

Model Performance in Simulating Global Monsoon Features: Skill Evolution across CMIP generations

Luz Adriana Gómez

D. C. Cruz, C. D. Hoyos, and P. J. Webster



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DE COLOMBIA

Global Monsoon

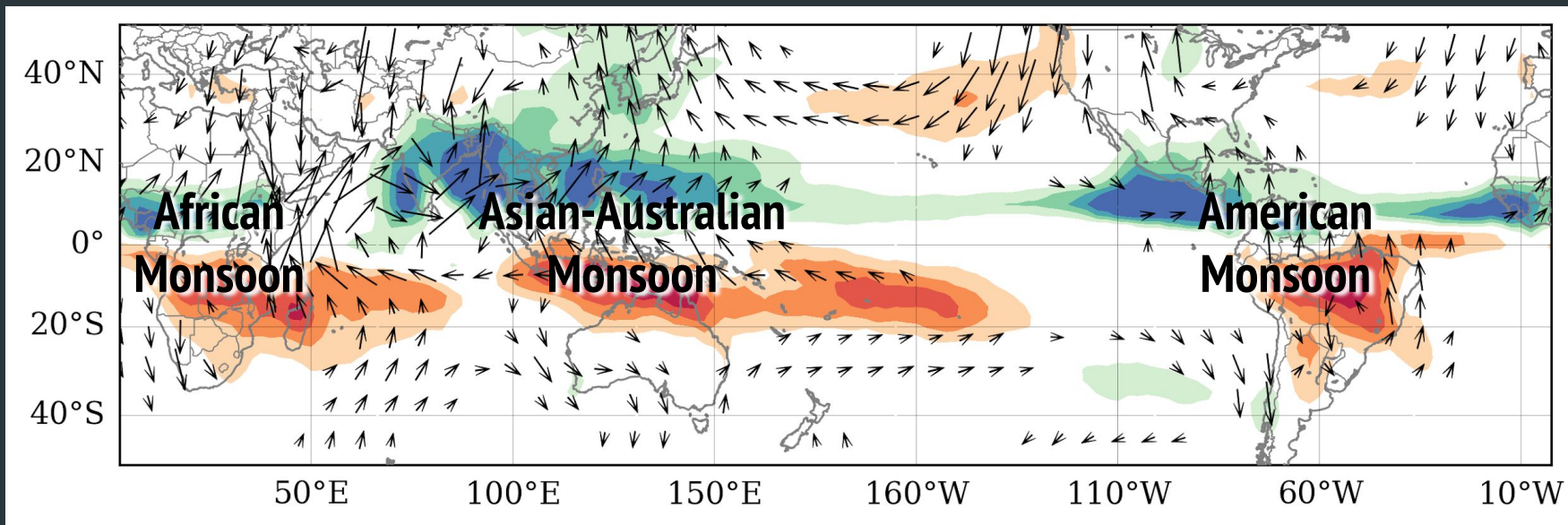
Webster, 1987

Trenberth et al., 2000

Wang and Ding, 2006, 2008

Liu et al. 2009

Wang et al., 2017



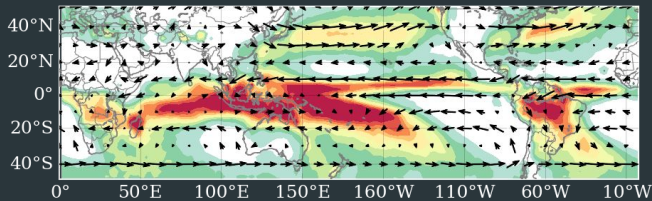
Global Monsoon Features

Wang and Ding, 2006, 2008

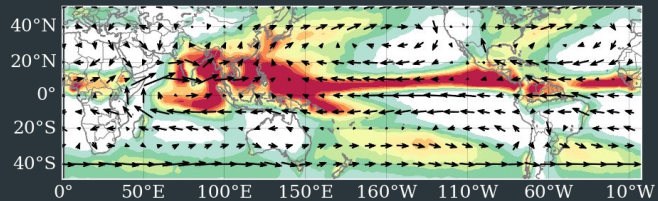
Wang et al. 2011

Seasonal Patterns

DJF



JJA



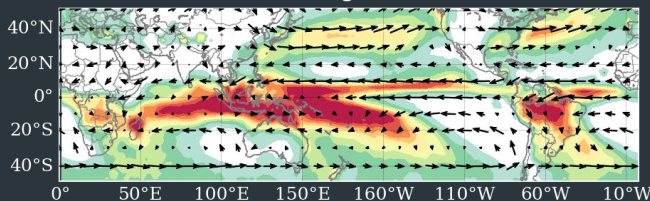
Global Monsoon Features

Wang and Ding, 2006, 2008

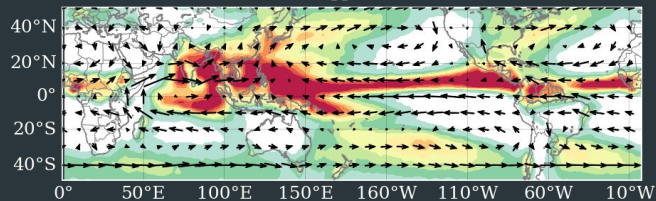
Wang et al. 2011

Seasonal Patterns

DJF



JJA

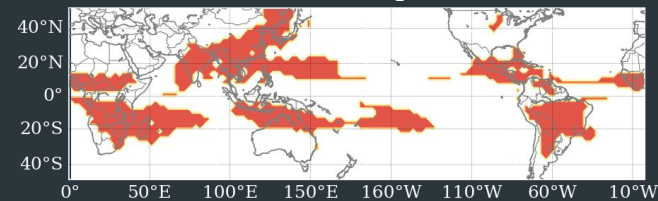


Global Monsoon Features

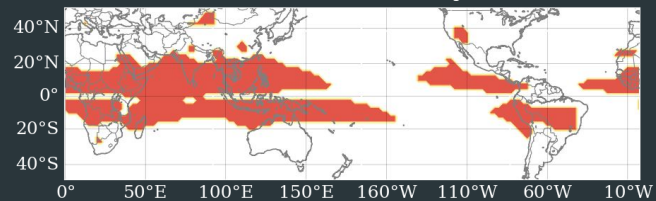
Wang and Ding, 2006, 2008
Wang et al. 2011

GM Domain

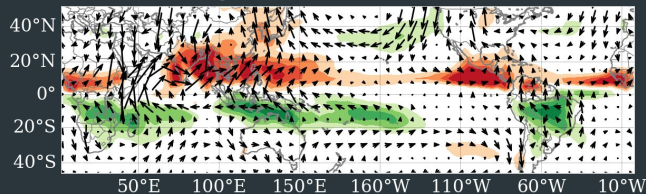
Global Monsoon Precipitation Domain



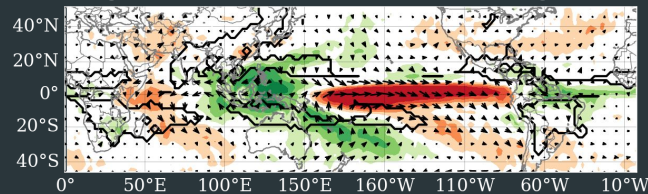
Global Monsoon Westerly Domain



Leading mode of annual variation



Regression onto interannual leading mode



Dominant modes of annual and interannual variation

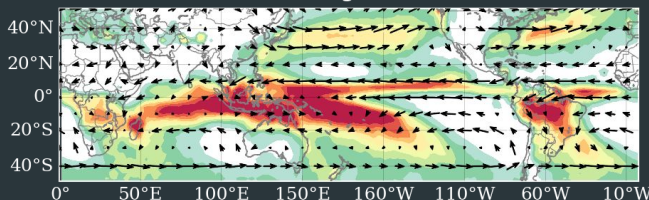
Seasonal Patterns

GM Domain

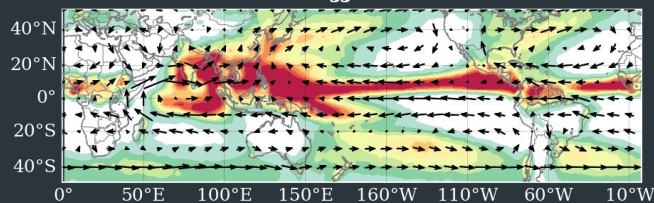
Global Monsoon Features

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

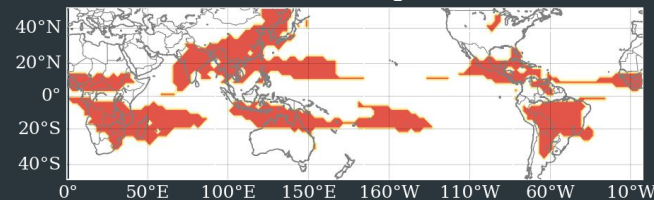
DJF



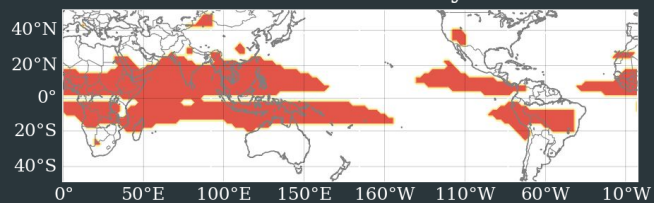
JJA



Global Monsoon Precipitation Domain



Global Monsoon Westerly Domain



Evaluation Criteria

Seasonal Patterns

Annual variation

**Inter-annual
variation**

**Global Monsoon
Domain**

Evaluation Criteria

Seasonal Patterns

Annual variation

Inter-annual
variation

Global Monsoon
Domain

Performance Metrics

Pattern
Correlation
Coefficient (PCC)

Normalized root
mean square
error (NRMSE)

Accuracy metrics

Evaluation Criteria

Seasonal Patterns

Annual variation

Inter-annual
variation

Global Monsoon
Domain

Performance Metrics

Pattern
Correlation
Coefficient (PCC)

Normalized root
mean square
error (NRMSE)

Accuracy metrics

Comparison

21 CMIP3

21 CMIP5

20 CMIP6

Evaluation Criteria

Seasonal Patterns

Annual variation

Inter-annual variation

Global Monsoon Domain

Performance Metrics

Pattern Correlation Coefficient (PCC)

Normalized root mean square error (NRMSE)

