北京大学
PEKING UNIVERSITY

REGIONAL PATTERNS OF FUTURE RUNOFF CHANGES EMERGING FROM EARTH SYSTEM MODELS CONSTRAINED BY OBSERVATION

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Summer School 2015

Background

Water allocation

Landsat satellite image

Reservoirs/Power production

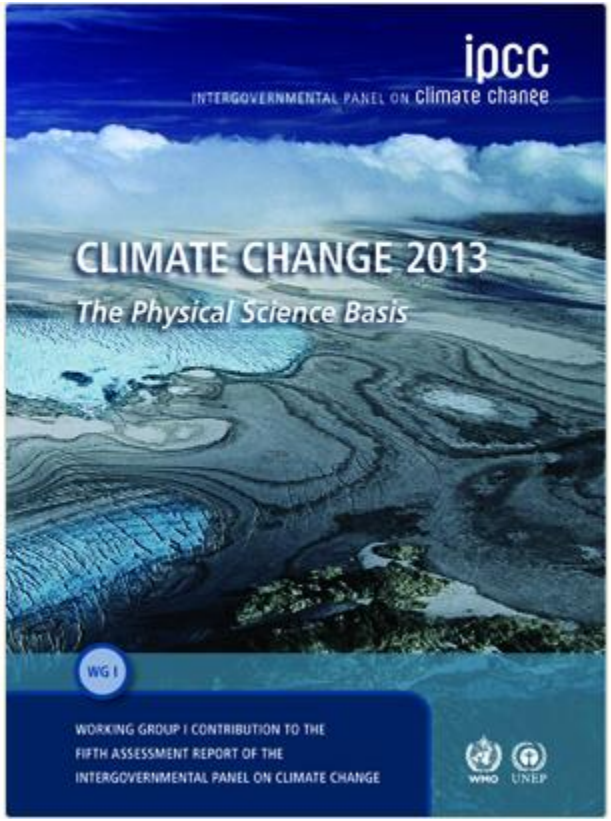
Runoff/Streamflow forecast?

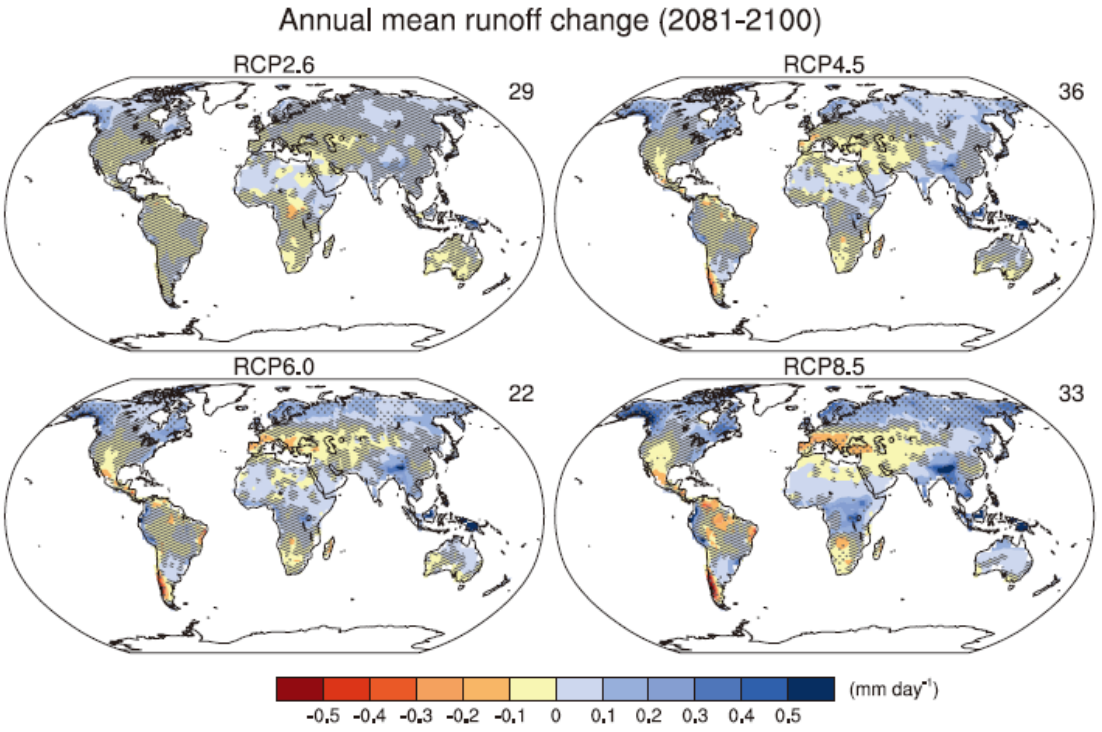
Changes in land use/ climate

Flood and Drought

[*Oki and Kanae*, 2006; *Hall et al.*, 2013]

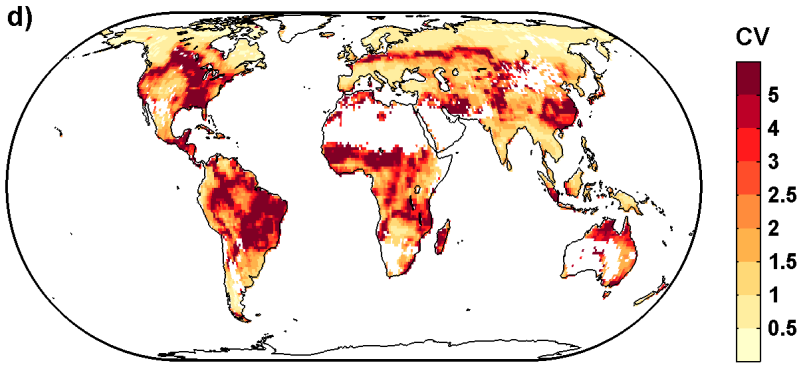
Introduction

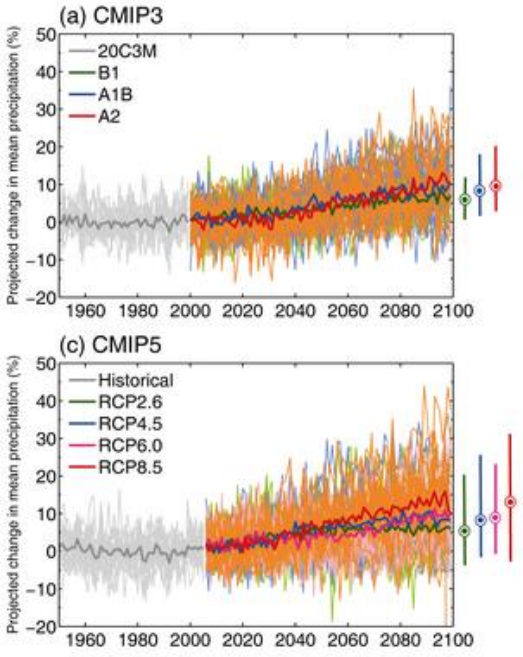


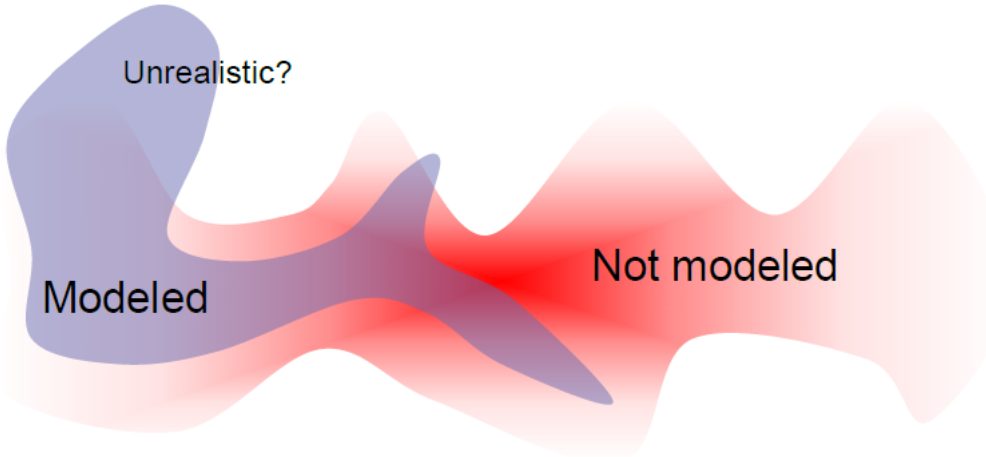


[*IPCC, AR5 WGI, Chapter 12, 2013*]

Introduction







Reality → Model: Abstraction

Described in Model

Model → Reality: Interpretation

[*Knutti et al., 2013*]

Method

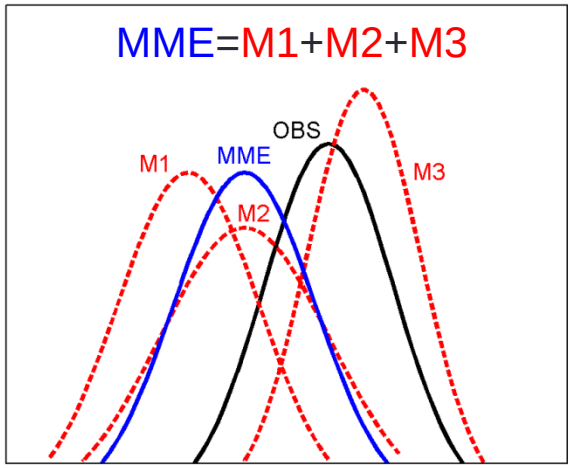
AOGCMs → Future scenarios → Project changes in runoff

