International Conference on Hydroinformatics

2014

Study On Optimization Of The Integrated Operation Of Dams Using Ensemble Prediction

Satoru Oishi

Hiroko Masuda

STUDY ON OPTIMIZATION OF THE INTEGRATED OPERATION OF DAMS USING ENSEMBLE PREDICTION

SATORU OISHI (1) HIROKO MASUDA (2),
(1): Research Center for Urban Safety and Security, Kobe University, Japan
(2): Student of Graduate School of Engineering, Kobe University, Japan

Flood control is one of the most important issues of reservoir operation. Rivers in island countries like Japan, Philippines and Indonesia that have smaller reservoirs than continental countries needs short-term reservoir operation for flood control. In Japan, typhoons give dominant amount of water to reservoirs. Prior releasing of water that makes effective use of the capacity of a reservoir requires the forecast of rainfall amount (hyetograph). Therefore, weather forecast of typhoons is indispensable for flood control. Oishi and Masuda (2013) developed the reservoir control operation model using stochastic dynamic programming with one week ensemble weather forecast. One week ensemble forecast consists of 51 members, gives many kinds of weather variables including rainfall amount, has lead time of one week. In fact, frequency of updating one week ensemble forecast is a problem for using it.

In the present study, a solution for the problem is proposed. For giving highly frequent updating, we propose to use typhoon ensemble forecast which issues four times a day but it does not include rainfall amount. By using a similarity index with observed typhoon tracks and latest ensemble forecast result, a method to give typhoon ensemble reasonable forecasted rainfall amount has been developed.

INTRODUCTION

Flood control is one of the most important issues of reservoir operation. Rivers in island countries like Japan, Philippines and Indonesia that have smaller reservoirs than continental countries needs short-term reservoir operation for flood control. In Japan, typhoons give dominant amount of water to reservoirs. Prior releasing of water that makes effective use of the capacity of a reservoir requires the forecast of rainfall amount (hyetograph). Therefore, weather forecast of typhoons is indispensable for flood control. Oishi and Masuda (2013) developed the reservoir control operation model using stochastic dynamic programming (SDP) with one week ensemble weather forecast (WEP) made by weekly ensemble prediction system (WEPS) issued by Japan Meteorological Agency (JMA). WEP consists of 51 members, gives many kinds of weather variables including rainfall amount.

In fact, frequency of issuing WEP is daily which is less frequent than requirement and it raises a problem for using WEP. In the present study, a solution for the problem by using Typhoon

Ensemble Prediction (TEP) made by Typhoon Ensemble Prediction System (TEPS) issued by JMA is proposed.

EMSEMBLE PREDITION SYSTEMS

Weekly Ensemble Prediction System (WEPS) and Typhoon Ensemble Prediction System (TEPS)

Japan Meteorological Agency (JMA) makes WEPS once a day from March 2001 by using a kind of General Circulation Model (GCM). JMA makes WEPS from 21 Japan Standard Time (JST) which is Greenwich Mean Time (GMT) plus 9 hours and it issues WEPS at 4 JST after numerical calculation. WEPS contains 51 ensemble sets of prediction which has 6 hourly data, 9 days lead time, both longitudinal and latitudinal resolution of 1.25 degree and 4 vertical layers (surface, 925hPa, 850hPa, 700hPa and 500hPa). WEPS comprises physical variables as surface pressure, altitude, temperature, wind speed, wind direction, humidity and surface rainfall amount.

JMA also makes TEPS from February 2008. JMA makes TEPS when typhoons exist or a tropical cyclone forecasted to be a typhoon exists. For making TEPS, JMA uses the same numerical model as WEPS. JMA makes TEPS four times a day (03, 09, 15, 21 JST). TEPS contains 11 ensemble sets of prediction which has the position (longitude and latitude) and pressure of typhoon center and wind speed. By using TEPS, we can expect the following advantage; i) high frequency of TEPS reduces error of prediction; ii) prediction of typhoon track and its spread gives better reliability.

