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Identifying and Forecasting Rainfall Using Image Processing Methods

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Abstract**—** In order to reduce the uncertainty in hydrological model predictions, this study lays out a method for obtaining rainfall forecasts by integrating the Weather Research and Forecasting (WRF) and the Regional Ocean Model System (ROMS) models. Precipitation forecasts for sub-basin regions are averaged out using this coupling model. In order to anticipate the water balance, this activity involves automatically analysing images and entering data into a hydrological model. The objective of this study is to provide a hand with rainfall forecasting estimate in order to monitor and analyse water balances.

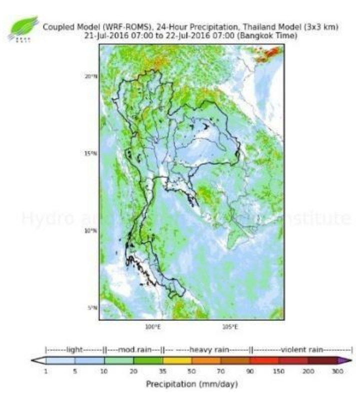
Keywords**— Rainfall forecasting, Image processing, Coupling weather with ocean model, Hydrological model.**

1. INTRODUCTION

Drought is a common problem in many parts of Thailand due to an imbalance between water availability and demand. As a result, there will be water shortages in agricultural areas, community water usage will become more competitive, and so on. Finding out if there is enough water in the region and how much is needed is possible with the aid of water balance analysis. In order to aid in the planning of future water consumption and to offer reliable information.

This study processes data from the ocean-atmosphere couple model that predicts future rainfall. In order to depict the rainfall projections, we have used the WRF-ROMS coupled model to generate WRF-ROMS pictures, as seen in Figure 1.

Figure 1. The image output of WRF-ROMS post-processing



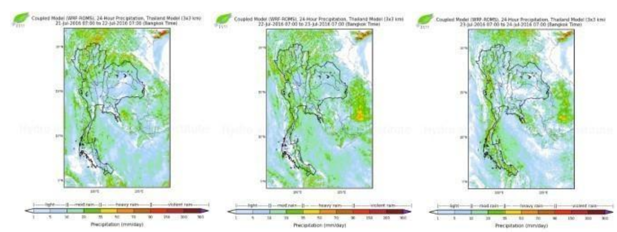


Figure 2. The daily WRF-ROMS rainfall images for 3 days forecast.

The WRF-ROMS model generates sets of pictures that may be used to analyse and present daily rainfall predictions over shorter time periods. The water balance analysis system also uses this WRF-ROMS rainfall data as inputs. Predictions of daily rainfall for the next three days are displayed in the photos in Figure 2. On top of that, every 12 hours, the WRF-ROMS model is executed and photos are generated.

Using an image processing approach, we can predict the quantity of rainfall for the Thai sub-basin for the next three days, including today. The output data is used for the purpose of analysing the rainfall quantity in each sub-basin in Thailand. This aids in water management and identifies places that may be experiencing drought due to a lack of water. Here, then, is an analysis of Thailand's water balance management based on precipitation prediction data. One input of the hydrological model used to evaluate the water balance in each sub-basin is the rainfall prediction amount, which is computed by using the fundamental functions of image processing. To find and extract images that depict and characterise the qualities of form or shape inside an image, image processing makes use of image segmentation and image analysis. A procedure known as image segmentation divides a picture into smaller, more manageable pieces. Using image segmentation, we can identify the pixels that make up the sub-basin borders in the regions that have been focused on. Set theory is used to formulate morphology. In order to measure the structuring element's fit inside the provided picture, the fundamental notion is to probe the image with a template shape or mask [14].

The remaining of this paper is organized as follows: Section 2 presents the data source is used in the research. Section 3 proposes the rainfall forecast estimation methodologies and the detail of each process including the related works. In section 4, the design and implementation of the rainfall forecasting estimation are shown. Finally, section 5 is the conclusion.

