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Session: HS7.4 – Future hydroclimatic scenarios in a changing world

Extreme future rainfall in Bologna: exploring climate scenarios depicted by CMIP6 models

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Introduction

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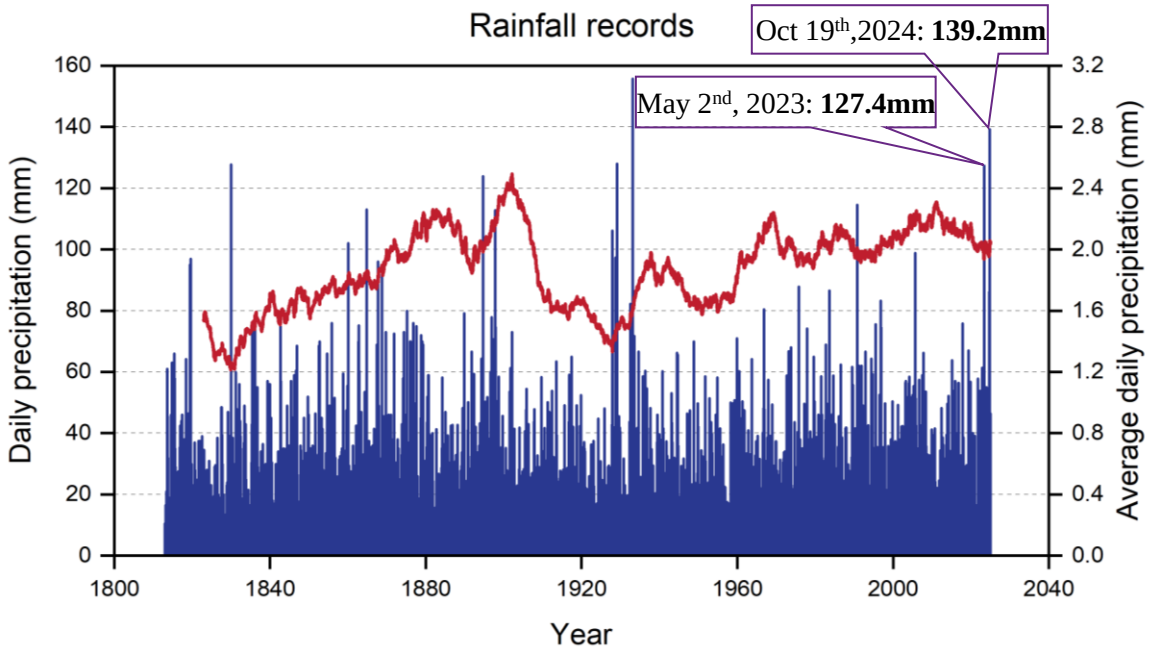
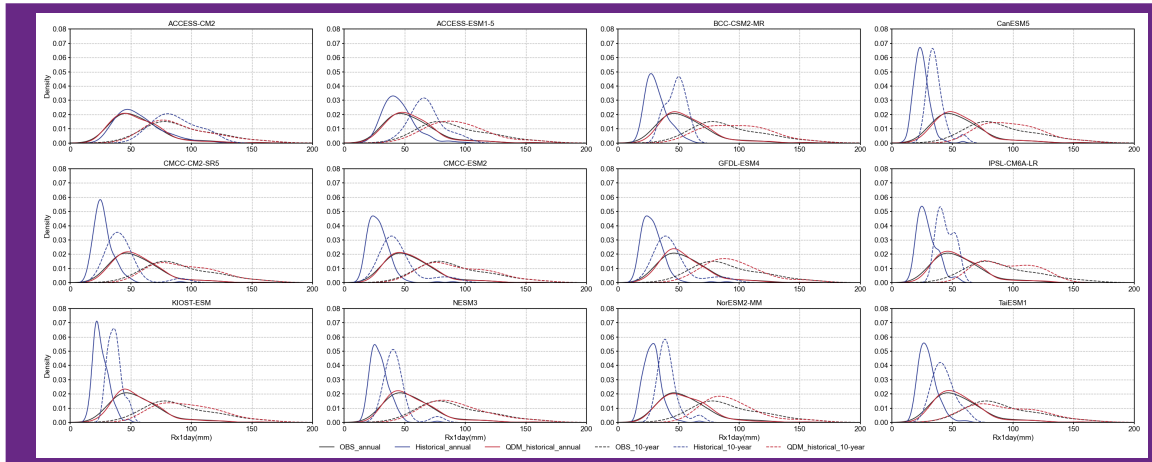
- **Aera:** Bologna, Italy (44.50°N, 11.35°E, 53.0m), has one of the longest daily rainfall records worldwide. It can provide essential information about extreme rainfall.

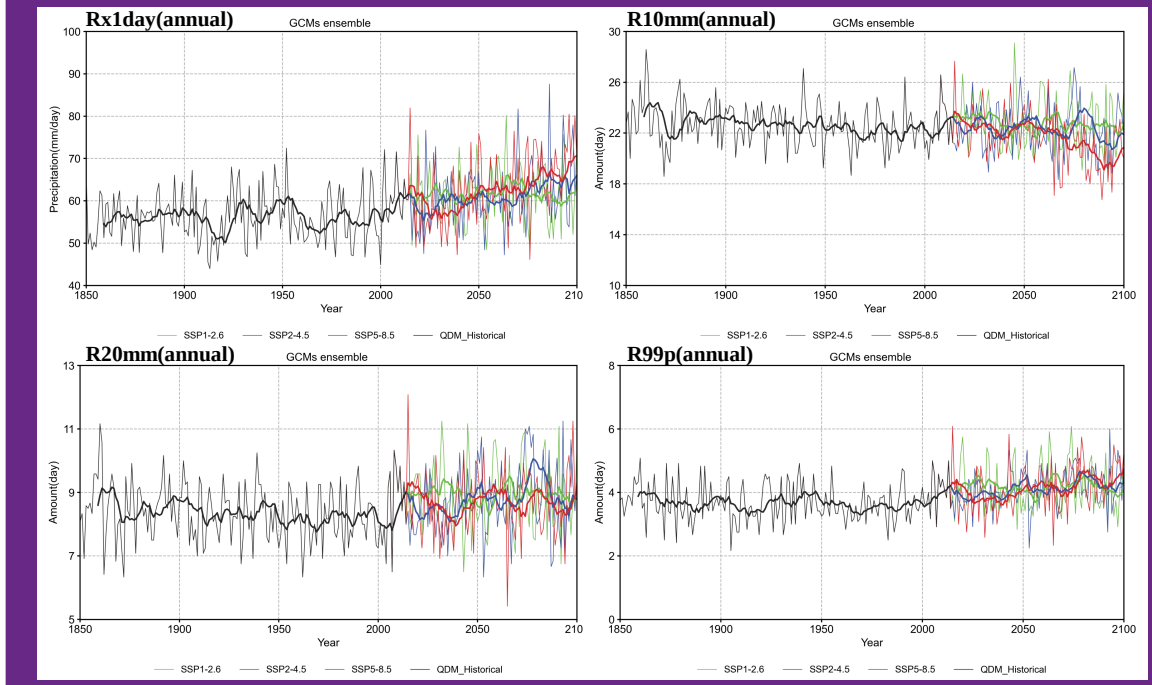
- **Aim:** (i) test the performances of up-to-date CMIP6 climate models in the reproduction of historical rainfall statistics and (ii) assess the projections for the XXIst century, with different emission scenarios.



Time series of 212 years (1813-2024) daily rainfall records in Bologna, along with 10-year moving average (red line).



Comparison of sample probability density of Rx1day for observations and GCM historical simulations.



Time series of extreme rainfall indexes for both historical and future projection of GCMs ensemble.

Workflows

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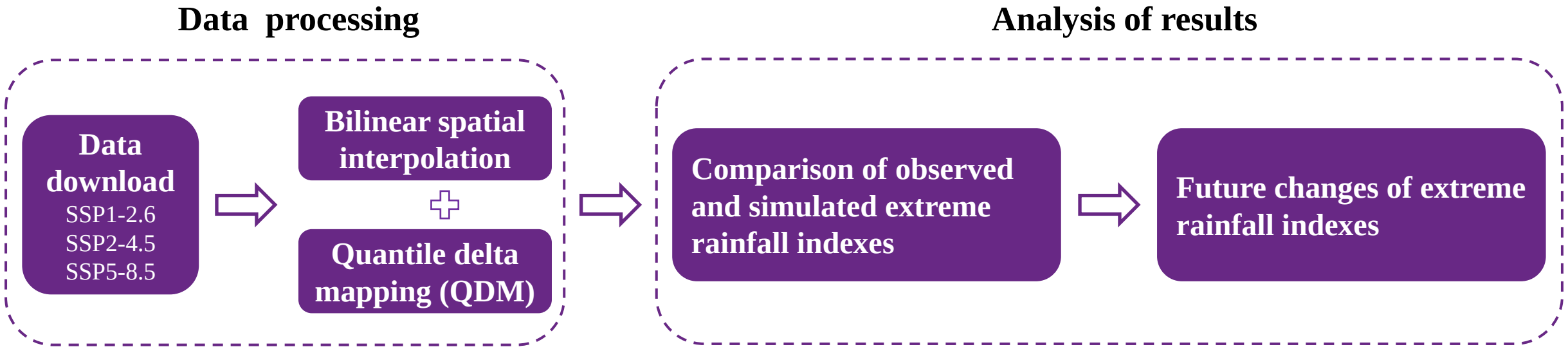

Rainfall observations data:
the European Climate Assess-Ment & Dataset (ECA&D)(https://climexp.knmi.nl).
General circulation model simulation (GCMs):
World climate research programme (WCRP) (https://esgf-node.ipsl.upmc.fr/search/cmip6-ipsl/)

Extreme rainfall indexes
Rx1day: the annual and 10-year maximum 1-day rainfall .
R10mm: the annual and 10-year number of heavy (>10 mm) rainfall days.
R20mm: the annual and 10-year number of very heavy (>20 mm) rainfall days.
R99p: the annual and 10-year number of days with rainfall greater than the 99th percentile of daily amounts.