Uncertainty analysis of TEPS and WEPS

TEPS has uncertainty because of their limitation of measurement, initial condition setting and numerical specifications. Here, problem that comes from numerical simulation is described.

The disadvantage of TEPS is their limitation of predicting pressure of typhoon center. For predicting the pressure of typhoon center accurately, it requires 5km resolution of numerical simulation where as the GCM has 60km resolution. The limitation of numerical resolution gives higher pressure as a prediction than actual situation. Then, the wind speed also is predicted weaker than actual. Figure 1 shows the tendency of the prediction error which is defined with

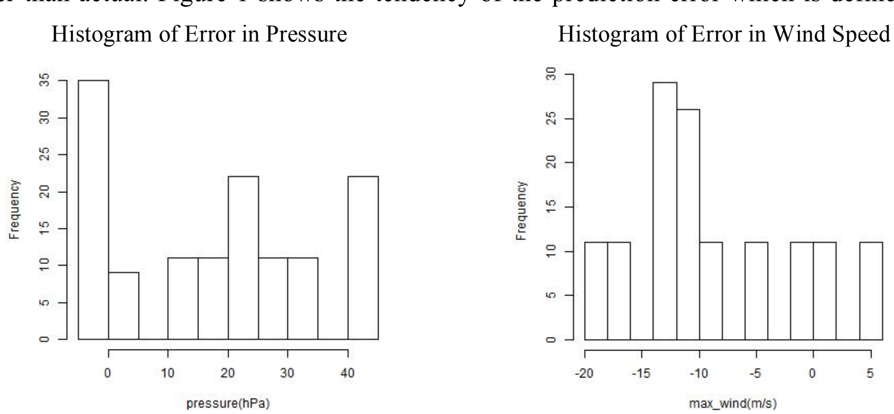

Figure 1. Tendency of the prediction error in pressure (left) and wind speed (right).

observation level from the predicted value. The figure shows that pressure is tend to be higher and the wind speed weaker in prediction.

As the purpose of ensemble numerical prediction, a WEPS has a range of predicted value which is called a "spread". Figure 2 and 3 show a better example and a worse example of the spread of rainfall amount, respectively. Figure 2 is the result of WEPS for Typhoon No.17 in 2012 (T1217), JELAWAT, and Figure 3 for Typhoon No. 09 in 2011, MUIFA. Both Figure 2 and 3 have horizontal axis showing time, and three vertical axes showing total amount of rainfall updating daily. A horizontal line shows the observed rainfall amount which is the correct value. Horizontal bars show the histogram of predicted amount of rainfall by WEPS. A set of horizontal bars starting from one vertical axis means a set of prediction spread obtained from a set of ensemble forecast issued daily. The bar graph in black color stretching downward from the horizontal arrow line in the lower part expresses hyetgraph. Figure 2 shows the reducing of uncertainty of prediction where the spread of left side of the figure is wide and one of the right side is sharp. Figure 3 shows the worst ensemble prediction among the present study which firstly gave lower amount of rainfall as forecast then prediction increased the amount of rainfall time by time and finally gave the over estimation.

COMBINING OF TEPS AND WEPS

Development of the combined model

In order to obtain more frequent ensemble rainfall forecast by using TEPS (4times a day), a model that combines TEPS and WEPS (once a day) has been developed. The concept of the combined model uses similarity of physical variables between TEPS and WEPS. Moreover rainfall amount of similar WEPS ensemble member is assigned to corresponding member of TEPS.

