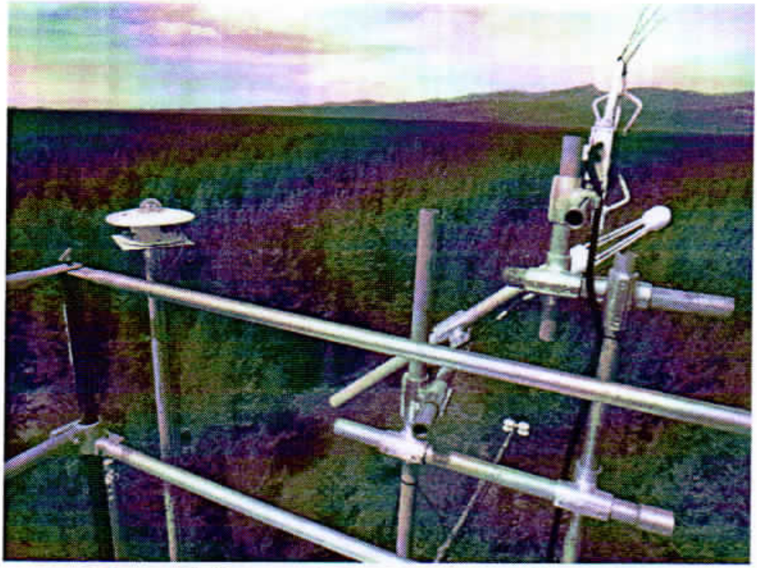

Figure 4. Research instruments at the study area

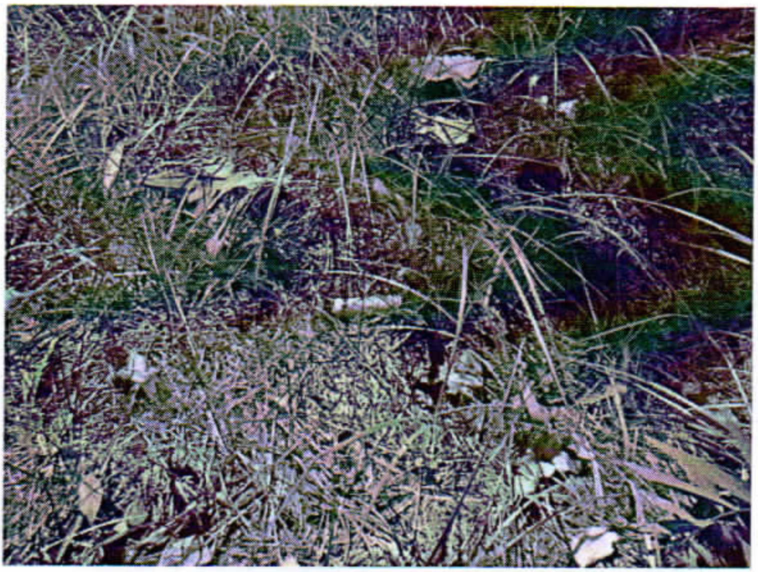

Figure 5. Soil condition at the study area

The soil condition captured in Figure. 5 is in the dry season.

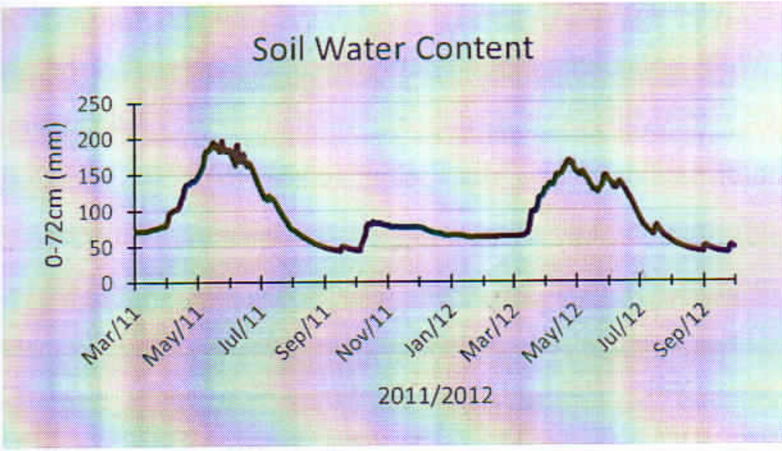

Figure 6. Soil water content condition

The soil water content in the study area from May to June 2011 was increase, it is because in that period the precipitation was high and it occurred from March to June, it reached more than 25 mm. Unlike, in the period of May to June 2012, the precipitation was stable and it reached the average of approximately 25 mm.

