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# Meta-heuristic Bayesian networks retrieval combined polarization corrected temperature and scattering index for precipitations

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ABSTRACT

This paper proposes Bayesian networks (BNs) that combine polarization corrected temperature (PCT) and scattering index (SI) methods to identify rainfall intensity. To learn BN network structures, meta-heuristic techniques including tabu search (TS), simulated annealing (SA) and genetic algorithm (GA) were empirically evaluated and compared for efficiency. The proposed models were applied to the Tanshui river basin in Taiwan. The meteorological data from the Special Sensor Microwave/Imager (SSM/I) of the National Oceanic and Atmospheric Administration (NOAA) comprises seven passive microwave brightness temperatures, and was used to detect rain rates. The data consisted of 71 typhoons affecting the watershed during 2000–2012. A preliminary analysis using simple meta-heuristic BNs identified the main attributes, namely the brightness temperatures of 19, 22, 37 and 85 GHz for rainfall retrieval. Based on the preliminary analysis of a simple BN run, the advanced BNs combined with SI and PCT successfully demonstrated improved rain rate retrieval accuracy. To compare the proposed meta-heuristic BNs, the traditional SI method, the SI-based support vector regression model (SI-SVR), and artificial neural network (ANN) were used as benchmarks. The results showed that (1) meta-heuristic BN techniques can be used to identify the vital attributes of the rainfall retrieval problem and their causal relationships and (2) according to a comparison of BNs combined with PCT and SI and artificial intelligence (AI)-based models (SI-SVR and ANN), in heavy, torrential, and pouring rainfall, models of BNs combined with PCT and SI provide a superior retrieval performance than that of AI-based models. Therefore, this study confirms that meta-heuristic BNs combined with PCT and SI is an efficient tool for addressing rainfall retrieval problems.



## 1. Introduction

Precipitation forecasting is among the most serious challenges for operational forecasting and research communities because flash floods extract a high human death and property damage toll. Taiwan is a well-known target for typhoons originating over the Northwestern Pacific Ocean. In addition to geographic and morphological factors, substantial amounts of rainfall resulting from typhoons typically cause flooding disasters, which can lead to considerable economic losses and human casualties. The average annual cost of typhoon-related damage in Taiwan is approximately US$500 million [1]. As an example, Typhoon Aere (August 23, 2004 to August 26, 2004) was a medium magnitude typhoon that generated a rainfall amount of over 900 mm, causing a total financial loss of approximately US$45.7 million and more than 15 fatalities. Typhoon Morakot (August 6, 2009 to August 10, 2009) generated a rainfall of 2500 mm over 5 days in southwestern Taiwan, resulting in 673 fatalities and more than US$600 million in damage [2]. Therefore, accurate forecasts of typhoon-induced rainfall amounts are essential for effective flood forecasting, operational warning systems, and decision-making processes [3]. In particular, reliable rainfall retrieval of heavy pouring rainfalls is vital for forecasters to issue accurate and timely public warnings [4].

Recently, satellites have provided valuable information regarding many crucial parameters of the global-scale hydrologica1 cycle, such as water vapor, precipitation, and snow cover. The emergence of spaceborne passive sensors has resulted in rainfall retrieval using microwave sensors attracting substantial interest [5]. Measurements using these sensors can supplement ground-based observations, where in situ measurements are limited [6]. Similar to most passive remote sensors, Special Sensor Microwave/Imager (SSM/I) sensors collect information by detecting electromagnetic waves. The various properties of these waves are influenced by Earth's atmospheric system [7]. The temperature measured by SSM/I is the brightness temperature of the object at the wavelength being measured. The advantage of microwave signals is that

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signals upwelling from the Earth surface can penetrate through cloud tops and directly detect the presence of precipitation particles within and below clouds. Therefore, SSM/I sensors have been shown to provide reliable information concerning instantaneous precipitation rates [8]. Numerous researchers have successfully estimated rain rates and cloud parameters based on passive microwave measurements [9–18].

Recently, artificial intelligence (AI) techniques have been analyzed for rainfall rate retrieval. Mahesh et al. [5] developed an artificial neural network (ANN) based on a rainfall estimation method by using the polarization-corrected temperature (PCT) and scattering index (SI) derived from SSM/I data, and compared it with existing power-law based algorithms. Wei and Roan [19] developed support vector machines for regression (SVR) and an SI overland approach and hybrid SI-SVR model for rain rate retrievals. They compared various rain rate retrieval methods, including single-channel regression, multi-channel linear regressions (MLR), SVR, and SI-SVR. However, underestimation of heavy rainfall during typhoons when using AI-based models (i.e., MLP, SVR, and SI-SVR) is a crucial problem. In addition, the function of AI-based models is similar to that of a black box. Because ANN and SVR are devices that function as black boxes, they capture "hidden" relationships between inputs and outputs with highly accurate approximations, although no definitive explanation of their processes.