Accuracy metrics

Comparison

21 CMIP3

21 CMIP5

20 CMIP6

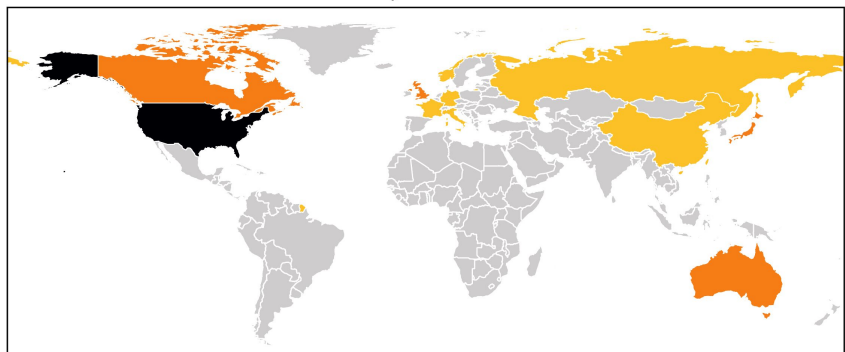
 **Improvement**

 **No-significant Improvement**

Global climate models used in the study

Horizontal resolution
1.1 - 5 degrees

models by country - CMIP3



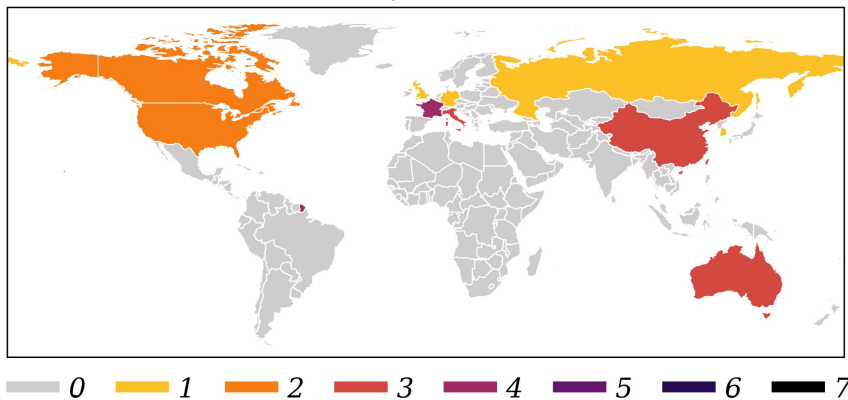
21
CMIP3

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

Global climate models used in the study

Horizontal resolution
0.8 - 5.6 degrees

models by country - CMIP5



21
CMIP5

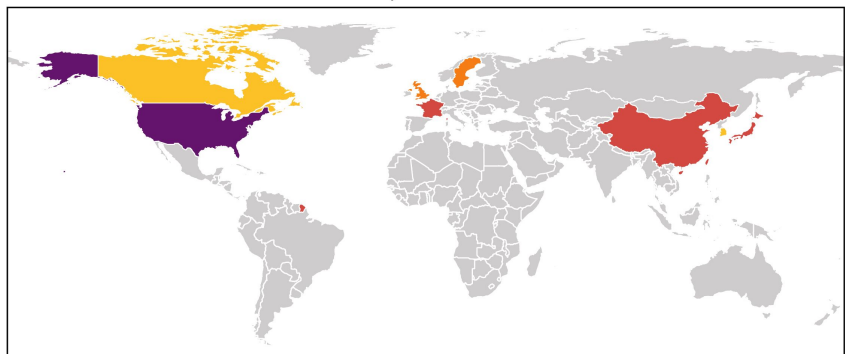
CanCM4
CanESM2
NorESM1-ME
HadCM3
NorESM1-ME
IPSL-CM5A-LR
CNRM-CM5.2
CNRM-CM5
IPSL-CM5A-MR
MPI-ESM-LR
CMCC-CESM
CMCC-CMS
CMCC-CMS
HadGEM2-AO
INMCM4.0
HadGEM2-ES
GISS-E2-R-CC
GISS-E2-H-CC
CSIRO-Mk3.6.0
CSIRO-Mk3L-1.2
ACCESS1.3

Global climate models used in the study

20
CMIP6

Horizontal resolution
0.7 - 2.8 degrees

models by country - CMIP6



0 1 2 3 4 5 6 7

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

Global climate models used in the study

21
CMIP3

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

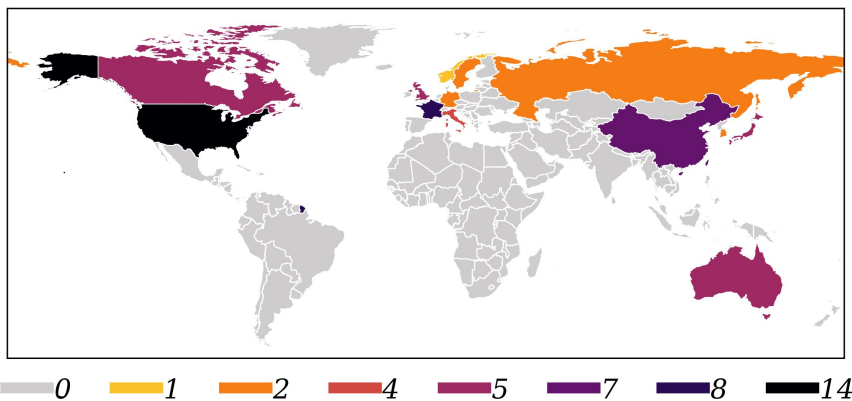
21
CMIP5

CanCM4
CanESM2
NorESM1-ME
HadCM3
NorESM1-ME
IPSL-CM5A-LR
CNRM-CM5.2
CNRM-CM5
IPSL-CM5A-MR
MPI-ESM-LR
CMCC-CESM
CMCC-CMS
CMCC-CMS
HadGEM2-AO
INMCM4.0
HadGEM2-ES
GISS-E2-R-CC
GISS-E2-H-CC
CSIRO-Mk3.6.0
CSIRO-Mk3L-1.2
ACCESS1.3

20
CMIP6

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

models by country - TOTAL

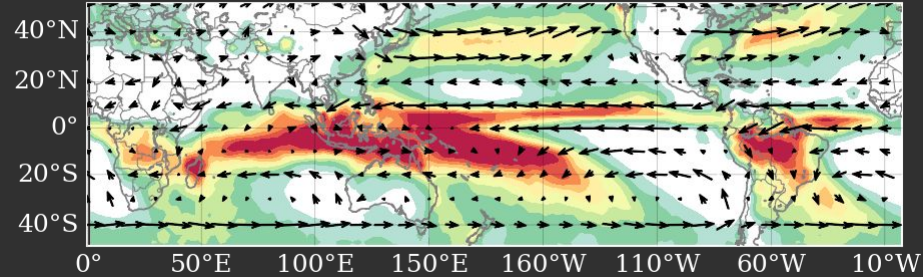


Seasonal patterns

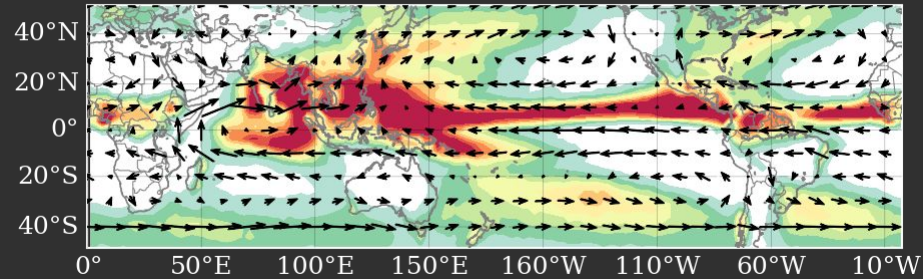
Precipitation (colors)

Surface winds 850hPa (vectors)

