# Framework and Architecture to Assess Viability of Rain Cloud Platform Cooling

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## Abstract

Data center cooling constitutes a significant overhead in existing terrestrial cloud data centres and platforms. This paper addresses the challenges arising from the necessity of cooling data centres by leveraging on environment friendly free-cooling. It proposes the post-hydrometeor cooling effect for temperature reduction in data centres. The post-hydrometeor cooling effect considers the effect of long duration hydrometeor showers on data center cooling. In leveraging the post-hydrometeor cooling effect, the paper proposes a novel weather station diversity architecture and data analytic framework. The weather station diversity architecture enables the acquisition of climate data. This enables the suitability of a given geographical region for hosting data centres that leverage on the post – hydrometeor cooling effect to be investigated. In addition, a data analytic framework is proposed. The data analytic framework presents algorithms that enable the decision making process as regards determining the suitability of a given location. In addition, performance evaluation shows that the cooling cost is reduced by up to 25% and by a minimum of 8.35% on average when the proposed hydrometeor cooling effect is incorporated in data center cooling.

## Keywords

Free Cooling, Cloud cooling, and Data Analytic model

## 1. INTRODUCTION

Cloud data centres require power for operation and cooling [1-2]. They use up to 40% of supplied electricity for cooling [3]. This has necessitated the need to design solutions that reduce the operational costs [4-5]. Cooling costs can be reduced by siting cloud data centres in cold climate locations [6 -7]; and also in the stratosphere and ocean. Stratosphere data centres leverage on stratospheric cooling. Underwater data centres also leverage on the ocean's sub-zero temperature.

The use of stratosphere and underwater based data centres requires that the cloud service provider acquires a high altitude platform and artificial reefs respectively. This increases the capital cost because stratosphere and underwater data centres are yet to be fully deployed like terrestrial data centres. Therefore, an approach that enables terrestrial data centres to leverage on free cooling without recourse to naturally cold locations is required.

This paper considers that rainfall events can provide free-cooling for future data centres. The cooling effect arises because rainfall events reduce environmental temperature and increase the available cold air. This presents a new perspective on the role of rainfall. Rainfall has been previously thought to have a negative effect on radio propagation because raindrops absorb or scatter radio signals. This gives rise to rain attenuation [8-9].

Physical parameters associated with rainfall events are used in quantitative precipitation estimation (QPE). Examples of such parameters are the rainfall rate and raindrop fall velocity. However, the suitability of QPE data to reduce data centre cooling costs requires additional attention. This paper discusses how QPE parameters can be used to leverage on free cooling for cloud data centres. In investigating how the acquired QPE data can be used to investigate viability of free cooling, this paper proposes a data analytic framework. The framework uses meteorological data to investigate the potential of leveraging on environmental free cooling. The free cooling effect is associated with environmental cooling after rainfall incidence and is called the post–hydrometeor cooling effect.

The viability of the post-hydrometeor cooling concept can be evaluated by measuring the volume of cold air after a rainfall event. This is challenging due to unavailability of instruments (for monitoring volume of moving cold air). An anemometer can be used to measure air volume. However, the use of anemometers is not suitable because they do not consider how meteorological parameters interact to determine the volume of available cold air after rainfall events.

In addition, the acquisition of parameters used for conducting QPE relies on the available of specialized instruments such as wind gauge, disdrometers and meteorological thermometers. The high costs of acquiring this type of meteorological thermometer limits the conduct of QPE related surveys by capital constrained organizations. Another suitable approach is to purchase the data from meteorological agencies. However, obtaining required data in this manner does not support the conduct of flexible applied meteorological research. This is because the research goal and the required dataset are pre-determined before obtaining the data. These approaches i.e. acquiring meteorological instruments or purchasing the data rely on having access to meteorological payload. Therefore, instrument availability influences the conduct of QPE related surveys or data analysis. However, significant meteorological data exists on the internet. This data can be used to conduct analysis related to the proposed data analytic framework. The use of meteorological data accessible online is proposed in the data driven approach.

The paper makes the following contributions:

First, the paper proposes post–hydrometeor cooling for terrestrial data centres. Post-hydrometeor cooling utilizes the ability of rainfall to reduce temperature (thereby increasing amount of natural occurring cold air) at different locations to realize data centre free cooling. The viability of post– hydrometeor cooling is investigated via a data analytic approach that considers events in which temperature is observed to increase or decrease after rainfall events. The data analytic approach uses data from weather stations. In the proposed network, weather station network comprises non-autonomous and autonomous weather stations in a weather station diversity mechanism. Data acquired by weather stations are aggregated in a cloud platform to investigate the viability of post-hydrometeor cooling in a given terrestrial location.