1 Comparison of observed and simulated extreme rainfall indexes

Comparison of observed and simulated extreme rainfall indexes

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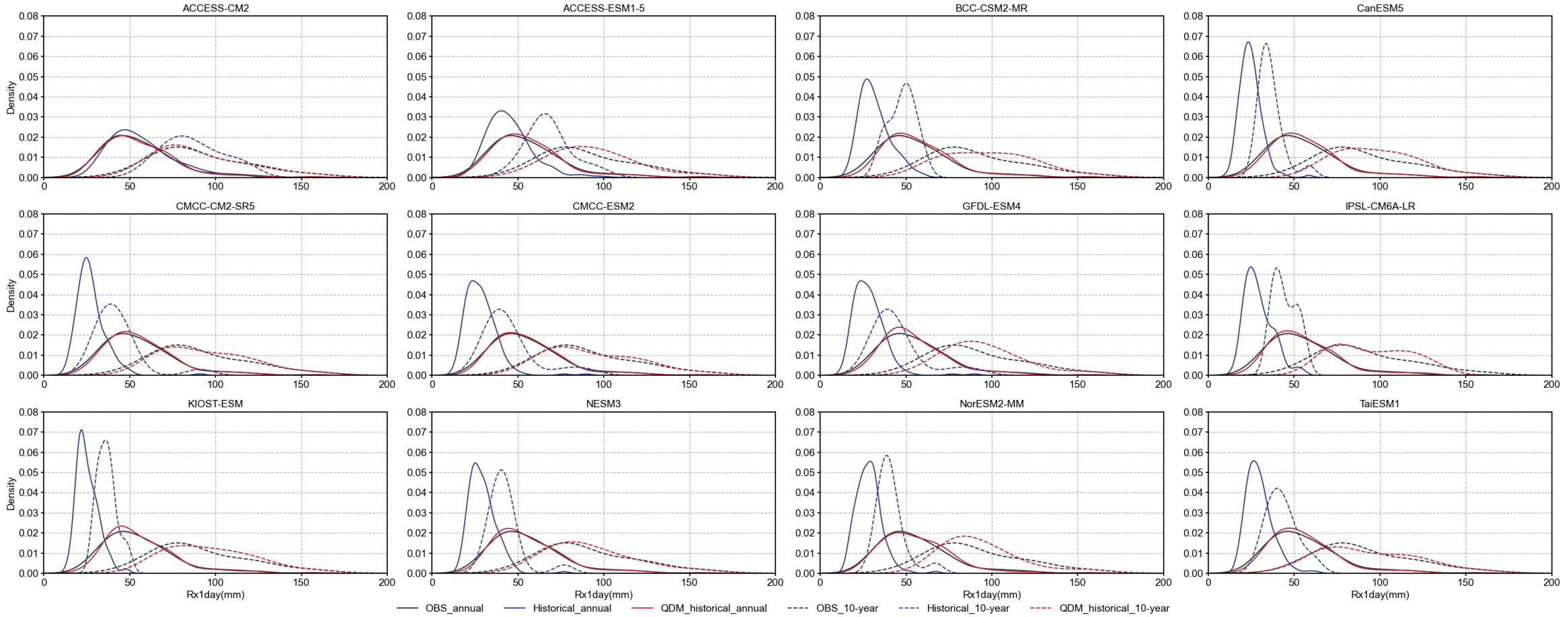
Rx1day: the annual and 10-year maximum 1-day rainfall

- The 12 original GCMs **underestimated** the Rx1day index.
- The GCMs after QDM bias correction show **better performance** in the Rx1day (annual) index. BCC-CSMA-MR, CanESM5, GFDL-ESM4, and NorESM2-MM **slightly overestimated** the Rx1day index, but they still show better performance than original GCMs.



Comparison of sample probability density of Rx1day for observations and GCM historical simulations.

Comparison of observed and simulated extreme rainfall indexes

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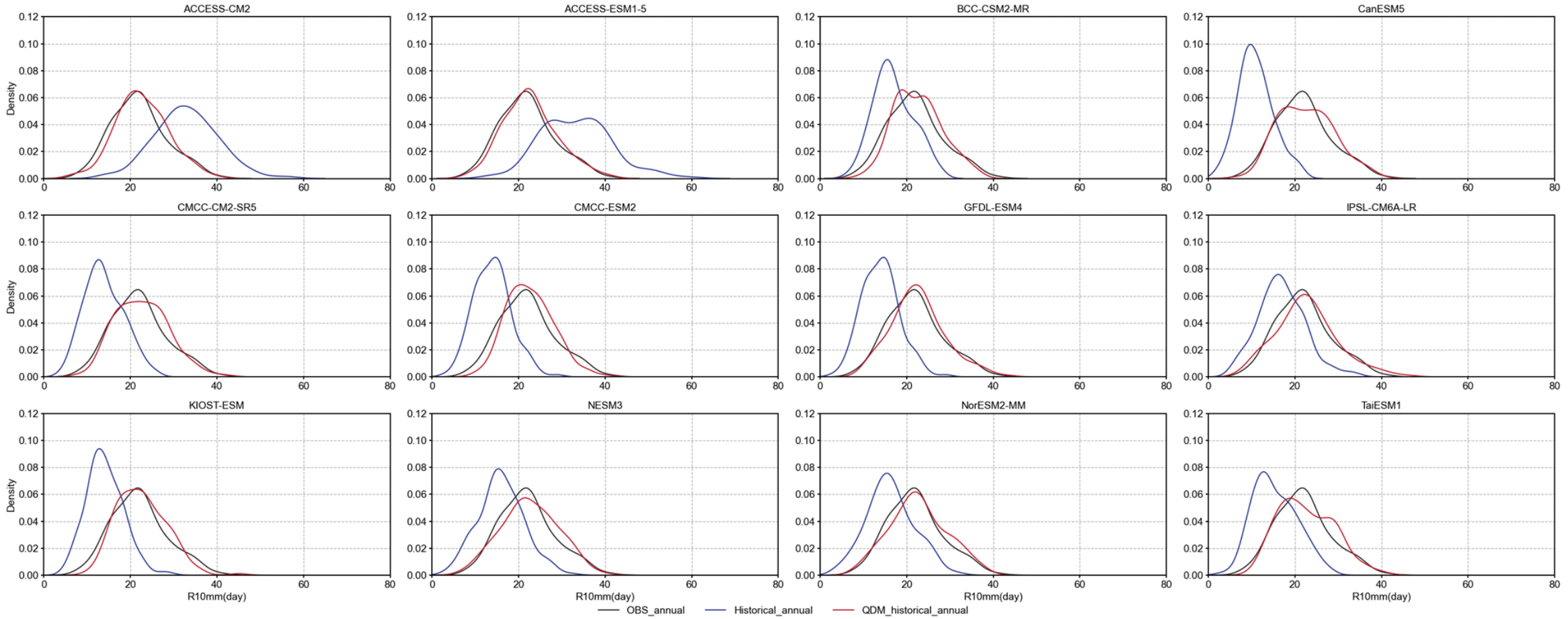
R10mm: the annual and 10-year number of heavy (>10 mm)

- The original GCMs **underestimated** the R10mm (annual), except ACCESS-CM2, ACCSS-ESM1-5.
- The GCMs after QDM bias correction show **better performance** in the R10mm (annual), but CanESM5, CMCC-CM2-SR5, TaiESM1 **slightly underestimated** the R10mm.



Comparison of sample probability density of R10mm (annual) for observations and GCM historical simulations.

Comparison of observed and simulated extreme rainfall indexes

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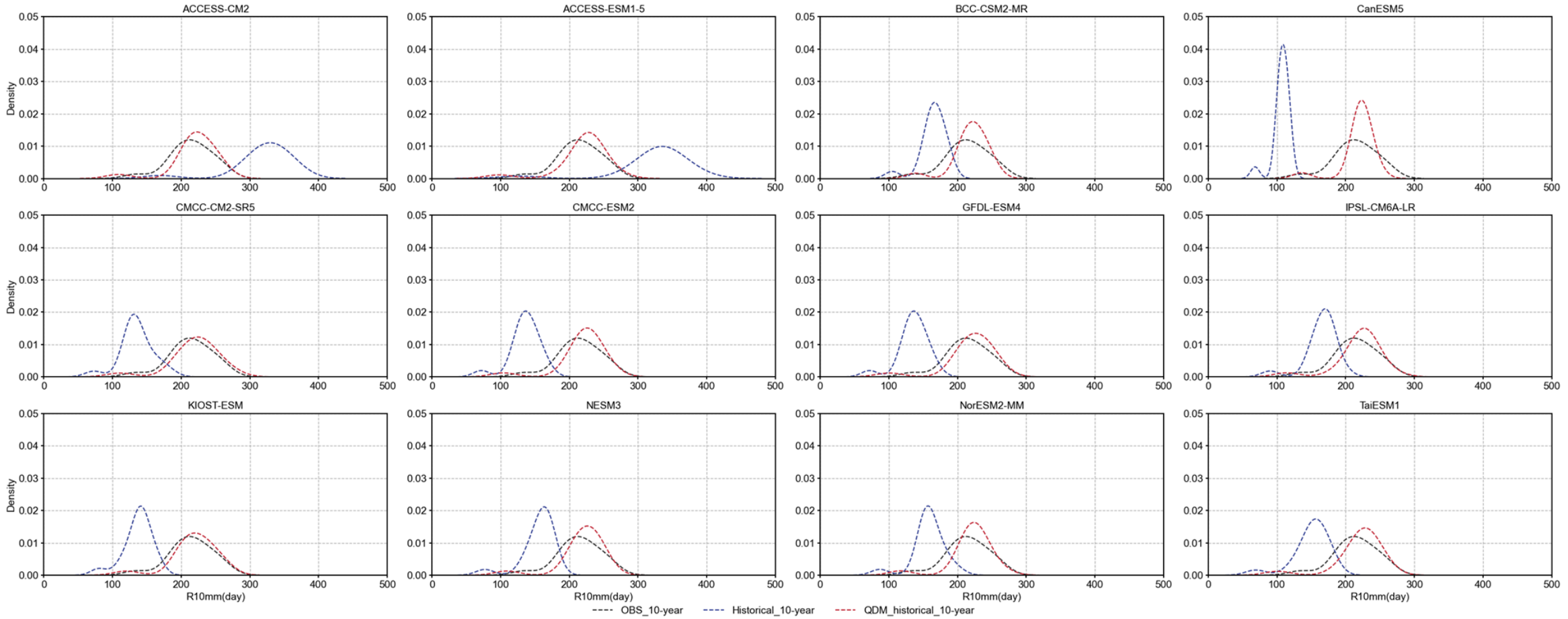
R10mm: the annual and 10-year number of heavy (>10 mm)

- The original GCMs **underestimated** the R10mm (10-year), except ACCESS-CM2, ACCSS-ESM1-5.
- The GCMs after QDM bias correction **overestimated** the R10mm (10-year) to varying degrees, except CMCC-CM2-SR5 and KIOST-ESM. But they still show **better performance** than original GCMs.