Objective

The objective of this discussion was to complete a performance accuracy assessment of the GCOM-C ET_{index} estimation algorithm, at a forested site, using actual measured flux data. This research completed the ground truth dataset observations; a latent heat flux measurement dataset using the eddy covariance. The solution should consider the correctness of the ground truth dataset to assess the accuracy and performance of the GCOM-C ET_{index} estimation algorithm. While some assumptions can simplify the model of the GCOM-C ET_{index} estimation algorithm, they may reduce some information. This discussion considered the missing information. The consistency of the accuracy between the information from the field observation and the GCOM-C ET_{index} estimation algorithm should be carefully and persistently checked. In addition, this book proposed adjustment approach to solve the overestimation problem when ET is computed using the GCOM-C ET_{index} estimation algorithm, particularly in the forested area.

Eddy Covariance System, Energy Balance and GCOM-C ET_{index}

Eddy Covariance System and Energy Balance

ET is a component of a unit that is important for environmental water management, and serves as an indicator of water productivity in a particular area. During the last several decades, several approaches have been used to estimate ET using satellite remote sensing for its spatial and temporal distribution. Tasumi et al., (2016a) developed an ET estimation model that uses a computer procedure to estimate ET. The model is termed the GCOM-C ET_{index} estimation algorithm. The GCOM-C ET_{index} estimation algorithm has limited information regarding its ET estimation accuracy. This is because it has been developed relatively recently (Tasumi et al, 2016b). This application was initially developed for Japan's GCOM-C satellite, which launched in December of 2017.

The most common technique for evaluating satellite-based ET predictions was a comparison of ET outputs to latent heat flux measurements using eddy covariance methods (e.g., Mu et al, 2007). Flux measurement data, such as AsiaFlux and AmeriFlux, measured by several researchers are now available to the public. Although the availability of measurement data using the eddy covariance system is considerable, serious attention is needed regarding some uncertainties from these data because of energy balance closure problems, mainly to estimate ET satellite-based evaluations. The energy balance closure problem is a well-known issue, and thus, flux measurements using eddy covariance methods are uncertain or fail to capture a portion of the energy flux.

Net radiation (Rn), defined as radiation balance (Eq. 1.1) and heat balance (Eq. 1.2), should be theoretically equivalent if advection is neglected. It is well-known as the energy balance as follows:

$$R_n = (1 - \alpha)R_s + (1 - \varepsilon)R_{lin} - R_{lout} \qquad (1.1)$$

where R_n is the net radiation, α is the surface albedo, R_s is the solar radiation, ε is the thermal emissivity of the surface and R_{lin} and R_{lout} are the incoming and outgoing longwave radiations, respectively.

$$R_n = H + LE - G \qquad (1.2)$$

where H is the sensible heat flux, LE is the latent heat flux, and G is the soil heat flux.

Energy flux estimated using the eddy covariance method (i.e., H and LE fusion, also known as "available energy"), however, leads to values lower than those indicated by radiation and soil heat observation. Wilson et al., (2002) discovered that the relative energy imbalance of 22 eddy covariance measurements in the United States and Europe was approximately 20%. Depending on the measuring location, the magnitude of the energy imbalance varies. Significant shortcomings (for example 40% or greater) occur in some areas, while in other locations no energy imbalance is identified.

In this study, the accuracy of the predicting algorithm for GCOM-C ET_{index} was examined using a flux dataset that was evaluated at an open forested site in Island Park in eastern Idaho, western USA, after examining the energy balance closure issue of the measurement flux. This study is the first to attempt to examine the algorithm's precision in a forested area. The findings of this research will therefore provide raw and useful data regarding the algorithm performance in a forested area.

