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Sensitivity of Columbia Basin Runoff to Long-Term Changes in Multi-Model Cmip5 Precipitation Simulations

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Abstract

In this study, we used precipitation elasticity index of streamflow, ε_P, to reflect on the sensitivity of streamflow to changes in future precipitation. We estimated precipitation elasticity of streamflow from: (1) simulated streamflow by the VIC model using observed precipitation for the current climate (1963–2003); (2) simulated streamflow by the VIC model using simulated precipitation from 10 GCM - CMIP5 dataset for the future climate (2010–2099) including two different pathways (RCP4.5 and RCP8.5) and two different downscaled products (BCSD and MACA). The hydrological model was calibrated at 1/16 latitude-longitude resolution and the simulated streamflow was routed to the subbasin outlets of interest i.e. Hungry Horse subbasin. We used hydrological model simulations from 19063-2003 and calculated streamflow sensitivities and precipitation elasticity for the same period using observed climate (case 1) and simulated climate (case 2). The runoff sensitivity to long-term (e.g., 30-year) average annual changes in precipitation is calculated based on the elasticity of streamflow for three different 30 year blocks (2010-40, 2040-70 and 2070-99), which are of importance to reservoir management in the Columbia River basin. These two cases and different periods are compared to assess the effects of forcing by different climate models and different pathways on the precipitation elasticity of streamflow.

Precipitation Elasticity of Streamflow

Following Sankarasubramanian et al. (2001), we used a non-parametric estimator for precipitation elasticity of streamflow (Eq. 1)

$$e_P = median\left(\frac{Q_t - \bar{Q}}{P_t - \bar{P}} * \frac{\bar{P}}{\bar{Q}}\right) \qquad (1)$$

In the second part of our study, the multiple model outputs from 10 GCMs are combined using a weighted averaging method. In this method, the inverse of the error variance of each model's output for each model cell is used to estimate the weight for that cell.

Study Area: Hungry Horse Subbasin (Columbia River)

In this study we selected Hungry Horse subbasin located in the Eastern Columbia River Basin as a test-bed since the performance of the hydrological model for calibration and validation period are good (KGE-M of 0.92 and 0.84 respectively). The abbreviation, KGE, stands for Kling and Gupta metric (Gupta and Kling, 2011)

