Journal of Japan Society of Civil Engineers, Ser.
B1 (Hydraulic Engineering), Vol. 68, No. 4, I_163-I_168, 2012.

INCREASE IN SIMPLE PRECIPITATION INTENSITY INDEX IN PANAMA

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The paper describes trends in climate change indices in the Republic of Panama by using long-term meteorological data sets from the Panama Canal and MRI-AGCM. Simple precipitation intensity index from eleven climate change indices shows the same trend, increasing at six meteorological stations around the Panama Canal. Forward projection (from 2080 to 2099) was carried out by using MRI-AGCM3.1S and 3.2S, which demonstrates an increase in simple precipitation intensity index in the entire area of Panama. The increase in simple precipitation intensity index may suggest that stronger precipitation will occur more frequently in the future in Panama.

Key Words **:** *SDII, Central America, MRI-AGCM, Mann-Kendall, projection, bias correction*

1. INTRODUCTION

The Republic of Panama, located in Central America, separates the Atlantic and Pacific Oceans by between one and a few hundred kilometers. Due to the varying distance from these oceans, Panama has a variety of meteorological conditions, which are advantageous for analyzing the influence of climate change on the subtropical environment. Moreover, Panama plays an important role in the international maritime trade due to Panama Canal, which is about 80 km in length.

The canal was opened in 1914, joining the Atlantic and Pacific Oceans, and has played a great role in the international maritime trade. The world's other significant canal, the Suez Canal, is different from the Panama Canal system as the former is an artificial sea-level waterway, while the latter consists of artificial lakes used as a channel for ship's passage. A lock system is used to freight ships up to 26 m above sea level, including the Miraflores and Gatun locks. Although the water level in the artificial lakes is sustained by the large rainfall inherent to a subtropical region, and a water reuse system reduces water loss by up to 60%, fresh water loss from the artificial lakes still occurs into the ocean when a lock is opened.

Continued development in the canal watershed and climate change may reduce rainfall in the watershed and overall sustainability of the system. It

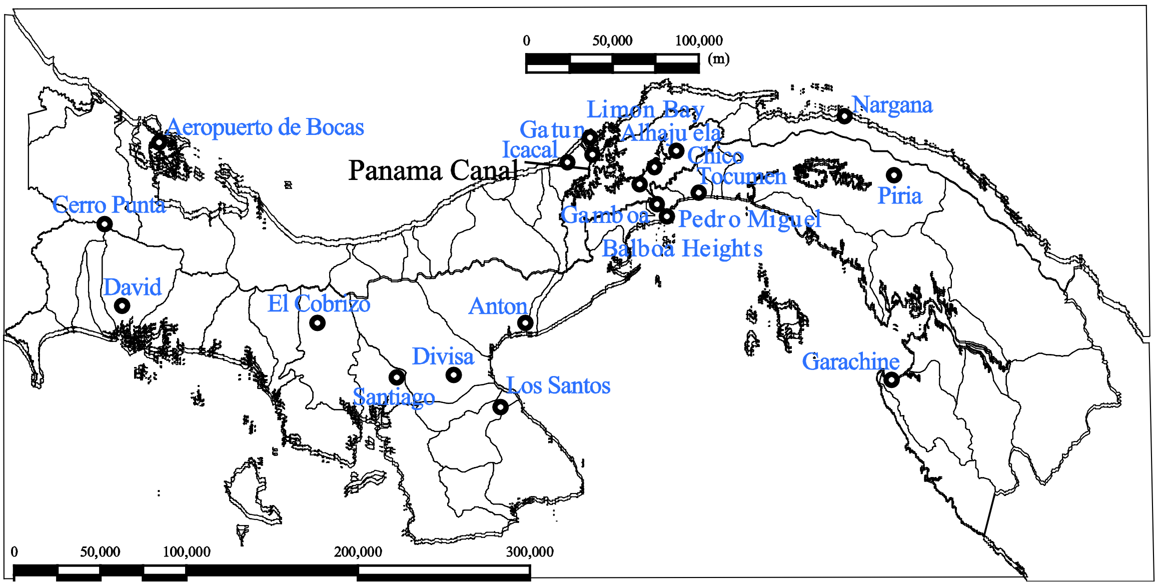

Fig.1 Meteorological stations in Panama. Thin lines indicate the boundary of each local district.

