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Implementation of the hyper-local real-time heatwave monitoring system for Yeongcheon in Korea

- Focusing on the temperature information system

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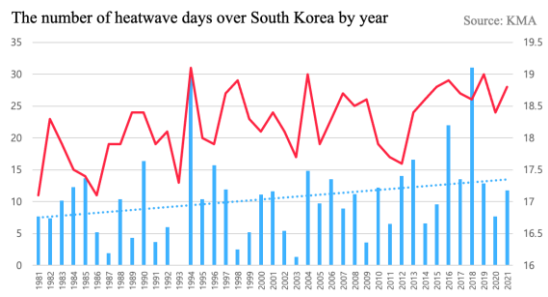
A B S T R A C T

Nano C&W has developed a heatwave information system for Yeongcheon to be prepared a thorough response to urban heatwaves by producing high-resolution temperature data using the demonstration technology 'AlphaMet' using only public meteorological data to produce city temperature data that can be linked to digital twins of Yeongcheon city. A comparison has conducted to verify accuracy of the temperature information with testbed of IoT (Internet of Things) meteorological observation equipment for a dozen of selected sites. This proposed information system may enhance decision-making support services in preparation for the effects of weather disasters such as heat waves and cold waves. The testbed has been selected with sites that are vulnerable to heat waves for geographical and social reasons, and establish a high-resolution (1km~30m) temperature data production system using the demonstration technology. In addition a monitoring web has been developed to provide real-time high-resolution temperature maps, location-based temperature forecast information, heatwave/cold wave forecasts and warnings, etc..

Key words: heatwave; hyper-local; real-time, public health, agriculture; preparedness, disaster management

1. Introduction

The heatwave has known as a silent killer coming with climate change. According to the climate change scenario AR6 announced by the Intergovernmental Panel on Climate Change (IPCC), the duration, frequency, and intensity of heatwaves in the 21st century are expected to increase. It is estimated that the social cost of human life and property damage due to the heat wave is up to 106 trillion won (Shin *et al.*, 2015). The national average maximum temperature and the number of heatwave days are increasing every year (Fig. 1).



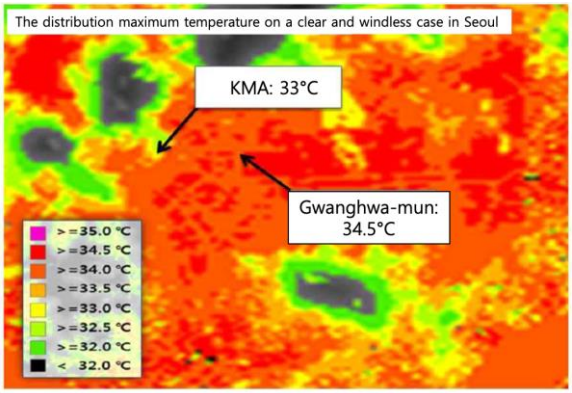
<Fig. 1> Number of heatwave days nationwide by year in Korea. The red solid line is the mean highest temperature by each year, and the bar graph is the number of heatwave days.

On the other hand, as the frequency of occurrence of cold waves increases in winter, extremes in temperature are expected to become increasingly serious (Jeon and Cho, 2015). As this extreme temperature phenomenon continues, damage occurs in various fields such as health, agriculture, and livestock industry.

Therefore, continuous temperature monitoring is necessary to establish policies to respond to natural disasters from heat waves and cold waves. Urban heatwaves and coldwaves cause various problems, including deterioration of public health, increased energy consumption, and urban pollution. In order to realize the smart city promoted by the government, it is essential to obtain high-resolution city-scale weather analysis and forecasting fields, which are the fundamental technologies of real-time meteorological information-based meteorological and climate convergence services.

In order to analyze the occurrence of heat waves/cold waves and to design the city considering the weather effects in the digital twin, it is necessary to monitor the temp`erature continuously in space and time. However, there are public meteorological stations in each region, but in non-metropolitan cities, the number of stations is limited, so there may be a gap between the stations. In

addition, the spatial distribution of temperature varies according to land cover and time (Fig. 2), so detailed spatial and temporal high-resolution data are needed to prepare for weather changes and predict the risk of heat waves and cold waves (Korea Environmental Institute, 2021). It is necessary to utilize 'AlphaMet', a demonstration technology that physically calculates three-dimensional meteorological data by reflecting the terrain effect in the existing public meteorological observation data.