Comparison of sample probability density of R10mm (10-year) for observations and GCM historical simulations.

Comparison of observed and simulated extreme rainfall indexes

R20mm:the annual and 10-year number of heavy (>20 mm)

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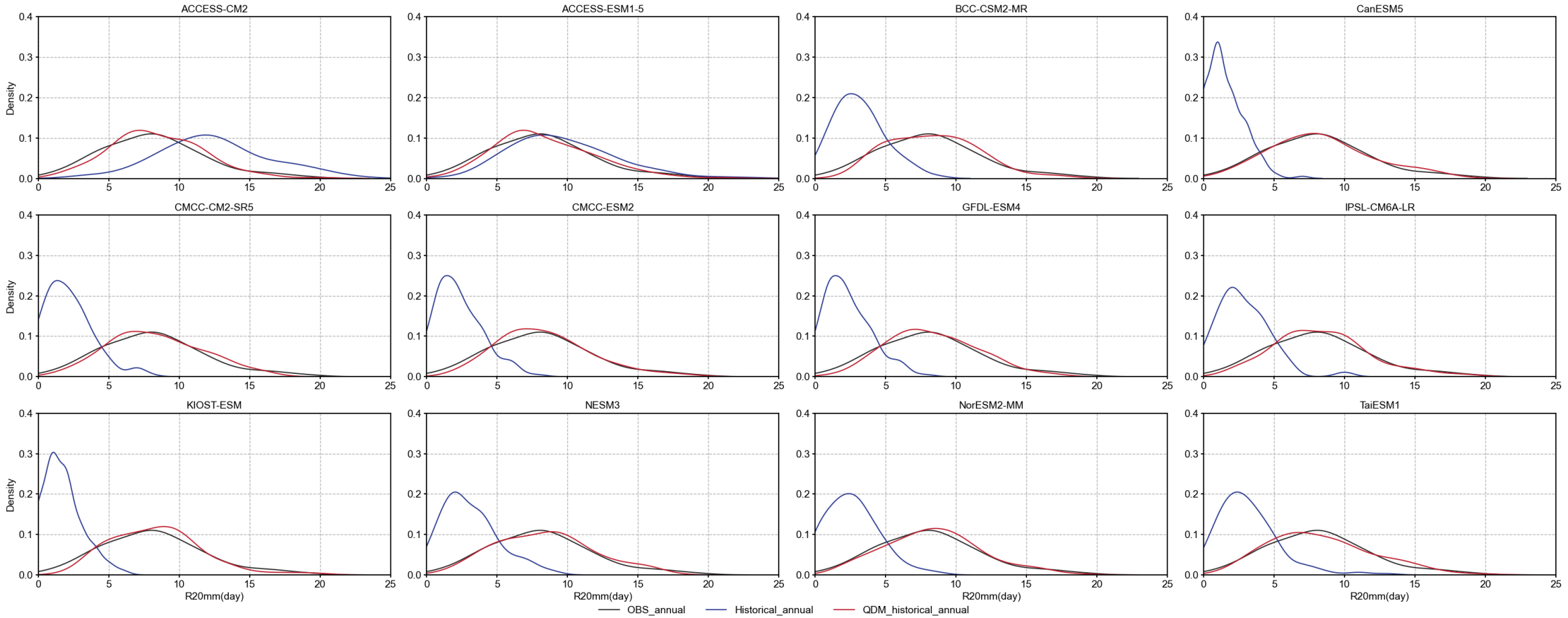
- The original GCMs **underestimated** the R10mm (10-year), except ACCESS-CM2, ACCSS-ESM1-5.
- The GCMs after QDM bias correction show **better performance** in the R20mm (annual).



Comparison of sample probability density of R20mm (annual) for observations and GCM historical simulations.

Comparison of observed and simulated extreme rainfall indexes

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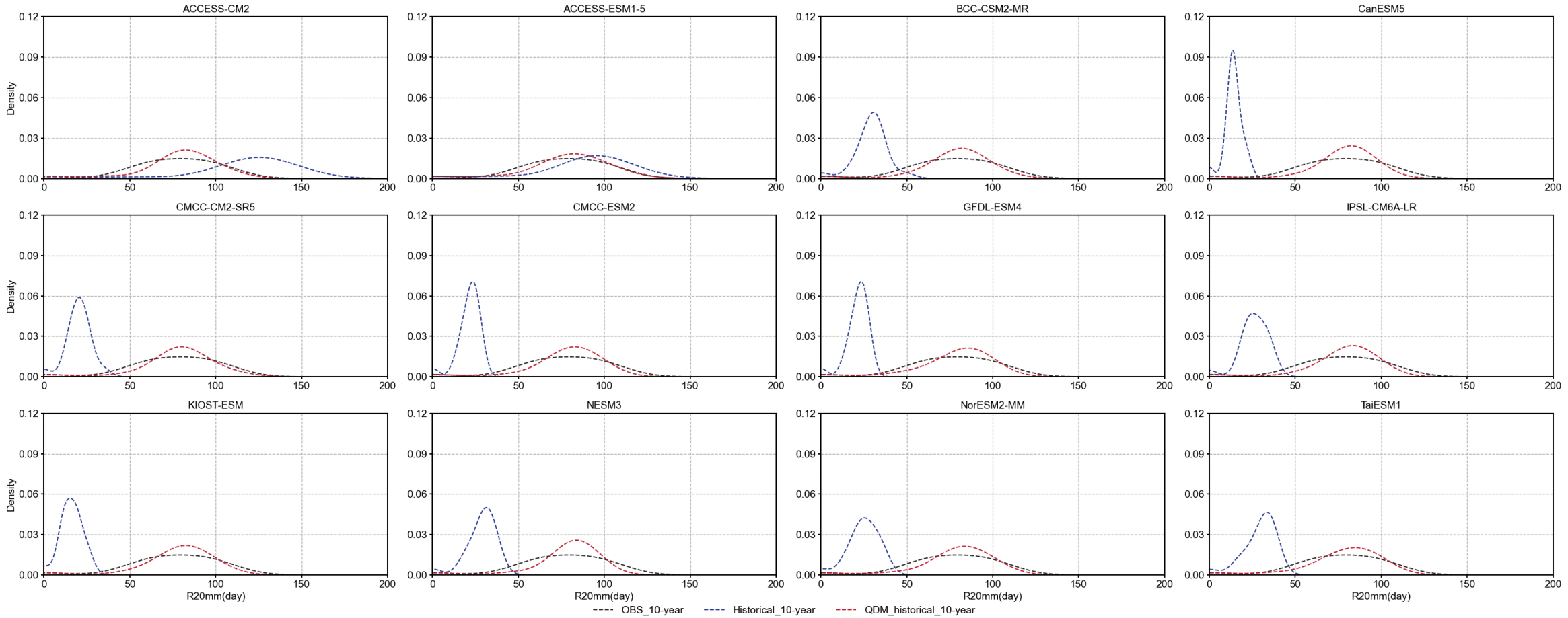
- The original GCMs **underestimated** the R10mm (10-year), except ACCESS-CM2, ACCSS-ESM1-5.
- The GCMs after QDM bias correction **slightly overestimated** the R20mm (10-year), but still show **better performance** than original GCMs.



Comparison of sample probability density of R20mm (10-year) for observations and GCM historical simulations.

Comparison of observed and simulated extreme rainfall indexes

R99p:the annual and 10-year number of days with rainfall greater than the 99th percentile of daily amounts

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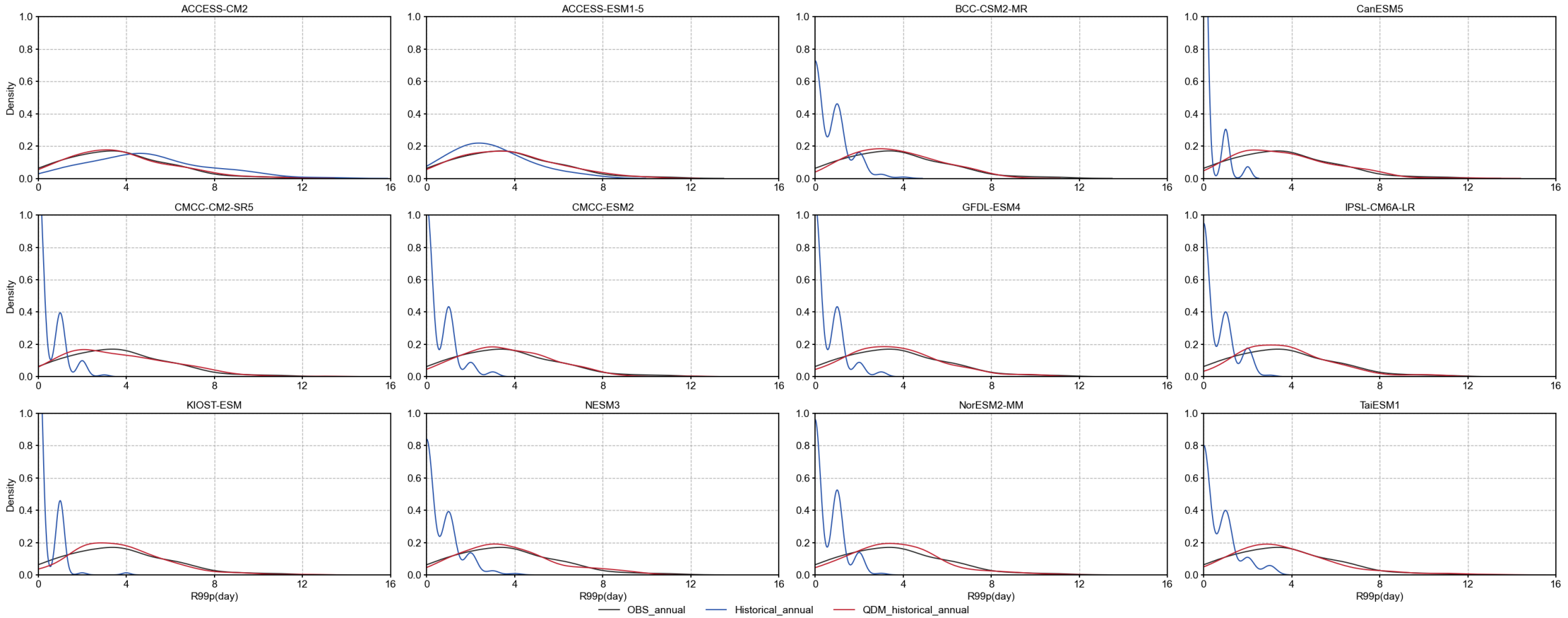
- The original GCMs **underestimated** the R10mm (10-year), except ACCESS-CM2, ACCSS-ESM1-5.
- The GCMs after QDM bias correction show **better performance** in the R99p (annual).



