# PRELIMINARY RESULTS OF RIVER FLOW SIMULATION FOR INDOCHINA PENINSULA REGION UNDER CLIMATE CHANGE

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A distributed flow routing model (1K-FRM) was used to project river discharge in Indochina Peninsula region. Topographic data used for the flow routing model is 5-min spatial resolution data which was processed from scale-free global stream-flow network dataset developed by Masutani et al. (2006). Input data for the routing model is the generated runoff data in the latest 20km general circulation model (GCM) dataset (MRI-AGCM3.2S), which has been developed by Meteorological Research Institute, Japan Meteorology Agency, for the present climate (1979-2008), the near future climate (2015 - 2044), and the future climate (2075-2104). The simulated river discharge for the present climate, the near future climate, and future climate experiment was compared to see the changes of flow in Indochina Peninsula region under climate change.

*Keywords: river discharge projection; scale-free stream-flow network; hydrological modeling*

## Introduction

Global warming has been having serious impacts on the Earth and its residents. Many studies have shown that even if the emission of greenhouse gases is reduced drastically, climate change will be irreversible in coming centuries. Frequencies and magnitudes of water-related disasters such as floods, droughts and water scarcity are predicted to increase due to changes of precipitation extremes.

To cope with water-related disasters induced by global warming mentioned above, projection of river discharge is necessary. In this regards, hydrological and flow routing models play an important role in transferring the climate model outputs into river discharge. Many researchers analyzed changes in future risks of floods and droughts using different scale and spatial resolution hydrological models: global scale with 1-degree spatial resolution runoff model (Hirabayashi et al., 2008); regional scale with 2-minute spatial resolution hydrological model (Kiem et al., 2008); and basin scale with 1-km spatial resolution runoff model (Hunukumbura et al., 2012).

In this study, a distributed flow routing model (1K-FRM) with kinematic wave flow approximation was applied for river discharge projection in Indochina Peninsula region under climate change. The original version of 1K-FRM was based on 1km spatial resolution topographic data extracted from USGS HydroSHEDS. With that high resolution, the requirement for computational resources is also high, and it takes a long computational time. For a balance of spatial resolution, computational resources, and application of hydrological models, 1K-FRM has been developed to use with scale-free stream-flow network dataset which was provided by Masutani et al. (2006).

In the second part, the processing of scale-free topographic data for 1K-FRM is introduced. The description of distributed flow routing model and future climate projection data generated by MRI-AGCM3.2S is shown in part 3 and part 4. In part 5, the changes of simulated river discharge for the near future climate to the present climate and the future climate to the present climate are discussed. And then, some conclusions will be given in the last part of this paper.

