Lessons from Typhoon RUSA; orographic rainfall[1]

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I. Basic characteristic

Typhoon RUSA influenced the Korean Peninsula during 31 August to 1st September 2002, and caused more than 250 deaths and economic loss of 5 billion US dollars. Most of the damage came from the heavy rainfall over the northeastern coastal cities that were induced by persistent upslope wind in the front-right sector of the approaching RUSA. RUSA maintained its strength until landfall at the south coast on the afternoon of 31st August. This unusual behavior may in part be due to the high sea surface temperature above 30 degrees in celsius around the south sea.

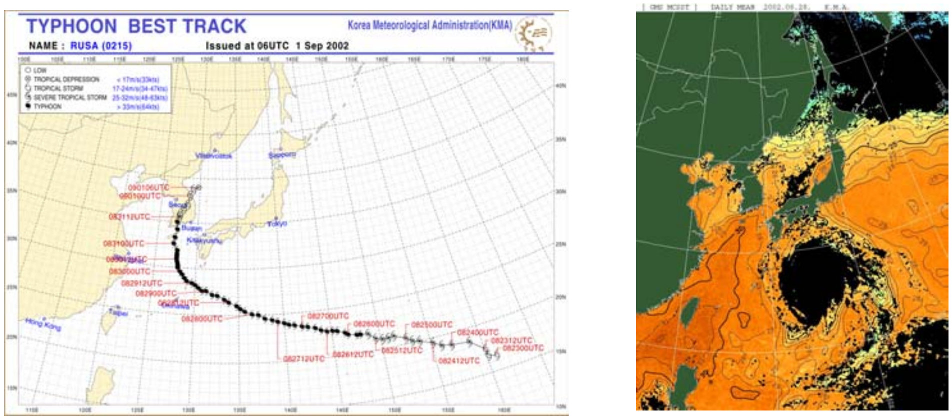

Fig. 1. *Best track of typhoon RUSA (left), and sea surface temperature (right) estimated from GMS satellite.*

The upper level trough over the Manjuria was far from RUSA moving across 30N on 30th August. RUSA continued to track northward with weak upper level flow until it passed through the Korean Peninsula. Moderately cold air mass was confronted with warm and humid air mass from RUSA around 40N.

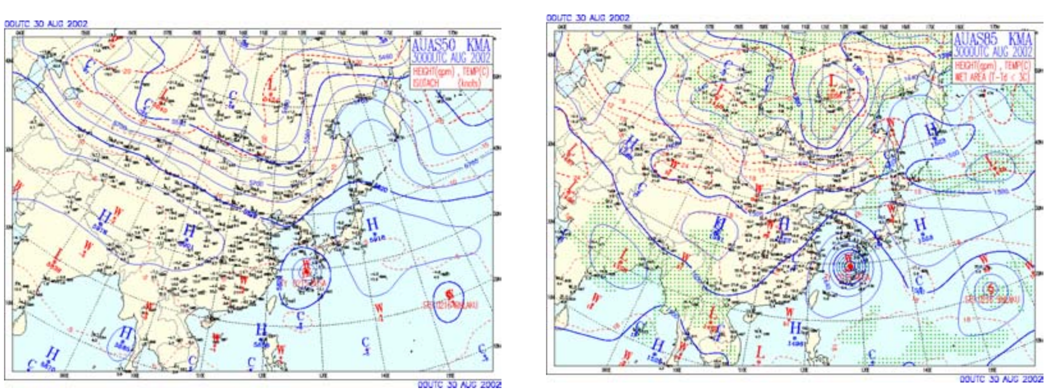

Fig. 2. *Geopotential height (solid) and temperature (dashed) at 500hPa (left) and at 850hPa (right).*

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1 *This note is to summarize the scientific lecture presented by the author during the 35th session of Typhoon Committee (Chiang Mai, Thailand, December 2002).*