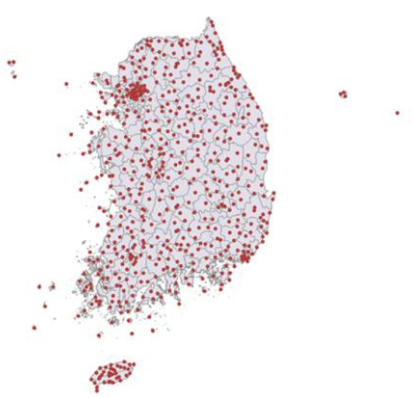


<Fig. 2> Distribution of the maximum temperature on a heat wave day. Source: National Institute of Meteorological Sciences (2017); Korea Environmental Institute (2021)

It is necessary to demonstrate a smart city that responds to urban disasters with a real-time temperature monitoring system. By applying the demonstration technology 'AlphaMet' to Yeongcheon, a representative heatwave city, the city temperature monitoring system is established, and the accuracy and effectiveness of the demonstration technology are verified to provide temperature information in the real life environment of citizens and help flexible decision-making in response to urban disasters. A data-driven city implementation is in demand. It is necessary to demonstrate a smart city that responds to urban disasters with a real-time temperature monitoring system. By applying the demonstration technology 'AlphaMet' to Yeongcheon, a representative heatwave city, the city temperature monitoring system is established, and the accuracy and effectiveness of the demonstration technology are verified to provide temperature information in the real life environment of citizens and help flexible decision-making in response to urban disasters. A data-driven city implementation is in demand.

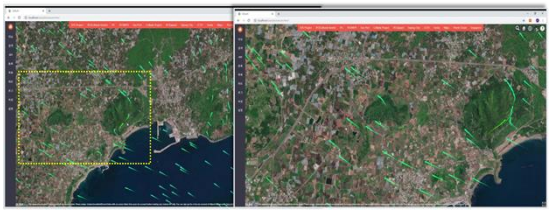
2. Demonstration technology/product conductivity/innovation

It is required to overcome the limitations of physical observation and seamlessly provide real-time and predictive data. However, as for the existing weather information, the measurement data of the observatory is used as a representative value of the surrounding area. Korea's meteorological observation network is relatively dense with an average interval of 13 km, but high-resolution data of less than 1 km are required in the industrial and smart city technology fields. However, in small towns and mountainous areas, the observation network is not dense, so data from observation stations several to tens of kilometers away are used as representative values (Fig. 3).



<Fig. 3> Distribution status of meteorological stations of Korea Meteorological Administration in 2020

AlphaMet technology of Nano C&W calculates the distribution of temperature, wind, and precipitation in three dimensions based on meteorological principles that consider topography or building characteristics, and can realistically reproduce the empty weather information between observation stations (Fig. 4). This technology is distinguished general spatial interpolation methods such as IDW, krigging, and TIN.



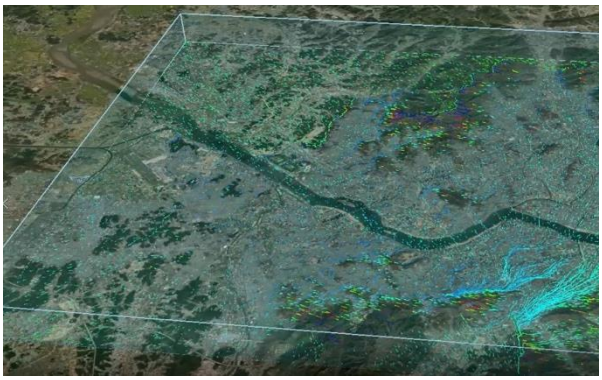
<Fig. 4> Example of displaying wind data at 30m resolution in the Jeju region of AlphaMet (implemented on Gaia 3D's mago3D platform)

In terms of computer operation, efficient super-resolution weather information service is possible. With the recent development of computing technology, domestic and foreign institutions and companies provide numerical forecasts on a scale of several kilometers, but there is a limit to commercialization because supercomputers are essential. Nano C&W's technology can provide specialized services for monitoring meteorological disasters such as heat waves, cold waves, and heavy rains by producing ultra-high-resolution meteorological data within 5 minutes with small-scale computing resources. In fact, it takes less than 5 minutes to produce real-time temperature/precipitation/wind data at 1km resolution across the country.

