Interesting StatisticalCharacteristics of Precipitation Extremes in Major River Basins of Japan using a Large Ensemble of Climate Simulations “d4PDF”

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Climate change impact has recently attracted strong public attention whenever severe water-related disaster occurs. Generally, very infrequent events such as the ones which occur once in 100 years are estimated based on the extreme value theory with the sample of annual maximum series(AMS) or peaks over threshold (POT). In this study,the relationship between basic statistical characteristics of extremes and probability distribution functionis focused. Usually AMS of extremeshave wide range of variety and one has to conduct frequency analysis on each data set for estimating extrapolating extremes. The Gumbel distribution is a two-parameter distribution and the parameters are closely related with the basic statistics; mean and variance. The characteristics of mean and variance are examined for the past and the future experiments of “Database for Policy Decision-Making for Future Climate Change” (d4PDF) in major six river basins in Japan. The d4PDF is a large ensemble of climate simulations with 20 km grid size. The past experiment consists of 50 ensembles of 60 years and the future of 90 ensembles of 60 years. As a result, it is found that the 100-year return level and ensemble mean of AMS in the investigated river basins are distributed along a regression line with errors of a rather limited range.Then, we can use this relationship in estimation of return levels without conducting frequency analysis. Further, this relationships between return level and the mean of AMS for different durations are on the same regression line. This relationship also provides a hint of bias correction of “ensemble climatic data” such as d4PDF.

Keywords—climate change; d4PDF; precipitation extreme

I. INTRODUCTION

There have been recently occurred many flood and sediment disasters which have caused people pain long after hazards settled. And also few media have reported without “record breaking“ and relationship with climate change impact. Since IPCC AR5 [1] has warned as “Extreme precipitation events over most of the mid-latitude land masses and over wet tropical regions will very likely become more intense and more frequent,” it has been getting more concern than ever and many reports on the possibility of huge disaster occurrence.

Floods and debris flow disasters are caused by extreme rainfall. A large ensemble of climate simulations with a 60 km atmospheric general circulation model and dynamical downscaling with a 20 km regional climate model have been performed to obtain probabilistic future projections of low-frequency local-scale events. The simulation outputs are available as “Database for Policy Decision-Making for Future Climate Change” (d4PDF) [2], which is intended to be utilized for impact assessment studies and adaptation planning for global warming. In this study, extreme precipitations in the major six river basins are investigated in terms of statistic characteristics and rare events such as 100 year return levels as well as future change.

II. USED DATA

The d4PDF consists of two kind of grid spacing, that is , 60km and 20km. The latter is regional downscaling simulations covering the Japan area by a regional climate model (RCM). The RCM used in this study are historical climate simulation: (1951-2010, 50 ensemble members) and future climate simulation: (2051-2110, 90 ensemble members). The future 90 ensemble members consists of 6 kinds 15 members simulations corresponding to different climatological SST warming patterns such as CCSM4, GFDL-CM3, HadGEM2-AO, MIROC5, MPI-ESM-MR, MRI-CGCM3 (CC, GF, HA, MI, MP, MR, respectively). With daily precipitation of 99 grids in the major six river basins; Tone, Ara, Kiso, Nagara, Shonai and Yodo in Fig. 1, daily, 2-day and 3-day annual maximum precipitations are extracted.

III. Method of Frequency Analysis

In estimating very infrequent extreme events, it has been applied extreme value distributions [3], [4]. Generalized Extreme Value distribution (GEV) is used for block maxima while Generalized Pareto distribution (GP) for Peaks Over Threshold. Both GEV and GP are three-parameter distributions but become two-parameter distributions, Gumbel and Exponential distributions when their shape parameter are zero, respectively. When dealing with block maxima, the simplest one is Gumbel distribution which has two parameters closely related to the statistics of block maxima.

