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# Urban Climate Zoning for Making "Hint Map for Urban Planning" - Analysis on the effect of sea breeze on summer diurnal temperature distribution pattern in Hiroshima plain -

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## 1. Background and objective

Urban warming which is due to urban heat island phenomenon and global warming has negative effects on the comfortability of outdoor environment, the health of inhabitants, the energy consumption for cooling and the urban ecosystem. Consequently, Urban Environmental Climate Maps (UECMs) are proposed as one of the decision support tools for the mitigating urban warming. UECMs can be used when stakeholders (citizen, planner, architect, specialist, and so on.) make decision on urban planning, architecture design, and environmental policy making. Actually, UECMs consists of a Climate Analysis Map (CAM) and a Hint Map for Urban Planning and Design (HM). About the HM, it is effective to indicate the recommendations and climatic resources for each zone which is classified from a climatic perspective. For making this map, at first, it is necessary to understand the factors of spatial temperature distribution patterns and classify into the zones based on the factors.

In coastal city, the sea breeze seems to have great influence on summer diurnal temperature distribution patterns. Understanding the spatial distribution of sea breeze effects will be helpful for making UECMs. Consequently, this study aims at making the maps of sea breeze effect distribution using the observed data and the results of numerical simulations in Hiroshima plain.

## 2. Research outline

### 2.1 Outline of study area

For this study, Hiroshima plain is selected as a targeted area (Fig.1). Hiroshima plain is formed on the Otagawa Delta. Hilly area spreads to the surroundings, and the plain touches the sea on the south. From the view of regional level, in this area located between the Shikoku Mountains and Chugoku Mountains, sea and land breeze often blow because seasonal winds blow slightly[1)].

### 2.2 Outline of meteorological observations

In order to understand the temperature distribution in Hiroshima plain, long-term multi point observation is performed by setting the 39 temperature sensors in instrument screens in Hiroshima plain (Fig.1). Observation period is from July 20, 2013 to September 23, 2013 and observation interval is 20 minutes.

### 2.3 Method

This study progressed via the following step: 1) Understanding the sea breeze effect distribution using the observed temperatures of 39 points. 2) Making the map of the sea breeze effect distribution using the meso-scale meteorological model. 3) Analyzing the relationship between the observed temperature and the local ventilation condition.

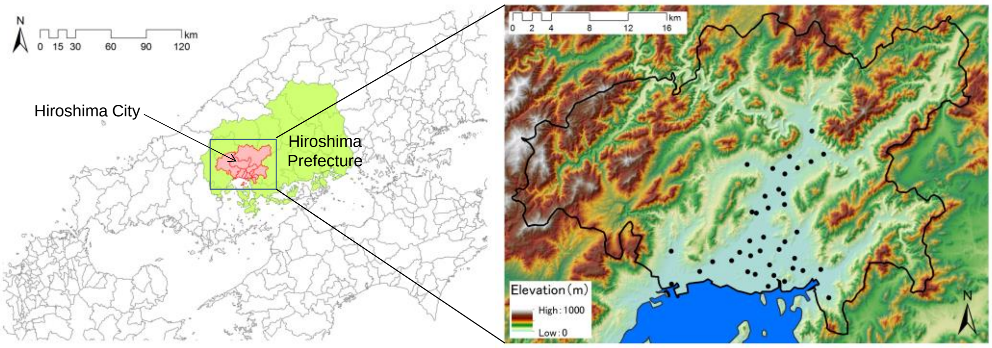



*Fig.1 Location of Hiroshima and observation points*

## 3. Understanding the sea breeze effect distribution using the observed temperatures

### 3.1 Extracting fine weather days

Typical summer fine weather days (35 days) were selected from all data (66 days) using the weather data of the Hiroshima Meteorological Observatory. Selecting criteria are as follows.

・ Daily precipitation is within 1 [mm].
・ Sunlight hours are 40 % or more of the possible duration of sunshine.
・ Daily maximum temperature is 30 °C or heigher.
・ The weather is not rainy.