North corresponds to the upper direction..

is thus important to evaluate future rainfall and develop sustainable operation policies. In this context this study aims to understand how changes in rainfall patterns may affect the canal watershed by analyzing a 100 year daily rainfall data set, as well as to assist projection of precipitation in Panama using MRI-GCM20[1) 2) 3) 4)].

2. CLIMATE CHANGE INDICES

(1) Long-term precipitation data in Panama

The Panama Canal was opened in 1914 and data from meteorological stations around the canal are available for about one hundred years from the early 1900s. Daily rainfall intensity data from six locations are considered in the following analysis: Alhajuela, Balboa Heights, Gamboa, Gatun, Limon Bay and Pedro Miguel (ALA, BHT, GAM, GAT, LMB, and PMG, respectively; **Fig. 1**).

Being located between the Atlantic Ocean and the Pacific Ocean Panama is unique from a meteorological aspect, having distinct climatic regions. In this study, the six stations were chosen from three different regions, the Atlantic Ocean side (GAT and LMB), the inland (ALA and GAM) and the Pacific Ocean side (PMG and BHT), respectively, in order to understand the long-term trend of precipitation in the different climate regions.

(2) Climate change indices

Climate change indices[5)] regarding precipitation were used in the trend analysis (*Rx*1day, *Rx*5day, *SDII*, *R*10mm, *R*20mm, *R*nnmm, *CDD*, *CWD* and *PRCPTOT*) as follows. Another two climate change indices related to precipitation, *T95pTOT* and *T99pTOT*, have already been investigated by Aguilar et al. (2005)[6)], which demonstrated that *T95pTOT* and *T99pTOT* have increased in the Central America.

$$Rx1\mathrm{day}_j = \max\left(RR_{ij}\right) \tag{1}$$

$$Rx5\mathrm{day}_j = \max\left(RR5_{ij}\right) \tag{2}$$

$$SDII_j = \frac{\sum_{w=1}^{W} RR_{wj}}{W} \tag{3}$$

$$R10\mathrm{mm}_j = \text{days } when\ RR_{ij} \geq 10 \text{ mm} \tag{4}$$

$$R20\mathrm{mm}_j = \text{days } when\ RR_{ij} \geq 20 \text{ mm} \tag{5}$$

$$Rnn\mathrm{mm}_j = \text{days } when\ RR_{ij} \geq \text{nn mm} \tag{6}$$

$$CDD_j = \mathit{Maximum\ length\ of\ dry\ spell} \quad where\ RR_{ij} < 1 \text{ mm} \tag{7}$$

$$CWD_j = \mathit{Maximum\ length\ of\ wet\ spell} \quad where\ RR_{ij} \geq 1 \text{ mm} \tag{8}$$

$$R95pTOT_j = \sum_{w=1}^{W} RR_{wj} \quad where\ RR_{wj} > RR_{wn}95 \tag{9}$$

$$R99pTOT_j = \sum_{w=1}^{W} RR_{wj} \quad where\ RR_{wj} > RR_{wn}99 \tag{10}$$

$$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij} \tag{11}$$

where, *Rx*1day is the annual maximum 1 day precipitation, *Rx*5day is the annual maximum consecutive 5 day precipitation, *SDII* is the simple precipitation intensity index, *R*10mm is the annual

Table 1 Climate change indices at six meteorological stations. nc means no clear trend by using Mann-Kendall trend test.

