ENVIRONMENTAL SCIENCES 2001 Vol. 10, No. S-1, 29~33
Bulletin of the Korean Environmental Sciences Society

Numerical Study of Snowfall Mechanism around Seoul Region

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(Manuscript received on December 26, 2000)

A numerical simulation was carried out to investigate the mechanism of snowfall around the Seoul region during a cold air-outbreak in the winter season. A particular case was selected for this study(Dec. 19, 1999). The inflow directions of the synoptic flow in the upper and lower levels were westerly and north-westerly, respectively. Plus, there was a deep trough and thermal ridge at a level of 500/700/850 hPa over the Bal-Hae region, in the northern part of the Korean peninsula.

According to the model results, snowfall occurred around the Seoul region with the simultaneous existence of a strong static instability in the lower atmosphere, northerly or westerly dry air advection, and strong thermal advection toward the Seoul region. There was a strong convergence and divergence of wind fields on the sea surface and in the upper level(3km), respectively, thereby indicating the existence of convective rolls in the clouds. The main energy source of convection over the Yellow sea was a sensible heat flux. The main moisture source was convection. Radiative cooling in the cloud layer intensified the static instability in the lower atmosphere.

Key words : corrosion potential, anodic current, Tafel, polarization, corrosion sensitivity

1. Introduction

In the winter, when cold air advects from the main land of China to the Korean Peninsula passing over the Yellow Sea, the thermodynamic properties of the atmospheric boundary layer are vulnerable to change because of large sensible and latent heat fluxes from the Yellow Sea. As cold air traverses the warm sea, the mixed layer becomes deeper, resulting in convective rolls that are related to the formation of cloud streets over the Yellow Sea. The formation of convective roll-induced cloud streets over the Yellow Sea is the major requirement for snowfall in the Seoul region.

The formation of convective rolls over a warm sea surface have been theoretically described by Kuettner1). He suggests that convective rolls are caused by a surface heat fluxes. Using observational data, including a special sounding during the BOMEX project, he found that the length of cloud streets varied from 20km to 500 km, with a spacing of 2 km to 8 km between cloud streets. He also measured the ratio of the width to the depth of the cloud streets, called the aspect ratio, and found that it was between 2 and 4. Furthermore, he observed a strong wind shear in the mean wind profile for cloud streets.

To explain the occurrence of convective rolls, Asai suggested that they are produced by buoyancy combined with wind shear and aligned parallel to the mean flow direction due to wind shear2). Nicholls observed cloud streets over the sea from an aircraft, and demonstrated that convective rolls strongly affect the transport of water vapor and momentum above the marine boundary layer3).

Numerical studies on the mesoscale vortices over the East sea were carrier out by Tsuboki4) and Nagata5). Tsukuboki studied the mechanism of mesoscale cyclogenesis based on the quasi-geostrophic dynamics along the west coast of Hokkaido in Japan. Based on an observational data analysis and linear instability analysis, he concluded that mesoscale cyclones, classified as polar-low, are formed as a result of baroclinic instability. Nagata investigated meso-beta-scale vortices along the East sea using a one-way triply-nested hydrostatic numerical model. The simulated disturbance is examined from the standpoint of the theory of barotropic shear instability. The agreement in the spatial scale and time scale for growth between the theory and the simulation, plus the energy analysis results, indicate that the determinant mechanism for the development of meso-beta-scale vortices is barotropic shear instability. Nagata also suggested that the effect of the topographically induced mechanical disturbance caused by the Korean Peninsula may affect the formation of the vortex. However, this was not directly investigated. Numerical studies of convective rolls over a warm sea surface were carried out by Kang and Kimura[6,7]. They suggested that the strong sensible heat flux from the warm sea surface is the main energy source of convective rolls.

Although the snowfall around the Seoul region has been intensively investigated over the past two decades, the mechanism of convective roll-induced snowfall around Seoul is still unknown. Accordingly, this study carried out a numerical simulation to investigate the mechanism of snowfall around the Seoul region during a cold air-outbreak in the winter season.

