Improvement of MOS Procedure for Rainfall Prediction

KOJI NISHIYAMA
Faculty of Engineering, Kyushu University, Japan

YOSHITAKA I
Kumamoto Prefecture, Japan

KENJI JINNO
Faculty of Engineering, Kyushu University, Japan

AKIRA KAWAMURA
Faculty of Engineering, Kyushu University, Japan

ABSTRACT: In this study, paying much attention to notable features obtained from spatial distributions of strongly related indices with rainfall, the improvement of fatal problems in constructing MOS for rainfall prediction in a BAIU season were discussed. As a result, it should be noted that the existence of well-defined convergence in an area of widely-distributed large precipitable water provides a requirement for the formation of heavy rainfall. However, in spite of some findings of physically significant relationship between heavy rainfall and associated indices, it seems that many studies and associated rainfall prediction systems have constructed physically meaningless relationships. The reason was found to be due to the application of small sampling area of GPV grid scale to the construction of MOS. In this case, a requirement for the construction of physically desirable relationship will be the application of a lager sampling area to the construction of MOS.

1 INTRODUCTION

A variety of numerical weather prediction models used in many countries provide useful information for precipitation forecast. However, in spite of the development and improvement of the model, the accuracy of precipitation forecast has been strongly affected by systematic errors originating from relatively coarse resolution and physically complicated precipitation processes in the prediction models. Therefore, instead of direct application of output results of the model to the precipitation forecast, an alternative technique represented by MOS (Model Output Statistics) has been applied. MOS means downscaling of model outputs by relating it to observed data of a specific area using statistical techniques including multiple linear regression and neural network. Therefore, results of MOS provide useful guidance for many varieties of weather predictions.

In this study, paying much attention to notable features obtained from spatial distributions of strongly related indices (precipitable water, convergence of air, convective available potential energy) with rainfall using GPV (Grid Point Value) explained in the next section and radar-AMeDAS composite images corresponding to spatial distribution of actual precipitation, our objectives are (1) to conduct physically-based consideration on dominant indices related with heavy rainfall in a rainy season (BAIU) in Japan and (2) to review a crucial problem on conventional construction of a statistical relationship between rainfall data and associated indices, and (3) to suggest a method for the improvement of fatal problems in constructing MOS for rainfall prediction in a BAIU season.

2 OUTLINE OF AVAILABLE DATA SETS FOR ANALYSIS

1.1 Grid Point Value (GPV)

The GPV is three-dimensionally interpolated grid data, based on the sounding data set observed by meteorological balloons twice a day at the same time (00 UTC, 12 UTC) in the world and the other data sets (ground meteorological data, satellite data, e.g.). The GPV data is constructed by the assimilation of these observed data into three-dimensionally interpolated grid data set through the calibration using the predicted data by the numerical prediction model of Japan Meteorological Agency (JMA). In addition, the GPV is modified for satisfying some physical relationships included in an actual atmosphere represented by the specific mesh size of 20 km, which is taken for the construction of the GPV of the specific area including Japan. The GPV on the basis of the above-mentioned procedures consists of wind (velocity and direction), temperature, dew point depression, geo-potential height with the function of pressure. The structure of the GPV is represented by the horizontal mesh of 20 km and the irregular vertical meshes divided into 21 layers between the ground and 100 hPa level. The GPV is available for various purposes as well as an initial condition of the prediction model.

However, since the GPV strongly depends on predicted outputs by JMA model as mentioned in the previous paragraph, it is unavailable for the diagnosis of heavy rainfall or squall line if the predicted outputs give inconsistent results with actual observed facts. In addition, the GPV has a drawback that it is unavailable for finding good correspondence of indices with heavy rainfall excepting the designated times, 0900 and 2100 JST. Therefore, the GPV should be treated carefully for the analysis of heavy rainfall, paying much attention to the above-mentioned features.

1.2 Radar-AMeDAS Composite Precipitation

JMA has the observational network consisting of 19 weather radars and the ground observational meso-network in Japan, AMeDAS (Automated Meteorological Data Acquisition System), which has the averaging observational resolution of 17 km and consists of rainfall, wind, temperature, sunshine duration, at the interval of 10 min. The calibration of radar-observed precipitation data with AMeDAS raingauge data precipitation provides radar-AMeDAS composite precipitation, named, the spatial distribution of hourly precipitation with 5 km horizontal fine resolution. The radar-AMeDAS composite images are used for comparisons with spatial distributions of indices for the detection of heavy rainfall.

