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Mehmet Demirel

Portland State University, mecudem@yahoo.com


Arun Rana

Portland State University

Hamid Moradkhani

Portland State University, hamidm@pdx.edu

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The effect of multi-model averaging of climate model outputs on the seasonality of rainfall over the Columbia River Basin

Mehmet Demirel (demirel@pdx.edu) - Arun Rana (arunrana@pdx.edu) - Hamid Moradkhani (hamidm@pdx.edu)

Department of Civil and Environmental Engineering - Portland State University



Abstract

The rainfall seasonality index is the measure of precipitation distribution throughout the seasonal cycle. The aim of this study is to compare the effect of different multi-model averaging methods on the rainfall seasonality index at each 1/16 latitude-longitude cells covering the Columbia River Basin. In accordance with the same, ten different climate model outputs are selected from 45 available climate models from CMIP5 dataset. The reanalysis precipitation data is used to estimate the errors in rainfall seasonality for the climate model outputs. The inverse variance method and statistical multi criteria analysis (SMCA) method were used to estimate the weights for each climate model output. The precipitation amounts from the climate model outputs were then averaged using these model weights. The rainfall seasonality index was estimated from: (1) observed reanalysis data; (2) averaged precipitation amount from ten combinations of CMIP5 outputs for the current climate (1979–2005) using inverse variance method; (3) averaged precipitation amount from the ten combinations of CMIP5 outputs for the current climate using SMCA. The results showed the no/little differences in rainfall seasonality index for each climate model averaging. Moreover, the multi-modelling of climate models resulted in relative improvements in the performance of the rainfall seasonality over the Columbia River Basin as compared to individual models. The estimated model weights for the current climate can be useful to combine the model outputs for the future climate.

Two Multi-model Averaging Methods: Inverse Var and Weights

In this study multiple model outputs are combined using two weighted averaging methods. In the first method, the weights are distributed over each model grid cell (1/16) and estimated based on the performance of each model over the reference historical period. In other words, the inverse of the error variance of each model's output for each model cell is used to estimate the weight for that cell. The second method is based on the statistical multi criteria analysis (SMCA) of each model. One weight for the model is used for all cells; therefore, it is a lumped approach as compared to the first method. It should be noted that the total of weights are equal to 1 for each cell (first method) or for all models (second method).

$$p(M_j|D) = \frac{1/\sigma_{\epsilon_j}^2}{\sum_{i=1}^k 1/\sigma_{\epsilon_i}^2} \quad (1)$$

$$\sigma_{\epsilon_j} = \sqrt{\sum_{t=1}^n (P_{t,j}^{sim} - P_{t,j}^{obj})^2} \quad (2)$$

$$P_{MMt} = \sum_{j=1}^k p_j * P_{t,j}^{sim} \quad (3)$$

where M_j is the climate model j , D is the calibration period (here 1950-2005), σ_{ϵ} is the model error variance, k is the number of climate models, $P_{t,j}^{sim}$ is the simulated precipitation at time t for climate model j and $P_{t,j}^{obj}$ is the observed precipitation.

Rainfall Seasonality Index

Rainfall Seasonality Index (SI_i), estimated by Eq (4), shows the variability of precipitation through the year (Walsh and Lawler, 1981).

$$SI_i = \frac{1}{R_i} \sum_{n=1}^{n=12} \left| X_{in} - \frac{R_i}{12} \right| \quad (4)$$

where R_i is the annual total precipitation for the particular year and X_{in} is the monthly actual precipitation for month n . The index does not provide details about the timing and amount of precipitation at monthly variations. However, its ease of calculation makes it an ideal tool for the analysis of spatial and temporal variations in precipitation. The index values can vary from zero to 1.83, where a zero value indicates that all months have equal rainfall and a value of 1.83 indicates that all rainfall occurs in one month (see Table 1).