AlphaMet of Nano C&W is a digital twin-specialized technology that rapidly reproduces the temperature and wind field between buildings. The computational fluid dynamics model widely used for urban-scale weather modeling requires a lot of computational resources and

takes a long time to calculate, so it is mainly used for urban wind road research instead of real-time. AlphaMet technology, developed for the purpose of producing detailed meteorological data reflecting the terrain effect, has been developed recently and succeeded in calculating the temperature and wind field using DSM (Digital Surface Model) data of 10 m or less, and the rooftops, streets and alleys of buildings of the temperature distribution was realistically realized (Fig. 5 and Fig. 6)).

<Fig. 5> Example of 1m resolution AlphaMet temperature on Teheran-ro, Seoul.



<Fig. 6> Example of application of AlphaMet Data's Smart City Digital Twin Platform (Gaia 3D mago 3D)

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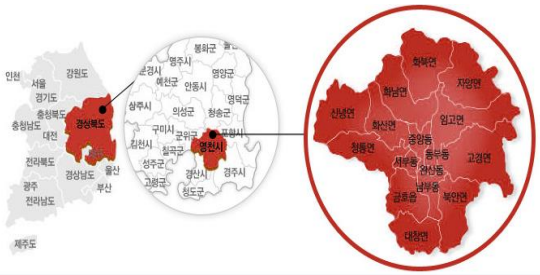
3. Results of the demonstration project

3.1 Status of test sites

3.1.1 Overview of the site

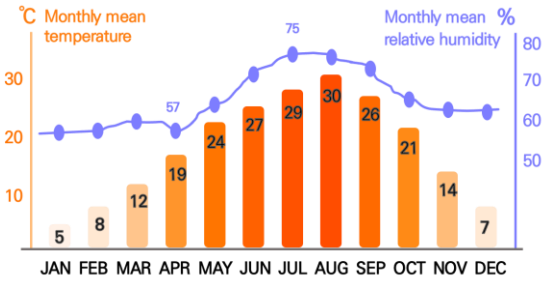
Yeongcheon-si, Gyeongsangbuk-do, which has geographical and social characteristics such as large temperature and annual temperature differences, is a city-rural complex city with a basin type (Fig. 7).



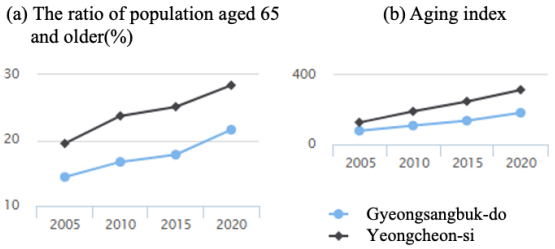
<Fig 7> Demonstration area coverage. Source: Yeongcheon City Hall. Source: Yeongcheon City

3.1.2 Target environment analysis

Yeongcheon-si, located in the southeastern part of Gyeongsangbuk-do, is a representative heatwave risk city in Korea. In summer, the moist air that has crossed the Taebaek Mountains becomes hot and dry and flows into the basin, making it vulnerable to heat waves and cold and dry climates in winter due to the continental climate. Unlike Pohang, which is located at the same latitude, the summer temperature is higher and the winter temperature is lower, so heat stress caused by the annual temperature difference is relatively high, so real-time temperature change monitoring is required (Fig. 8). Yeongcheon is an urban-rural complex city, and its vulnerability to heatwaves is increasing due to the increase in heatwaves and an aging population (Fig. 9).