Second, the paper proposes a multi-layer online driven QPE data analysis approach for the data analytic framework. In the multi-layer online driven QPE, an autonomous search of global meteorological databases is conducted to investigate the viability of the proposed post – hydrometeor cooling effect. This approach relies on internet connectivity and not having access to costly meteorological payload and is suitable for capital constrained organizations. The paper also develops relations describing the variation between different meteorological parameters. These relations enable us to determine the viability of using the post–hydrometeor cooling for data centres sited at a given location. The paper also presents a scheduling architecture enabling under-utilized data centres to be used by subscribers for workload execution.

Third, the paper formulates and investigates how the incorporation of the proposed post-hydrometeor cooling effect reduces cooling power used by data centres.

This paper recognizes that a significant number of surveys have studied the relations between rainfall and temperature as seen in [10-13]. However, they have not studied the relations between meteorological parameters and temperature from the perspective of free cooling in cloud computing.

The rest of this paper is organized as follows. Section 2 presents the data acquisition architecture for the proposed data analytic approach. Section 3 describes relations between considered parameters. Section 4 focuses on performance investigation. Section 5 concludes the paper.

## 2. DATA ACQUISITION ARCHITECTURE

This section presents the meteorological data acquisition network architecture. It is divided into two parts. The first part presents relations between weather stations and the cloud platforms. The second part discusses the proposed multi-layer online driven QPE.

### 2.1 Weather Stations – Cloud Platform Relations

The occurrence of rainfall events reduces environmental temperature necessitating the emergence of bio-meteorology [14–15]. Biometeorology is concerned with studying how environmental temperature influences human health. The proposed data analytic approach considers the usefulness of data fusion in assessing the viability of the post-hydrometeor cooling effect. The analysis is done using fused data obtained from disdrometer networks and temperature sensors.

The disdrometer networks comprise video and non–video disdrometers. Non-video disdrometers acquire data on the rainfall rate and rain drop velocity. Video disdrometers acquire data on the drop size distribution of raindrops in a given area. Additional sensors and instruments in a weather station also measure air temperature, air pressure and air speed. The acquired parameters are recorded alongside the epoch of parameter measurement and data acquisition. The measurement is conducted at multiple locations. This is necessary to determine the most suitable location for leveraging on post hydrometeor cooling.

The data record is created by a user utilizing the computing entities at each weather station. This is feasible in the case for weather stations sited in easy to access locations. However, the scenario where weather stations have accessibility challenges is feasible. The use of automated weather stations (AWSs) is suitable in this case. AWSs have operational benefits in comparison to existing conventional weather stations [16-17].

AWSs are deployed in difficult to access locations. They capture all the aforementioned meteorological parameters. The use of AWSs is beneficial and enables a data record to be obtained across multiple locations. Nevertheless, the use of non-automated weather stations (NAWSs) is beneficial. For example, NAWSs can be accessed with ease of data retrieval. This is beneficial when wireless network connectivity is poor or absent.

The data analytic approach operates in the framework of intelligent weather station diversity architecture. The intelligent weather station diversity architecture deploys and uses NAWSs and AWSs. The architecture of the proposed weather station diversity mechanism showing relations between the AWSs, NAWSs and cloud platform is shown in Figure 1.

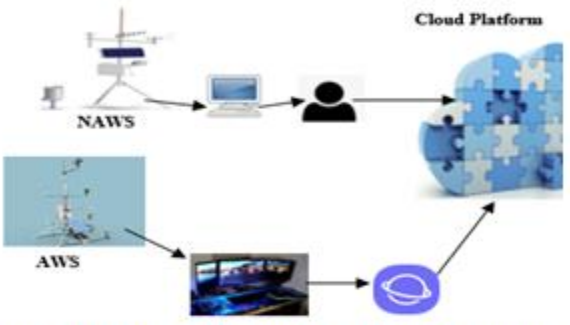
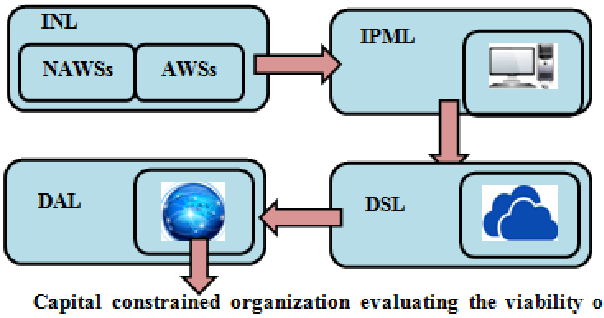


Figure 1: Proposed weather station diversity architecture.