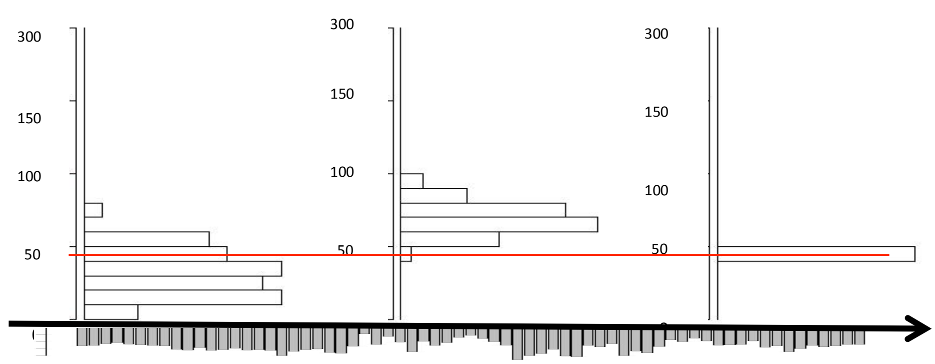

Figure 2. Transition of spread of WEPS for T1217; red line shows total amount of rainfall; three vertical axes show updating of WEPS and predicted rainfall amount; horizontal bars show histogram; vertical bar in gray color show hyetgraph.

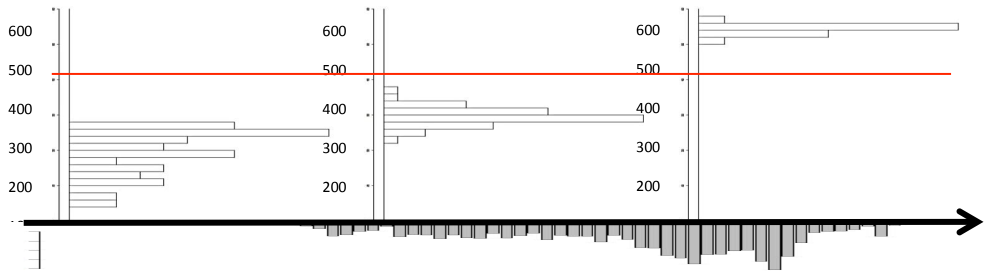

Figure 3. Same as Figure 2 but for T1109.

In order to measure the similarity, first, impact of each variables on forecasting rainfall amount has been analyzed by multiple regression analysis in which correlation among error of each predicted variable in WEPS such as rainfall amount at a target point as an explained variable, longitude and latitude of typhoon center, distance between typhoon center and target point, center pressure of the typhoon and wind speed as explaining variables. Table 1 shows results of multiple regressions. It shows that correlation coefficient R^2 were less than 0.5 in 2012 and 2013. It means some revision of WEPS has been accomplished and numerical ensemble prediction has been improved to have less correlation in errors of physical variables including rainfall amount. Even correlation coefficient were low, t-value of the error of pressure toward error of rainfall amount has significant value. Therefore, we are using pressure as an index of similarity. However, the track of the center of typhoons was thought to be an index of similarity, therefore, we are using distance as the other index of similarity. Finally, we proposed a couple of combined model of TEPS and WEPS by using similarity of distance which is called TEPS_WEPS(distance) model and using similarity of distance and pressure which is called TEPS_WEPS(distance, ps) model.

Figure 4 shows an example on T1217 where the forecast of WEPS was reasonable as shown on Figure 2. It shows the time series variation of observed rainfall shown as amedas, mean of WEPS forecasts, TEPS_WEPS(distance) model forecasts, TEPS_WEPS(distance, ps) model forecasts. According to Figure 4, these models gave reasonable forecasts. Figure 5 shows the other example on T1109 where the forecast of WEPS was not good as shown on Figure 3. When the WEPS was worse, the proposed model of TEPS_WEPS gave slightly better forecast.

Table 2 shows summary of the root mean square error (RMSE) of the forecast for all typhoon which the present study has dealt with. According to the Table 2, TEPS_WEPS (distance, ps) model gave smaller RMSE than WEPS in 7 out of 14 typhoons. Deeper analysis for T1106 and T1112 has been conducted because TEPS_WEPS (distance, ps) gave much bigger RMSE in these typhoons. It was rain in the southern part of Shikoku island where topography usually affects the rainfall distribution during passing of a typhoon. The model proposed in the present study did not take such a local topography into account. Then, the model gave worse forecast than WEPS model which took the topography into account. However, our target basin in the study was not in southern part of Shikoku island. Then, we can use the result of model with reasonable accuracy.

