EVALUATION OF HIGH-RESOLUTION WEATHER FORECASTS IN TROPICS USING SATELLITE PASSIVE MILLIMETER-WAVE OBSERVATIONS

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ABSTRACT

This paper evaluates high-resolution weather forecasts in tropics. The fifth-generation NCAR/Penn State Mesoscale Model, MM5, was used to forecast 79 storms spanning a year over Thailand and nearby regions at 5-km resolution. MM5 forecasted brightness temperatures and those coincidentally observed by the passive millimeter-wave Advanced Microwave Sounding Units (AMSU) aboard NOAA-16 satellite were compared. MM5-forecasted surface precipitation rate, peak vertical wind, and water paths for rainwater, snow, graupel, the sum of rainwater, snow, and graupel, cloud liquid water, and cloud ice were also compared with AMSU estimates. Results show that MM5 forecasts statistically agree with those observed by AMSU. MM5 over-forecast large ice particles for some storms. Morphology, intensity, and area of storms forecasted by MM5 are generally similar to AMSU observations, but with location differences. MM5 can provide useful high-resolution forecasts for tropical storms about 8 hours in advance. Forecast accuracy could be improved by using higher-resolution and more accurate initial and boundary conditions, satellite data for location correction during the forecast, and a more accurate weather prediction model.

Index Terms—high-resolution weather forecasting, numerical weather prediction model, precipitation, meteorology, satellite, tropics.

1. INTRODUCTION

Weather forecasting at high spatial resolution in tropical climates is challenging and is more difficult than that in extra-tropics. Most clouds in tropics are formed by convective instabilities that can arise in minutes to hours and have limited horizontal extent. Strong convective precipitation produces heavy rainfall that could lead to natural disasters, such as flooding and landslide, which cause losses of lives and economy. Thailand is located in tropics and has often been affected by intense storms. Accurate weather forecasting at high spatial resolution can help reduce losses.

Gridded analyses and forecasts at every 3 hours from 0Z to 24Z from U.S. National Center for Environmental Prediction (NCEP) global numerical weather prediction model, Global Forecast System (GFS) [9], were used as initial and boundary conditions. The GFS data are at 0.5 degree lat/lon spatial resolution with 64 pressure levels from
the ground to 0.27 mbar. Since the resolution of GFS data is ~50 km in tropics, MM5 requires ~4 hours or more to generate realistic forecasts at 5-km resolution [1]. Since precipitating convective cells are relatively small and can change rapidly, it is difficult to forecast them accurately for long time. MM5 forecasts used for evaluation in the paper are between 8 and 12 hours after MM5 initial time. Forecasts at 5-km resolution were interpolated vertically to pressure levels from 10 to 1000 mbar. The time difference between MM5 forecasts and AMSU observations is within 7.5 minutes.

3. REPRESENTATIVE STORMS

Fig. 1 shows center locations of the 79 representative storms over Thailand and nearby regions, where numbers 1-12 stand for January - December. They were chosen using NOAA-16 AMSU observed brightness temperatures and AMP precipitation estimates. At least five storms were chosen per month during December 2006 - November 2007. Each storm has the size of 950 km by 950 km.

4. ADVANCED MICROWAVE SOUNDING UNIT (AMSU)

AMSU aboard NOAA-15, -16, -17, -18, -19, and Metop-A satellites is the passive millimeter-wave radiometer. It was first launched aboard NOAA-15 in May 1998. It is composed of 2 units, AMSU-A and –B, where the Microwave Humidity Sounder (MHS) substitutes AMSU-B on NOAA-18, -19, and Metop-A. AMSU-A observes 15 channels, mostly near the 54-GHz oxygen absorption band and the 22.35-GHz water vapor resonance, with spatial resolution of 50 km at nadir. AMSU-B observes 5 channels, mostly near the 183-GHz water vapor resonance, with spatial resolution of 15 km at nadir. AMSU scans ~2200 km across track with 30 AMSU-A and 90 AMSU-B viewing angles. The maximum scan angles are 48.33 and 48.95 degrees for AMSU-A and –B, respectively.

5. COMPUTATION OF MM5 FORECASTED BRIGHTNESS TEMPERATURE

The computation of MM5 forecasted brightness temperatures employed 1) MM5 domain-3 forecasts at 5-km resolution, 2) a two-stream radiative transfer model, TBSCAT [10], 3) electromagnetic models, F(λ) [1], for icy hydrometeors, 4) atmospheric transmittance models [11]-[12], and 5) complex permittivities for water [13] and ice [14]. Land surface emissivity was assumed to be uniformly random from 0.91 to 0.97. Sea emissivity was computed using FASTEM [15]. To compare MM5-forecasted with AMSU-observed brightness temperatures, MM5-computed brightness temperatures at 5-km resolution were convolved with a Gaussian function having full width at half maximum of 50 and 15 km for AMSU-A and –B channels, respectively.