### 2.2 Architecture for Online based QPE

The architecture of the proposed multi-layer online driven QPE comprises four layers. The first layer is the instrument layer (INL). The second layer is the instrument and parameter meta-data abstraction layer (IPML). The third layer is the data storage layer (DSL). The fourth layer is the data access layer (DAL). The INL describes the aggregation of meteorological data via AWSs and NAWSs. The IPML comprises information on the meteorological parameters, epoch of data observation, and instrument capability. The DSL functionality is realized via the cloud computing platform and provides storage for the data acquired in the IPML. The DAL provides an access to the internet and enables the user i.e. capital constrained organization to access the data stored in the DSL. A relation between the INL, IPML, DSL, and DAL is shown in Figure 2.



Capital constrained organization evaluating the viability of using the post–hydrometeor cooling effect.

Figure 2: Relations between the different layers in the proposed multi – layer online driven QPE.

## 3. PROPOSED APPROACH – RELATIONS

This section presents the relations that constitute the data analytic framework and are executed in the cloud platform. These relations are evaluated using the data obtained from the DAL by the capital constrained organization. The relations serve three purposes. The first is determining the most suitable location where rainfall incidence leads to the most significant drop in environmental temperature. This is done for all epochs in the data record. The second is determining if the reduction in environmental temperature occurs for duration sufficiently long enough enable the data center to leverage on free cooling. The third is enabling the ranking of different locations in consideration of their capability to provide post-hydrometeor cooling to data centres.

Let $\alpha$ be the set of locations where AWSs and NAWSs are deployed.

$$\alpha = \{\alpha_1, \alpha_2, \dots, \alpha_I\} \quad (1)$$

Where $I$ is the total number of weather stations.

Let $R_r(\alpha_i, t_y), v(\alpha_i, t_y), d(\alpha_i, t_y), a_t(\alpha_i, t_y), a_p(\alpha_i, t_y)$ and $a_v(\alpha_i, t_y)$; $t_y, t_y \epsilon\ t, t = \{t_1, t_2, .., t_E\}$ denote the rainfall rate, rain velocity, drop size distribution, air temperature, air pressure and air velocity obtained by the weather station at the $\mathrm{i}^{\mathrm{th}}$ location, $\alpha_i$, $\alpha_i \epsilon\ \alpha$ at epoch $t_y$ respectively.

The parameters $R_r(\alpha_i, t_y)$, $v(\alpha_i, t_y)$ and $d(\alpha_i, t_y)$ are obtained during a rainfall event. The parameters $a_t(\alpha_i, t_y), a_p(\alpha_i, t_y)$ and $a_v(\alpha_i, t_y)$ are obtained by the weather station after the occurrence of the rainfall event.

The data analysis algorithm determines how hydrometeor incidence influences the reduction in air temperature at a location across multiple epochs. The location $\alpha_i$ has the smallest drop in air temperature if:

$$max(\theta_1, \theta_2, \theta_i) = \theta_i \tag{2}$$

$$\theta_1 = |a_t(\alpha_1, t_y) - a_t(\alpha_1, t_{y-z})|, a_t(\alpha_1, t_{y-z}) > a_t(\alpha_1, t_y) \tag{3}$$

$$\theta_2 = |a_t(\alpha_2, t_y) - a_t(\alpha_2, t_{y-z}), a_t(\alpha_2, t_{y-z})| > a_t(\alpha_2, t_y) \tag{4}$$

$$\theta_i = |a_t(\alpha_i, t_y) - a_t(\alpha_i, t_{y-z})|, a_t(\alpha_i, t_{y-z}) > a_t(\alpha_i, t_y) \tag{5}$$

The influence of the rainfall rate on air temperature is also investigated. This is important when rainfall events occur in a random fashion at different epochs. In this case, the rate of change of the air temperature with respect to the rate of change of the rainfall rate at a given location is an important metric that should be determined. This enables the designer to determine how a change in the rainfall rate reduces the air temperature. The rate of change of the air temperature with respect to the rainfall rate is denoted $\beta_1(\alpha_i)$ for the location $\alpha_i$ and is given as:

$$\beta_1(\alpha_i) = \frac{a_t(\alpha_i, t_y) - a_t(\alpha_i, t_{y-z})}{R_r(\alpha_i, t_y) - R_r(\alpha_i, t_{y-z})} z < y \tag{6}$$

In (6), $\beta(\alpha_i)$ is given in OC per (mm/hr.) and describes how a change in the rainfall rate between different epochs influences a drop or rise in the air temperature.