Table 1. Result of multiple regression among rainfall amount with the other physical variables,

	R^2	t-value				
(1day)		distance	latitude	longitude	pressure	wind speed
0918	0.20	0.71	-0.96	-1.31	6.00	2.61
1004	0.73	3.61	-1.40	3.35	-13.37	-0.167
1007	0.64	1.59	-7.46	6.65	9.63	6.06
1009	0.79	-5.88	-6.61	5.95	-14.65	-1.18
1109	0.68	-2.89	-4.98	0.75	5.74	-0.54
1115	0.74	-2.37	2.49	-4.62	1.06	-8.66
1204	0.03	1.03	-2.22	1.25	-0.85	-0.20
1210	0.24	3.91	0.25	-1.91	-4.30	-0.74
1215	0.47	1.22	-3.08	2.04	-10.28	0.88
1216	0.10	-3.83	3.36	-1.52	-2.74	-0.08
1217	0.20	1.52	1.77	-0.01	3.37	2.29
1304	0.38	1.23	5.67	-0.69	-6.19	-0.02

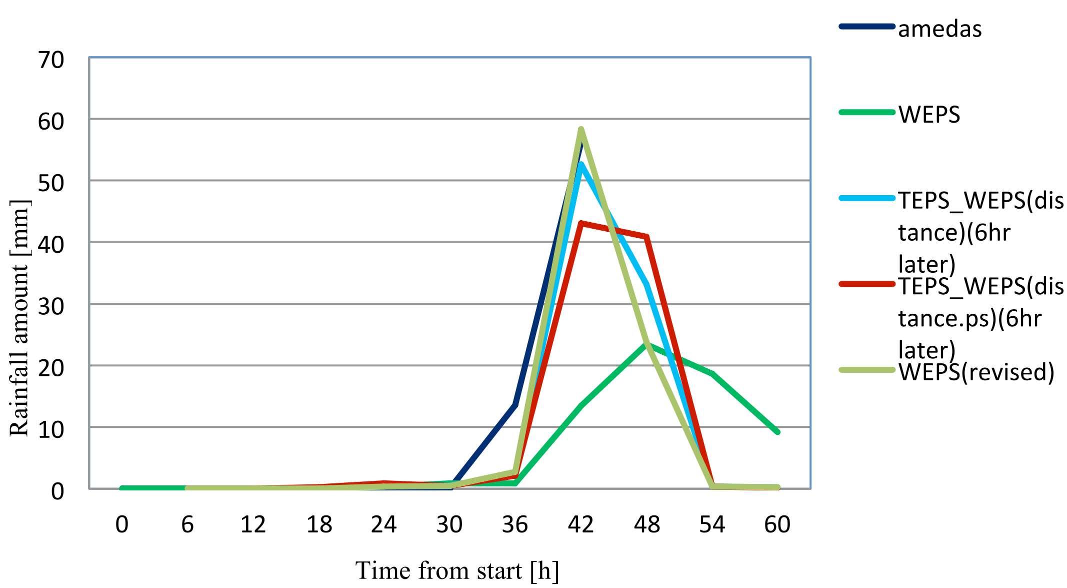

Figure 4. Result of observed (amedas) and forecasted (the other) amount of rainfall in case of T1217.

