P2.28 SOME COMMON INGREDIENTS FOR HEAVY OROGRAPHIC RAINFALL AND THEIR POTENTIAL APPLICATION FOR PREDICTION

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1. Synoptic and mesoscale environments conducive to heavy orographic rainfall

Based on previous studies of heavy orographic precipitation events which have occurred over the US (e.g. Maddox et al. 1978; Pontrelli et al. 1999) and southern Alps (e.g. Buzzi and Foschini 2000; Massacand et al. 1998), Lin et al. (2001) summarized that the synoptic and mesoscale environments conducive to heavy orographic rainfall in the Alps are: (1) a conditionally or potentially unstable airstream impinging on the mountains, (2) a very moist LLJ, (3) steep mountains to help release instability, (4) an upper-tropospheric shortwave trough approaching the threat area (which helps to enhance low-level upward motion), and (5) an upper-tropospheric quasi-stationary high pressure ridge.

Fig. 1a shows the accumulated 3-h rainfall for 9/20/12-15UTC 1999 during the MAP IOP2 heavy orographic rainfall event. The rainfall accumulated during the whole event (9/19/13UTC-9/21/01UTC 1999) in the Lago Maggiore region ranges from 100 to 300 mm (Lin et al. 2002). The rainfall region during the 12-h period ending at 1999/9/20/00UTC extended from the Gulf of Genoa to the Lago Maggiore region, with the heaviest precipitation focused in the Lago Maggiore area. The maximum 3-h rainfall amount reached 50 mm. This heavy rainfall area was associated with the impinging trough, which brought in from the Ligurian Sea air of high moisture content. Similar to the previously discussed historical events, the upper-level pressure ridge located to the east of the approaching deep shortwave trough is quasi-stationary. The rainfall started in the Lago Maggiore region, which is located in the concave topography region of the southern slopes of the European Alps. During the period of 9/20/00-12UTC, the heavy rainfall encompassed the entire southern slopes of the Alps, where the maximum rainfall amount reached a value higher than 130 mm. As also found in previous studies of historical flash flooding events over the southern Alps, the low-level jet is very moist, which has a tongue of high moisture with water vapor mixing ratio (q_v) covering northern Italy and the Lago Maggiore region. This high moisture tongue was increasing during the heavy rainfall period for the next 12 h.

Lin et al. (2001) found the following common synoptic and mesoscale features are essential for producing heavy orographic rainfall associated with a tropical storm or depression in Taiwan and Japan: (1) A steep mountain helps to release instability; (2) A tropical storm or depression helps enhance the low-level jet (LLJ); (3) The LLJ is highly conditionally (i.e. high CAPE) and potentially unstable; and (4) A quasi-stationary synoptic system, such as a typhoon in Taiwanese cases or a stationary front in Japanese cases, acts to impede or slow the movement of the convective system over the mountains.

2. Some common ingredients for producing heavy orographic rainfall

Following Alpert (1986) and Doswell et al. (1996), Lin et al. (2001) proposed that the total precipitation (in *m*) produced might be determined by

$$P = (r / r_w) E \left[\boldsymbol{V_H} \cdot \nabla h + w_{env} \right] q \, L_s / c_s \, . \qquad (1)$$

Doswell et al. (1998) has used a form similar to $\boldsymbol{V_H} \cdot \nabla h$ to diagnose three episodes of heavy rainfall in the western Mediterranean. Therefore, Eq. (3) indicates that a heavy orographic rainfall requires significant contributions from any combination of the following essential ingredients: (1) An incoming flow with high efficiency, (2) an intense low-level jet, (3) steep orography, (4) favorable (e.g. concave) mountain geometry and a confluent flow field, (5) strong environmentally-forced *w*, (6) a high moisture flow upstream, (7) the presence of a large, pre-existing convective system, (8) impeded movement of the convective system, and (9) a conditionally or potentially unstable low-level flow. Ingredient (9) is required for a deep convective system, which is often the case for heavy orographic rainfall events.

It appears that the common synoptic and mesoscale conditions conducive to heavy orographic rainfall over US, Alpine, Taiwan, and Japan mountains belong to a subset of the above listed essential ingredients. Although a high CAPE is not consistently observed for US and Alpine heavy orographic rainfall events, this remains to be investigated.

