Long-term precipitation changes in the Baiu and Akisame seasons in Japan over the past 120 years (1901–2020)

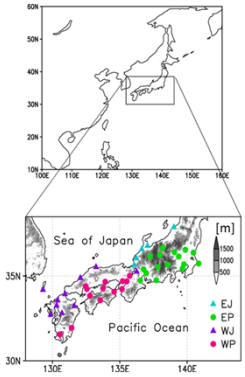
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1. Introduction

There are two major rainy periods in Japan. The first one appears in early summer and is called the “Baiu” season, which occurs associated with the development of the Asian summer monsoon. The second one is recognized in early autumn and is called the “Akisame” season, which occurs associated with the southward migration of a frontal zone and effects of tropical cyclone activity.

This study investigates long-term variations in precipitation during the major rainy periods in Japan—the Baiu (June–July) and Akisame (September–October) seasons—using precipitation records from 44 weather stations over the past 120 years, focusing on exploring similarities and differences in the long-term changes between the two rainy seasons.

2. Data and analysis



- Daily precipitation data at 44 weather stations in Japan Meteorological Agency in western to eastern Japan.
- June to October during the period 1901–2020
- Mean and extreme precipitation are investigated.

Figure 1 Location of meteorological stations used in this study. Different colors indicate different regions: Sea of Japan side of eastern Japan (EJ), Pacific side of Eastern Japan (EP), Sea of Japan side of Western Japan (WJ), and Pacific side of Western Japan (WP). Shading indicates topography height (unit: m).

3. Mean precipitation

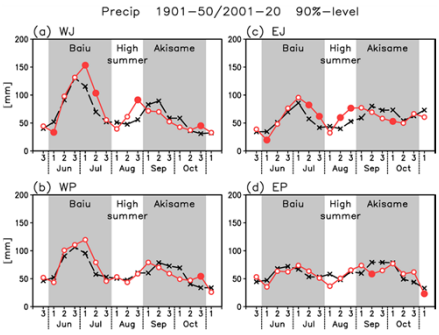


Figure 2 Regionally averaged 10-day **precipitation amounts** (mm) during late May to early November for 1901–1950 (dashed black line) and for 2001–2020 (solid red line). Filled circles denote statistical significance at the 90% confidence level for the difference between the two periods. Numbers 1, 2, and 3 for each month along the horizontal axis denote 1st – 10th, 11 – 20th, and 21st – 30th (or 31st), respectively.

- **Baiu** season: **Precipitation amount** increases in the mid-late stages, suggesting an intensification and seasonal delay for the Baiu precipitation.
- **High summer** season: Dry spell becomes shorter in WJ and EJ.
- **Akisame** season: Precipitation peak becomes less clear in the latter period.

4. Heavy precipitation (freq. of precip. > 100mm/d)

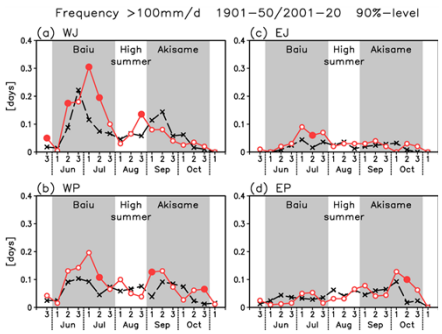


Figure 3 As Figure 2, but for the number of days with precipitation over 100 mm (**R100mm**).

- **Baiu** season: The **R100mm** frequency largely increase especially in WJ, where the timing of the peak shifts from late June to early July.
- **Akisame** season: The **R100mm** frequency increase in many regions, but the frequency peak in WJ become less clear in the latter period.

5. Differences in the long-term changes between the Baiu and Akisame seasons

Table 1 Linear trends for the regional averages for surface-air temperature (**SAT**), **precipitation amount**, the seasonal maximum 1-day precipitation total (**Rx1d**), and the number of days with precipitation over 100mm (**R100mm**) during 1901–2020. Underlined (double underlined) denotes statistical significance at the 90 % (95 %) confidence level for a two-sided test, based on the Mann–Kendall trend test.