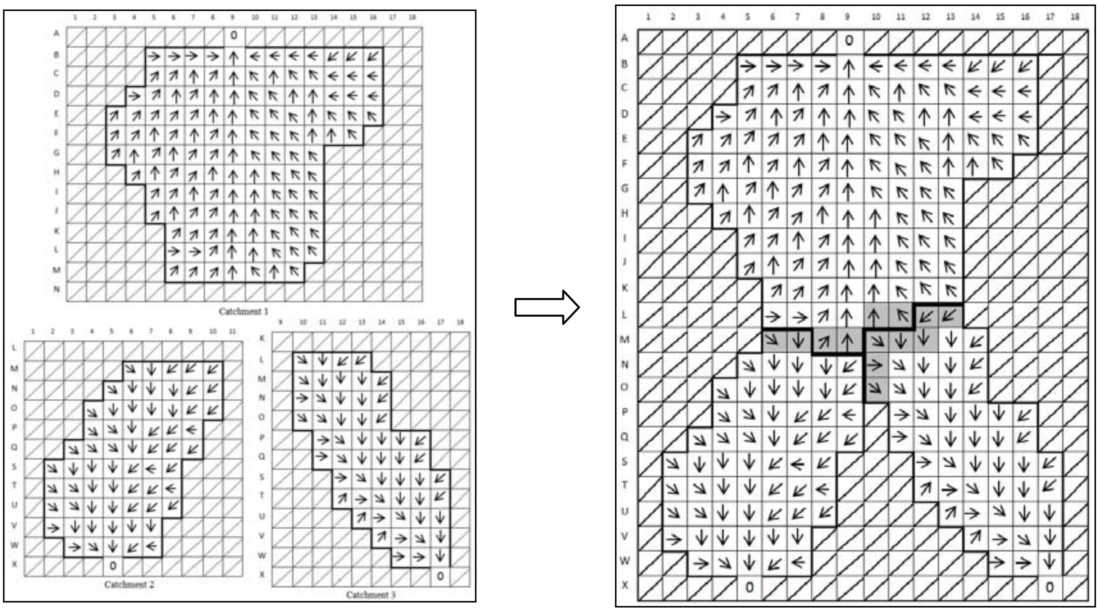
## Topographic data processing

For hydrological models which are grid based, topographic parameters (elevation, river length, flow direction, etc.) and simulation processes are determined at every grid cell. So, the data volume and computational resources are proportional to the number of grid cells which themselves increase quadratically for each doubling of the horizontal spatial resolution. As a result, finer spatial resolution grids require higher computational resources and longer computational time.

Therefore, to ensure the balance of spatial resolution, computational resources, and application of hydrological models, several algorithms for generating stream-flow networks for macro-scale hydrological models have been presented. Masutani et al. (2006) developed a scale-free global stream-flow network creation method as the basis of basin-wide hydrologic analyses for any integrated river basins. The most important advantage of this method is to conserve fundamental hydraulic information based on the finest-resolution stream-flow channel network, on any spatial scale. They provided a dataset of stream-flow networks with 11 different scales from high resolution (3s ≈ 90 meters, 6s, 9s, 12s, 15s), medium resolution (30s, 1 min, 2 min, 3 min), to low resolution (5 min, 10 min ≈ 20 km). And it enables hydrological models independent of spatial resolution.

However, the dataset consists of topographic data of individual river basins. To run a hydrological model with study area covering many river basins, it is needed to join those individual topographic data into a large topographic map that suits the study area. Hence, required physiographic information for hydrological models such as catchment area, river length, elevation, slope, and flow direction will be processed and joined into a large topographic map.

One of the most important things that need to be considered to join individual river basins data into a large topographic map is how to process the data of overlapped grid cells at the boundary of those river basins. The proposed solution to process topographic data of overlapped gridded cells at the boundary of joined river basin is to keep the topographic information of grid cells that have larger area. Overlapped grid cells with smaller area will be removed but cell area will be added into the neighbour cells following its flow direction. This will keep catchments area unchanged when they are joined into a large topographic map. Flow direction of grid cells that flow into removed cells will be changed to neighbour cells in the same basin. Figure 1 shows an example of joining flow direction data.



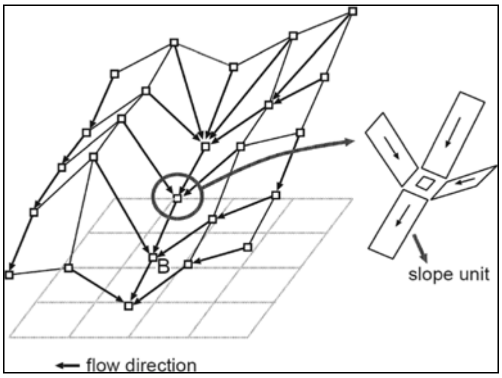

(a) (b)

**Figure 1: An example of flow direction data before (a) and after joining (b) (Arrows: flow direction; gray cells: overlapped cells; bold lines: basin divides)**