2. Model descriptions and case study

The KMA(Korea Meteorological Administration) version of MM5(Fifth-Generation NCAR / Penn State Mesoscale Model) was used as the numerical model, which is a regional-scale primitive equation model that can be configured hydrostatically or nonhydrostatically[8]. It uses a terrain-following coordinate in pressure and solves its finite-difference equations with a time-split scheme using a leapfrog operator. A multiple, moving, overlapping nesting capability exists with a two-way interactivity and predefined nest ratios of 3:1. Its boundary-layer physics package can be either a simple bulk aerodynamic parameterization or a more detailed scheme based on a revised version of Blackadars Planetary Boundary Layer(PBL) model. The atmospheric radiation option provides longwave and shortwave schemes that interact with the atmosphere, including cloud and precipitation fields, as well as with the surface. Large scale and convective precipitation modules were included in the model, and large-scale processes were treated explicitly. Marshall-Palmer size distributions were assumed for rain and snow, and solid and liquid water were allowed to coexist. Options for deep cumulus convection included parameterizations based on Kuo and a modified Arakawa-Schubert scheme that included a moist convective-scale down draft[8]. The Lambert conformal projection was used as the map projection. The imposed resolution constraints limited these to 23 layers for this study. The vertical levels selected were σ: 1.00, 0.99, 0.98, 0.96, 0.93, 0.89, 0.85, 0.8, 0.75, 0.7, 0.65, 0.6, 0.55, 0.5, 0.45, 0.4, 0.35, 0.3, 0.25, 0.2, 0.15, 0.1, 0.05, and 0.0.

A case was selected for the current study(refer Fig. 1). Fig. 1 shows the satellite image corresponding to heavy snowfall in the Seoul region. The inflow directions of the synoptic flow in the upper and lower levels were westerly and northwesterly, respectively. There was a deep trough and thermal ridge at a level of 500/700/850 hPa over the Bal-Hae region, northern part of Korean peninsula.

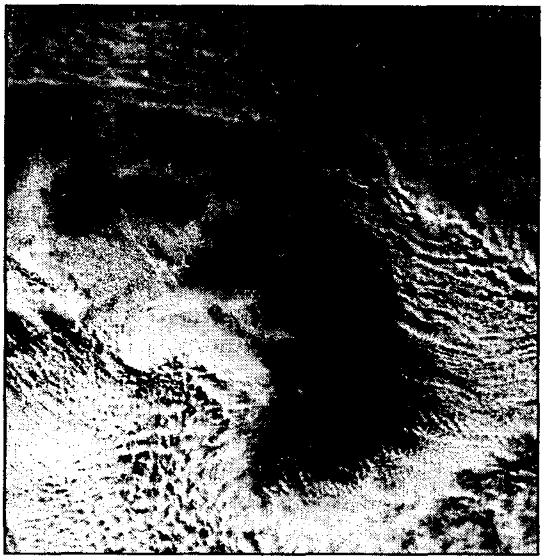

Fig. 1. Satellite image for 07 UTC Dec. 19, 1999. Note that the Seoul region is covered with cloud corresponding to heavy snowfall in the Seoul region.

3. Results

Fig. 2 shows the spatial distributions of the cloud drops simulated by MM5 after 18 hours of integration. The thin solid lines represent the contours of the topography with an interval of 200m, and the thick dark area indicates a three-dimensional distribution of the cloud mixing ratio. The isosurface of the cloud drops corresponded to 0.3 g/kg. The shape of the simulated cloud was quite similar to the satellite image(See Figs. 1 and 2). Although there was some difference in the cloud distribution inland of the Seoul region, the spatial distribution of cloud over the Yellow sea agreed quite well with the satellite image. This confirms that MM5, as utilized in the current study, can be used as an effective numerical weather prediction model for investigating the mechanism of snowfall around the Seoul region. Snowfall around the Seoul region occurred when the following conditions existed simultaneously, a strong static instability in the lower atmosphere, northerly or westerly dry air advection, and strong thermal advection toward the Seoul region.

