Model performance in simulating the Global Monsoon: Skill evolution across CMIP generations

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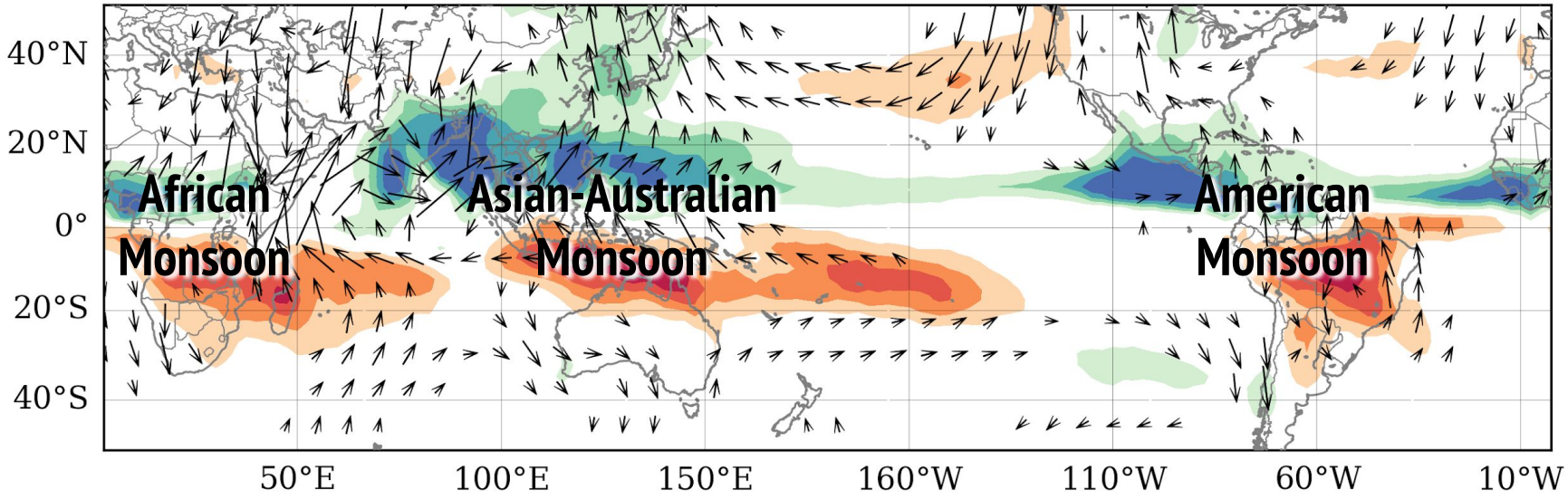
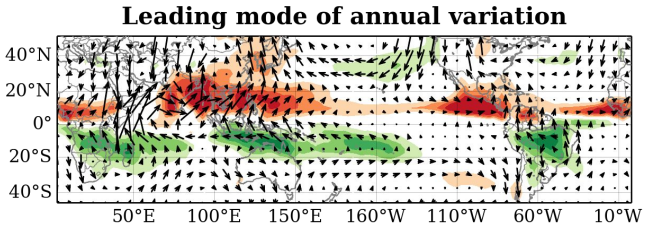
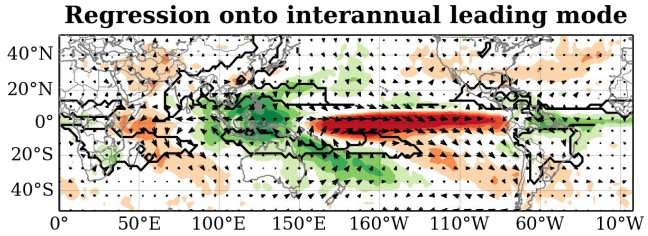
Global Monsoon

Webster, 1987
Trenberth et al., 2000
Wang and Ding, 2006, 2008
Liu et al. 2009
Wang et al., 2017







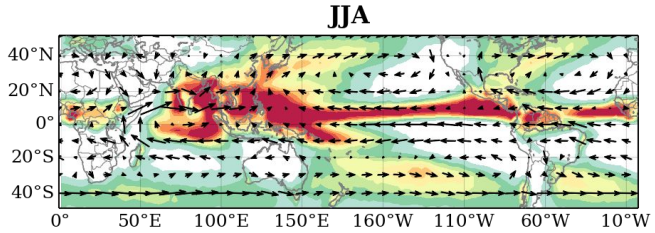
Dominant modes of annual and interannual variation

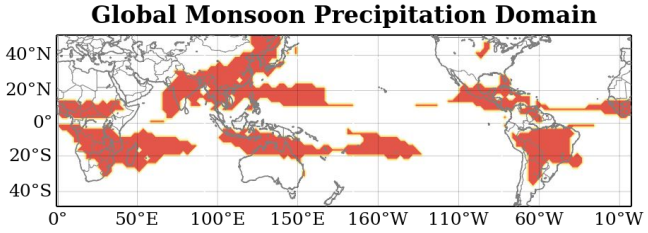
Seasonal Patterns

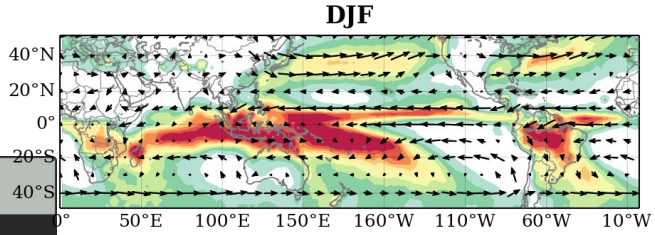
GM Domain

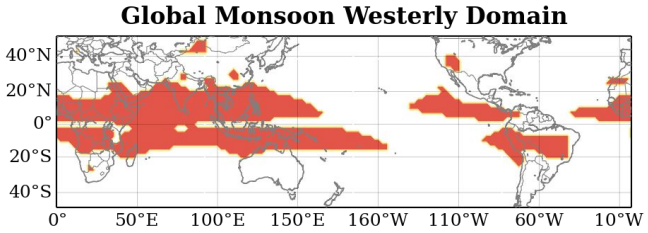
Global Monsoon Features

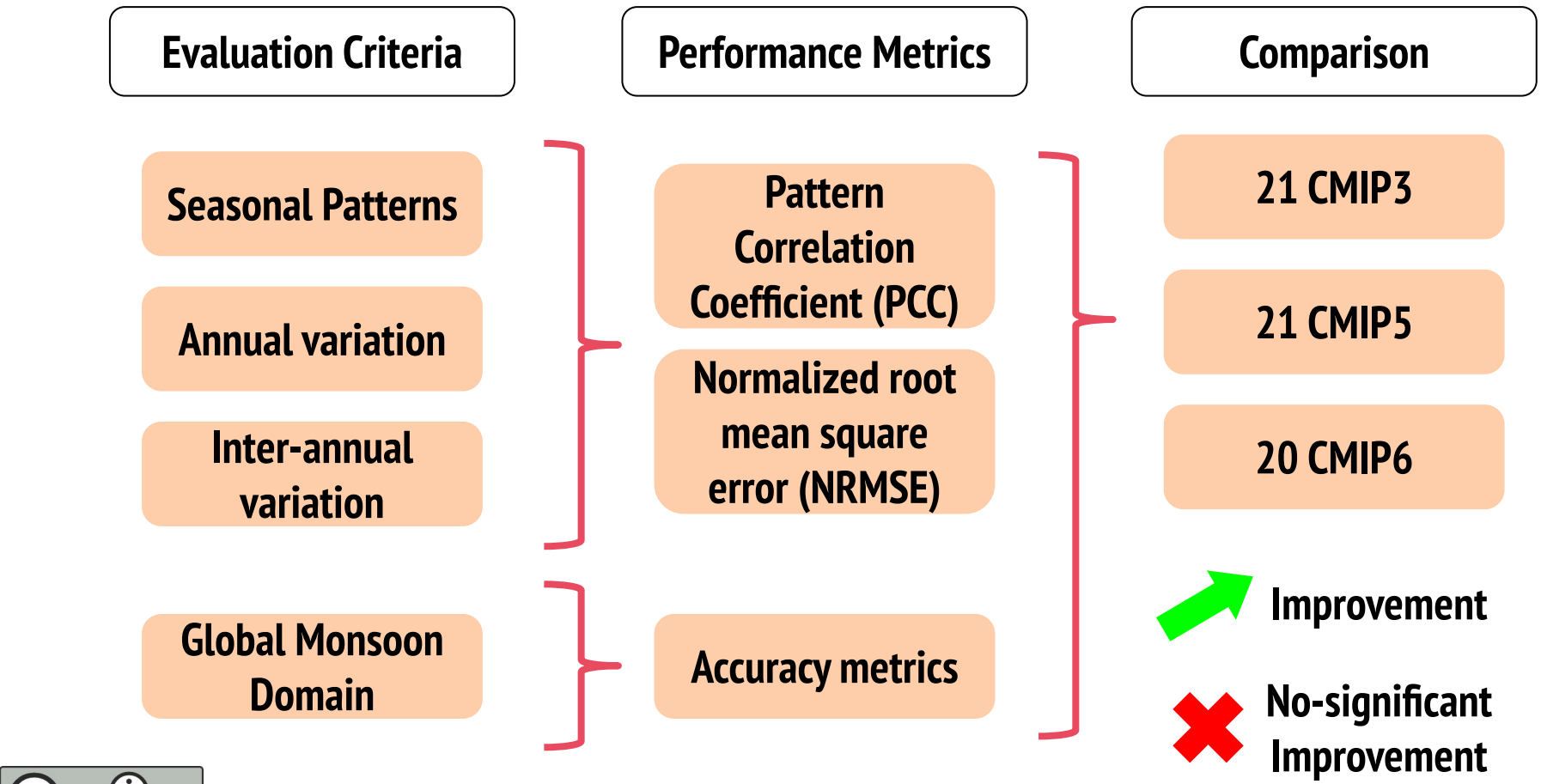
Wang and Ding, 2006, 2008
Wang et al. 2011







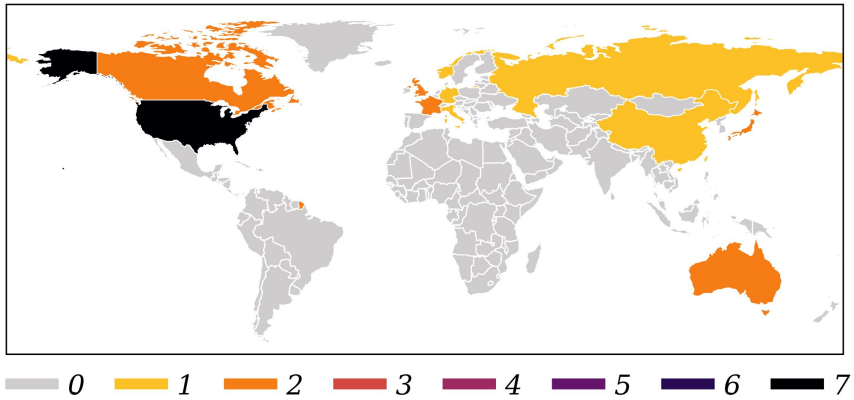



Evaluation Criteria
Performance Metrics
Comparison
Seasonal Patterns
Annual variation
Inter-annual variation
Global Monsoon Domain
Pattern Correlation Coefficient (PCC)
Normalized root mean square error (NRMSE)
Accuracy metrics
21 CMIP3
21 CMIP5
20 CMIP6
Improvement
No-significant Improvement

Global climate models used in the study

Horizontal resolution
1.1 - 5 degrees

models by country - CMIP3



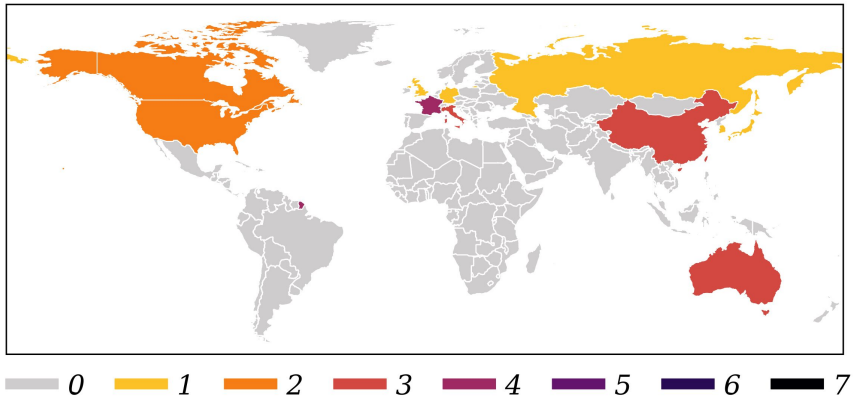
22 CMIP3

BCCR-BCM2.0
CGCM3.1
CGCM3.1-t63
CNRM-CM3
CSIRO-MK3.0
CSIRO-MK3.5
GFDL-CM2.0
GFDL-CM2.1
GISS-AOM
GISS-MODEL-E-H
GISS-MODEL-E-R
IAP-FGOALS1.0g
INGV-ECHAM4
INMCM3.0
IPSL-CM4
MIROC3.2-HIRES
MPI-ECHAM5
MRI-CGCM2.3.2A
NCAR-CCSM3.0
NCAR-PCM1
UKMO-HADCM3
UKMO-HADGEM1