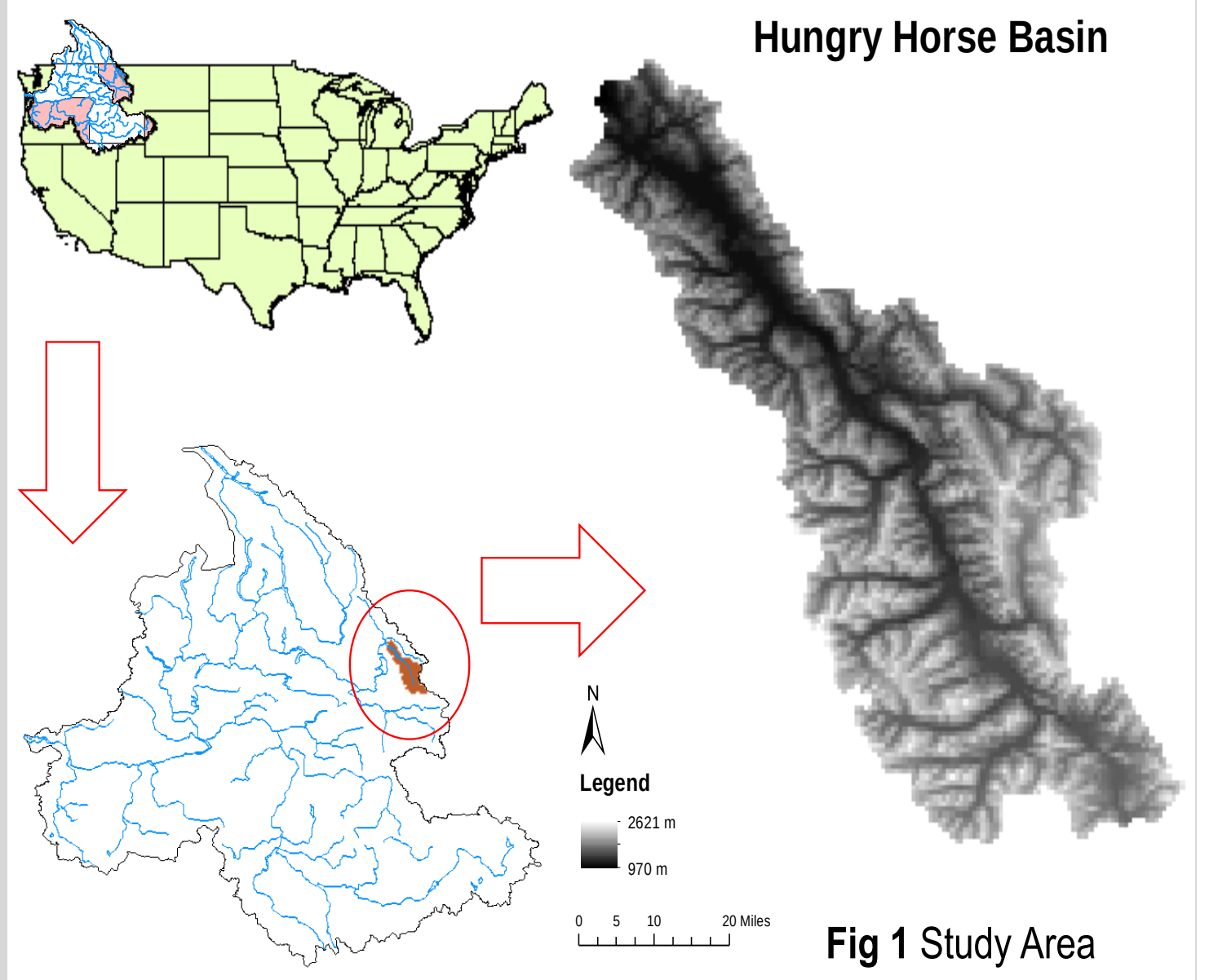


Fig 1 Study Area

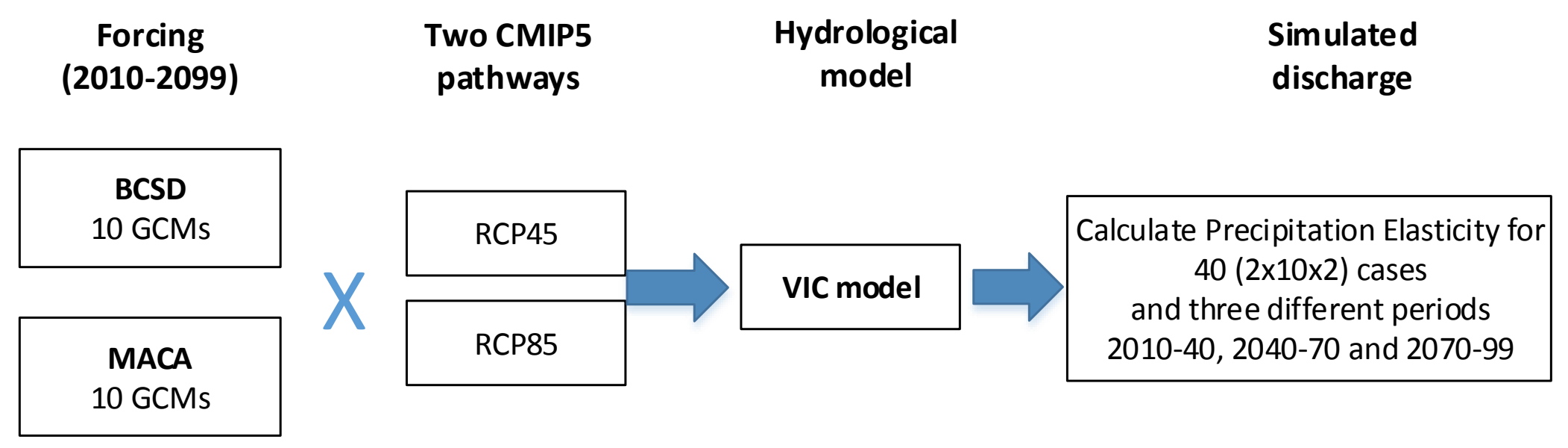
CRB Basin area: 567.000 km^2
Climate: Varies from moist, maritime conditions in the western parts of the basin to semi-arid and arid conditions in the south-eastern part.