AOGCMs → Historical simulation

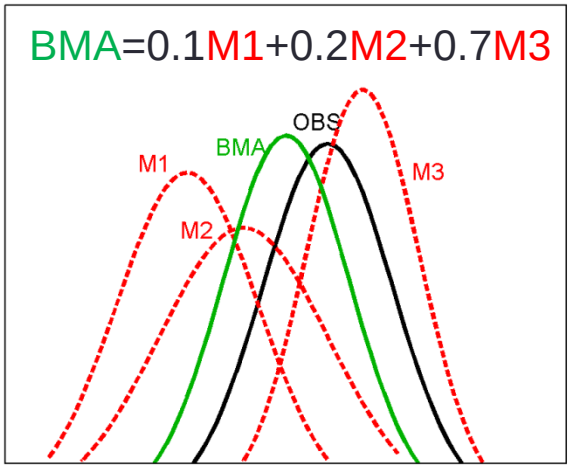
Observed records

Historical simulation + Observed records → Find the optimal model weights

Multi-model ensemble (MME)



Bayesian model averaging (BMA)



Method

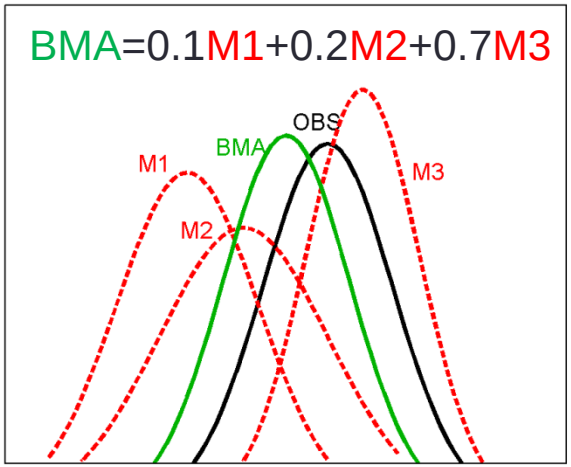
AOGCMs → Future scenarios → Project changes in runoff

AOGCMs → Historical simulation, Observed records → Find the optimal model weights

$$f(\mathbf{Z}|\mathbf{Y}_1^h, \ldots, \mathbf{Y}_k^h) = \sum_{k=1}^{K} w_k g_k(\mathbf{Z}|\mathbf{Y}_k^h),$$

Z -- Historical data
Y^h – hindcasts for model M_k
$g_k(Z|Y^h)$ -- the conditional distribution of Z given that M_k is the "best" model.

Bayesian model averaging (BMA)



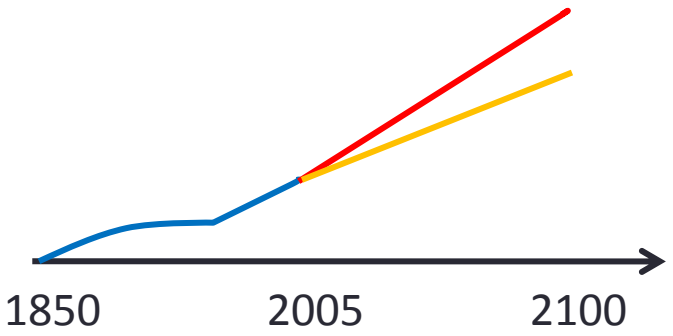
Data

Runoff/Discharge

- 17 AOGCMs (Historical, RCP4.5 and RCP8.5)
- UNH-GRDC Composite runoff
- In-situ river discharge record

RCP4.5 (stabilization near 2100)

RCP8.5 (GHG continue to increase)



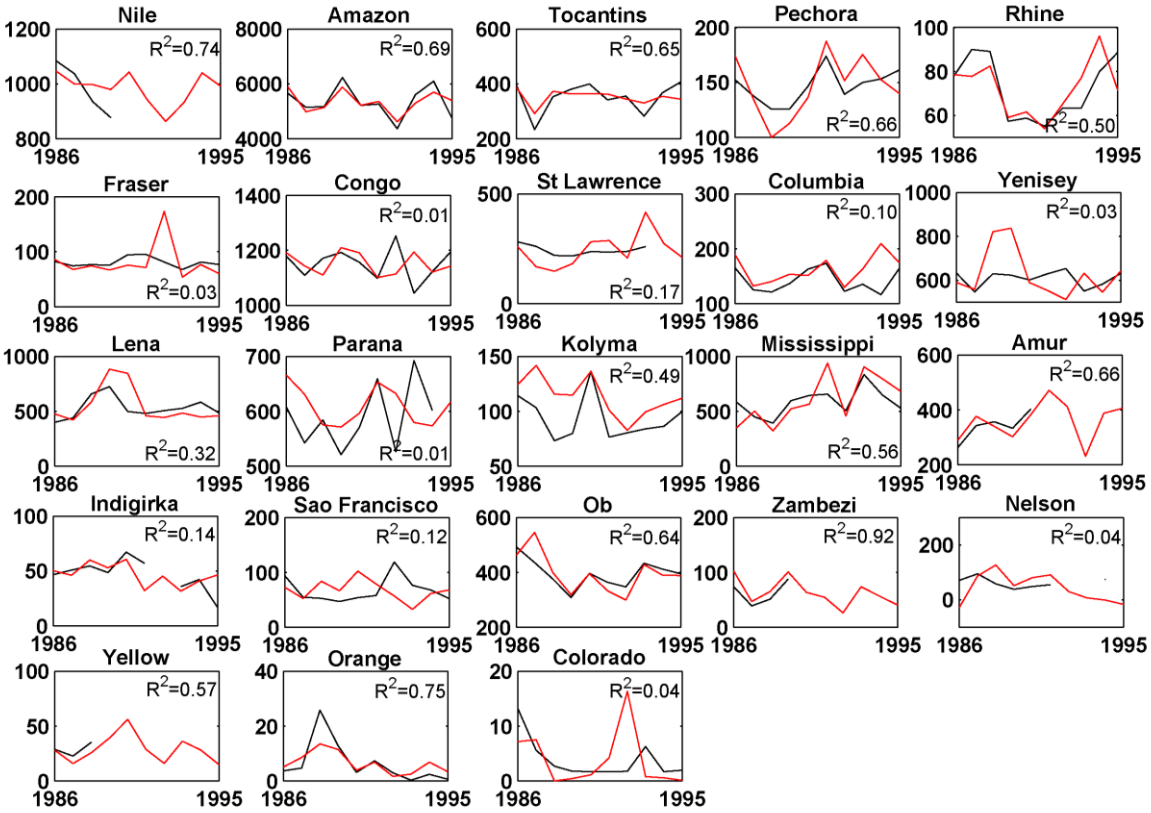
Climate

- Precipitation data (6 datasets)
- Evapotranspiration (3 datasets)

