7.6 **MODELING THE RESPONSE OF MULTI-SCALE WINDS IN A MOUNTAINOUS COASTAL REGION TO SST CHANGES OVER THE EAST SEA IN KOREA**

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1. INTRODUCTION

The ocean communicates its thermal inertia to the atmosphere largely via the surface turbulent fluxes of sensible and latent energy (Deser et al., 2003). These turbulent fluxes, in turn, depend upon a single oceanic variable, the sea surface temperature (SST). The SST variations are associated with several atmospheric parameters including the near-surface wind speed, air temperature, and relative humidity in coastal areas. Especially, research into coastal processes is hampered by the lack of detailed observations (Jeffry et al., 1998). Understanding the SST effects on the physical processes of wind fields is a key factor in mesoscale circulation over the coastal regions.

Numerical modeling is one of the most suitable ways to simulate the effects to SST changes and in addition, it is also a much more economical and convenient way. However, the numerical studies can be categorized into two different fields such as meso-scale (10 km – 100 km) and micro-scale (100 m – 1 km) because there is no single model that can be used in both fields (Li et al., 2007). Thus numerical studies have been performed separately focusing on either meso-scale or micro-scale problems and there seems to be a gap between the two fields. Some efforts have already been done in order to partially compensate for the deficiencies (Ehrhard et al., 2000). Fang and Coauthors (2004) and Li et al. (2007) introduced a multi-scale numerical modeling system that includes meteorological model and city-block scale model.

In this paper, a multi-scale numerical modeling system composed of the Advanced Research WRF (ARW) and the Computational Fluid Dynamics (CFD) codes known as FLUENT is introduced. In the present study, attention is only given to multi-scale (meso- and micro-scale) winds in a mountainous coastal region. The effects of the SST changes on meso-scale winds were quantitatively analyzed using WRF. In order to understand the effects of the changed meso-sclae winds due to the SST variations on micro-scale winds, the FLUENT using the boundary and initial conditions generated by WRF was made in fine domain. The results of micro-scale winds were also analyzed.

2. DESCRIPTION OF THE MULTI-SCALE NUMERICAL MODELING SYSTEM

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The multi-scale numerical modeling system consists of two parts, namely, WRF for the meso-scale simulation and FLUENT for the micro-scale simulation. Thus multi-scale numerical modeling system can provide meteorological information in a coastal urban area from meso-scale to micro-scale.

2.1 WRF CONFIGURATION

The WRF is a next generation, fully compressible, Euler non-hydrostatic meso-scale forecast model with a run-time hydrostatic option (Skamarock et al., 2005). The model uses terrain-following hydrostatic pressure coordinate system and Arakawa-C grid staggering for horizontal discretization. The advanced Noah land surface/hydrology model (LSM) coupled to the WRF model provides surface sensible and latent heat fluxes, and surface skin temperature in the lower boundary (Chen and Dudhia, 2001). The Urban Canopy Model (UCM) is a single layer model, used to consider the effects of urban geometry on surface energy balance and wind shear for urban regions (Kusaka et al., 2001). It is described in more detail by Skamarock et al. (2005).

The WRF simulation was performed for the period of 0000 UTC 9 August – 0000 UTC 16 August 2007 using five levels of nested grids with horizontal grid resolutions of 40.5, 13.5, 4.5, 1.5 and 0.5 km, respectively (Fig. 1).

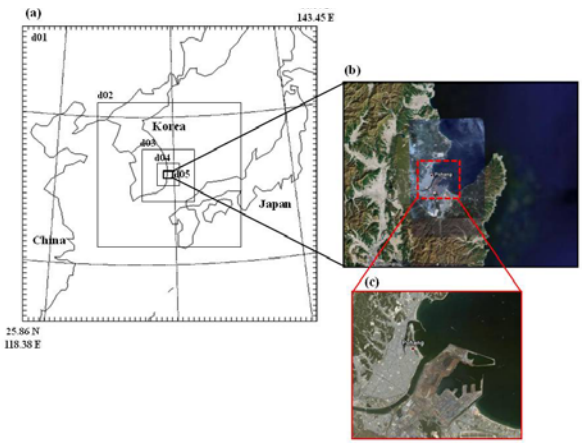

Fig. 1. Modeling domains. (a) Five nested grids with horizontal grid resolutions of 40.5 (d01), 13.5 (d02), 4.5 (d03), 1.5 (d04) and 0.5 (d05) km used in WRF model. Domain is enlarged from the left to the upper right and the lower right. (b) Topographic details of last domain (d05) and (c) domain for FLUENT modeling.