The rate of change of the air temperature with respect to the rain drop velocity and DSD is also evaluated using the data acquired by weather stations. Let $\beta_2(\alpha_i)$ and $\beta_3(\alpha_i)$ denote the rate of change of the air temperature with respect to the rain drop velocity and rate of change of air temperature with respect to the DSD respectively.

$$\beta_2(\alpha_i) = \frac{a_t(\alpha_i, t_y) - a_t(\alpha_i, t_{y-z})}{v(\alpha_i, t_y) - v(\alpha_i, t_{y-z})} z < y \tag{7}$$

$$\beta_3(\alpha_i) = \frac{a_t(\alpha_i, t_y) - a_t(\alpha_i, t_{y-z})}{d(\alpha_i, t_y) - d(\alpha_i, t_{y-z})} z < y \tag{8}$$

Furthermore, relations between the air speed and air temperature is examined. This is also done to determine how changes in the air speed are related to the air temperature. A change in the air speed can also influence air temperature. This change might not necessarily be associated with the occurrence of rainfall events. A change in air speed can lead to the onset of the abundance of cold air before and after the occurrence of the rainfall events. The rate of change of the air temperature with respect to the air speed for location $\alpha_i$ is denoted $\gamma_1(\alpha_i)$ and given as:

$$\gamma_1(\alpha_i) = \frac{a_t(\alpha_i, t_y) - a_t(\alpha_i, t_{y-z})}{a_v(\alpha_i, t_v) - a_v(\alpha_i, t_{y-v})} z < y \tag{9}$$

In addition, the relations between the air pressure and air temperature is also examined and evaluated in the parameter $\gamma_2$ and given as:

$$\gamma_2(\alpha_i) = \frac{a_t(\alpha_i, t_y) - a_t(\alpha_i, t_{y-z})}{a_p(\alpha_i, t_y) - a_p(\alpha_i, t_{y-z})} z < y \tag{10}$$

The parameters $\theta_i, \beta_1(\alpha_i), \beta_2(\alpha_i), \beta_3(\alpha_i), \gamma_1(\alpha_i)$ and $\gamma_2(\alpha_i)$ are computed using the data acquired by the weather stations and stored in the cloud computing platform.

A high value of $\beta_1(\alpha_i)$ signifies that a significant change in the rainfall rate results in a corresponding change in the value of the air temperature. This influences the change in the air temperature. In the event that the value of $\beta_1(\alpha_i)$ is positive, this implies that an increase in the rainfall rate results in a significant increase in the air temperature. Furthermore, in the event that the value of $\beta_1(\alpha_i)$ is negative, this can be interpreted to mean that an increase in the rainfall rate results in a reduction in the air temperature. A negative value of $\beta_1(\alpha_i)$ can also be obtained when a reduction in the rainfall rate results in a reduction in the air temperature. Such behaviour can be obtained due to the influence of teleconnections.

The value of $\beta_2(\alpha_i)$ can also be positive or negative. In this case, low value i.e. negative values are also beneficial. A negative $\beta_2(\alpha_i)$ value implies that increase in the rain drop velocity results in a reduction in the air temperature at a given location. Negative values can also be obtained when the raindrop velocities reduce at later epochs in comparison to earlier epochs. In the case of this work, it is assumed that there are a large number of rain drops. Hence, negative values of $\beta_2(\alpha_i)$ are beneficial.

The information on the number of rain drops can be leveraged to make a decision on the role of the values of $\beta_2(\alpha_i)$. The parameter $\beta_3(\alpha_i)$ enables the influence of the DSD on the air temperature to be investigated. A negative value of the parameter $\beta_3(\alpha_i)$ is also considered beneficial. However, it is important that the negative value arises wholly from a reduction in temperature at a later epoch in comparison to an earlier epoch. This is important in making a decision on the influence of rain drop diameter on the suitability of the concerned location for leveraging on the post-hydrometeor cooling effect.

The parameters $\beta_1(\alpha_i), \beta_2(\alpha_i)$ and $\beta_3(\alpha_i)$ are derived from micro-structural properties of rainfall during the rainfall event. The parameters $\gamma_1(\alpha_i)$ and $\gamma_2(\alpha_i)$ are obtained from the environmental parameters that arise after the occurrence or in the absence of a rainfall event. A high value of $\gamma_1(\alpha_i)$ indicates that air velocity results in an increase in the air temperature. This indicates an entrance of hot air into the surrounding environment. A negative value also indicates that a negative temperature i.e. decreasing temperature is associated with increasing air speed. This is obtainable when there is a rush of the cold air into the location for a long duration.