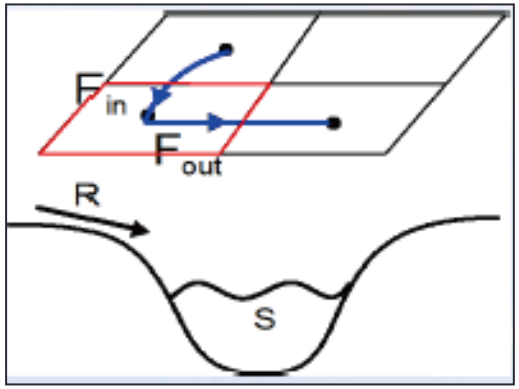
CRU GPCC GPCP
UdelP PREC/L CPC

EC-MTE CSIRO WB-MTE

Data



Routing Model

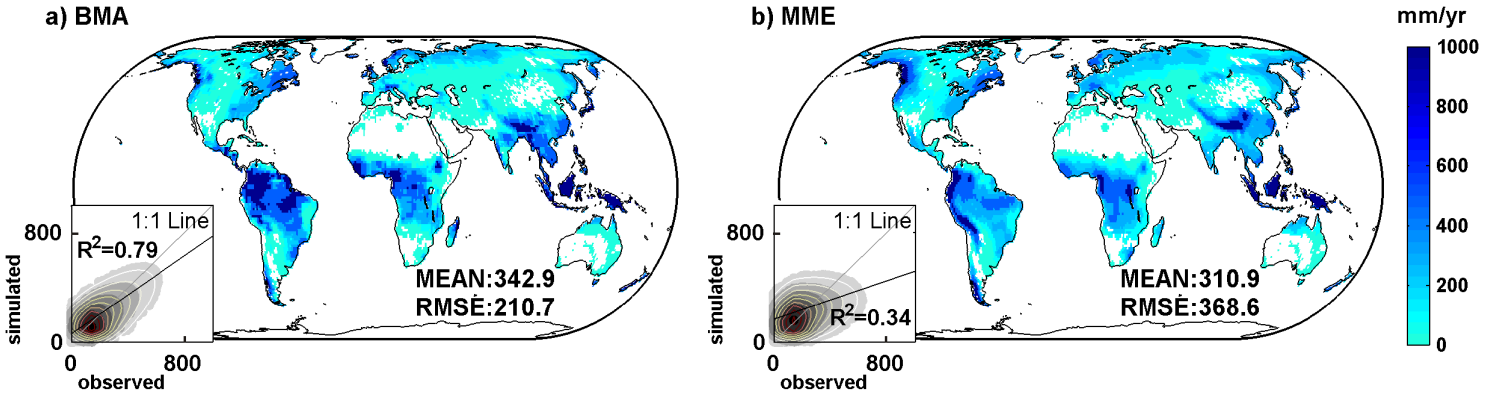


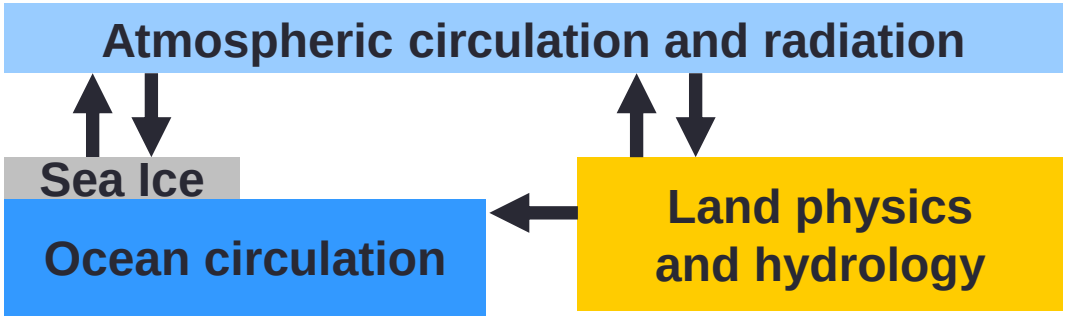
UNH-GRDC runoff → **routing** → **Discharge record**

[*Miller et al.*, 1994]

Results: BMA v.s. MME

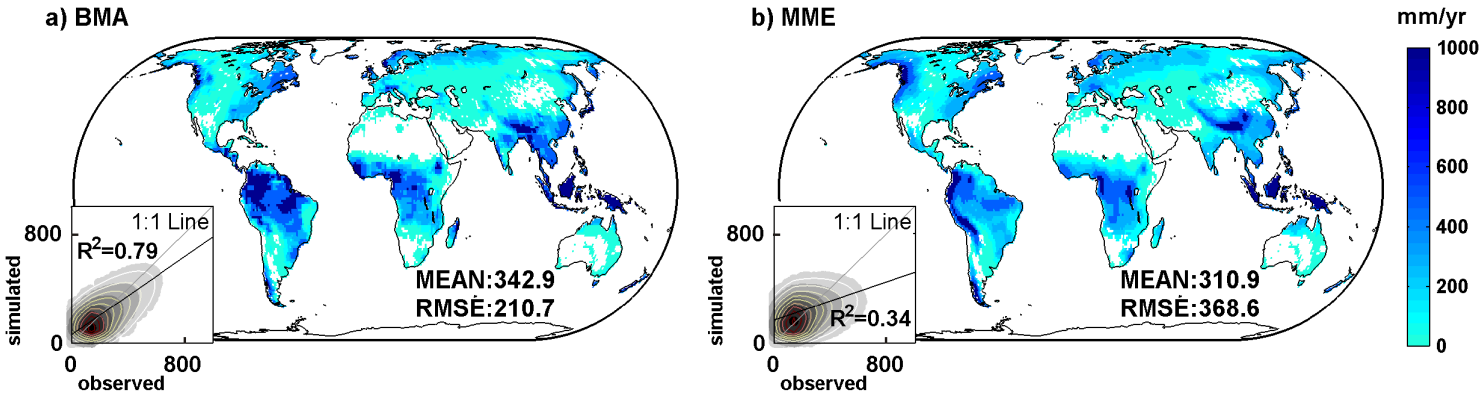
Mean patterns of annual runoff (1986-1995) simulated by multi-model ensemble

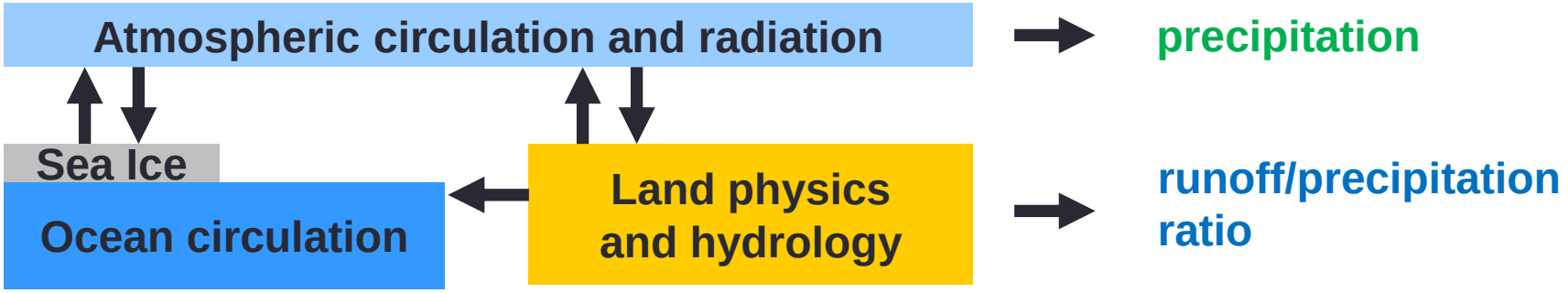




Q: Models do not capture runoff because of biased climate (e.g. rainfall) or because of biased LSMs?

Results: BMA v.s. MME



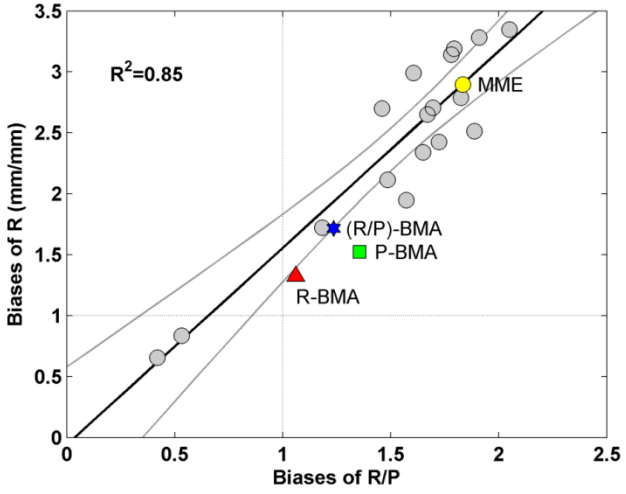


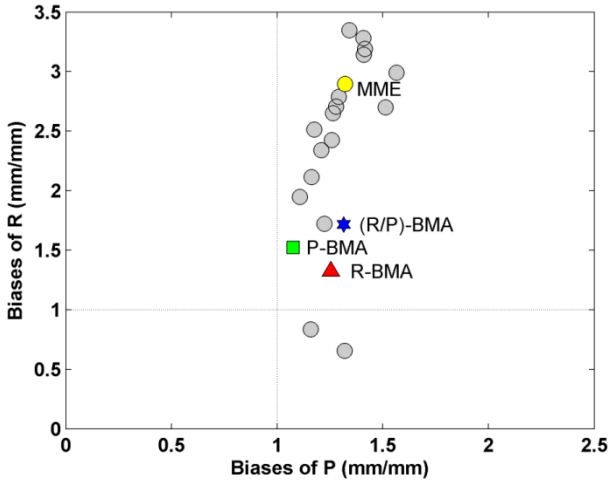
Q: Models do not capture runoff because of biased climate (e.g. rainfall) or because of biased LSMs?