Global climate models used in the study

Horizontal resolution
0.8 - 5.6 degrees

models by country - CMIP5



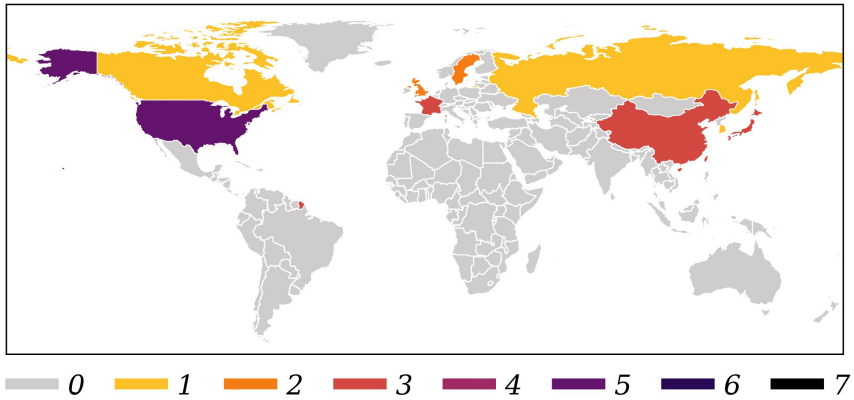
22 CMIP5

ACCESS1.3
CMCC-CESM
CMCC-CMS
CMCC-CM
CNRM-CM5.2
CNRM-CM5
CSIRO-Mk3.6.0
CSIRO-Mk3L-1.2
CanCM4
CanESM2
GISS-E2-H-CC
GISS-E2-R-CC
HadCM3
HadGEM2-AO
HadGEM2-ES
INMCM4
IPSL-CM5A-LR
IPSL-CM5A-MR
MIROC5
MPI-ESM-LR
NorESM1-ME
NorESM1-M

Global climate models used in the study

Horizontal resolution
0.7 - 2.8 degrees

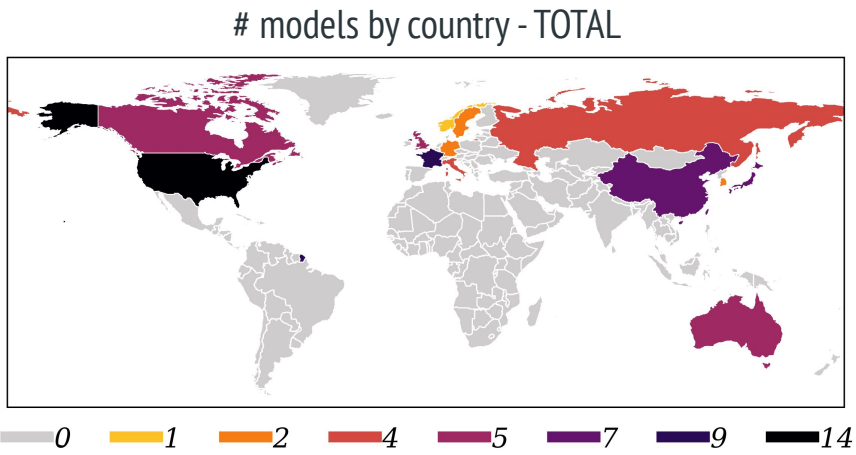
models by country - CMIP6



21 CMIP6

BCC-CSM2-MR
BCC-ESM1
CAMS-CSM1.0
CESM2
CNRM-CM6.1
CNRM-ESM2.1
CanESM5
E3SM-1.0
EC-Earth3-Veg
EC-Earth3
GFDL-ESM4
GISS-E2-1-G
GISS-E2-1-H
HadGEM3-GC31-LL
INM-CM5.0
IPSL-CM6A-LR
MIROC-ES2L
MIROC6
MRI-ESM2.0
SAM0-UNICON
UKESM1.0-LL

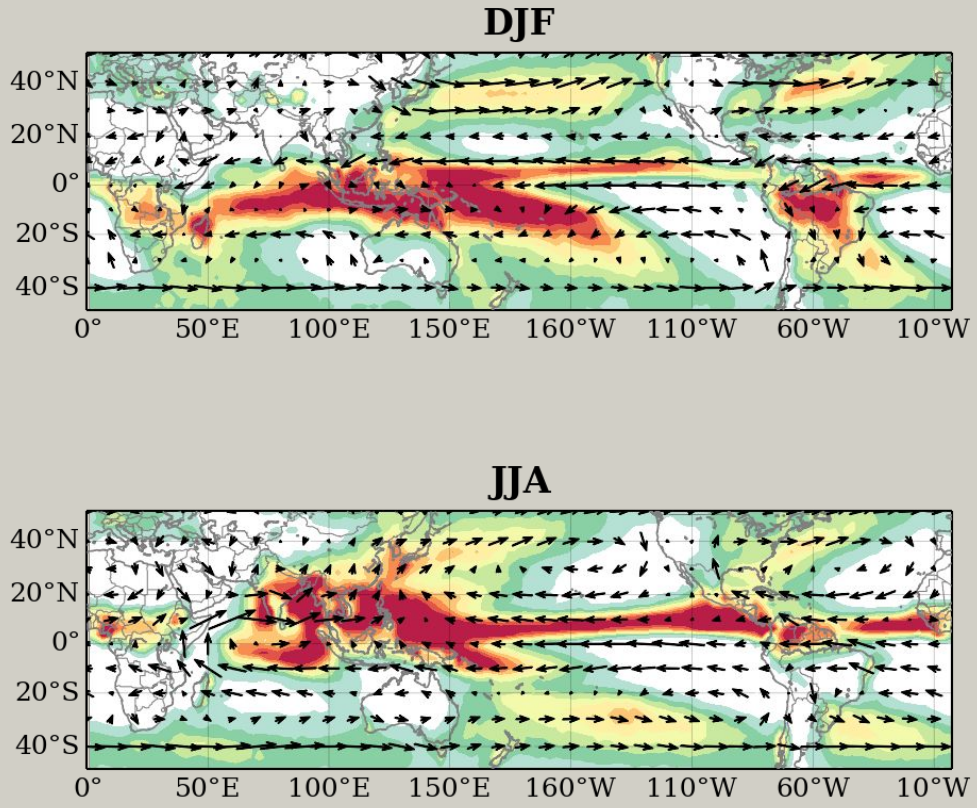
Global climate models used in the study



22 CMIP3	22 CMIP5	21 CMIP6
BCCR-BCM2.0	ACCESS1.3	BCC-CSM2-MR
CGCM3.1	CMCC-CESM	BCC-ESM1
CGCM3.1-t63	CMCC-CMS	CAMS-CSM1.0
CNRM-CM3	CMCC-CM	CESM2
CSIRO-MK3.0	CNRM-CM5.2	CNRM-CM6.1
CSIRO-MK3.5	CNRM-CM5	CNRM-ESM2.1
GFDL-CM2.0	CSIRO-Mk3.6.0	CanESM5
GFDL-CM2.1	CSIRO-Mk3L-1.2	E3SM-1.0
GISS-AOM	CanCM4	EC-Earth3-Veg
GISS-MODEL-E-H	CanESM2	EC-Earth3
GISS-MODEL-E-R	GISS-E2-H-CC	GFDL-ESM4
IAP-FGOALS1.0g	GISS-E2-R-CC	GISS-E2-1-G
INGV-ECHAM4	HadCM3	GISS-E2-1-H
INMCM3.0	HadGEM2-AO	HadGEM3-GC31-LL
IPSL-CM4	HadGEM2-ES	INM-CM5.0
MIROC3.2-HIRES	INMCM4	IPSL-CM6A-LR
MPI-ECHAM5	IPSL-CM5A-LR	MIROC-ES2L
MRI-CGCM2.3.2A	IPSL-CM5A-MR	MIROC6
NCAR-CCSM3.0	MIROC5	MRI-ESM2.0
NCAR-PCM1	MPI-ESM-LR	SAM0-UNICON
UKMO-HADCM3	NorESM1-ME	UKESM1.0-LL
UKMO-HADGEM1	NorESM1-M	

Seasonal patterns

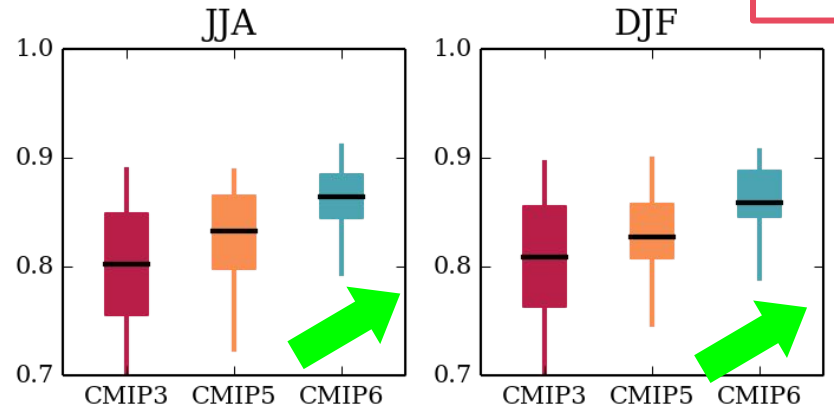
Precipitation (colors)
Surface winds 850hPa (vectors)



