Numerical Simulation of Heavy Snowfall over the Ho-Nam Province of Korea in December 2005 using WRF

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1. Introduction

Several studies related to winter precipitation of the Korean peninsula have been performed using mesoscale models. Jung et al. (2005, JKMS) examined the dynamical and thermadynamical characteristics of snowfall associated with extratropical cyclone on 4-5 March 2005 using the MM5 model. He found that sensible heat and latent heat fluxes from the surface are responsible for about 70% of the snowfall amount over the Korean peninsula. Lee and Lee (1993, JKMS) studied the mechanism of snowfall over the eastern part of the Korean peninsula using the Regional Atmospheric Modeling System (CSU RAMS. Tropoli and Cotton. 1982) model and suggested the governing factors of the snowfall in the eastern part of Korea: low-level wind direction, wind speed, orography, extents of air mass transformation and persistence of synoptic pressure pattern favorable for snow fall in the eastern part of Korea. Also they found out that when the wind direction is perpendicular to the ridge, development of precipitation is fastest and strongest. Ahn et al. (1998, JKMS) showed that the correct prescription of SST as a boundary condition in a model can result in considerable amount of differences in simulating mesoscale atmospheric variables. It is because the Korean peninsula is surrounded by oceans. Especially during the wintertime, the Kuroshio current from the south coast has close correlation with climate and weather. Related to the mechanism associated with air mass transformation, Byun (2005, Yonsei Univ.) showed that WRF and MM5 models generate too much precipitation during the winter season.

In December 2005, there was a climate extreme over the southwestern part of the Korean peninsula (Ho-Nam province), accompanied by significant amount of snowfall. Associated with such a heavy rainfall, a continental high-pressure system was stronger than normal and the oceanic low was deepened, leading to the intensification of the cold surges over the Korean peninsula (Fig. 1a). Under these synoptic situations, the central part of the peninsula experienced an extremely cold period, whereas the heavy snowy days lasted over the southwestern part (KMA 2005). KMA (2005) reported that these unusual heavy snowfall events were induced by the warm sea surface temperature over the Yellow Sea that was 4-6 K higher than a climatology (Fig 1b). We can find several heavy snowfall days during December 2005, especially from 4 to 5, from 13 to 17 and from 21 to 23 December 2005 (Fig. 2). There was an abundant snow cloud formation because of strongly developed continental high system and abnormally high SST.

(a) (b)

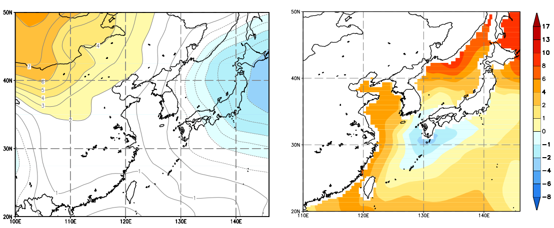

Fig. 1. (a) Surface pressure anomaly (mb) in December 2005 and (b) sea surface temperature anomaly (K), over a climatology during 1979-2003.

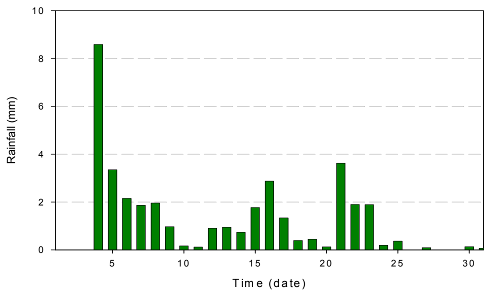

Fig. 2. Daily precipitation (mm) averaged over the Ho-Nam Province of korea (34.5°N-36°N, 126°E-127.5°E).

The objective of this paper is to examine the influence of the warm SST anomalies in 2005 on the formation of the snowfall extreme over the Ho-Nam province. Sensitivity experiments of the simulated winter precipitation to SST anomalies are designed in the Advanced Research WRF (ARW; Skamarock et al. 2005, WRF hereafter). In addition, we conducted another sensitivity test of the simulated snowfall to vertical resolution. The purpose of this experiment is to investigate the role of vertical resolution in simulating precipitation during the winter season.

Section 2 describes the numerical experiments conducted in this study, with their results being discussed in section 3. Concluding remarks appear in the final section.

2. Numerical Experimental Setup

The WRF model version 2.1.1 is used in this study. In this study, the physics packages include the WSM6 microphysics scheme (Hong and Lim, 2006), the Kain-Fritsch cumulus parameterization scheme (Kain and Fritsch, 1993), the Noah land-surface model (Chen and Dudhia, 2001), the Yonsei University planetary boundary layer (PBL) (Hong et al., 2006), a simple cloud-interactive radiation scheme (Dudhia, 1989), and Rapid Radiative Transfer Model (RRTM) longwave radiation (Mlawer et al., 1997) schemes.

The model configuration consists of a nested domain configuration centered at the Korean peninsula defined in the Lambert conformal space. The inner grid (domain 2, 100 × 100), with a resolution of 18km, is nested by a 54-km grid model (domain 1, 80 × 80) by two way interaction. Initial and boundary conditions are based on the NCEP-NCAR reanalysis (Kalnay et al., 1996). The simulations were executed from 0000 UTC 1 December to 0000 UTC 31 December 2006, which is forced by the reanalysis data that are available at 6-hour intervals.

