*The Second International MAHASRI/HyARC Workshop on Asian Monsoon and Water Cycle. 181-190. Nhatrang Vietnam, August 2011.*

# Large-scale circulation and precipitation over Vietnam region during a Mei-yu period: The role of the upper-level jet

Nguyen Minh Truong, Vu Thanh Hang, Bui Hoang Hai, and Cong Thanh

*Faculty of Hydrology, Meteorology and Oceanography, Hanoi University of Science*
*334 Nguyen Trai, Thanh Xuan, Hanoi*

**Abstract**. Using the NCAR-NCEP reanalysis data to simulate the Mei-yu front occurring from 10 to 14 June 2005, the Regional Atmospheric Modeling System (RAMS) model gives simulations which show that the Mei-yu front may lead to heavy rainfall over all Vietnam region. It also appears that the development of the front coincides with the intensification of the upper-level jet. When the upper-level jet is artificially weakened at the western and eastern boundary regions, the amplitude of the East Asia cold trough is remarkably reduced over Japan, and mesoscale disturbances are observed in the lower troposphere, which associate with mesoscale changes in the simulation rainfall. These demonstrate that the upper-level jet may excite and steer mesoscale disturbances at lower levels as suggested by previous observational studies.

*Keywords*: Mei-yu front, Mei-yu precipitation, upper-level jet, mesoscale disturbances.

## 1. Introduction

The Mei-yu (or Baiu in Japanese) front is a well-known phenomenon embedded in the Asia summer monsoon, which is a high-impact weather system and plays an important role in water resources in countries where it occurs. The Mei-yu studies may be divided into two common frameworks: the Mei-yu season diagnosis and the Mei-yu front diagnosis. For the Mei-yu season diagnostic framework, for example, Wang et al. (2003) used a highly resolved regional climate model to simulate precipitation in the Mei-yu season from 26 April to 31 August 1998. Their 4-month simulations showed that rainfall associated with the Mei-yu front over the Yangtze River basin (26°-32°N, 110°-122°E) was less convective. Conversely, convective rainfall dominated in south China. Sampe and Xie (2010) diagnosed the large-scale environment favorable for the Meiyu-Baiu season and found a close relation between the warm advection and upward motion, indicating the importance of the warm advection for the Meiyu-Baiu formation.

For the Mei-yu front diagnostic framework, abundant research focuses on principal weather systems associated with the Mei-yu front. Chien et al. (2002) verified the precipitation forecast skill of the MM5 model and exhibited that during the Mei-yu season in 1998, many mesoscale convective systems (MCS) developed along the front and moved toward Taiwan. Zhang et al. (2003) also used MM5 to depict conditions for the formation of mesoscale features embedded in a mature MCS, including lower-level jet, upper-level jet, mesolow, and mesohigh etc. Also interested in the Mei-yu internal structures is Chen et al. (2006) who analyzed mechanisms producing lower-level jets, jet intensification, and the retreat of the Mei-yu front near Taiwan. In their study, the potential vorticity generated and latent heat released by MCS, along with the adjustment to geostrophic balance, were emphasized as the major mechanisms. So far, the Mei-yu studies have recognized the important roles of the Tibetan Plateau, moisture sources, and western Pacific subtropical high (WPSH). Qian et al. (2004) demonstrated that the moisture flux from the Bay of Bengal played an essential role in Mei-yu precipitation in 1998. The WPSH location might be important in that it would decide where moisture comes from, the South China Sea or Bay of Bengal (Ninomiya and Shibagaki 2007, Sampe and Xie 2010).

It is worthy to note that Vietnam may seriously be affected by the Mei-yu circulation in almost all cases because the front is the northern limit of the southwest monsoon flow that brings a tremendous amount of moisture from tropical oceans to the Indochina Peninsular. The Mei-yu front, therefore, becomes a major concern to Vietnam. Unfortunately, there is almost no study involving such problem. Thus, the present study aims at how the Mei-yu front affects precipitation in Vietnam through a case study from 10 to 14 June 2005. Section 2 describes data and experimental configurations applied to the Regional Atmospheric Modeling System (RAMS). Results and discussions are given in Section 3 followed by conclusions.