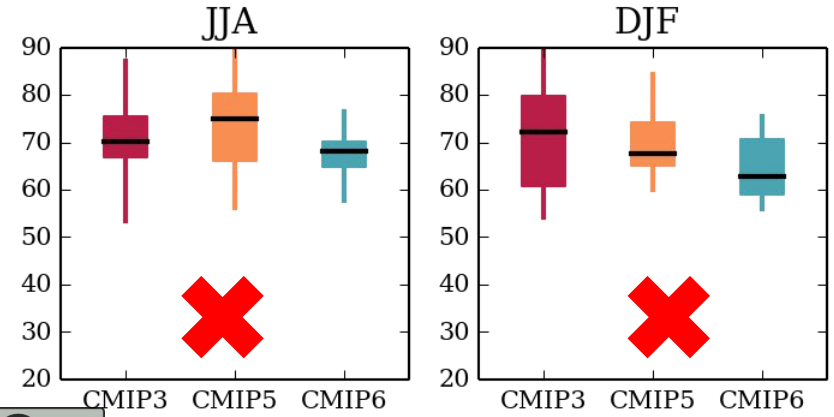
Precipitation

High magnitude errors remain for CMIP6 models

PCC: Spatial Patterns

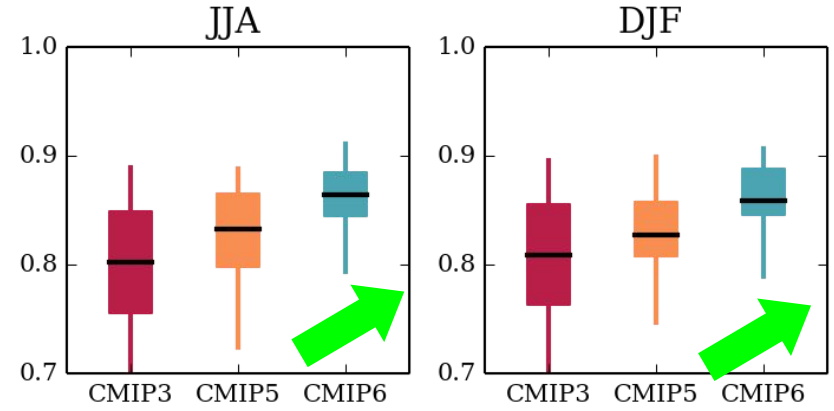


NRMSE: Magnitude

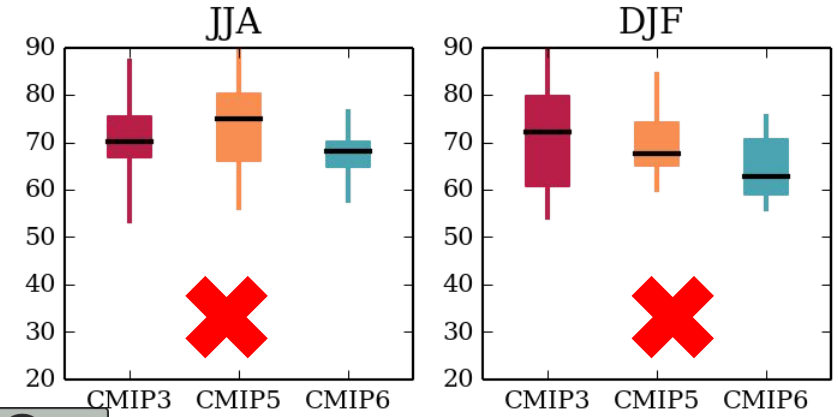


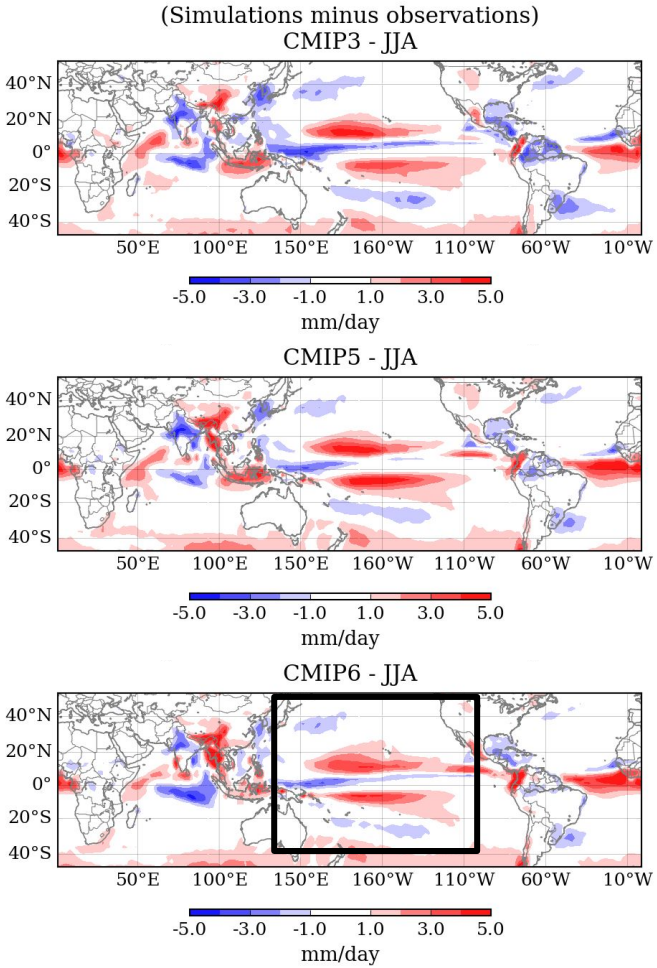
Precipitation

PCC: Spatial Patterns



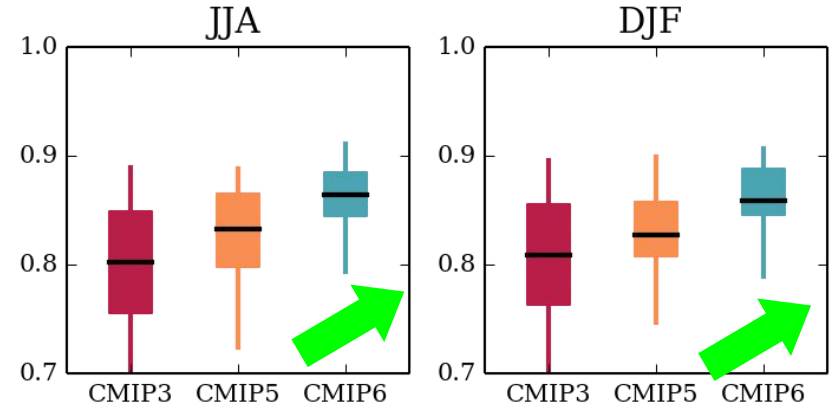
NRMSE: Magnitude



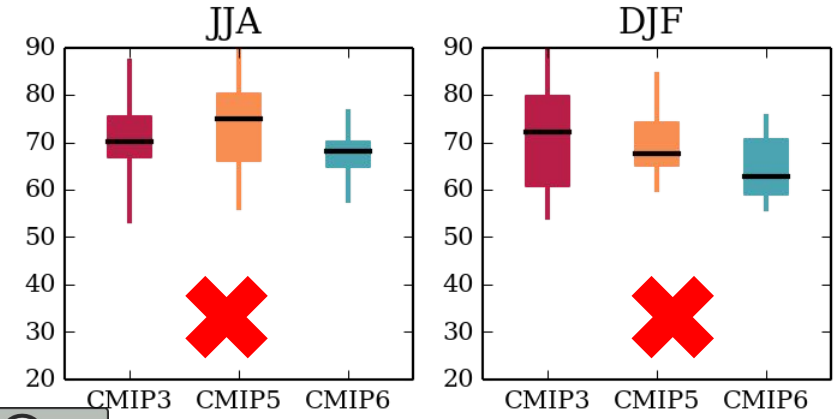


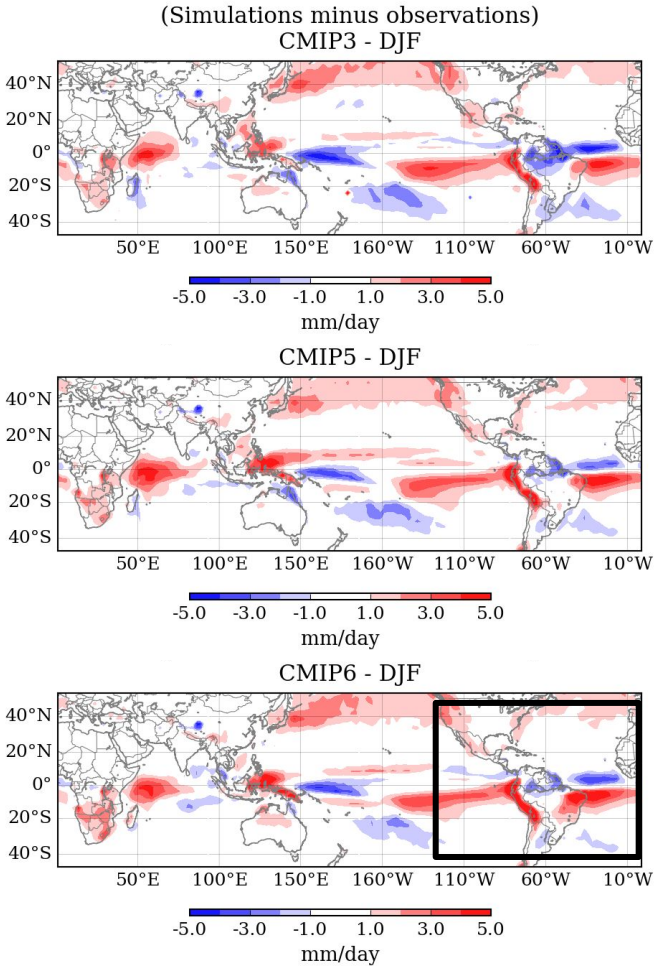
Precipitation

PCC: Spatial Patterns



NRMSE: Magnitude



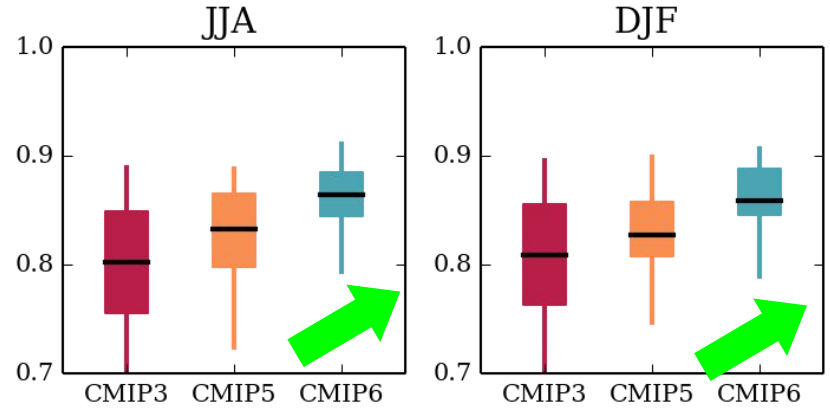


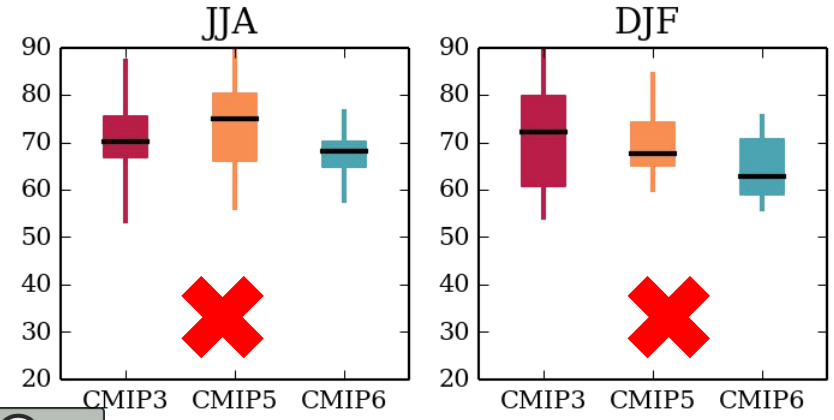
Precipitation

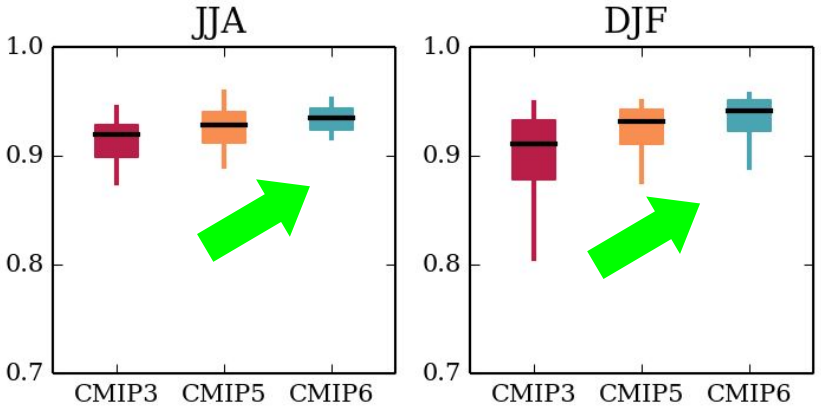
Surface Winds

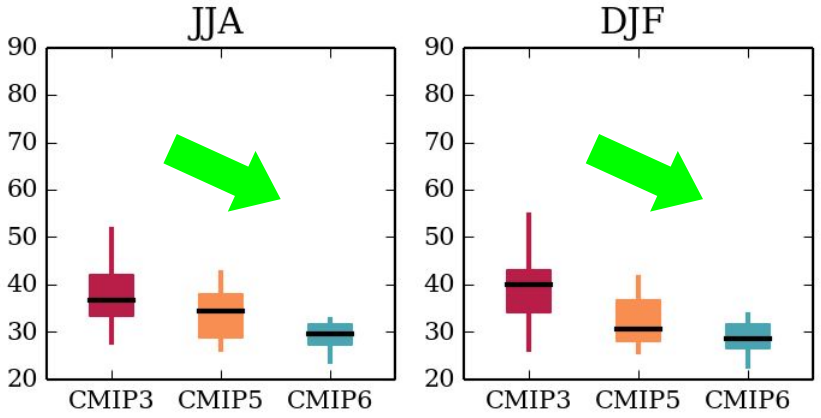
PCC: Spatial Patterns

NRMSE: Magnitude

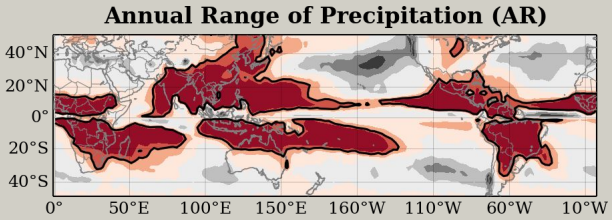


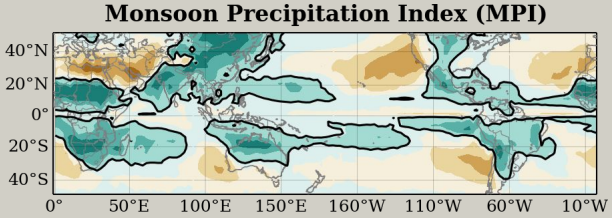


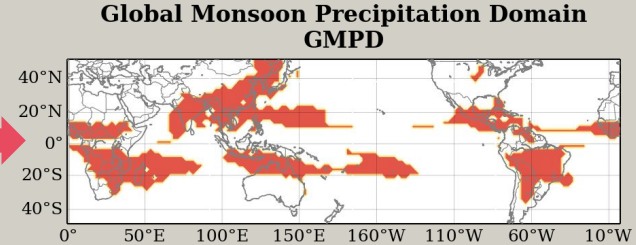


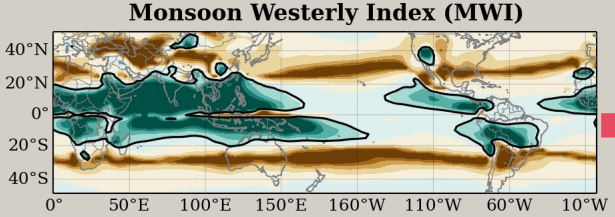


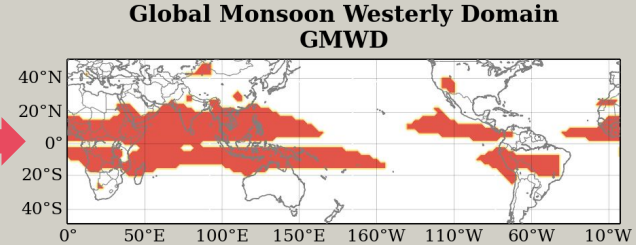
Global Monsoon Domain









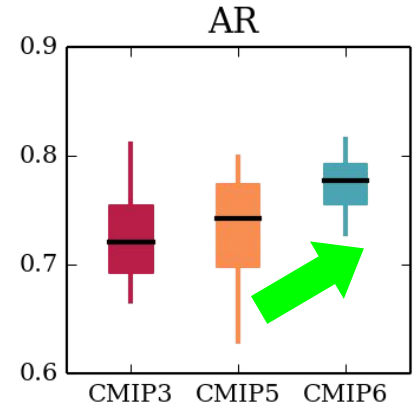


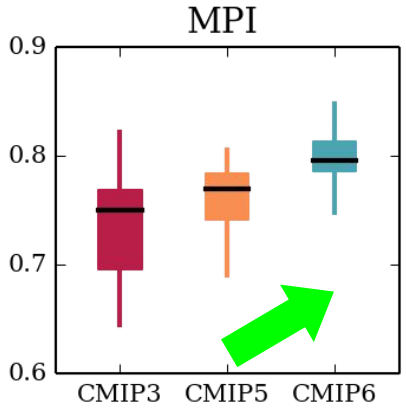
(Wang, B., & Ding, Q., 2008)