Precipitation:

- Strong control of topography on precipitation.
- 2500 mm/year along the crest of Washington Cascades
- 1000-1800 mm/year in the northern Rocky Mountains, the west slope of the continental divide

Hungry Horse area: 1654 sq mi (~4284 km^2) and max historical peak discharge (year 1964) = 1578 cms ~55727 cfs

Flow Chart



Forcing (2010-2099)

- **BCSD** 10 GCMs
- **MACA** 10 GCMs

X

Two CMIP5 pathways

- RCP45
- RCP85

Hydrological model

VIC model

Simulated discharge

Calculate Precipitation Elasticity for 40 (2x10x2) cases and three different periods 2010-40, 2040-70 and 2070-99

Fig 2 Conceptual diagram of the elasticity analysis

Results: VIC model runs using BCSD and MACA forcing

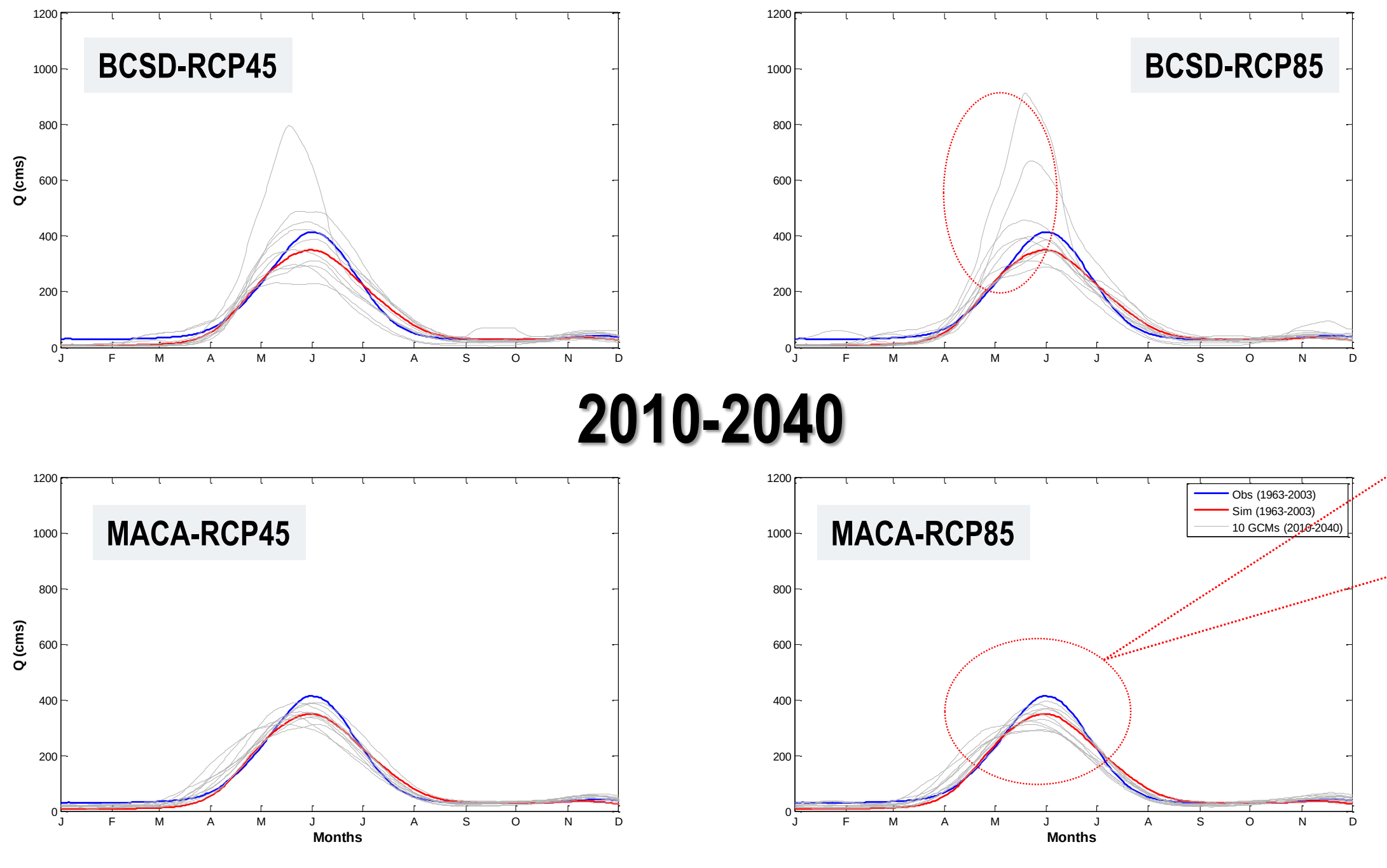


Fig 3 Discharge (monthly average) in the control period 1960-2003, with a 3 year spin-up, and in 2010-2040 based on two downscaling methods and two scenarios.