The model is initialized by real boundary conditions using NCAR-NCEP's Final Analysis (FNL) data having a resolution of 1 degree by 1 degree. The microphysical subgrid processes are represented by the scheme described by Lin et al. (1983). The Betts-Miller-Janjic Scheme (Janjic, 2000) is used to represent cumulus parameterization. Rapid Radiative Transfer Model (RRTM) long-wave radiation parameterization by Dudhia (1989) is used to represent the long wave and short wave radiation processes, respectively. The Yonsei University PBL parameterization (Hong et al., 2006) is used to represent the PBL over the domain.

2.2 FLUENT CONFIGURATION

The commercial CFD codes known as FLUENT are adopted in the multi-scale modeling system for their rich mathematical models and, especially, for their powerful capability to cope with complex-shaped boundaries (Li et al., 2007). FLUENT has already been successfully applied in the micro-scale issues in the Urban Surface Layer (USL), such as the wind safety problem caused by high-rise buildings in an urban area (Li et al., 2004). In this study, FLUENT is combined with WRF by offline way, which means that the boundary and initial conditions necessary for driving the FLUENT simulation on micro-scale winds are taken from the simulated results of WRF. FLUENT simulation is performed in a quasi-steady way, which means that the temporal evolution is completely determined by WRF (Li et al., 2007). The computational domain of 11,000 m × 9,000 m × 1,000 m size was set to perform FLUENT simulation depicted as an idealized city block (Fig. 2).

As for micro-scale issues, one of the key factors to determine the accuracy of the numerical simulation is the turbulence closure model adopted in the simulation (Gosman, 1999). Realizable κ - ε model put forward by Shin et al. (1995) is the best one among all k - ε models in the Reynods-Averaged Navier-Stokes (RANS) framework integrated in the FLUENT codes (Li et al., 2004) – here, κ is turbulent kinetic energy and ε is its dispersion rate (Li et al., 2007). The realizable κ - ε model was directly applied in this study.

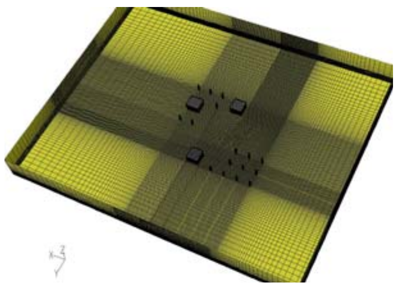

Fig. 2. The computational domain for the FLUENT simulations depicted as an idealized city block.

3. DATA AND STUDY METHODS

As illustrated in Fig. 1, target area of this study is mountainous coastal region with a complex terrain and shoreline located over the East Sea in Korea. Most major cities and industrial complexes are located near the coastline or, at least, where the effect of sea/land breeze is important. Along the shoreline of the Young-il Bay resides the Pohang steel works, one of the largest industrial complexes in Korea. They have mountains in the backside or are surrounded by mountains. Meteorology in this area is largely determined by interactions between high mountains in the east of the Korean peninsula and the East Sea.

Most meteorological data sets do not contain SST data. The SST is typically added to the model as a constant field at the initial times for all time periods or an extra input at each model input time. In this study, the SST is used as an extra input with FNL data in the WRF model (each 6-hourly interval). The SST observations obtained from the National Centers for Environmental Prediction/Marine Modeling and Analysis Branch (NCEP/MMAB). The daily SST is produced on 1/2 and 1/12 degree (latitude, longitude) grid, with a two-dimensional variational interpolation analysis of the most recent 24-hours buoy and ship data, satellite-retrieved SST data from NOAA-17 AVHRR. Fig. 3 indicates averaged SST distribution of (a) 1/2 and (b) 1/12 degree grid used during modeling period. The SST ranges between 16 ℃ and 30 ℃. The highest water temperatures are observed over the South Sea and warmer surface waters are flowing toward the north. The high-resolution SST, which is 1/12 degree, describes spatial distribution of more detailed temperature along the shoreline, especially over the East Sea.