1.3 Indices of Heavy Rainfall

The convergence of air into a stationary BAIU front causes the simultaneous accumulation of large amount of water vapor and the continuous supply of the subsequent unstable condition. Here, CONV show the convergence of air. CONV is calculated from wind data at the designated pressure levels of the GPV. The relationship is given as the next equation.

$$CONV=\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y} \tag{1}$$

, where u is the western wind component and v southern wind component. The convergence of air containing large amount of water vapor in lower layers provides the chance to cause the generation of heavy rainfall through updraft due to convergence and the simultaneous increase in the instability of atmosphere due to the supply of large amount of water vapor.

Next, Precipitable Water (PW) is calculated by vertical integration of water vapor amount from 1000 hPa (P_0) to 100 hPa (P_T). The equation is given by

$$PW= \frac{1}{g}\int_{P_T}^{P_0} q\,dp \tag{2}$$

, where g is the gravitational acceleration, and q water vapor mixing ratio, and p atmospheric pressure. PW is an important indicator of atmospheric stability because the instability of atmosphere increases drastically if the supply of water vapor into a specific area is invigorated.

Finally, Convective Available Potential Energy (CAPE) shows the work done by positive buoyant force from Level of Free Convection (LFC) to equilibrium level corresponding to transition level from positive to negative buoyant force. In other words, CAPE is transferred into kinetic energy of convection, which shows the strength of a generated convective cloud. The equation is given by

$$CAPE = R_d \int_{p_{LFC}}^{p_{CT}} (T_p - T_e)\, d(\ln p) \qquad (3)$$

, where T_p is the temperature of air parcel lifted from the 1000 hPa (p_0) level and T_e the temperature of ambient atmosphere at the same pressure level as T_p and R_d the gas constant of dry air. P_{CT} and P_{LFC} show the pressure at the cloud top and at Level of Free Convection (LFC), respectively.

3 SPATIAL RELATIONSHIP BETWEEN THE INDICES AND RAINFALL

During a rainy season (BAIU) in Japan, many thunderstorms occur frequently and widely along a BAIU front, which maintains its strength and becomes stationary with repeating a slight movement along a latitudinal direction in the Japan Islands according to dynamical equilibrium between the 'warm' Pacific high pressure system and the 'cold' northern high pressure system. Heavy thunderstorms in this season occur as follows. Since supplied abundant warm and humid air continuously into the BAIU front from the south under the influence of Pacific high pressure contributes to the generation and maintenance of strong atmospheric instability as pointed out by Akiyama (1973). Consequently, heavy thunderstorms occur frequently along the BAIU front and cause serious disasters involving intense flood due to heavy rainfall, dangerous tornadoes, wind gusts with a downburst which occasionally contains hailstones, etc. This study provides some discussion on spatial distributions of strongly related indices with rainfall cases occurring on June 11 and 29, 1999, which are, hereafter, called case 1 and case 2, respectively.

The rainfall of case 1 occurred under active and stationary BAIU front over the western area of the Pacific Ocean, away from the Kyushu. On the other hand, in case of the rainfall of case 2, a small cyclone formed over the prevailing BAIU front in the East China Sea passed through the north side of the Northern Kyushu early in the morning, developing its strength. A squall line along a cold front extending toward the south-west from the cyclone could be confirmed in radar-AMeDAS precipitation images (see Fig. 1d). The squall line with the cold front went southward and led to heavy rainfall more than 70 mm/h at some observational points in Fukuoka and the subsequent urban flood damage including inundation due to internal runoff with strong wind gusts and two weak tornadoes.

In this section, the indices estimated from the GPV at 0900 JST in two rainfall cases are compared with heavy rainfall distribution at the same time. In general, since the indices of PW, CONV, CAPE strongly contributes to the development and maintenance of atmospheric instability, it is expected that these indices provides important information on the generation of heavy rainfall.