## 2. Data and experimental configurations

The initial conditions for the RAMS simulations are specified by using the NCEP-NCAR Reanalysis data (Kalnay et al. 1996). These data consist of horizontal wind, temperature, relative humidity, and geopotential height on 17 isobaric surfaces with a horizontal grid interval of 2.5° × 2.5°. The boundary conditions are updated every 6 h using the same data source. The sea surface temperature (SST) data is the weekly SST given by NOAA (Reynolds et al. 2002).

Centered at 35°N-108°E, the domain of the present study respectively includes 207 × 161 grid points in the zonal and meridional direction with a grid spacing of 45 km. The model grid contains 30 levels and is vertically stretched with a 1.15 ratio. The lowest grid spacing is 100 m and the maximum vertical grid spacing is set to 1200 m. The convective parameterization scheme (CPS) is the modified Kain-Fritsch scheme described by Truong et al. (2009) where a new trigger function, closure assumption, and equation to compute updraft velocity are developed. The CPS is activated every 5 minutes.

## 3. Results and discussions

### *3.1 Mei-yu front evolution*

Figure 1 illustrates the evolution of the Mei-yu front system at 700 hPa from 10 to 13 June 2005 at 1200 UTC. At the early stage, a hot low occurs immediately to the southeast of the Tibetan Plateau, and the Mei-yu front is found to originate from the eastern flank of the plateau and extends eastward about 32°N. A weak cold trough concurrently locates east of the Korean peninsula (Fig. 1a). As time elapses, the hot low broadens toward northern Vietnam while the cold trough amplifies and propagates to the east, and the Mei-yu front starts to develop toward Japan (Fig. 1b,c). On the last day when the hot low weakens, another cold trough is re-established in northern China and the process seems to repeat (Fig. 1d).

