AN ANALYSIS OF MM5 PERFORMANCE FOR FOUR MAJOR SNOWSTORMS OVER THE KOREAN PENINSULA

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1. INTRODUCTION

Forecasters often have difficulty with accurately forecasting snowstorms in Korea due to the relatively small areas they impact and the variability in snow amounts they produce over particular regions. The majority of the snowstorms are associated with three weather patterns or regimes: (1) West Sea Low; (2) Shanghai Low; and (3) Post frontal snow squalls often referred to as "sea effect" events. In 1998 AF Weather Agency initiated a high-resolution numerical weather prediction window for the Western Pacific region (36 km) and another window for the Korea-Japan area (12 km). AFWA utilizes the Penn State University (PSU) National Center for Atmospheric Research (NCAR) Mesoscale Model Version 5 (MM5), which was declared operational at the center in October 1997. In late 1998 a high-resolution 4-km MM5 window was developed specifically for the Korean peninsula. In 1999 AFWA, attempting to save resources and retain accuracy, changed the window resolutions to 45 km, 15 km and 5 km, respectively. This paper will annotate the ability of the MM5 to forecast these difficult snow events. Four storms will be analyzed, two of them being post frontal systems, one a Shanghai Low, and the final one being a strong West Sea Low.

2. OVERVIEW OF DATA AND ANALYSIS

For each of the four cases, MM5 output was compared to observational data to include surface observations, upper air data, radar imagery, and satellite imagery. The MM5 output included surface level winds, sea level pressure, surface temperature, upper level winds, stability indices including Total Totals, snow accumulation, and model-derived radar reflectivity.

2.1 *Sea Effect Event of 6-7 Jan 2000*

On the morning of 6 Jan 2000 forecasters at the 607 WS had a decision to make on the amount of snow that would fall in the area of the Demilitarized Zone (under the auspices of the Second Infantry Division) from late on 6 Jan to late on 7 Jan. After most cold fronts pass through the Korean peninsula, the southern coasts on the western side of South Korea will get inundated with an average of 3-5" of snow, with some places like Kunsan receiving 30-36 inches within a couple of days. These bands will rarely affect Seoul and northern South Korea, as there is a large fetch of land (west and north of Seoul) that will stabilize and dry up the cloud systems before they hit the capital. Winds behind the front are mostly WNW, but there have been cases when the wind would be WSW and the bands of snow and moisture would make their way northward.

On the morning of 6 Jan, the forecasters thought the winds (over the next 24-36 hours) would be WSW, based on the persistency of the observations along the western coast. An advisory went out to military customers regarding heavy snow along the entire western coast and the 2nd ID area. At about 1100L, the first MM5 model charts from the 06 Jan 1800Z model run appeared and forecasters noticed that the model had predicted a change in the direction of winds from Seoul northward (WSW to WNW). Based on this new output and extended discussion, the forecasters scaled back the snow advisory, which now had no significant amounts forecasted for many areas north of the capital city. Before the 607 WS got the new warning out, the 2nd ID had called an emergency crisis action meeting to address the initial snow advisory. When the new advisory arrived most were not happy, even with the detailed discussion of the wind. The forecasters had made an excellent decision, as in the end Seoul received a trace, Osan 3-4 inches, and Kunsan about 5". The MM5 wind and snowfall predictions were right on the mark.

2.2 *Shanghai Low Snowstorm of 7 Jan 2001*

On 5 Jan 01 forecasters at the 607 WS noticed the potential for a major winter storm to hit the Korean peninsula within the next 48 hours. Questions revolved around how much snow would fall and which locations would get snow and which would get rain. The general consensus was that areas north of Taegu would receive 3-4" of snow some time between 07 Jan 0300L and 08 Jan 0900L, with other areas receiving mostly rain; some areas in areas north of Taejon (as well as higher elevations around the country) were expected to get 6-8". The 48 km MM5 window from 05 Jan 1800Z (Figure 2a) predicted mostly 0-2" of snow over the ROK except for a small area of 2-5" (higher elevations of southern ROK) and >2" over areas north and east of Seoul (stretching southward along the Taebaks to locations south of Kangnung). The forecasters at the 607th thought that

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the MM5 was underforecasting the amounts of snow; the model has had difficulty with snow amounts when the temperature was forecast to be at or above freezing. The one interesting feature that MM5 did catch was the potential of convective instability that often leads to enhanced snow amounts. Total Totals for areas off west coast (Fig 2b) and northeastward to the North Korean/ROK border (on the east coast) were forecasted to be 48-50, indicating the potential for thundersnow and locally heavy amounts of snow over the Korean peninsula from Kunsan northward.