6. AMSU MIT PRECIPITATION RETRIEVAL PRODUCTS (AMP)

AMSU MIT Precipitation retrieval products (AMP) are retrieved using the AMP algorithm [4]-[5]. The algorithm is the first to successfully retrieve precipitation over snow-covered land and sea ice [4]. The retrieved global products include surface precipitation rate (mm/h), peak vertical wind (m/s), and water paths (mm) for rainwater, snow, graupel, the sum of rainwater, snow, and graupel, cloud liquid water, and cloud ice. Both near real-time and historical global retrievals are available. [5] has shown good agreement between AMP precipitation estimates and those measured by 787 global rain gauges. AMP version 4 [5] products were used in this paper. MM5 forecasts at 5-km resolution were convolved with a Gaussian function having full width at half maximum of 15 km, which is the resolution of AMP estimates.

7. RESULTS

Figs. 2 and 3 compare histograms of AMSU-observed (dark) and MM5-forecasted (dashed) brightness temperatures over 79 storms for AMSU-A and –B channels, respectively, where each histogram bin is 1 K. AMSU-A channels 9-15 responds mostly to the altitudes above clouds and hence are not considered. The histogram comparisons show small biases between AMSU and MM5 brightness temperatures for AMSU-A channels 5-8 of 1.49, 1.2, -4.92, and -3.23 K, respectively. Results in Fig. 2 and other figures were corrected for the biases. These biases could be from AMSU miscalibration, GFS data, MM5 forecasts, or radio frequency interference. Figs. 2 and 3 show good statistical agreement between AMSU and MM5 brightness temperatures. The most obvious discrepancies are in AMSU-A channel 4 (52.8 GHz) and AMSU-B channel 1 (89 GHz), where MM5 is colder than AMSU. This is because MM5 over-forecast large ice aloft for some storms.
Since most AMSU-A channels center in oxygen absorption bands and their weighting functions peak at different altitudes, they are sensitive to temperature profiles. The agreement between MM5 and AMSU-A brightness temperatures shows that MM5-forecastsed temperature profiles are in agreement with truth.

Fig. 4 compares AMSU-observed and MM5-forecastsed brightness temperatures (TBs) at 183±7 GHz (AMSU-B channel 5), AMSU-retrieved and MM5-forecastsed surface precipitation rate (RR, mm/h) for 3 storms. Fig. 5 compares AMSU estimates and MM5 forecasts for surface precipitation rate (RR, mm/h); water paths (mm) for rainwater (R), snow (S), graupel (G), the sum of rainwater, snow, and graupel (RSG), cloud liquid water (C), and cloud ice (I); and peak vertical wind ($W_p$, m/s) for a storm system on August 6, 2007. Results show that morphology, intensity, and area of storms forecasted by MM5 are generally similar to AMSU observations, but there are some location differences. Comparisons for other storms showed similar results.

Fig. 6 shows the scatter plot between AMSU-estimated and MM5-forecastsed numbers of precipitating pixels per storm for 79 storms, where a pixel is called precipitating when surface precipitation rate is greater than 0.5 mm/h. The figure shows that although there are some differences between AMSU observations and MM5 forecasts, their precipitating area agree quite well with the correlation coefficient of 0.73.

8. SUMMARY AND CONCLUSIONS

This paper evaluates MM5 weather forecasts for tropical storms at high spatial resolution. MM5 forecasted brightness temperatures and precipitation parameters at 8-12 hours in advance for 79 storm systems over Thailand and nearby regions were shown to statistically agree with AMSU observations. MM5 and AMSU observations are generally similar in terms of morphology, intensity, and area coverage. The difference between MM5 forecasts and AMSU observations could be due to 1) low spatial resolution (0.5 degree) and errors of GFS data used for initialization, 2) rapid change and small horizontal extent of convective instabilities, and 3) errors in
MM5 physics. MM5 can provide useful high-resolution forecasts about 8 hours in advance.

Fig. 5. AMSU estimates and MM5 forecasts for surface precipitation rate (RR, mm/h); water paths (mm) for rainwater (R), snow (S), graupel (G), the sum of rainwater, snow, and graupel (RSG), cloud liquid water (C), and cloud ice (I); and peak vertical wind (Wp, m/s) for a storm system on August 6, 2007.

Fig. 6. Scatter plot between AMSU-estimated and MM5-forecasted numbers of precipitating pixels per storm for 79 storms, where a pixel is called precipitating when surface precipitation rate is greater than 0.5 mm/h.

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10. REFERENCES