When the cumulative distribution function $F(x)$ of Gumbel distribution is expressed by (1) with variable x,

$$F(x) = \exp\left\{-\exp\left(-\frac{x-\xi}{\alpha}\right)\right\} \quad (1)$$

the location parameter ξ and shape parameter α have following relationships (2) with the mean μ and standard deviation σ of the block maxima sample.

$$\alpha = \frac{\sqrt{6}}{\pi}\sigma \ ,\xi = \mu - 0.5772\alpha \quad (2)$$

After α and ξ determined, one can estimate nonexceedance

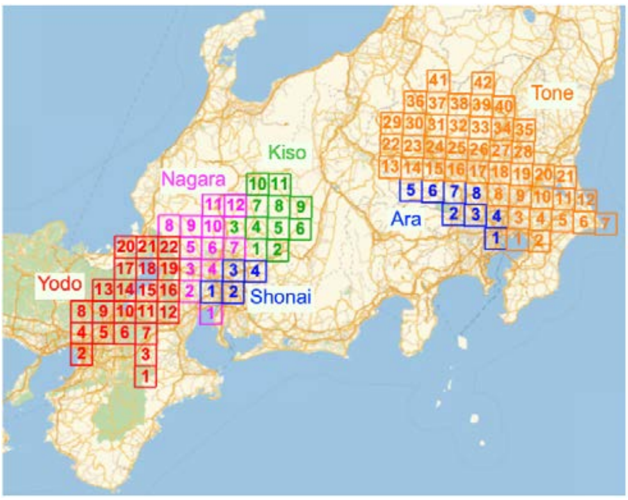

Fig. 1. Locations of Target six Major River Basins in Japan

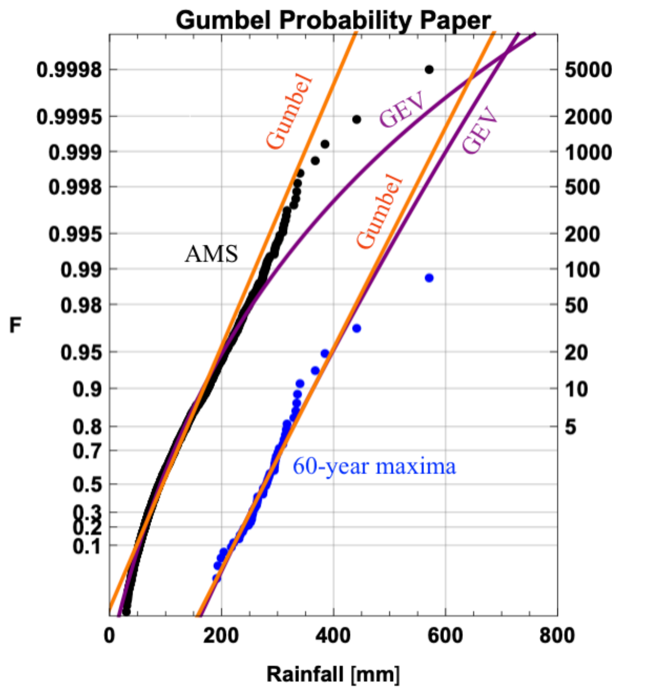

Fig. 2. Comparison of Probability plots and fits of AMS (Black) with 60-year maxima (Blue)

probability$F$ and return period, or return level with (3).

$$x = \xi - \alpha \log\{-\log(F)\} \quad (3)$$

A. Block Size of Block Maxima

While one has to select block size in applying block maxima, AMS which is a kind of block maxima with a year as a block, has been conventionally used widely without careful examination. The d4PDF is a huge database which has 50 or 15 ensemble members of 60 years simulations. If we deal with the database as a serial simulation, we have 3,000 years AMS for the historical climate simulation and 900 years AMS for the future one. On the other hand, if we take a 60-year period as a block, we have 50 “60-year maxima.” Anyway, if a sample come from a population of Gumbel distribution, the probability plots fall on a straight line on the Gumbel probability paper. Further, different block sizes yield different location parameters but the same scale parameters. Fig. 2 compares AMS plot and 60-year maxima one. In the AMS plot, the lower part looks different from upper part. At the height of 100-year return period, plotted points show different return level from both of Gumbel distribution and GEV. In this AMS, that data less than 90 mm occupy a half of the whole sample and show different tendency with upper part might be a reason of the disagreement. On the other hand, the 60-year maxima plot at which F=0.4 corresponds to 100-year return period agrees with both distributions well. In this example, the scale parameters are different from each other. Based on this difference, 60-year maxima is used for estimating 100 year return level in this study. Still, AMS is important in practical situation, the relationship between AMS and 60-year maxima will be prepared.