At 10 pm local time the majority of precipitation was off the southwest coast of Korea as a low pressure system continued to develop northwest of Shanghai, China. A strong baroclinic leaf could be seen in eastern China; this system would soon intensify quickly upon entrance into the West Sea. Thunderstorms could be clearly seen stretching from the West Sea to just east of Taiwan around 05 am on 7 Jan. By 09 am there were convective cells embedded within the main precipitation bands oriented east-west along the western coast of Korea; many Koreans and Americans heard thunder as the snow intensities picked up along the west coast. Snow had started to fall lightly in Seoul at about 0530 am and increased in intensity by 08 am. The consolidated radar image (1200L, figure 3) from the Korean Meteorological Administration (KMA) depicted evidence of Conditional Symmetric Instability, as there were two defined parallel bands of precipitation oriented perpendicular to the main southwesterly mid level flow. Thunder could be heard around Seoul and Suwon, indicating that the MM5 had a good handle on regional convection for the storm 30 hours in advance. Snow continued to fall north of Taegu, northeast of Kunsan, and north of Kangnung (east coast) until about noon. At that time rain started to mix in with the snow (Taejon and Suwon areas) as the low pressure system closed in on Kunsan and warm air infiltrated the mid levels of the atmosphere.

In the end snow amounts were as much as 4 times higher over the central portion of the peninsula than the MM5 had predicted and about twice in the northern areas of Seoul. This indicated that while the MM5 had predicted the potential for enhanced instability, it did not correctly forecast the overall structure of the atmosphere that would have led to 100% snow as opposed to mixed rain and snow. Convection had a role in overturning the atmospheric profile, advecting colder air from the upper levels to the lower levels ahead of the warm air tongue. If there had not been a convective component, most of the precipitation for this storm would have been rain or at best mixed rain and snow.

2.3 *"Korea Storm of the Century" (14-15 Feb 01)*

Late in the evening of 14 Feb forecasters at the 607th WS saw the potential for a light snow event as a small disturbance made its way eastward across China. At 0300L on 15 Feb, a disorganized low pressure system had entered the West Sea just east of China (figure 4a, 4b is 0600L). As flurries started to fall in Inchon, just west of Seoul, the forecasters put out their first advisory for 2-3 inches of snow for most of northern half of ROK. The KMA radar composite depicted large longitudinally-oriented bands of precipitation running across the Seoul area just after sunrise. The belief at the time was that the overall event would entail light snowfall, mainly across the northern ROK. Snow began to fall in Seoul around 0530L, and continued at a light pace until about 0900L; the moisture associated with this snow evolved with a southwesterly jet ahead of the developing West Sea Low. From 0500 to 0600L, the storm appeared to be evolving as the cloud shield became solid and consistent in texture. The snow intensified over Seoul as the northern band of moisture started to segregate from the mesoscale low and moved across the northern ROK. The low pressure system moved eastward at the same pace as the separated cloud mass, moving onshore around 1200L (Fig 5). It was at the time of this onshore approach that snowfall had been the most intense over the northern ROK; of interest is the comparison of radar data to MM5 forecast (Fig 6). Snow continued for another 3-4 hours, decreasing to snow flurries by 1530L. Most regions of the northern ROK had picked up more than 8" (about 20 cm) of snow, to include Seoul which had recorded 11" by nightfall on 15 Feb. Snow amounts decreased in a remarkable fashion as one proceeded south toward Osan and Taejon; there was also a dramatic change in temperature between Seoul and points to the south. Seoul was just below freezing at –2.0 ^{o}C most of the storm while places like Taejon, 150 km to the south, were well above +6.0 ^{o}C. It will be interesting to see how MM5 did for this storm.