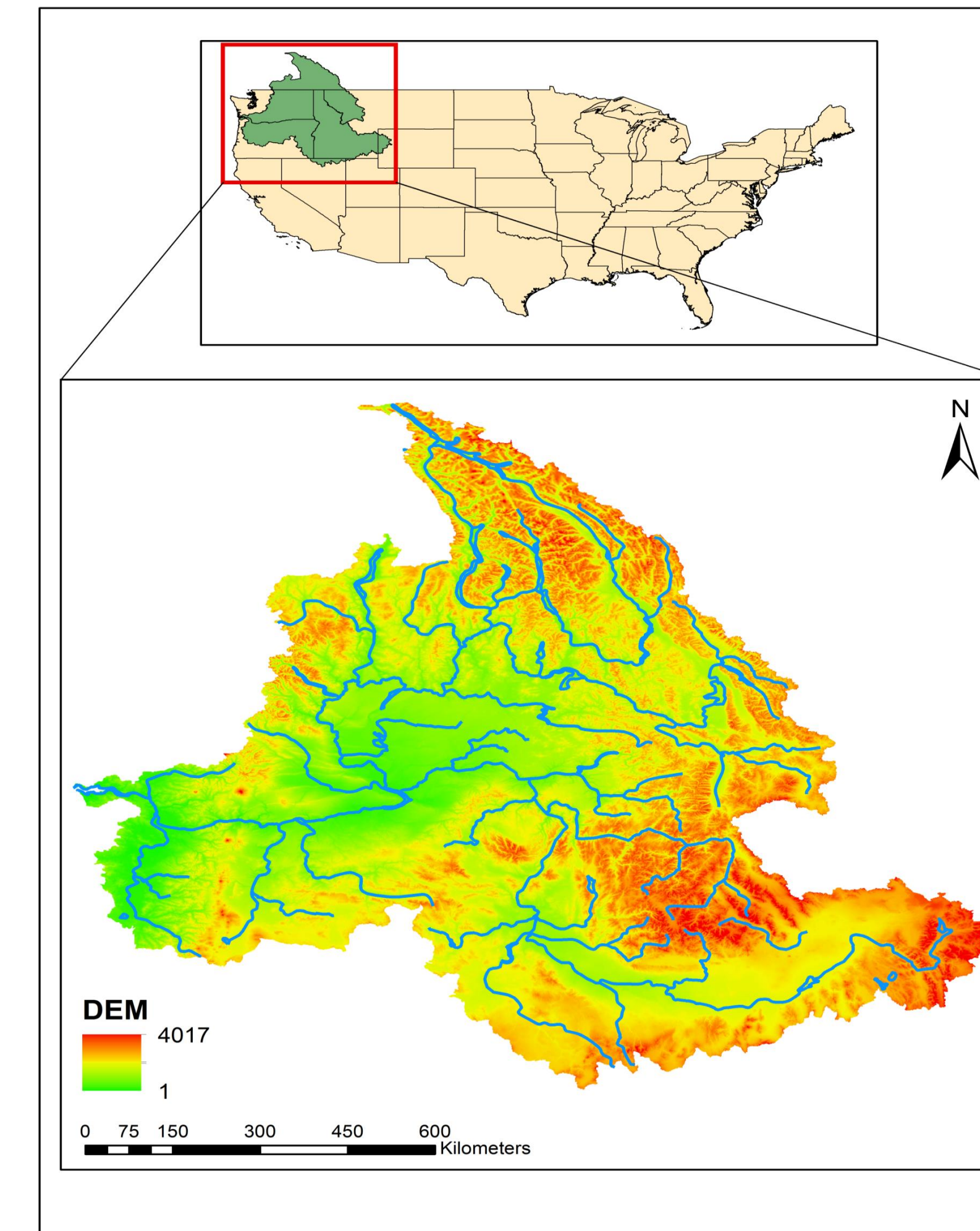
A long-term average $\overline{SI_i}$ for each cell may subsequently be calculated from the accumulated SI_i s over a longer period like 30 years in Eq (5).

$$\overline{SI_i} = \frac{1}{30} \sum_{j=1}^{j=30} SI_{ij} \quad (5)$$

Table 1 Precipitation regimes indicated by the SI_i

SI_i	Precipitation regime
< 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 drier 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