GCOM-C ET_{index} Estimation Algorithm

The GCOM-C ET_{index} assessment method (Tasumi et al., 2016a) measures actual surface evapotranspiration via satellite and climatic data analysis of energy and water availability. The system measures land surface ET by integrating daily satellite-observed surface heat and global or regional climate data. The system adopts a traditional reference ET method (ET_o, Allen, et al. 1998) to promote the use of this index without restricting to crops or vegetation by renaming the satellite crop index to the Evapotranspiration Index (ET_{index}) as follows:

$$ET = ET_{index} \times ET_o \qquad (1.3)$$

ET_{index} is computed as follows:

$$ET_{index} = C_{adj}\frac{T_s(dry)-T_s(act)}{T_s(dry)-T_s(wet)} \tag{1.4}$$

where $T_s(act)$ is the instantaneous actual surface temperature from satellite thermal observation (°C) at the satellite overpass time and $T_s(wet)$ and $T_s(dry)$ are the hypothetical wet and dry surface temperatures (°C), which are the computed instantaneous surface temperatures at the satellite overpass moment assuming the surface has zero sensible heat flux and zero latent heat flux, respectively.

ET_{index} reflects the surface temperature estimated soil wetness. ET_o is calculated by near-surface weather information (solar radiation, air temperature, vapor pressure, and wind velocity) measured on the ground or via a model and reflects the accessibility of surface energy for evapotranspiration.

Satellites with high-frequency monitoring systems, such as GCOM-C, complete the $T_s(act)$ observation only once over a few days at a maximum, depending on cloud cover and the time resolution of the completion of the satellite image. The algorithm includes an interpolation operation when information regarding surface temperatures detected via satellite is not accessible (Tasumi et al, 2016b).

In Eq. 1.4, the C_{adj} coefficient is an empirical variable of modification for the algorithm and was determined to be 1.23. The empirical variables in the algorithm are used to estimate $T_s(wet)$ and $T_s(dry)$ as long as solar radiation, and some wind effect, strongly influence the ground temperatures under these severe circumstances. $T_s(wet)$ is calculated in the following formula:

$$T_s(wet) = C_1 R_s + C_2 - \sin\left(2\pi \frac{DoY + C_3}{365}\right) \times f_{lat} \tag{1.5}$$

where DoY is the day of the year, flat is a function of latitude calculated in Eq. 1.5, and C1 to C3 are calibration constants determined as 0.06, -30.34, and 37, respectively, for the Northern Hemisphere.

$$f_{lat} = -0.0021 \times Lat^2 + 0.3449 \times |Lat| - 2.9864 \tag{1.6}$$

where Lat is latitude in degrees (positive northern part) and the standard variable of Flat should be restricted, Flat is greater than or equal to 0, and Flat is less than or equivalent to

10 (0≤ flat≤10). Ts(dry) is computed using the following formula:

$$T_s(dry) = T_s(wet) + (-0.0023u + 0.0301) \times R_s \qquad (1.7)$$

where u is the wind speed assessed 2 m above the ground (m s-1).

Note that the sequence of formulas is only applicable to clear-sky situations when the surface temperature is measurable via satellite. For rainy days or those without satellites overpassing, the ET_{index} must be measured using a separate technique such as interpolation using the nearest image data. Tasumi et al., (2016b) proposed to choose a minimum ET_{index} value for 16 consecutive days and use the value as a representative ET_{index} for 16 days, in case there is at least one cloud-free day during the 16 days, as cloud contamination increases the ET_{index} value. For automated application with GCOM-C satellite observations and MODIS observations, ET_{index} is described as the proportion of the real evapotranspiration $(T_s(act))$ to the reference evapotranspiration (ET_o). ET_{act} is therefore calculated according to Eq. 1.3, where ET_o is the daily reference evapotranspiration established by the United Nations Food and Agriculture Organization (Allen et al, 1998). A recent update of the algorithm includes a topographic factor for altitude change and the topographical effect of ground temperature on soil wetness (Tasumi et al, 2019).