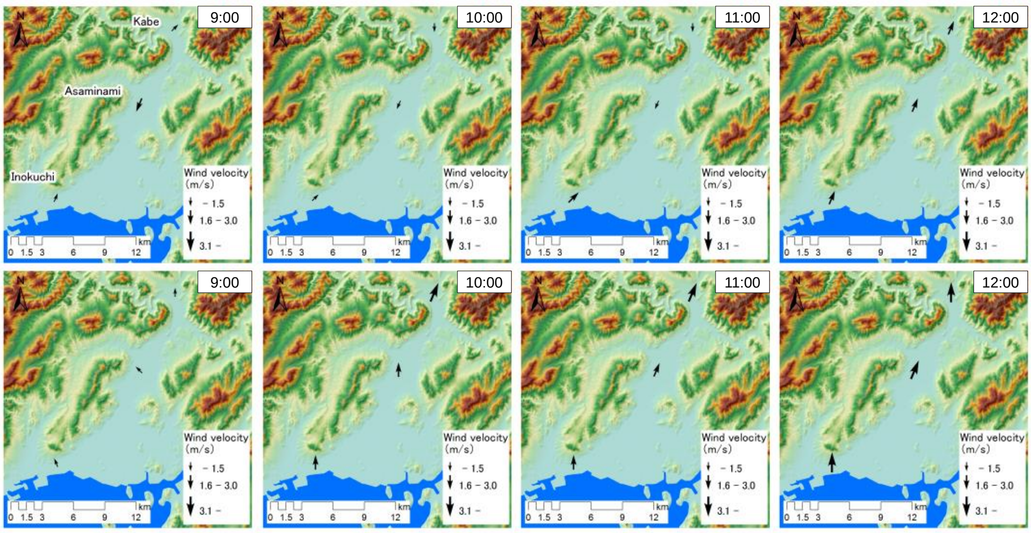
### 3.2 Daily wind patterns classification

At first, classification criteria are made by using the sea and land breeze determining method[1)] (Table1). Secondly, daily wind pattern classification is performed by applying these criteria to the wind direction data of typical summer fine weather days (35 days) (Hiroshima Meteorological Observatory, the hours). In the classification, a "wind from the coast" is defined as "wind blowing from the direction, SE, SSE, S, SSW, SW, WSW, and W", "wind from the land" is defined as "wind blowing from the direction, NW, NNW, N, NNE, NE, ENE and E" ,there are many days which are classified the pattern C.

It can be seen that there are two patterns in pattern C by examples like as shown in Fig.2. Actually, the first pattern (C-1) is the days that wind blows without time lag between coastal area and inland area, and second pattern (C-2) is the days that wind blows from coastal area to inland area gradually. Therefore, pattern C is classified into these two patterns by applying the criteria (Table2) to the wind direction and speed data (air pollution monitoring stations; Inokuchi, Asaminami and Kabe).

*Table1 Criteria of classification and results*

| Wind pattern | Criteria | Classification result |
|---|---|---|
| Pattern A<br>Sea breeze doesn't blow | 1) Wind from the coast doesn't blow from 13:00 to 16:00 for more than 3 hours. | Sep. 5, Sep. 17 |
| Pattern B<br>Sea breeze blows, but land breeze doesn't blow | 1) Wind from the coast blows from 13:00 to 16:00 for more than 3 hours.<br>2) Wind from the land doesn't blow from 3:00 to 6:00 for more than 3 hours. | July 24, July 25, Aug. 9 |
| Pattern C<br>Land and sea breeze blow<br>(typical sea breeze day) | 1) Wind from the coast blows from 13:00 to 16:00 for more than 3 hours.<br>2) Wind from the land blows from 3:00 to 6:00 for more than 3 hours. | July 20, July 21, July 22, July 26, July 31, Aug. 6, Aug. 7, Aug. 8, Aug. 10, Aug. 11, Aug. 12, Aug. 13, Aug.14, Aug. 15, Aug.16, Aug. 17, Aug. 18, Aug. 19, Aug. 20, Aug. 21, Aug. 27, Aug.28, Sep. 10, Sep. 13, Sep. 14, Sep.19, Sep. 20, Sep.21, Sep. 22, Sep. 23 |




In Aug. 12, Wind from the coast blows gradually from coastal area to inland area, lastly sea breeze blows in all points at 12:00. On the other hand, in Aug. 16, Wind from the coast blows in all points without time lag at 10:00.