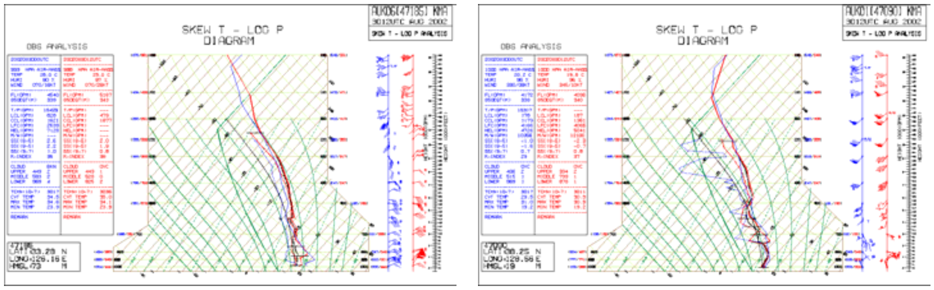

Fig. 3. Soundings at southern island and northeastern coast; Jeju (left) and Sokcho (right) at 00UTC (blue) and 12 UTC (red) 30th August 2002.

The vertical distribution of temperature was close to moist-adiabatic profile in both soundings, but the thick mid and upper level south westeries are confronted with the cool ocean-boundary layer northeasteries at Kangneung in the midnight 30th August 2002.

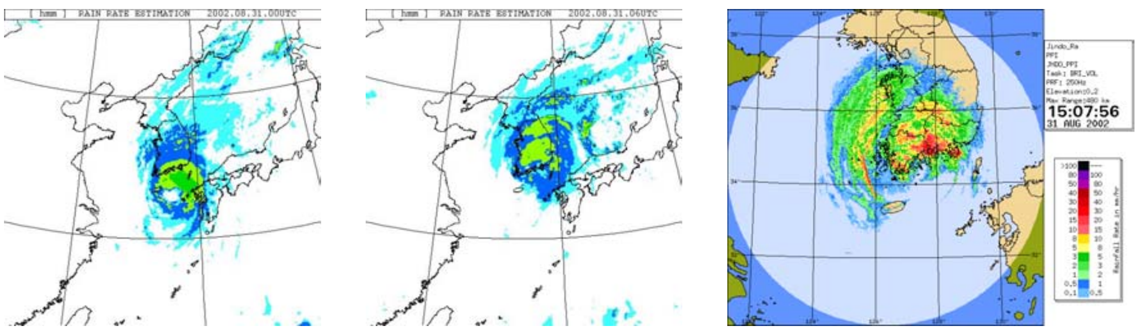

Fig. 4. *Rainfall rate estimated from the GMS satellite measurement at 00UTC (left) and 06UTC (middle) 31st August 2002. The dark green color corresponds to 12-16mm per hour. The rainfall rate from Doppler radar (Jindo) is shown in the right frame. The dark red color corresponds to 30 mm/hr. The satellite estimate is quite accurate for most of inland areas except for southern mountainous areas (max. about 1,000-1,500 m from sea level) where twice or three times more rainfall rate was observed from the Doppler radar.*

The maximum rainfall rate estimated from the GMS satellite amounts to less than 200 mms, if the intense spiral band of RUSA persists in a region for 12 hours. (Fig. 4). This estimate is quite good except for the mountainous areas, as measured from the dense rain gauge network (Fig. 5). Eastern slope of both Jeju Island (Fig. 6) and northeastern mountain range (Fig. 7) recorded 50mm/hr in average with maximum of about 100 mm/hr near Kangneung, northeastern costal city. The stationary front between the mid latitude cold air mass and tropical air mass of RUSA intersects the north-south oriented mountain range, which might contribute for the enhanced rainfall by orography near northeastern coasts.

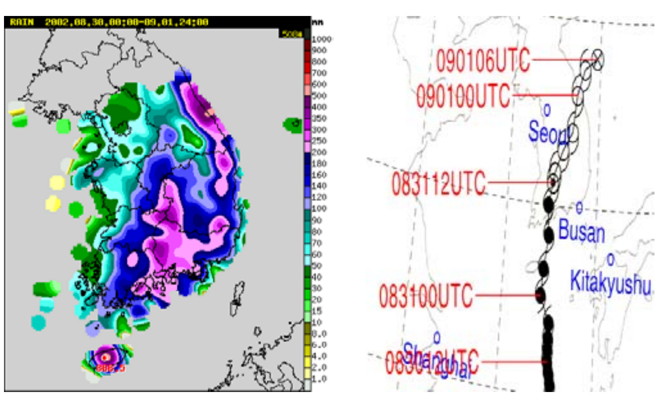

Fig. 5. *Accumulated rainfall amount from 00UTC 30th to 15UTC 31st 2002 measured from more than 440 automatic rain gauge stations. The maximum rainfall amount is about 200-400mms for most of inland regions, except for high mountain range in Jeju Island and northeastern coast where about 1,000mms were recorded. More than 870mm/day was recorded in Kangneung district, which is the maximum value ever measured so far. The corresponding track of RUSA was duplicated in the right frame.*