The variation associated with $\gamma_2(\alpha_i)$ describes relations between the air temperature and air pressure. A negative value of $\gamma_2(\alpha_i)$ indicates a decreasing temperature–pressure gradient. A high value of $\gamma_2(\alpha_i)$ is indicative of an increasing temperature–pressure gradient. In this case, it is important to verify that an increase or decrease in the air pressure is associated with a decreasing temperature during the data analysis. This enables us to determine if the post-hydrometeor cooling effect is associated with increasing air pressure in the environment.

## 4. SELECTION AND ARCHITECTURE ASPECTS

This section focuses on how the variables are used to make a decision on selecting the most suitable location. The most suitable location is one in which the post-hydrometeor effect is considered to have the best cooling effect.

The discussion is divided into three parts. The first part focuses on selecting the most suitable region and the parameters computed in the data analytics process. The second part discusses the role of post–hydrometeor cooling in the context of data center cooling. The third part considers how the incorporation of the post–hydrometeor cooling influences data center design considering data center size and architecture.

## 4.1 SELECTION OF SUITABLE LOCATION

The analysis to compute the values of $\theta_i$ , $\beta_1(\alpha_i), \beta_2(\alpha_i), \beta_3(\alpha_i)$ , $\gamma_1(\alpha_i)$ and $\gamma_2(\alpha_i)$ is done using the computing resources aboard the cloud computing platform. This is done for the different locations and also considers the duration for which the post-hydrometeor cooling effect is active. The location $\alpha_i$ is considered to be most suitable if:

$$min(\beta_c(\alpha_1), \beta_c(\alpha_2), \dots, \beta_c(\alpha_i), \dots, \beta_c(\alpha_I)) = \beta_c(\alpha_i), \quad c \in \{1,2,3\} \tag{11}$$

The relation in (11) can be used to develop a rank of most suitable regions from the acquired data present in the cloud computing platform. This ranking operation enables regions to be ranked in a pattern of the most suitable regions to the least suitable regions considering the effect of the post-hydrometeor cooling effect.

In addition, (11) considers the case of long duration rainfall events. In the case where rainfall duration is not sufficiently long, the natural climate and not rainfall occurrence provides the natural cooling effect. The occurrence of rainfall for a long duration enables the occurrence of more rain drops with large range of velocity values and drop diameter. Hence, the expression in (11) is considered feasible.

The parameters $\gamma_1(\alpha_i)$ or $\gamma_2(\alpha_i)$ are evaluated for ranked locations. This enables cloud platform designers to determine the onset from which the post-hydrometeor cooling effect can be leveraged to obtain data center free cooling. The value of $\gamma_1(\alpha_i)$ and $\gamma_2(\alpha_i)$ is observed for different epochs (with each epoch having a pre-defined duration). If $\gamma_1(\alpha_i) \rightarrow -s\, ; s > 0$; $a_t(\alpha_i, t_{y-z}) > a_t(\alpha_i, t_y)$, an increase in the air velocity reduces surrounding air temperature at the epoch $t_y$. This implies that the hydrometeor cooling effect can be leveraged at the epoch $t_y$ for the location $\alpha_i$. A similar inference can be made for $\gamma_2(\alpha_i)$.

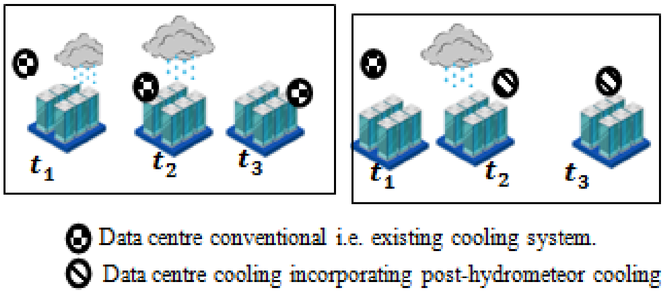
## 4.2 DATA CENTRES & PROPOSED COOLING

Data centres leverage on different cooling strategies. Examples of data center cooling strategies are air conditioning systems [7], leveraging on cold water from nearby streams, lakes and rivers [18-20] and relying on the cold climate to provide cold air. The approaches in [18-20] consider terrestrial data centres. The post-hydrometeor cooling effect focuses on investigating the viability of leveraging on cold air in the environment for data center cooling. Cold air can be used in naturally cold climates due to the naturally low temperature.