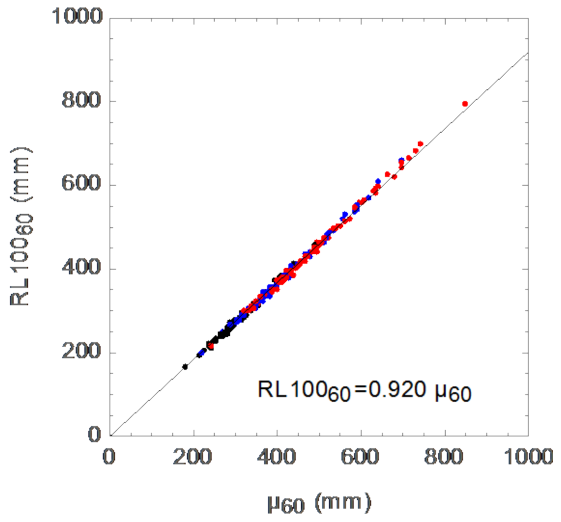

Fig. 3. Relationship between 100-year Return Level and Ensemble Mean of 60-year Maxima for 1(Black),2(Blue) and 3(Red) day Precipitation at 6 River Basins

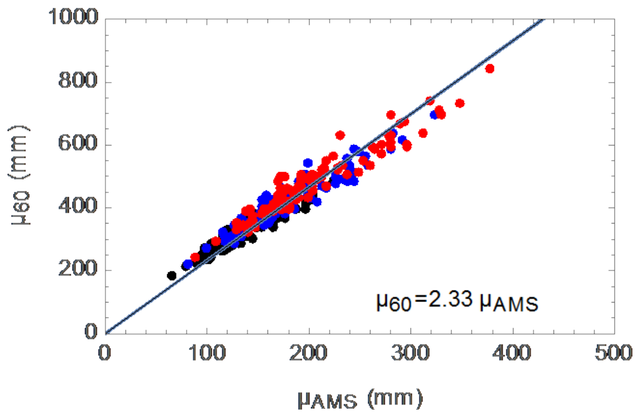

Fig. 4. Relationship between Ensemble Mean of 60-year Maximum Series and that of AMS for 1(Black),2(Blue) and 3(Red) day Precipitation at 6 River Basins

IV. RESULT

In this section, the result with the historical climate simulations(past) is shown first, and then that of the future one, finally, bridge information between past and future.

A. Relationship between 100-year Return Level and Ensemble Mean of 60-year Maxima (Past)

Fig. 3 shows the relationship between 100-year return level and ensemble mean of 60-year maxima precipitation. It includes plots for each grid of six river basins and durations such as 1, 2 and 3 day. It is very interesting that all plots are almost on a single straight line. It shows that we can tell a 100-year return level of any duration at any grid in any river basin examined here with just ensemble mean of 60-year maxima regardless of grid location and duration.

B. Relationship between Ensemble Mean of 60-year Maxima and that of AMS(Past)

Fig. 4 shows the relationship between ensemble mean of 60-year maxima and that of AMS including plots for each grid of six river basins and durations. The plots are almost distributed around the regression line but rather fluctuating. However, it shows very solid relationship tendency. Using Fig. 3 and 4, you can tell 100-year return level with just ensemble mean of AMS regardless of grid location and precipitation duration. If necessary, it is possible to prepare it for each location against each river basin with each detailed information. Fig.5 shows the same relationship for respective basin. In Ara, Shounai and Yodo river basins, fluctuations are relatively small. But Tone river basin which is the largest one and showing rather wide fluctuations needs further investigation.

C. Relationship between Ensemble Mean of 2-day and daily Annual Maximum Precipitation at each River Basin(Past)

In above results, plots of 1-, 2- and 3-day precipitation always combined in to a diagram. It is valuable if there are some good relationship between daily and 2-day precipitation. Fig. 6 shows this relationship using ensemble mean for each river basin. While regression lines are different from basins, they fit very well. Fig. 7 shows the relationship between the ratio of 2-day precipitation to daily and the ratio of 3-day precipitation to daily. Using above mentioned relationships, once get the information of AMS daily precipitation, one can reach to 100-year return level of any of daily, 2-day and 3-day precipitations by way of estimating 60-year maxima.