First of all, features of PW distributions are examined. The flow of a large amount of moisture along the Pacific high caused the formation of large PW as shown in Figs. 1b and 1e and wind field of Figs. 1c and 1f. However, remarkable feature of PW distribution is characterized by wide distribution of large PW. Therefore, the spatial distributions of PW show no suitability for specifying heavy rainfall area represented by rain-band appearing in the radar-AMeDAS composite images of Figs.1a and 1d.

In the next analysis, based on the observed fact that convectively active areas associated with propagating squall lines were located inside mesoscale regions of convergence with the magnitude of convergence reaching approximately $10^{-4}\,s^{-1}$ as shown by Fankhauser (1969, 1974), some features of spatial distributions (see Figs. 1c and 1f) of CONV at the 925 hPa pressure level are examined here. The area enclosed by dashed lines in the figures corresponds to the convectively dominant area with the magnitude of convergence more than $10^{-4}\,s^{-1}$. Therefore, the dominant convergence areas at the 925 hPa in both cases are approximately consistent with heavy rainfall area or close to rainfall area. These features give an indication for specifying the dominant area of heavy rainfall.

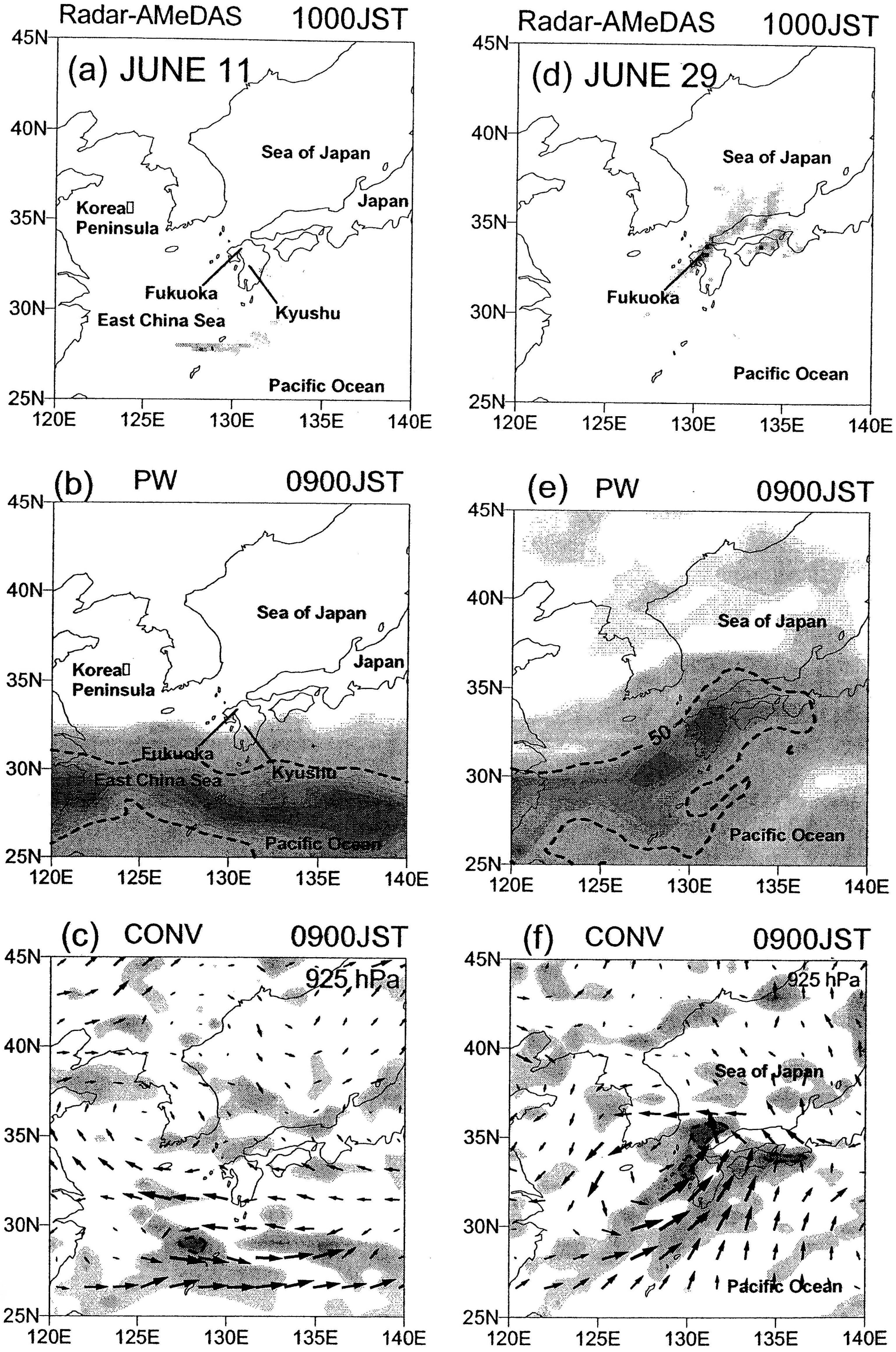

Fig. 1 Spatial distributions of Radar-AMeDAS precipitation and the corresponding indices (Precipitable Water, Convergence). The left and right figures indicate rainfall cases on June 11 and 29, respectively.

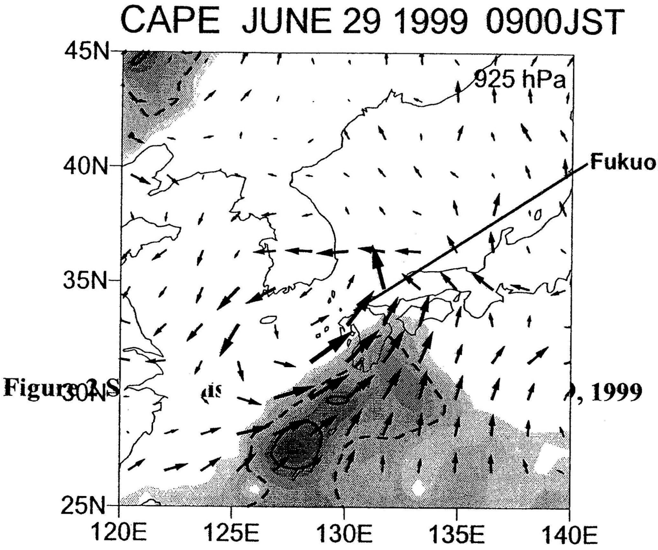

Fig. 2 Spatial distributions of CAPE on June 29, 1999

Finally, CAPE indicates the magnitude of the energy consumed for convection. In general, CAPE becomes large value before the formation of heavy rainfall and, on the other hand, small or zero value during the activity of heavy rainfall due to the reason that the generation of atmospheric instability due to large amount of water vapour into the squall line in a BAIU front is balanced with the release of the energy from unstable condition into neural one through the convective activity in the squall line as also shown in Ninomiya (2000). Therefore, the existence of dominant area of CAPE indicates the situation in which the energy is not released