DJF

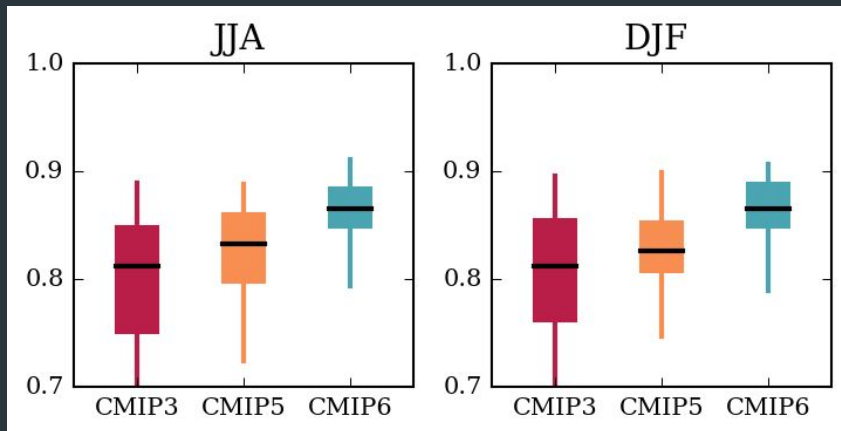


JJA

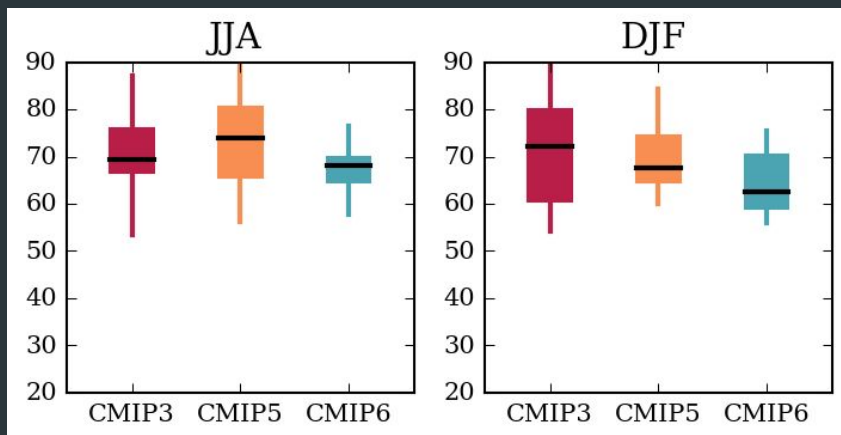


Precipitation

PCC:
Spatial Patterns



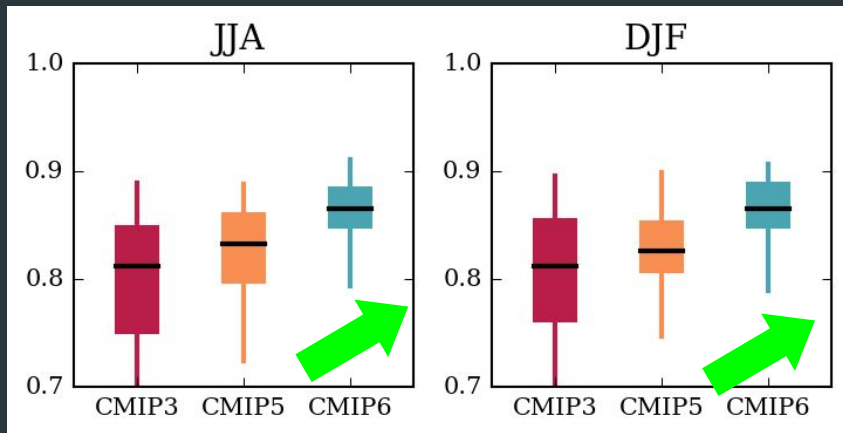
NRMSE:
Magnitude



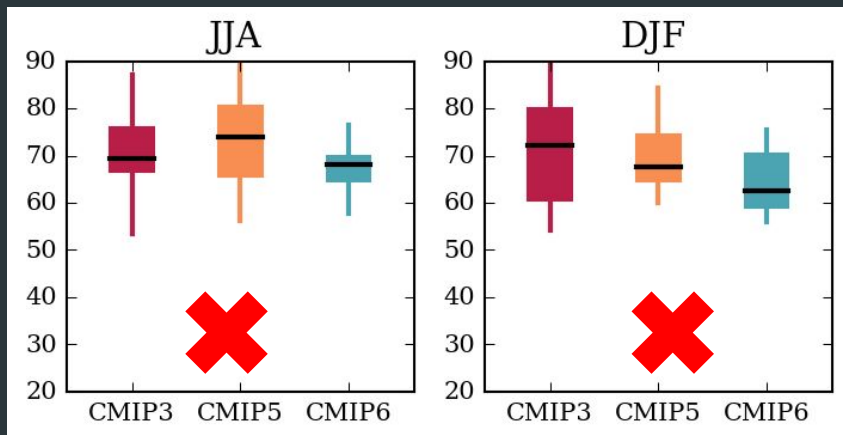
Precipitation

High magnitude errors remain
for CMIP6 models

PCC:
Spatial Patterns

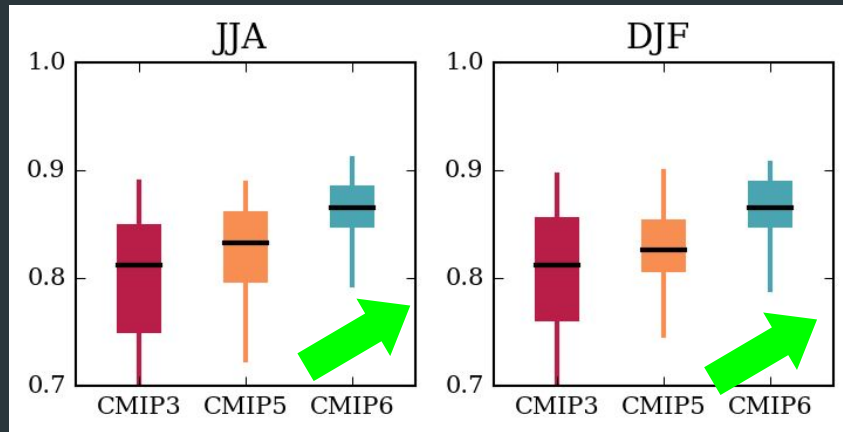


NRMSE:
Magnitude

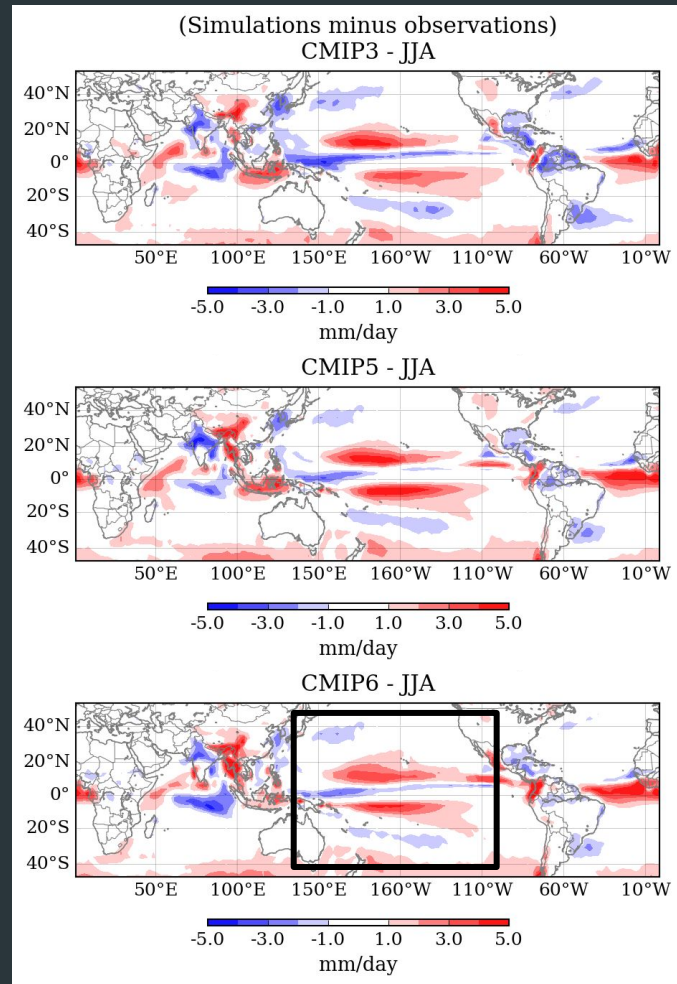
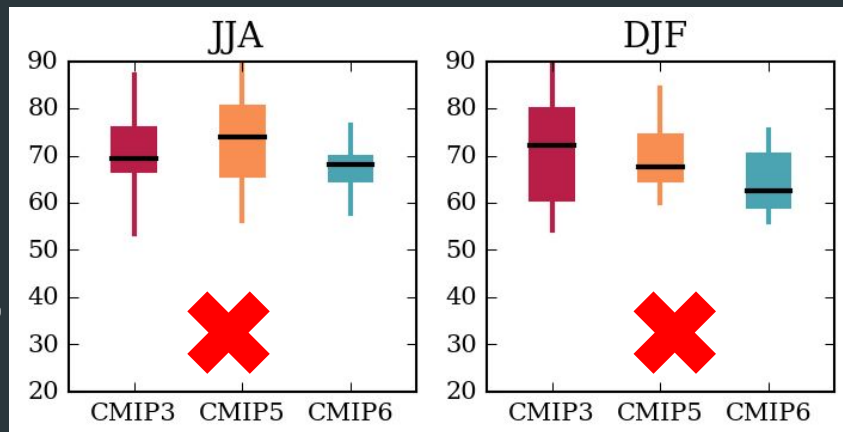


Precipitation

PCC:
Spatial Patterns

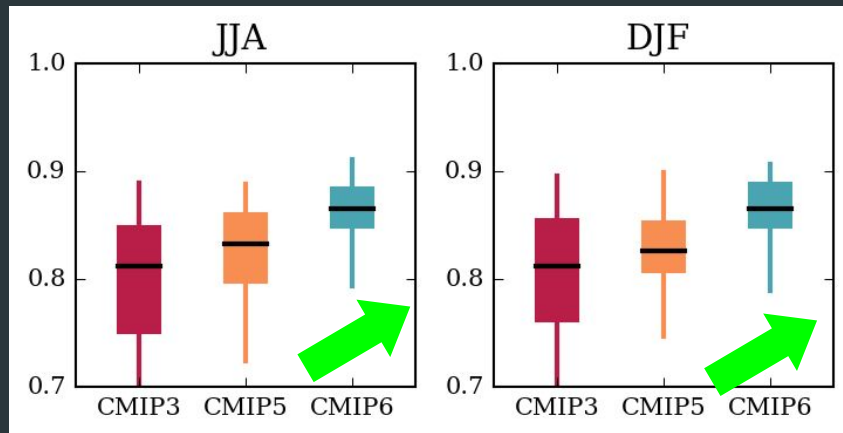


NRMSE:
Magnitude

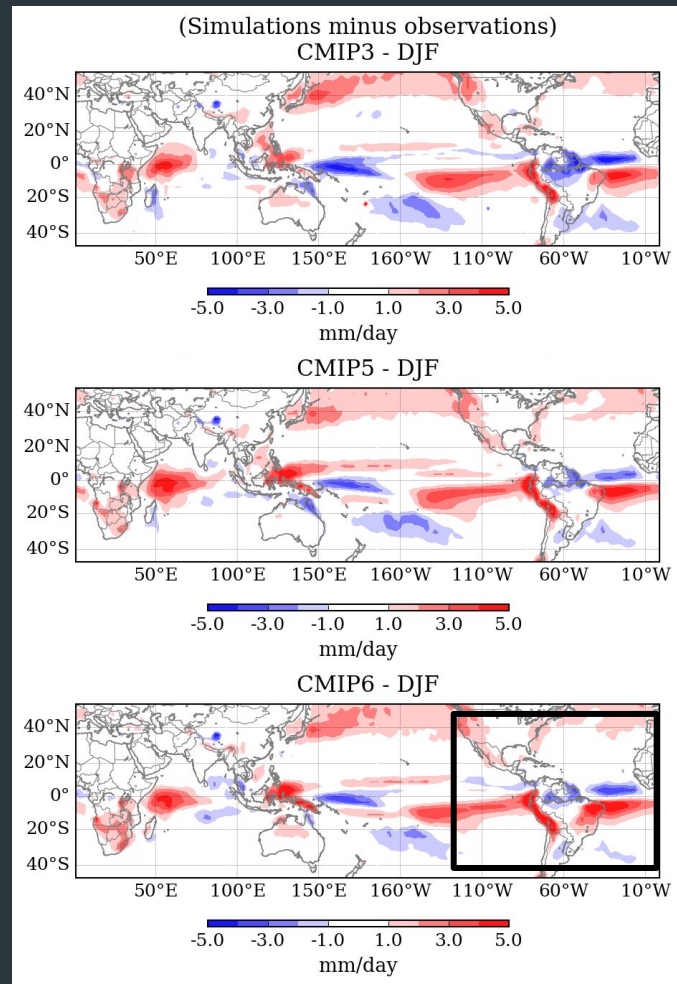
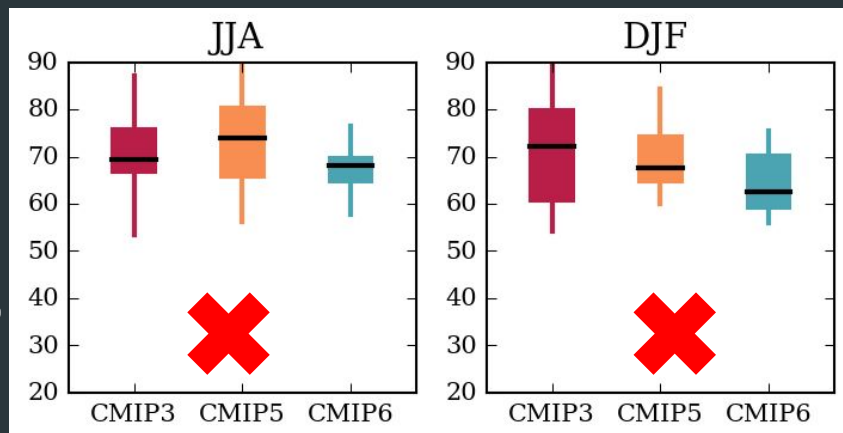


Precipitation

PCC:
Spatial Patterns



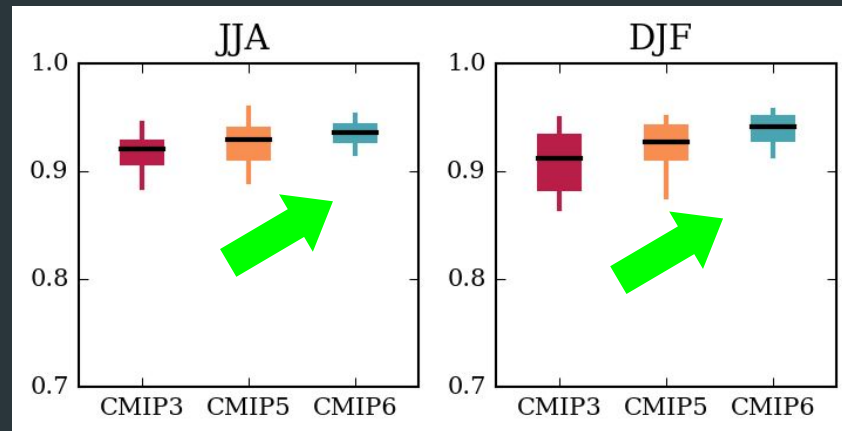
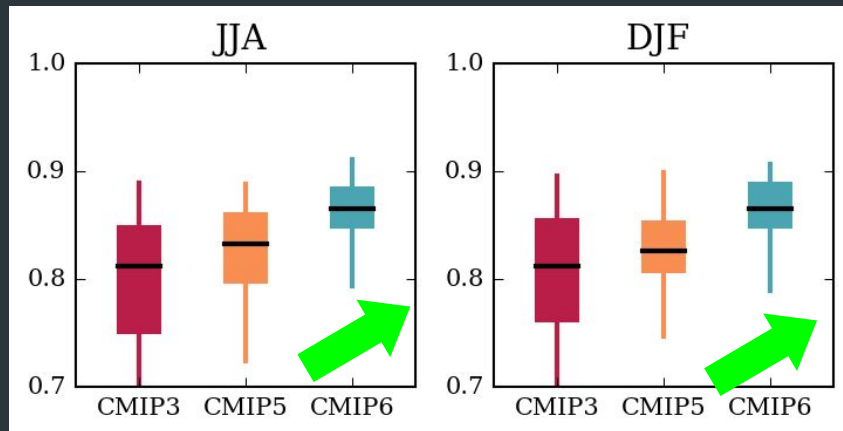
NRMSE:
Magnitude



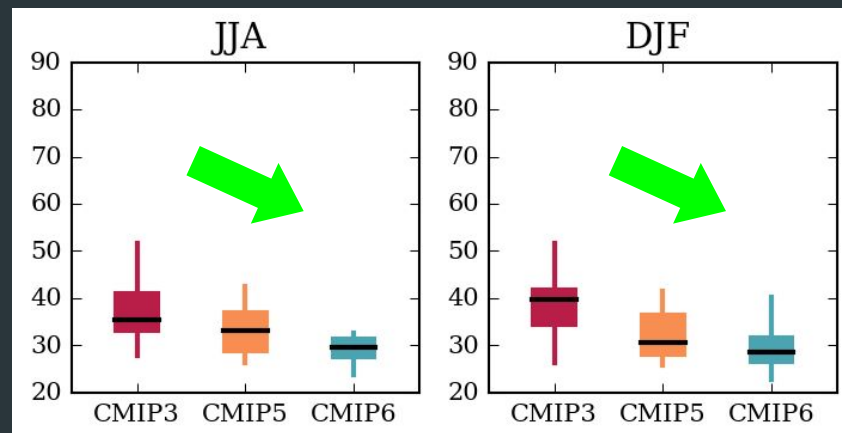
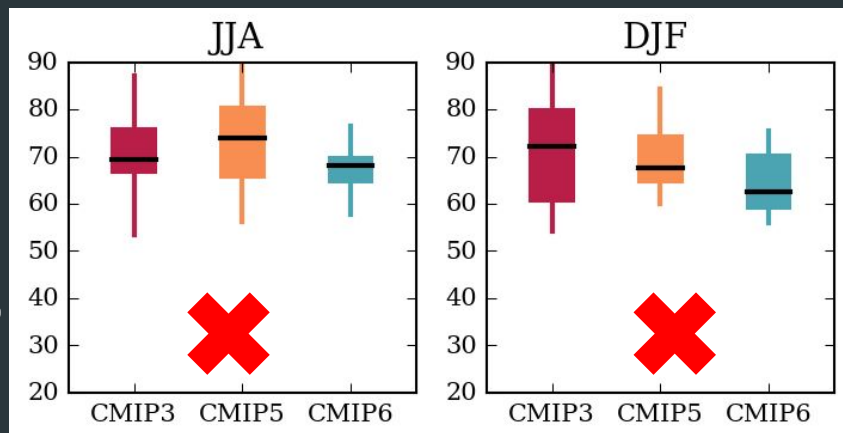
Precipitation