The MM5 output from the 04 Feb 1800 GMT run gave a very good indication of how the model was handling the rapidly developing storm. The 48-hour snow accumulation total product (Fig 7a) showed a very distinct swath of heavy snow extending from Inchon across the peninsula to Sokcho and Kangnung. The model had 12+" for areas just west of Seoul, where strong winds off the sea could add to snow totals from the storm itself. The model showed warming temperatures for most of the southern two-thirds of the country, with the freezing line cutting across the land about 60-70 km south of Seoul. The composite reflectivity forecasts of the model showed the persistent band of snow across the northern ROK, but did not show the longitudinally-oriented bands of snow associated with the low. The model timed the development of the low very well, as well as the arrival of the low on the peninsula. It was a little slow on the exact timing of when snow would stop, predicting a 15 Feb, 1900 local termination whereas the actual time snow ended in Seoul was 1700L. The model did very well with the forecast of surface temperatures showing only areas north of Wonju (central South Korea) and north east of Osan below freezing (figure 7b).

2.4 *Late Winter Post Frontal Snow (3-4 Mar 01)*

The first weekend of March 2001 came in like a lion for South Korea. The third edition of the Seoul Marathon was about to take place (4 Mar, with the first author of this paper as a runner) and a major cold front was sweeping through eastern China. The 02 Mar 00Z and 02 Mar 18Z runs of the MM5 were used to see how the model fared for this system. With a comparison of the model (45-km window, 02 Mar 00Z run, 24 hour forecast) and analysis data (03 Mar 00Z) the meteorologist would have noted that although the 850 mb and surface sea level pressure patterns and isotherms were very much correctly forecasted (Fig 8), the 700 mb and 500 mb temperatures were as much as 5-7 °C underforecasted when compared to analysis. Total Totals behind the front were expected to stay well above 45 in northern South Korea, with surface winds expected to remain westerly most of the time from 03 Mar 12Z to 04 Mar 12Z. Forecasters thought areas around Seoul would get 1-2" of snow during the night of 3 Mar after the front passed, and they were correct. The question was whether or not more snow showers would hit Seoul during the course of the marathon on 4 Mar; temperatures at the surface were expected to fall into the 20s by late Sunday morning. The 15-km MM5 run from 02 Mar 18Z (Fig 9) had strong westerly winds forecasted for areas around Seoul down the coast to just north of Kunsan; composite reflectivity forecasts had light snow over the northern part of South Korea and 3-hour snow accumulation charts had the same area under the gun for light-moderate snow showers. Overall the model handled the strong frontal system very well as it showed the potential for convective snow showers well beyond the passage of the cold front itself; the combination of correct instability indices, accurate depiction of strong westerly winds (up to 700 mb), and soundly forecasted precipitation rates made life easier on 607 WS forecasters.

6. CONCLUSION

Four Korean winter storms, one occurring in the winter of 1999-2000 and the other three during the winter of 2000-2001, were analyzed to see how the AFWA MM5 model performed with snow storms over the small peninsula. Except for incorrectly forecasting the exact detail of snow bands, incorrectly forecasting isotherms in the upper levels, and not identifying the actual time of the snow termination, the MM5 handled predictions for snow accumulation very well due to accurately forecasted wind directions, surface temperatures, and instability patterns along the west coast of Korea.

ACKNOWLEDGMENTS

Thanks go to Mr. Gordon Brooks of AFWA for collecting MM5 model runs. The DoD Center for Geosciences at CSU-CIRA provided both the funding and basis for this research on Korean winter storms.