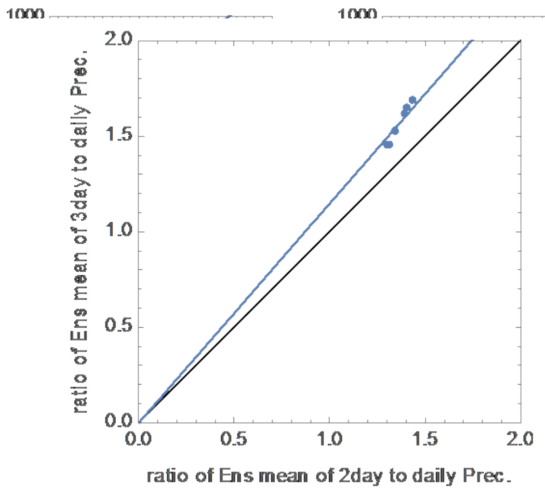

Fig. 7. Relationship between Ensemble Mean of 60-year Maximum Series and that of AMS for 1-(Black),2-(Blue) and 3-day(Red) Precipitation at 6 River Basins

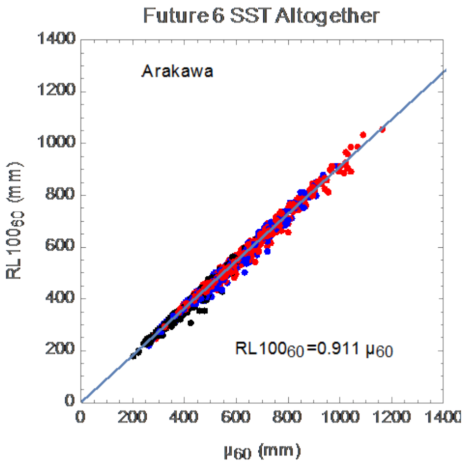

Fig. 8. Relationship between 100-year Return Level and Ensemble Mean of 60-year Maxima for 1-(Black),2-(Blue) and 3-day(Red) Precipitation at 6 River Basins for 6 SST Pattern Altogether

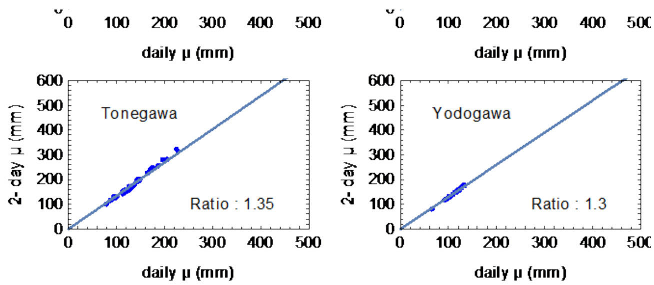

Fig. 6. Relationship between Ensemble Mean of 60-year Maximum Series and that of AMS for 1-(Black),2-(Blue) and 3-day(Red) Precipitation at 6 River Basins

Next, the relationship in the future climate simulations is investigated.

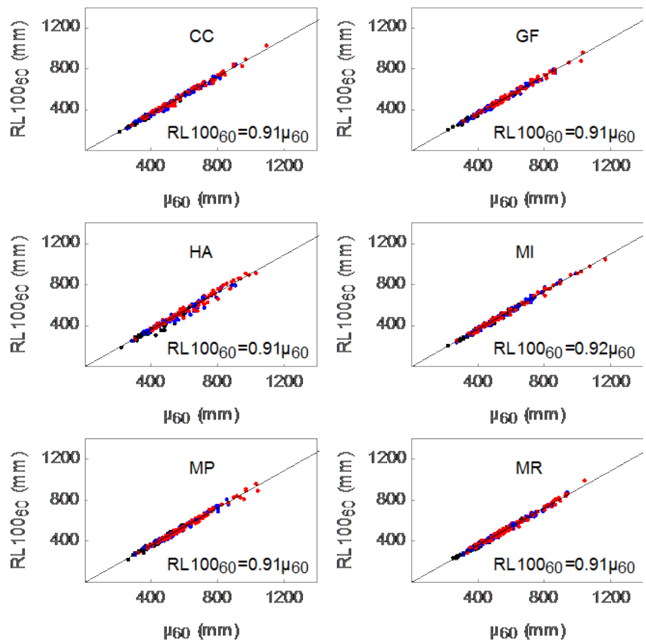

Fig. 9. Relationship between 100-year Return Level and Ensemble Mean of 60-year Maxima for 1(Black),2(Blue) and 3(Red) day Precipitation at 6 River Basins for each SST Pattern