yet. Actually, as shown in Figs. 1d and 2, there were few heavy storms in the dominant area of CAPE, located to the south of the squall line and, on the other hand, in the squall line near the BAIU front, the values of CAPE indicate zero values, which show stable or neutral atmospheric condition. Therefore, CAPE over a squall line gives no direct information for the detection of heavy rainfall. From the above-mentioned complicated feature, CAPE is not used for the analysis of the next section.

4 CRUSIAL PROBLEM ON CONVENTIONAL METHOD AND ITS IMPROVEMENT

This section reviews a crucial problem on conventional method for constructing a statistical relationship between rainfall data and associated indices using physically significant indices of PW and CONV in the previous section. In general, prediction model indicates no accuracy of short term rainfall prediction. Therefore, in advance, it is important for useful guidance for rainfall prediction to select dominant indices related with observed rainfall on the basis of statistical and physical procedures, and to subsequently construct statistical relationship (MOS) by relating past many rainfall data with model-simulated outputs in a specific area using statistical techniques including multiple linear regression and neural network. However, it seems that there has been a crucial problem in constructing the MOS relationship. In general, for the construction of a statistically significant relationship between predicted outputs and observed precipitation, predictors are selected from model outputs obtained at a grid point closest to a specific observed point as shown in the methodology of Kurigowski et al. (1998) and Hall et al. (1999). In these cases, it would be quite difficult to select strongly related indices with observed precipitation because a spatial distribution of a strongly related index predicted by the model shows no consistency with that of actual precipitation. Thus, there will be a tendency that many of conventional statistical methods have related rainfall data with model-simulated outputs within a small grid scale. This methodology will provide physically meaningless relationships due to the selection of a small sampling area in spite of the fact that rainfall is strongly affected by the indices given here.