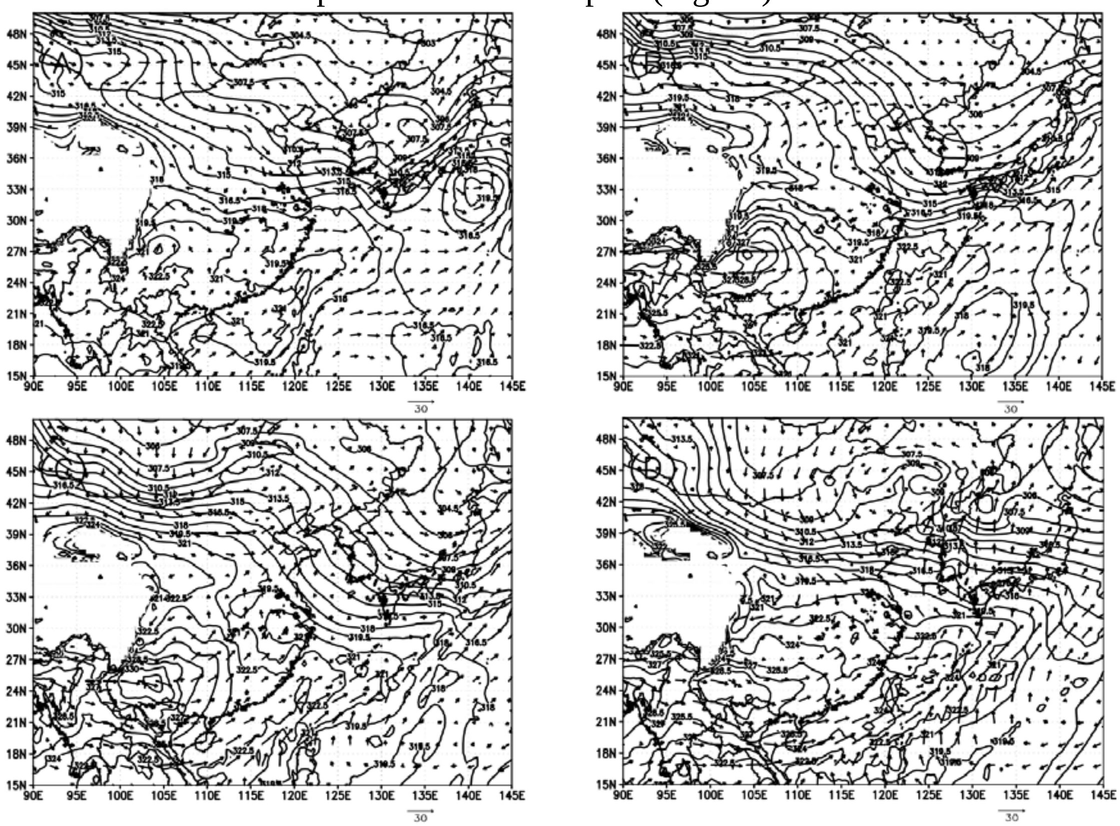


Figure 1. Simulated virtual potential temperature and wind vector at 700 hPa on 10 (a), 11 (b), 12 (c), and 13 (d) June 2005 at 1200 UTC. Contour interval is 1.5$^{o}$K.

It is apparent that midlatitude westerly wind prevails to the north of the front, while west-to-southwest flow (lower-level jet) develops and blows across the Indochina peninsula on those days, which is presumed to be moisture supply to the Mei-yu precipitation. At 300 hPa level, the cold trough is much more amplified to create an upper-level jet that blows along the northern flank of the Tibetan Plateau toward Japan. The Mei-yu front is observed to develop along with the intensification of the upper-level jet (not shown).

### *3.2 Mei-yu precipitation*

Total rainfall accumulated for 24 (a), 48 (b), 72 (c), and 96 (d) h model integration is given in Fig. 2, which is in good agreement with TRMM and observed rainfall (not shown). The Mei-yu precipitation clearly appears in form of a band extending from central China to Japan and evolves in association with the development of the front. In addition, another long band of heavy rainfall locates over the lower-level jet, from the Indochina peninsula to the south of Japan.

It is worthy to mention that a large amount of stations observed rainfall exceeding 25 mm day$^{-1}$ in northern, southcentral, and southern Vietnam, which is compatible with the Mei-yu rainfall in China. This means whenever meteorological centers warn heavy rainfall associated with the Mei-yu/Baiu front in China and/or Japan, Vietnamese forecasters may pay attention of possibility of heavy rainfall occurring in northern and central Vietnam at least[1]. It is interesting that although the simulated precipitation spreads over all East Asian regions on the first two days, it appears much narrower and lighter over India and the tropical Indian Ocean. Thus, this case study is a good example suggesting again that the East Asian summer monsoon, which can be classified as a subtropical monsoon system, is not a simple extension to the east of the South Asian summer monsoon (Ding and Chan 2005).