<Fig. 8> Annual temperature difference in Yeongcheon



<Fig. 9> Gyeongsangbuk-do and Yeongcheon-si population over 65 years old and aging index. Source: SGIS Statistical Geographic Service

3.2 Overview of Demonstration Technology and Product

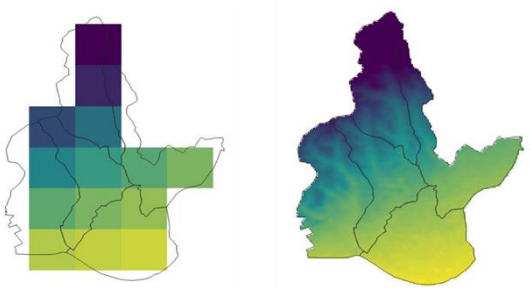
3.2.1 Demonstration method

In the course of years of research and development, the innovative technology AlphaMet, which has been recognized for patent acquisition and smart city utilization, is demonstrated in Yeongcheon and its effectiveness is verified. For temperature monitoring in the demonstration area, the temperature module of AlphaMet, a high-resolution meteorological and climate data production solution, is applied as a demonstration technology. AlphaMet consists of temperature, precipitation, wind, atmospheric pressure, and wet bulb temperature detailed modules. Each module is individual, so it is possible to select and use the necessary weather elements.

3.2.2 Demonstration project implementation scenario

In order to apply the demonstration technology, the real-time detailed city temperature data and city temperature map production system of Yeongcheon with AlphaMet will be established as follows:

- Establishment of a system that produces real-time temperature data of Yeongcheon in 1 km x 1 km resolution every hour with demonstration technology
- Establish a real-time collection system for real-time meteorological observation data and numerical model data (LDAPS) from the Korea Meteorological Administration and use it as input data to AlphaMet, and produce predictive data 36 hours from now
- Use 1km, 30m resolution public DEM data to calculate the terrain effect of AlphaMet (Fig. 10)



<Fig. 10> Difference between 1 km resolution and 30m resolution in small administrative districtsI(Dongbu-dong).

- Since temperature maps are prepared in units of administrative districts, data are produced with different resolutions according to administrative district area, population, and density
- For densely populated areas and small administrative districts (Jungang-dong, Dongbu-dong, Seobu-dong, Nambu-dong, Wansan-dong), create a city temperature map by producing temperature data with a resolution of 30m x 30m
- On the other hand, for the administrative districts of eup/myeon in the outskirts of the city, which have a small population and mostly mountainous areas, create a city temperature map with 1 km-resolution data.

To verify the demonstration technology, the accuracy of the data produced by the demonstration technology is verified after the temperature is measured at more than 10 verification points in the demonstration area (Fig. 11).

<Fig. 11> Yeongcheon-si IoT Weather Station Installation Status for Demonstration Technology Verification

- Temperature measurement for verification by selecting a verification point through on-site inspection through consultation with the customer and installing 10 or more IoT meteorological observation equipment
- In addition, AWS(automatic weather station) observation data from 12 sites operated by the Yeongcheon Agricultural Technology Center is collected and used for verification.
- Comparing the real-time temperature data in Yeongcheon-si produced by empirical technology with the actual measurement to obtain RMSE, MAE, correlation coefficient, and verification of accuracy and significance of temperature time series

* Root Mean Square Error (RMSE): A measure commonly used when dealing with the difference between an estimated value or a value predicted by a model and a value observed in the real environment, suitable for expressing precision

* Mean Absolute Error (MAE): An intuitive index that converts the difference (Error) between the actual value and the predicted value into an absolute value and interprets the error as the averaged value

* Correlation coefficient: An index that shows how a change in one variable among two variables changes according to a change in the other variable. It is an index that numerically summarizes the degree and direction of correlation between variables.

- Introduced a thermal imaging camera system to a place with a large floating population to identify the road temperature distribution during a heat wave

Establish and operate a monitoring web for demand management managers in order to utilize the demonstration technology

- Real-time Yeongcheon-si temperature data, city temperature map, thermal imaging camera image, heat wave vulnerability analysis result, etc. to be built by the administrator to monitor the web
- Search for policy utilization and service plan for citizens through evaluation of demand for the functions and usability of the monitoring web

4. Comparison and verification of IoT observed temperature and AlphaMet temperature data

Demonstration Technology the real-time (1-hour interval) temperature data of AlphaMet was compared with the PWS observed temperature values of 10 monitoring points.