Results: Source of biases

OPTIONS:

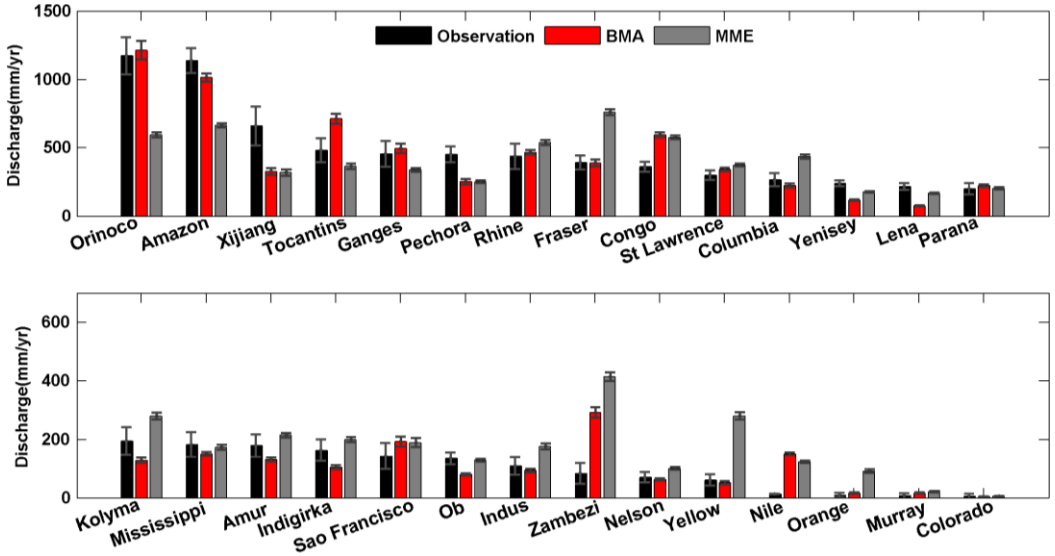
- **R-BMA: minimize the biases of R(runoff)**
- **P-BMA: minimize the biases of P(precipitation)**
- **(R/P)-BMA: minimize the biases of R/P**

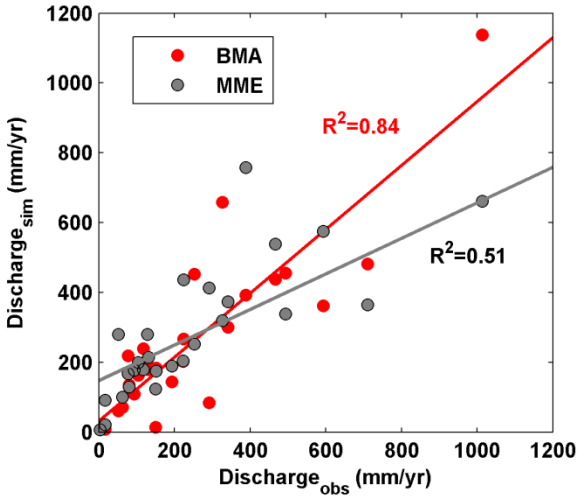




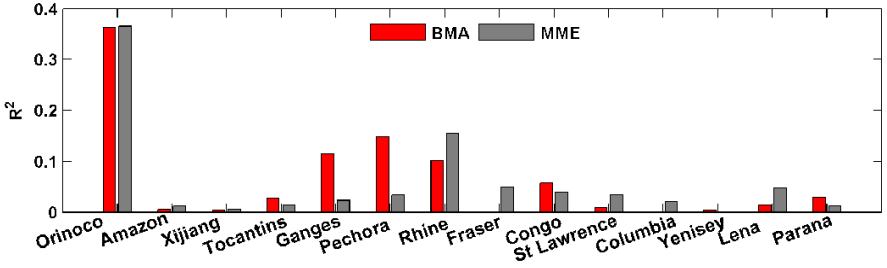
- ✓ **The inter-model spread of runoff is mainly related to model differences in the R/P that relates to LSMs.**
- ✓ **The biases of runoff originate primarily from biased LSMs.**

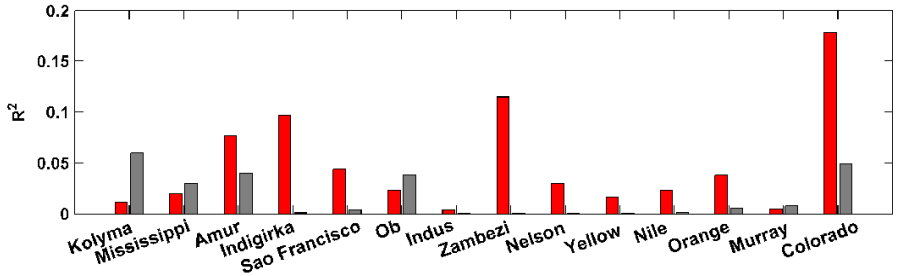
Results: BMA v.s. MME





Interannual Variability of Discharge

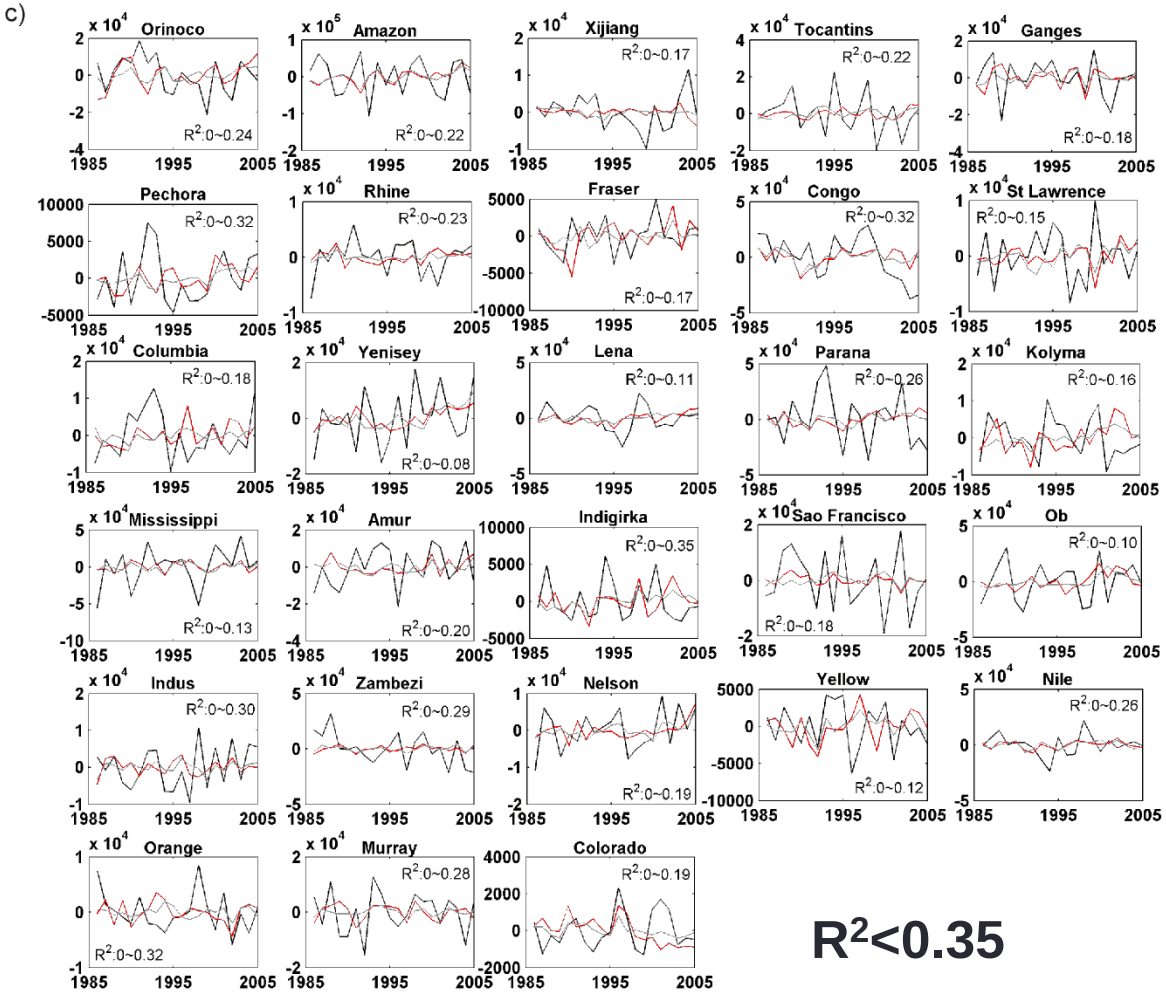




R^2<0.2?

Results: BMA v.s. MME

Interannual variability of precipitation

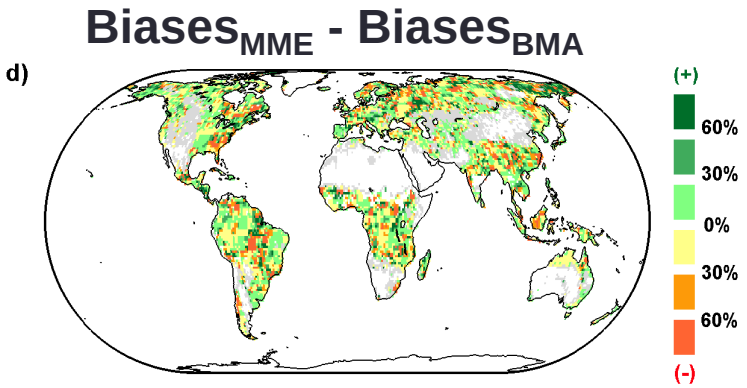


AOGCMs' forcing data:

- Solar forcing data
- CO_2 emissions
- GHG concentration data
- Land-use data

$R^2<0.35$

Results: BMA v.s. MME



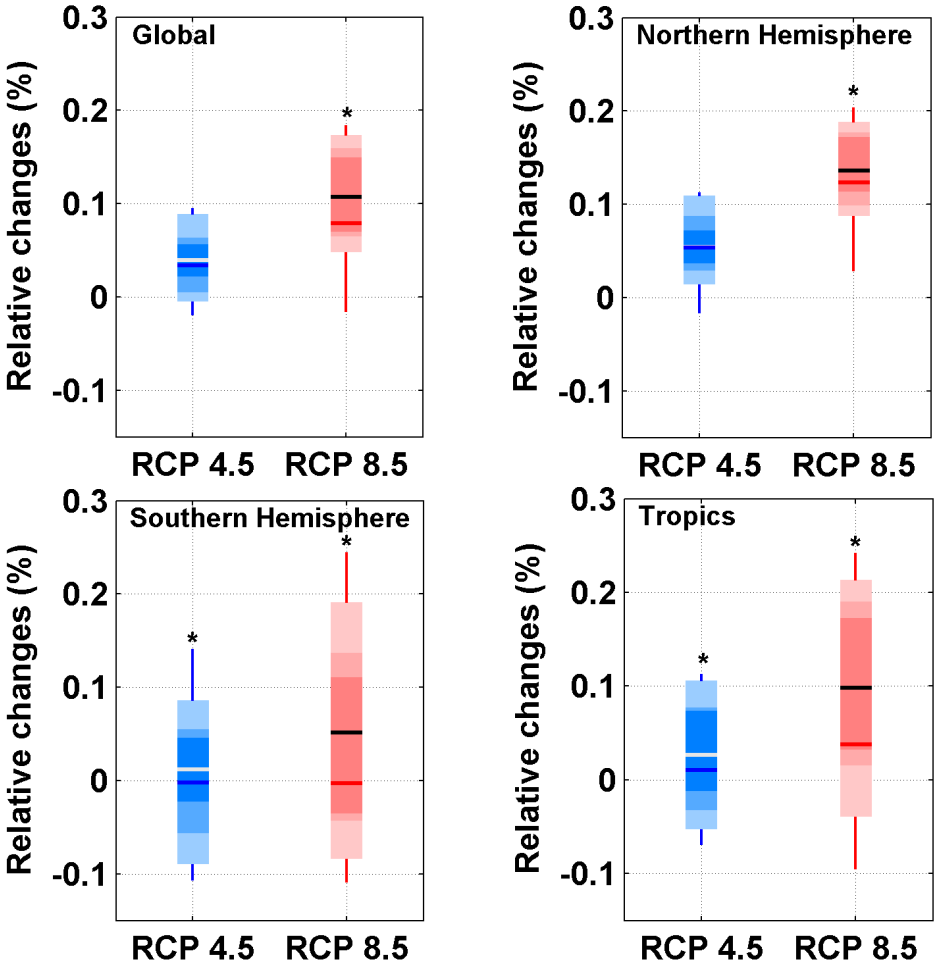
Water Balance Equation

$$\frac{\partial S(t)}{\partial t} = P(t) - R(t) - ET(t) = 0$$

Figure shows the differences between MME- and BMA-based biases of 5-year-average runoff changes (∆) between 1986-1990 and 2001-2005, where the runoff is calculated as the difference between P and ET.

Results: Projected changes

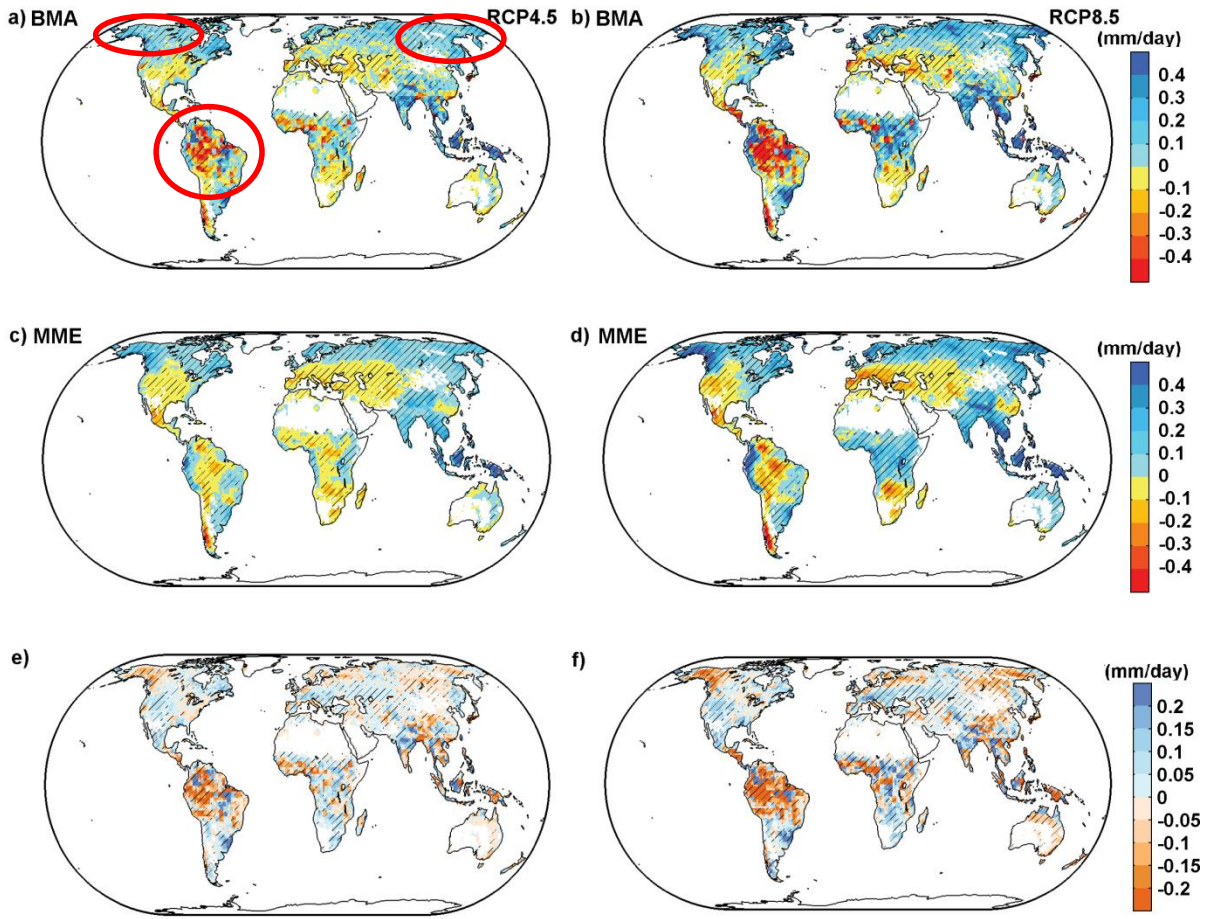
Projected changes in runoff over the period of 2081-2100 relative to the period of 1986-2005.



Differences in runoff between the BMA and the MME, are not significant for the Global, Northern Hemisphere but they are significant in the Southern Hemisphere and the tropics in RCP4.5.

Results: Projected changes

projected runoff changes between 2081-2100 and 1986-2005

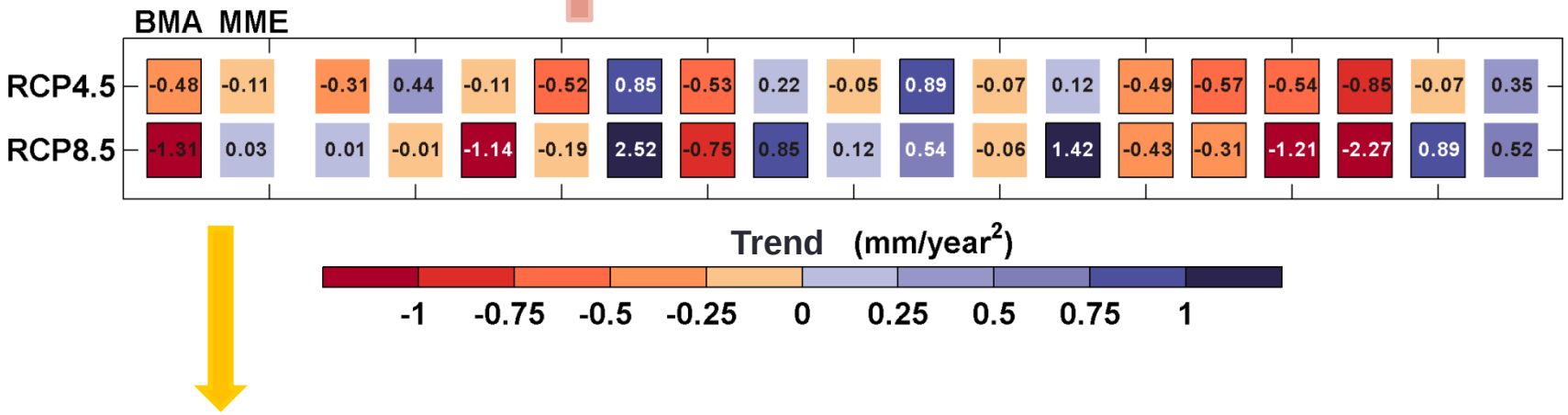


Results: Projected changes

Amazon Basin

RCP4.5: 11(6) AOGCMs ↓ 6(2) AOGCMs ↑

RCP8.5: 9 (6)AOGCMs ↓ 8(4)AOGCMs ↑



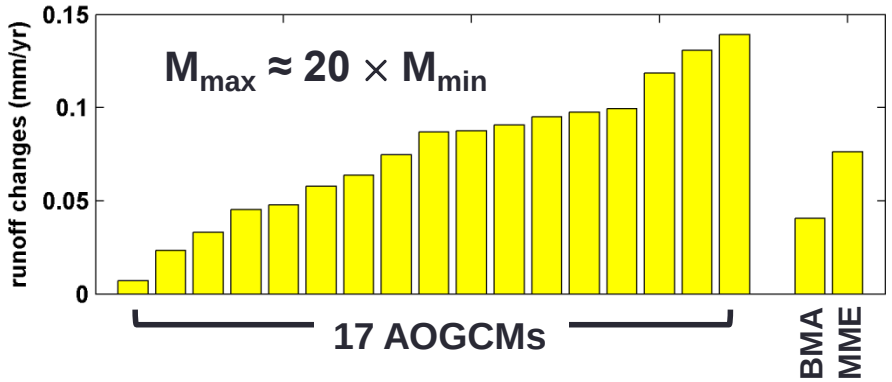
	Difference		Inter-model spread
RCP4.5:	0.37mm/yr²	~	0.50 mm/yr²
RCP8.5:	1.34 mm/yr²	>	1.09 mm/yr²