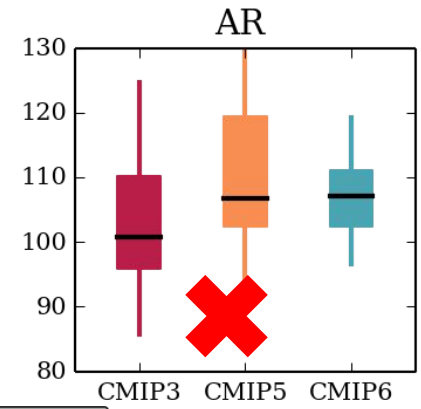
Precipitation

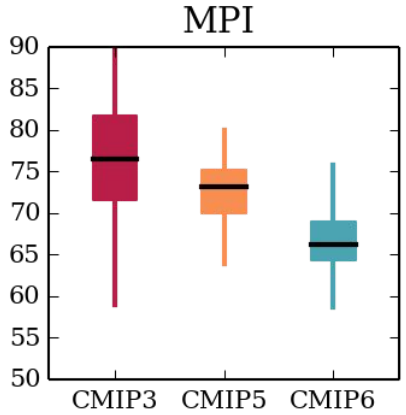
PCC: Spatial Patterns

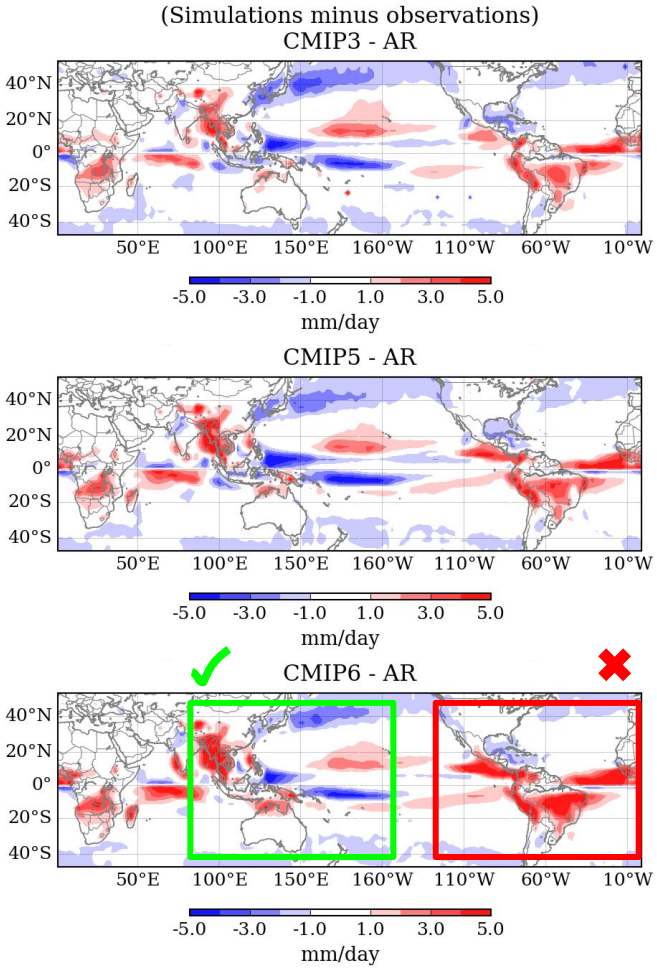
NRMSE: Magnitude





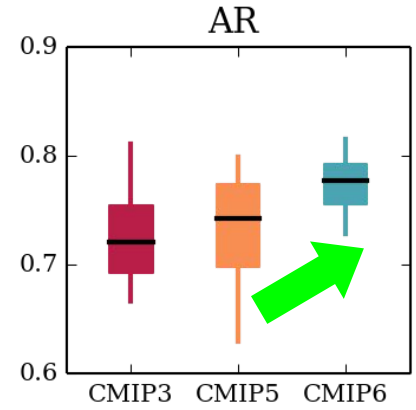


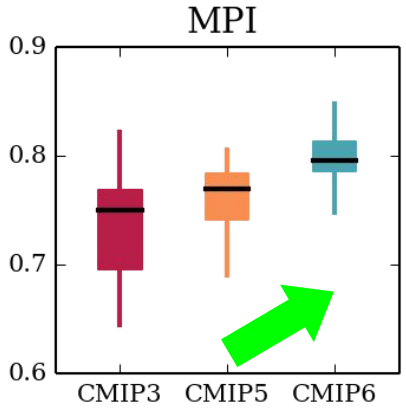




Precipitation

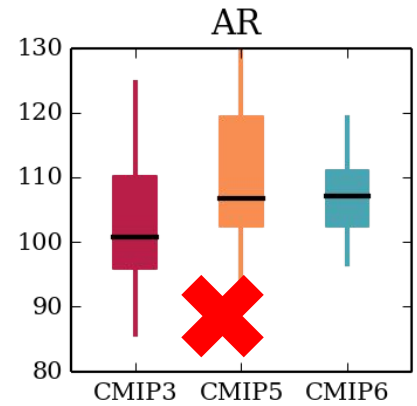
PCC: Spatial Patterns

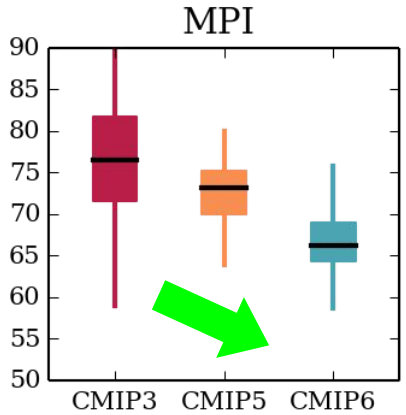


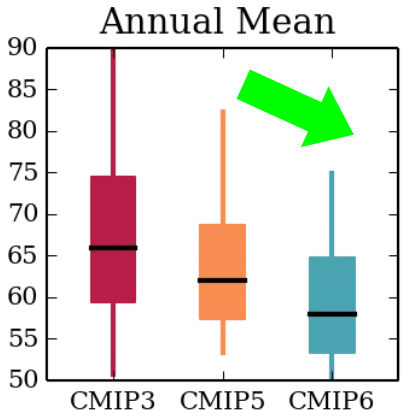


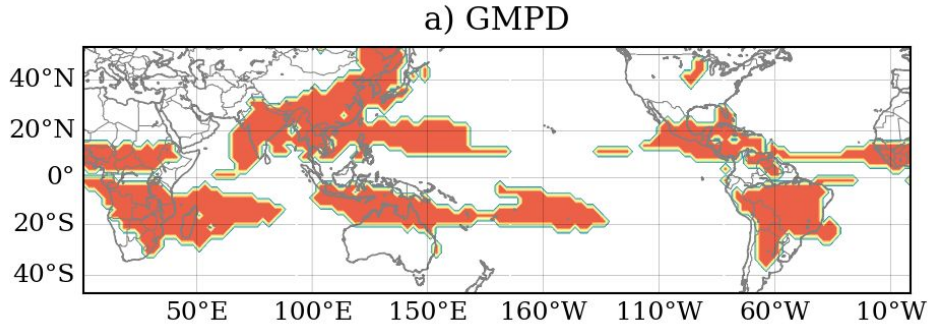
Improvement in simulating annual mean precipitation, but important biases in seasonal mean precipitation