The post-hydrometeor cooling effect considers locations with high rainfall and long rainfall months. In this case, the post-hydrometeor cooling effect serves in an assisting role to cool data centres in these locations. However, new data centres can be built to leverage on the post-hydrometeor effect for reducing cooling costs. This is beneficial because the existing data centres do not consider the post-hydrometeor cooling effect.

The incorporation of the post-hydrometeor cooling enables data centres to leverage on the rainfall patterns in different locations. It is assumed that fibre optic network links are accessible at locations where weather stations are sited.

The role of the post – hydrometeor cooling in data centre operation is shown in Figure 3 and Figure 4. The scenario in Figure 3 (left) shows the case where existing data centre cooling approach is utilized in epochs $t_1, t_2$ and $t_3$. In this case, there is rainfall event at the epoch $t_2$. However, the post-hydrometeor effect is not leveraged at the third epoch i.e. $t_3$.
The scenario presented in Figure 3 (left) shows the case where there is rainfall event at the epoch $t_1$. Existing cooling approach is utilized in the first epoch i.e. $t_1$. The proposed post –hydrometeor cooling effect is leveraged for data centre cooling at the second epoch $t_2$ and the third epoch $t_3$.



**Role of the post-hydrometeor effect in data centre cooling. Figure 3: (left) showing data centre cooling in the absence of the proposed post–hydrometeor cooling effect. Figure 4: (right) showing how the proposed post–hydrometeor cooling effect for data centres cooling in two epochs.**

## 4.3 SCHEDULING AND PROPOSED COOLING

Leveraging on the proposed post-hydrometeor cooling effect requires re-designing data centres. Currently, data centres have not been designed to leverage on the post-hydrometeor cooling effect. Leveraging on the post-hydrometeor cooling effect reduces the cooling costs during the high rainfall months. This benefit is realizable without harvesting rain water.

Data centres can have different sizes depending on the number of hosted servers. This paper proposes that the post-hydrometeor cooling effect should be leveraged when the expansion of data centres is required. In this case, new servers are not added to a data center when expansion is required. Instead, the new servers are sited in locations where they can leverage on the post–hydrometeor cooling effect. The distributed data centres are interconnected via fibre optic links. Data centres located in regions where they can leverage on the post-hydrometeor cooling effect can be scheduled to execute large computational workloads during epochs where $\beta_1(\alpha_i)$ has the lowest values. The results on the parameters obtained from AWSs and NAWSs are used to determine changes in the ability of the post-hydrometeor cooling effect at the considered locations.

The incorporation of the hydrometeor cooling effect requires the re – design of the workload scheduling mechanism for cloud data centres. This is necessary because of the availability of additional servers that leverage on free cooling via the post–hydrometeor effect.

The flowchart for the proposed workload scheduling mechanism is shown in Figure 5. In Figure 5, it is assumed that data centres leverage on the post-hydrometeor cooling effect for the same duration. The cloud service provider monitors the compute resource usage on all data centres that leverage on the post-hydrometeor cooling effect; and those utilizing other cooling mechanisms. However, the consideration in this case does not include data centres sited in other physical locations such as the ocean and the stratosphere. The compute resource monitoring entity (CRME) monitors the computational resource utilization.

The CRME enables the cloud platform operator to determine the utilization status of all data centres. In executing its intended functionality, the CRME utilizes a data center specific utilization threshold. The information on the data center specific utilization threshold differs for each data center. The utilization threshold is different for each data center. This is necessary to account for the fact that the data centres have different number of servers. The flowchart in Figure 5 assigns computing workloads from subscriber to a data center leveraging on the post-hydrometeor cooling effect.

## 5. FORMULATION AND ANALYSIS

The post-hydrometeor cooling effect is intended to reduce the data center cooling costs. Hence, the use of post-hydrometeor cooling effect should reduce data centre cooling costs and enhance power usage effectiveness (PUE). This section is divided into two parts. The first part formulates the cooling costs and the PUE. The second part presents the simulation results.

### 5.1 PERFORMANCE FORMULATION

Let $\varsigma$ denote the set of air cooled terrestrial data centres such that:

$$\varsigma = \{\varsigma_1, \varsigma_2, \dots, \varsigma_S\} \tag{12}$$

Where S is the total amount of terrestrial data centres constituting the cloud platform.