	*Rx*1day mm/day	*Rx*5day mm/5days	*SDII* mm/day	*R*10mm days	*R*20mm days	*R*30mm days
Gatun	nc	nc	1.9	nc	nc	nc
Limon Bay	nc	-53	2.2	nc	-7.3	-4.1
Alhajuela	nc	nc	1.8	nc	nc	nc
Gamboa	nc	nc	2.1	5.5	nc	nc
Balboa Heights	nc	nc	2.7	10.2	6.8	nc
Pedro Miguel	nc	nc	4.2	6.4	4.2	nc

	CDD days	*CWD* days	*CDD* mm	*CWD* mm	*PRCPTOT* mm
Gatun	13	-3.0	nc	nc	nc
Limon Bay	15	-3.7	nc	nc	-662
Alhajuela	nc	-2.5	nc	nc	nc
Gamboa	nc	-3.2	nc	nc	nc
Balboa Heights	nc	nc	nc	nc	191
Pedro Miguel	nc	nc	nc	nc	nc

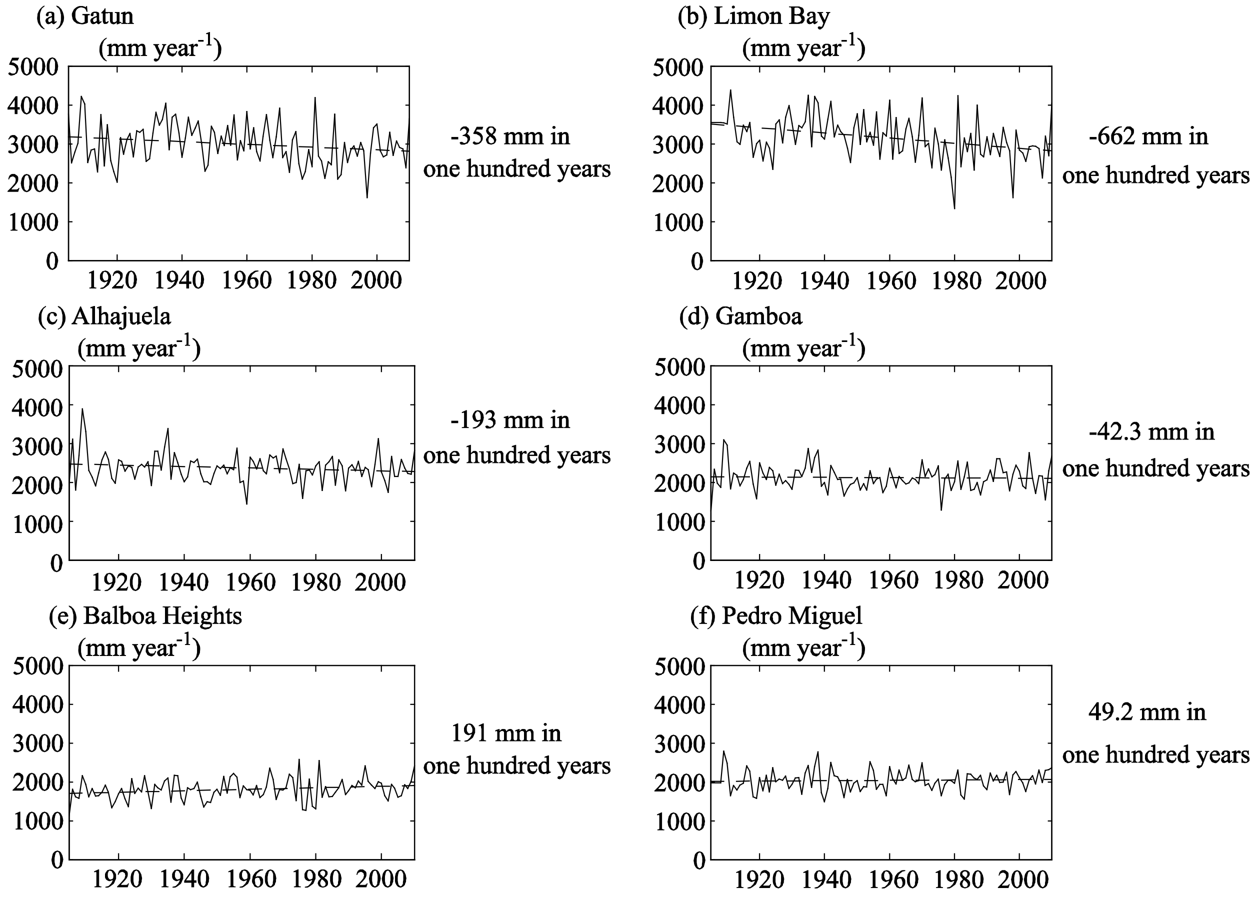

Fig.2 Annual total precipitation at six meteorological stations. Broken lines indicate linear approximation by using least-squares method. (a) Gatun. (b) Limon Bay. (c) Alhajuela. (d) Gamboa. (e) Balboa Heights. (f) Pedro Miguel.