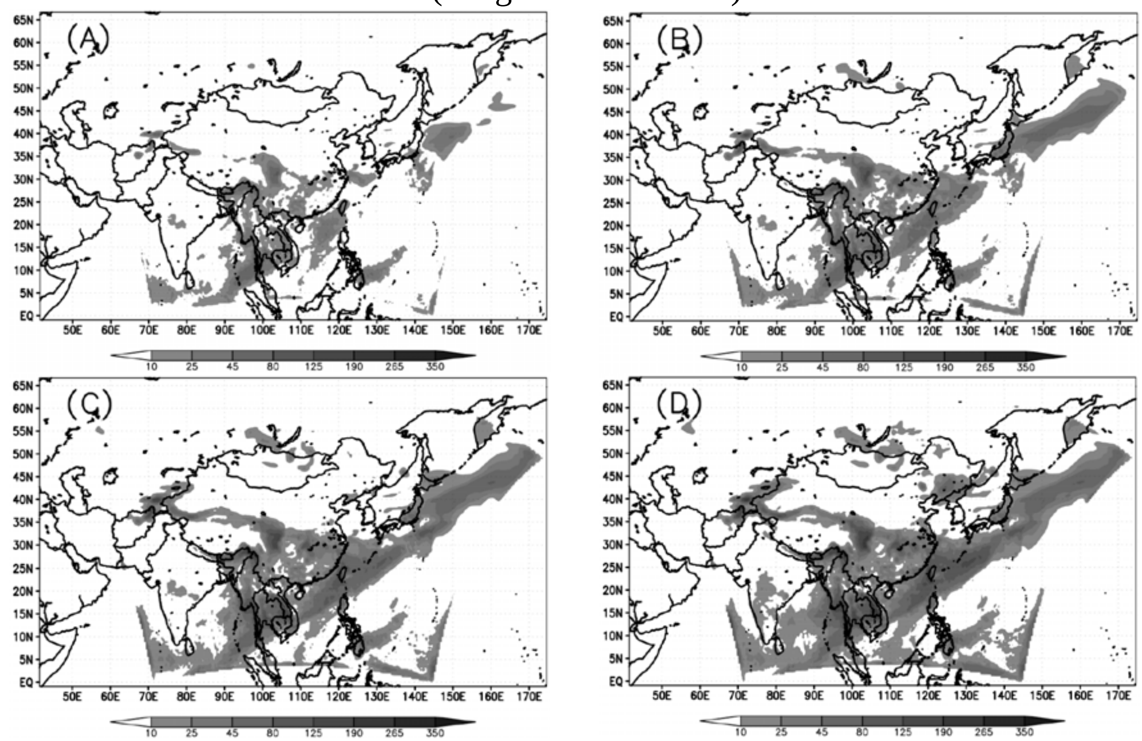


Figure 2. Total rainfall (mm) accumulated for 24 (a), 48 (b), 72 (c), and 96 (d) h model integration, starting from 0000 UTC 10 June 2005.

### *3.3 Role of the upper-level jet*

In the Mei-yu studies, the upper-level jet appears as a key factor for the development of the Mei-yu front system. In order to clarify, an experiment is set up where the wind speed is reduced at the western and eastern boundary region by

$$|V| = 45 + 0.3\left(|V| - 45\right), \quad |V| \geq 45 \text{ m s}^{-1}$$

$$|V| = |V|, \quad |V| < 45 \text{ m s}^{-1}$$

which ensures that the only portion of the wind speed exceeding 45 m s$^{-1}$ is reduced by 70%, so the wind field is only modified in the layer from about 500 hPa upward, although it should remain smooth with the same direction. It is assumed that the

[1] The authors have found the same situation for a large number of cases

boundary regions are so far that they do not make significant noise in the interior domain. To be convenient, this experiment is denoted by Jmod while the experiment in the previous section is Ctrl.

