Physical-guided neural network model with attention mechanism to simulate paddy field water temperature variations

アテンション機構を備えた物理則に基づくニューラルネットワークによる水田水温変動のシミュレーション

○謝　文鵬*、木村　匡臣**、高木　強治*、飯田　俊彰***

WENPENG XIE, MASAOMI KIMURA, KYOJI TAKAKI, TOSHIAKI IIDA

1. Introduction

In order to mitigate high or low-temperature damage of rice, it is desired that the variation of water temperature of ponding water in paddy fields would be predicted and appropriately controlled. While various water temperature simulation models have been proposed so far, it is still required to improve the observed temperature variation's reproductivity and reduce the calculation time and cost.

In the present study, a hybrid model coupling a physical process model with a neural network model to simulate the temperature variation of ponding water in paddy fields is proposed with emphasis on incorporating the attention mechanism.

The objectives of this study are 1. to validate the physical-guided neural network model with the attention mechanism using the observed water temperature and meteorological data at the actual paddy fields. 2. to evaluate the importance of each input variable by analysis of the calculated values of the attention weight in the attention input layer in the proposed model.

2. Materials and Methods

A schematic representation of the proposed model consisting of two main components is shown in **Figure 1**. The 2-layer heat balance model is based on the energy conservation equation defined by meteorological parameters and paddy field conditions to produce time series of predicted ponding water temperature in paddy fields. LSTM includes a recurrent neural network that extracts long and short-term trends from the given time series data. Attention mechanisms identify the salient parts of the input for each instance using the magnitude of the attention weights. This study uses the attention matrix to weight the input features. For neural networks, the attention weights express how much the features contribute to the prediction results. The model can learn the weights of each feature by itself to speed up the model learning.

Because it is known that the density of the vegetation layer has a significant effect on the daily pattern of water temperature in paddy fields, the vegetation growth status parameter (K_L) was introduced in the model, the value of K_L is obtained using the method proposed by Xie et al. (2021).

The data set was fed to the hybrid model containing an attention mechanism input layer and two LSTM layers during training. The output water temperature from the hybrid model was corrected through backpropagation.

3. Data and Experiment

The observed meteorological data and paddy field condition data at actual paddy fields located

*東京大学大学院農学生命科学研究科 Graduate School of Agricultural and Life Sciences, The University of Tokyo

**近畿大学農学部 Faculty of Agriculture, Kindai University　　***岩手大学農学部 Faculty of Agriculture, Iwate University

キーワード：水田水温、深層学習、PGNN

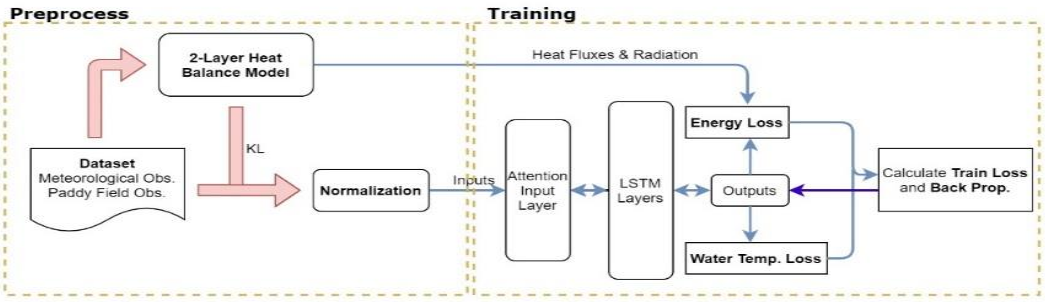

Figure 1. **Overview of interpretable framework of Physical-Guide Neural Network.**

in Japan were used to train and test the proposed model, including air temperature, solar radiation, wind speed, atmospheric pressure, relative humidity, precipitation, irrigation & drainage water temperature, and water depth.

Two calculation experiments were performed using Pytorch with RTX 2060 GPU. Experiment 1 aimed to evaluate the performance of the proposed model. The predicted ponding water temperature accuracy was compared to other conventional methods, including the conventional physical process model (2-Layer heat balance model) and the conventional deep learning model (LSTM). Experiment 2 examined the interpretability of the model, referring to the magnitude of the attention weights which were calculated in the model.

4. Results and Discussion

In Experiment 1, it was shown that the proposed hybrid model well reproduced the observed water temperature in the actual paddy fields. The average RMSE of the predicted ponding water temperature was 1.39°C, while the average RMSE by the conventional 2-layer heat balance model and that by the LSTM model were 1.69°C and 1.56°C, respectively.

It seemed that the valuable information would be provided by the value of the attention weight of each input variable in Experiment 2. The average and the variance of the attention weight of each variable are shown in **Figure 2**. The proposed hybrid model gave more attention to the solar radiation, the air temperature, and the water depth, indicating that these three variables play an essential role in bringing about the superiority of the proposed hybrid model. It is reasonable to consider that solar radiation and air temperature are the most fundamental variables for the thermal system of actual paddy fields because they directly relate to heat transfer. It is also reasonable that the attention mechanism showed the importance of the water depth because water depth represents the volume of water which determines the heat capacity of the ponding water. Although the average attention weight was not so high for K_L, its standard deviation was small, indicating that K_L plays a relatively stable role in the water temperature calculation.

Acknowledgements This research was supported by KAKENHI Grant Number 21H02309 from the Japan Society for the Promotion of Science (JSPS).

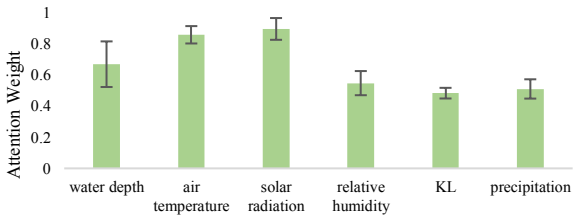

Figure 2. The average attention weight of each feature. (The bars represent the standard deviation)

Xie, W, et al.(2021). Simulation of water temperature in paddy fields by a heat balance model using plant growth status parameter with interpolated weather data from weather stations. *Paddy and Water Environment*, *19*(1), 35–54.