Study Area: Columbia River Basin

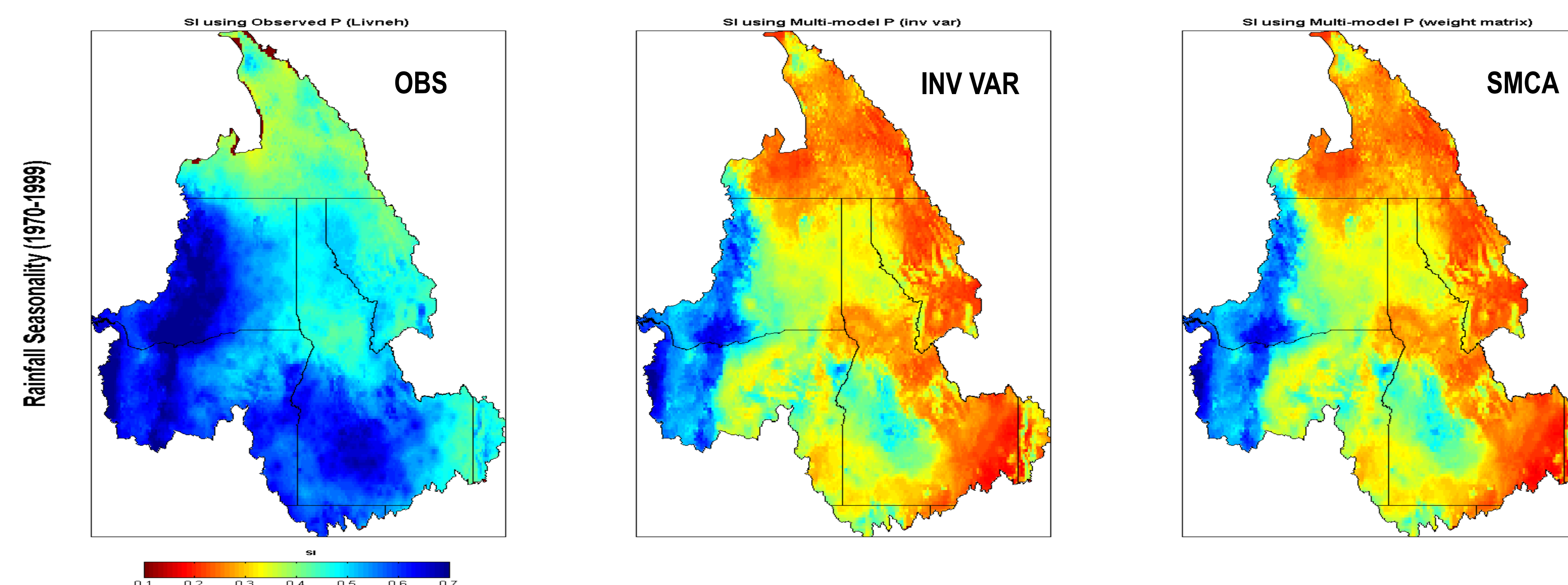


Basin area: 567,000 km² (seven states-85% and part of British Columbia-15%)

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
- 200-400 mm/year in Columbia Plateau in Washington and Snake River Plain



Findings

- SI of observed dataset in CRB indicates a seasonal pattern in South-east and south-west region with rather seasonal with short drier season in extreme east part of the basin.
- Rainfall is equally spread throughout the with a definitive wetter season in northern parts (rocky mountain chain) with central part depicting the pattern closer to eastern parts of the basin.
- As per Multi-model climate series with both the techniques, the SI index is spatially different compared to observed.
- Western region of the basin is preserving the behavior of seasonality of rainfall as represented by observations.
- Eastern and Northern part reveals SI less than equal to 0.2 which represents that the rainfall is spread equally throughout the year.
- Central region of CRB represents equal spread but with definite wetter season.
- There is particularly no visible difference between the seasonality accessed from the two different multi-modelling methods.
- GCM downscaled using statistical methods seem not been able to replicate the observations on finer resolution.
- Though the Multimodal time series failed to replicate the observations but this is relative huge improvement when compared to individual model results.

Conclusion

In this study we found significant differences between observed climate and multi-model of 10 GCM precipitation simulations for the historical part. Although the two multi-model methods are quite different the results revealed similar seasonality characteristics for Columbia River Basin. This can be from the fact that the seasonality index is a averaged index over 30 year period and monthly totals.

Our ultimate goal is to use the results of this multi-model simulated precipitation as input for hydrological models. The uncertainty revealed by this study is crucial and should be taken into account for hydrological modelling practices.

Acknowledgment

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