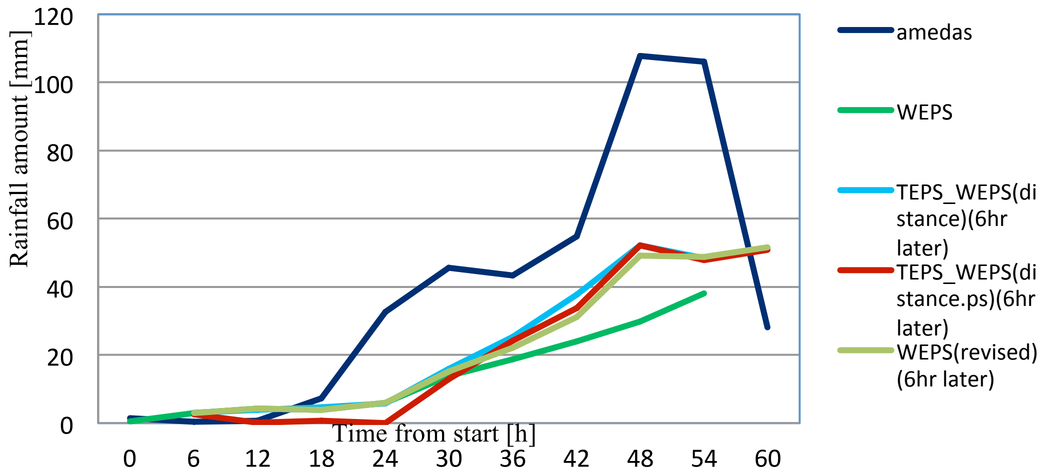

Figure 5. Same as Figure 4 but T1109.

Table 2 Root mean square error of rainfall forecast made by WEPS and models proposed,

RMSE (mm)	Available from 6hours later				Available from12hours later		
	WEPS	TEPS_WEPS (distance)	TEPS_WEPS (distance,ps)	WEPS (revised)	TEPS_WEPS (distance)	TEPS_WEPS (distance,ps)	WEPS (revised)
0918	18.9	9.1	9.6	8.7	9.9	8.3	8.0
1004	7.6	7.9	8.8	8.7	8.1	9.0	8.7
1007	13.6	15.4	10.4	10.0	7.4	10.0	10.0
1009	1.5	1.5	0.3	1.5	1.2	1.2	1.5
1106	34.0	33.1	32.8	33.0	33.1	33.1	33.2
1109	36.6	27.5	29.4	30.4	27.9	32.2	29.5
1112	45.3	46.2	45.8	45.7	45.8	45.0	45.6
1115	44.2	45.9	45.8	45.9	45.5	45.6	45.5
1204	33.1	23.3	24.4	24.6	23.2	20.1	24.6
1210	7.5	8.8	9.1	10.4	9.7	9.5	10.4
1215	9.5	13.3	14.6	13.7	13.8	13.6	13.6
1216	11.2	9.6	6.0	8.3	4.3	5.5	8.8
1217	16.8	4.5	7.1	4.2	4.7	6.7	4.2
1304	2.5	1.4	1.7	1.9	1.9	2.3	2.1
total	16.9	14.8	11.5	14.0	14.3	11.3	13.9

APPLICATION OF TEPS_WEPS MODEL TO RESERVOIR OPERATION

Stochastic DP

The present study have applied the result of the model proposed to the same reservoir operation by using the same Dynamic Programming (DP) and Stochastic DP (SDP) as Oishi and Masuda (2013). The target typhoon and target basin was the same as the literature mentioned above. The difference from the literature was that the present study additionally applies ensemble set of TEPS_WEPS(distance) and TEPS_WEPS(distance ps) for DP .

Result and discussion

The result is shown in Table 3 as damage function which gives smaller amount as better operation. Table 3 shows that the best operation has been done by using DP with perfect forecast and the second best was SDP by using all ensemble members of WEPS. TEPS_WEPS(distance) gave slightly worse result than DP by using ensemble mean.