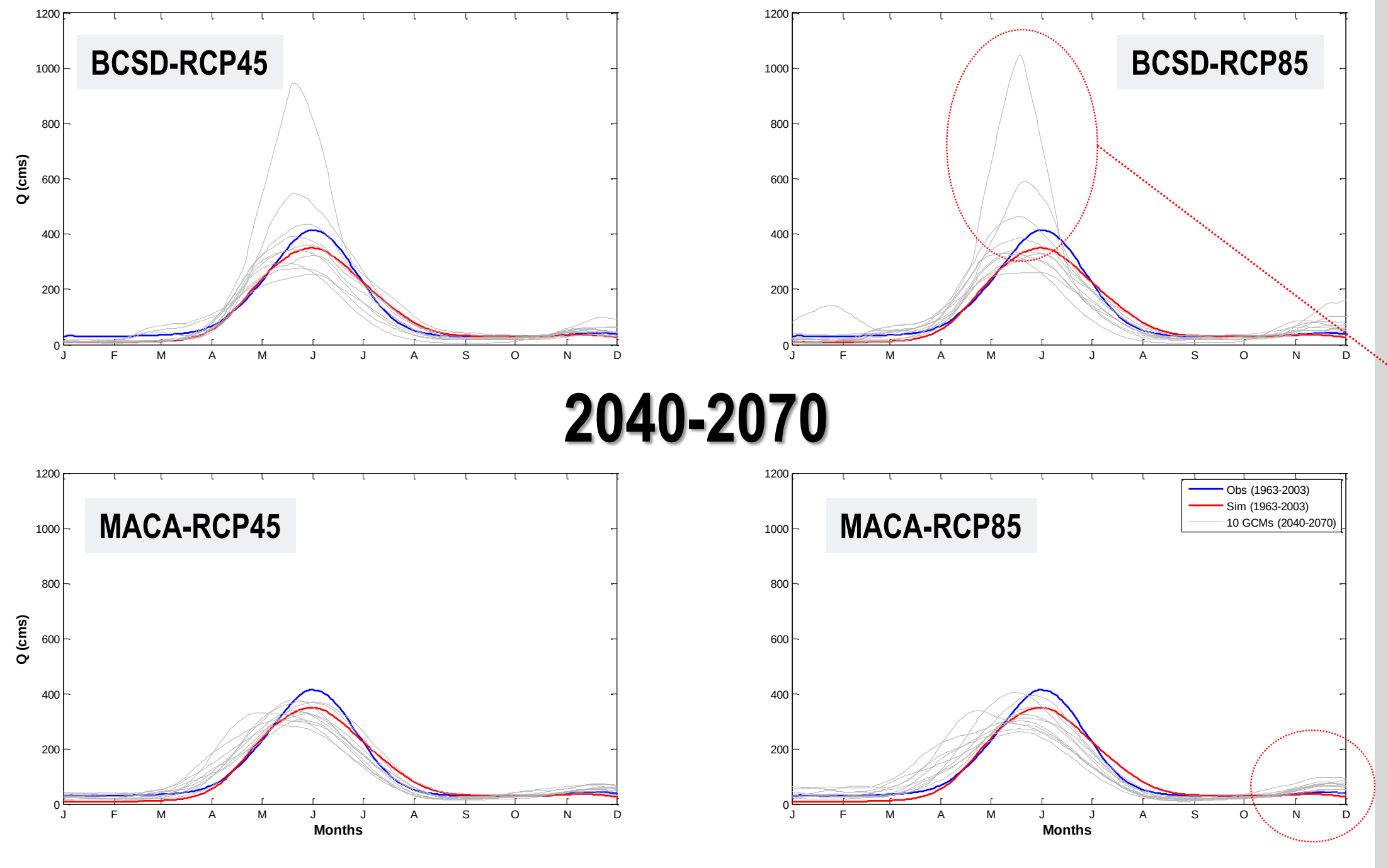


Fig 4 The same as Fig.3 except for the period 2040-70

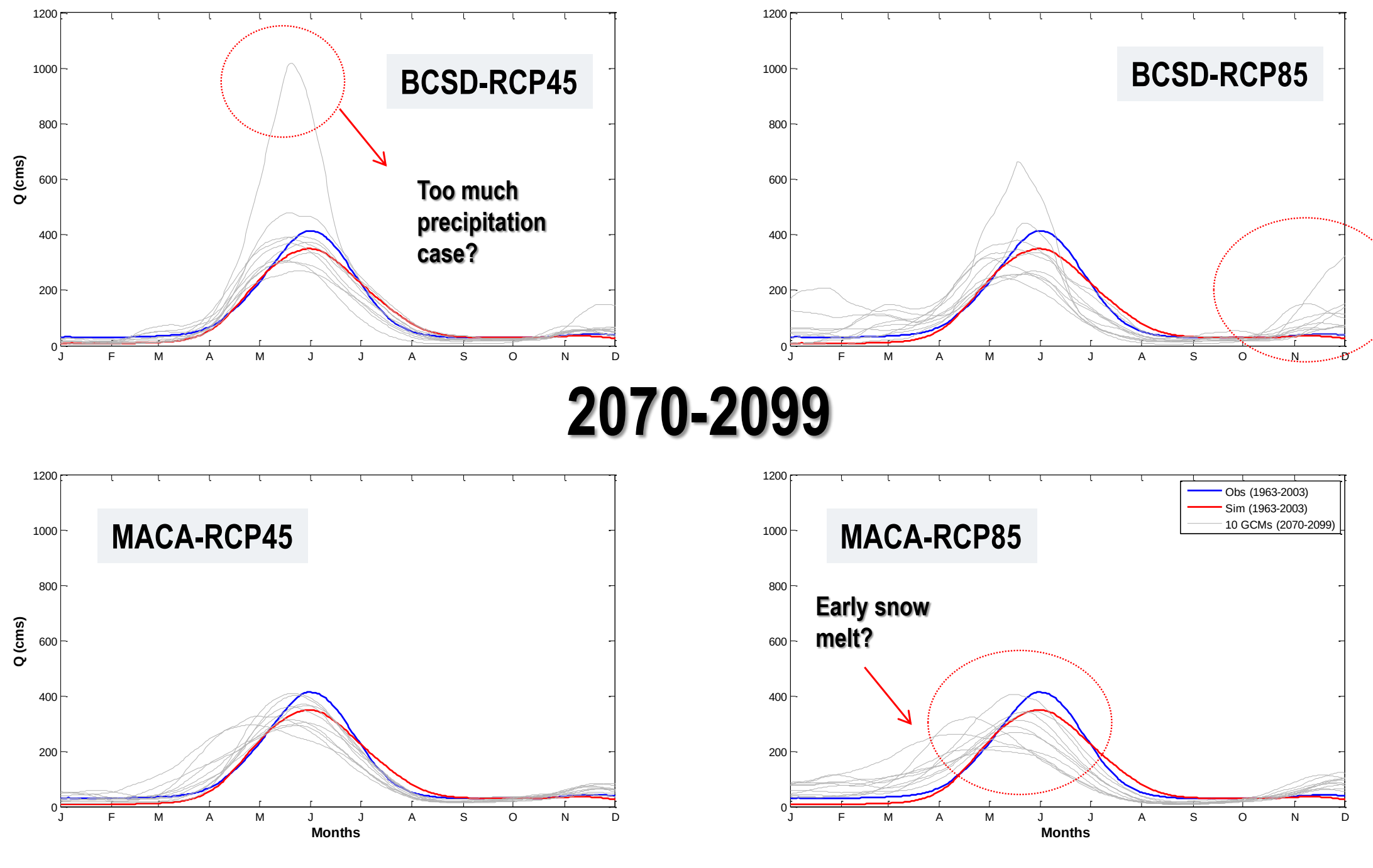


Fig 5 The same as Fig.3 except for the period 2070-99

Results: Precipitation Elasticity of Streamflow and P-Seasonality

SI index	Table 1: Legend for Precipitation Seasonality in Fig.6
< 0.19	Precipitation is equally spread throughout the year
0.20 – 0.39	Precipitation is equally spread throughout the year, but with a definite wetter season
0.40 – 0.59	Rather seasonal with a short direr season
0.60 – 0.79	Seasonal
0.80 – 0.99	Markedly seasonal with a long dry season
1.00 – 1.19	Most precipitation in less than three months
>1.20	Extreme seasonality, i.e. almost all precipitation occurs in 1-2 months