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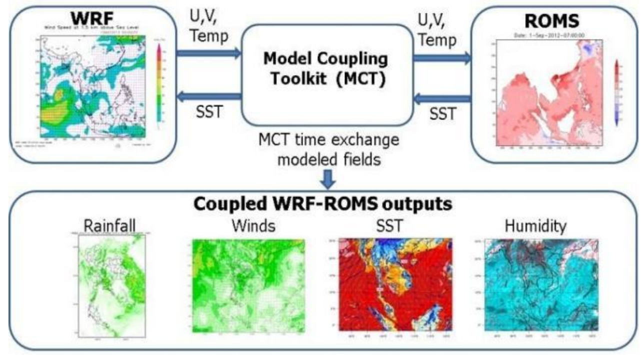
2. DATA SOURCE

Managing the water balance in sub-basin regions of Thailand is one challenge that arises from the hydrological model findings. Its purpose is to measure and balance the inflow and outflow of water in different areas. On top of that, it's a crucial instrument for carrying out water resource and infrastructure operations efficiently. More and more, Thai hydrological and meteorological predictions are being relied upon. One input of the hydrological model for analysing the water balance in the short-term prediction is the rainfall forecast amount, which is produced by the meteorological model. This section discusses the rainfall prediction data from the Weather Research and Forecasting (WRF) model that is coupled with the Regional Ocean Model System (ROMS) model. Figure 3 shows the method for linking the WRF-ROMS model. The Modelling Environment for Atmospheric Discovery (MEAD) project at the National Centre for Supercomputing Alliance [2] includes the first outcome of combining WRF with ROMS. One of the most effective tools for weather forecasting right now is the coupling WRF-ROMS model. Heat fluxes are exchanged between models of the atmosphere and the ocean.

Mesoscale numerical weather prediction system WRF-The Weather Research and Forecasting Model [10] is developed to meet the demands of operational forecasting as well as atmospheric research. In the late 90s, a group of organisations including the National Centre for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (represented by NCEP and the (then) Forecast Systems Laboratory, or FSL), the Air Force Weather Agency (AFWA), the Naval Research Laboratory, the University of Oklahoma, and the Federal Aviation Administration formed a partnership to develop WRF. There are several features that the WRF model can provide. As an example, there are a number of choices for lateral boundary conditions in both real-data and idealised simulations, as well as nudging in three dimensions for analysis and observation, regional and worldwide applications, digital filter initialization, and so on [10]. Short-term weather predictions are the primary focus of the WRF model. Weathher, wind speed and direction, temperature, and more may all be foretold with this model. That data collection, saved in NetCDF format, is the end product of this model.
Many scientific fields make use of ROMS, the Regional Ocean Modelling System, an ocean model that is free-surface, terrain-following, and based on basic equations. Scholars from Rutgers University, the University of California, Los Angeles, and other institutions throughout the globe worked on the model's development and maintenance. The physical and numerical algorithms used in ROMS are precise and efficient. In addition, it has constructed grids, various nesting levels, and vertical mixing methods [6].



(WRF: Weather Research and Forecasting Model / ROMS: Regional Ocean Modeling System)

3. METHODOLOGY

A. Related Works

Using image processing techniques, the authors of reference [3] suggested retrieving the necessary weather forecasting pictures from large data storage. The only method used in this study is the shape feature extraction process based on morphological processes. Digital cloud image processing methods for rainfall forecasting are detailed in reference [7]. In order to record the cloud's state, the Cloud Mask Algorithm is used. Also, the K-Means Clustering method is used for cloud type categorization. The characteristics influencing the Indian monsoon were computed using digital image processing methods in reference [9]. In order to determine whether or not it is raining, the picture segmentation technique is used to determine the cloud status, sky status, and cloud kinds.
When it comes to flood predictions, rainfall forecasts are now taking precedence. The integration of hydrological forecasting data with meteorological predictions was suggested in reference [8]. It is able to alert people to the possibility of floods by employing meteorological model-based precipitation projections. One effective technique for water management and flood prevention is climatological or seasonal forecasting, as detailed in reference [15]. Afterwards, this data may be used to enhance reaction times during emergencies.