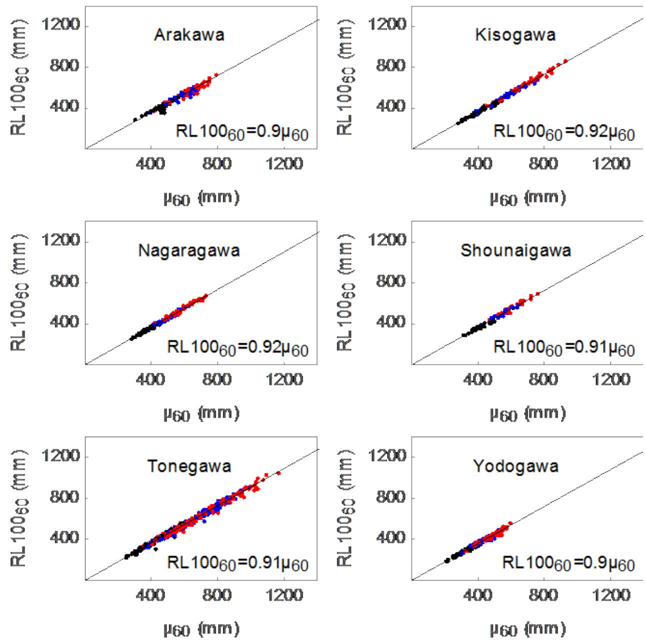

Fig. 10. Relationship between 100-year Return Level and Ensemble Mean of 60-year Maxima for 1(Black),2(Blue) and 3(Red) day Precipitation of all SST Pattern for each River Basins

D. Relationship of 100-year Return Level with Ensemble Mean of 60-year Maxima(Future)

Fig. 8 shows the relationship of 100-year return level with ensemble mean of 60-year maxima. The future climate simulations consist of six kinds SST patterns. In this figure, all result of six SST patterns are joined altogether. The most scattering are in Tone river basin. While the plots become rather scattered, plot tendency is similar to the past experiment

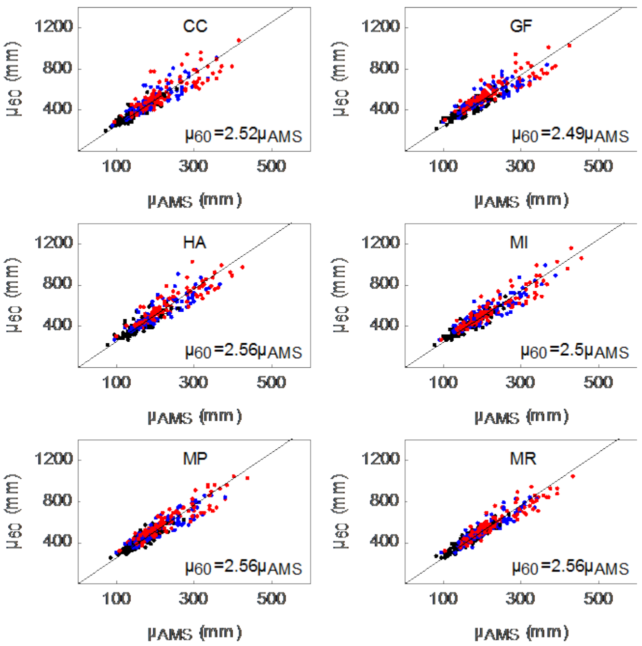

Fig. 11. Relationship between Ensemble Mean of 60-year Maxima and that of AMS of 1(Black),2(Blue) and 3(Red) day Precipitation in 6 River Basins for each SST pattern (Future)