Let $\mathscr{b}(\varsigma_r), \varsigma_r \epsilon \varsigma$ denote the amount of cold air used in cooling the $r^{th}$ data center $\varsigma_r$. In addition, let $\mathscr{k}_1(\varsigma_r)$ denote the amount of cold air available via free air cooling (without considering the role of the post-hydrometeor cooling effect).

Furthermore, let $\mathscr{k}_2(\varsigma_r, t_y)$ denote the amount of cold air available via the post-hydrometeor cooling effect. The cooling power associated with the $r^{th}$ data center $\varsigma_r$ is denoted $P_c(\varsigma_r)$. The cooling power associated with cooling the data center $\varsigma_r$ in the absence of any form of free cooling is given as $P_c(\varsigma_r)$. The cooling power in the event that free air cooling is used to aid an existing air cooling strategy is denoted $P_C^1(\varsigma_r)$. In addition, the cooling power in the event that the proposed post-hydrometeor cooling effect is used to the cool data centres is denoted $P_C^2(\varsigma_r)$.

The parameter $P_C^2(\varsigma_r)$ considers that the proposed hydrometeor cooling effect is leveraged after a rainfall incidence in the concerned location.

$$P_C^1(\varsigma_r) = P_c(\varsigma_r)\left(1 - \frac{\mathscr{k}_1(\varsigma_r)}{\mathscr{b}(\varsigma_r)}\right) \tag{13}$$

$$P_C^1(\varsigma) = \sum_{r=1}^{S} P_c(\varsigma_r)\left(1 - \frac{\mathscr{k}_1(\varsigma_r)}{\mathscr{b}(\varsigma_r)}\right) \tag{14}$$

$$P_C^2(\varsigma_r) = P_c(\varsigma_r)\left(1 - \frac{I(\varsigma_r, t_y)\mathscr{k}_2(\varsigma_r, t_y)}{\mathscr{b}(\varsigma_r)}\right) \tag{15}$$

$$P_C^2(\varsigma) = \sum_{r=1}^{S}\sum_{Y=1}^{Y} P_c(\varsigma_r)\left(1 - \frac{I(\varsigma_r, t_y)\mathscr{k}_2(\varsigma_r, t_y)}{\mathscr{b}(\varsigma_r)}\right) \tag{16}$$

$P_C^1(\varsigma)$ and $P_C^2(\varsigma)$ are the total power spent in cooling data centers in a cloud platform incorporating free air cooling and proposed post-hydrometeor cooling respectively.

$I(\varsigma_r, t_y) \epsilon \{0,1\}$ is the post-hydrometeor cooling indicator. $I(\varsigma_r, t_y) = 0$ and $I(\varsigma_r, t_y) = 1$ signifies that cooling is unrelated and is related to the proposed hydro-meteor cooling effect respectively.

### 5.2 PERFORMANCE ANALYSIS

The performance analysis is done using parameters in Table I.