*Fig.2 Examples of wind pattern C (upward : August 12, downward : August 16)*

*Table2 Criteria of sub classification and results*

| Wind pattern | Criteria | Classification result |
|---|---|---|
| Pattern C-1<br>The wind from coast in a rush<br>(19 days) | Wind from the coast at a velocity of 1 [m/s] or greater blows in all 3 points after blowing wind from the coast at a velocity of 1 [m/s] or greater within one hour in coastal area (Inokuchi). | July 20, July 21, July 22, July 26, July 31, Aug. 6, Aug. 7, Aug. 8, Aug. 10, Aug. 13, Aug. 15, Aug.16, Aug. 17, Aug. 18, Aug. 19, Aug. 20, Aug. 21, Sep.19, Sep. 20 |
| Pattern C-2<br>The wind from coast gradually<br>(11 days) | Wind from the coast at a velocity of 1 [m/s] or greater blows in all 3 points after blowing wind from the coast at a velocity of 1 [m/s] or greater for more than two hours in coastal area (Inokuchi). | Aug. 11, Aug. 12, Aug.14, Aug. 27, Aug.28, Sep. 10, Sep. 13, Sep. 14, Sep.21, Sep. 22, Sep. 23 |

### 3.3 The sea breeze effect distribution

At first, the observed temperature difference between pattern C-1 (the days that land and sea breeze blow.) and pattern A (the days that sea breeze doesn't blow.) is calculated by using the method proposed in previous research[2)]. In the same way, the observed temperature difference between pattern C-2 and pattern A is also calculated. This temperature difference is defined as hourly sea breeze effect.

In each patterns (pattern C-1 and pattern C-2), the sea breeze effect at 11:00 and 14:00 is shown in Fig.3. From these figures, it can be seen that the effect of sea breeze for mitigating urban warming is relatively larger in coastal area and the effect is smaller in inland area. Especially, as for the sea breeze effect at 11:00, there is no large difference of sea breeze effect distribution between pattern C-1 and pattern C-2, although there is difference of following wind blowing patterns at 11:00. Therefore, as for pattern C-1, it is considered that the effect of sea breeze for mitigating urban warming is small in inland area at 11:00 and this wind seems to be different from sea breeze.

Third, the hourly correlation coefficient of the sea breeze effect between pattern C-1 and pattern C-2 is calculated (Fig.4). From this figure, it is considered that these two patterns are similar. Therefore, the map of hourly sea breeze effect is made by using the all data of pattern C. The map of 14:00 is shown in Fig.5 as an example.