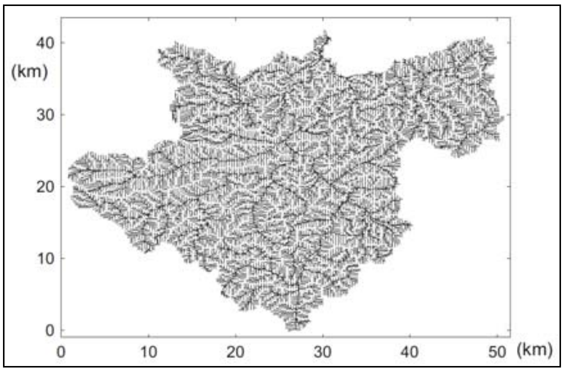
## Flow routing model

### Watershed model

The topography of the catchment is modelled using the 8-direction method which assumes the flow direction one-dimensionally to the steepest gradient direction. Each slope element determined by the flow direction is represented by a rectangle formed by the two adjacent nodes of grid cells. The watershed model is developed using Digital Elevation Models (DEM). Catchment topography is represented by a set of slope units. For each slope unit, its area, length and gradient used for a flow model are easily calculated. Schematic drawing of a watershed model using the eight direction method and an example of flow direction information derived from a grid-based DEM are shown in Figure 2.




(a)




(b)

**Figure 2: Schematic drawing of a watershed model using the 8-direction method (a) and an example of flow direction information derived from DEM (b)**

Topographic data used in this study is the 5-min spatial resolution DEM processed from scale-free stream-flow network dataset which was provided by Masutani et al. (2006).

**Flow model**

A kinematic wave model is applied to all slope units and runoff is routed according to the flow direction information. The basic form of the kinematic wave flow equation is:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_L(x,t) \tag{1}$$

$$Q = \alpha A^m, \quad \alpha = \frac{\sqrt{i_0}}{n}\left(\frac{1}{B}\right)^{m-1}, \quad m = \frac{5}{3} \tag{2}$$

where, A(x, t) is the flow cross-sectional area, Q(x, t) is the flow discharge, $q_L(x, t)$ is the lateral inflow per unit length, $i_0$ is the slope, n is the Manning roughness coefficient, and B is the width of the flow. Equation (1) is the continuity equation and is derived from the principle of mass conservation within a control volume. Equation (2) is derived from Manning's or Chezy's laws which are flow resistance laws of open channel uniform flow.

**GCM data used for river flow projection**

River discharge projection used data provided by the latest GCM (MRI-AGCM3.2S) with resolution of about 20km which has been developed by Meteorological Research Institute, Japan Meteorology Agency. River discharge was calculated using flow routing model 1K-FRM with input data is GCM daily runoff generation data which was projected by MRI-AGCM3.2S.

## Results and Discussion

Simulations for Indochina Peninsula region was carried out to investigate the changes of river discharge under climate change with 30 years simulated time for each climate experiment: the present climate experiment (1979-2008), the near future climate experiment (2015-2044), and the future climate experiment (2075-2104). The study area cover five big river catchments including Mekong River basin; Irrawaddy River basin and Salween River basin in Myanmar; Chao Phraya River basin in Thailand; and Red River basin in Vietnam (see Figure 3).