Comparison of sample probability density of R99p (annual) for observations and GCM historical simulations.

Comparison of observed and simulated extreme rainfall indexes

R99p:the annual and 10-year number of days with rainfall greater than the 99th percentile of daily amounts

- The original GCMs **underestimated** the R10mm (10-year), except ACCESS-CM2, ACCSS-ESM1-5.
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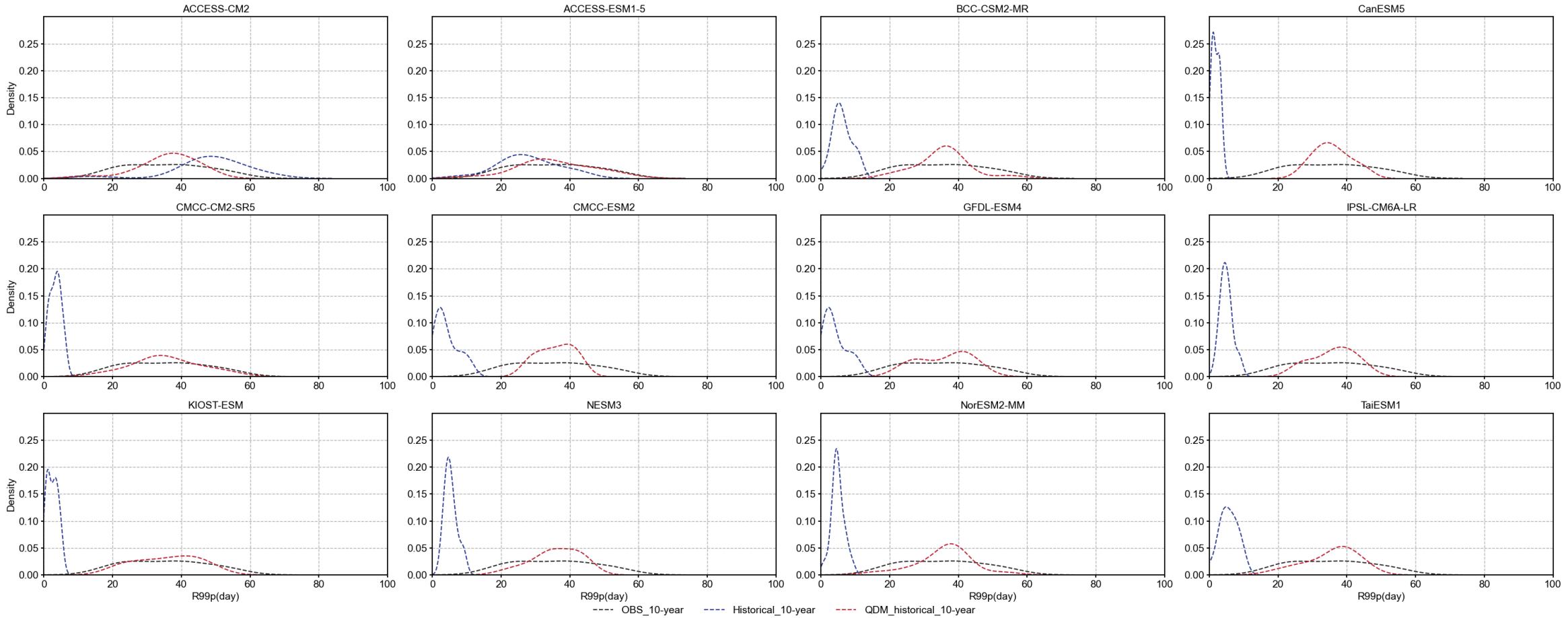

Comparison of sample probability density of R99p (10-year) for observations and GCM historical simulations.

2 Future changes of extreme rainfall indexes

Future changes of extreme rainfall indexes

Rx1day:the annual and 10-year maximum 1-day rainfall

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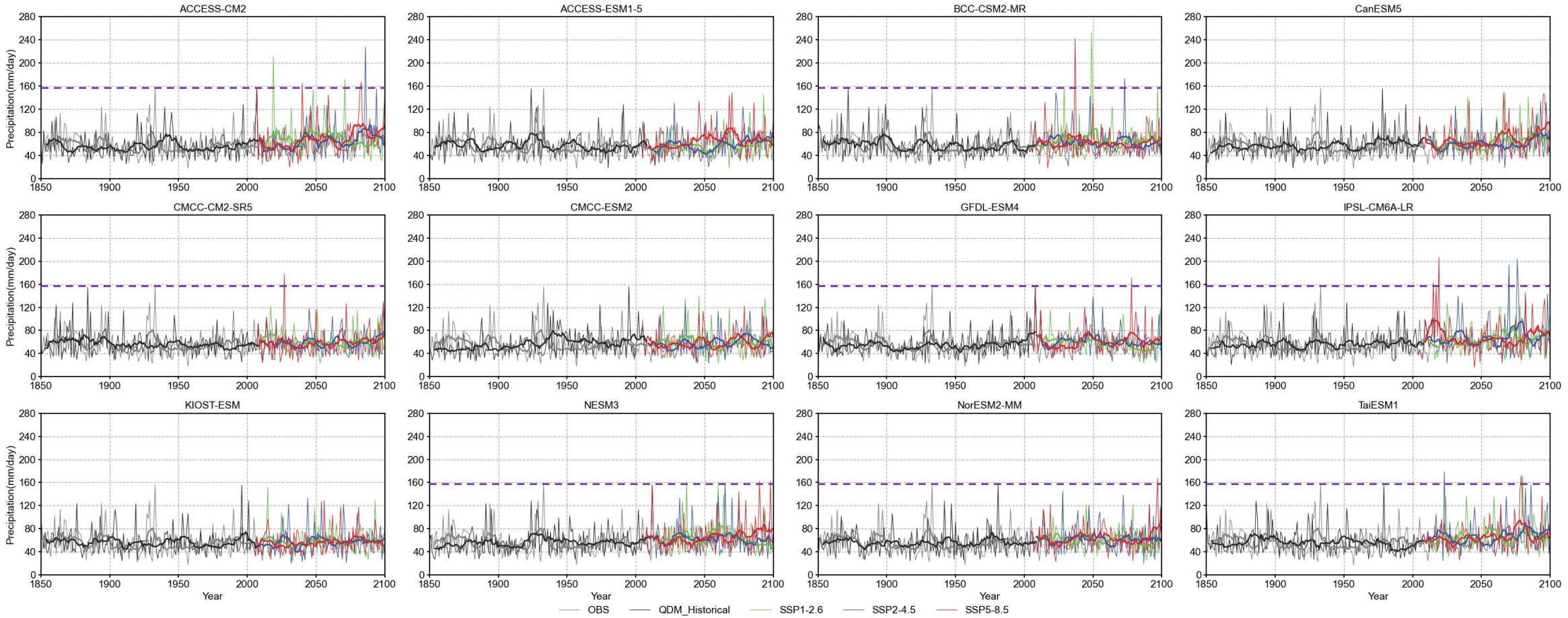
- Under the high emissions scenario (SSP5-8.5), most models predict an **increasing trend** in Rx1day in the future.
- Some models show that Rx1day **far exceeds the maximum observed(155.7mm)** under different scenarios.



Time series of Rx1day (annual) for both GCMs historical and future projection. The bold line represents the 10-year moving average. The purple dotted line indicates the largest 1-day rainfall on record.

Future changes of extreme rainfall

Rx1day:the annual and 10-year maximum 1-day rainfall

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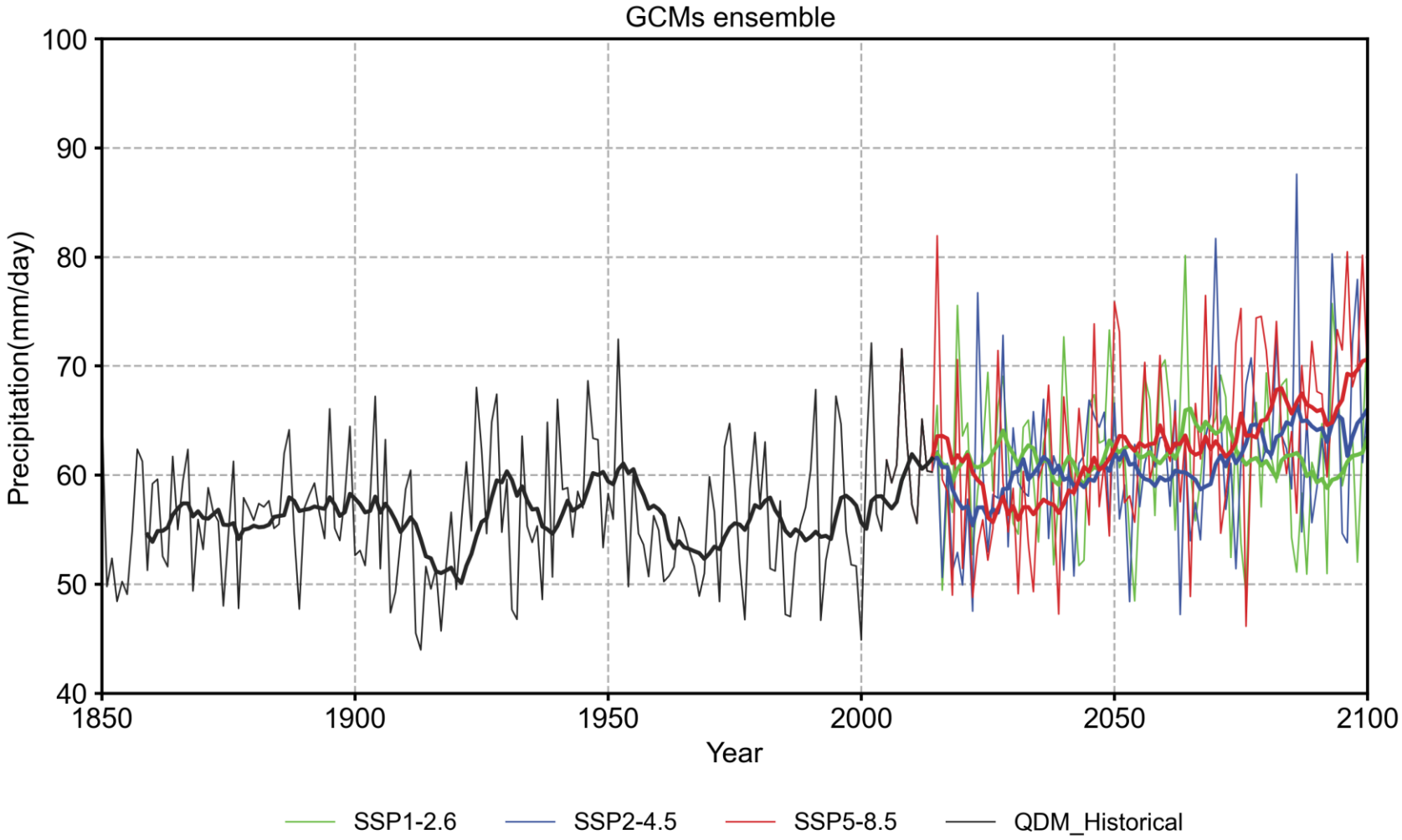
GCMs ensemble shows an **upward trend** with different scenarios in Rx1day in the future.