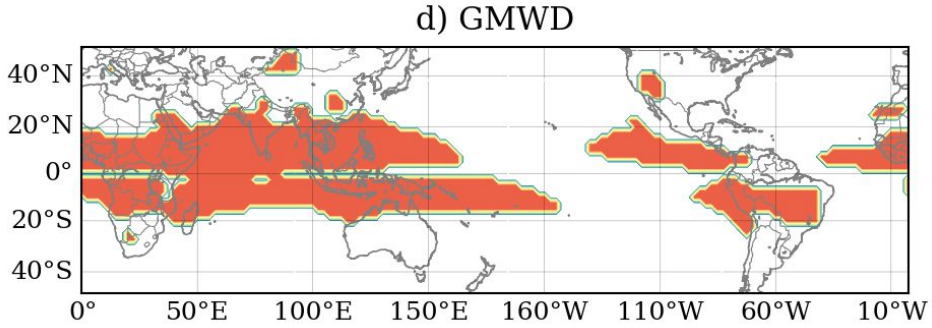
NRMSE: Magnitude







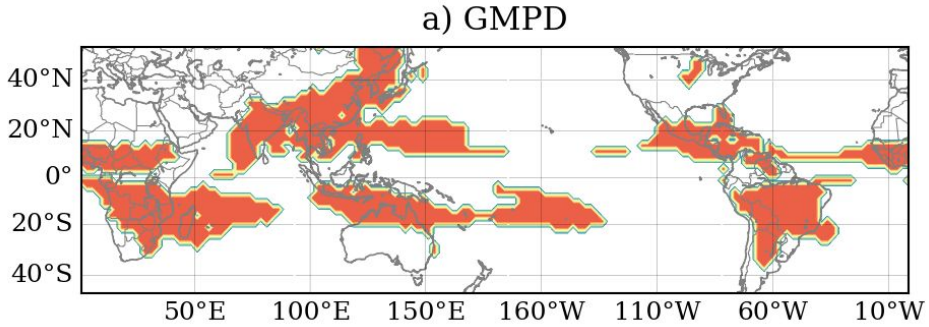


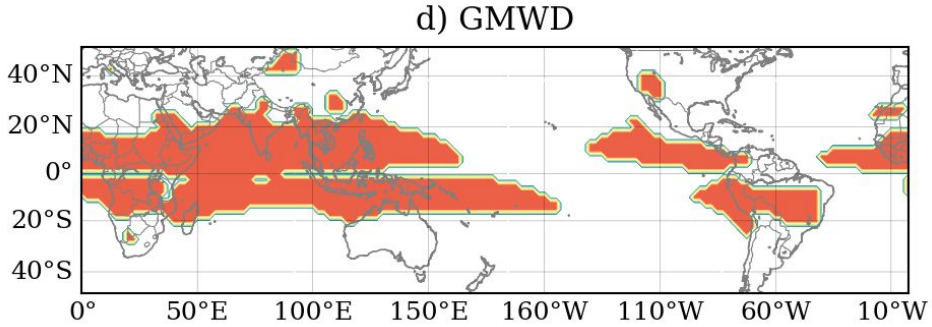


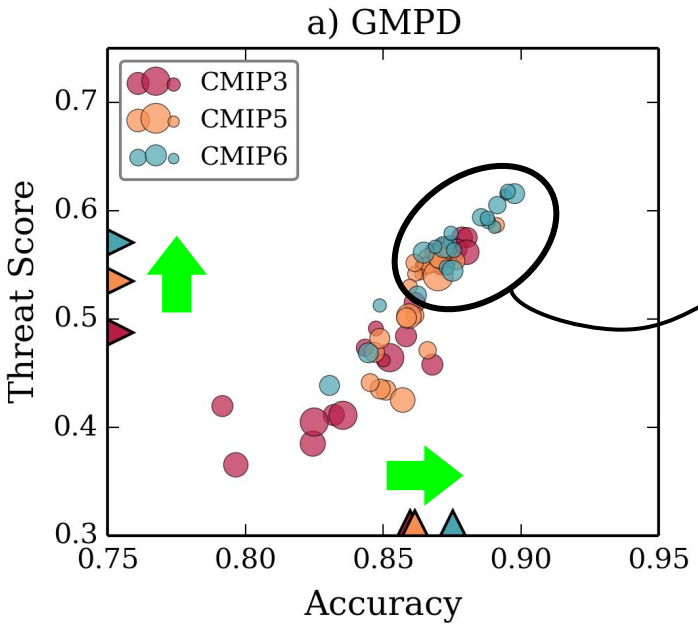
Performance Metrics

$$Threat\ \ Score = \frac{hits}{hits + misses + false\ \ alarms}$$

$$Accuracy = \frac{hits + correct\ \ negatives}{total}$$



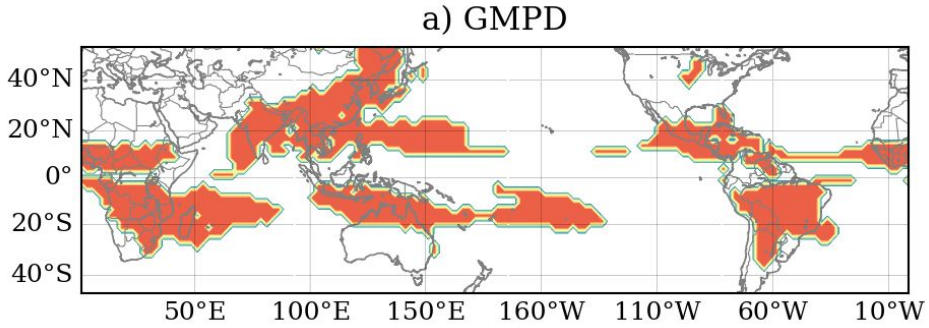


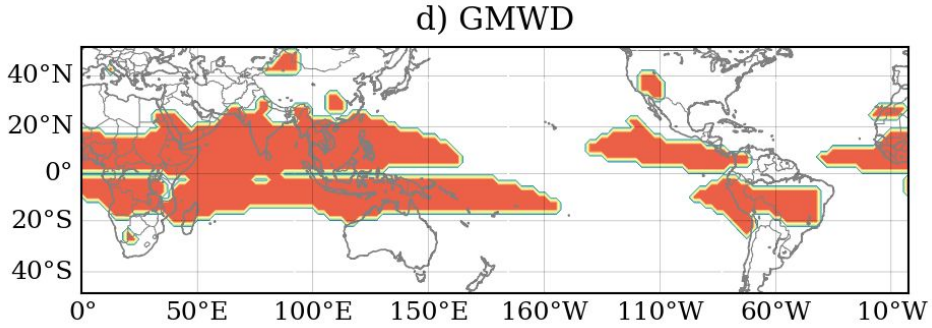


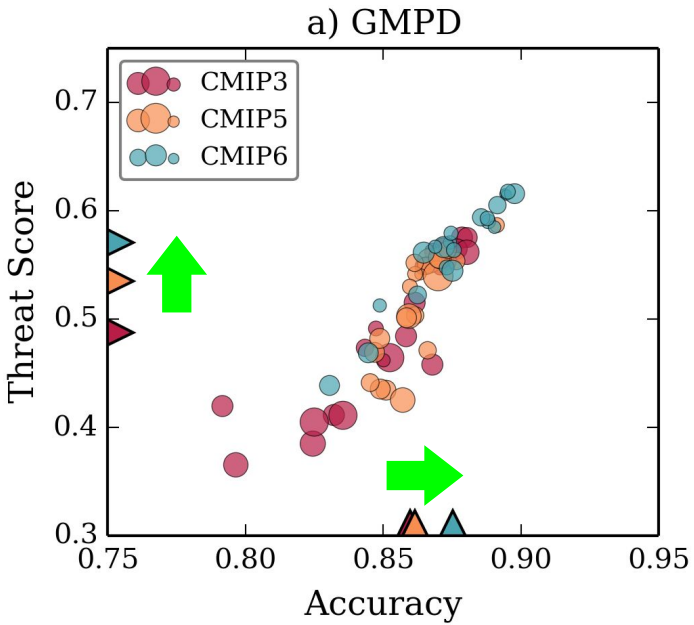
GMPD is well captured in most of the GCMs

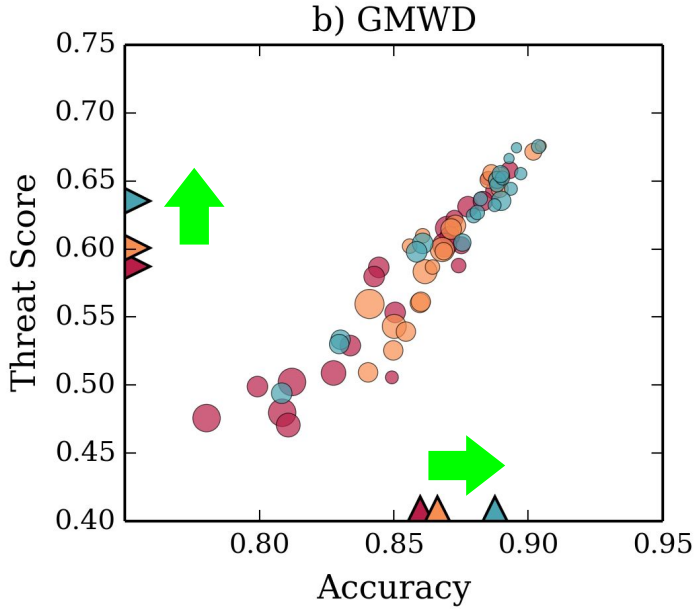
Reduction of dispersion among CMIP6 models

No direct relationship between model performance and horizontal model resolution

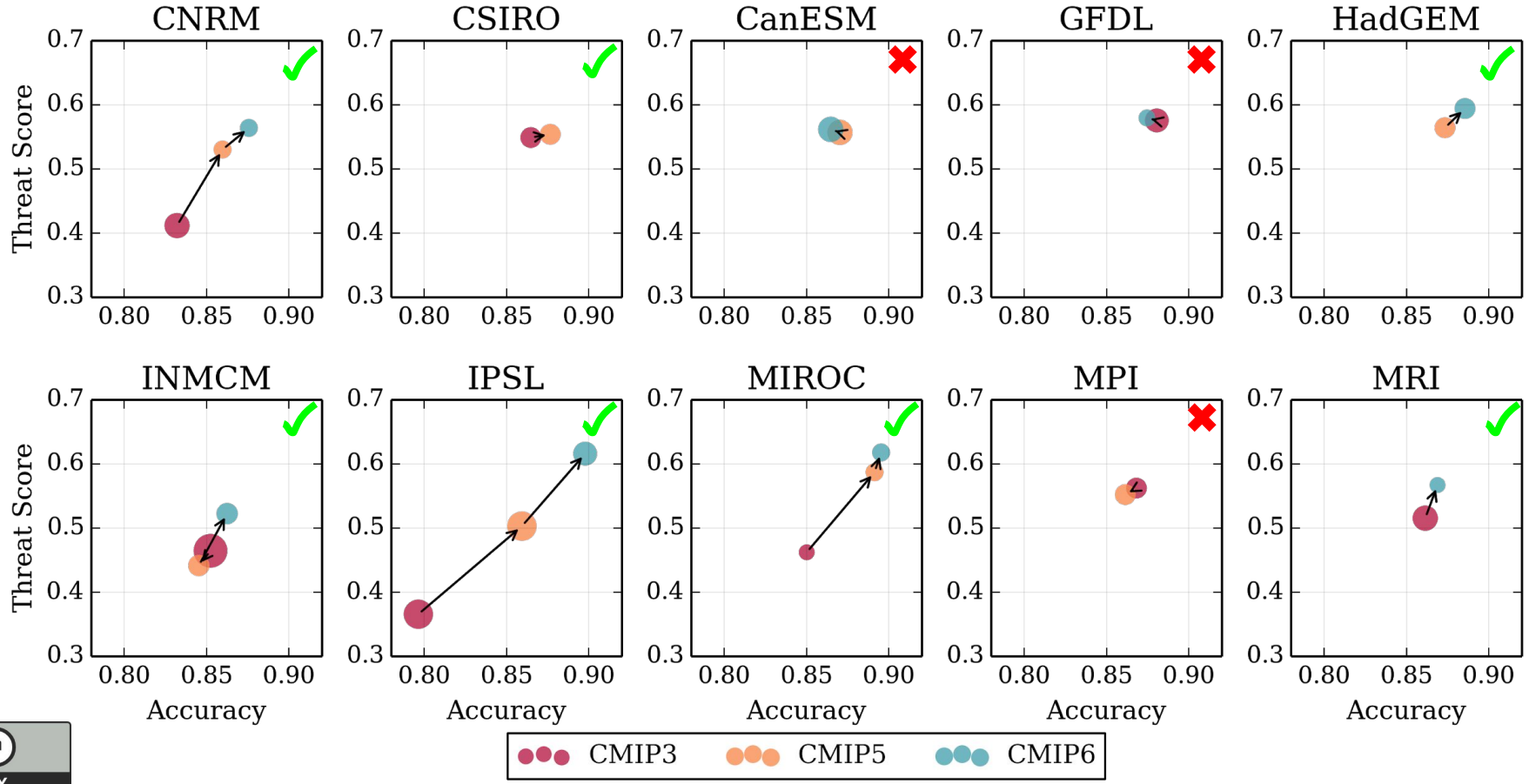

a) GMPD
40°N
20°N
0°
20°S
40°S
50°E
100°E
150°E
160°W
110°W
60°W
10°W


d) GMWD
40°N
20°N
0°
20°S
40°S
0°
50°E
100°E
150°E
160°W
110°W
60°W
10°W

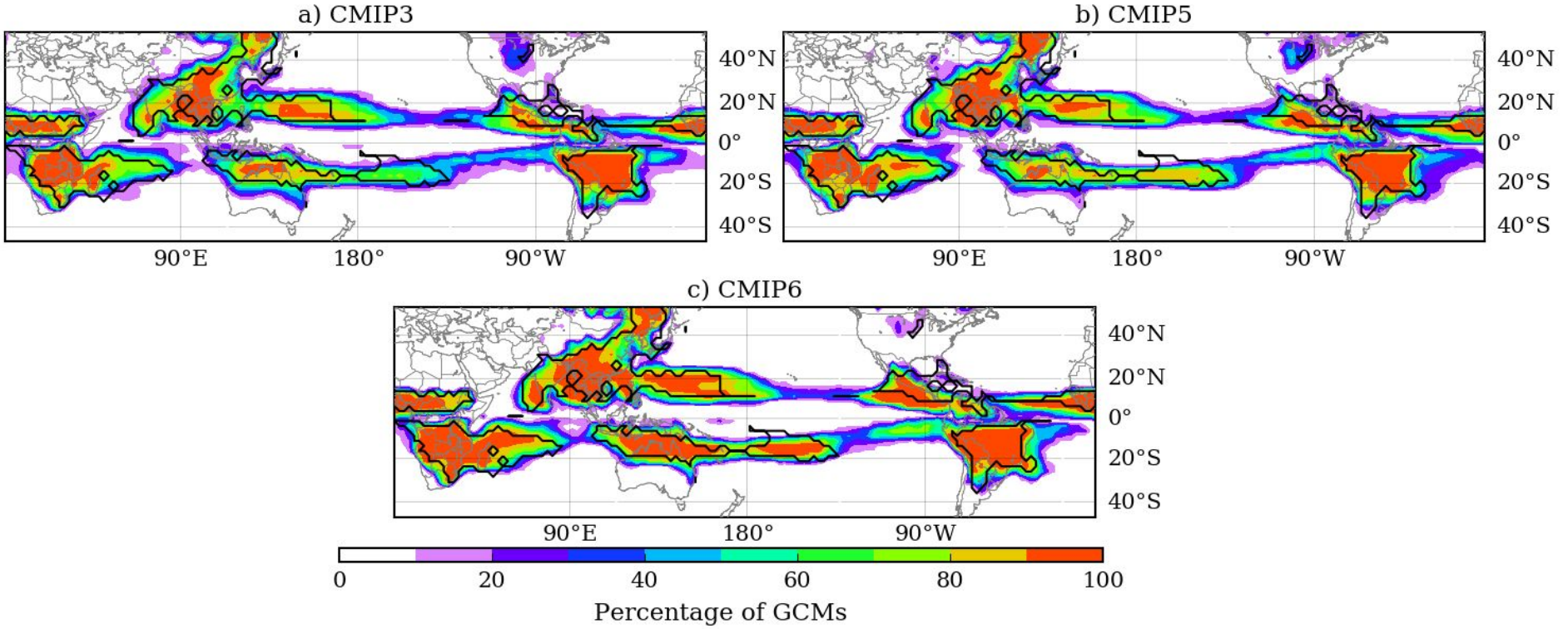

a) GMPD
CMIP3
CMIP5
CMIP6
Threat Score
Accuracy
0.3
0.4
0.5
0.6
0.7
0.75
0.80
0.85
0.90
0.95


b) GMWD
Threat Score
Accuracy
0.40
0.45
0.50
0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95