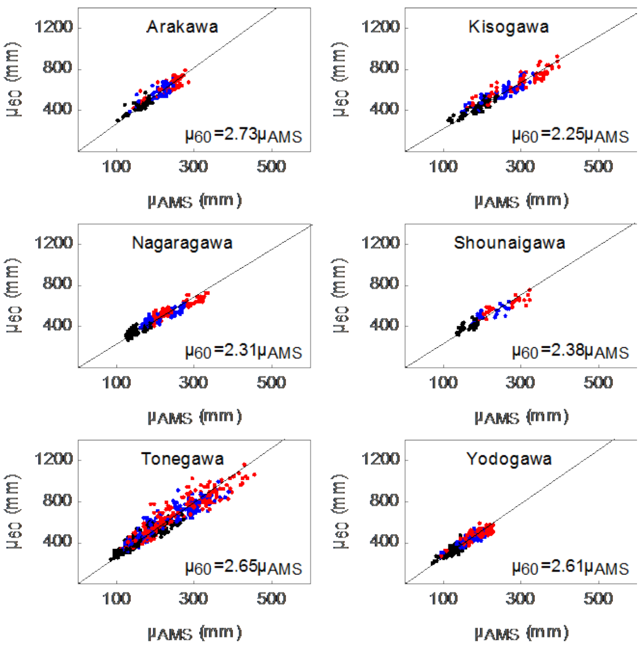

Fig. 12. Relationship between Ensemble Mean of 60-year Maxima and that of AMS of 1(Black),2(Blue) and 3(Red) day Precipitation of all SST Pattern for each River Basins (Future)

and the slope of regression line is very similar to the past one. In order to examine this relationship for each SST pattern, see Fig. 9. Among six SST patterns, MI has the least error while it includes the deepest 3-day precipitation. On the other hand, HA has the largest error. The extent of scattering depends on the SST pattern but the regression lines have similar slopes. Fig. 10 shows similar diagram to Fig. 9 basin by basin. You can see Tone has many plots ranging widely. However, Ara has fewer plots than Tone but scattering situation is similar to

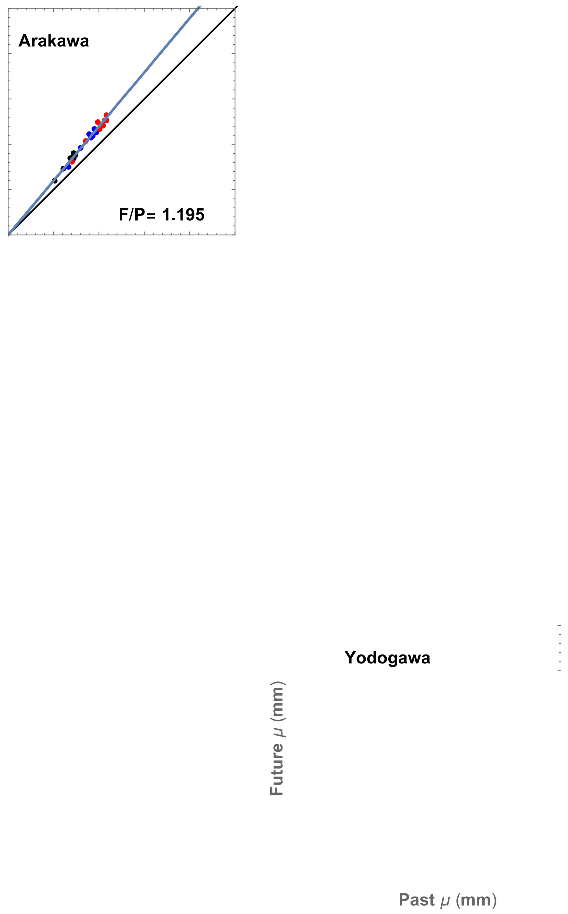

Fig. 13. Relationship between Ensemble Mean of AMS in Future and that of Past of 1(Black), 2(Blue) and 3(Red) day Precipitation (Mean of all SST Pattern for each River Basins)

Tone. The regression slope at each basin depends on river basin.

E. Relationship between Ensemble Mean of 60-year Maxima and mean of AMS(Future)

Fig. 11 shows relationship between ensemble mean of 60-year maxima and mean of AMS of 1- (Black), 2- (Blue) and 3-day (Red) precipitation in 6 River Basins for each SST pattern. All SST patterns shows slope of regression line of about 2.5 but with large errors. MI has the least errors among six SST patterns.

Fig. 12 shows the same data as Fig. 11 basin by basin. You can see each river basin has rather different regression slope and in Nagara, Shonai and Yodo, plots are relatively close to the regression line but the other basins have rather large errors especially in Tones river basin. These diagrams are enough to grasp overall characteristics but seem not sufficient to know the value corresponding to the ensemble mean of 60-year maxima. In order to do so, we have to prepare translation tables.