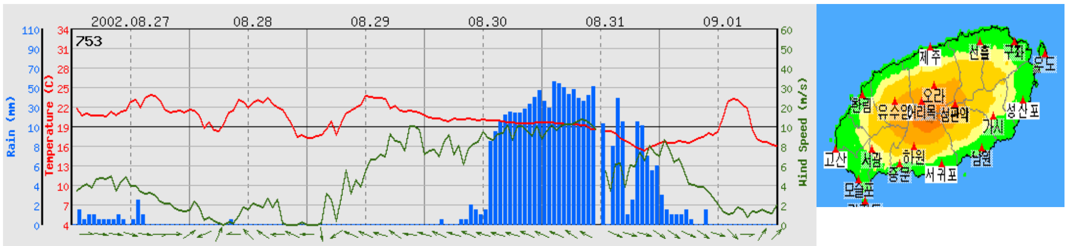

Fig. 6. *Time series at Mt. Hanra in Jeju Island (Earimok AWS station at about 1,500m from sea level, near the center of Jeju island shown in the right frame). The maximum rainfall rate is about 50mms per hour. The RUSA passed nearby around noon 31st August 2002 as the wind shifts from easterly to westerly. Hourly rainfall (blue stick), temperature (red) and wind speed (green)*

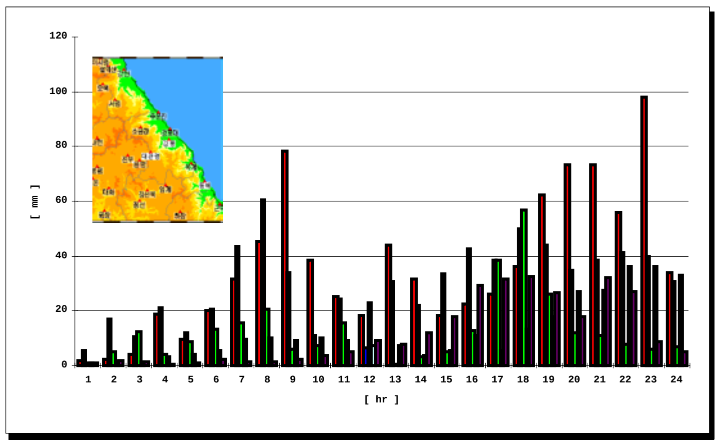

Fig. 7. *Hourly rainfall rate from several rain gauge stations near northeastern coastal city Kangneung on 31st August 2002. The maximum rate is about 90mms per hour, and the average rate is about 50mms per hour.*

II. Model simulations

The numerical models at the Korea Meteorological Administration predicted the tracks of RUSA fairly well, even though the models had left hand bias in the early period of simulation (Fig. 8).

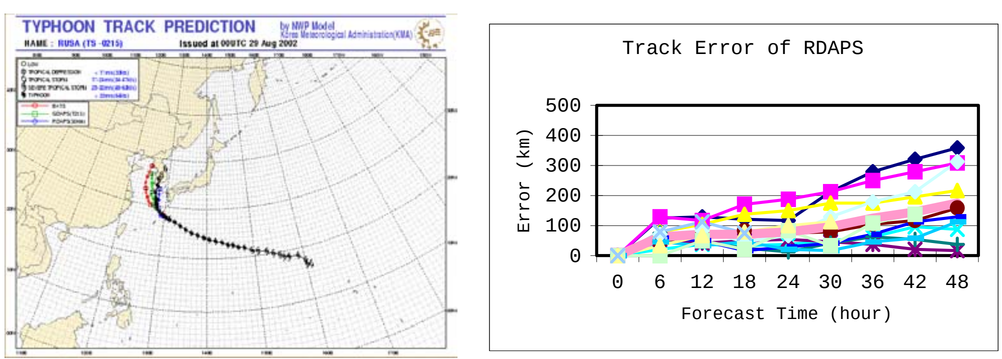

Fig. 8. *Model tracks of RUSA with initial condition at 00UTC 29th August 2002 (left); global spectral model (green), regional model (blue), and barotropic model (red). The track errors in units of meter are shown in the right frame for the regional model. Colors refer to different initial times until RUSA made landfall. The track errors gradually reduced from 300 kms to 100 kms as RUSA approached the Korean Peninsula. The details of specification of numerical models were described in the country report.*