Therefore, the construction of physically and statistically desirable relationship will require the consideration of larger sampling area more than 20 km. In this study, for the improvement of the crucial problem, our study considers sampling area of 0.2 degrees equivalent to 20km, and the other larger sampling areas of 0.5 and 1.0 degrees, centering the GPV point nearest to Fukuoka city for detecting rainfall and indices in the Northern Kyushu in Japan as shown in Fig. 3. Triangles indicate radar-AMeDAS grid points. Circles indicate GPV points. In this case, PW is calculated from the GPV point nearest to Fukuoka and, on the other hand, CONV is selected as the maximum of three maximum values selected in three pressure levels (850, 900, 950 hPa) of lower layers in each sampling area. On the other hand, selected rainfall data is maximum hourly rainfall detected within 3 hours after the GPV times of 0900 and 2100JST in each sampling area.

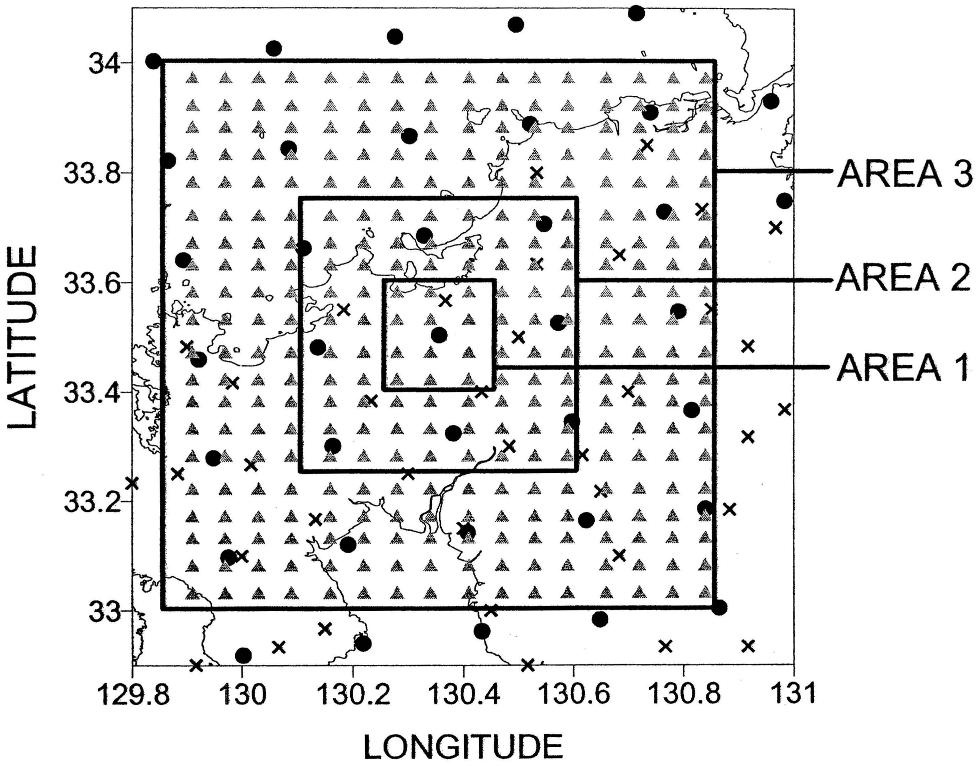

Fig. 3 Sampling area of 0.2 degrees (AREA 1) equivalent to 20km, and the other larger sampling areas of 0.5 (AREA 2) and 1.0 degrees (AREA 3). Green triangles indicate radar-AMeDAS grid points. Blue circles indicate GPV points. Cross marks indicate AMeDAS points.