Lin et al. (2001) also provided rough estimates of the index $U(\partial h / \partial x) q$ for some common ingredients apparently responsible for producing heavy orographic rain in the US, the European Alps, and East Asia. These include the low-level wind (*U*), mountain slope ($\partial h / \partial x$), and water vapor mixing ratio (*q*). They found that for Alpine events, the index is > 4.7

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(except for the South Ticino case). For the Taiwanese and Japanese cases, it has a relatively high value (e.g. > 6) and the proposed index is roughly proportional to the observed maximum rainfall rates. For US events, it appears that the index has a lower value, but is still >2.7. With w_{env} included, the index should be able to reach a higher value (comparable to those estimated for the Taiwanese and Japanese cases).

Fig. 1b shows the total precipitation (in mm) for the period of 1999/9/20/12-15UTC of MAP IOP2 simulated by MM5 with 5-km resolution and simple ice parameterization of microphysical moist processes. The model overpredicted the rainfall intensity, i.e. 68 mm versus observed amount of about 40 mm. The simulated rainfall distribution is reasonably well except that near the southern end of the French Alps. Fig. 1c shows the rainfall distribution predicted by the flux model using the orographic moisture flux, $(\boldsymbol{V_H} \cdot \nabla h)\,q$ at 9/20/12UTC. A similar flux model has also been used by Alpert (1986) and Doswell et al. (1998). The horizontal resolution is 5 km and the predicted fields are valid at 9/20/12UTC 1999, which is within the heaviest rainfall period. From the figure, it can be seen that the horizontal distribution of the rainfall (Fig. 1c) compares fairly well with 3-h observed rainfall (Fig. 1a) and model predicted rainfall distribution (Fig. 1b). The total amount of the rainfall may be estimated by multiplying the predicted flux in Fig. 1c by $(r / r_w)ED$ by assuming $r = 1\,kg\,m^{-3}$, $r_w = 10^3\,kg\,m^{-3}$, $E = 1$, and $D = 10800\,s$. Thus, the maximum rainfall predicted by the flux model over the Lago Maggiore region is about 68 mm, which also overpredicted the observed maximum of 40 mm. Fig. 1d shows the rainfall distribution predicted by the flux model with the general vertical moisture flux, wq. The flux model with general vertical moisture predicted the rainfall distribution better than the orographic moisture flux, especially over the southern Alpine slopes. There was no heavy rainfall predicted over the eastern part of the southern Alpine slopes. The rainfall distribution also shows a heavy rainfall belt from the Mediterranean Sea to the Lago Maggiore region, which appears to reflect the rain produced by convergence zone associated with the eastward moving front-trough system. Similar to the orographic moisture flux model, the total amount of precipitation may be roughly estimated by multiplying 10.8 to get P in mm, which gives a maximum value of about 70 mm.

Figs. 2a-d show the observed rainfall for the period of 2000/8/22/12-15UTC during the passage of Typhoon Bilis (2000) over Taiwan, simulated rainfall by COAMPS with 15-km resolution for the same period, the rainfall predicted by the orographic moisture flux at 12UTC, and the rainfall predicted by the general moisture flux at 12UTC, respectively. The COAMPS simulated rainfall distribution compares reasonably well with the observed pattern except the rainfall in southern tip of Taiwan, although the rainfall amounts are overpredicted. The flux models are able to predict the rainfall distribution over the mountain area reasonably well. The rainfall amounts are underpredicted by the flux model.

The MM5 simulated rainfall distribution of Tropical Storm Rachel (1999) over Taiwan compares reasonably well with the observed pattern except the rainfall in west-central Taiwan, although the rainfall amounts are overpredicted. The flux models are able to predict the rainfall distribution over the mountain area. The rainfall amounts are underpredicted by the flux model.

3. Concluding Remarks

By applying the flux model to MAP IOP2 event, Typhoon Bilis (2000) and Tropical Storm Rachel (1999), we found the orographic rainfall distributions predicted by the flux model compare well with observed rainfall distributions.