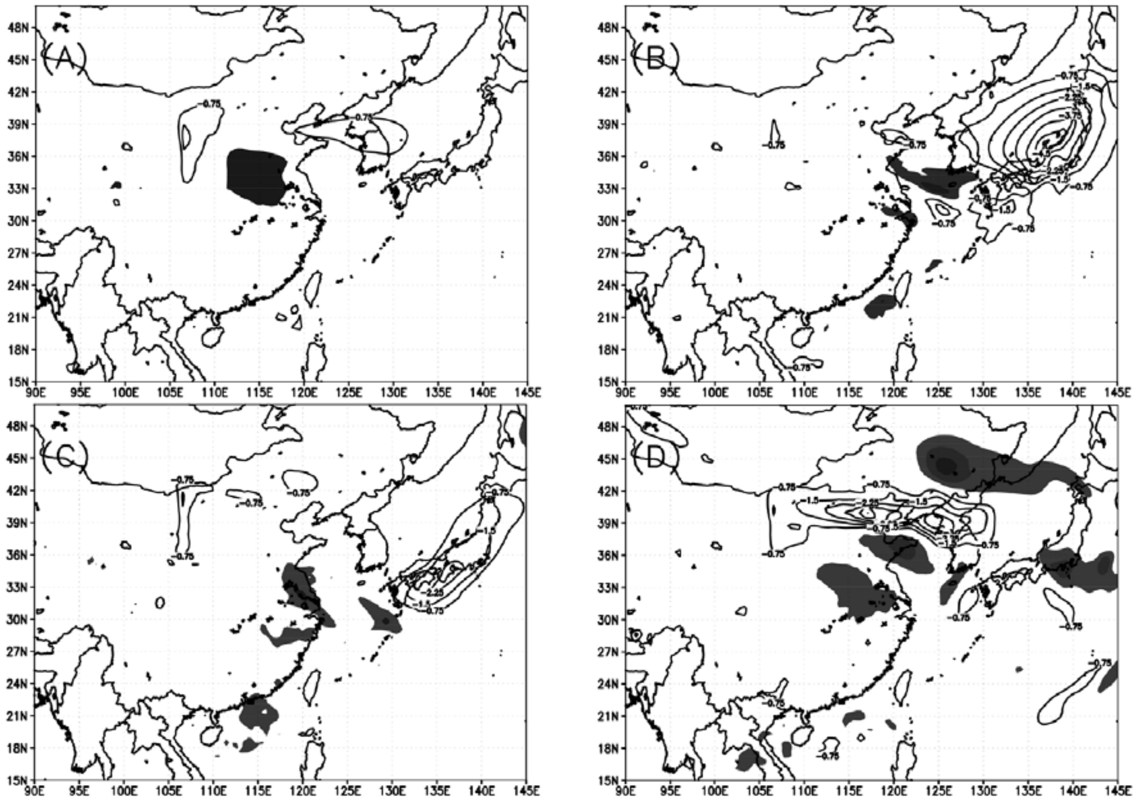

Figure 3. Difference in 300-hPa virtual potential temperature between the Ctrl and Jmod experiment on 10 (a), 11 (b), 12 (c), and 13 (d) June 2005 at 1200 UTC. Shaded areas show positive value and solid contours indicate negative value at intervals of 0.75°K. Zero lines are omitted.

Figure 3 shows the difference in 300-hPa virtual potential temperature between the Ctrl and Jmod experiment from 10 to 13 June 2005 at 1200 UTC. It is apparent that the difference is not significant until 1200 UTC 10 June (Fig. 3a), with a “cooling” on the cold side and a “warming” on the warm side of the front section over the Korean peninsula and northern China, when the upper-level jet does not yet develop. Subsequent to the intensification of the upper-level jet, the Mei-yu front is dramatically “cooling” over whole Japan (Fig. 3b,c), where Sampe and Xie (2010) found upper-level climatological disturbances nearby. This means whenever the upper-level jet weakens the amplitude of the cold trough is reduced, and isentropic surfaces are less tilted. The “cooling” and “warming” distribution become more complicated on the last day when the cold trough propagates to the east, leading to northward movement of the front section over Japan, and another cold trough is re-established in northern China as mentioned above (Fig. 3d).

To further investigate the impact of the upper-level jet on the lower troposphere, Fig. 4 presents the difference in 700-hPa virtual potential temperature between the two experiments. The wind speed is certainly less than 45 m $s^{-1}$ at this level so changes in temperature should be attributed to the upper-level jet. It appears that almost no change occurs on the first day when the upper-level jet do not mature (Fig. 4a). On the next days, however, mesoscale "cooling" and "warming" areas coexist in both time and space along the Mei-yu front and lower-level jet (Fig. 4b,c,d) with a time lag as compared to those at 300-hPa level. This suggests that the upper-level jet excites and steers mesoscale disturbances that may propagate eastward (Ding and Chan 2005, Yasunari and Miwa 2006).