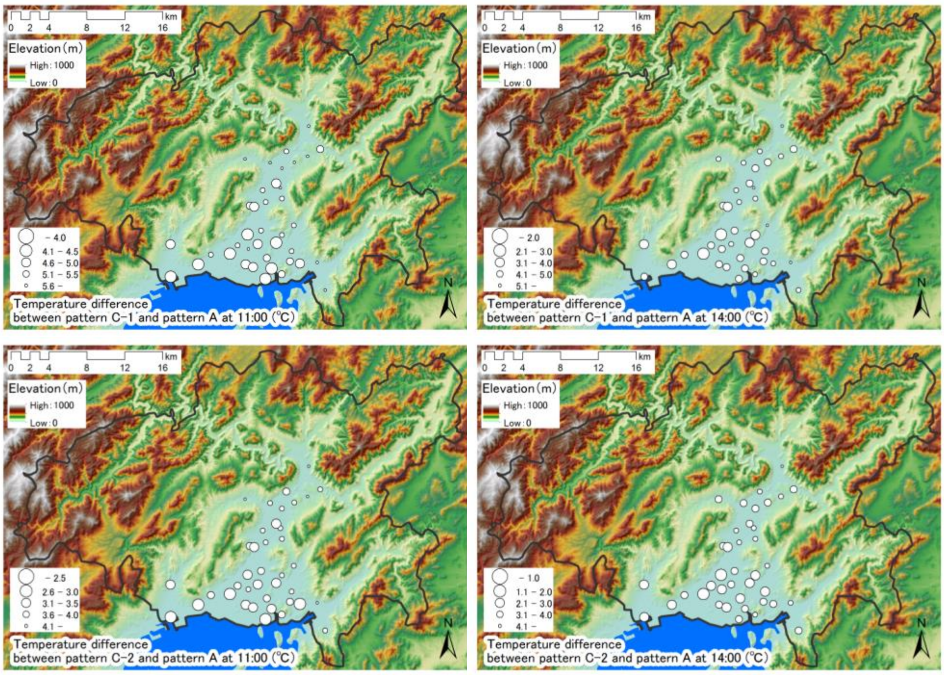



*Fig.3 Sea breeze effect distribution of pattern C-1 and pattern C-2*


*Fig.4 Correlation coefficients between pattern C-1 and pattern C-2 of sea breeze effect*

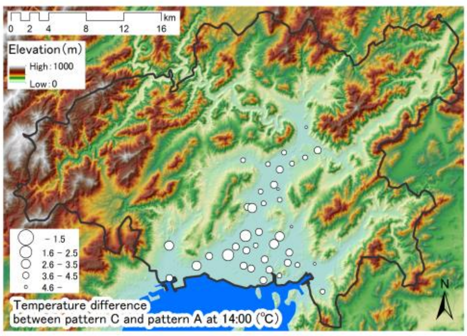



*Fig.5 Sea breeze effect distribution of pattern C (14:00)*

## 4. Making the map of the sea breeze effect distribution using the meso-scale meteorological model

### 4.1 Usage model and calculation condition

WRF-ARW ver. 3.0 are used in this study. The calculation domain is shown in Fig.6. A nesting technique is used: Domain 1 is a 120×120 grid with spatial resolution of 3km. Domain 2 is a 103×103 grid with a spatial resolution of 1km. Analyses of Domain 2 are conducted. Table3 presents the calculation conditions. The calculation periods are from August 4, 2013 to August 17, 2013 (including the days of pattern C) and from August 30, 2013 to September 12, 2013 (including the day of pattern A). Fig.7 shows the inputted land cover data. In this study, the simulation results of the August 10-16 (pattern C) and September 5 (pattern A) are used in analysis.

### 4.2 Results and discussion

In order to confirm the calculation accuracy, the comparison of the simulation results and observed data is performed on the temperature, wind velocity, and wind direction. According to the results of comparison, the difference between simulation results and observed data is small.

And, the temperature distribution at 2.0m height and the wind distribution at 10.0m height (14:00; August 13) are shown in Fig.8 as an example. From these results, it can be seen that the temperature in coastal area is relatively lower, but that in inland area is relatively higher. Also, the wind from the coast is prevailed in whole Hiroshima plain.

### 4.3 Making the map of the sea breeze effect distribution

Plain area which is defined as satisfying the following criteria is targeted in analysis since this section.

- Elevation is less than 50 [m].
- Land cover is not like “mixed forest” and “waters”.

The hourly sea breeze effect (temperature difference between pattern C and pattern A) are calculated and mapped. The results of 11:00 and 14:00 are shown as examples in Fig.9. The sea breeze effect is relatively larger in coastal area and the effect is smaller in inland area. Therefore, the hourly correlation coefficients between sea breeze effect of pattern C based on the observed temperature and that based on numerical simulation results are calculated (Fig.10). From this result, the spatial distribution pattern of sea breeze effect made from the numerical calculation is similar to the one which is made from the observed temperature. However, the correlation coefficient between temperature distribution and wind distribution is relatively lower on pattern C. From these analyzing results, it is considered that representing the sea breeze effect by using wind velocity is difficult.