count of days when daily precipitation is more than 10 mm, *R*20mm is the annual count of days when daily precipitation is more than 20 mm, *R*nnmm is the annual count of days when daily precipitation is more than nn mm, *CDD* is the maximum length of dry spell where daily precipitation is less than 1 mm, *CWD* is the maximum wet spell where daily precipitation is more than 1 mm, *T95pTOT* is the annual total precipitation where daily precipitation is more than the 95 percentile of daily precipitation on wet days, *T99pTOT* is the annual total precipitation where daily precipitation is more than the 99 percentile of daily precipitation on wet days, *PRCPTOT* is the annual total precipitation, RR_{ij} is the daily precipitation on day i in period j, $RR5_{ij}$ is the consecutive 5 day precipitation on day i in

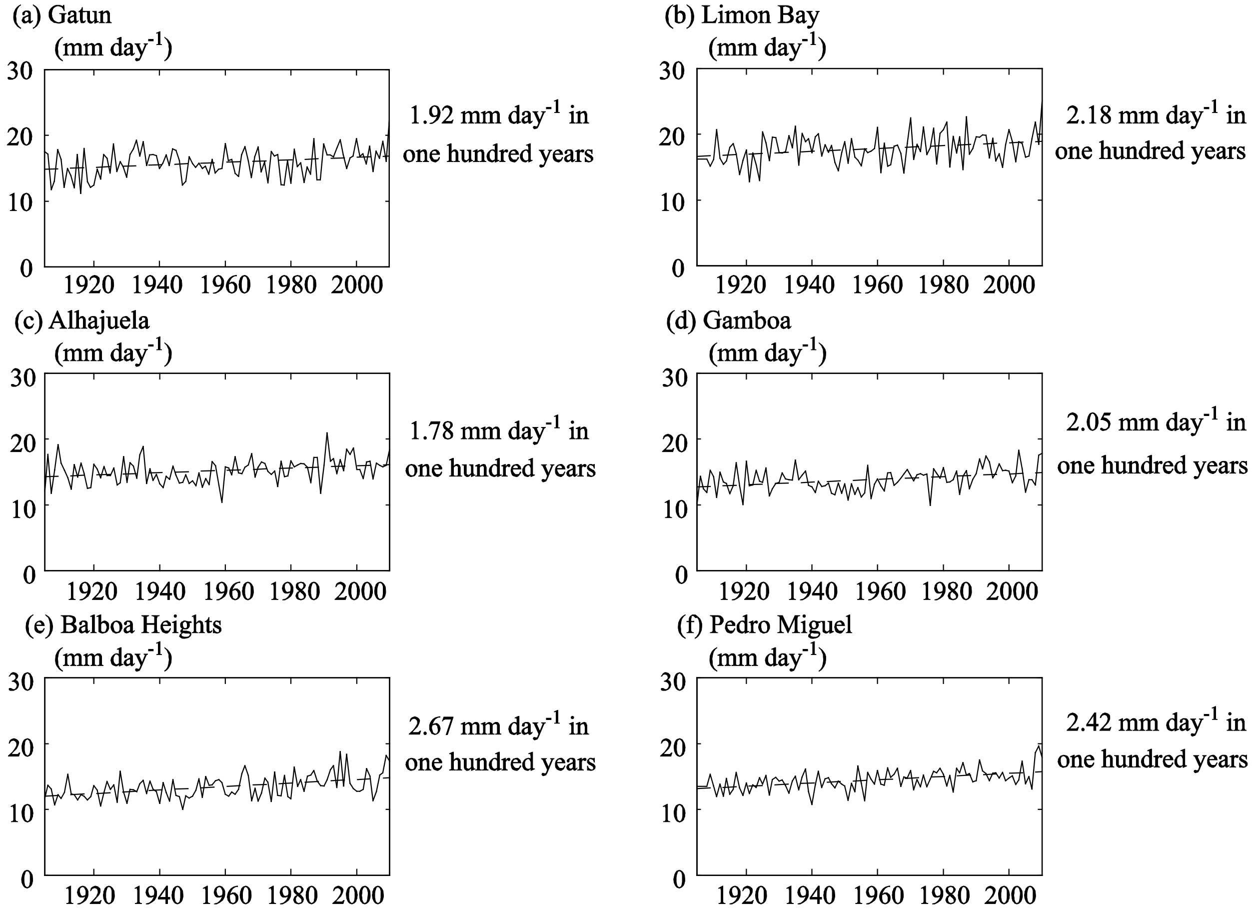

Fig.3 Simple precipitation intensity index at six meteorological stations. Broken lines indicate linear approximation by using least-squares method. (a) Gatun. (b) Limon Bay. (c) Alhajuela. (d) Gamboa. (e) Balboa Heights. (f) Pedro Miguel.

period j, RR_{wj} is the daily precipitation in period j when daily precipitation is more than 1 mm, W is the annual count of days when daily precipitation is more than 1 mm, $RR_{wj}95$ is the 95 percentile of daily precipitation in period j and $RR_{wj}99$ is the 99 percentile of daily precipitation in period j.

(3) Trend of climate change indices