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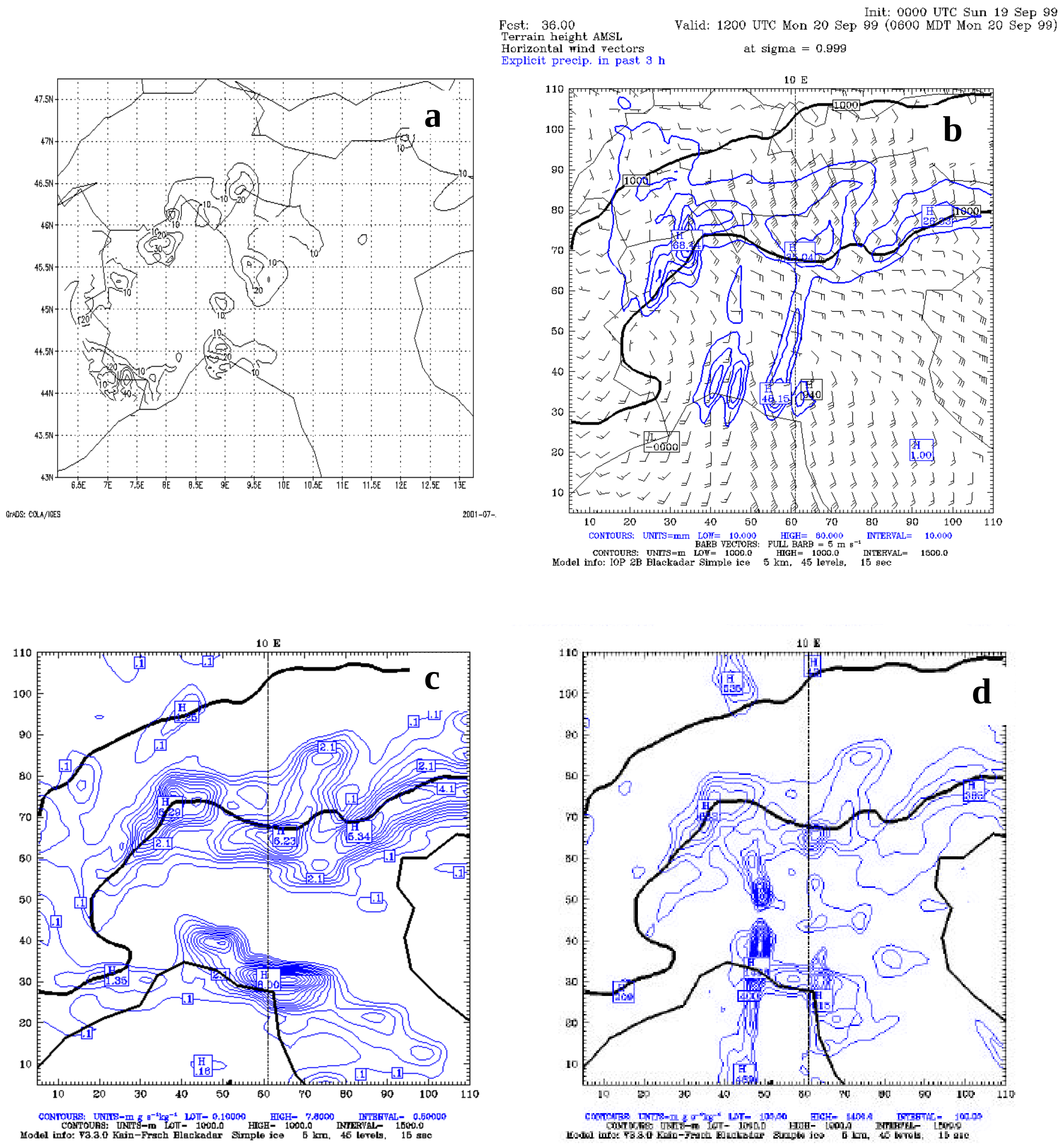

Fig. 1: (a) Observed 3-h rainfall (in mm) for 1999/9/20/12-15UTC during the MAP IOP2 heavy orographic rainfall event, (b) same as (a) except simulated by MM5, (c) the orographic moisture flux ($[\boldsymbol{V_H} \cdot \nabla h]q$) at 12UTC using MM5 predicted wind and oisture fields, and (d) same as (c) except for the general moisture flux (wq).