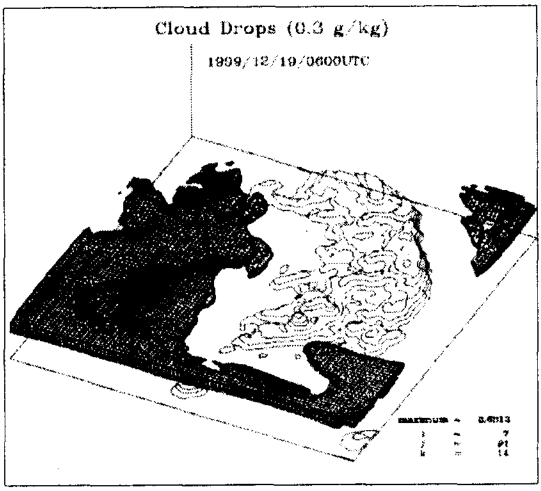

Fig. 2. Isosurface(dark area) of simulated cloud drops for 06 UTC Dec. 19, 1999. The thin line indicates the terrain height of South Korea. The simulated cloud over the Yellow sea is similar to the satellite image, as shown in Fig. 1.

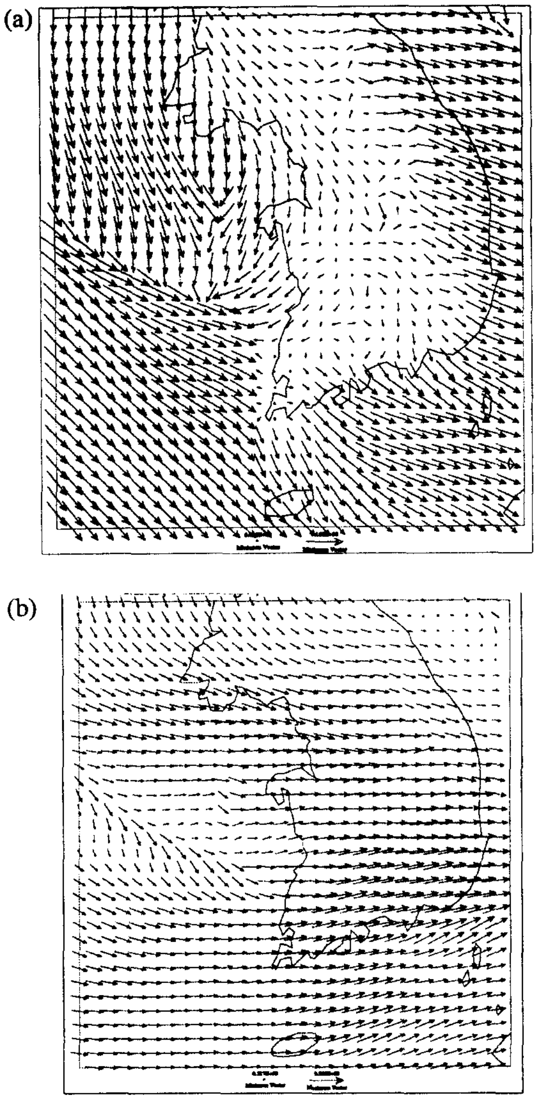

Fig. 3. Simulated wind vector at surface (a) and 3 km height (b), respectively. There is a convergence and divergence of the wind vector at the surface and in the upper layer (3 km), respectively, thereby indicating the existence of convective rolls.

Fig. 3 shows the simulated wind vector at the surface (a) and at a 3km height (b), respectively. The thin solid lines in both figures represent the coastal line of South Korea. The maximum wind velocities of Fig. 3a and Fig. 3b were 16.0 m/s and 32 m/s, respectively. This figure clearly shows the divergence and convergence of the wind vector in the upper and lower levels in the Yellow Sea region, respectively, thereby contributing to the existence of convective rolls. This means that cloud streets are accompanied by convective rolls according to the cloud shape. As such, there will be no convective roll without divergence and convergence. A strong convergence in the lower marine boundary layer results in a large amount of moisture accumulation into that layer. The existence of a strong divergence in the upper layer means that the moisture accumulated in the lower layer is transported to the upper boundary because of the strong upward velocity in the convective roll. Based on the synoptic conditions, snowfall around the Seoul region occurred under the following simultaneous conditions, a strong static instability in the lower atmosphere, northerly or westerly dry air advection, and strong thermal advection toward the Seoul region. The model result also showed a strong static instability (see Fig. 5), north-westerly flow(see Fig. 3b), and strong vertical thermal advection(see Fig. 4).