To address these problems, a meta-heuristic Bayesian network (BN) is employed to identify rainfall rates. Because BNs are based on probability theory, they serve as powerful knowledge representation and reasoning tools in conditions of uncertainty. Compared with AI-based models, BNs can represent causal relationships using expert knowledge and generally manage known principles and variable relationships. This study proposes a new BN that combines PCT and an SI approach for rain rate retrievals from the remote sensing observations of SSM/I satellites, which have not previously been examined. Meta-heuristic BNs were employed to identify crucial inputs and brightness temperatures of 19, 22, 37, and 85 GHz, as measured by SSM/I are commonly found to be efficient for rainfall retrieval. In addition, various meta-heuristic algorithms have been developed. This study employed well-known techniques, including simulated annealing (SA), genetic algorithm (GA), and a tabu search (TS), to identify the optimal network structures for BNs. To empirically evaluate and compare the proposed BN-based models combined with PCT and SI, traditional SI established by Ferraro and Marks [11], SI-SVR developed by Wei and Roan [19], and the ANN used in Mahesh et al. [5] were selected as benchmarks.

## 2. Bayesian network and meta-heuristic algorithm

A Bayesian causal relationship can be used to describe the graphical structure in a network-based representation of an expert's cognition. Graphical representations of an expert's knowledge based on probability theory are also BNs. In recent years, the BN approach has been validated in many fields both theoretically and experimentally [20–25]. Nadkarni and Shenoy [25] indicated that causal relationships have been extensively used in the field of management science to represent salient factors, knowledge, and conditions that influence decision making [26,27].

According to Osman and Kelly [28], a meta-heuristic can be broadly defined as "an iterative generation process which guides a subordinate heuristic by combining intelligently different concepts for exploring and exploiting the search space." Recent research indicates that modern heuristic methods, such as SA [29,30], GA [31–33], and TS [34,35], can be employed for considerable combinatorial optimization problems. For instance, SA was inspired by metallurgical annealing, a technique that involves the heating and controlled cooling of materials to increase crystal size and reduce defects [36]. GA has a population of BN structures and allows them to mutate and apply crossover to generate offspring. The optimal network structure established during this process is then returned [37]. TS uses memory to select appropriate moves. It is an iterative method that attempts to reach the global optimum of an objective function by moving from one solution to another that is located in the neighborhood of the previous one [38]. The BN learning approach uses evolutionary techniques to find effective BN scoring structures. In this paper, the BN learning approach based on meta-heuristic algorithms was applied to determine an efficient BN scoring structure.

## 3. Experiment data

In this study, a meteorological event was used as a diagnostic tool to infer rain rates. The experiment site was the Tanshui river basin in Taiwan (Fig. 1), which is located along the main path of Northwestern Pacific tropical cyclones and affected by an average of four typhoons per year. The spatial range of the watershed spans 24.43°N–25.19°N latitudes and 121.20°E–121.86°E longitudes (covering an area of 2726 km$^2$) [19]. Metropolitan Taipei is located within this region and has a population of approximately 6 million. In the summer and fall seasons, tropical cyclones accompanied by torrential rainfall occur frequently because of the subtropical climate [39].

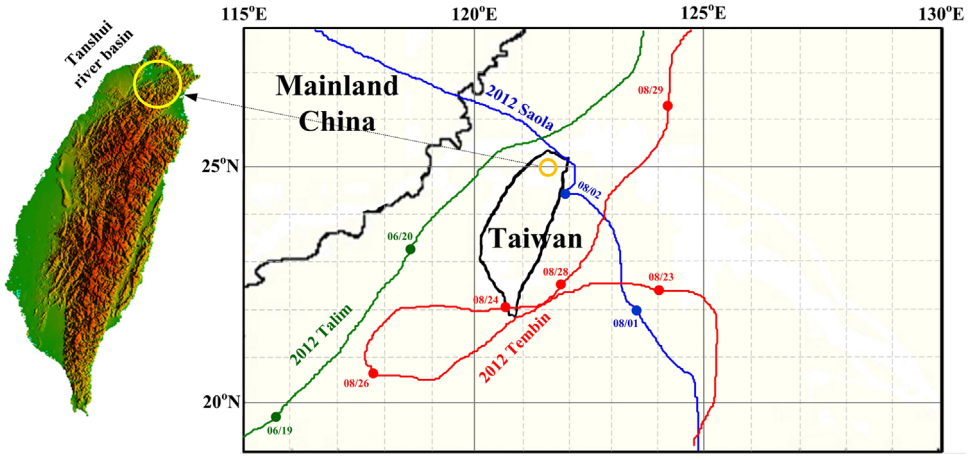


**Fig. 1.** Topography of Taiwan and historical tracks of typhoons in 2012 impacting Northern Taiwan.