Based on the procedure, dependence of PW and CONV on rainfall is investigated in each sampling area. Here, RADAR-AMeDAS rainfall data are categorized into 4 groups consisting of no rainfall (0 mm/h), light (1-10 mm/h), moderate (10-30 mm/h), and heavy rainfall (more than 30 mm/h). The group of no rainfall is compared with those of moderate and heavy rainfall, and, on the other hand, that of light rainfall. The results are shown in Fig. 4. The figure indicates the distributions of categorized rainfall groups plotted with PW and CONV. Any group shifts towards more convergence with an increase in a sampling area. In particular, the groups of moderate and heavy rainfall correspond to still more convergence related strongly with rainfall-inducing system in the larger sampling area 2 and 3. The still larger shifts, in other words, means the selection of a larger sampling area contributes to the detection of well-defined convergence zone related with heavy rainfall. Focusing on area 3, the group of heavy rainfall requires precipitable water more than 50mm and approximately half of the category correspond to convergence more than the magnitude of 10^{-4} s^{-1} and, therefore, the result provides physically significant relationship. On the other hand, the group of no rainfall distributes under the PW less than 40mm and the CONV less than that of 10^{-4} s^{-1}. Therefore, it can be confirmed that there is no overlap between 'no' rainfall and heavy rainfall. From these results, application of a lager sampling area to MOS will contribute to the construction of physically and statistically desirable relationship.