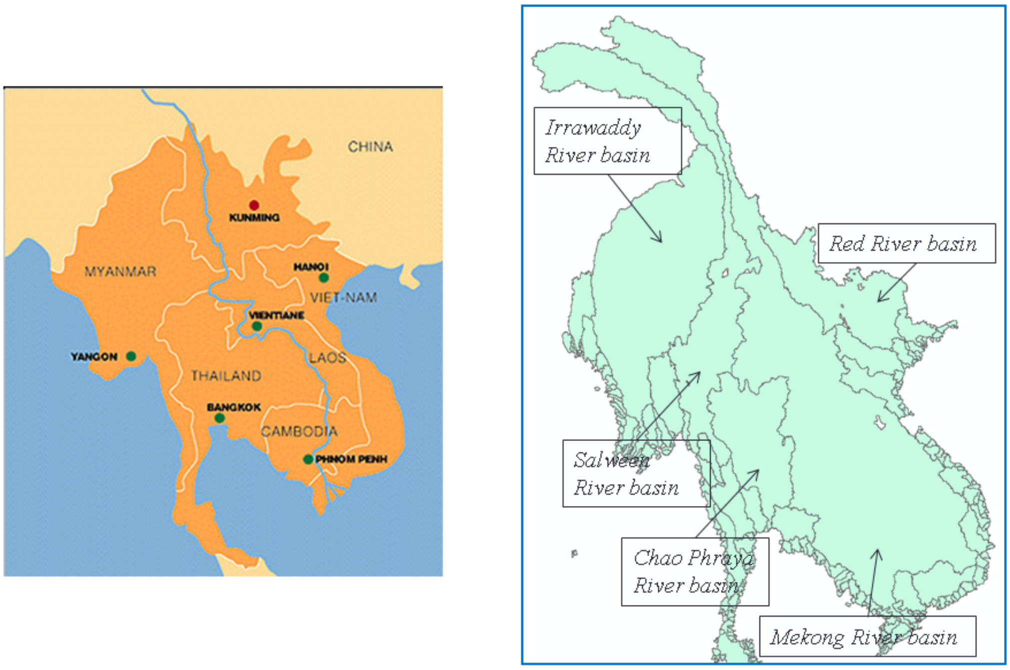


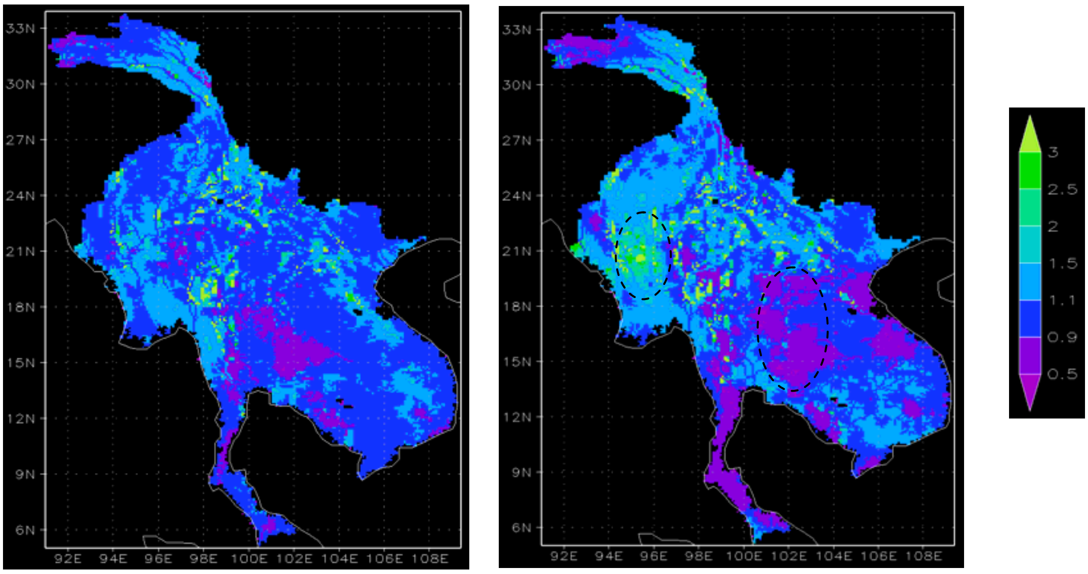

**Figure 3: Map of the study area, Indochina Peninsula region**

The annual average discharge, mean of annual maximum discharge and mean of annual minimum discharge for each climate experiment were calculated. Then, the ratio of discharge values mentioned above for the near future climate to the present climate and the future climate to the present climate were calculated for comparison to see the changes of river discharge between the present climate, near future climate and future climate.

### Comparison of annual average discharge in 30 years between the near future climate and the present climate, the future climate and the present climate

Ratio of annual mean discharge for the near future climate to the present climate, and the future climate to the present climate is shown in Figure 4.