Region	Baiu (June-July)						Akisame (September-October)					
	SAT	Precipitation		Rx1d		R100mm	SAT	Precipitation		Rx1d		R100mm
	℃/100yr	%/100yr	%/℃	%/100yr	%/℃	%/100yr	℃/100yr	%/100yr	%/℃	%/100yr	%/℃	%/100yr
EJ	1.03	10.8	10.5	13.2	12.7	88.9	1.23	-7.6	-6.2	10.9	8.9	35.5
EP	1.07	-4.2	-3.9	-3.1	-2.9	-24.9	1.29	-4.0	-3.1	15.5	12.0	58.3
WJ	1.30	12.0	9.2	23.5	18.1	75.3	1.48	-14.1	-9.6	-10.9	-7.4	-37.5
WP	1.37	7.0	5.1	11.7	8.5	57.1	1.70	-2.6	-1.6	8.4	4.9	52.5
EJ+WJ	1.23	11.7	9.5	20.8	16.9	77.0	1.41	-11.8	-8.3	-5.3	-3.7	-28.6
EP+WP	1.22	1.5	1.2	4.3	3.5	27.1	1.49	-3.4	-2.3	12.3	8.2	55.7
EJ+EP	1.05	-0.8	-0.8	0.7	0.6	-5.9	1.27	-4.9	-3.9	14.6	11.5	56.0
WJ+WP	1.33	9.3	7.0	17.2	12.9	66.3	1.56	-7.6	-4.9	-0.4	-0.3	8.4
ALL	1.23	5.2	4.2	10.4	8.4	48.0	1.45	-6.3	-4.3	6.4	4.4	27.3

- The **SAT** trends show significant increases for both seasons, with slightly larger increases in the **Akisame** season.
- The trends for **precipitation amount** are opposing between the **Baiu** and **Akisame** seasons, with some regional differences.
- The Intensity and frequency of heavy precipitation (**Rx1d** and **R100mm**) have increased overall for both seasons, with much higher increase rates for the **Baiu** season.
- Prominent positive trend of **Rx1d** (18.1 %/K) is observed in WJ during the **Baiu** season.

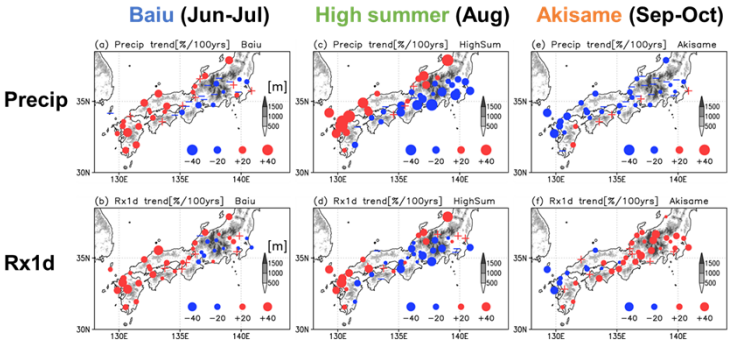


Figure 4 Geographical distribution of the linear trend [%/100 yrs] of (upper panels) **precipitation amount** and (lower panels) **Rx1d** for 1901–2020 during **(a, b)** the Baiu season (June–July), **(c, d)** the high summer season (August), and **(e, f)** the Akisame season (September–October). The cross (minus) indicates absolute values of less than 5 %/100 yrs with an increasing (decreasing) trend. Shading indicates topography height (unit: m).

- There are similar spatial patterns for the **Baiu** and **high summer**: increasing trends in western Japan and on the Sea of Japan side, while decreasing trends on the Pacific side of eastern Japan. This pattern may be caused by an enhancement of southwesterly moisture flows associated with the East Asian monsoon and its interaction with topography.
- The spatial pattern for the **Akisame** season is markedly different from those of the other two seasons, suggesting that different mechanisms may be important.

6. Summary

- **The total amount of Baiu precipitation has increased over the 1901–2020 period, mainly during the mid–late stages of the season (late June to July) over regions on the Sea of Japan side of the country.**
- **Conversely, the precipitation amount during the Akisame season has decreased, mainly during the mid-stage (late September to early October) over all regions.**
- **The frequency and intensity of heavy precipitation have generally increased in both seasons, but the trends are much stronger for the Baiu season than for the Akisame season.**
- **It is noteworthy that the observed trends differ greatly between the Baiu and Akisame seasons, because similar differences between the two rainy seasons are found in the results of global warming simulations.**

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- Endo, H., A. Kitoh, R. Mizuta, and T. Ose, 2021: Different future changes between early and late summer monsoon precipitation in East Asia. J. Meteor. Soc. Japan, 99, 1501-1524, doi:10.2151/jmsj.2021-073.

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