Nine climate change indices were computed from 1905 to 2010 at the six meteorological stations from the Atlantic Ocean side (GAT and LMB), the inland (ALA and GAM) and the Pacific Ocean side (PMG and BHT) (**Fig. 2 and Fig. 3**). Mann-Kendall trend test[7] was applied into nine climate change indices for investigating their temporal trends (**Fig. 2, Fig. 3 and Table 1**). In this study, an attempt was made to analyze the "nn" in *R*nnmm over the range 30 to 100 with an interval of 10, but this did not demonstrate any clear trend or specific tendency between “nn” values. A value for “nn” of 30 is shown as an example of the results for *R*nnmm.

Along the Atlantic Ocean coast, the total annual rainfall (PRCPTOT) decreased 660 mm in the 2000s compared to the 1900s (LMB), compared to an increase of 190 mm at the Pacific Ocean coast station (BHT) (**Fig. 2**). Interestingly, all the *SDII* at six meteorological stations increased, with the increase in *SDII* at the Pacific Ocean side the largest: 3 to 4 mm/day/100years (**Fig. 3**). The increase in *SDII* may be due to the decrease in the maximum wet spell, *CWD*, which is related to the annual count of days, *W*. Therefore, this may suggest that more frequent, stronger precipitation may occur around the Panama Canal if the observed trend continues.

3. BIAS CORRECTION[8),9),10),11)] USING MRI-AGCM

The long-term precipitation data analysis based on climate change indices supports the increase in *SDII* at all meteorological stations around the Panama Canal, also suggesting that there may be an the increase in *SDII* in the entire area of the Republic of Panama in the future. To confirm the hypothesis of increasing *SDII* in Panama, it is necessary to investigate *SDII* at meteorological stations not only around the Panama Canal. However, long-term precipitation data is only