Surface Winds

PCC:
Spatial Patterns

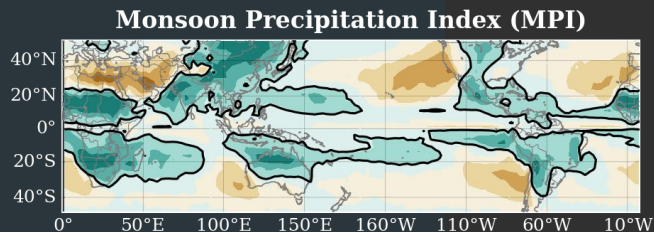
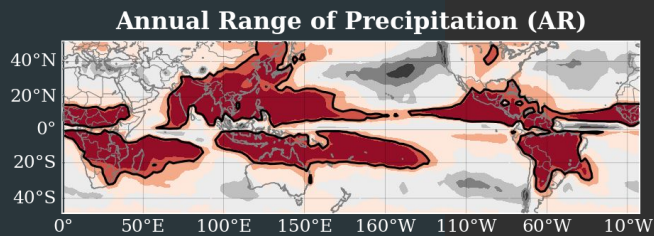


NRMSE:
Magnitude

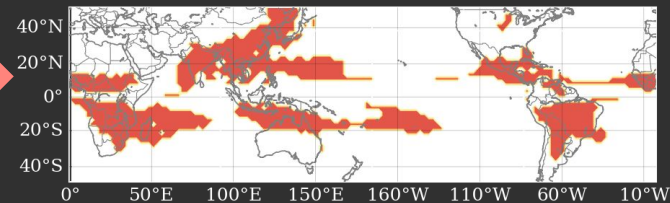


Global Monsoon Domain

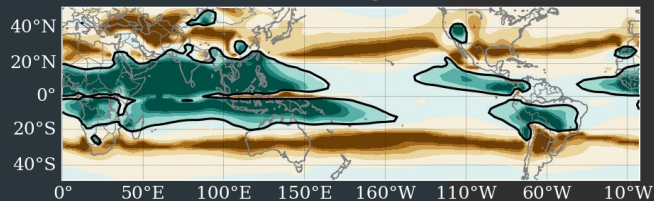
(Wang, B., & Ding, Q., 2008)



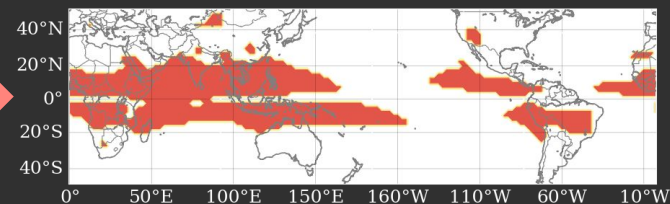
**Global Monsoon Precipitation Domain
GMPD**



Monsoon Westerly Index (MWI)

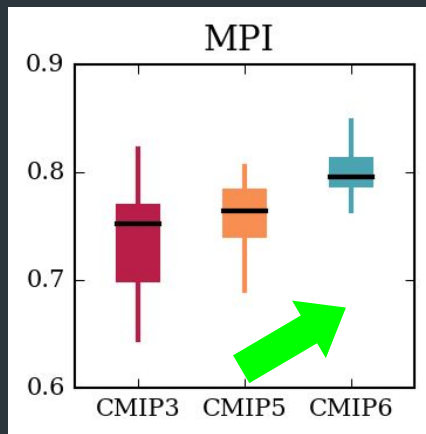
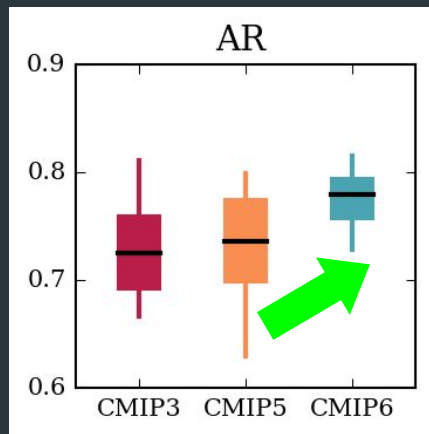


**Global Monsoon Westerly Domain
GMWD**

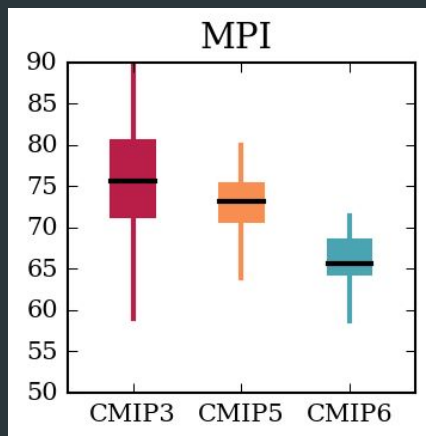
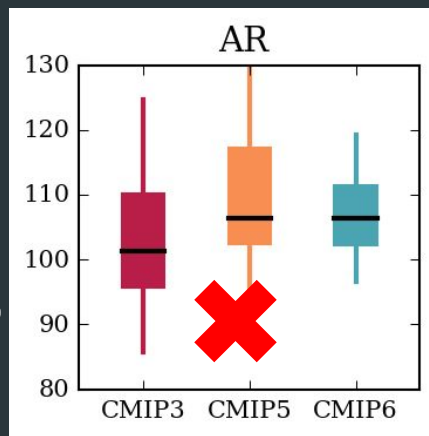


Precipitation

PCC:
Spatial Patterns

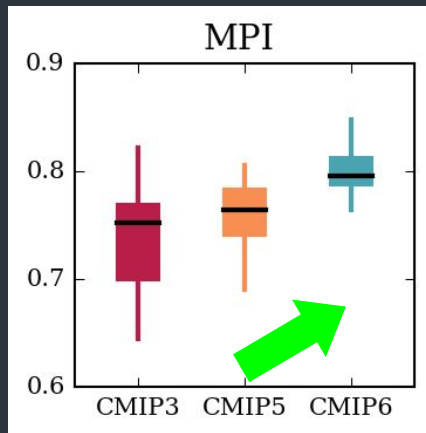
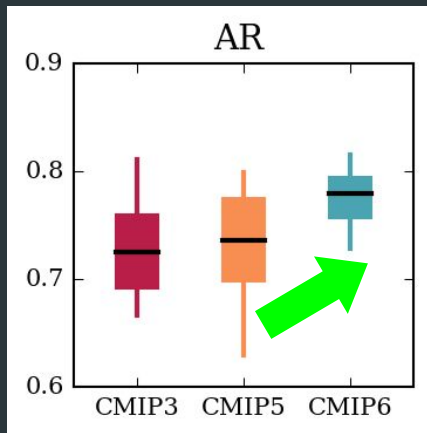


NRMSE:
Magnitude

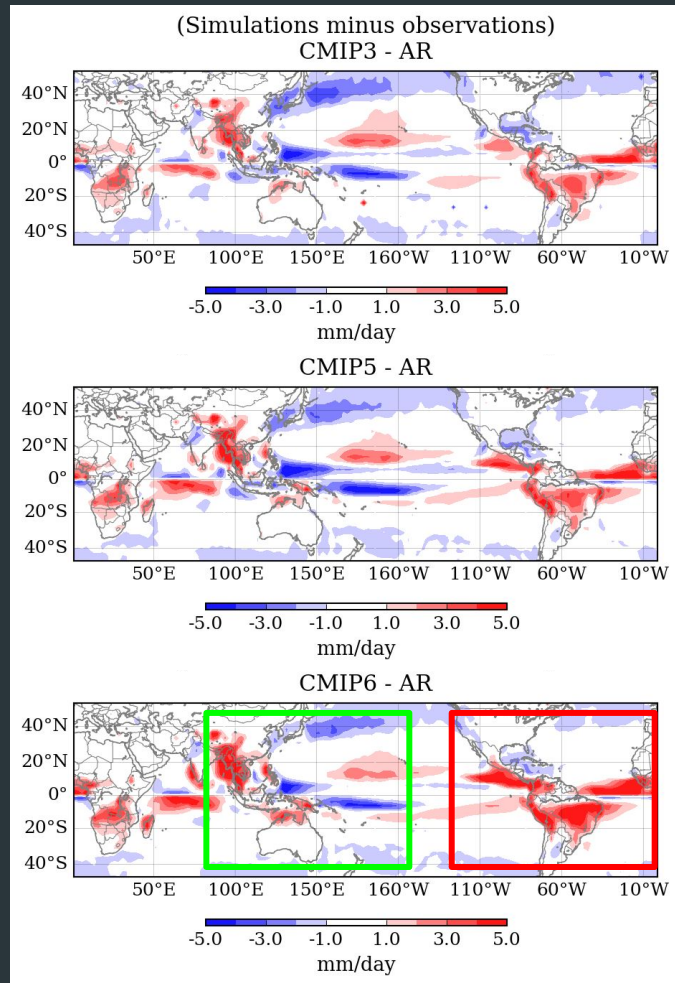
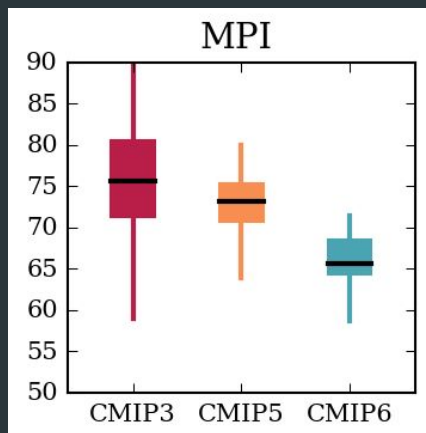
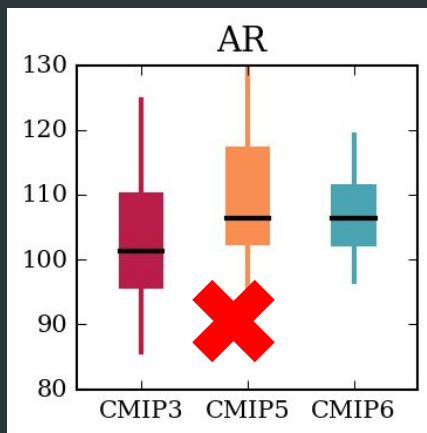


Precipitation

PCC:
Spatial Patterns

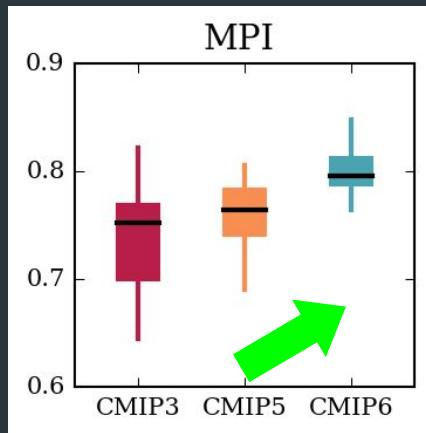
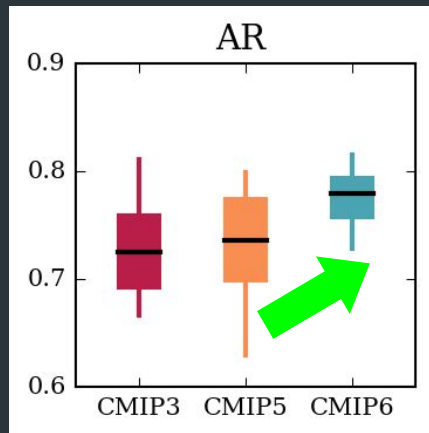