B. Image Processing

Each step of the rainfall forecasting estimate process makes use of a variety of foundational technologies. At its core, morphological operations include erosion. It is used on binary pictures to blur the edges of pixels in the foreground [13]. In order to calculate the sub-basin area from pictures, the spatial data is used. In addition, the WRF-ROMS model produces the rainfall prediction pictures used in this system. The followings detail all of the aforementioned technologies.

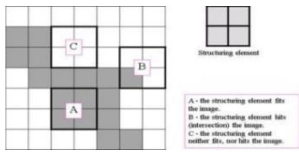


Figure 4. Morphological operation: an image with a structuring element.

1) morphological aspect of images is that they are composed of coordinates. A set of non-linear processes pertaining to the form of picture features constitute morphological image processing. When working with binary images, morphological processes depend on the pixel values' relative ordering. In a binary picture, any set of linked pixels may be considered an object. Binary pictures include information about the objects' shape, size, and position, which are called properties. In morphological methods, a structuring element is a tiny form or template used to explore a picture. As seen in Figure 4 [12], the structuring element is placed in every conceivable spot inside the picture and then compared to the surrounding pixel neighbourhood. Similar to how convolution kernels are used in linear image filtering, structural components are used in morphological image processing.

2) Erosion: To execute erosion on a binary picture, we put the structuring element's centre pixel (value 1) on each foreground pixel in a sequential fashion. This foreground pixel will be transformed into a background pixel if any of its neighbours have the value 0. Image A is formally described as $A \ominus B$ when it is eroded by structural element B. Dilation and erosion work mechanically similarly to spatial filtering's convolution kernels. As it glides across the picture, the structural element's centre pixel will cover more and more pixels in the foreground and background, respectively. Each pixel's new value is based on the values of neighbouring pixels in the areas specified by the structural element [1]. Damage to a binary picture as a consequence of erosion is seen in Figure 5 [1].

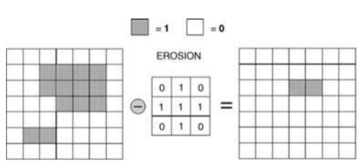


Figure 5. Erosion: a foreground pixel only remains a foreground pixel if the 1s in the structuring element (in this example, a cross) are totally contained within the image foreground. If not, it becomes a background pixel.

C. Geographic Information System

A Geographic Information System or GIS dataset is the spatial representation of real-world features. These features are described with their attributes that are the non-spatial data. There are two ways to represent the feature and attribute of data in a GIS: as vector data types or as raster data types. Both data types are the basic data structures for storing GIS data [11].

Coordinates are the primary data format for the vector GIS layer. It uses the three pillars of geographic information systems (GIS)—points, lines, and polygons—to depict the physical characteristics. The points on the map stand for various places like towns, wells, schools, and so on. Any feature, such a river, road, train, etc., that connects two or more locations is represented by a line. A polygon may be used to depict a border or a near route. The capacity to keep several attribute data points for every feature is a benefit of vector type [11]. Figure 6 depicts the aforementioned three characteristics. Data is divided into equal-sized cells or pixels in the raster GIS data layers, which reflect real-world characteristics [11]. Figure 7 depicts the structure of the raster data. There is a hard limit of one value per raster pixel.

In this study, the sub-basin regions of Thailand were separated using the vector data type that was superimposed on top of a map. Subsequently, the mask was created by converting the vector map to a raster picture. The 71 sub-basins in Eastern Thailand that are shown in Figure 7 are the regions of interest.

Figure 6. Three vector data representations of real world features.

Figure 7. The raster data is segmented into 71 sub-basins in Eastern Thailand.