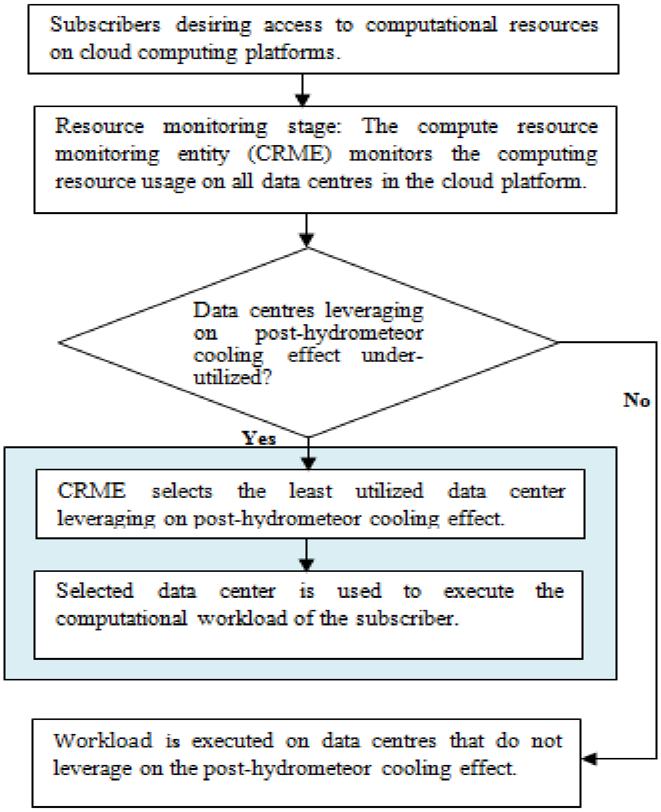


**Figure 5: Flowchart showing the selection of data centres leveraging on the post-hydrometeor cooling effect.**

**Table I: Simulation Parameters.**

| Parameter | Value |
|---|---|
| Minimum data centre operating power (MW) | [0.52 0.25, 0.73] |
| Maximum data centre operating power (MW) | [9.48, 9.84, 13.39] |
| Mean power spent in operating data center | [4.50, 5.17, 7.06] |
| Proportion of data center spent in cooling [3]. | 40% |
| Ratio: $\mathscr{k}_1(\varsigma_r)$: $\mathscr{b}(\varsigma_r)$ | [0.2;0.4;0.6] |
| Ratio: $\mathscr{k}_1(\varsigma_r)$: $\mathscr{k}_2(\varsigma_r, t_y)$ | [0.2;0.45;0.7] |

The simulation result for the cooling power is shown in Figure 6 and Figure 7. Figure 6 shows the cooling power obtained for a data centre comprising up to 20 servers. In this case, data centres leverage on free air cooling (differs from post-hydrometeor cooling). Figure 7 also shows the cooling power obtained for a data centre comprising up to 20 servers. The data centres leverage on the post-hydrometeor cooling.

In the simulation, hydrometeor incidence increases cold air by an average of 8.5%. Results show that the use of free air cooling techniques reduces cooling power in comparison to when free cooling approach is used. This is expected. The results in Figure 6 and Figure 7 have a similar variation. This is because of the relatively low value by which hydrometeor incidence reduces environmental temperature and increases cold air. In Figures 6 and 7, each value of the ratio corresponds to data centres in different locations. Analysis shows that utilizing the proposed hydrometeor cooling effect reduces the cooling costs by at least 8.3% and up to 25% on average.

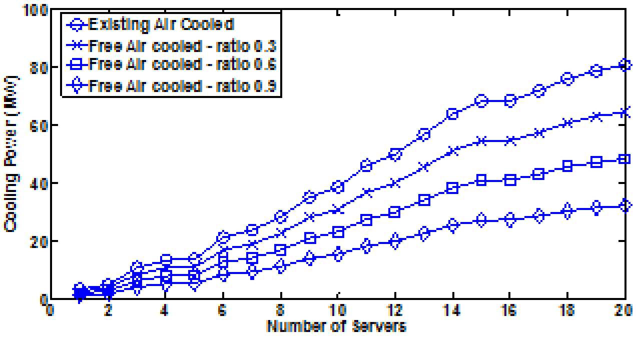


**Figure 6: Simulated results for the cooling power with existing air cooled method and free air cooling approach.**

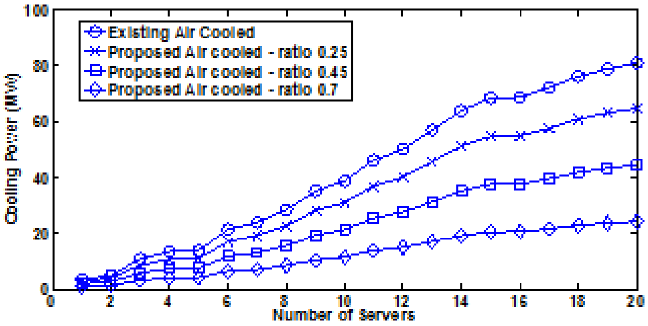


**Figure 7: Simulated results for the cooling power with existing air cooled method and proposed air cooling approach.**

## 6. CONCLUSION AND FUTURE WORK

This paper proposes that the environmental effect of rainfall can be leveraged to reduce the cooling effect of data centres. In this regard, the paper proposes the post-hydrometeor cooling effect for data centres. The proposed post-hydrometeor cooling effect differs from the existing approach of siting data centres in cold climatic regions. This is because the post- hydrometeor cooling effect leverages on the ability of long duration rainfall effects to reduce environmental air temperature. This increases the amount of cold air that is available in different locations. In addition, the paper proposes a data acquisition approach leveraging on the proposed novel weather station diversity architecture. Data acquired via the novel weather station diversity architecture is processed via the proposed data analytic framework. Additional work is required to investigate and assess the cooling cost reduction benefits derivable from using the proposed post-hydrometeor cooling effect. It is also required to investigate if the consideration of the role of the precipitation estimation as proposed can be adopted in future cloud radio access networks. Performance analysis shows that cooling cost is reduced by up to 25% on average when the proposed hydrometeor cooling effect is incorporated in data center cooling.

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