Results: Projected changes

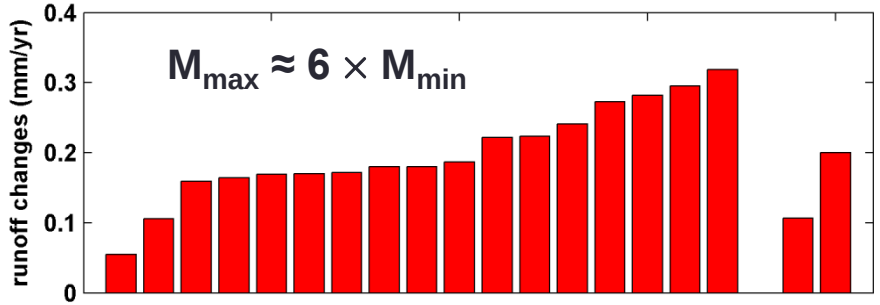
Alaska and Siberia

The models agree for the sign but not with the magnitude of runoff changes.

RCP4.5

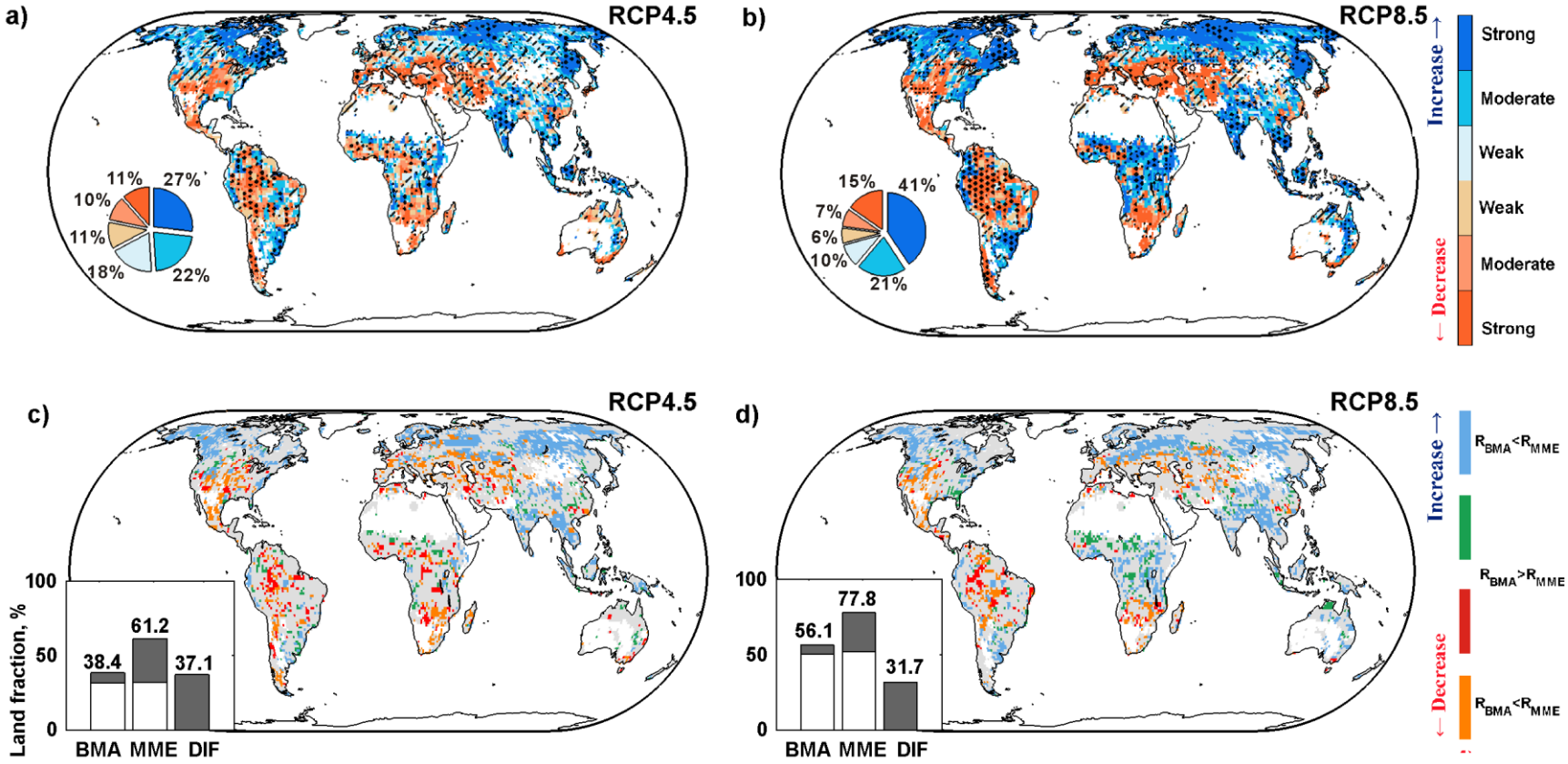


RCP8.5



MME ≈ 2 × BMA

Results: Significance of projected changes



MME 61.2% ~ BMA 38.4%
(15.9%&46.3%) (11.6%&26.8%)

MME 77.8% ~ BMA 56.1%
(20.7%&57.1%) (15.5%&40.6%)

Conclusion

- **Do BMA-based projections have greater reliability?**

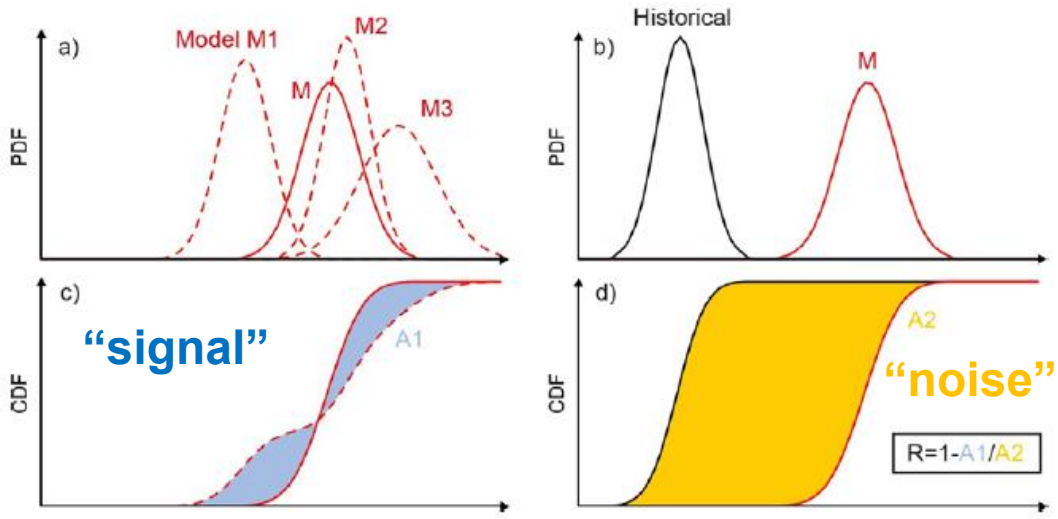
  NO!

- **Large differences in runoff changes between weighted and un-weighted ensembles indicate that the projection in runoff changes remains challenging.**
- **A focused effort is still required for narrowing inter-model spread of LSMs.**

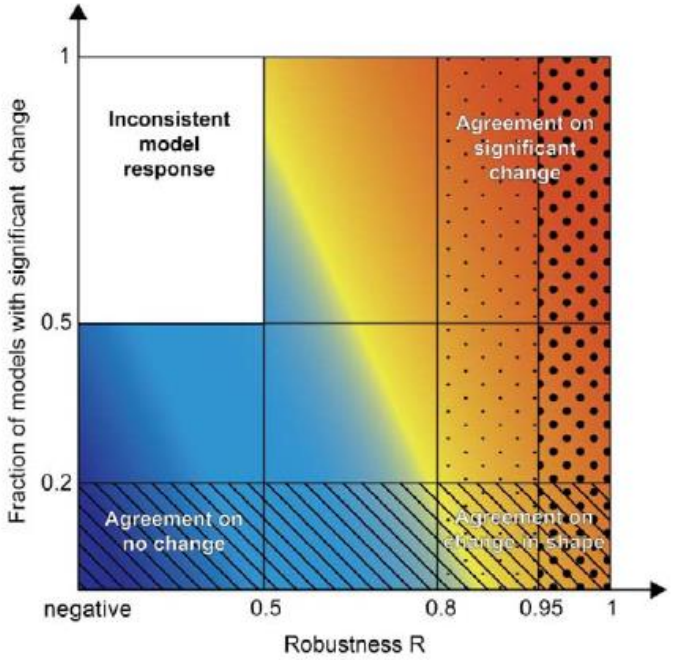
Thanks a lot for your attention!