Performance by group of models - GMPD

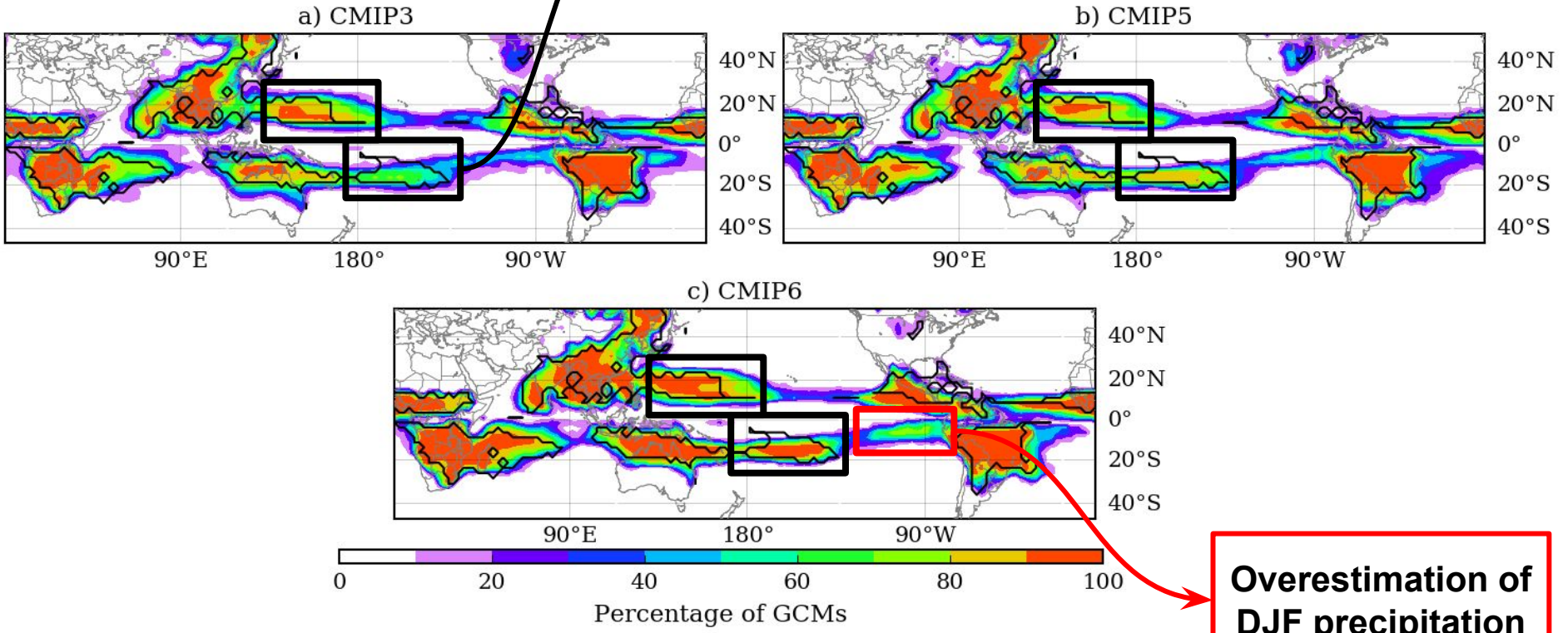


Intermodel agreement - GMPD



Oceanic regions

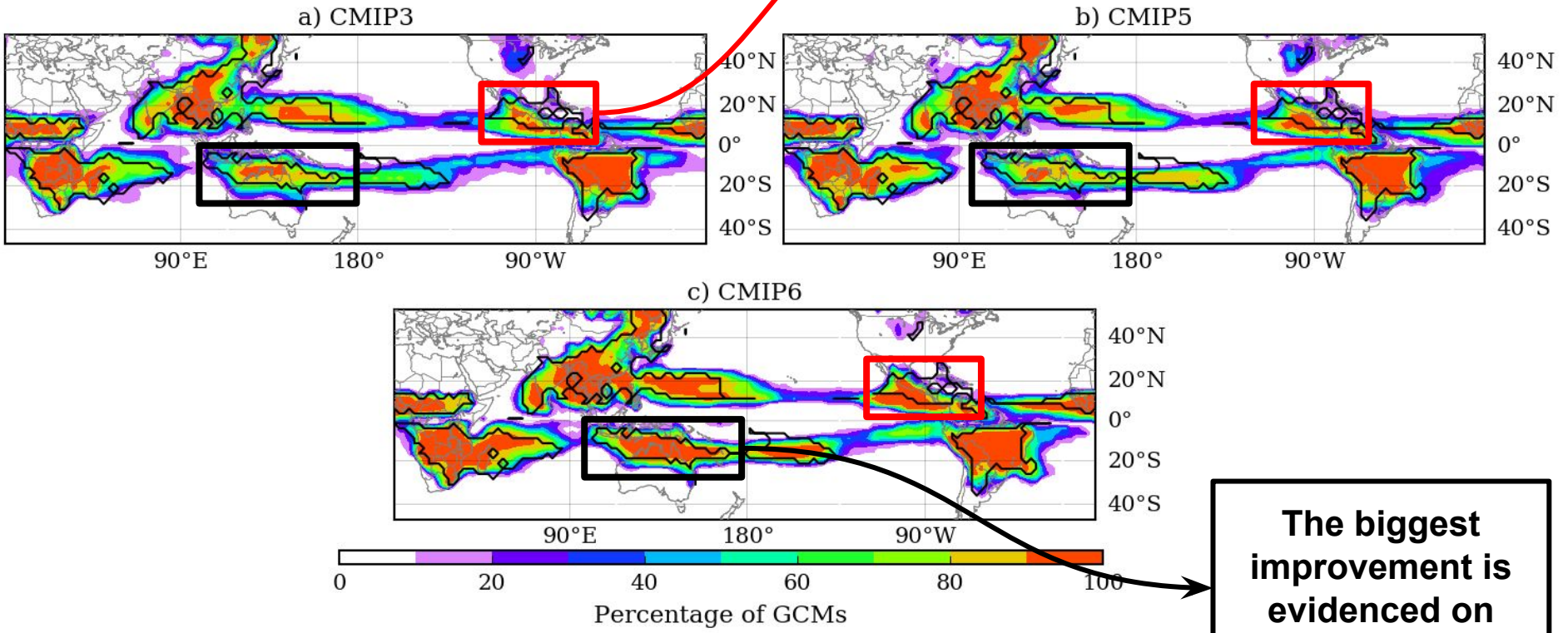
Higher agreement in ocean monsoon precipitation



Overestimation of DJF precipitation

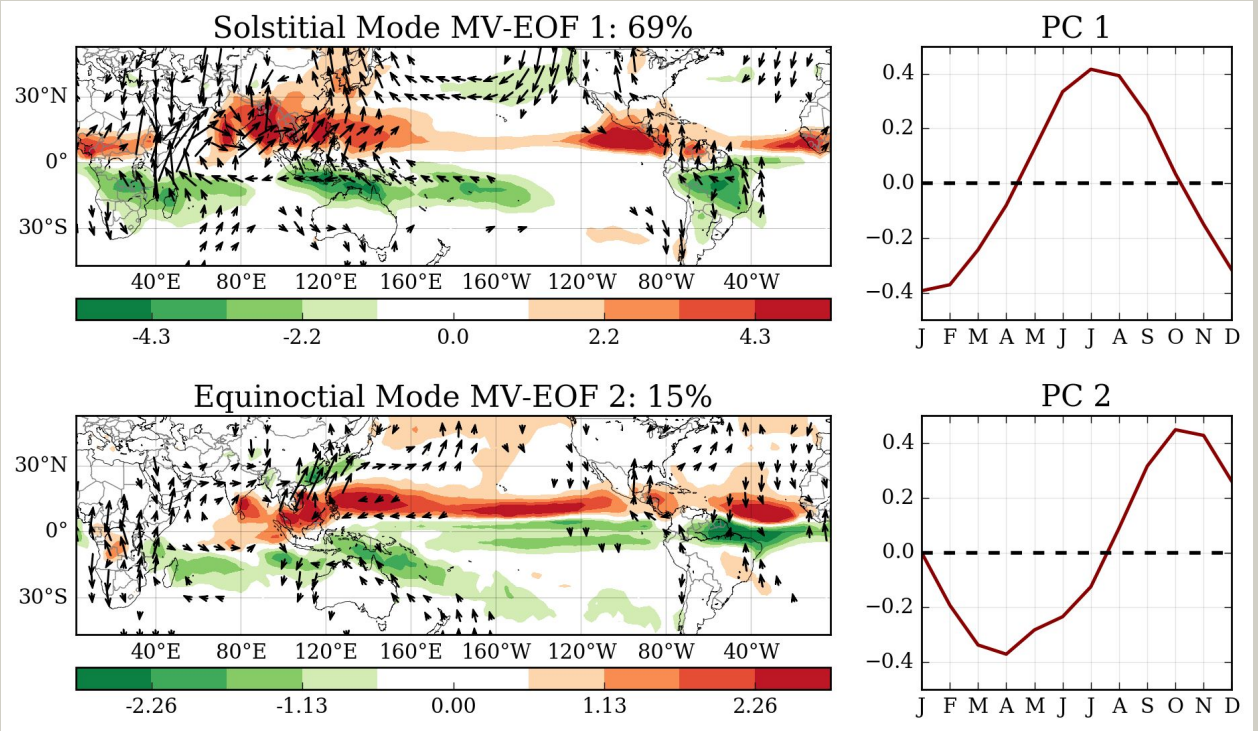
Land regions

No significant improvement in simulating NAM



The biggest improvement is evidenced on Australian region

Leading modes of annual variation



Multivariate empirical orthogonal functions (MV-EOF)
12-month climatology from precipitation and surface winds

$N_{[o,s]}$: number of grid points from observations (o) or each model (s)
12: months (for climatology)
EV: Eigenvectors (dim 12x12)