*Table3 Calculation condition*

| | | |
|---|---|---|
| Period | | August 4–17, 2013 and August 30– September 12, 2013 |
| Vertical grid | | 28 layers (Surface ～ 100hPa) |
| Horizontal grid | | Domain1 : 3km dimension 120×120, Domain2 : 1km dimension 103×103 |
| Meteorological data | | Meteorological Agency Meso Objective Analysis Data (every 3 hour, 10km grid, 20 layers)<br>NCEP Re-analysis global objective analysis data (every 6 hour, 1° Grid, 17layers) |
| Land data | Elevation | Numerical Map (Resolution about 250) |
| | Land cover | Digital National Land Information (Resolution about 100)<br>Land cover mesh data in urban area of Digital National Land Information (Resolution about 100)<br>Building use data of Basic Surveys Concerning City Planning in Hiroshima city<br>Data collection of Arc GIS (Esri Japan Corporation)<br>Actual vegetation map of Ministry of the Environment |
| Microphysics | | Purdue Lin scheme |
| Radiation | Long wave | Rapid Radiative Transfer Model (RRTM) Longwave |
| | Short wave | MM5 (Dudhia) Shortwave |
| PBL scheme | | Mellor–Yamada–Janjic PBL |
| Surface scheme | Urban area | Urban Canopy Model (UCM) |
| | Nonurban area | Noah LSM |
| Cumulus parameterization | | None |
| FDDA | | None |

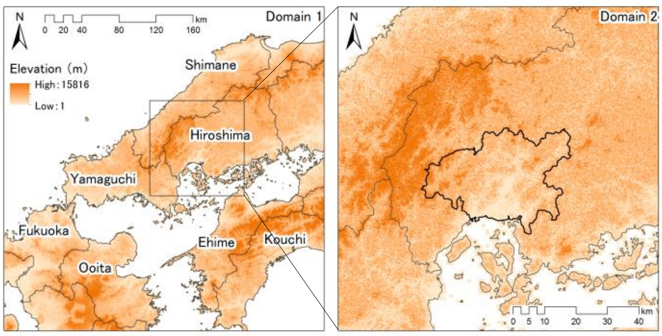



*Fig.6 Calculation domains*

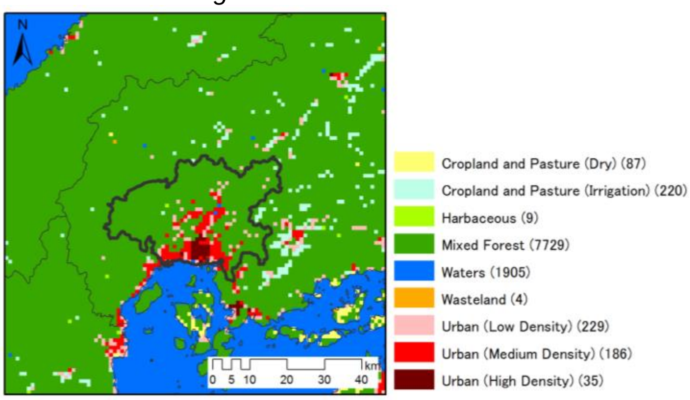



*Fig.7 Land cover data (The number of meshes is in parenthesis)*

### 4.4 The difference of sensible heat advection by area

In order to analyze the factor of temperature difference between pattern C (the days that sea breeze blows) and pattern A (the days that sea breeze doesn't blow), the hourly sensible heat advection is calculated on representative three meshes (Fig.9) in August 13 (pattern C-1) and August 12 (pattern C-2). This calculation is based on the method proposed in reference 3.

Next, the calculation results of each mesh are shown in Fig.11. From these figures, it can be seen that the absolute value of sensible heat advection in coastal area (mesh A) is relatively larger in all time. This is because the sea breeze effect is relatively larger. Also, the sensible heat advection in middle area (mesh B) is large at 12:00, and that in inland area (mesh C) is large at 16:00. This is because that sea breeze reaches to inland area by gradually. According to these results, the temperature difference pattern between "the days that sea breeze blows" and "the days that sea breeze doesn't blow" is influenced by sea breeze.