D. The Rainfall Forecast Calculation

The amount of rainfall calculating from WRF-ROMS outputs used the coordinates obtained from the mask to find and extract the rainfall volume in each pixel. The rainfall amounts were calculated from RAINC and RAINNC variables and TIMES variables of WRF-ROMS model outputs. The rainfall amounts were accumulated in daily time frames. That meant each time frame had the increased cumulative rainfall until the last of daily time frames. The number of time frames depends on the determined term in forecasts of WRF-ROMS model such that if WRF-ROMS is defined to predict 3 days, it should have 25, 49, and 73 time frames of the output, respectively. However, (1) is the formula to sum every the hourly rainfall and (2) is the equation to calculate the daily accumulated rainfall.

$$R_{An} = \sum_{n}\sum_{h} R(T_{h+(n*24)}) \qquad (1)$$

$$R_{daily} = R_{An+1} - R_{An} \quad ; n > 0$$
$$R_{daily} = R_{An} \quad ; n = 0 \qquad (2)$$

where $h = \{1, 2, 3, ..., 25\}$ is each time frame on one day, R_{An} is the rainfall forecasting all time frames on n days, and $n = \{0, 1, 2\}$.

The daily rainfall amount was taken to calculate the average rainfall in each area with dividing by the number of pixels in that area. For example, 10th sub-basin's rainfall amount equaled to 200 mm. and divided by the number of pixels of its area which was 20 pixels, so it would be 200/20 and equaled to 10.00 mm. This calculation can be written a formula as (3).

$$R_{Avg.} = R_{An} / P_s \quad (3)$$

where P_s is total number of pixels in sub-basin area.

1) DESIGN AND IMPLEMENTATION

The rainfall forecast amount of each sub-basin is estimated and to be the input of hydrological model. The information obtained from the analysis of this process can be used for monitoring the water volume and water balance management in sub-basin areas of Thailand. It helps communities to prepare for planting. Thus, the process is described in thefollowing.

A. Process Flow

As the flow in Fig. 8, the rainfall forecast amount process applied the image segmentation and analysis technologies. Its processes can be divided into the following steps.

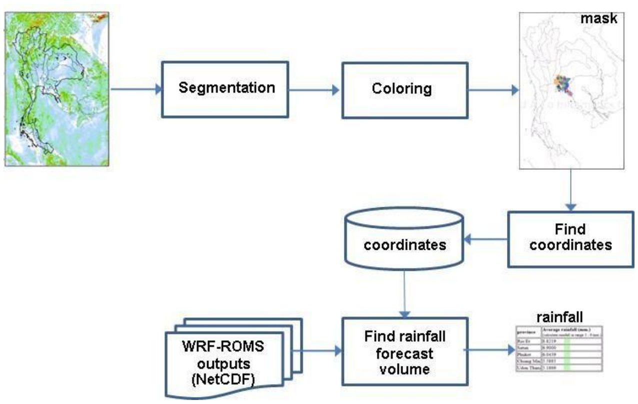


Figure 8. The rainfall forecast amount process flow.

B. Segmentation

Segmentation is the process of separating photos based on what's interesting. Messages such as time, date, rainfall scale, and so on make up the standard picture outputs of WRF-ROMS post-processing. The visual portion of the frame containing the boundaries of Thailand is our primary focus from these photographs. The next step was to create a mask or template by cropping the relevant portion of the output photographs.

In order to begin separating the original pictures, we needed to identify the four corners of the image, as shown in Figure 9. Second, as shown in Figure 10, these four corner pixels were used in the photo editor program's cutting procedure.

The next step of the segmentation is the unwanted color elimination. The eliminated colors were the colors that represent the ranges of rainfall amounts. However, the white color (RGB: 255,255,255) was used to instead the colors which were deleted. After eliminating unwanted colors out, it would not have the color of rainfall amounts in the image. Therefore, the spatial boundary of the image remained is shown in Fig. 11.

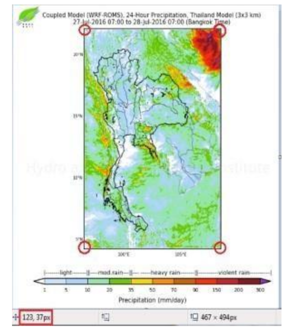


Figure 9. The WRF-ROMS output image with four corner pixels.

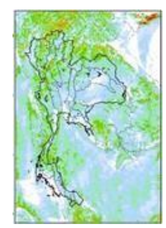


Figure 10. The WRF-ROMS output image is crop.

Figure 11. The WRF-ROMS output image that the colors are eliminated.