The changes of annual average discharge between near future climate and the present climate showed a slightly increasing of average flow with the ratio smaller than 1.5 at the most upper part of Mekong River basin, Salween River basin and Irrawaddy River basin; from central to lower part of Irrawaddy River basin; western part of Vietnam. Only eastern part of Chao Phraya River basin shows a trend of decreasing in river flow with the ratio is between 0.5 and 0.9.



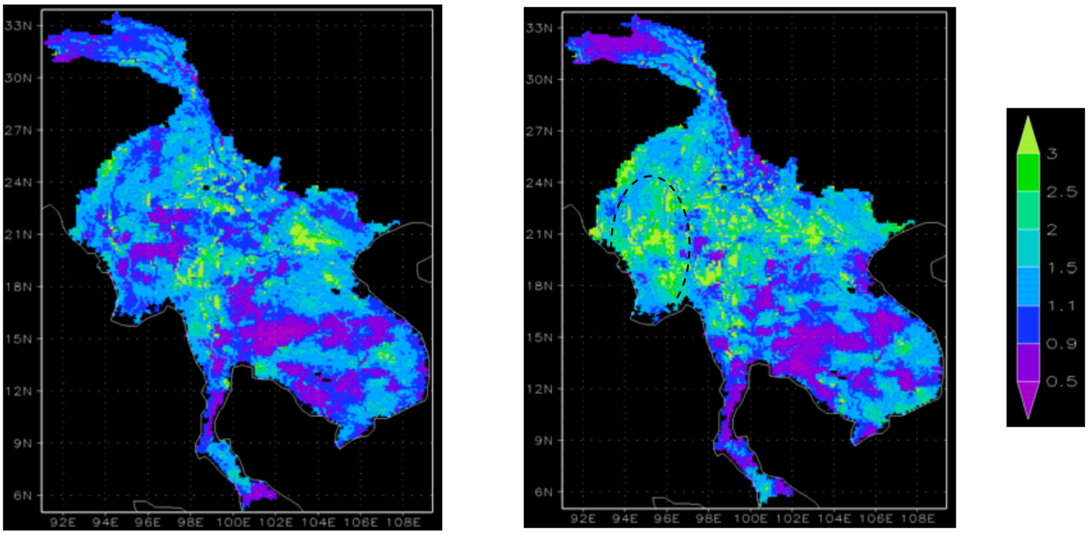

(a) (b)

**Figure 4: Ratio of annual mean discharge for the near future climate to the present climate (a), and the future climate to the present climate (b)**

A same trend with higher intensity can be seen in the figure that shows the comparison of the future climate and the present climate. We can see that the changes in area and ratio range become larger, especially at the lower part of Irrawaddy and eastern part of Chao Phraya.

**Comparison of mean of annual maximum discharge in 30 years between the near future climate and the present climate, the future climate and the present climate**

In Figure 5, the ratio of mean of annual maximum discharge for the near future climate to the present climate was compared with those for the future climate to the present climate. For the near future climate, the mean of annual maximum discharge has significant changes at upper part of Red River basin and lower part of Salween River basin. It becomes more visible in the future climate experiment. Irrawaddy River basin showed a noticeable increasing of mean of annual maximum discharge in the future climate experiment. The ratio at some areas are larger than 2.5. It means the risk of flooding at those areas will increase.