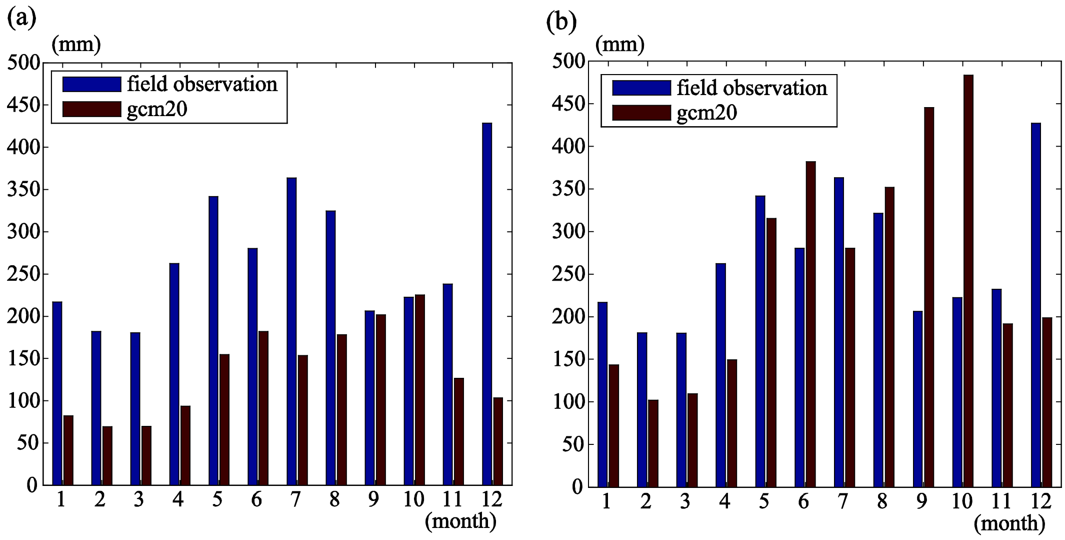

Fig.4 Twenty year-mean monthly precipitation at Aeropuerto. (a) Field observation and MRI-AGCM3.2S. (b) Field observation and modified MRI-AGCM3.2S (Bias is corrected.).

available at the meteorological stations around the Panama Canal, with other meteorological stations recording precipitation from the 1970s. This section, thus, made an attempt to investigate the applicability of MRI-AGCM3.1S and 3.2S by using *SDII* from 1980 to 1999 in the entire area of Panama.

(1) Bias correction of precipitation in Panama

Daily precipitation was analyzed at 14 field observation stations: three on the Atlantic Ocean coast, six on the Pacific Ocean coast and five in inland (**Fig. 1**). To investigate the applicability of MRI-AGCM3.1S and 3.2S in Panama, seasonal changes in rainfall were compared with field observations. Single grid-point data corresponding to the field observation stations, five grid-point mean data including the nearest four stations and nine grid-point mean data surrounding the field observation stations were computed as GCM output (**Table 2**). The error is defined as the summation of square of the difference of twenty-year mean monthly precipitation between field observation and GCM output from January to December. Since nine grid-point mean data has the highest correlation with the field observations, nine grid-point data was used through the following analyses.

Twenty year mean monthly precipitation showed good correspondence to field observation, though the MRI-AGCM total rainfall is a slight underestimate (**Fig. 4**). It appears that the GCM produces smaller rainfall intensity relative to field observations, except when rainfall intensity was less than 1 mm day^{-1} (**Fig. 5**). The incidence of rainfall of less than 1 mm day^{-1} are about 65 and 300 days in one year in the field observations and GCM, respectively, which suggests the necessity for careful selection of downscaling techniques.

Table 2 Error computed between field observation and MRI-AGCM. Under bar indicates the minimum error among three different grid-data sets (unit: mm).

	MRI-AGCM3.1S			MRI-AGCM3.2S		
Station name	one grid-point	five grid-point	nine grid-point	one grid-point	five grid-point	nine grid-point
Aeropuerto	1.02E+05	6.63E+04	5.88E+04	5.27E+05	3.38E+05	3.00E+05
Anton	6.18E+03	6.21E+03	7.44E+03	8.87E+04	4.56E+04	4.54E+04
Cerro punta	6.74E+04	4.23E+04	3.55E+04	3.38E+04	3.76E+04	3.85E+04
Chico	3.82E+04	4.29E+04	4.64E+04	5.90E+04	3.19E+04	2.32E+04
David	4.88E+04	3.74E+04	4.01E+04	1.83E+05	1.56E+05	1.52E+05
Divisa	1.52E+04	1.45E+04	1.49E+04	1.98E+05	8.28E+04	7.42E+04
El Cobrizo	2.17E+05	2.15E+05	2.08E+05	1.87E+05	2.03E+05	1.86E+05
Garachine	1.84E+05	2.18E+05	2.14E+05	1.23E+05	2.73E+05	2.96E+05
Icacal	2.28E+05	2.28E+05	2.27E+05	3.02E+05	2.22E+05	2.16E+05
Los Santos	3.97E+04	5.24E+04	5.51E+04	1.57E+05	1.41E+05	1.75E+05
Nargana	1.69E+04	1.14E+04	9.73E+03	1.25E+04	1.48E+04	2.11E+04
Piria	4.92E+04	6.25E+04	6.36E+04	1.32E+05	1.34E+05	1.35E+05
Santiago	2.96E+04	3.37E+04	3.60E+04	1.21E+05	7.55E+04	6.12E+04
Tocumen	1.78E+04	1.50E+04	1.34E+04	3.14E+04	3.50E+04	3.77E+04