The **SSP5-8.5** scenario shows a **significant upward trend**. The SSP2-4.5 scenario shows a slow upward trend. The SSP1-2.6 is relatively smooth.

It indicates the **intensity** of annual extreme rainfall will **increase** in the future.



Time series of Rx1day (annual) for both historical and future projection of GCMs ensemble . The bold line represents the 10-year moving average.

Future changes of extreme rainfall

Rx1day:the annual and 10-year maximum 1-day rainfall

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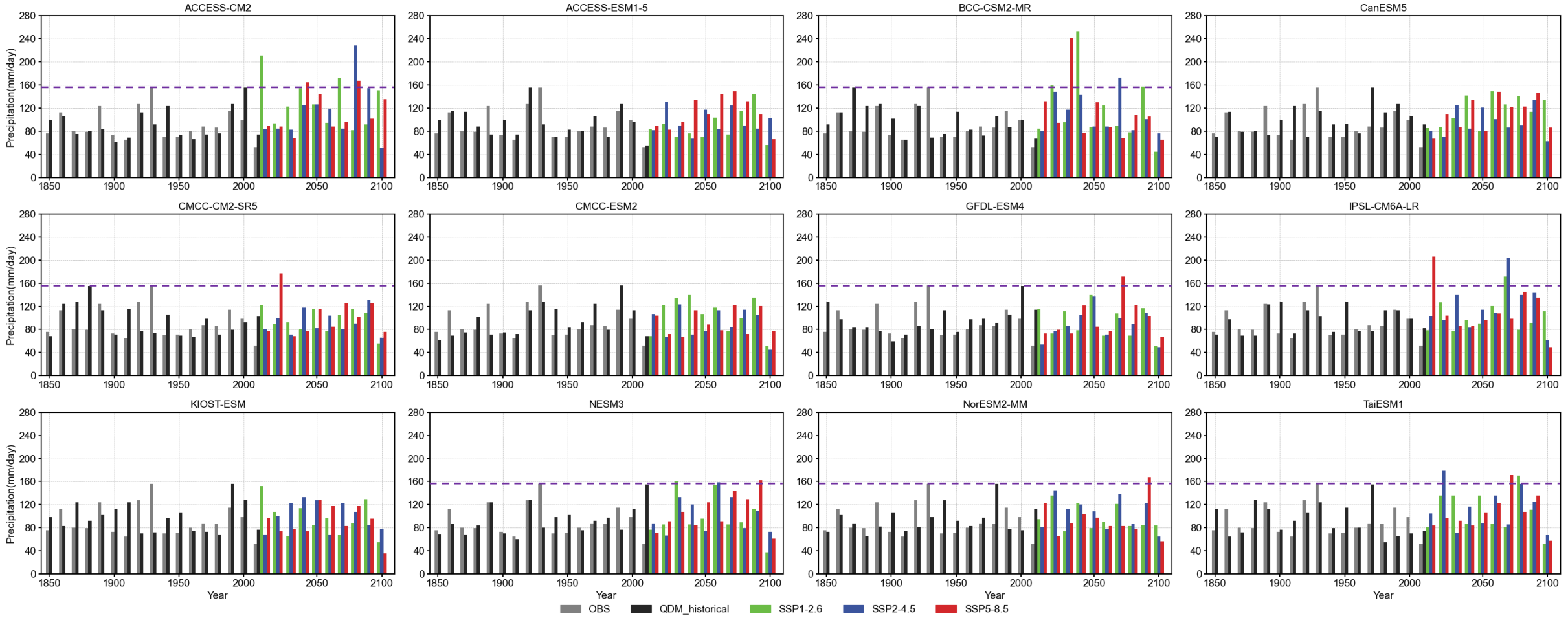
- Under the high emissions scenario (SSP5-8.5), most models predict an **increasing trend** in future Rx1day, well above historical levels, highlighting the exacerbating effect of high emissions on extreme precipitation events in the context of global warming.
- Under the low emissions scenario (SSP1-2.6), the increase in extreme precipitation is **relatively moderate**.



Rx1day (10-year) for both GCMs historical and future projection.

Future changes of extreme rainfall

R10mm:the annual and 10-year number of heavy (>10 mm)

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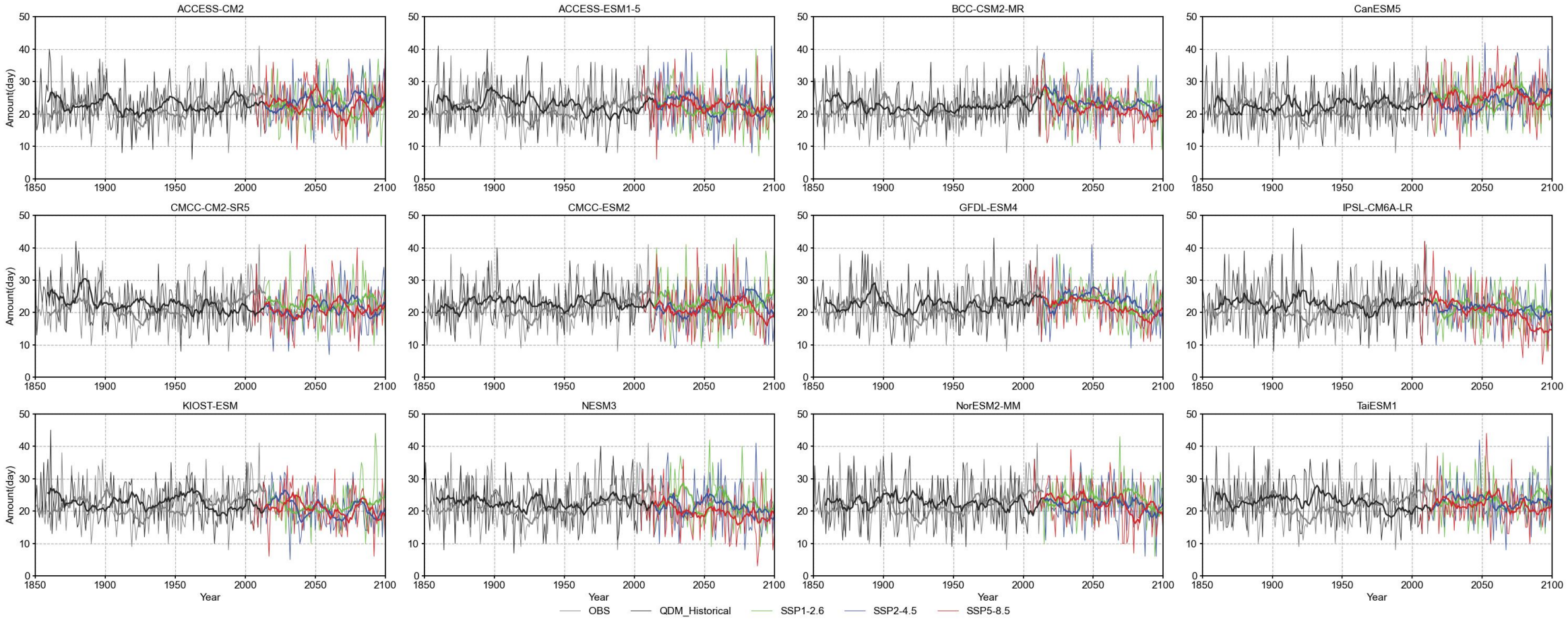
- Several models (e.g., BCC-CSM2-MR, IPSL-CM6A-LR, NESM3, etc.) has a **decreasing trend**, which is especially significant in high emission scenarios in R10mm.
- The remaining models fluctuate but generally tends to be **stable**.



Time series of R10mm (annual) for both GCMs historical and future projection. The bold line represents the 10-year moving average.