The rainfall distribution predicted from the regional model (MM5, 10km resolution with 33 vertical levels) was qualitatively corresponding to the observation (Fig. 9 vs. Fig. 5). The orographic rainfalls over eastern coast were reasonably simulated in particular. The orographic rainfall amount is proportional to the horizontal resolution of the model. The rate of enhancement of orographic rainfall was 30-50% of the rate of reduction of horizontal mesh size in the case of RUSA (Table 1).

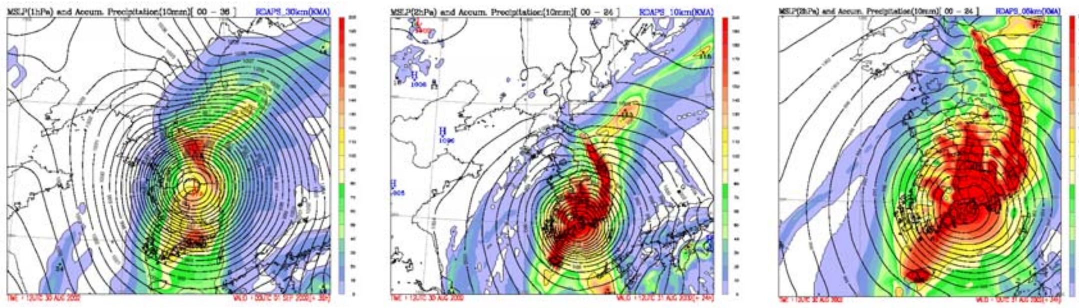

Fig. 9. *Twenty-four accumulated rainfall amount predicted by the regional model with mesh size of 30km (left), 10km (middle), and 5km (right). Valid time is during 12UTC 30th to 12UTC 31st August 2002 with initial condition at 12UTC 30th. The dark red color corresponds to 200mm/day. The maximum rate with meshes of 30km, 10km, and 5km are 199mm, 348mm, and 452mm, respectively.*

Table 1. Sensitivity of rainfall with horizontal resolution

Initial state	Global model	Regional model		
	55km	30km	10km	5km
8.28. 12UTC	50			
8.29. 00UTC	100			
8.29. 12UTC	150			
8.30. 00UTC	140	123		
8.30. 12UTC	130	199	348	452
8.31. 00UTC	90	157	577	813

(unit: mm/ day)

III. Implication

The orographic rainfall by tropical cyclone is a well-defined phenomenon to the forecasters. That is: the upslope wind side from the cyclonic wind is the favorable area for orographic rainfall. However, the serious question to forecasters is the maximum amount of rainfall induced by orography. It depends on the persistency of upslope wind (or duration), slope of the mountain, strength of wind or intensity of tropical cyclone, radius of strong wind around center of tropical cyclone, and/or synoptic environment such as cold pool associated with mid-latitude system.

When RUSA approached the Korean Peninsula, the forecasters were well acquainted with the conceptual model of orographic rainfall and the models provided good tracks and reasonable rainfall distribution patterns. However that knowledge was not sufficient to forecast the unusual event. The recorded rainfall amount about 900mms/day was unprecedented, and it was a real challenge to predict something that never occurred before. The forecasters were reluctant to push her/his decision forward beyond the history with the state of art scientific knowledge.

To tackle this problem, the downscaling of predicted precipitation from the limited area model is required. For the orographic rainfall, the sensitivity of rainfall amount on the variation of horizontal resolution may provide some hint to adjust the model output. The experience from RUSA shows that the rainfall amount predicted from the 5km mesh roughly comparable to 50-80% of the orographic rainfall expected. In the meantime, it is desired to introduce the concept of probability for the rare event based on the statistical interpretation of past records, and on the application of ensemble prediction system.