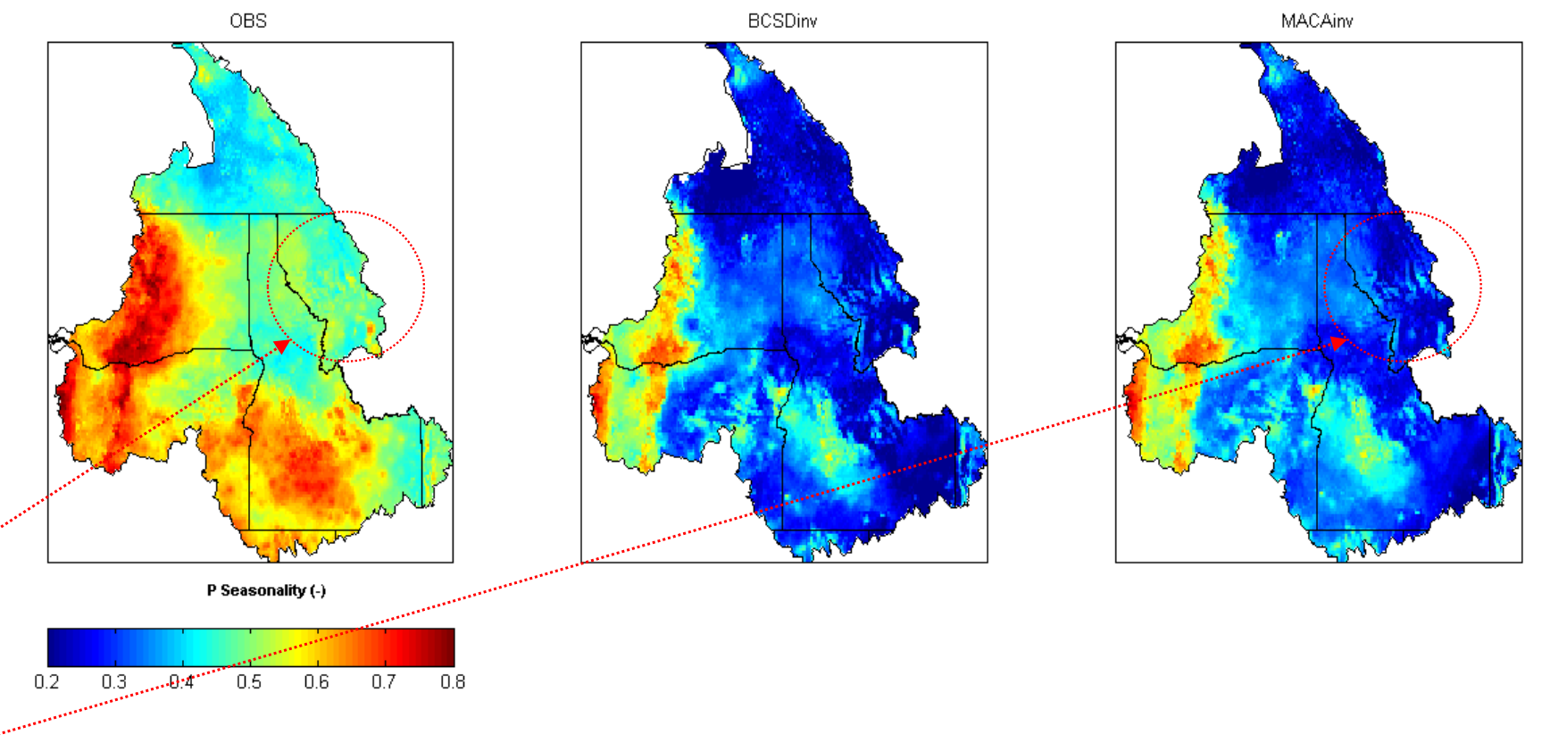


Fig 6 Precipitation seasonality for observed (1970-99) and multi-model BCSD and MACA data for the historical period (1970-99) using inverse variance method.

Precipitation seasonality in observed and downscaled GCM data are different (Fig 6).

Why?

Downscaling effect?

Figure 3 shows that the uncertainty in summer discharge is high for BCSD data. There is also a clear shift (earlier peak) in annual maximum summer discharges for both BSCD and MACA data, RCP85 pathway in particular. However, there is not much difference between simulated discharges using MACA-RCP85 and MACA-RCP45 data for the periods 2010-2040 and 2040-2070 (**Fig 4**).