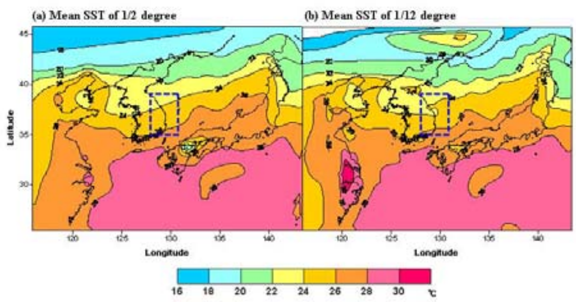

Fig. 3. Mean SST distribution of (a) 1/2 and (b) 1/12 degree grid used during modeling period.

In order to analyze the effects of changed meso-scale winds due to the SST variations (1/2 and 1/12 degree) in a mountainous coastal regions, WRF simulations with three cases were performed. Base case (case 1) is for the comparison with cases considering SST effects which only utilize the FNL 1 degree initial data. Two cases are additionally designed with SST of horizontal resolution of 1/2 (case 2) and 1/12 (case 3) degree grid, respectively. For all cases, wind data in PBL (~ 1 km) were extracted from the WRF simulated results and were then fed into the FLUENT model to understand potential effects of the changed meso-scale winds on micro-scale winds in a coastal urban area

4. MESO-SCALE AND MICRO-SCALE WIND RESULTS COSIDERED THE SST EFFECTS

Model results were analyzed for both the nighttime and the daytime due to distinct diurnal variations in atmospheric circulation with time. The wind fields of the case 1 – 3 at 0300 LST and 1500 LST on 11 August 2007 are shown in Fig. 4.

For all cases, weak land breeze was simulated in the coastal area since the SST was higher than the ground temperature at 0300 LST. The wind pattern near coastal line covering Yeong-il Bay is somewhat complicated because of interactions between mountains and the bay water. The southwesterly flows along the shoreline formed a convergence zone with the southeasterly breezes near Yeong-il Bay in the case 3 and their intensity were strong than the other cases.

At 1500 LST, as the ground is heated by the solar radiation, all three cases show that a strong sea breeze (southeasterly) induced by strong temperature gradient develops and are dominant over the coastal area. While the slight differences of simulated wind direction among three cases were found along the shoreline. The case 3 shows conversion of wind direction from southeasterly over the sea to easterly at the sea/land boundary compared to uniform southeasterly in the other cases.

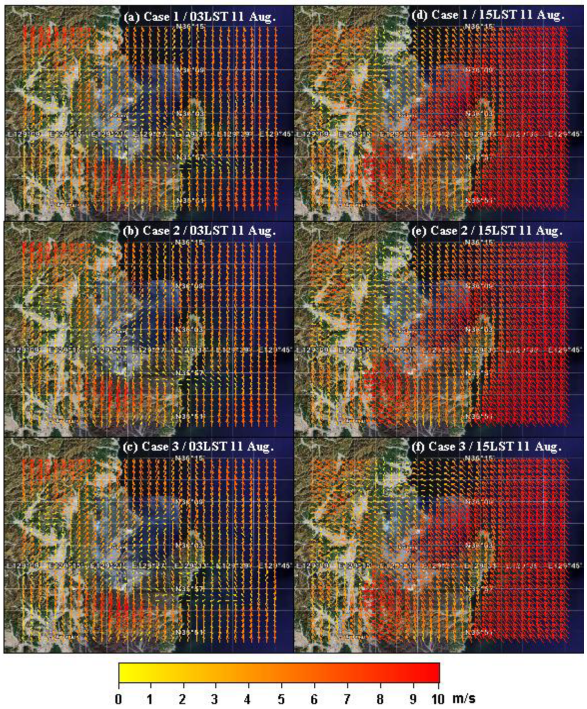

Fig. 4. Wind fields at 10 m above ground level simulated with WRF on the fine grid (d05). (a) case 1, (b) case 2 and (c) case 3 at 0300 LST and (d) case 1, (e) case 2 and (f) case 3 at 1500 LST 11 August 2007.

The difference maps of the estimated wind speed were depicted in Fig. 5. The calculation of differences were conducted by subtracting case 2 from case 1 (for analyzing the effects of the changed wind speed due to 1/2 SST) and case 3 from case 2 (for analyzing the effects of the changed wind speed due to 1/12 SST).

At 0300 LST, weak wind speed was simulated on most of the sides of sea in case 2. While case 3 contributed to the strong wind speed simulations near the Yeong-il Bay and along coastline than case 2. The magnitude reaches maximum 3 m s^{-1} in Yeong-il Bay. At 1500 LST the wind speeds in inland were represented higher or lower according to regional topography in case 2. However generally case 3 was simulated weak wind speeds of about 1 m s^{-1} near the shoreline and over the sea than case 2.