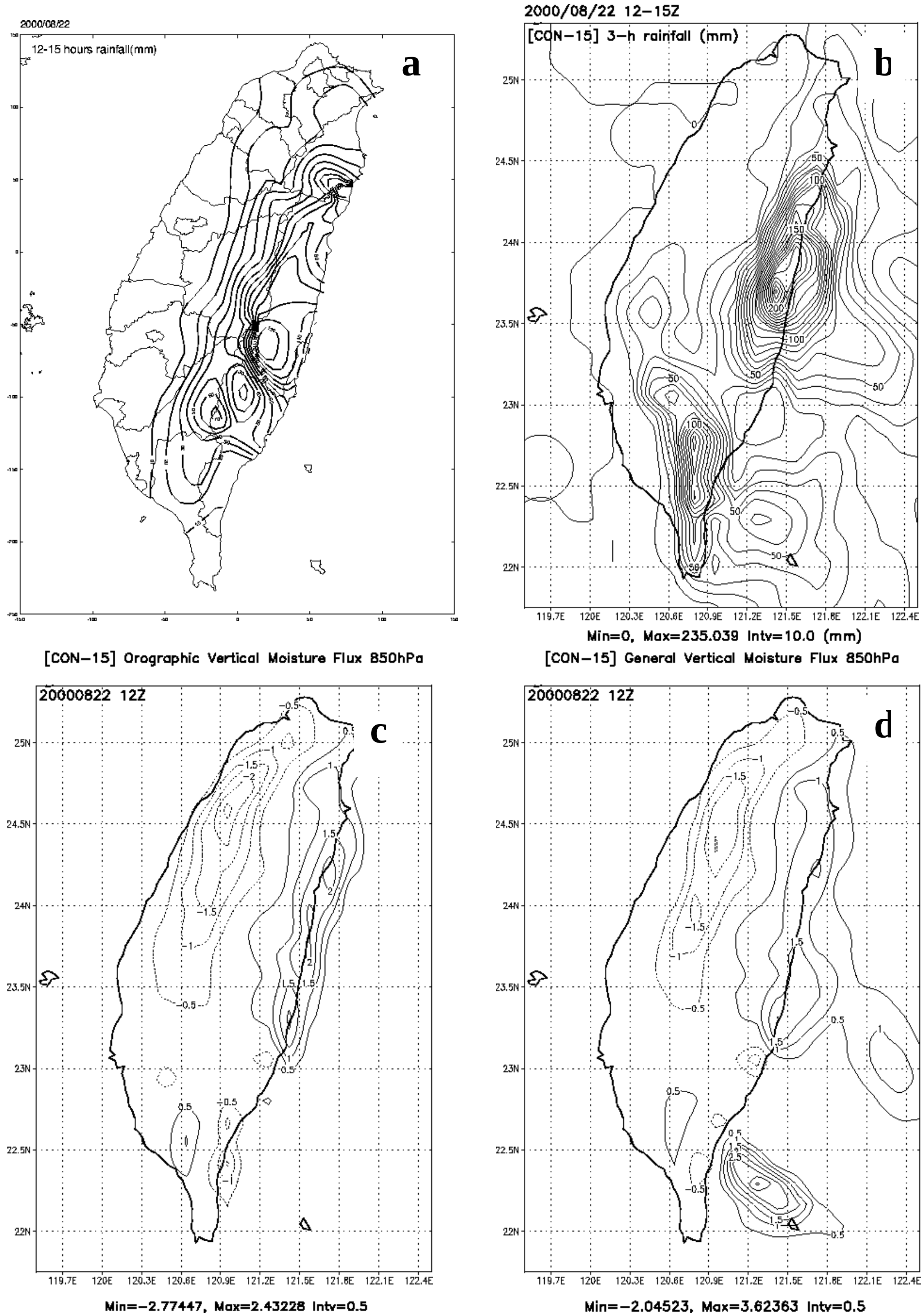

Fig. 2: (a) Observed 3-h rainfall (in mm) for the period of 2000/8/22/12-15UTC during the passage of Typhoon Bilis over Taiwan, (b) same as (a) except simulated by COAMPS, (c) the orographic moisture flux at 12UTC using COAMPS predicted wind and moisture fields, and (d) same as (c) except for the general moisture flux.