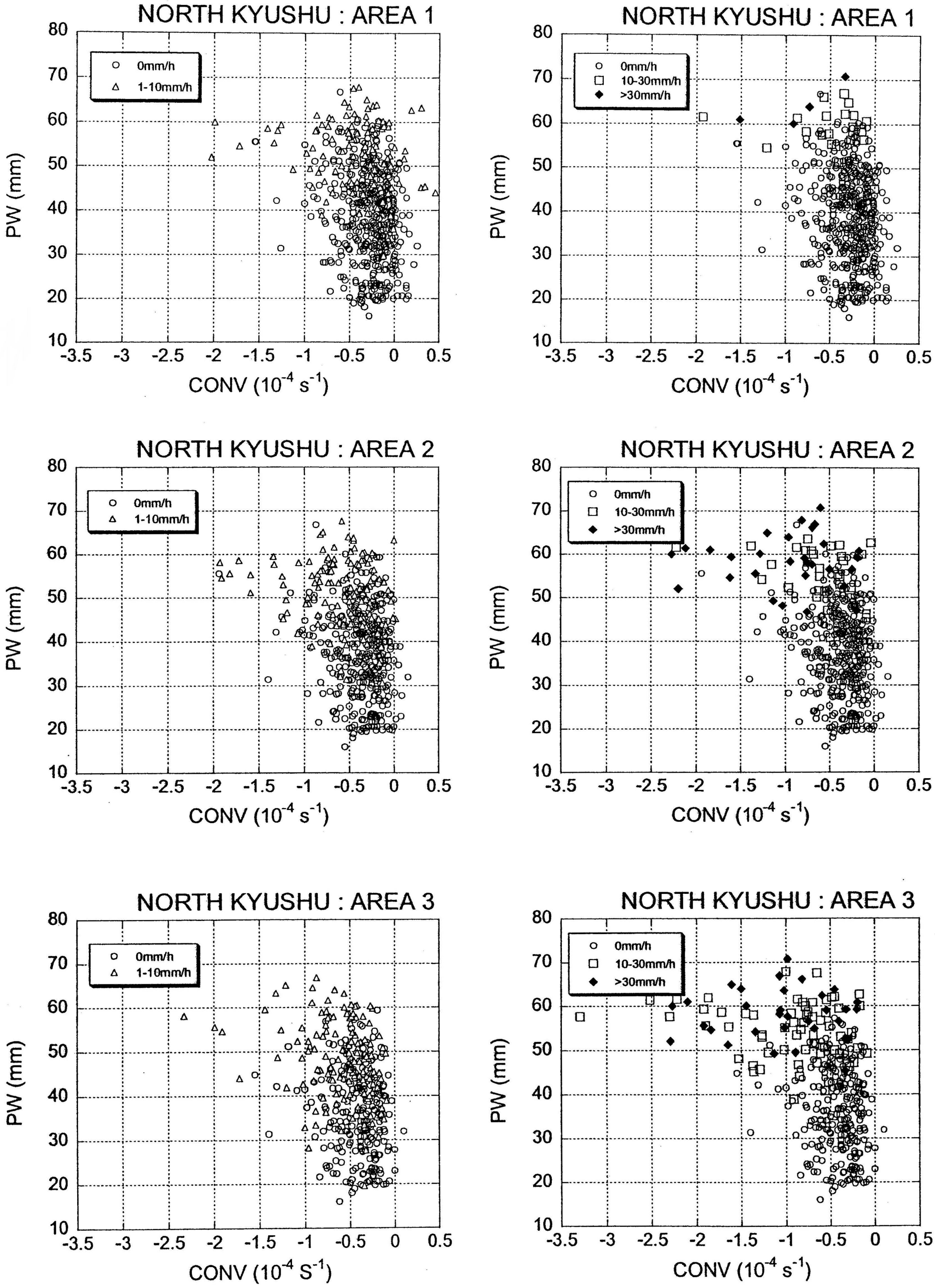

Fig. 4 The dependence of categorized rainfall groups on PW and CONV. 4 groups consist of no rainfall (0 mm/h), light (1-10 mm/h), moderate (10-30 mm/h), and heavy rainfall (more than 30 mm/h).

5 SUMMARY

A variety of numerical weather prediction models used in many countries provide useful information for precipitation forecast. However, the accuracy of the prediction has not reached practical level of quantitative prediction due to relatively coarse resolution and physically complicated precipitation processes in the prediction models. Therefore, the present weather prediction for providing useful precipitation guidance in many countries adopts an alternative technique represented by MOS (Model Output Statistics), which means downscaling method of prediction model outputs by relating it to observed data of a specific area using statistical techniques including multiple linear regression and neural network. In general, for the construction of a statistically significant relationship between predicted outputs and observed precipitation, predictors are selected from model outputs obtained at a grid point closest to a specific observed point. However, the MOS seems to contain some fatal problems in selecting strongly related indices with observed precipitation. Therefore, in this study, paying much attention to notable features obtained from spatial distributions of strongly related indices (precipitable water, convergence of air, convective available potential energy) with rainfall using GPV (Grid Point Value) explained in the next section and radar-AMeDAS composite images corresponding to spatial distribution of actual precipitation, our objectives are (1) to conduct physically-based consideration on dominant indices related with heavy rainfall in a rainy season (BAIU) in Japan and (2) to review a crucial problem on conventional construction of a statistical relationship between rainfall data and associated indices, and (3) to suggest a method for the improvement of fatal problems in constructing MOS for rainfall prediction in a BAIU season.

The existence of large PW provides a requirement for the formation of heavy rainfall. Well-defined CONV in the area affected by large PW provides significant information for specifying dominant area of heavy rainfall. CAPE gives no direct information for the detection of heavy rainfall. Therefore, heavy rainfall is strongly and directly affected by the combination of PW and CONV. These are important indices to be selected for heavy rainfall prediction. However, despite some findings of physically significant relationship between heavy rainfall and associated indices, it seems that many studies and associated rainfall prediction systems have constructed meaningless statistical and physical relationships by applying small sampling area of GPV grid scale to the construction of MOS. The reason was found to be due to the application of small sampling area of GPV grid scale to the construction of MOS. In this case, a requirement for the construction of physically desirable relationship will be application of a larger sampling area to the construction of MOS.

6 REFERENCES

Akiyama, T. (1973). The large-scale aspects of the characteristic features of the Baiu front. *Papers in Meteor and Geophys*. 24: 157-188.

Fankhauser, J. C. (1969). Convective processes resolved by a mesoscale rawinsonde network. *J. Appl. Meteorol.* 8: 778-798.

Fankhauser, J. C. (1974). The derivation of consistent field of wind and geopotential height from mesoscale rawinsonde data. *J. Appl. Meteorol.* 12:1330-1353.

Ninomiya, K. (2000). Large- and meso-α-scale characteristics of Meiyu and Baiu front associated with intense rainfalls in 1-10 July 1991, J. Met. Soc. Japan, 78: 141-157.

Hall, T and Brooks. H, E and Doswell, C. H. (1999). Precipitation forecasting using neural network. *Weather and Forecasting*. 14:338-345.

Kuligowski, R. J and Barros. A, P. (1998). Localized precipitation forecasts from a numerical weather prediction model using artificial neural network. *Weather and Forecasting*. 13:1194-1204.