Future changes of extreme rainfall

R10mm:the annual and 10-year number of heavy (>10 mm)

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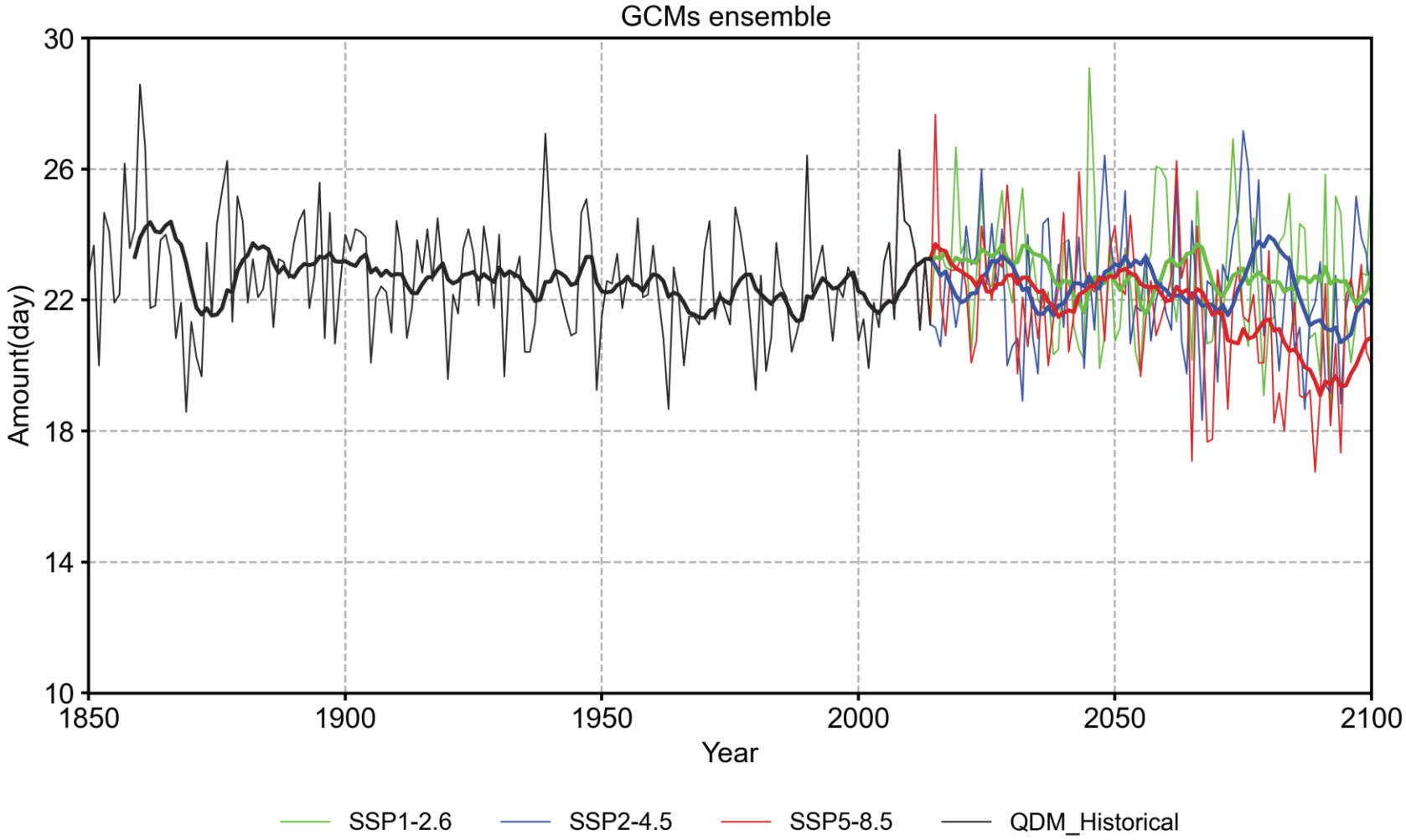
GCMs ensemble shows a **download trend** with different scenarios in R10mm in the future.

The **SSP5-8.5** scenario **decreases significantly after 2050** in R10mm. The SSP1-2.6 and SSP2-4.5 shows a **slow downward trend** in R10mm in the future.

The **frequency** of extreme rainfall **(R10mm)** is likely to **decrease** under different emission scenarios, which in some areas may mean longer drought periods.



Time series of R10mm (annual) for both historical and future projection of GCMs ensemble. The bold line represents the 10-year moving average.

Future changes of extreme rainfall

R10mm:the annual and 10-year number of heavy (>10 mm)

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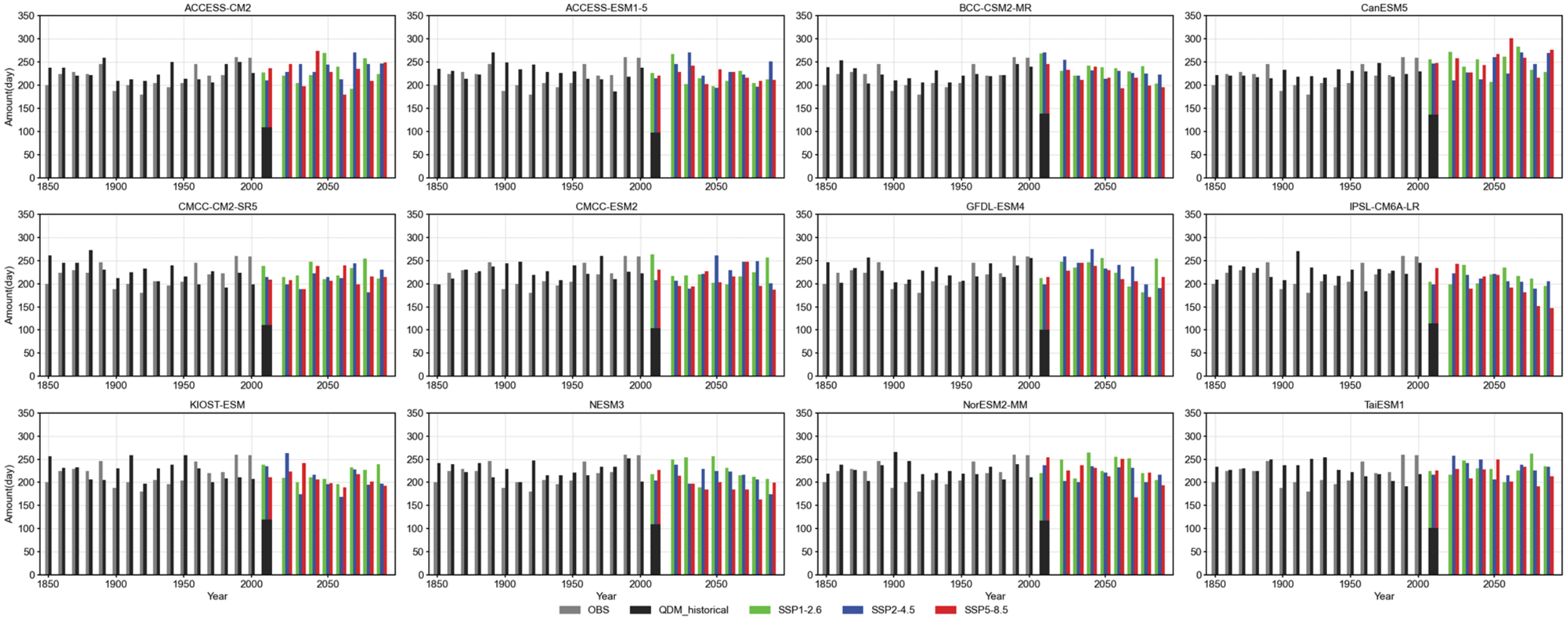
- Most of the models show a **stable** or **slightly decreasing trend** in R10mm under different emission scenarios.
- CanESM5 model shows an **increase** in R10mm under SSP5-8.5, which may mean that the model is more sensitive to different emission scenarios.



Histogram of R10mm (10-year) for both GCMs historical and future projection.

Future changes of extreme rainfall

R20mm:the annual and 10-year number of heavy (>20 mm)

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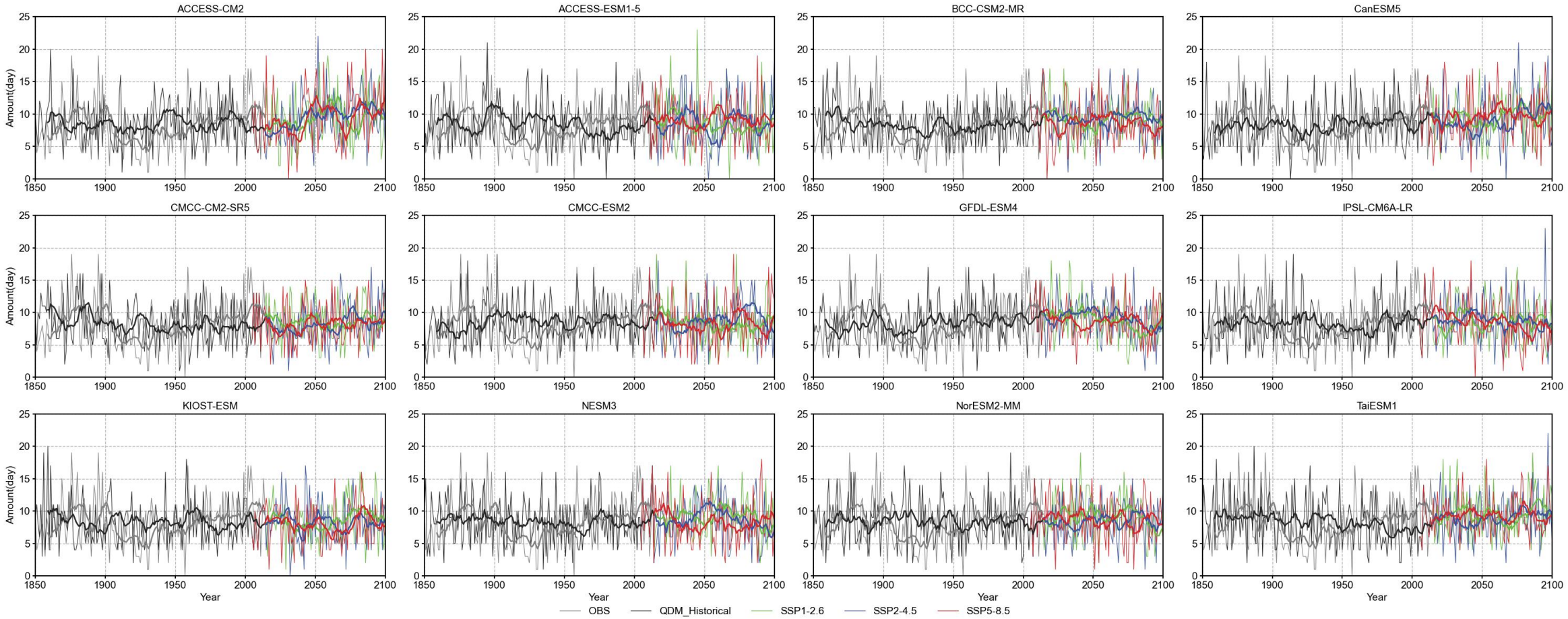
- Most models remain **stable** in R20mm in the future, with insignificant differences between different emission scenarios.