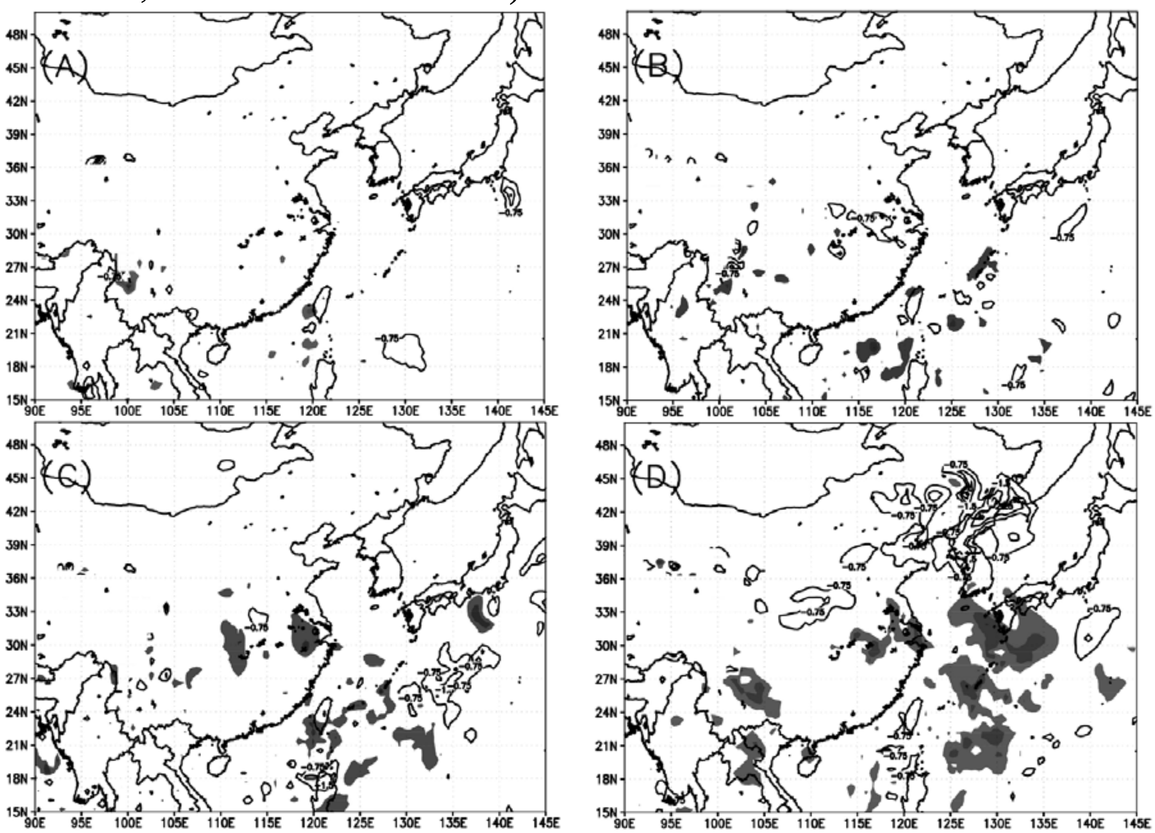


Figure 4. Same as Fig. 3 except at 700 hPa.

The difference in total rainfall accumulated for 24, 48, 72, and 96 h model integration between the Ctrl and Jmod experiment is given in Fig. 5. Similar to the difference in 700-hPa virtual potential temperature, the increase and decrease of total rainfall coexist and show at the mesoscale. The difference is small on the first two days (Fig. 5a,b), but becomes noticeable on the last two days (Fig. 5c,d). This again demonstrates the mesoscale impact of the upper-level jet. It is interesting that the weakening of the upper-level jet leads to an increase of rainfall in the central Indochina peninsular where the lower-level jet crosses over. The reason may be the increase of moisture flux convergence over the region.

## 4. Conclusions and remarks

The Mei-yu front system is a high-impact weather system that is frequently observed in the East Asian summer monsoon circulation and plays a key role in water resource management of the countries where it appears. In terms of circulation, Vietnam may be affected by this system. Despite that, the questions of how Vietnam is actually affected and what is the role of the upper-level jet have not been made and answered, especially in terms of heavy rainfall over complex terrains.