Results: Significance of projected changes

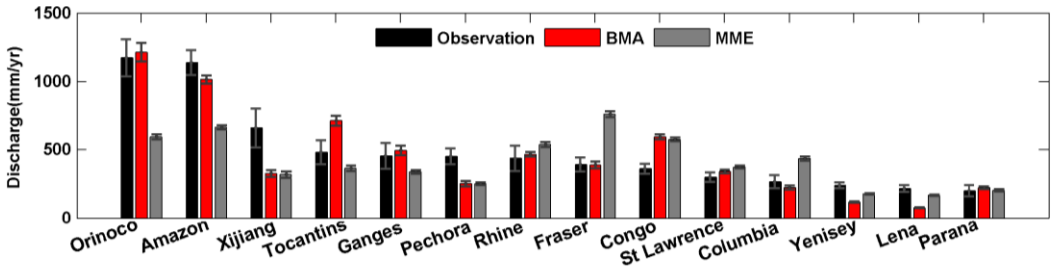
The ratio of model spread to the predicted change (noise to signal)

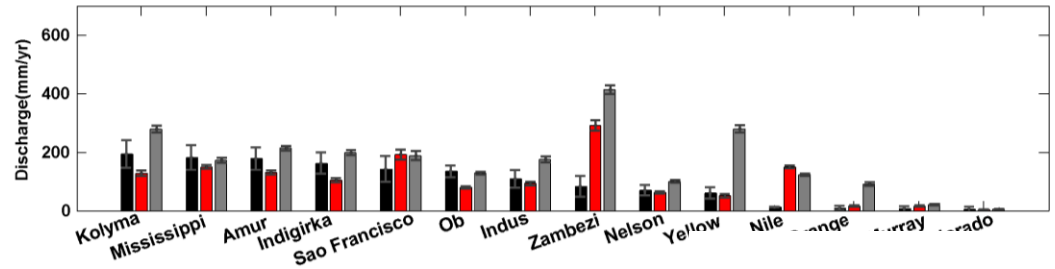


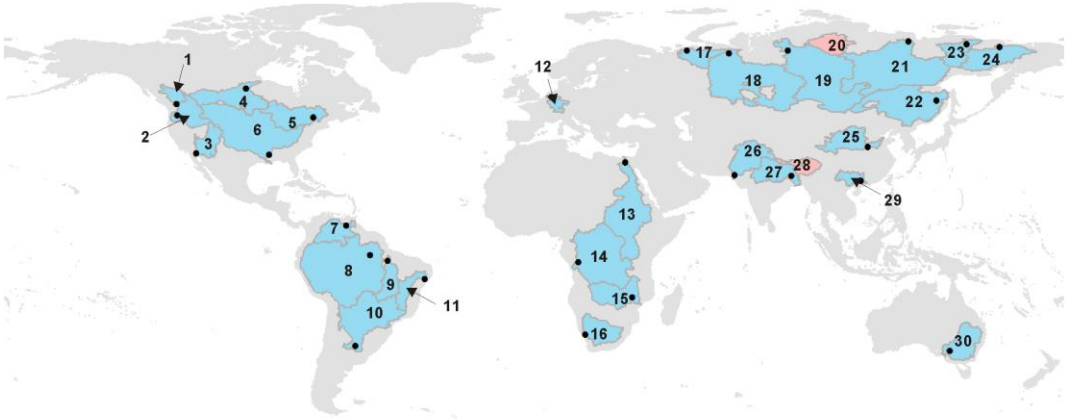
R = 1 – A1/ A2



Compare: two standard deviations of variability?







North America
1 Fraser
2 Columbia
3 Colorado
4 Nelson
5 St Lawrence
6 Mississippi

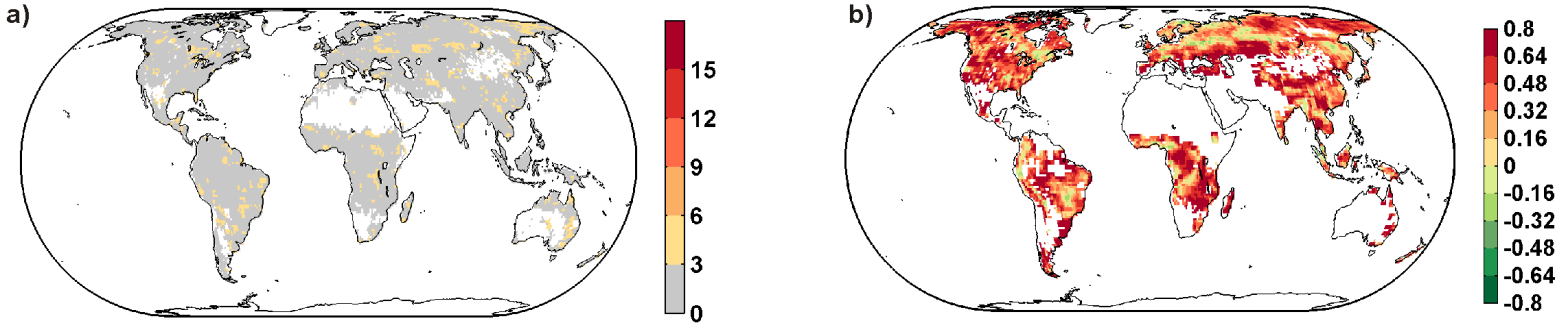
South America
7 Orinoco
8 Amazon
9 Tocantins
10 Parana
11 Sao Francisco

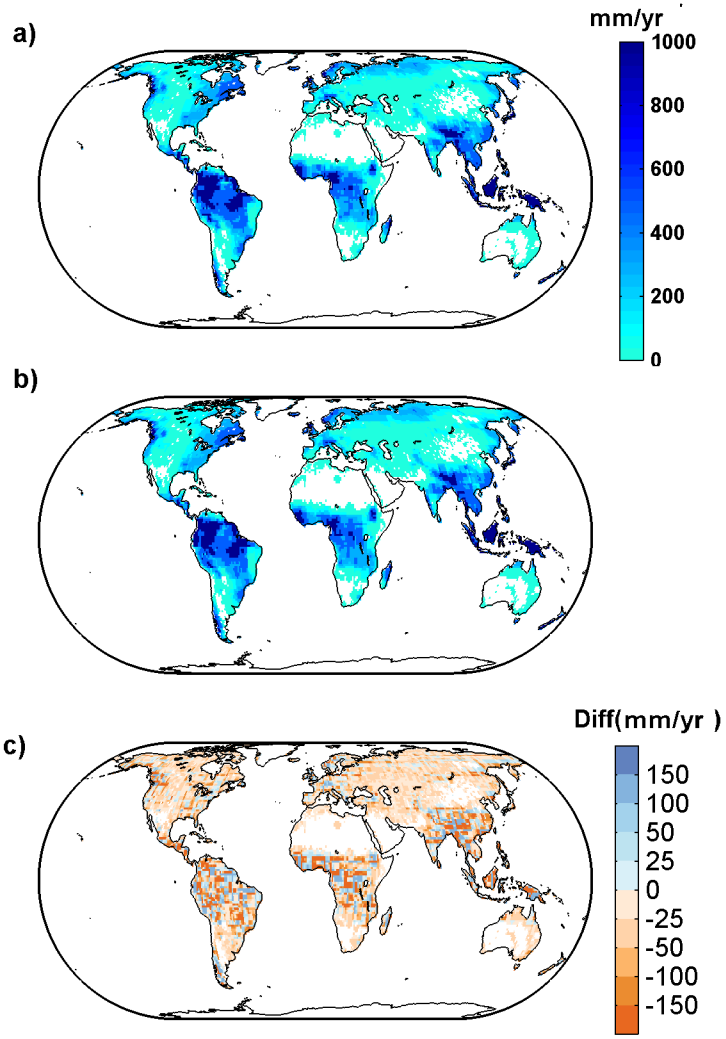
Europe
12 Rhine

Africa
13 Nile
14 Congo
15 Zambezi
16 Orange

Asia and Australia
17 Pechora
18 Ob
19 Yenisey
20 Khatanga
21 Lena
22 Amur
23 Indigirka
24 Kolyma
25 Yellow
26 Indus
27 Ganges
28 Brahmaputra
29 Xijiang
30 Murray

Figure S4 a) Number of models (out of a total 17 models) showing a significant trend of historical runoff for the period 1986-1995 ($P<0.05$ according to the Mann-Kendall test); **b)** The correlation coefficient of historical mean annual runoff for the period 1986-1995 and future runoff changes between 1986-2005 and 2081-2100 across 17 AOGCMs