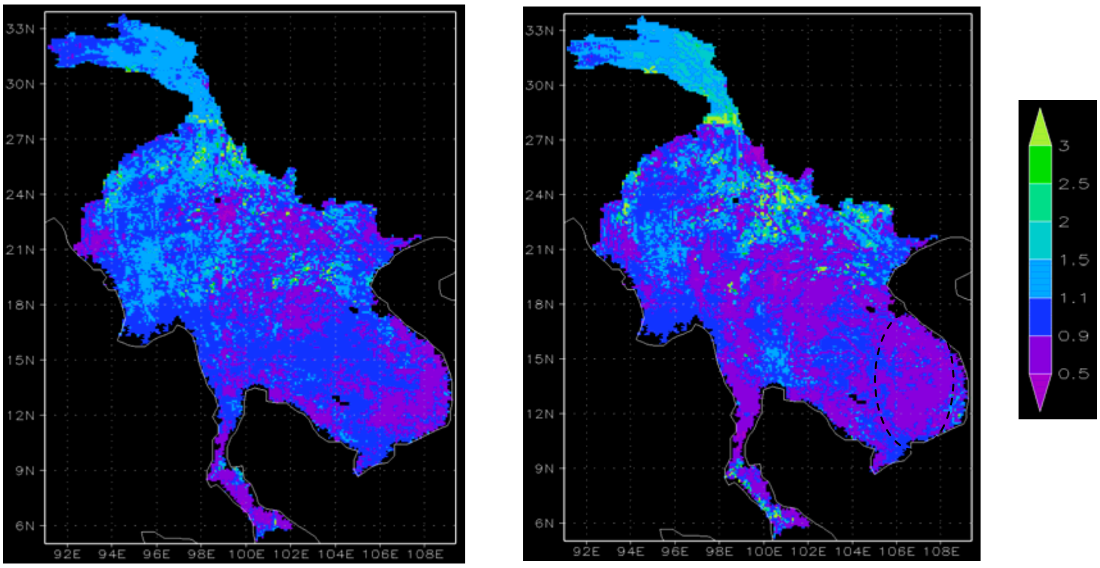



(a) (b)

**Figure 5: Ratio of mean of annual maximum discharge for the near future climate to the present climate (a), and the future climate to the present climate (b)**

**Comparison of mean of annual minimum discharge in 30 years between the near future climate and the present climate, the future climate and the present climate**

Figure 6 shows the ratio of mean of annual minimum discharge for the near future climate to the present climate, and the future climate to the present climate.




(a) (b)

**Figure 6: Ratio of mean of annual minimum discharge for the near future climate to the present climate (a), and the future climate to the present climate (b)**

From Figure 6, it can be seen that there is a decreasing trend in the southeast part of Indochina Peninsula, especially the southern part of Vietnam. And this trend became more clearly in the future climate experiment. Then, drought risk can be expected to increase in Indochina Peninsula region in the future.

## Conclusion

In this paper, the processing of scale-free topographic data was presented. A dataset of scale-free stream-flow network dataset for Indochina Peninsula with 5-min spatial resolution was processed and used for flow routing model 1K-FRM.

The changes of river discharge in Indochina Peninsula region for 3 climate experiments (present, near future, and future) were also analyzed. The input data was taken from the latest 20km resolution GCM dataset (MRI-AGCM3.2S). The changes in the risk of flood and drought in the region can be seen.

## Acknowledgement

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## References

Hirabayashi, Y., Kanae, S., Emori, S., Oki, T., Kimoto, M. (2008). Global projections of changing risks of floods and droughts in a changing climate. Hydrological Sciences Journal, Vol. 53 (4), 2008, pp. 754 - 772.

Hunukumbura, P. B., Tachikawa, Y. (2012). River discharge projection under climate change in the Chao Phraya river basin, Thailand, using the MRI-GCM3.1S dataset. Journal of the Meteorological Society of Japan, Vol. 90A, 2012, pp. 137 - 150.

Kiem, A. S., Ishidaira, H., Hapuarachchi, H. P., Zhou, M. C., Hirabayashi, Y., Takeuchi, K. (2008): Future hydro-climatology of the Mekong river basin simulated using the high-resolution Japan Meteorological Agency (JMA) AGCM. Hydrological Processes, Vol. 22, 2008, pp. 1382 - 1394.

Masutani, K., Akai, K., Magome, J. (2006): A new scaling algorithm of gridded river networks. Japan Society of Hydrology and Water Resources, Vol. 19, No. 2, 2006, pp. 139 - 150.

O'Donnell, G., Nijssen, B., Lettenmaier, D. P. (1999): A simple algorithm for generating stream-flow networks for grid-based, macro-scale hydrological models. Hydrological Process, Vol. 13, 1999, pp. 1269 - 1275.