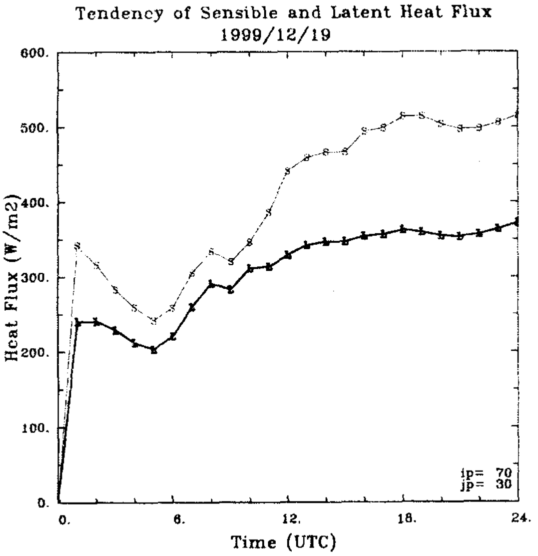

Fig. 4. Time tendency of sensible heat flux (S) and latent heat flux in Yellow sea for one day. The maximum values of the sensible and latent heat fluxes are 520 W/m^2 and 380 W/m^2, respectively. The ratio of the sensible and latent heat flux for the maximum value is about 1.37.

The time tendency of the sensible heat flux (S) and latent heat flux (L) in the Yellow sea for one day is shown in Fig. 4. Although both fluxes were the initially same, the sensible flux became dominant after 1.5 hours. The maximum values of the sensible and latent heat fluxes were 520 W/m^2 and 380 W/m^2, respectively. The ratio of the sensible and latent heat flux for the maximum value was about 1.37. The main energy source of the convective rolls over the Yellow sea was sensible heat flux (see Fig. 4). The radiative cooling in the cloud layer intensified the static instability of the lower atmosphere. The main moisture source was convection.

Fig. 5 indicates the time tendency of the PBL (Planetary Boundary Layer) height in the Yellow sea for one day. There were three perturbation peaks in the tendency of the PBL height up to 18 UTC. This means that the convective rolls over the Yellow sea were not stationary due to the changing thermodynamic property of the air mass in the marine boundary layer. The maximum height of the PBL was about 2.7 km at 11 UTC. The PBL height reached a stable state after 18 UTC. This means that the snowfall around the Seoul region decreased.

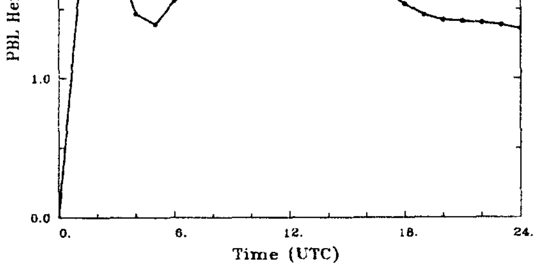

Fig. 5. Time tendency of PBL(Planetary Boundary Layer) height in Yellow sea for one day. There are three perturbation peaks in the tendency of the PBL height due to the changing thermodynamic property of the air mass in the marine boundary layer. The maximum height of the PBL is about 2.7 km at 11 UTC and a stable state was reached after 18 UTC.

4. Summary

The snowfall around the Seoul region was successfully simulated by MM5. The well developed cloud (see Fig. 1) in the simulation was in good agreement with the satellite image (see Fig. 2). The following four results were obtained: 1) There was a strong convergence and divergence of wind fields at the sea surface and in the upper level, respectively, thereby indicating the existence of convective rolls. 2) A strong sensible heat flux from the sea surface was the main energy source of the convective rolls. 3) The convective rolls gathered a large amount of moisture due to convergence in the lower marine boundary layer, and this convergent moisture was transferred to the upper boundary layer based on the strong vertical motion in the rolls. 4) There were several perturbations of the PBL height in the cloud layer as a result of the changing thermodynamic property of the air mass in the marine boundary layer.

Acknowledgement

This research was carried out as part of "A Study on Improving Weather Forecasting Skills using a Supercomputer" by the Meteorological Research Institute / KMA.

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