Observations

Simulations

$3N_O$

12

pr *u* *v*

EOF

Observed ***EV***

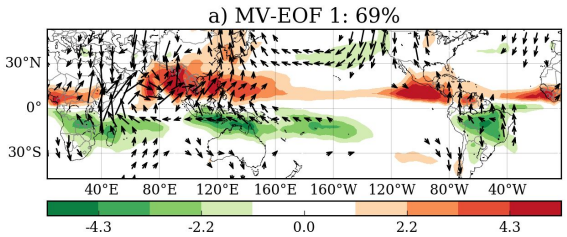
Projection

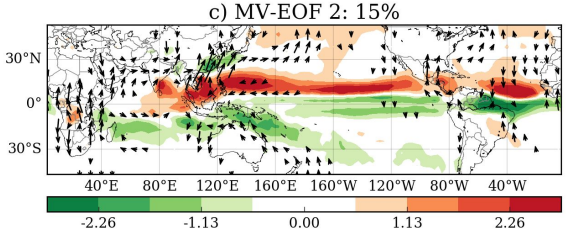
$3N_S$

pr *u* *v*

12

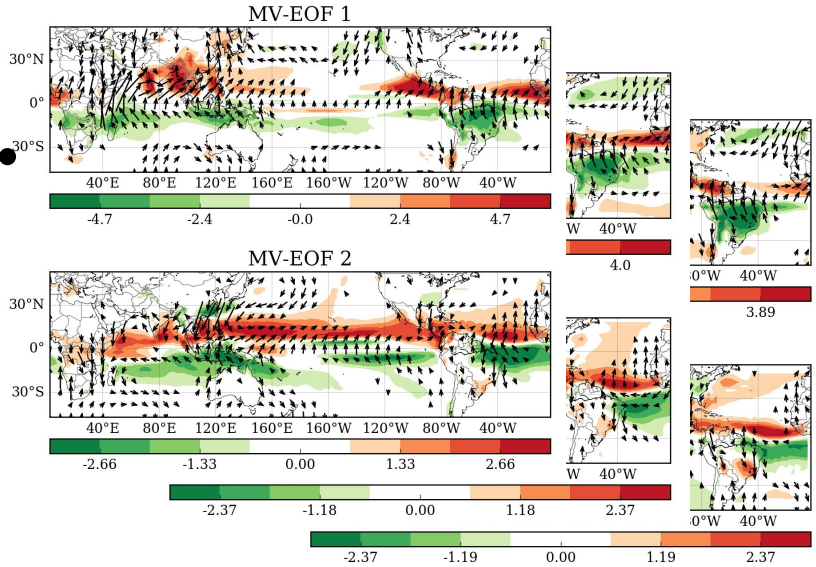
CMIP6 CNRM-CM6-1





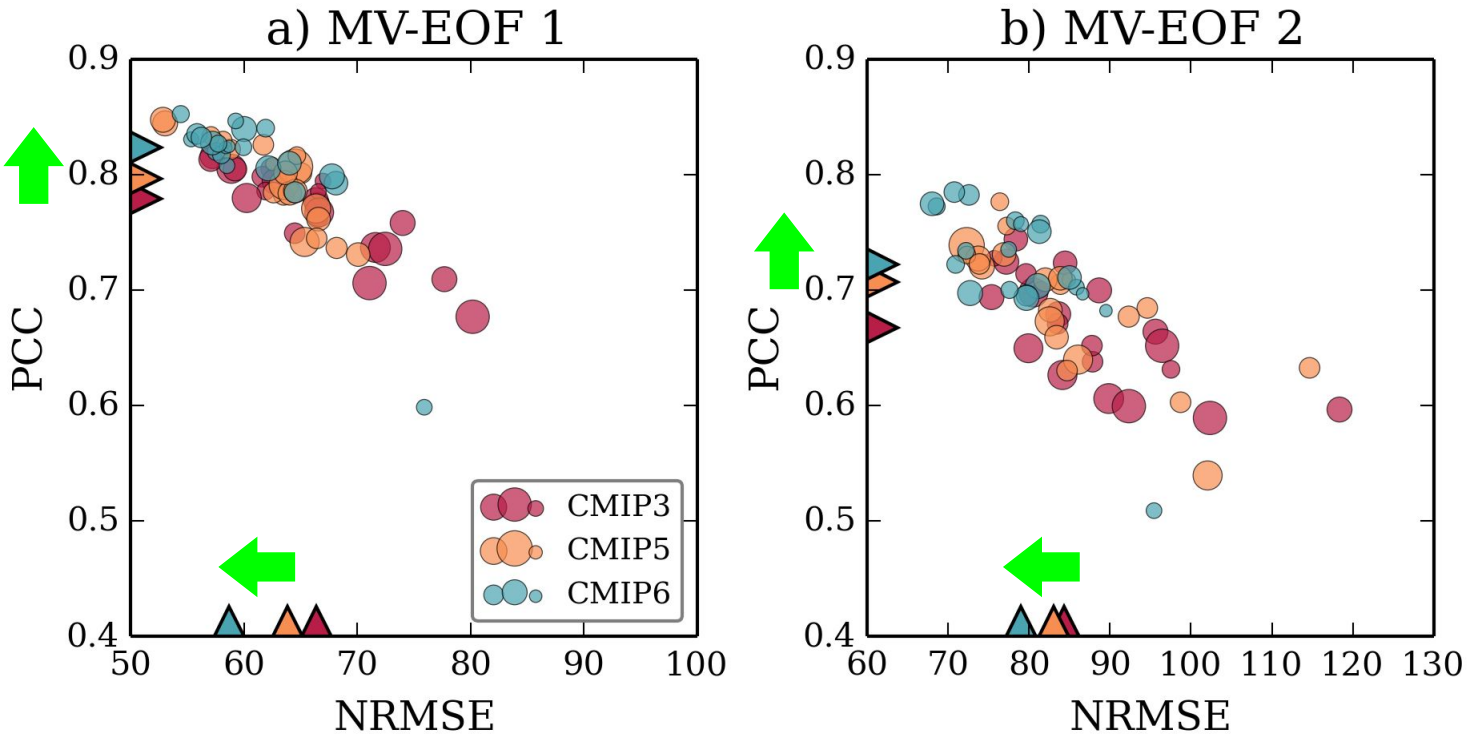
Interpolation to reference resolution

PCC
NRMSE



Model Performance

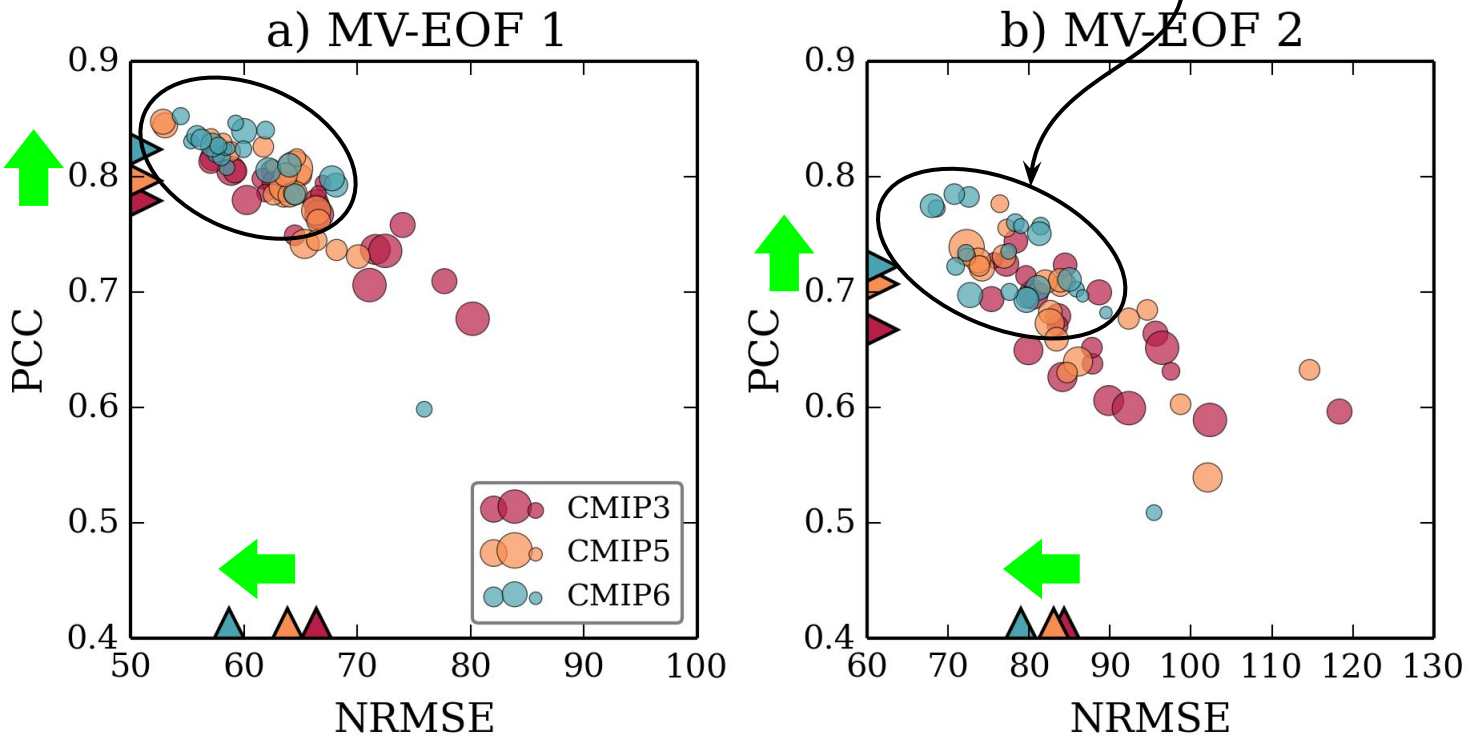
Overall improvement capturing leading modes



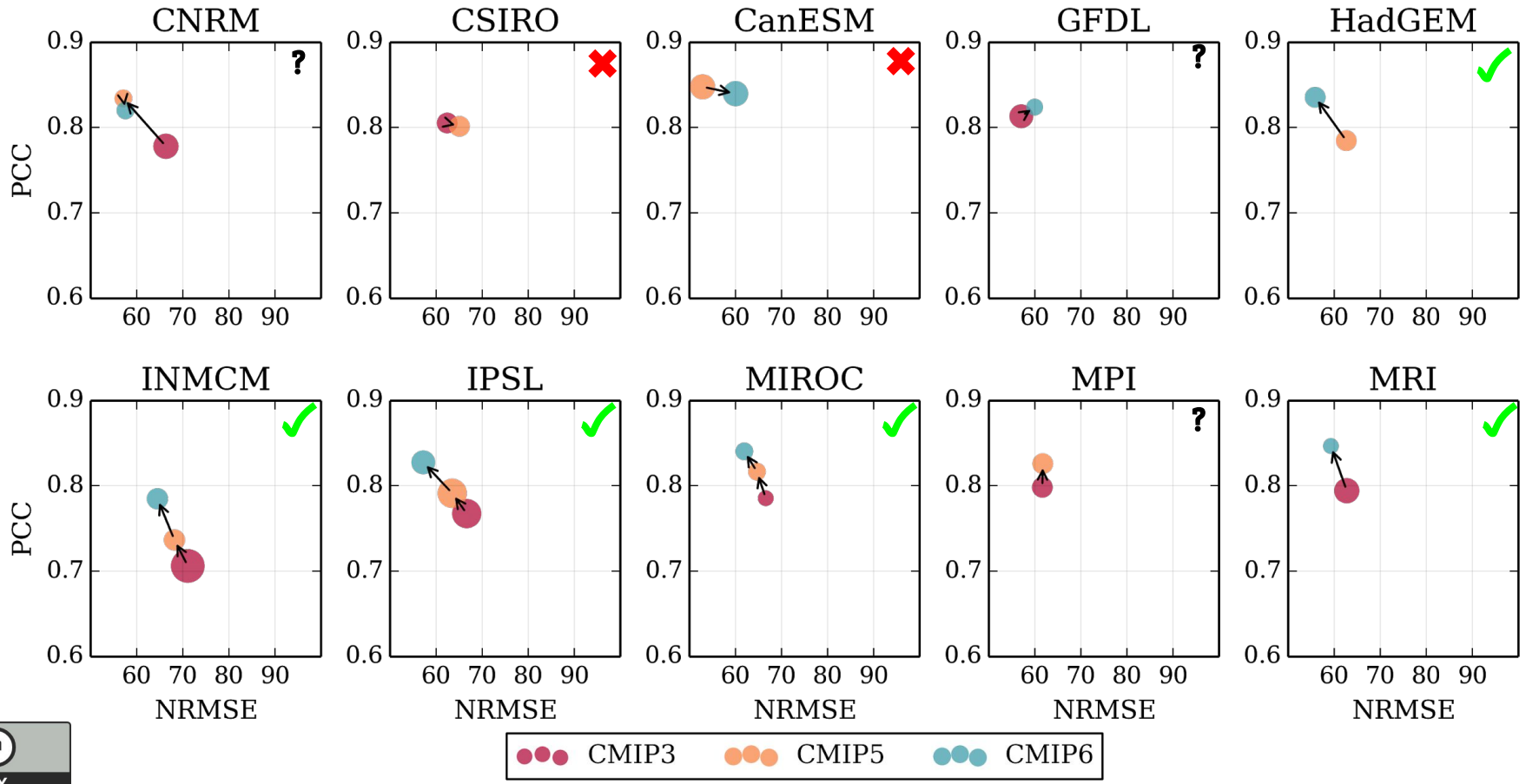
Model Performance

Overall improvement capturing leading modes

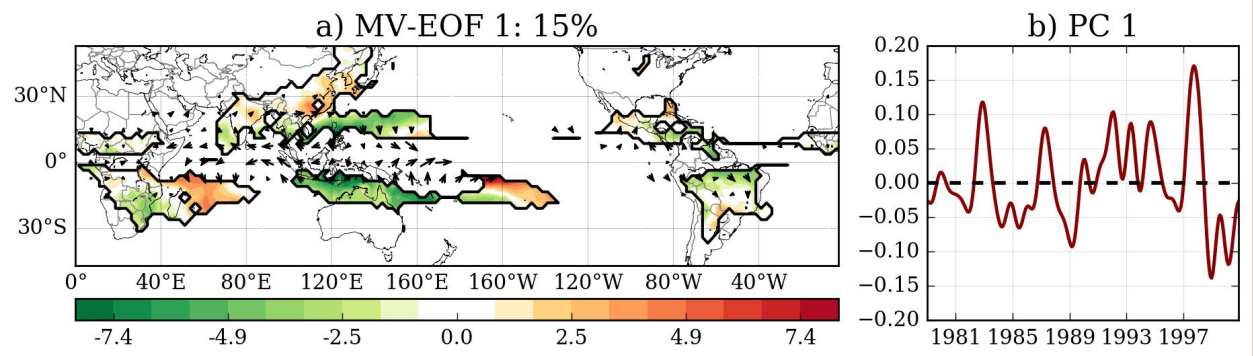
Reduction of dispersion among CMIP6 models