NRMSE:
Magnitude



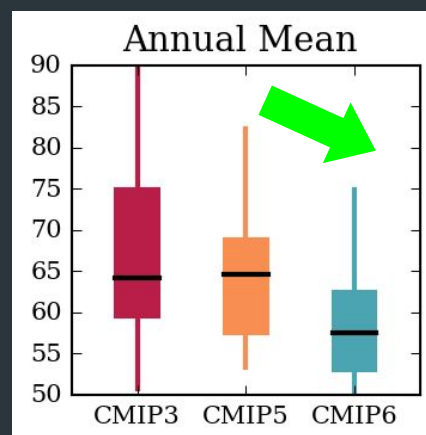
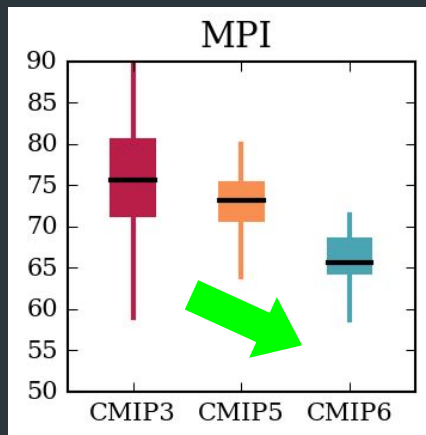
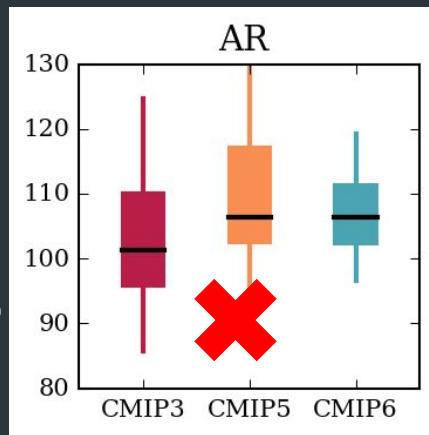
Precipitation

PCC:
Spatial Patterns

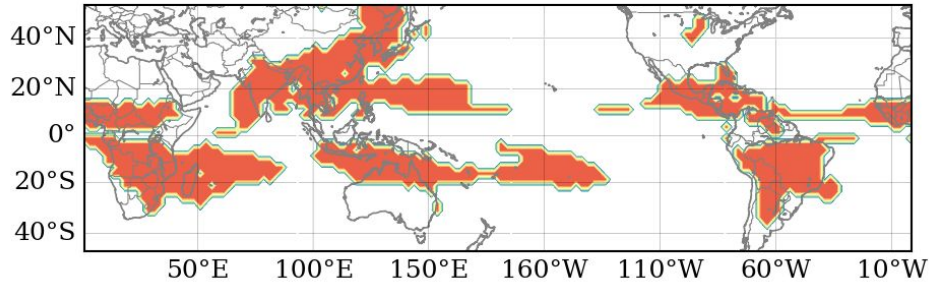


Improvement in simulating annual mean precipitation, but important biases in seasonal mean precipitation

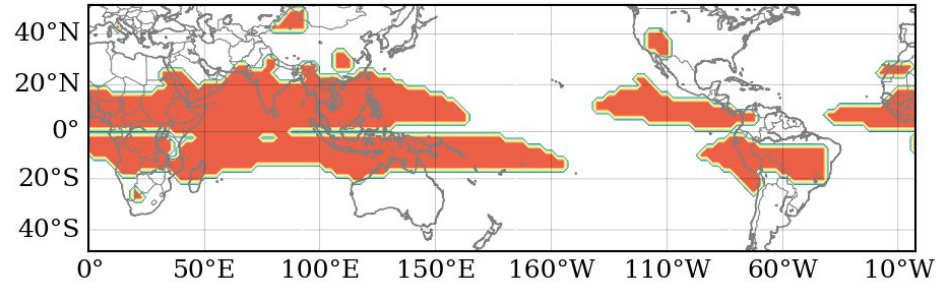
NRMSE:
Magnitude



a) GMPD



d) GMWD

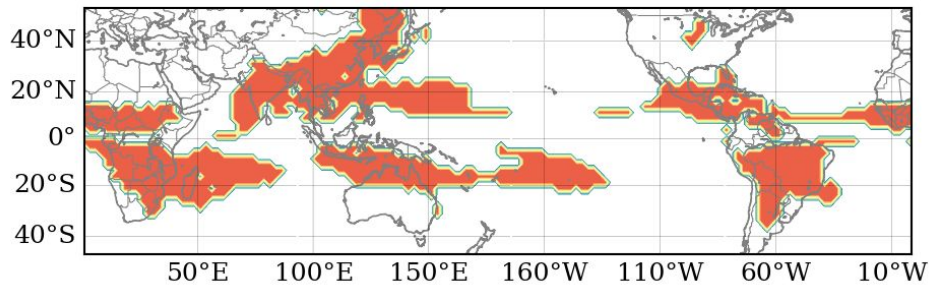


Performance Metrics

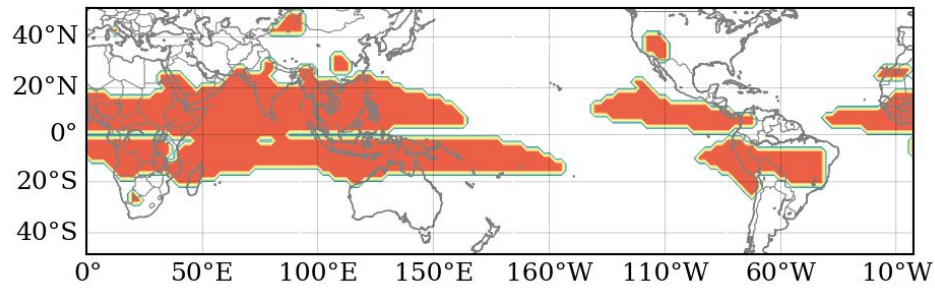
$$\textit{Threat Score} = \frac{\textit{hits}}{\textit{hits} + \textit{misses} + \textit{false alarms}}$$