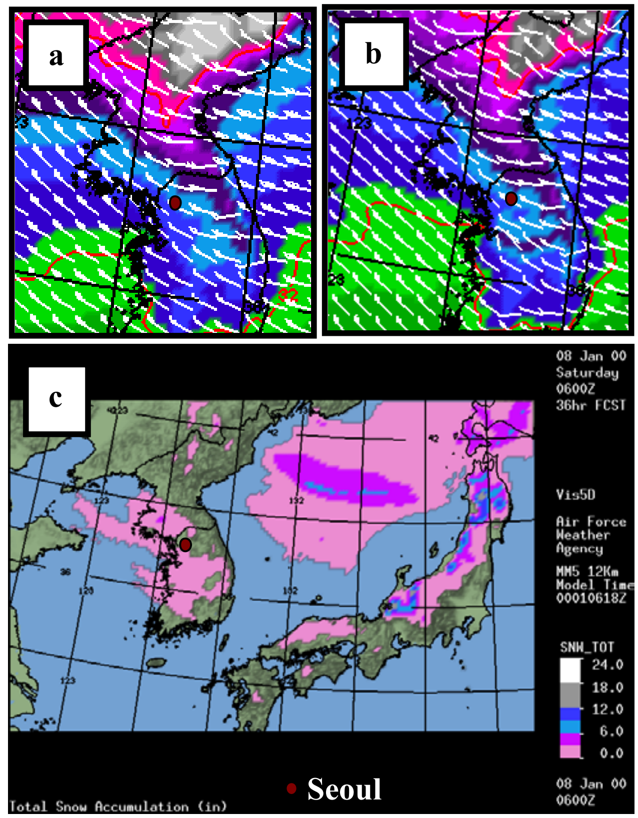

Figure 1: (a) MM5 (06 Jan 18Z) 12-km 12 hour surface wind and temperature forecast; (b) MM5 (06 Jan 18Z) 12-km, 36 hour run (same parameters); (c) MM5 12-km 48 hour snowfall forecast

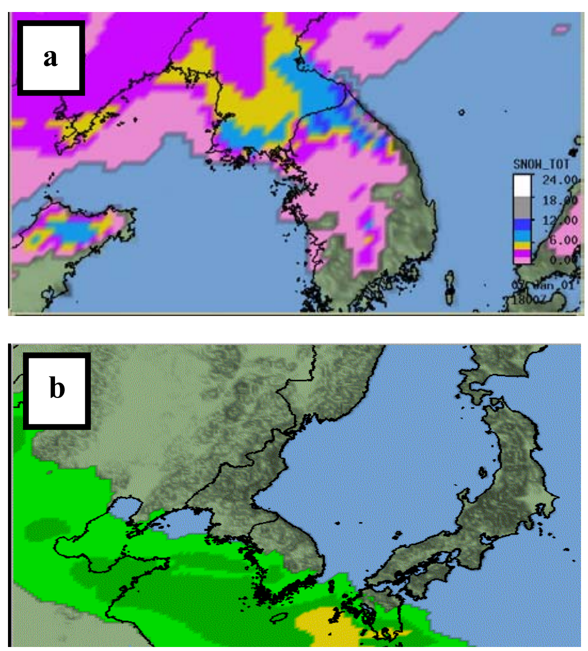

Figure 2: (a) MM5 (05 Jan 18Z) 15-km 48 hr snow accumulation forecast; (b) MM5 (05 Jan 18Z) 15-km 30 hr forecast of Total Totals (green is GTE 45, dark GTE 50)

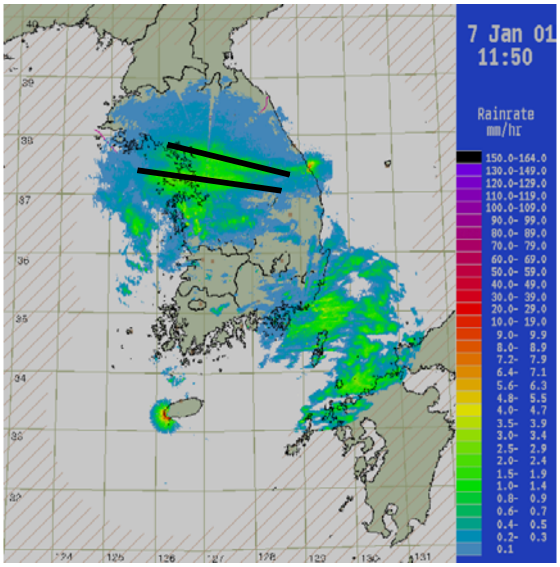

Figure 3: KMA consolidated radar image at 07 Jan 1200L; note two parallel bands of snow (CSI symbol)

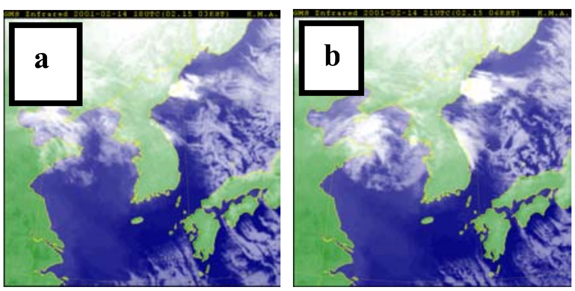

Figure 4: (a) KMA GMS satellite imagery for 15 Feb 01 at 0300L; (b) KMA imagery for 0600L