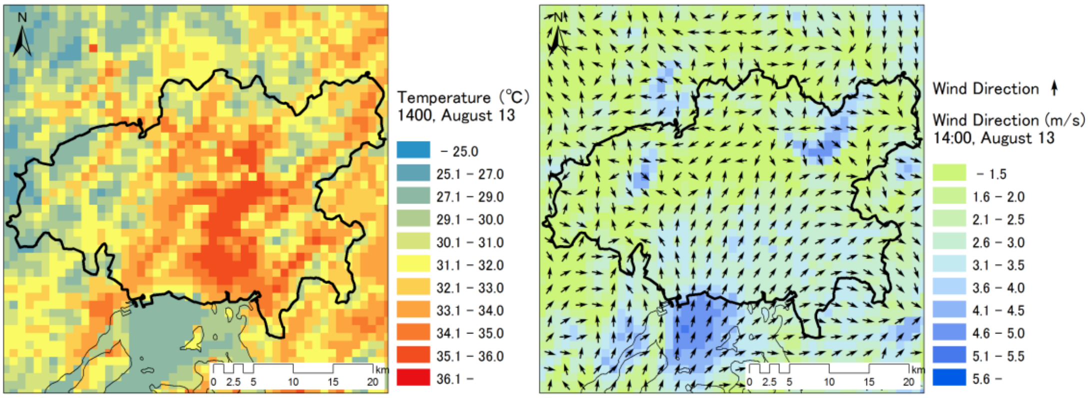



*Fig.8 Simulation results*

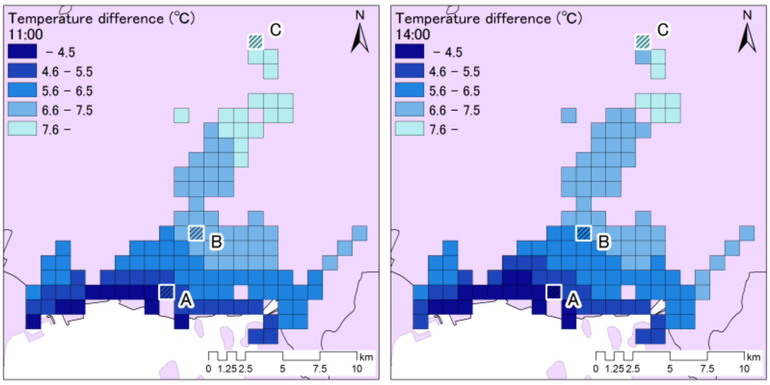



*Fig.9 Sea breeze effect of Pattern C (Left: 11:00, Right: 14:00)*

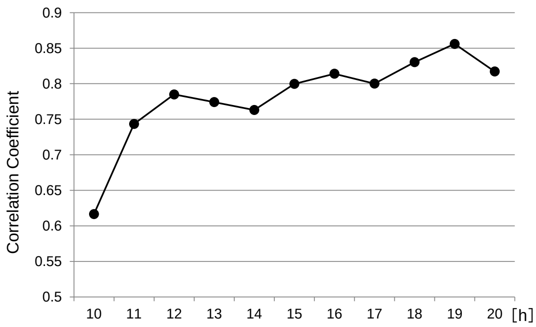



*Fig.10 Hourly correlation coefficient between sea breeze effect based on observed data and sea breeze effect based on numerical simulations*