- Analysis period: 2022.03.17. ~ 2022.05.16.
- Target variable: hourly temperature data
- Analysis points: Gogyeong-myeon (1), Geumho-eup (1), Nambu-dong (1), Daechang-myeon (2), Bukan-myeon (1), Sinnyeong-myeon (1), Wansan-dong (2), Hwanam-myeon (1) A total of 10 branches

The analysis method is as follows, where *P* is the calculated AlphaMet data and *O* is the observed temperature using PWS.
- Root Mean-Squared Error (RMSE)

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P-O)^2}$$

- Mean Absolute Error (MAE)

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|P-O|$$

- Pearson Correlation Coefficient

$$Pearson\ Corr.Coef. = \frac{\sum_{i=1}^{n}(P_i-\bar{P})(O_i-\bar{O})}{\sqrt{\sum_{i=1}^{n}(P_i-\bar{P})^2}\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2}}$$

Before comparative verification with AlphaMet, the reliability of the IoT observation temperature value was checked. The PWS, a device used for IoT observation, is a simple weather observation device, and the observation environment is not met like AWS. It was checked whether the observed temperature values were similar. In both Daechang-myeon and Wansan-dong, the correlation coefficient between the two PWSs was 0.999, RMSE less than 0.28, and MAE less than 0.20. It was judged that the influence of the environment was not significant.

As a result of comparison and verification of IoT observation temperature and AlphaMet temperature data, the correlation coefficient between the calculated and observed values of AlphaMet temperature at all points was 0.99 or more, MAE was less than 0.8℃, and RMSE was less than 1.1℃, which met the performance goals (Table 1) .

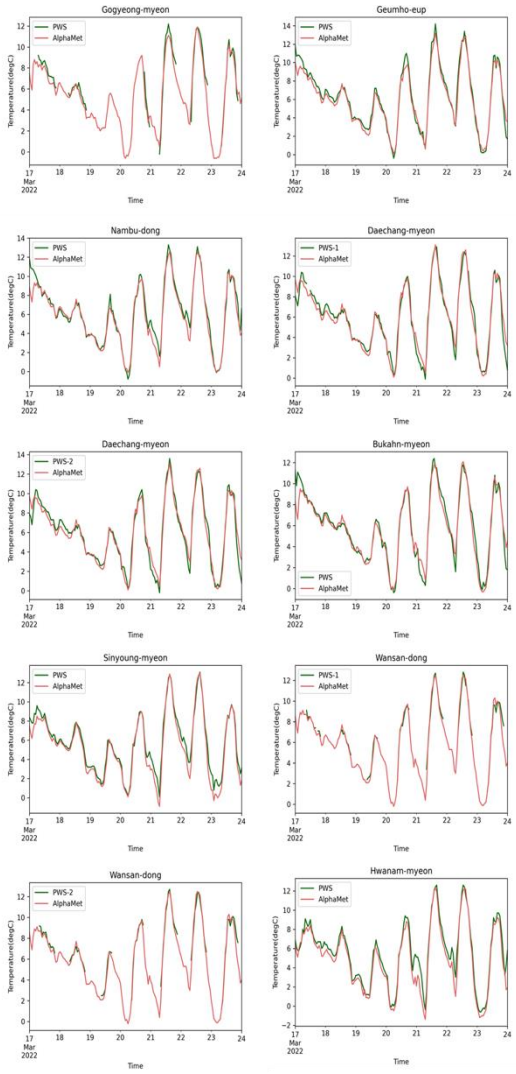
<Table 1> IoT Observed Temperature and AlphaMet Comparison Verification Results

Verification point	RMSE(℃)	correlation coefficient	MAE(℃)
Gogyeong-myeon	0.873	0.992	0.676
Geumho-eup	0.805	0.993	0.614
Nambu-dong	0.919	0.992	0.616
Sinyeong-myeon	1.021	0.994	0.777
Bukahn-myeon	0.952	0.991	0.683
Hwanam-myeon	1.001	0.994	0.749
Daechang-myeon-1	0.828	0.993	0.632
Daechang-myeon-2	0.869	0.992	0.638
Wansan-dong-1	0.741	0.993	0.518
Wansan-dong-2	0.717	0.993	0.505

In the time series graph comparing the changes in the AlphaMet temperature (pink solid line) and the PWS observed temperature (green solid line) over time, it was confirmed that the daily maximum temperature was simulated somewhat lower than the actual temperature in AlphaMet and the daily minimum temperature somewhat higher. (Fig. 12). This is expected to be an error that may occur because AlphaMet details the temperature at a height of 2 m while PWS is installed at a height of 4 to 6.5 m from the ground. The reason for installing the PWS in such a high place is to install it higher than 2m for safety reasons and the conditions for installing observation equipment that must be open. Considering this, it can be concluded that the calculated AlphaMet value changes with similarity to the actual observation value, and the difference between the two values is not large, so the accuracy is very high.