F. Relationship between Ensemble Mean of AMS in Future and that of Past of 1(Black), 2(Blue) and 3(Red) day Precipitation (Mean of all SST Pattern for each River Basins)

After looking at the characteristics of the past climate simulations and the future climate simulations, finally, we need a bridge between the past climate and the future climate. While the 60-year maxima have solid relationship with 100-year return level, the 60-year maxima are not so popular and the characteristics not well-known. In contrast, AMS is widely used and people has common knowledge about AMS including magnitude of it. Fig. 13 shows the relationship between ensemble mean of AMS in future and that of the past for each River Basins. The ratios of the future to the past of them are different from river basins and range from 1.1 to 1.2 with the average at 1.16. In Kiso, Nagara and Tone, you may need more detailed translation information.

V. Discussion

In the previous section, various statistics relating to 100-year return level are investigated. Fig. 14 shows relationships connecting them each other. Suppose that you have a mean value of AMS of some location of this area in the past and wants to know 100-year return level of 2-day precipitation, you can proceed with Fig. 6, then Fig. 4 and 5, finally Fig. 3. If you happen to know 60-year maxima, then use just Fig. 3 which has very solid relationship to 100-year return level. For the future climate, Fig. 13 can be a bridge between the past and the future, then just same manner needed. When you want to know about the future extremes, you have to recognize there are rather large uncertainty, especially, in relationship between 100-year return level and AMS.

It is amazing that the relationships between 100-year return level and ensemble mean of 60-year maxima in the past (Fig. 3) and the future (Fig.8) are very close even their range is much different. It impliesthat the structure of extremes might be kept even in the future.

Facing recent huge water-related disasters one after another, increasing magnitude of possible hazard has been worried about. For the future risk management, frequency analysis with just observed data is not useful. The extremes from the future projections such the ones used in this study are important. However, most projections usually contain "bias" which is necessary to be removed. When the simulation is just one case, the result can be compared to the observation. With many simulation ensemble members, however, it is difficult to compare them with the observation. Fig. 3 indicates mean 60-year maxima and 100-year return level havevery close connection with a single simple formula over rather large area. Hence, it is important to prepare statistics of observed extremes similar to Fig. 3. It can be a weak but robust backbone of bias correction.

VI. Conclusion

The author has interested in frequency analysis and trend analysis of recent precipitation which cause water-related disasters. Many researchers in the field of climate change impact assessment have been tackled with bias correction [5],

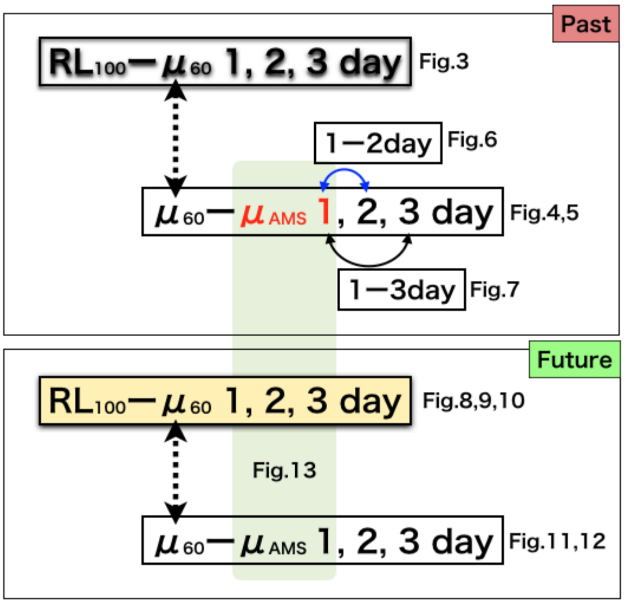

Fig. 14. Relationship among statistic characteristics connecting 100-year return level

[6]. With the advent of huge ensemble database such as d4PDF, condition of bias recognition is so much different. Before that, such as quantile mapping correction method had been widely applied in bias correction. However, after the advent, it looks as if we lost the compass of this field. In this situation, the information as Fig. 3 might be a new light on this problem.

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