Performance by group of models - Annual MV-EOF1



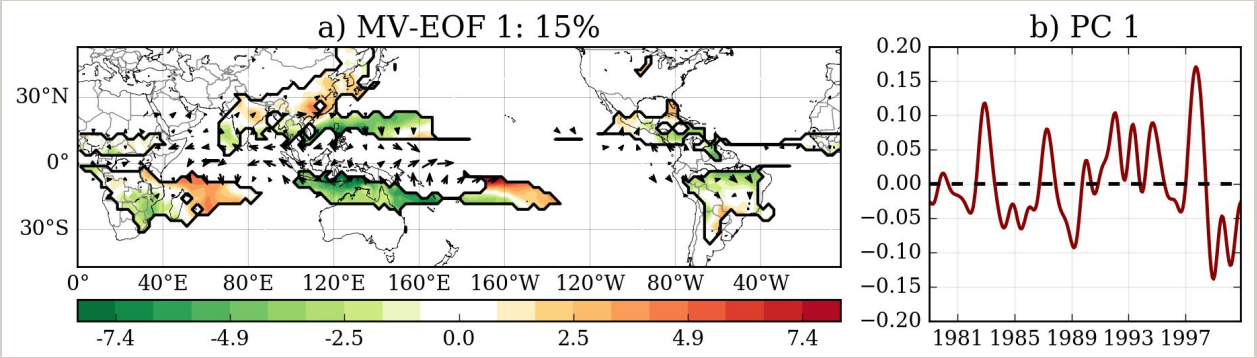
Inter-annual variability

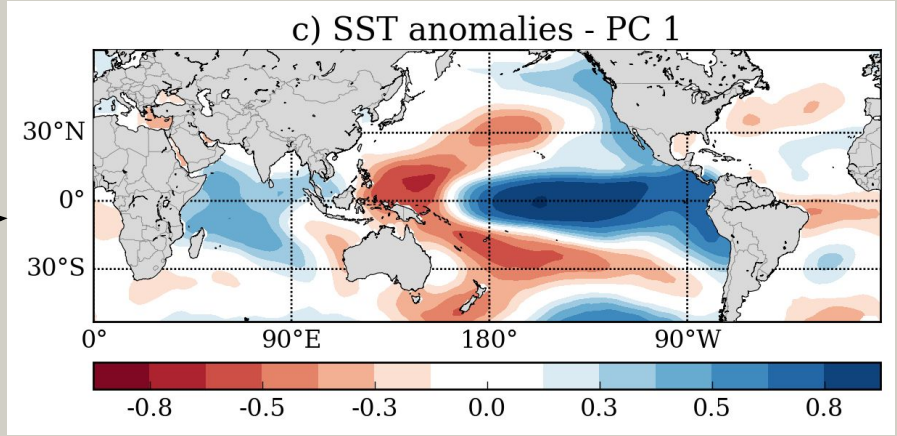


Multivariate empirical orthogonal functions (MV-EOF) monthly anomalies from precipitation within GMPD and surface winds within GMWD (1979-2000)

Inter-annual variability

ENSO-related mode





Multivariate empirical orthogonal functions (MV-EOF) monthly anomalies from precipitation within GMPD and surface winds within GMWD (1979-2000)

N: number of grid points in reference resolution

Observations

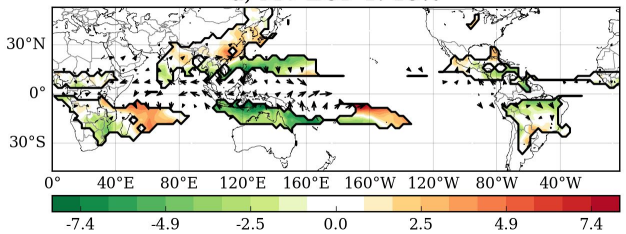
3N

1979-2000

pr *u* *v*

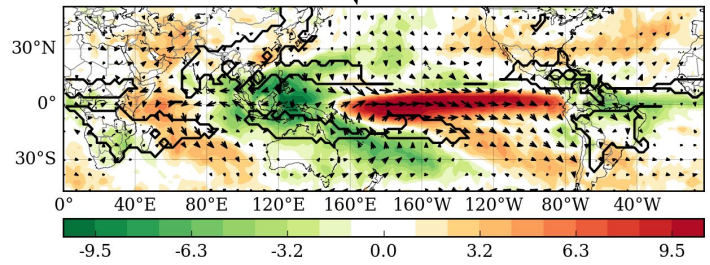
EOF

a) MV-EOF 1: 15%



Precipitation within **observed GMPD** and surface winds within **observed GMWD**

Projection of global anomalies of precipitation and surface winds onto inter-annual leading mode



PCC
NRMSE

Simulations

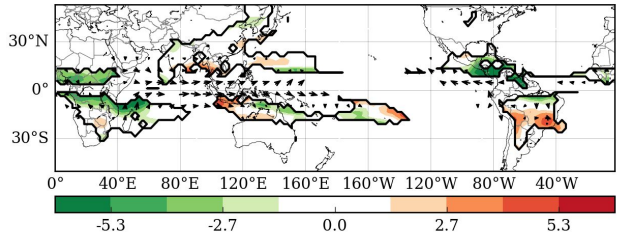
3N

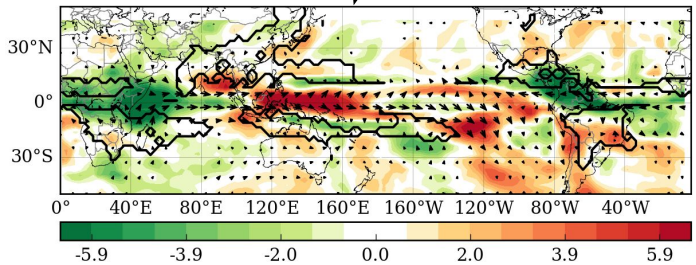
1979-2000

pr *u* *v*

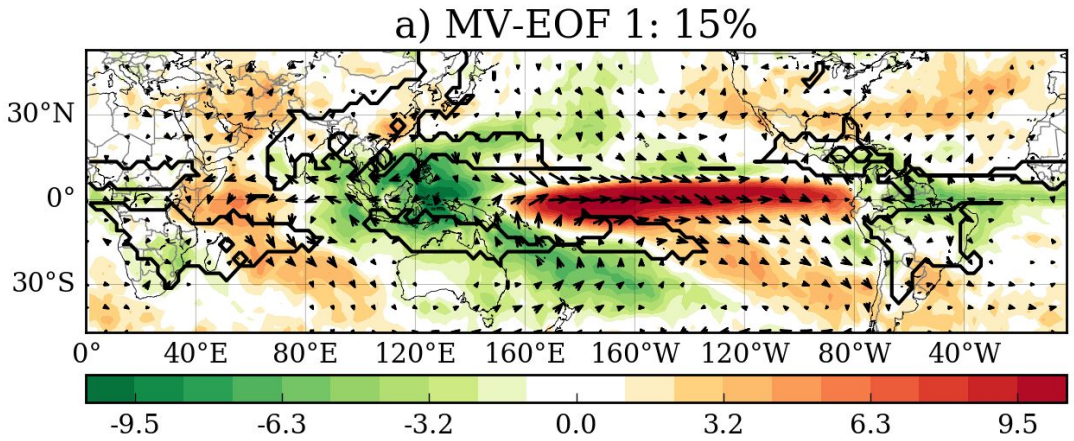
EOF

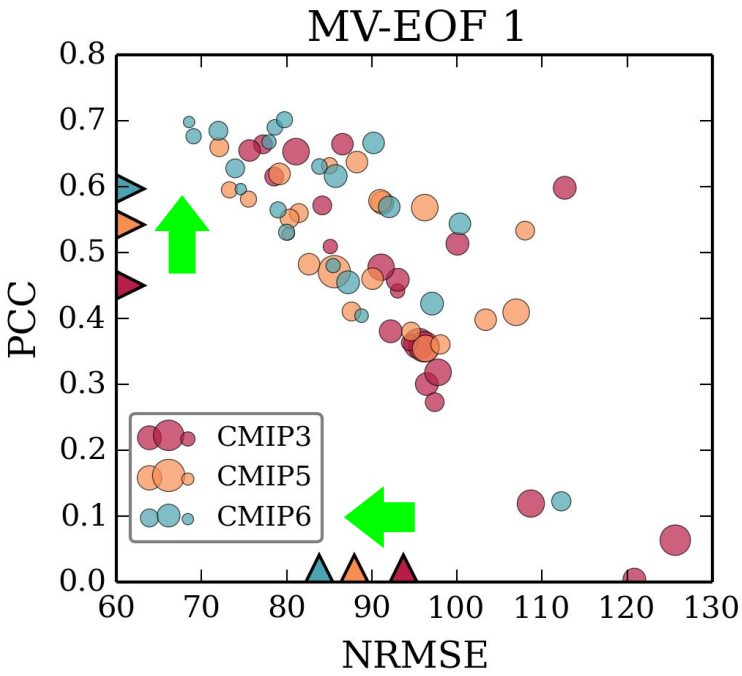
INMCM3.0 MV-EOF 1





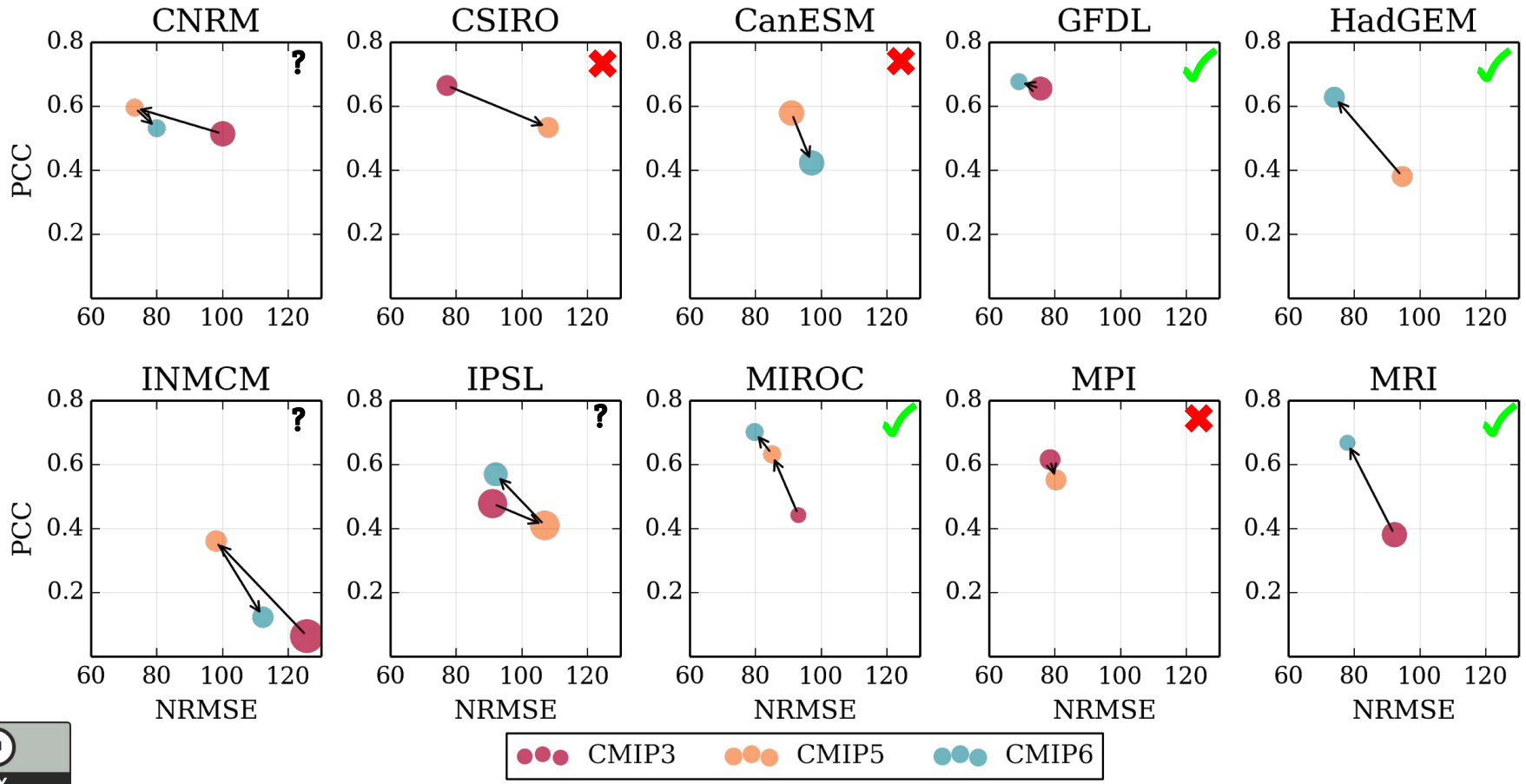
Model Performance





Lower performance compared to annual variation

Performance by group of models - Inter annual MV-EOF1



Summary and Conclusions

- Global monsoon domain and annual leading modes are well captured in most of the GCMs.
- CMIP6 models show a significant improvement especially over the Asian-Australian monsoon region.
- Model simulations are still affected by large biases, in terms of seasonal precipitation and interannual variability.
- It is relevant to point out that dispersion among GCMs was considerably reduced within CMIP6, except for interannual variability.
- We do not find a direct relationship between model performance and horizontal resolution.