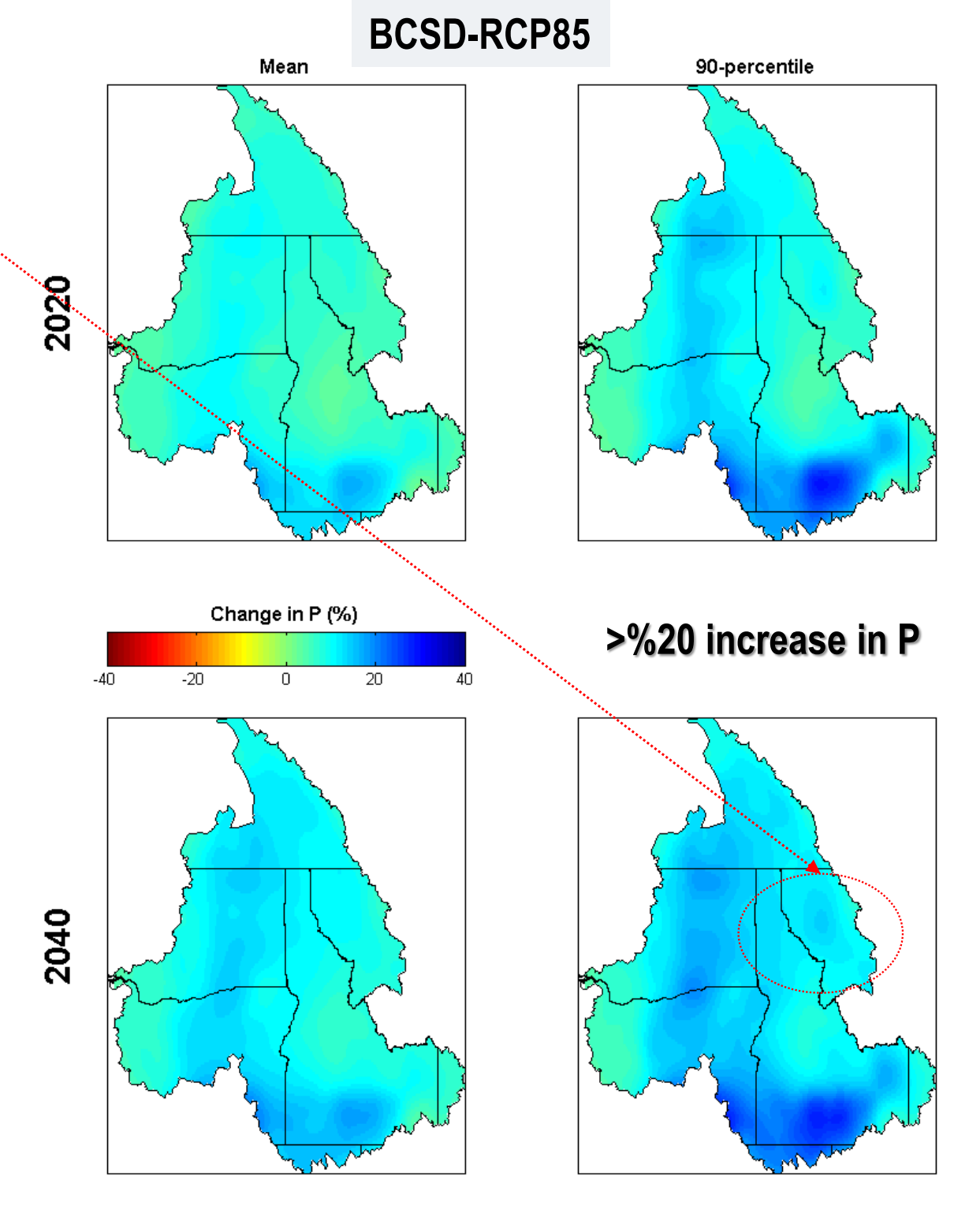


Fig 7 Change in Precipitation (%) for 2020s (upper row) and 2040s (bottom row) as compared to the observed (1970-99) period. Precipitation is estimated from multi-model BCSD-RCP85 data.

Figure 5 shows the simulated monthly discharges for the period 2070-2099 at the outlet of the Hungry Horse subbasin using VIC model and the simulated inputs from BCSD and MACA for two pathways i.e. RCP45 and 85. The spread of the spaghetti plots increases for far future simulations showing higher uncertainties in the forcing. This is the case especially for RCP85 pessimistic pathway and both summer and winter periods in BCSD and MACA datasets.

Figure 7 shows that the increase in BCSD Precipitation is expected to be more than %20 by 2040s in some parts of CRB. In MACA dataset the increase in Precipitation is lower than that in BCSD (not shown here). Simulated discharges using MACA data are therefore smoother than those by using BCSD data. In addition to the changes in simulated precipitation and streamflow series at Hungry Horse subbasin, we estimated precipitation elasticity of simulated streamflow using observed and simulated inputs (**Fig 8**).