C. Map Coloring

Figure 12 shows the process of adding colours to each boundary region using a unique colour after removing all colours from the picture until just the border area remained. The pixels of each provincial border were calculated using the picture that was filled with colours in the province regions. The quantity of rainfall may then be determined in the following phase by using a set of the given pixels.

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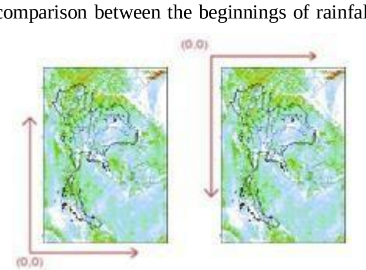
Figure 12. The WRF-ROMS image which the colors were added in sub-basin area was used to be the mask.

D. The Pixels Finding Process

To determine the exact locations of the borders between each sub-basin, a map picture created using the Map Colouring phase was used as a mask or template. During the Map Colouring procedure, a unique colour was applied to each sub-basin. Thus, sub-basins were identified and their coordinates were derived from the photos using the colours. As a mask, these coordinates were gathered. The model's output, rainfall data recorded in NetCDF files, was organised by latitude and longitude. Nevertheless, the image's starting pixel, which is (0, 0), did not correspond to the real-world beginning location in the NetCDF file. Contrary to what you might expect from an image, the starting pixel in NetCDF is located at (0, 0) in the lower left corner. Hence, in order to get the matching starting point, the mask picture was vertically rotated. The techniques of collecting and storing pixels are depicted in Figures 13–15.

The border extraction was used to determine the colour in each sub-basin region. The map colouring process, which involves filling in each region with colour, is where the colour codes were derived. In addition to using the colour codes (R, G, and B) for each colour to fill the picture, we also utilised these codes to identify the borders of the subbasins. We only gathered coordinates if they were within the regions of the visually appealing colours. Take the 10th sub-basin (R, G, B) as an example; its colour code was discovered to be (66, 53, 148). Using this colour code, we were able to locate the region and preserve its coordinates, as seen in Figure 16. In order to determine the average rainfall in each region, a large number of colour pixels were also gathered. The method was repeated until all of the sub-basin areas of interest were covered. In order to generate a mask picture, all of the coordinates were recorded in the.py format, which is exclusive to Python. We used the Python programming language to create the programme for this project.

Figure 13. A comparison between the beginnings of rainfall data in NetCDF



(left) and the pixel from the image (right).

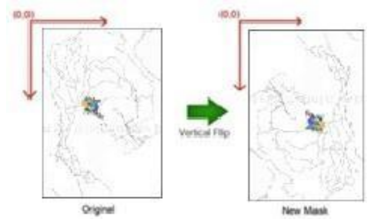


Figure 14. The vertically rotation of the mask image.

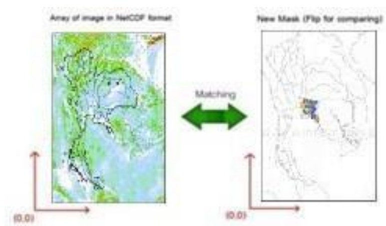


Figure 15. A comparison between the NetCDF's beginning and the mask image beginning.

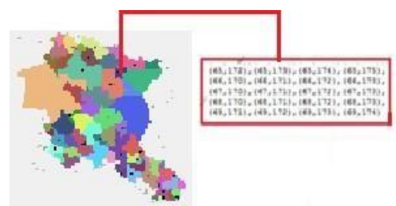


Figure 16. A sample of 10th sub-basin area and its coordinates.

CONCLUSION

For the purpose of tracking the daily rainfall quantities in the seventy-one sub-basins in Eastern Thailand, as well as the three-day prediction, an estimate system based on image processing technology has been created. The WRF-ROMS model processing may be used to obtain these rainfall forecasts. To create this system, researchers in Eastern Thailand used image segmentation, a fundamental method in image processing, to divide the basins into 71 smaller ones. This study's results are the water balance model's uncertainty in daily rainfall quantities forecasted for 71 sub-basins.

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