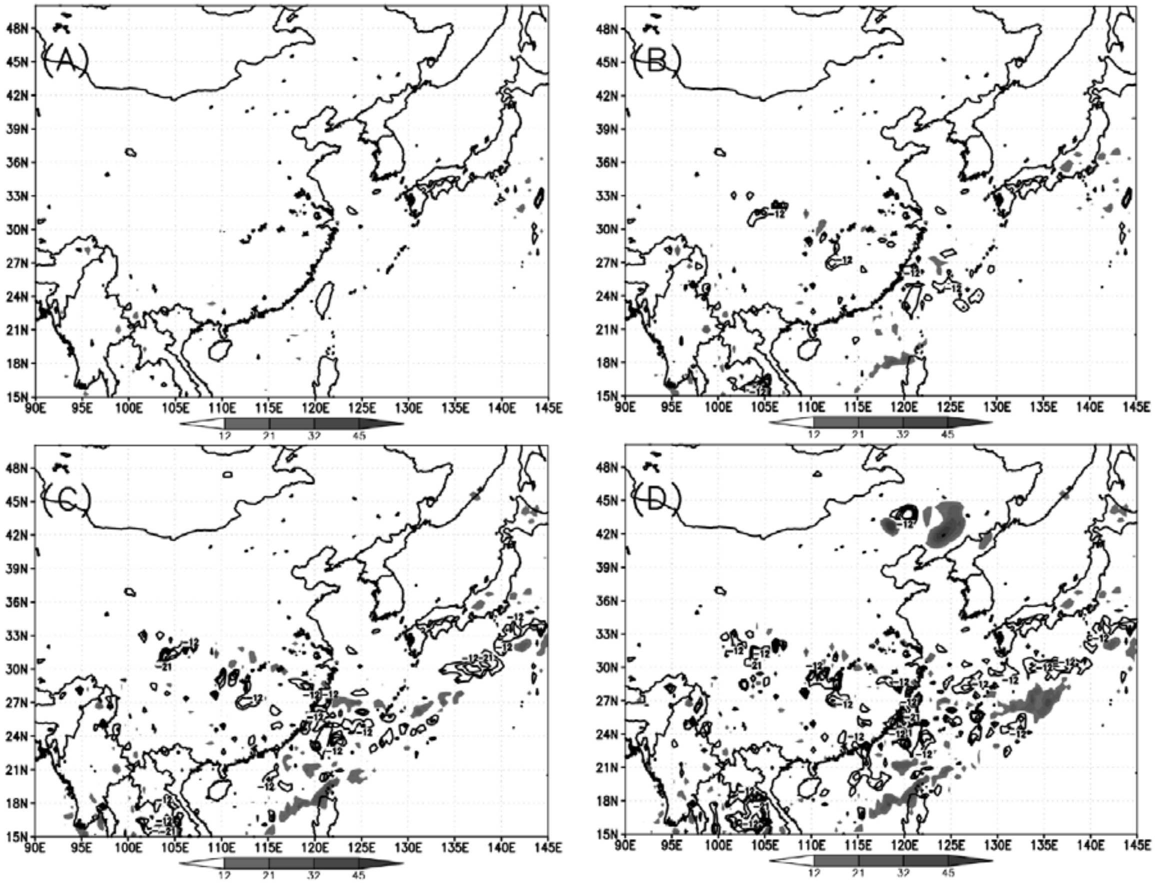

Figure 5. Difference in total rainfall (mm) accumulated for 24 (a), 48 (b), 72 (c), and 96 (d) h model integration between the Ctrl and Jmod experiment, starting from 0000 UTC 10 June 2005. Shaded areas show positive value and solid contours indicate negative value at intervals given by bar. Zero lines are omitted.

In the present study, the Mei-yu period from 10 to 14 June 2005 is investigated. The RAMS simulations show that the front appears as a belt of dense potential temperature isotherms, extending from central China to Japan. At the same time, a hot low locates to the southeast of the Tibetan Plateau. When the low intensifies, the front section weakens in China while a cold trough is amplified near the East Asia shoreline, leading to the intensification of the front section to the south of Japan. When the trough propagates eastward, the Mei-yu front may be re-strengthened in China. A west-to-southwest lower-level jet traverses the Indochina peninsular toward the front section over Japan, and becomes a major moisture source of the Mei-yu front system. At 300-hPa level, the Mei-yu front develops along with the intensification of the upper-level jet that blows along the northern flank of the Tibetan Plateau toward Japan.

The simulated precipitation shows that the Mei-yu rainfall is well organized in form of a band extending from central China to Japan. It is worthy to remind that wide heavy rainfall occurs in many provinces in Vietnam during this period. Heavy rainfall along the lower-level jet is even larger than the Mei-yu rainfall in central China. At operational point of view, Vietnamese forecasters should pay attention whenever meteorological centers warn heavy rainfall associated with the Mei-yu/Baiu front in China and/or Japan.