Results: Precipitation Elasticity of Streamflow and P-Seasonality

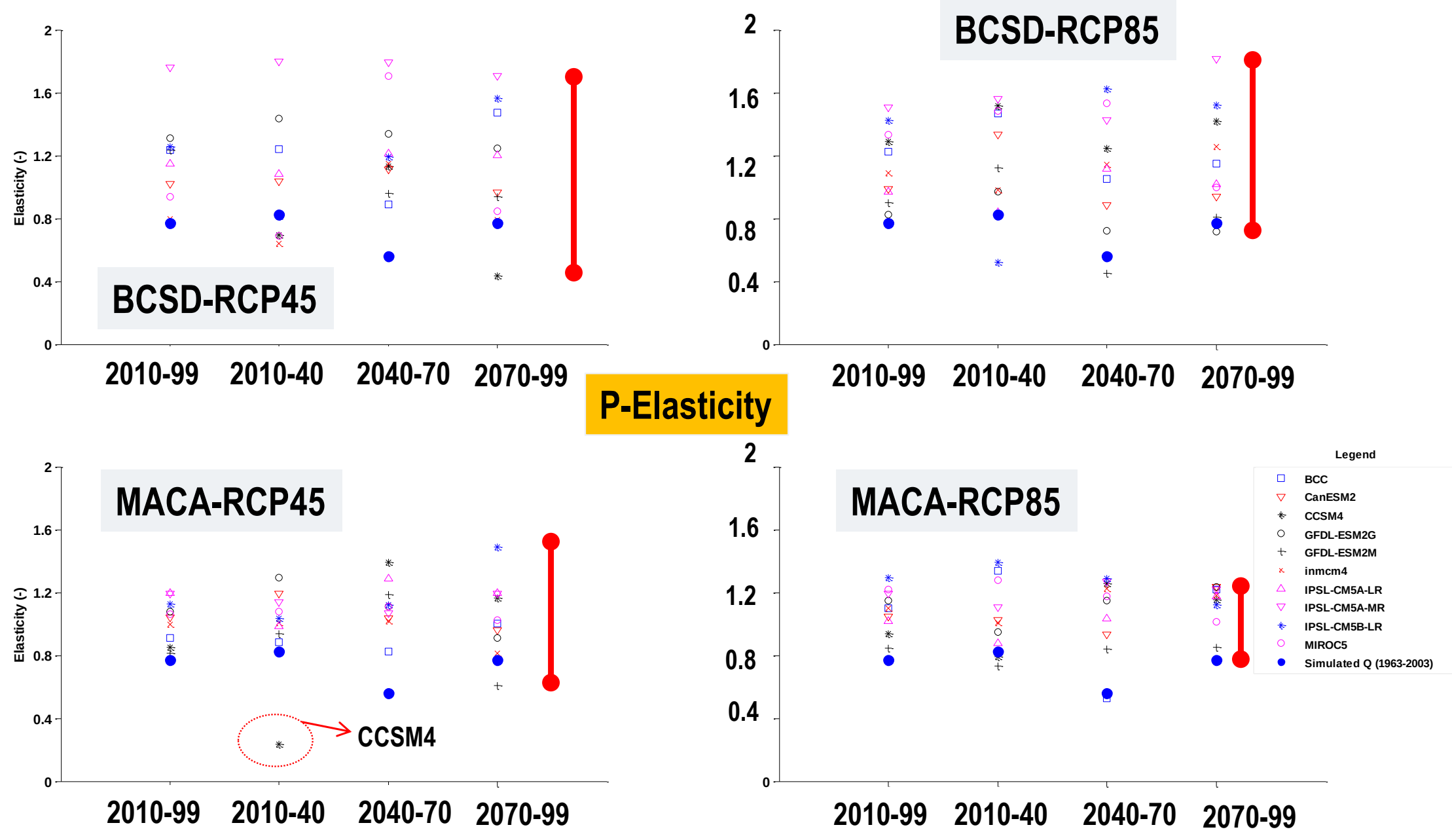


Fig 8 Precipitation elasticity of simulated streamflow using deterministic forcing (1960-2003) and simulated forcing by 10 GCMs downscaled by two methods i.e. BCSD and MACA for the future period (2010-99).

Figure 8 shows the precipitation elasticity of streamflow using 90 year block and three 30 year block data. This is done to assess the trends in elasticity for different periods. The precipitation elasticity estimates are between 0.5 and 1.9 (i.e. a 10% change in precipitation would change streamflow by 5-19% on-average). It is interesting to note that the uncertainty in precipitation elasticity for BCSD is higher than that for MACA. It is interesting to note that there is a clear decreasing trend in elasticity for MACA-RCP45, whereas MACA-RCP85 shows slightly decreasing trend in precipitation elasticity.

Conclusion

- We found significant differences in simulated discharges, precipitation seasonality and precipitation elasticity of streamflow using BCSD and MACA datasets.
- The ranges in precipitation elasticity of streamflow using BCSD forcing are higher than those for MACA showing the uncertainty in downscaled forcing.
- We used precipitation elasticity of streamflow to asses the climate change impacts on streamflow. However, other processes are also important in streamflow generation and temperature and PET elasticity of streamflow should also be considered to explain the changes in streamflow dynamics.
- We used Jan-Dec period in our precipitation elasticity calculations. However, the period Oct-Sept should also be tested as Fu et al (2007) found better performance in elasticity estimation due to the higher correlation between Q and P for the generic hydrological year definition i.e. the period from October to September as compared to Jan-Dec.

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