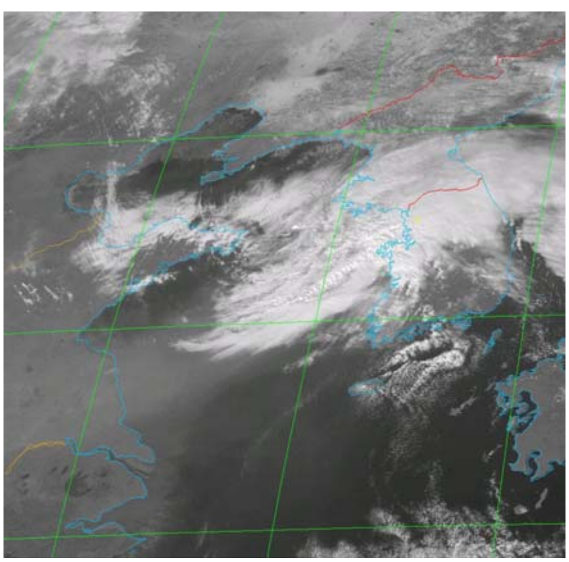

Figure 5: GMS visible satellite imagery for 15 Feb 1230L

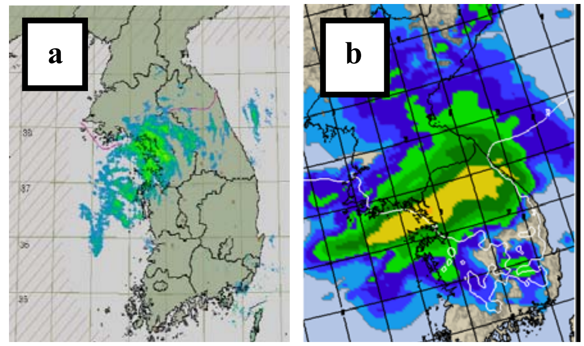

Figure 6: (a) KMA consolidated radar image at 15 Feb 1100L; (b) MM5 (14 Feb 18Z) 5-km 9 hour forecast of composite reflectivity. Note how MM5 tries to carry snow out too far east and does not show banding.

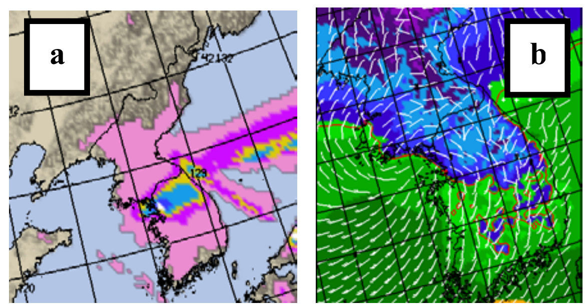

Figure 7: (a) MM5 (14 Feb 18Z) 15-km 48 hour snow accumulation forecast (bluish tones are GTE 6"); (b) MM5 (14 Feb 18Z) 5-km 9 hour temperature and wind forecast.(blue is < 32 ^{o}F).

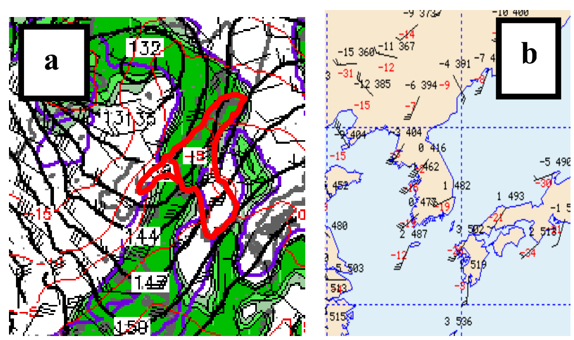

Figure 8: (a) MM5 (02 Mar 00Z) 45-km 24 hr 850 mb height-temp chart; (b) Hong Kong Met 850 mb chart.

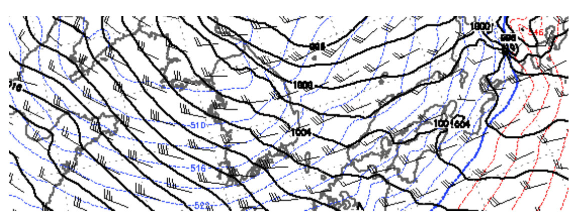

Figure 9: MM5 (02 Mar 18Z) 15-km 36 hr 1000-500 mb thickness, SLP, sfc wind forecast