Time series of R20mm (annual) for both GCMs historical and future projection. The bold line represents the 10-year moving average.

Future changes of extreme rainfall

R20mm:the annual and 10-year number of heavy (>20 mm)

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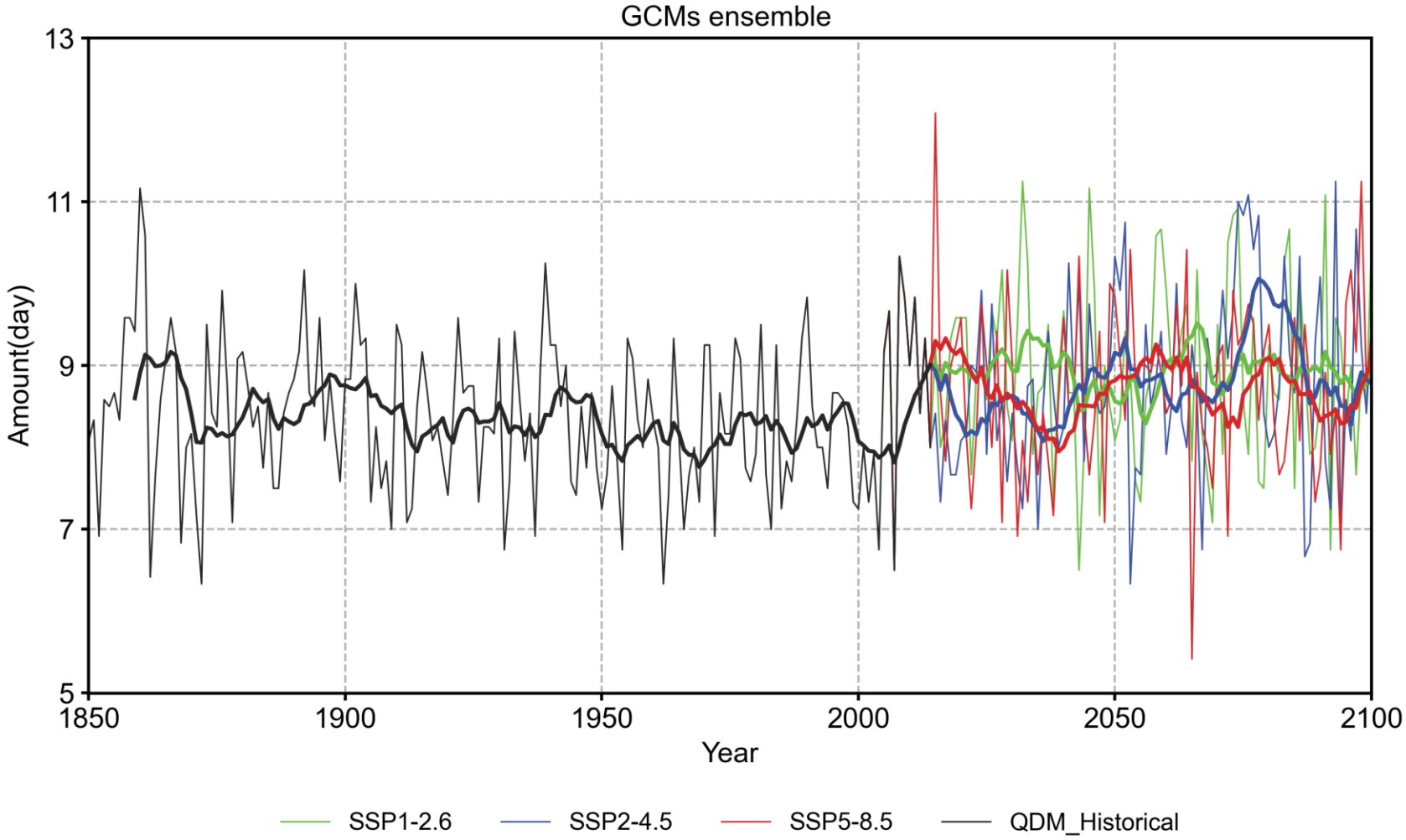
GCMs ensemble shows a generally **stable trend** in R20mm in the future, with gaps that are not significant in different emission scenarios.

The SSP5-8.5 and SSP2-4.5 emission scenarios are volatile but remained stable overall in R20mm in the future. The SSP1-2.6 emission scenario has been in a smoother state.

The **frequency** of extreme rainfall may **not change much** under different emission scenarios.



Time series of R20mm (annual) for both historical and future projection of GCMs ensemble. The bold line represents the 10-year moving average.

Future changes of extreme rainfall

R20mm:the annual and 10-year number of heavy (>20 mm)

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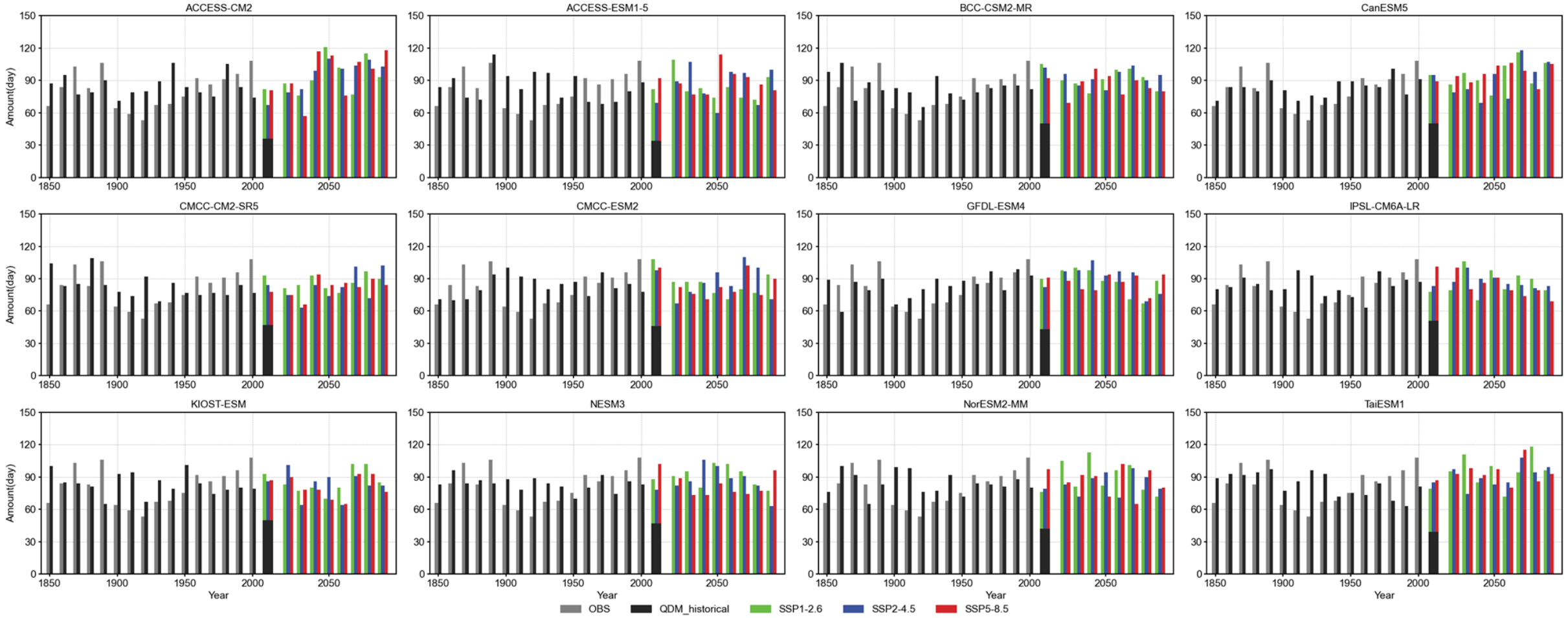
- Most of the models show a **stable trend** in R20mm under different scenarios.



Histogram of R20mm (10-year) for both GCMs historical and future projection.

Future changes of extreme rainfall

R99p:the annual and 10-year number of days with rainfall greater than the 99th percentile of daily amounts

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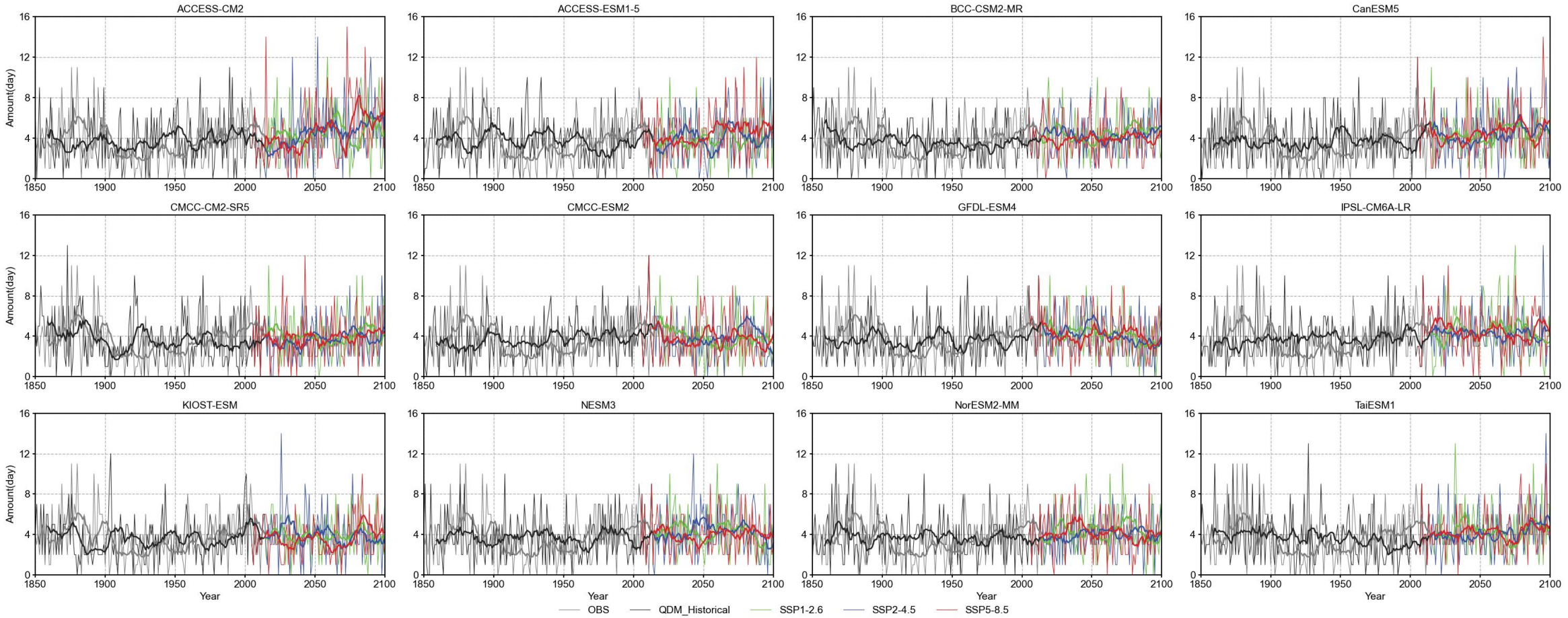
- The ACCESS-M2 model fluctuates more in R99p in the future, especially in the ssp585 scenario, with **a clear upward trend after 2070**.
- The rest of the models are **relatively smooth with a slow upward trend**.