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

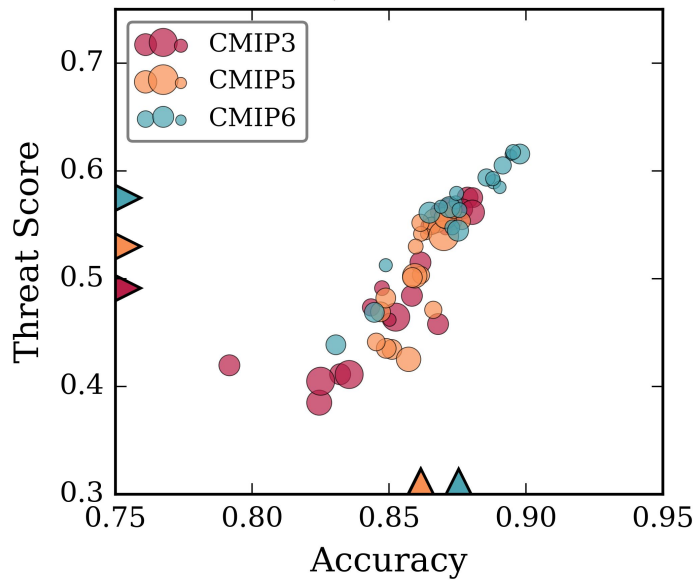
a) GMPD



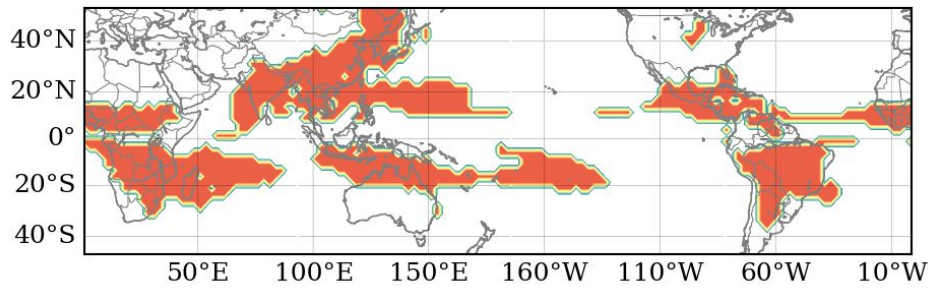
d) GMWD



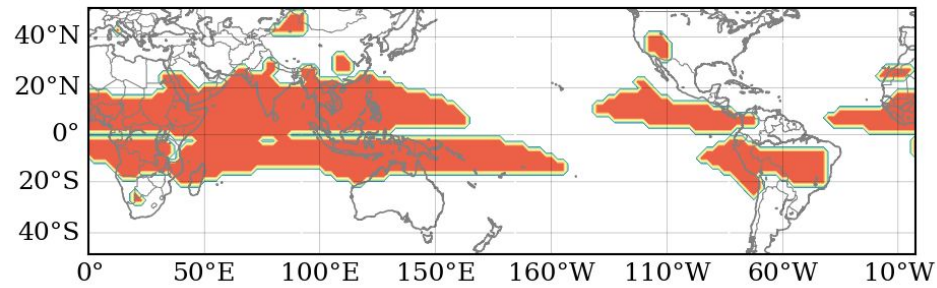
a) GMPD



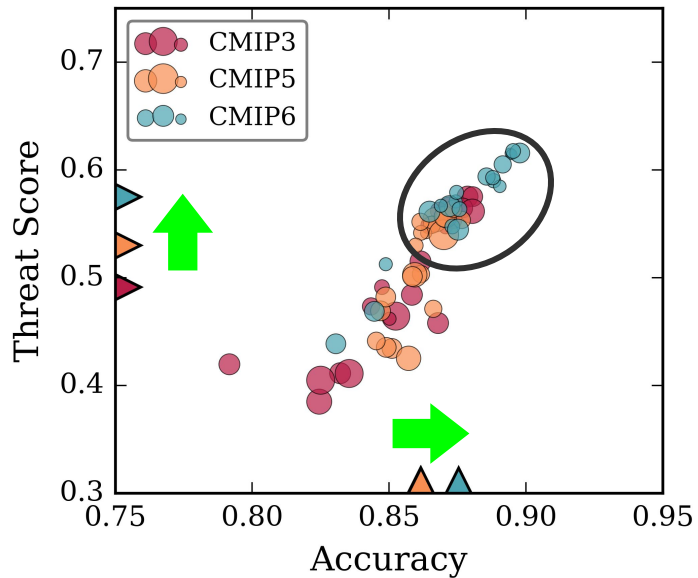
a) GMPD



d) GMWD

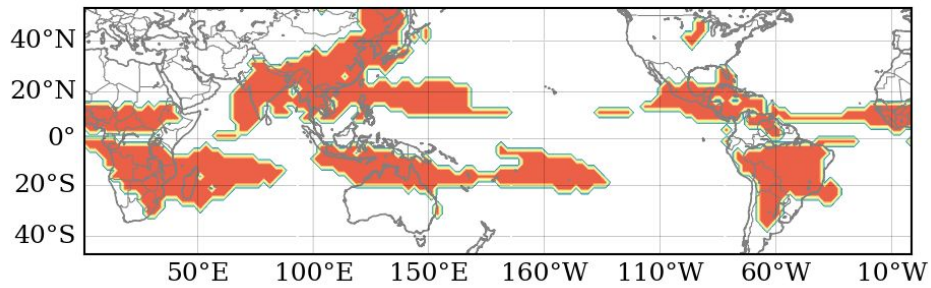


a) GMPD

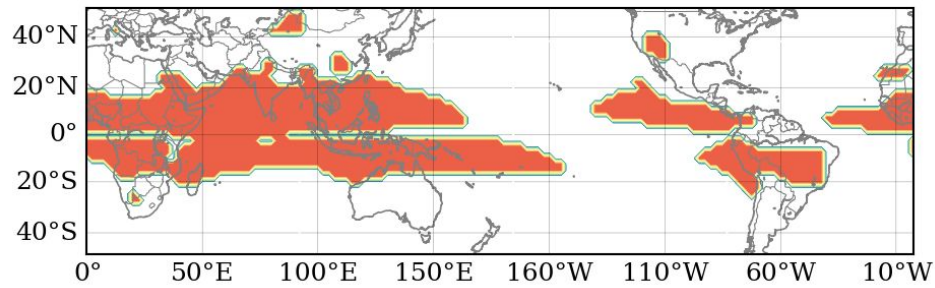


GMPD is well captured in most of the GCMs

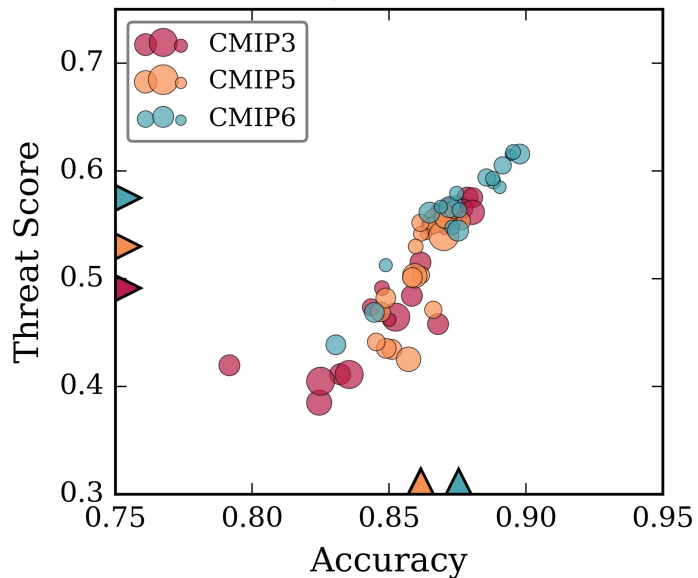
a) GMPD



d) GMWD

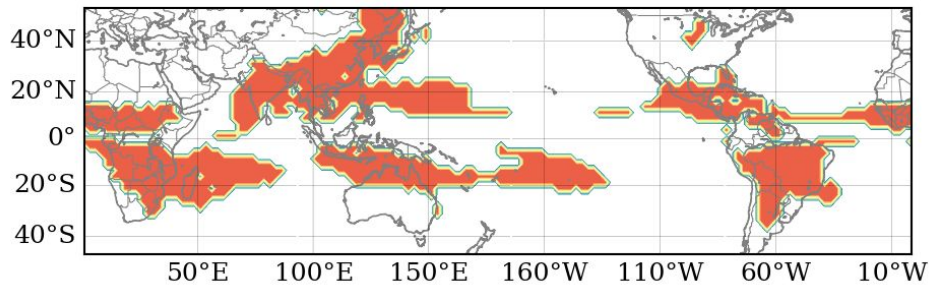


a) GMPD

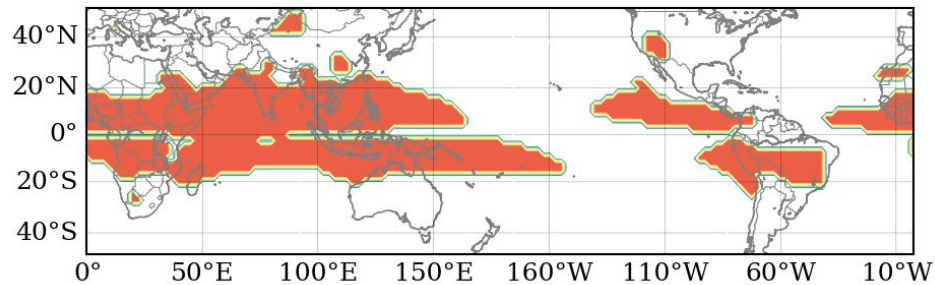


No direct relationship between model performance and horizontal model resolution

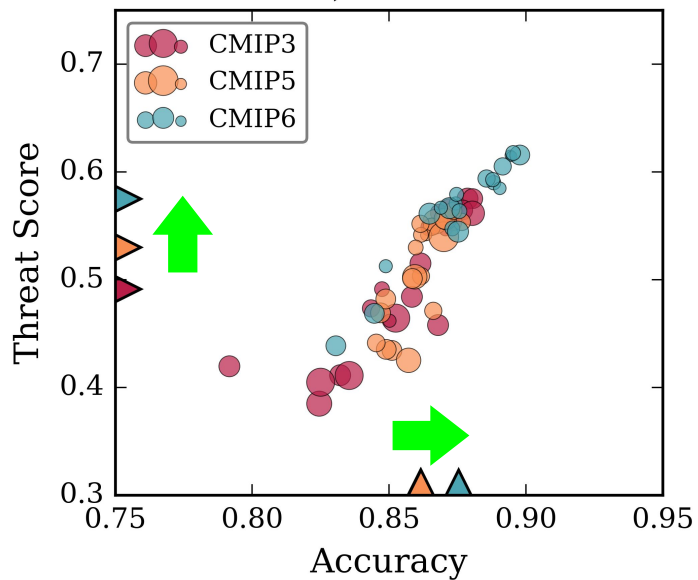
a) GMPD



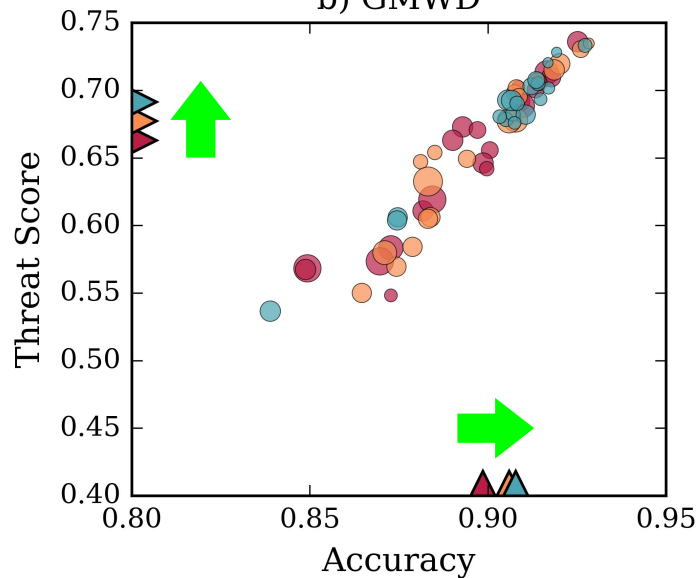
d) GMWD



a) GMPD

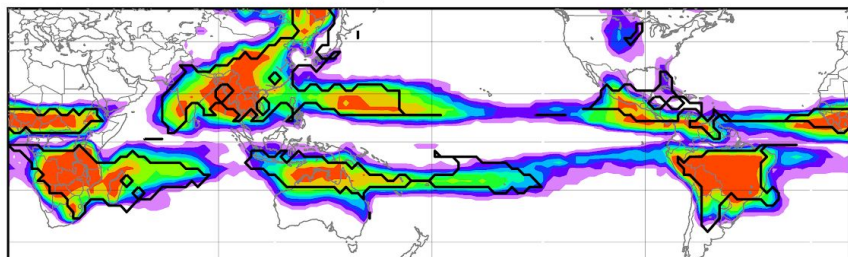


b) GMWD



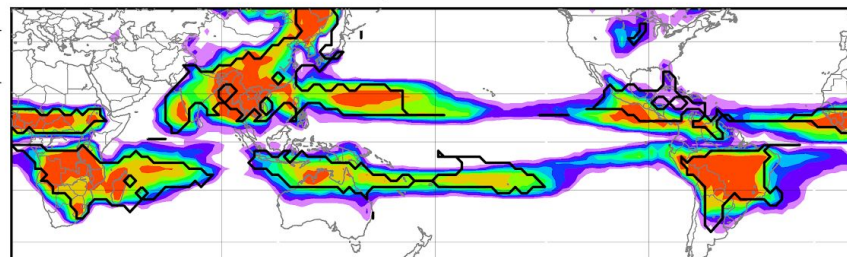
Intermodel agreement - GMPD

a) CMIP3



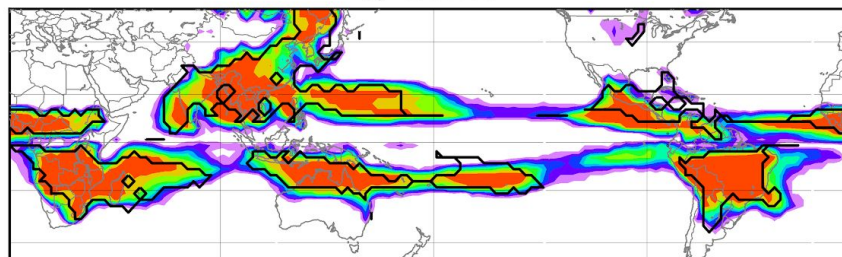
90°E 180° 90°W

b) CMIP5



90°E 180° 90°W

c) CMIP6



90°E 180° 90°W

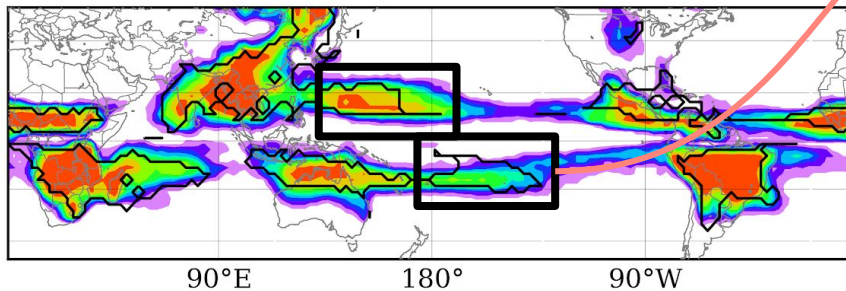


Percentage of GCMs

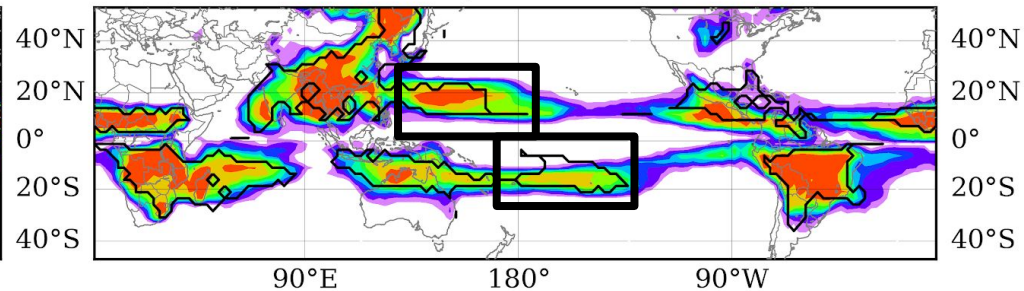