(2) Bias correction and SDII

We make an attempt to apply stochastic downscaling, bias correction, into the reproduction of hourly precipitation, and investigate the duplicability of *SDII*. As being discussed in the previous subsection and shown in **Fig. 5**, the probability density function of precipitation was not found to be modeled by a normal distribution. Therefore, a bias correction method based on a cumulative density function was applied in this study (**Table 3**).

Comparisons of SDII between the present field observations and MRI-AGCM3.1S and 3.2S demonstrates that the mean absolute difference between field observation and MRI-AGCM3.1S output is twice as much as MRI-AGCM3.2S (**Table**

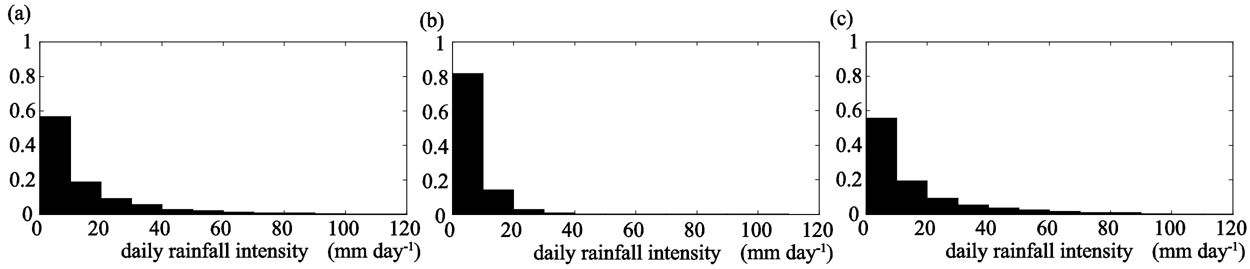

Fig.5 Probability density function at Aeropuerto. (a) Field observation. (b) MRI-AGCM3.2S. (c) Modified MRI-AGCM3.2S.

3). Therefore, MRI-AGCM3.2S is found to have better duplicability compared to MRI-AGCM3.1S.

4. CONCLUSIONS

1) Trend analysis of long-term precipitation data from 1905 to 2010 reveals that the total annual rainfall decreased by 660 mm in the 2000s compared to the 1900s along the Atlantic Ocean station, compared to an increase of 190 mm at the Pacific Ocean coast station.
2) Simple precipitation intensity index was found to increase by 1 to 4 mm day^{-1} over one hundred years at the all meteorological stations around the Panama Canal.
3) Comparisons of *SDII* reveals that MRI-AGCM3.2S has more duplicability compared to MRI-AGCM3.1S.

ACKNOWLEDGMENT: This work has been supported by the Japan Society for the Promotion of Science and the Japanese International Cooperation Agency.

Table 3 Simple precipitation intensity index in the present (field observation: FO) and (MRI-AGCM3.1S and 3.2S).

Station name	Field observation 1980-1999	MRI-AGCM 3.1S 3.1S-FO	MRI-AGCM 3.2S 3.2S-FO
Aeropuerto	16.0	-0.490	-0.320
Anton	13.9	-0.543	-0.143
Cerro punta	9.9	-0.225	-0.133
Chico	16.0	-0.289	-0.310
David	18.0	-0.639	0.273
Divisa	16.4	-0.544	0.035
El Cobrizo	21.2	-0.443	0.254
Garachine	13.4	-0.421	0.027
Icacal	18.0	-0.554	-0.681
Los Santos	12.7	-0.368	0.438
Nargana	24.9	-0.430	-0.678
Piria	16.3	-0.954	0.151
Santiago	16.7	-0.420	-0.018
Tocumen	14.8	-0.391	-0.339

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(Received September 30, 2011)