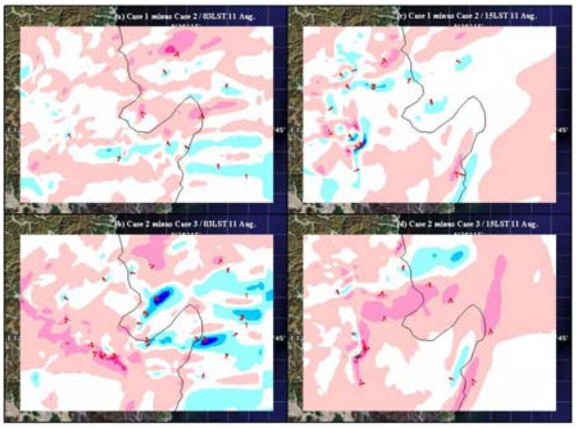

Fig. 5. The difference maps of the simulated wind speeds. (a) case 1 minus case 2 and (b) case 2 minus case 3 at 0300 LST and (c) case 1 minus case 2 and (d) case 2 minus case 3 at 1500 LST on 11 August 2007.

The three cases were simulated over the idealized city block using FLUENT in Fig. 6. The computational domain was established as illustrated Fig. 3. The input data of the FLUENT simulation is set up the meteorological data from surface to 1 km height by the user defined function (UDF) module. In the results of idealized simulations, an appreciable variation of winds in each case can be found around buildings. The FLUENT results obtained from WRF using 1/12 degree SST would be more reasonable to be taken as the representation of the meteorological status on the city-block scale than the other cases.

5. SUMMARY AND CONCLUSION

The effects of the SST changes on meso-scale wind fields were quantitatively analyzed using WRF with high-resolution SST observations from coastal buoys, ships and AVHRR-NOAA-17. WRF simulations were first compared in three different horizontal resolutions of SST data to exam the sensitivity of meso-scale winds to SST changes. In addition, in order to understand the effects of the changed meso-scale winds on micro-scale winds in a coastal urban area, FLUENT modeling using the boundary wind fields generated by WRF was performed for fine domain.

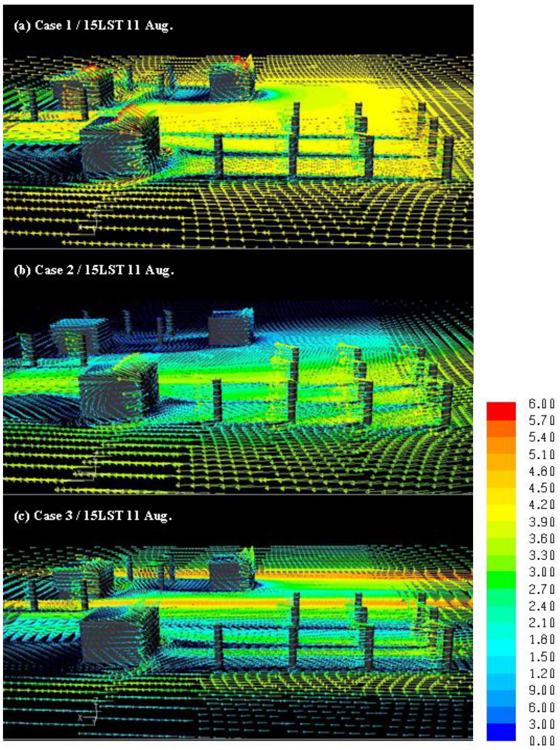

Fig. 6. Wind vectors (m s^{-1}) simulated with FLUENT in the idealized city block at 1500 LST 11 August 2007.

The results showed that the SST variations can affect multi-scale wind fields over the mountainous coastal area: a small but appreciable change in winds was largely found along the coastal line for the simulation with high-resolution SST of 1/12 degree, especially inland near the shoreline where diurnal wind and temperature variations were markedly different from those of outer sea. Interestingly, the FLUENT simulation for test cases with the idealized city block showed that even small change in meso-scale winds such as the sea breeze could lead to the significant influence on micro-scale urban winds. To assess these effects more accurately, we are currently in the process of incorporating the real-world urban geometry in the modeling.

Acknowledgements

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