Oceanic regions

Higher agreement in ocean monsoon precipitation

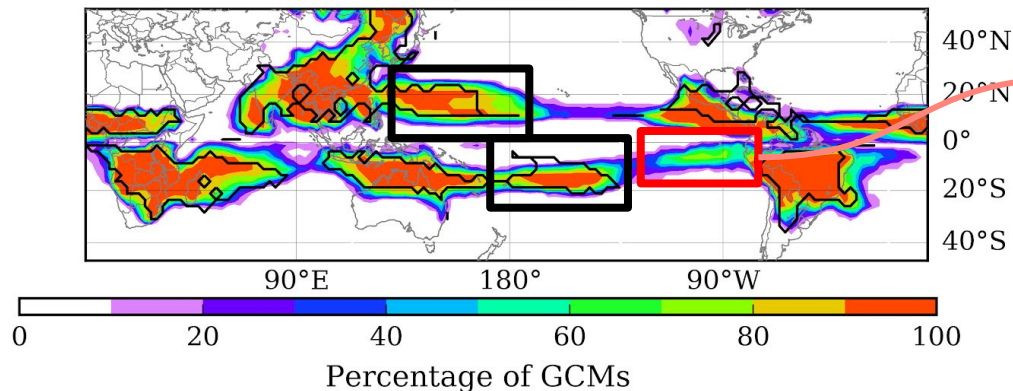
a) CMIP3



b) CMIP5



c) CMIP6

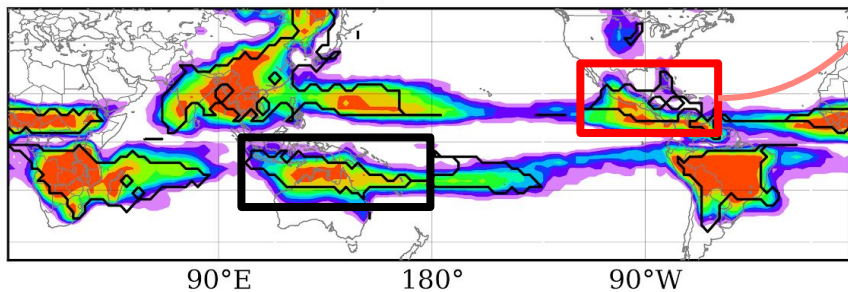


Overestimation of DJF precipitation

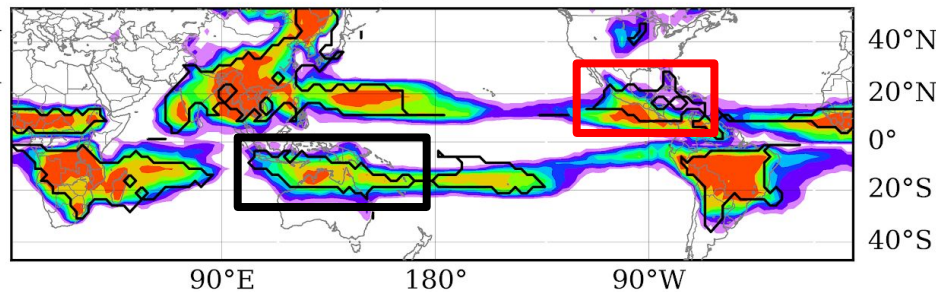
Land regions

No significant improvement in simulating NAM

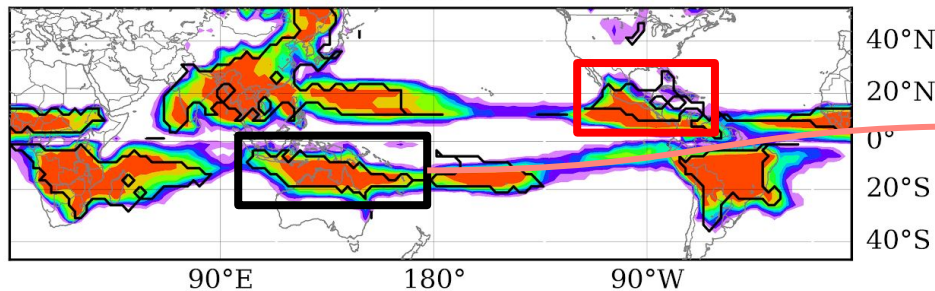
a) CMIP3



b) CMIP5



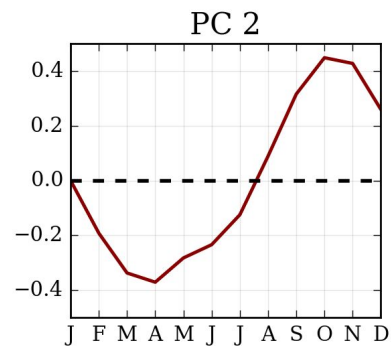
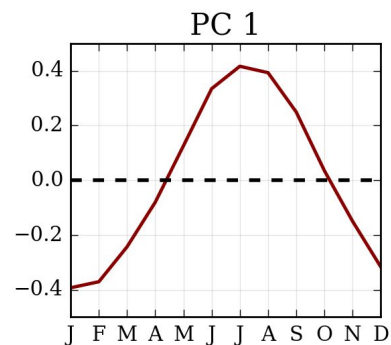
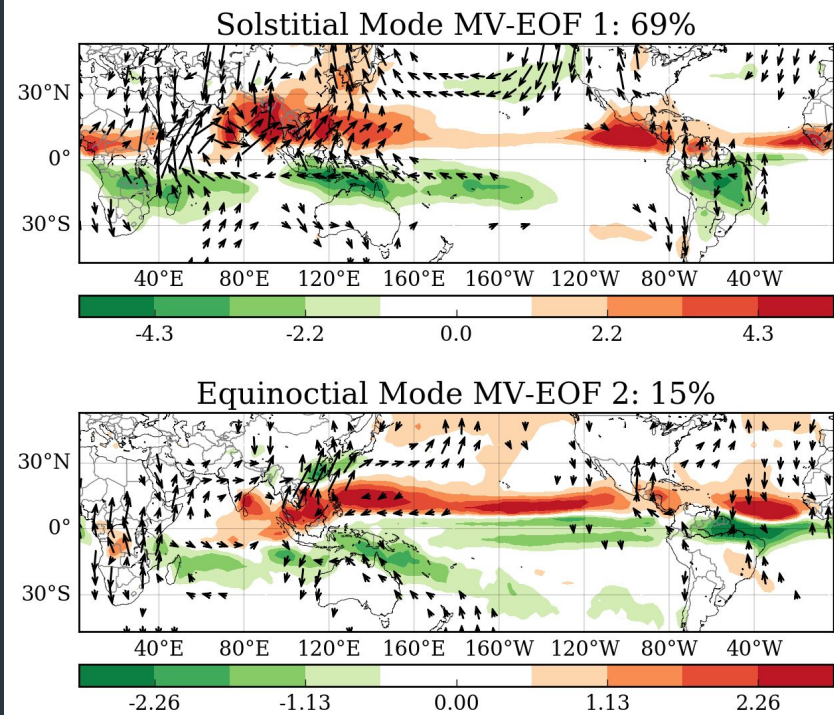
c) CMIP6



Percentage of GCMs

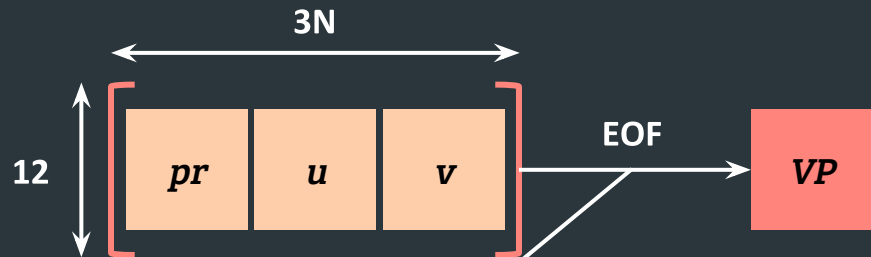
The biggest improvement is evidenced on Australian region

Leading modes of annual variation

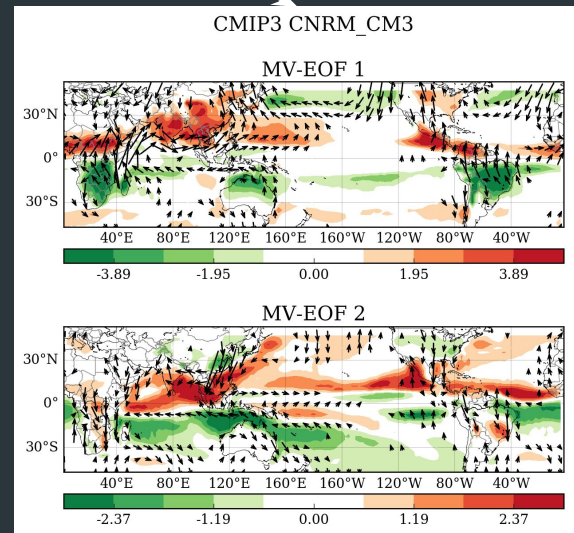
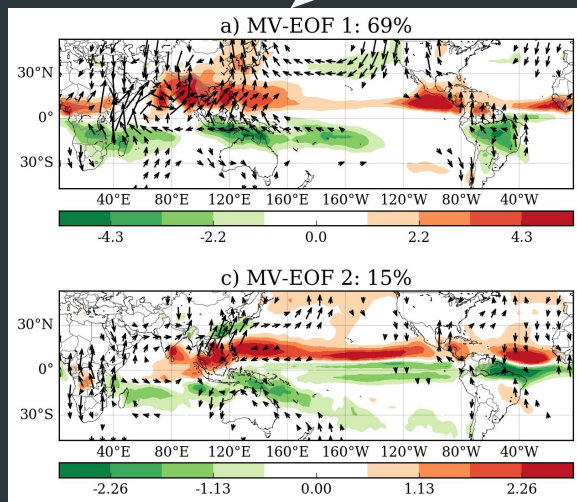
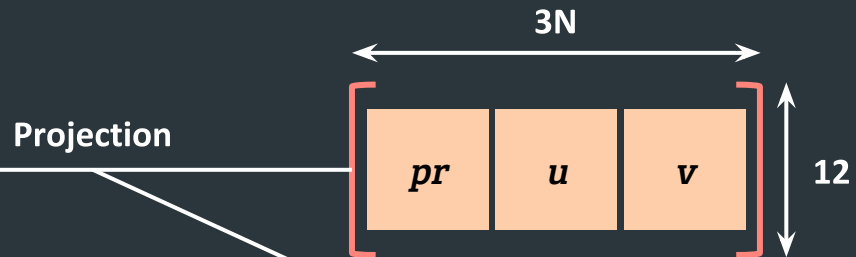


Multivariate empirical orthogonal functions (MV-EOF)
12-month climatology from precipitation and surface winds

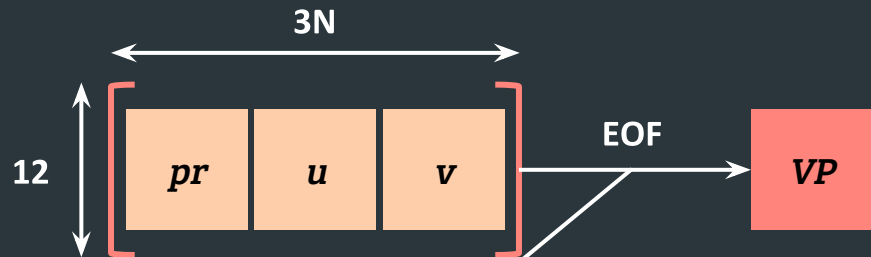
Observations



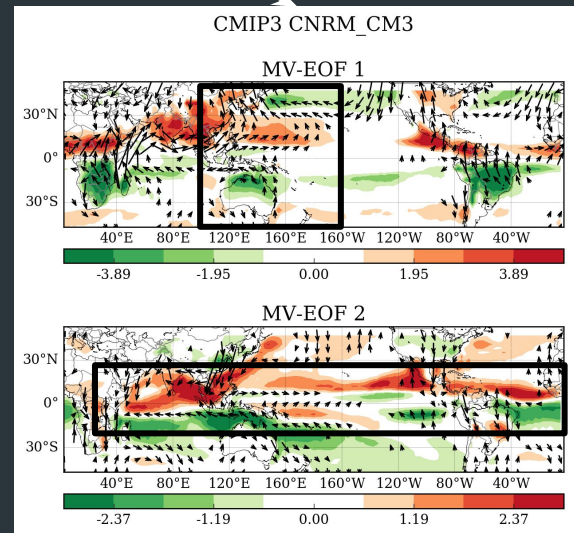
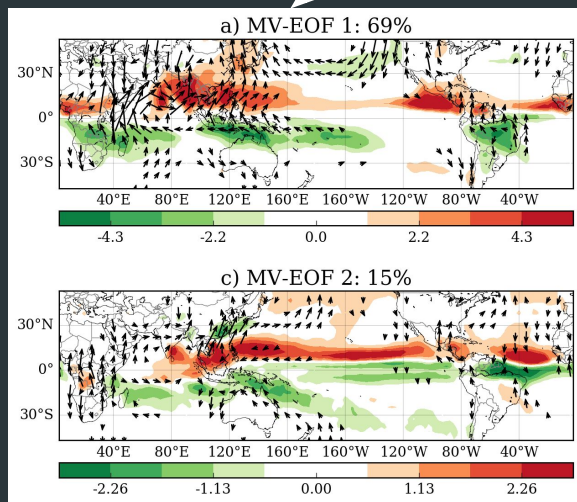
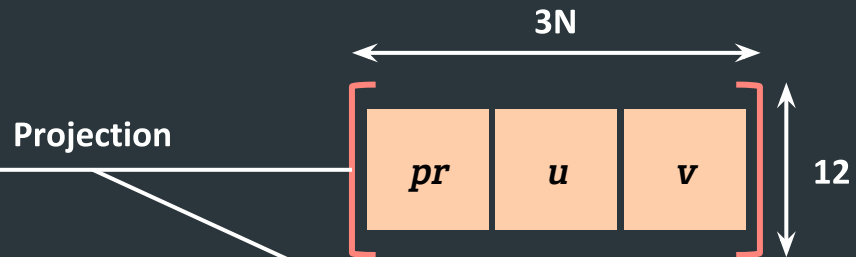
Simulations