Table 3 Result of DP and SDP using WEPS and TEPS_WEPS models with damage function,

	Damage function using in DP		Damage function using in DP
Ad hoc operation actually conducted	5.00	TEPS_WEPS (distance) DP	2.39
Operation under flood control rules regulated in dam operation manual	6.13	TEPS_WEPS(distance)DP(revised)	2.47
DP with perfect forecast	2.24	TEPS_WEPS (distance, ps) DP	2.41
SDP with WEPS	2.31	TEPS_WEPS(disatance, ps)DP(revised)	2.41
DP with Ensemble mean of WEPS	2.34		

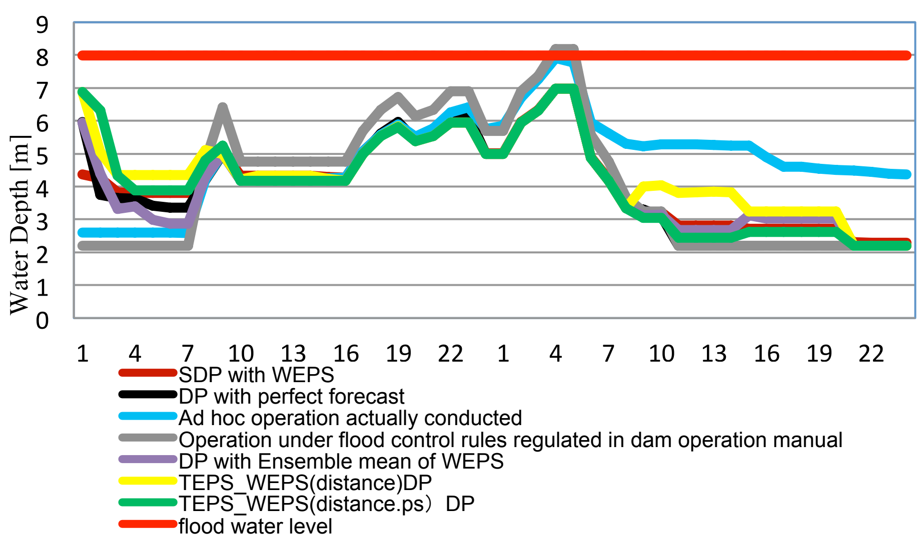

Figure 6. Water level at the evaluating point in the river; red horizontal line shows design flood.

Figure 6 shows the water level at a point at which the river authority evaluates the river water level for flood control. Figure 6 consists of various result in which red horizontal line was design flood water level, gray, the result of operation under flood control rules regulated in dam operation manual, light blue, one of ad hoc operation taken by the dam integrated management offices and ones of SDP and DP by using WEPS, TEPS_WEPS model. The figure shows that cities might suffer flood when they conducted operation under flood control rules regulated in dam operation manual and that ad hoc operation which was actually conducted by the dam integrated management offices prevented cities from severe damage by flood. Moreover, the SDP and DP by using WEPS as well as the proposed method would give safe margin of 1.2m of water level. Unfortunately, the present study did not improve flood control by proposing TEPS_WEPS models. However, TEPS_WEPS model gave more frequent updating the forecast without reducing the accuracy.

These appropriate operation made by SDP and DP by using WEPS and TEPS_WEPS models comes from the prior releasing of stored water from reservoir which depends on the forecasted amount of water exceeding the dam capacity. Then, the reservoirs had enough space to store flood.

CONCLUSION

In the present study, the authors proposed a method which gives highly frequent prediction of rainfall amount when typhoon comes. The method was named as TEPS_WEPS model and they combined the results of weekly ensemble prediction system (WEPS) and typhoon ensemble prediction system (TEPS). The TEPS_WEPS models produced reasonable forecast of rainfall amount with 6 hours updating frequency where as WEPS is updated every day.

The TEPS_WEPS models have been applied the same typhoon event as Oishi and Masuda (2013) has dealt with. TEPS_WEPS models reduced water level by 1.2m from operation under flood control rules regulated in dam operation manual and 0.9m from ad hoc operation actually conducted by he dam integrated management offices.

These results show the efficiency of the models proposed in the present study. For better understanding of the advantage and disadvantage of the model proposed in the present study, application of the model into several typhoon events are needed.

REFERENCES

[1] Oishi S and Masuda H., "Study on Optimization of the Integrated Dam Operation using Ensemble Prediction in the Upper Reaches of the Nabari River", Proceedings of 35th IAHR World Congress , IAHR, (2013).