4. Establishment and operation of monitoring web for Yeongcheon-si disaster response managers

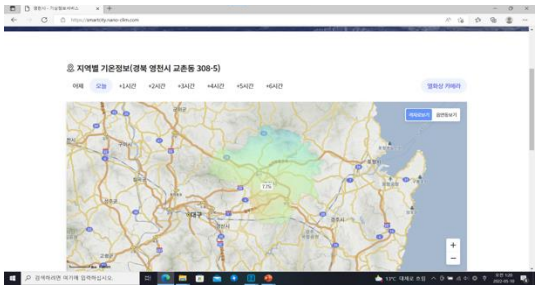
The Yeongcheon-si temperature monitoring web, which can provide empirical results, has been established. Currently, so that only the person in charge of the relevant department can access it, the member can be managed by receiving the membership application and creating an account.



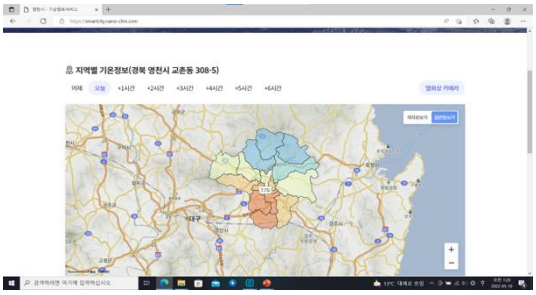
<Fig. 12> AlphaMet-Observed Value (PWS) Time Series Graph by PWS Verification point

Using the Kakao Map API, a grid unit city temperature map image and an average temperature map of eup, myeon and dong were displayed on the map (Fig. 13 and 14).

In this heatwave information system, if you click on the map or search for an address according to the spatial information properties included in the AlphaMet temperature data, the temperature value of the location is displayed. In addition, you can use the bookmark function to register an area of interest and move easily. In addition, the status of special warnings issued by the Korea Meteorological Administration (heat wave, cold wave, strong wind, dryness) that have been in effect for the cities and counties adjacent to Yeongcheon-si are delivered in conjunction with the API. Here, the UV index of the Korea Meteorological Administration, the possible stroke index, the freezing probability index (November to March), and the current status of the sensible temperature (May to September) are delivered by linking with the API.



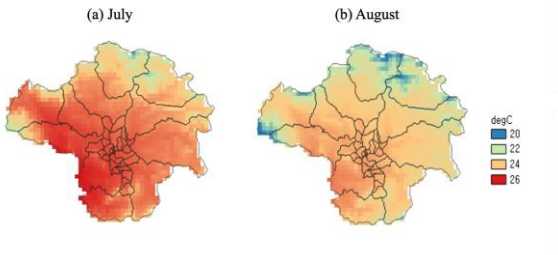
<Fig. 13> Grid unit temperature map



<Fig. 14> Temperature map of eup, myeon and dong units

In the past (July-August 2021), the vulnerability of heat waves using high-resolution monthly average temperature data in Yeongcheon was presented through the following analysis.

- Comparison of monthly average temperature data for 1km in Yeongcheon-si in July-August 2021
- Completion of construction of daily average/highest/lowest temperature data for each eup, myeon and dong for the past 30 years
- The average monthly maximum temperature in July 2021 is higher than in August (Fig. 15)

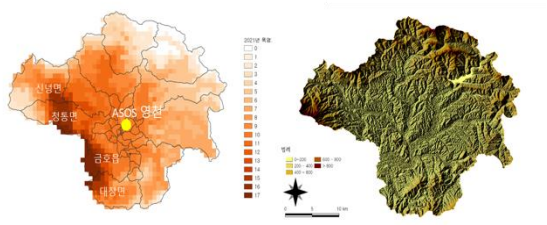


<Fig. 15> Average monthly temperature in Yeongcheon-si in July and August 2021

Using AlphaMet data, calculate the days with the highest daily temperature of 33°C or higher in the summer of 21

- More than 15 days of heat in Geumho-eup, Cheongtong-myeon, Sinnyeong-myeon, and Daechang-myeon, which are the basins, more than the ASOS Yeongcheon branch, which is the standard for heat wave warning issued by the Korea Meteorological Administration

* The actual heatwave warning issued by the Korea Meteorological Administration is based on the ASOS Yeongcheon branch.