Four sets of experiments are carried out. The OBS_23z experiment uses the observed SST during December 2005 as the surface boundary condition. The number of vertical layers is 23. The CLM_23z experiment uses a climatology value of SST during from 1979 to 2003. The OBS_43z and OBS_63z experiments are the same as in the OBS_23z but for the number of the vertical grid being 43 and 63, respectively. These experiments will provide the effect of vertical resolution on regional climate run. The height of the lowest model level, that is the height of surface layer, is the same for all the experiments, with about 30-50 m.

3. Results and discussion

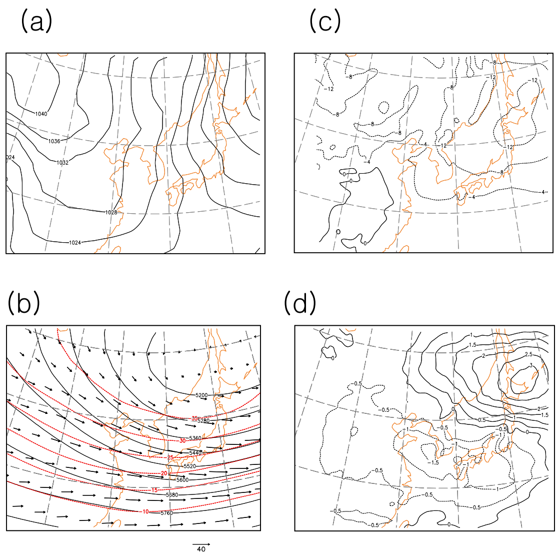

Fig. 3. (a) Analyzed sea level pressure (mb), (b) 500mb wind vectors, geopotential height (solid line, m) and temperature (dashed line, ℃) averaged during the December 2005, (c) sea level pressure difference (OBS_23z-RA2) and (d) 500mb temperature difference

Figure 3 shows the analyzed sea level pressure and 500mb temperature fields and their differences from the OBS_23z experiment. The model with observed SST captured the distribution of atmospheric pressure well, but underestimated the pressure over the northern part of the domain (Figs. 3ac). This result enhances the pressure gradient over the Korean peninsula. At 500 mb (Figs. 3bd), a warm bias is seen over the northeastern part and cold bias over the southwestern part of domain. This large scale bias enhances thermal instability over the southwestern part of Korea, increasing the amount of simulated snowfall.

Table 1 shows a comparison of the statistics of simulated precipitation over the Korean peninsula. Table 1 shows that the WRF overestimates the precipitation over the Korean peninsula even though the regional climate run reproduces the observed precipitation fairly well in terms of the distribution and position of heavy snow fall (not shown). This result is in agreement with the study of Byun (2005).

Table 1. The pattern correlation coefficients (PC) and bias score of the 1-month accumulated precipitation over South Korea with respect to the observation ending at 0000 UTC 31 December 2005, averaged over the region of the Korean peninsula (Whole domain).

	Precipitation		
	Correlation	Bias score	Average (mm)
OBS_23z	0.58(0.63)	14.25(2.98)	88.16(134.8)
CLM_23z	0.55(0.76)	11.83(2.42)	73.21(109.43)
OBS_43z	0.57(0.65)	13.55(2.99)	83.86(135.44)
OBS_63z	0.56(0.65)	13.16(2.92)	81.43(132.39)

Table 2. Sensible heat flux, latent heat flux averaged over the region of Ho-Nam province (Whole domain).

	Heat Flux	
	LH	SH
OBS_23z	965.70(514.83)	682.07(354.50)
CLM_23z	586.03(411.44)	488.53(293.20)
OBS_43z	965.27(517.80)	694.85(361.62)
OBS_63z	960.91(514.26)	699.46(349.35)

Figure 4 compares the 1-month accumulated simulated precipitation obtained from the two different experiments during the period from 0000 UTC 1 to 0000 UTC 31 December 2005. Precipitation amount from the CLM_23z experiment with climatological SST is smaller than that from the OBS_23z experiment using the observed one during the December 2005. Difference of precipitation amount is distinct near the coast region. Increased SST gives the positive (negative) effect in the western (eastern) part of Korea. Because of the westerly wind during the simulation period, western (eastern) part of the peninsula is affected by the ocean (continent). Thus southwestern part of Korea (Ho-Nam province) has more precipitation in the OBS_23z experiment by directly being affected by increased SST; however, the distribution and position of precipitation band is not significantly affected by the SST.

The difference of simulated precipitation to the SST can be explained by the comparison of the large scale environment. Figure 5a shows the vertical profiles of the differences in averaged temperature over the heavy precipitation region centered in Ho-Nam province. The results from the CLM_23z experiment shows the lower temperature near the surface compared to the OBS_23z experiment. But this difference becomes smaller in the upper part of troposphere. In terms of moisture field (Fig. 5b), two experiments represent the highest difference at a level of 850mb. More water vapor and thermal instability in the OBS_23z experiment can be attributed to the differences in the amount of precipitation.