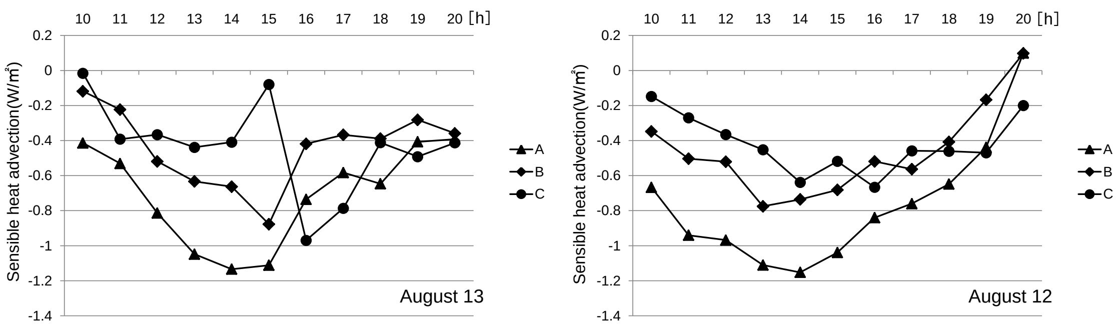



*Fig.11 Sensible heat advection of pattern C-1 (August 13) and pattern C-2 (August 12)*

## 5 Analyzing the relationship between the observed temperature and the surrounding ventilation condition

It is considered that the temperature in each place is influenced by not only sea breeze effect that is regional factor but also surrounding ventilation condition that is local factor. Therefore, in this section, analysis of the relationship between the observed temperature (14:00) and the surrounding ventilation condition by using the rate of building blocking (RRB) is performed. RRB indicates the degree of building blocks in a particular direction of the temperature observation points. Also, this index can be calculated by ArcGIS 3D-Analyst tool. In this study, a particular direction is defined as SSW.

First, the RRB is calculated on all temperature observation points (39 points). Next, the correlation coefficient between these RRB and average temperature at 14:00 for each zone in Fig.9 are calculated (Fig.12). Each zone is integrated to following two zones because observation points are limited in number; 1) the area which is affected by sea breeze 2) the area which is not affected by sea breeze. According to this figure, the temperature in the area which is affected by sea breeze is influenced by surrounding ventilation condition. On the other hand, the temperature in the area which is not affected by sea breeze is not influenced by surrounding ventilation condition. Therefore, it is considered that the effect of surrounding ventilation condition is larger in the south area of plain.

## 6 Summary

In this study, the map of the sea breeze effect is made hourly. On the other hand, from the perspective of making the HM, it is necessary to make the comprehensive map of the sea breeze effect. For example, in reference 2, the totalized map is made by using the average of maximum temperature difference between “the days that sea breeze blows” and “the days that sea breeze doesn’t blow” in a day. As a trial, the comprehensive map of sea breeze effect distribution is made by applying this method to the simulation results (Fig.13). In the future, it is needed to make UECMs based on this kind of comprehensive map, and understanding the factors of temperature distribution in mountainous region is also made.

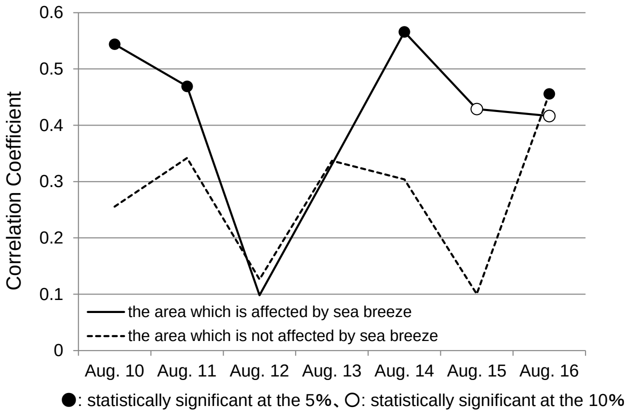



*Fig.12 Correlation coefficient between RRB and average temperature at 14:00*

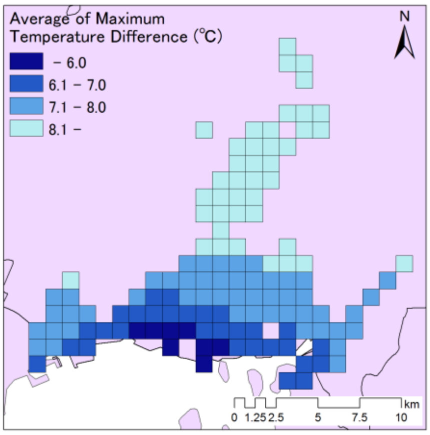



*Fig.13 Map of the sea breeze effect distribution*

## References

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