<Fig. 16> Number of days of heatwave in July-September 2021 with elevation map of Yeongcheon

5. Discussions and Conclusions

The effectiveness of AlphaMet, a demonstration technology that produces temperature data very similar to reality without additional installation of an observatory, has been demonstrated. The superiority of AlphaMet technology was demonstrated by implementing the technology to build the meteorological big data of smart cities in local governments where the number of public meteorological data is small and it is difficult to introduce a dense IoT observatory and observe drones. AlphaMet data accuracy was verified with temperature data from 22 locations directly measured at the test site. In preparation for various problems (observation environment, quality control, prevention of civil complaints and safety accidents, etc.) encountered in the process of installing IoT meteorological observation equipment for verification, the effectiveness of AlphaMet introduction was also demonstrated in terms of safety and maintenance.

Through the demonstration project, a service foundation was prepared to provide demonstration technology to users. If the current ~36h predicted temperature data is produced every hour and a series of processes that are expressed as a GIS-based temperature map are established as a system, and a website that provides them is developed and a pilot service is being implemented, the service will start in earnest in 2023. The temperature data produced by the empirical technology was visualized as a GIS-based temperature map and time series graph for easy visual understanding.

Based on the practicality of the demonstration technology, it is necessary to establish not only the level of research but also the use of measures such as measures against the heat wave this summer.

In the future, it is expected that smart cities will be applied not only in temperature, but also in precipitation and wind detailing technology. Through active publicity of the empirical results, we are pursuing continuous diffusion to spread the results, and the ‘temperature monitoring web’, which has been built for those concerned with demanding parties, is operated even after the end of the project to accumulate user experience and to be linked to work.

Through this heat wave information system service, it is possible to solve the problems of convenience for citizens due to heat waves and cold waves based on urban temperature spatial analysis. Compared to the additional installation of Automatic Weather Station (AWS), when AlphaMet is introduced, it is possible to reduce the introduction cost by 52.3% and to provide weather information without a gap. In addition, through real-time temperature monitoring and heat/cold wave forecasting, it is now possible to provide important information support for decision-making such as operation of a sprinkler truck and operation of heating and cooling facilities. For example, it became possible to present policy rationales such as ice box and bottled water beach project for bus stop in preparation for heat wave, operation of a shelter from the sweltering heat, and installation of shade curtains. In addition, when a heat wave or cold wave is expected in the residential areas for the vulnerable groups in natural disasters, it is possible to respond to disasters in advance, such as emergency road sprinkling, freezing prevention, and provision of blankets.

In addition, by analyzing and providing detailed temperature big data for the past 30 years, which is the basis of smart cities and smart agriculture, analysis and response strategies for crop cultivation due to climate change are established, and farmhouse information such as pests and soil moisture and weather big data are convergence to help farmers Decision support services are now available. It can be used as meteorological big data in each smart city field such as urban heatwave/cold wave as well as disaster response such as flood, mobility, and healthcare. was built In particular, it is possible to provide personalized service by providing the weather information of the place where people live, not the standard of the observatory, and calculating the stroke risk index, freezing index, and heat stroke index based on location information.

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Profile

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He is CEO and founder of C&W Co. Ltd. since 2018. He is also a Professor Emeritus in the Department of Environmental Atmospheric Sciences of the Pukyong National University. His primary field of research is disaster prevention, early warning, and the regional impact of climate change. He has published more than 150 research papers and 28 books. He had been the President of Asia Oceania Geosciences Society, Atmospheric Science Section, and Editor-in-chief of Advances in Geosciences for 2008-2010. He had also been the President of the Korean Meteorological Society and the President of the KOREN/APII/TEIN user group for 2008-2009. He served as the president of the Korean Quaternary Association for 2007-2008.

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