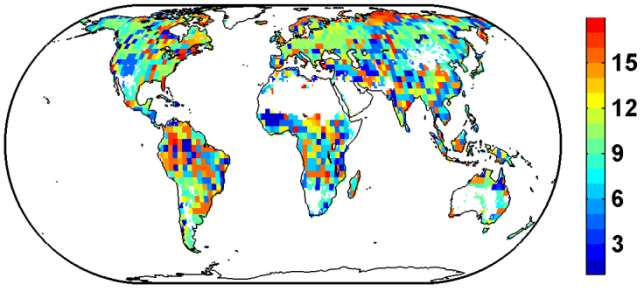




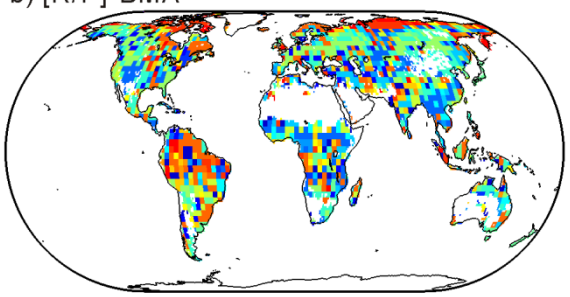
3×3 spatial window

5×5 spatial window

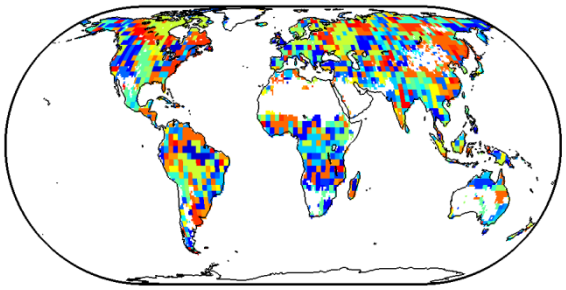
a) BMA



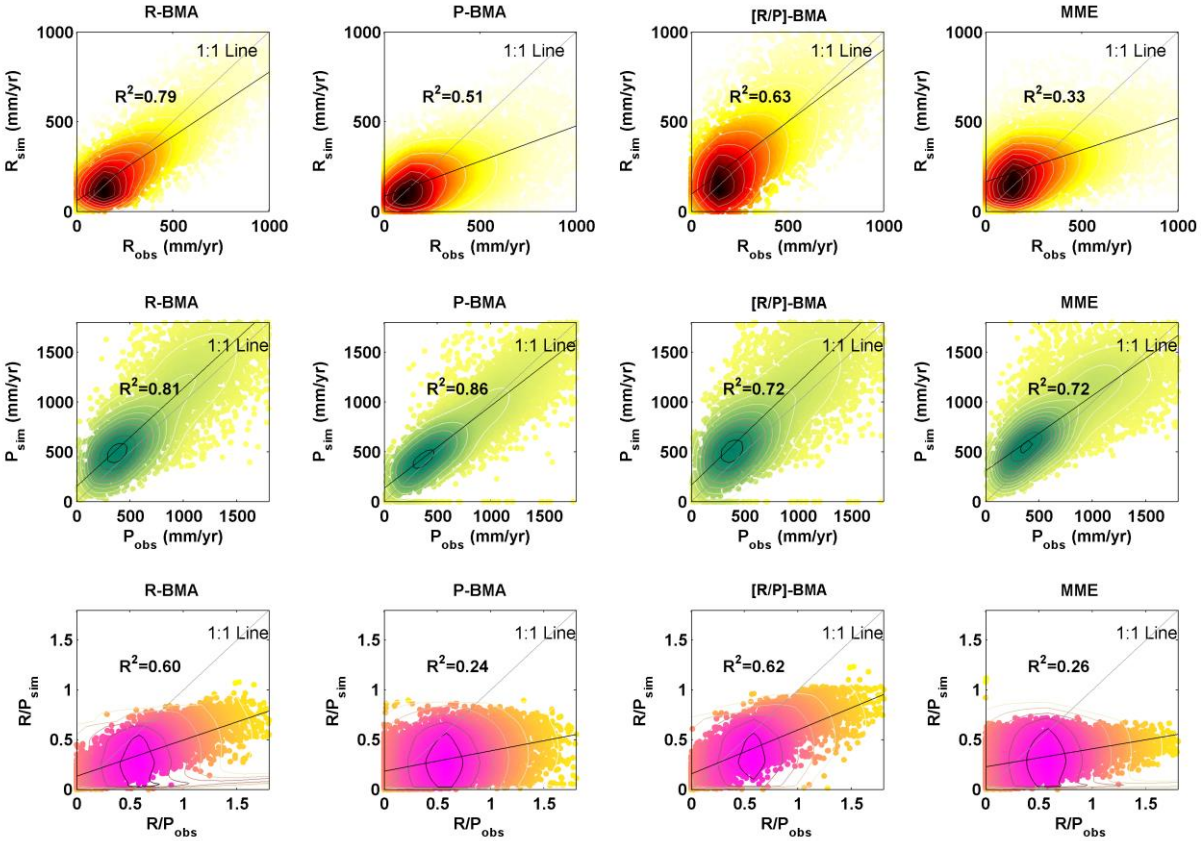
b) [R/P]-BMA



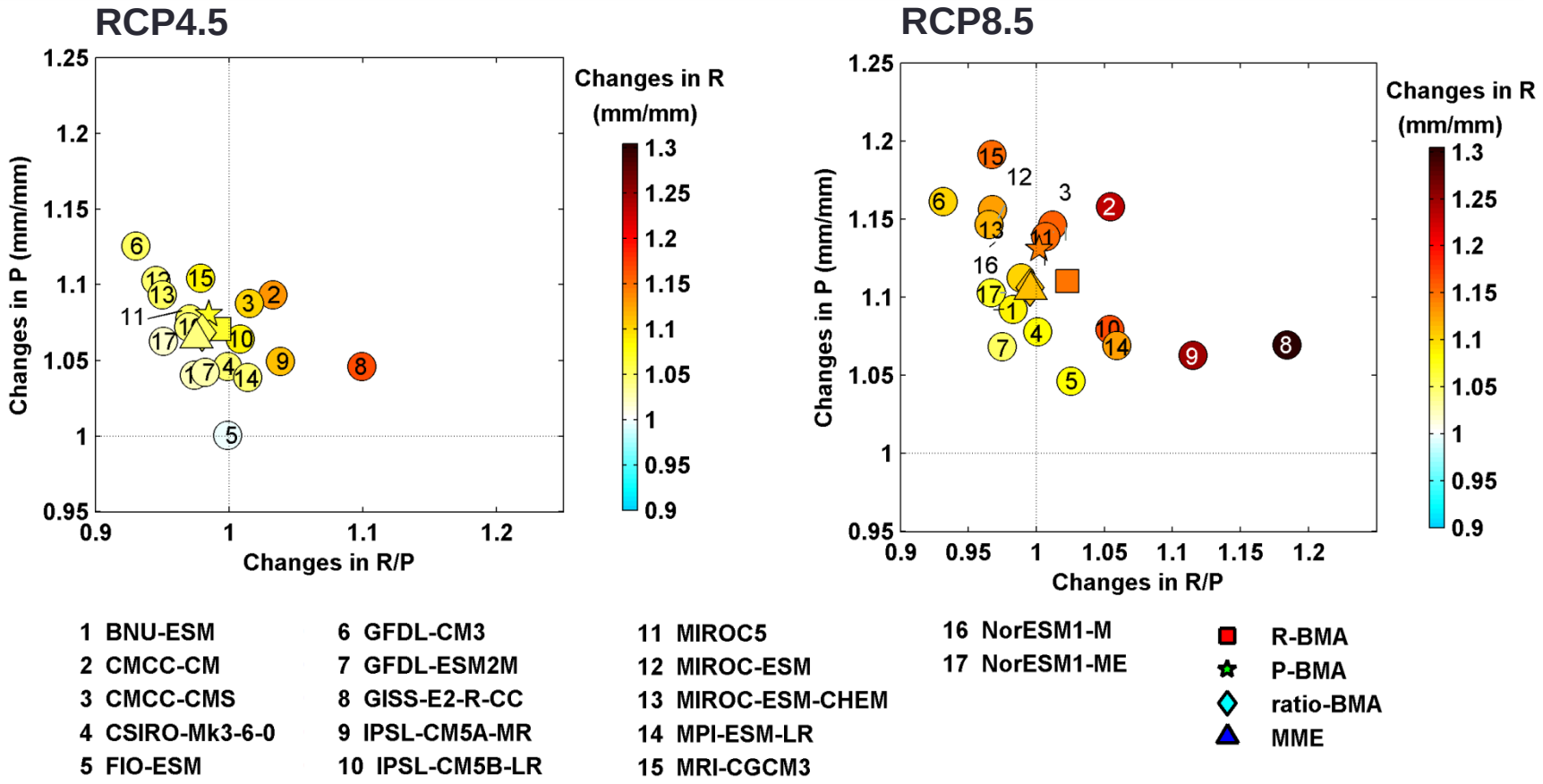
c) P-BMA



the relationship of the simulated and observed runoff, precipitation and the ratio R/P.



Results: Divers of changes



The result suggests that different models have different drivers of changes in runoff. For the runoff changes estimated by the runoff-based BMA, precipitation changes is the major driver.