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Sea breeze effect mapping for mitigating summer urban warming: For making urban environmental climate map of Yokohama and its surrounding area

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ABSTRACT

Temperatures in urban area rise; therefore, it is necessary to consider the mitigation of urban warming. Considering that, in coastal areas such as Yokohama, an effective mitigation could be based on sea breeze patterns during summer daytime, this study aims at analyzing the relationship between temperature distributions and sea breeze fronts. Eventually, the target of this paper could be the creation of an Urban Environmental Climate Map (UECM) showing mitigation measures for each zone. Firstly, fine weather days are extracted and the sea breeze blowing patterns are classified in the target area. Secondly, the wind and temperature distribution patterns are mapped using WRF. The results obtained enable the mapping of the sea breeze fronts and the analysis of the relationship between temperature distributions and sea breeze fronts. Finally, a spatial zoning is performed. The results are presented as follows: 1) Sea breeze blowing patterns are classified into three patterns; 2) Based on the numerical simulation results and the temperature data observed in coastal areas, southwest wind has a cooling effect; 3) The target area is classified into "Sea breeze arrival zone" and others based on the presence of a see breeze; 4) An UECM showing proper mitigation measures is proposed.

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1. Introduction

The urban heat island (UHI) phenomenon and global warming have combined to cause temperature rises in urban area including Japanese cities (Oke, 1987; Ichinose, 2009). Such factors have caused adverse effects on human health and urban ecosystems in addition to uncomfortable outdoors environments and an increase in the energy consumed for cooling. Therefore, mitigation measures for urban warming are needed that include improvements in land cover and ventilation as well as reductions in anthropogenic heat release (Yamamoto, 2006).

Especially in Japan, where many cities are located in coastal areas, effective mitigation could employ the effects of sea breeze during summer daytime hours (Ichinose et al., 2009). For this purpose, mapping the sea breeze front is an efficient method for understanding the spatial distribution of its cooling effect (Gamo, 1991). In addition, it has been shown that the sea breeze cooling effect has an influence on the temperature distribution on three different scales during summer daytime. At the regional scale, Kaneko (2002) analyzed weather data from 51 stations and satellite remote sensing data to determine that the ground surface temperature is influenced not only by sunlight and land use but also by an advection effect of the heat caused by the sea breeze. At the urban scale, an analysis of long-term multi-point measurement data of temperatures and observed wind conditions has demonstrated that the time for temperature increase mitigation is earlier in coastal areas than in the inland areas of Sendai (Junimura and Watanabe, 2008). Research at this scale has aimed to understand the distribution of the sea breeze cooling effect using point data. Finally, at the district scale, Ashie et al. (2009) analyzed the relationship between urban structures and the sea breeze cooling effect using numerical simulations based on computational fluid dynamics (CFD). They pointed out that in high-density urban areas, high-rise and low-coverage urban structures could be efficient tools for improving the thermal and ventilation environment.

Efficient mitigation measures also depend on the local climatic characteristics; thus, it is necessary to take appropriate measurements for each area (Sasaki et al., 2008). Therefore, inspired by the German “Klimaatlas (Climate Atlas in Germany)” (VDI 3787, 1997; Ren et al., 2012), the Urban Environmental Climate Map (UECM) has been proposed in Japan as a planning support tool to show the proper measurement distribution for urban warming mitigation.

Ren et al. (2011) reviewed the availability of such maps for several cities worldwide. In Hong Kong, for example, Ng and Ren (2015) created both the Urban Climatic Analysis Map and the Urban Climatic Recommendation Map. The former was developed by combing input layers including wind information, a thermal load map, and a dynamic potential map on GIS to synergize the urban climatic evaluations and related understandings. Actually, in their study, physiological equivalent temperature (PET) was used as an indicator to balance the thermal load and wind dynamic. The Urban Climatic Recommendation Map is based on the Urban Climatic Analysis Map. These maps allow visualization of areas with high temperature and inadequate ventilation and show measurements for each zone. He et al. (2015) created a thermal load map using the GIS data such as topographic height, the sky view factor, open water, and green space and a ventilation potential map using building height, roughness length, building coverage, and woodland. Then, an Urban Climatic Analysis Map was produced by overlapping these two maps. As a zoning technique in Japan, Moriyama and Takebayashi (1999) produced “Klimatope” which is a local climate spatial unit based on land cover conditions. Klimatope controls the heat budget near the ground surface and can be classified by using the normalized difference vegetation index (NDVI). Recently, Stewart and Oke (2012) proposed the Local Climate Zone (LCZ) technique to perform zoning of ground surfaces from a local climate perspective. Several researchers have also performed local climate zoning with LCZ using only the ground surface conditions (Picone and Campo, 2015; Cai et al., 2016).

However, as previously mentioned, sea breeze affects the local climate in coastal urban areas as much as the ground surface condition; therefore, zoning of urban areas by the sea breeze effect is necessary. For example, Kitao et al. (2012) used the wind velocity to estimate the sea breeze cooling effect. They calculated the mean wind velocity for every 1 km mesh in summer based on a numerical simulation result for wind velocity from a meso-scale *Weather* Research and Forecasting WRF model for the Osaka region and mapped it using expectation degree.

Considering the challenges of these previous studies, it is important to analyze the sea breeze cooling effect according to zone by estimating the sea breeze front location from the perspective of Japanese

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