(a) (b)

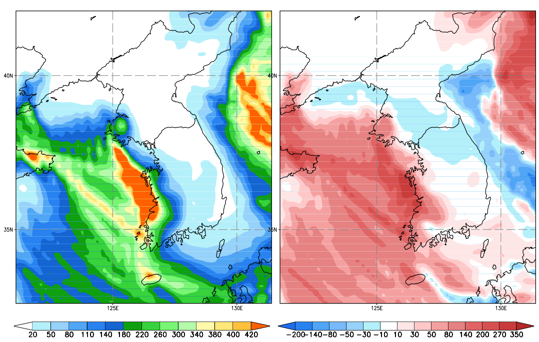

Fig. 4. Accumulated precipitation (mm) during the period from 0000UTC 1 to 0000UTC 31 December 2005, obtained from the (a) OBS_23z, (b) the difference (OBS_23z-CLM_23z)

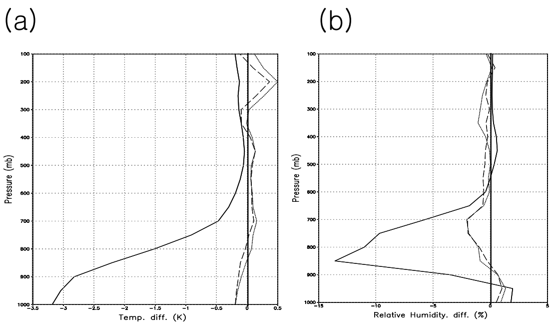

Fig. 5. Vertical profiles of the differences in (a) temperature, (b) relative humidity, the CLM-23z minus OBS-23z (solid line), OBS_43z minus OBS_23z (long-dashed line) and OBS_63z minus OBS_23z (dotted line) experiments, averaged over the Ho-Nam province (123E-126E/34.5N-36.5N)

Figure 6 shows that the amount of simulated precipitation is affected by vertical resolution. As the number of vertical layers increases, the amount of precipitation becomes smaller, especially over the Ho-Nam province. The difference between the OBS_43z and OBS_63z experiment is smaller than that between the OBS_23z and OBS_43z experiments. Over the Yellow Sea and the East Sea, there is no apparent tendency for the model result to converge toward negative or positive signal of precipitation amount as the resolution increases.

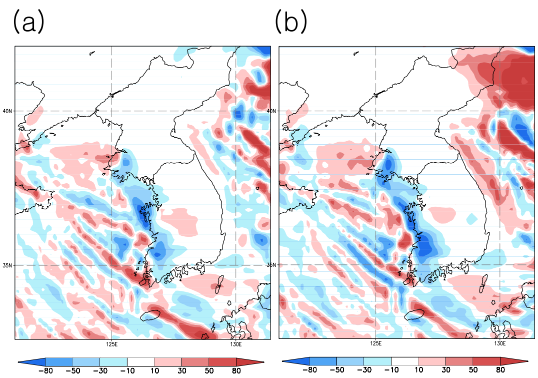

Fig. 6. Differences in 1-month accumulated precipitation (mm) during the period from 0000UTC 1 to 0000UTC 31 December 2005, (a) OBS_43z minus OBS_23z, and (b) OBS_63z minus OBS_23z experiments.

It is seen that the OBS_43z, OBS_63z xperiments represent a similar deviation from the OBS_23z experiment in the moisture field and temperature (Fig. 5). Moistening and cooling near the surface and drying and warming in the middle troposphere are significant. The reason can be attributed to the differences in mixing efficiency. The more mixing occurs as resolution decrease. Thus, experiment with 23 layers has very efficient mixing than other experiments. This leads a warm bias at the surface and a cold bias in the middle troposphere. The OBS_23z experiment produces the largest amount of precipitation because of the largest thermal instability, and followed by the OBS_43z, the OBS_63z in that order (Table 1 and Figure 6). Differences of latent heat and sensible heat flux between the experiments with varying vertical resolution are much smaller than those in the sensitivity test of SST (Table 2). Simulated latent heat and sensible heat are not affected by designing a vertical resolution.

Even though the effect of changing resolution is smaller than that of changing the SST (Fig. 4. and Fig. 6.), result of experiment obtained increased vertical resolution agrees well with the observed feature by reducing the amount of precipitation. Therefore, it is concluded that the model simulation with increased vertical layers gives a significant improvement in the amount of surface precipitation.

In conclusion, the experiment with the climatology value of SST tends to cause the amount of the precipitation reduce, leading to a reduced thermal instability and amount of water vapor near the surface. Also model simulation with increased vertical layers shows the reduced amount of precipitation over the southwestern part of the Korean peninsula (Ho-Nam province) by reducing the mixing efficiency, implying the importance of vertical resolution in the model in simulating the snowfall associated with an air mass transformation over the Yellow Sea during the wintertime.

Acknowledgements
This research was supported by the SRC program and by the Korea Meteorological Administration Research and Development Program under Grant CATER_2006-2204.