Time series of R99p (annual) for both GCMs historical and future projection. The bold line represents the 10-year moving average.

Future changes of extreme rainfall

R99p:the annual and 10-year number of days with rainfall greater than the 99th percentile of daily amounts

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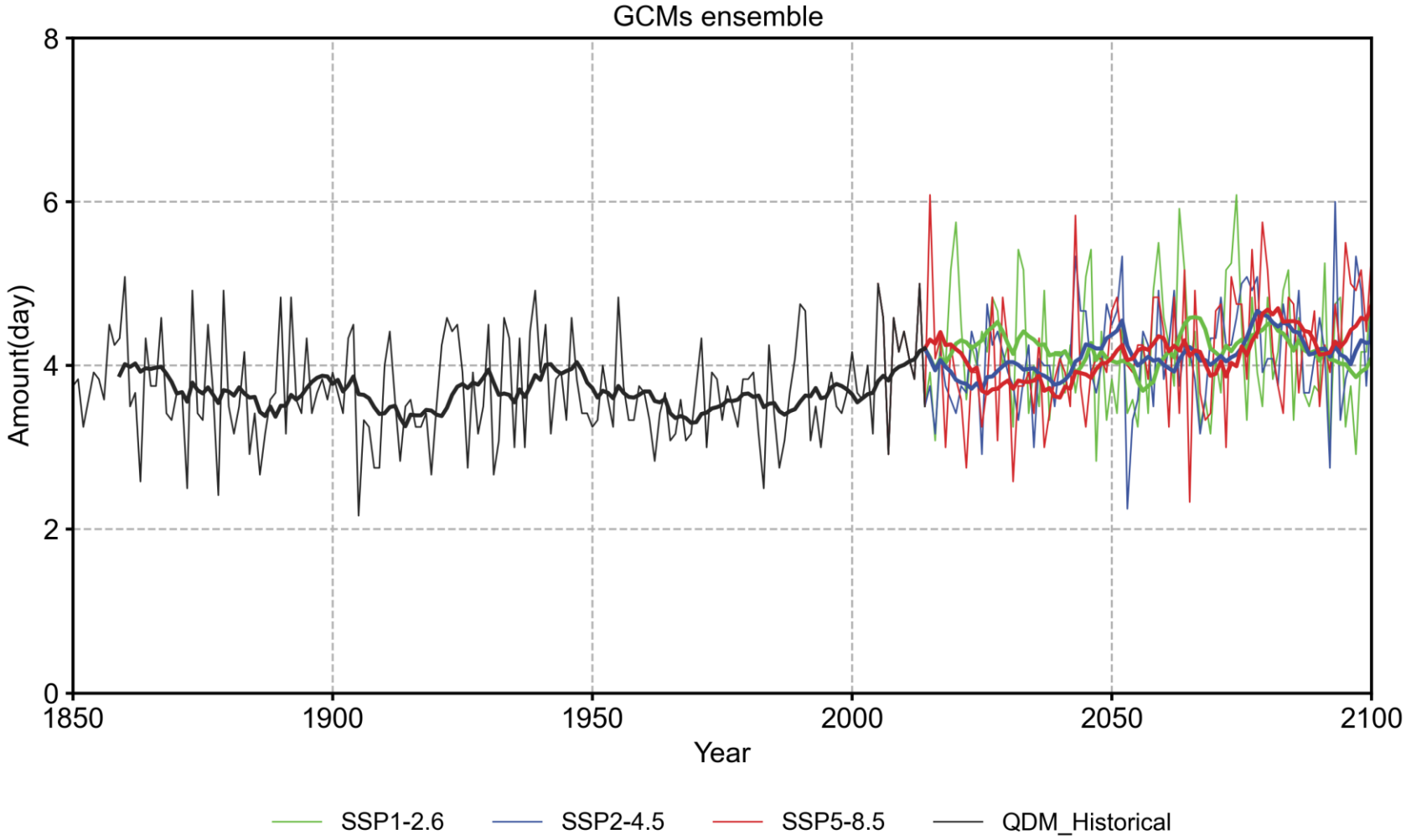
GCMs ensemble shows **a slow upward trend** with different emission scenarios in R99p in the future, with no significant difference between different emission scenarios.

The **frequency** of extreme rainfall **(R99p)** is likely to **increase slowly** under different emission scenarios. The difference in the effect of varying emission scenarios on R99p is not significant.



Time series of R99p (annual) for both historical and future projection of GCMs ensemble. The bold line represents the 10-year moving average.

Future changes of extreme rainfall

R99p:the annual and 10-year number of days with rainfall greater than the 99th percentile of daily amounts

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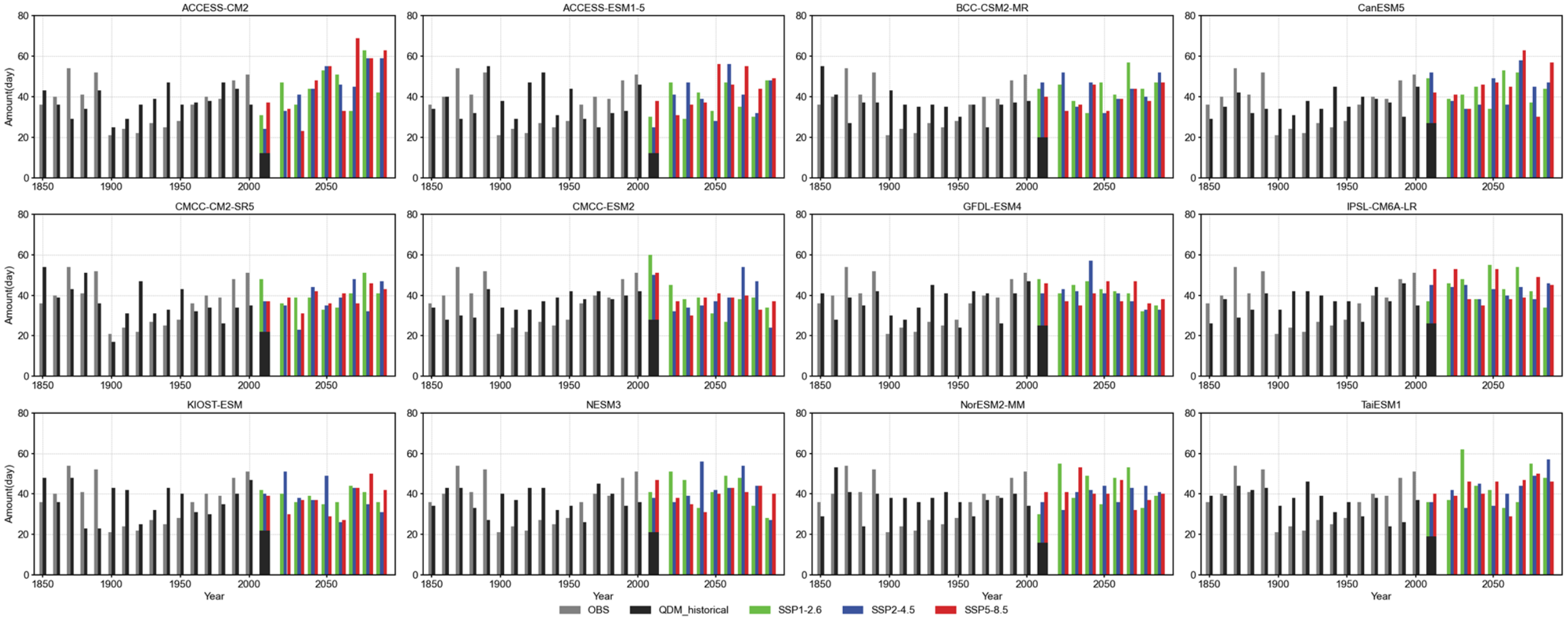
- Most of the models show **a stable trend** in R99p under different scenarios in the future.
- The ACCESS-CM2 models show **an increase** in R99p under SSP2-4.5 and SSP5-8.5 emission scenarios in the future.



Histogram of R99p (10-year) for both GCMs historical and future projection.

Conclusions

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- The GCMs after bias correction show better performance in the reproduction of historical rainfall statistics (Rx1day, R10mm, R20mm and R99p).

- **Rx1day** shows **an upward trend** with different scenarios in the future. Especially the SSP5-8.5 emission scenario shows a significant upward trend.
- **R10mm** shows **a downward trend** in the future. Especially under the SSP5-8.5 emission scenario, the R10mm declines significantly after 2060.
- **R20mm** is **generally stable** in the future, with gaps but not significant in different scenarios.
- **R99p** shows **a slow upward trend** in the future under different scenarios.

- Extreme future rainfall may change significantly. Especially under the SSP5-8.5 scenario, **extreme rainfall intensity** (Rx1day) **increases** significantly while **extreme rainfall frequency** (R10mm) **decreases**. It indicates that extreme short-duration rainfall is intensifying. Moreover, Extremely heavy rainfall frequency (R99p) slightly increase under different scenarios.

Thanks for your time and attention!!