The weakening of the upper-level jet respectively induces “cooling” and “warming” areas on the cold and warm side of the front at 300 hPa. The strongest “cooling” occurs over Japan indicating the weakening of the cold trough near the East Asia shoreline. Such areas have along-front scale equivalent to the synoptic scale, while their cross-front scale belongs to the mesoscale. Although the upper-level jet exists above 500 hPa, the simulations show the alternate presence of mesoscale disturbances in the lower troposphere in both time and space. As a result, the difference in total rainfall also appears at the mesoscale with a noticeable increase of rainfall in the central Indochina peninsular where the lower-level jet crosses over. This clearly proves that the upper-level jet excites and steers mesoscale disturbances propagating eastward toward Japan and adjacent seas.

## Acknowledgement

This research was supported by the Vietnam’s National Foundation for Science and Technology Development under Grant NAFOSTED-105.10-2010.09. NCEP-NCAR Reanalysis data provided by the NOAA-CIRES ESRL/PSD Climate Diagnostics branch, Boulder, Colorado, USA, from their Website at http://www.cdc.noaa.gov/. Weekly sea surface temperature is provided at ftp://ftp.emc.ncep.noaa.gov/cmb/sst/oisst_v2/.

## References

[1] Chen, G. T.-J., C.-C. Wang, and L.-F. Lin, 2006: A diagnostic study of a retreating Mei-yu front and the accompanying low-level jet formation and intensification. *Mon. Wea. Rev.*, **134**, 874-896.

[2] Chien, F.-C., Y.-H. Kuo, and M.-J. Yang, 2002: Precipitation forecast of MM5 in the Taiwan area during the 1998 Mei-yu season. *Wea. Forecasting*, **17**, 739-754.

[3] Ding, Y., and J. C. L. Chan, 2005: The East Asian summer monsoon: An overview. *Meteorol. Atmos. Phys.*, **89**, 117–142.

[4] Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-year reanalysis project. *Bull. Amer. Meteor. Soc.*, **77**, 437-471.

[5] Ninomiya, K., and Y. Shibagaki, 2007: Multi-scale features of the Meiyu-Baiu front and associated precipitation systems. *J. Meteor. Soc. Japan*, **85**, 103-122.

[6] Qian, J.-H., W.-K. Tao, and K.-M. Lau, 2004: Mechanisms for torrential rain associated with the Mei-yu development during SCSMEX 1998. *Mon. Wea. Rev.*, **132**, 3-27.

[7] Reynolds, R. W., N. A. Rayner, T. M. Smith, D. C. Stokes, and W. Wang, 2002: An improved in situ and satellite SST analysis for climate. *J. Climate*, **15**, 1609-1625.

[8] Sampe, T., and S-P. Xie, 2010: Large-scale dynamics of the Meiyu-Baiu rainband: Environmental forcing by the westerly jet. *J. Climate*, **23**, 113-134.

[9] Truong, N. M., T. T. Tien, R. A. Pielke Sr., C. L. Castro, and G. Leoncini, 2009: A modified Kain-Fritsch scheme and its application for simulation of an extreme precipitation event in Vietnam. *Mon. Wea. Rev.*, **137**, 766-789.

*The Second International MAHASRI/HyARC Workshop on Asian Monsoon and Water Cycle. 181-190. Nhatrang Vietnam, August 2011.*

[10] Wang, Y., O. L. Sen, and B. Wang, 2003: A highly resolved regional climate model (IPRC-RegCM) and its simulation of the 1998 severe precipitation event over China. Part I: Model description and verification of simulation. *J. Climate*, **16**, 1721-1738.

[11] Yasunari, T., and T. Miwa, 2006: Convective cloud systems over the Tibetan Plateau and their impact on meso-scale disturbances in the Meiyu/Baiu frontal zone: A case study in 1998. J. Meteor. Soc. Japan, 84, 783-803.

[12] Zhang, Q.-H., K.-H. Lau, Y.-H. Kuo, and S.-J. Chen, 2003: A numerical study of a mesoscale convective system over the Taiwan strait. *Mon. Wea. Rev.*, **131**, 1150-1170.