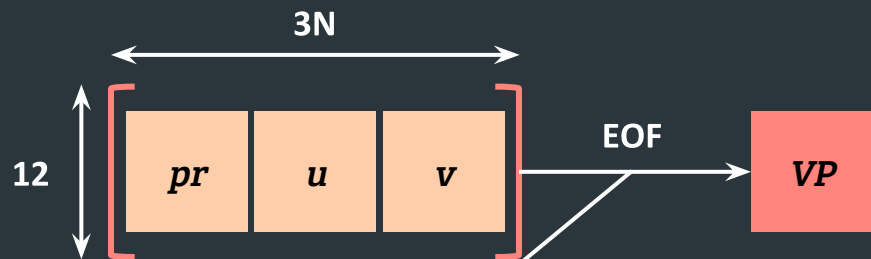
Observations



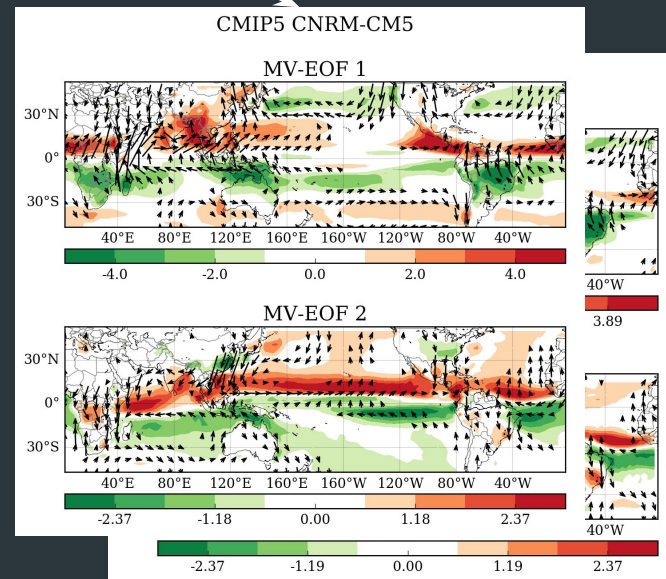
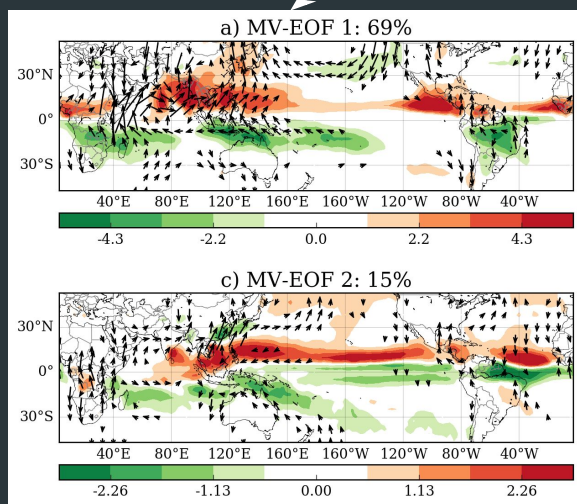
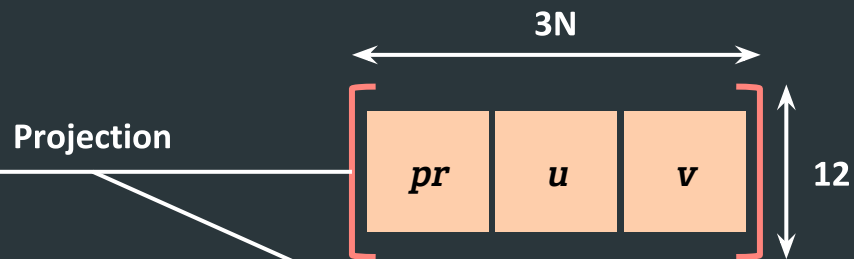
Simulations



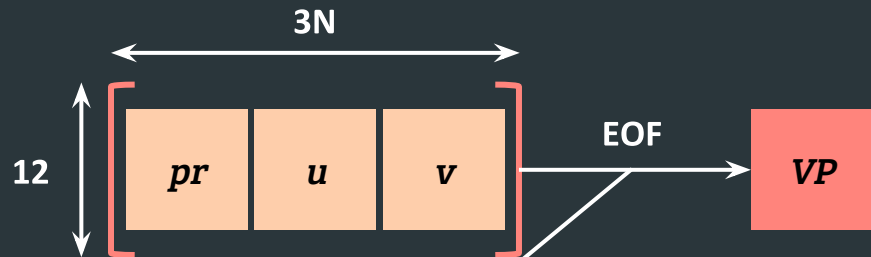
Observations



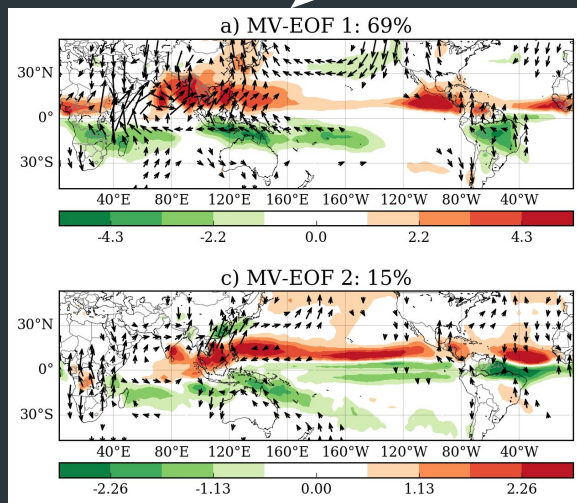
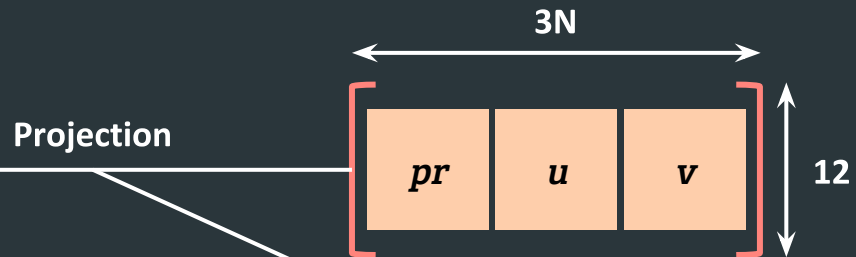
Simulations



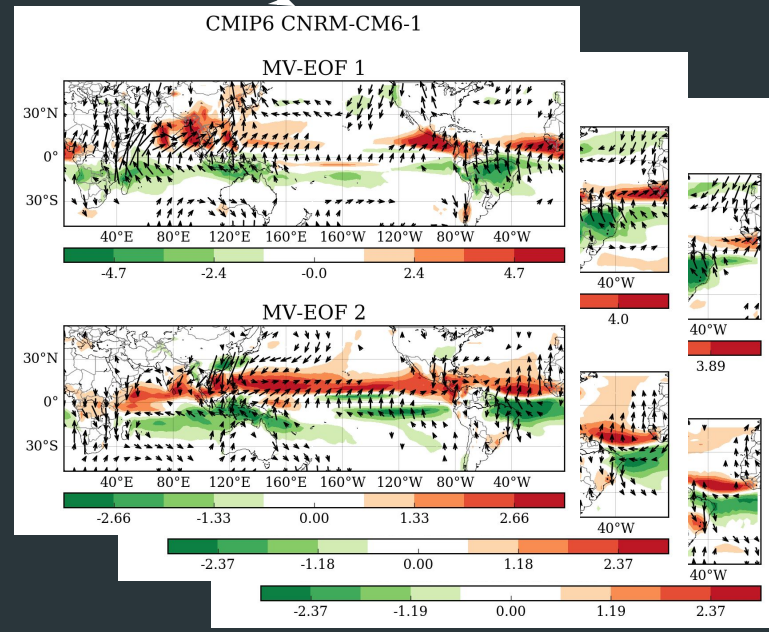
Observations



Simulations

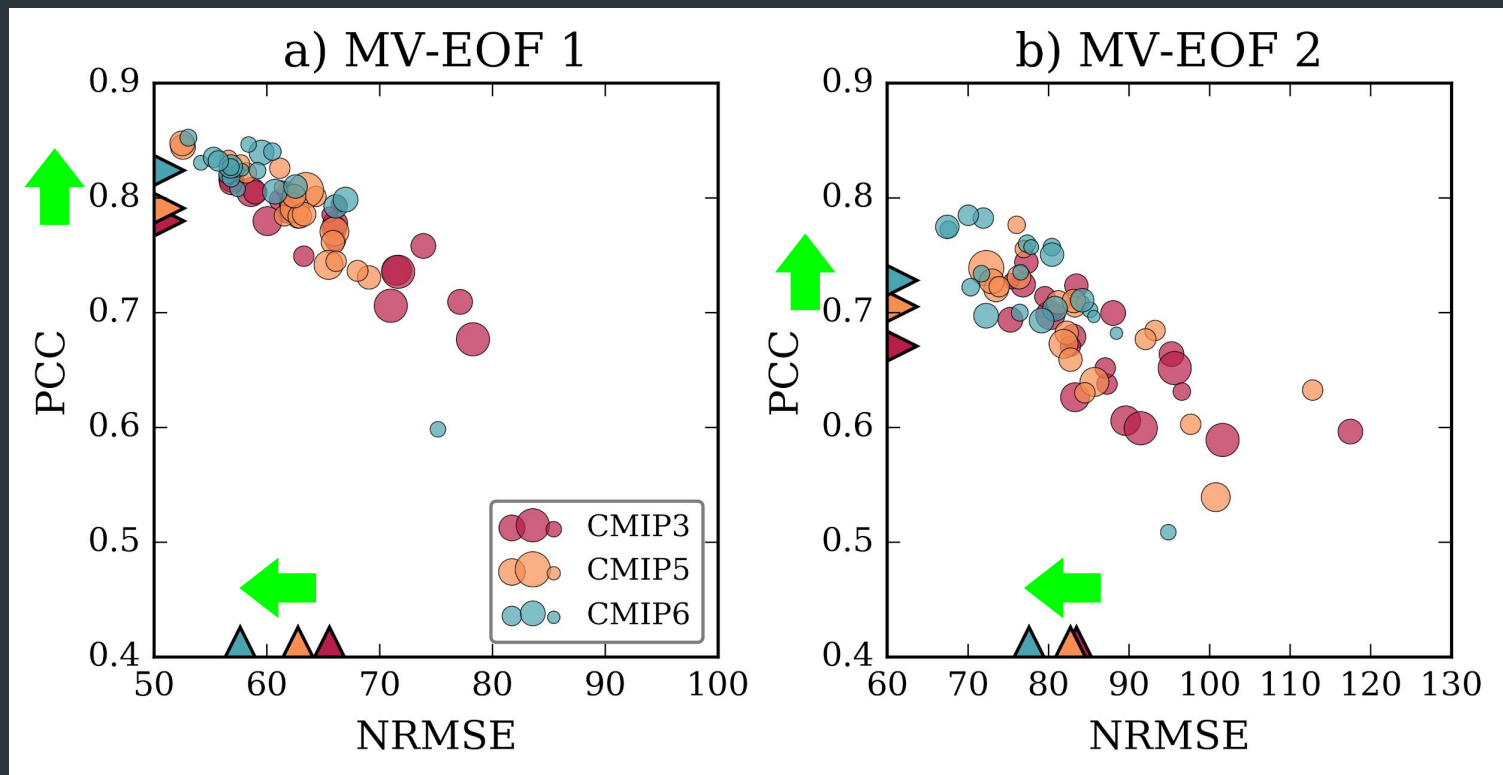


PCC
NRMSE



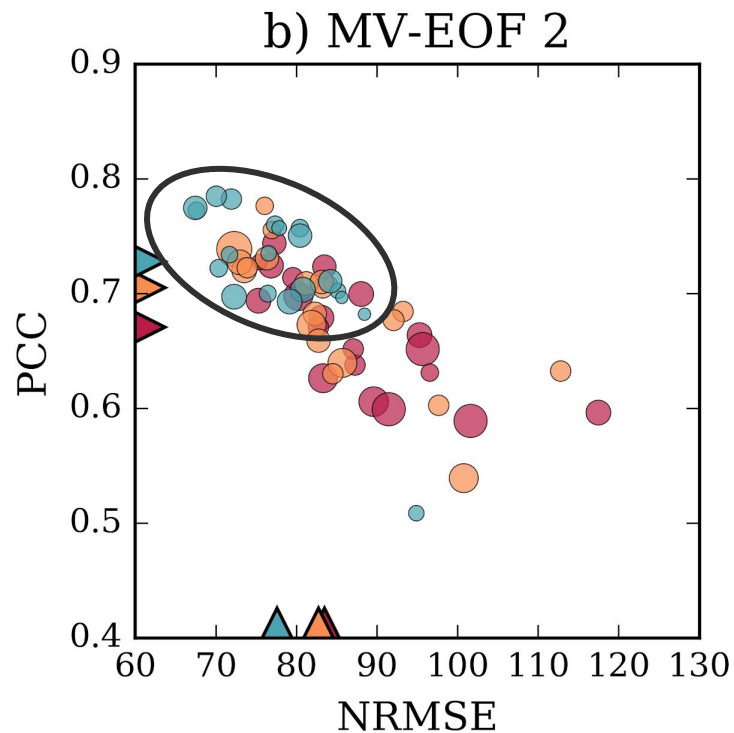
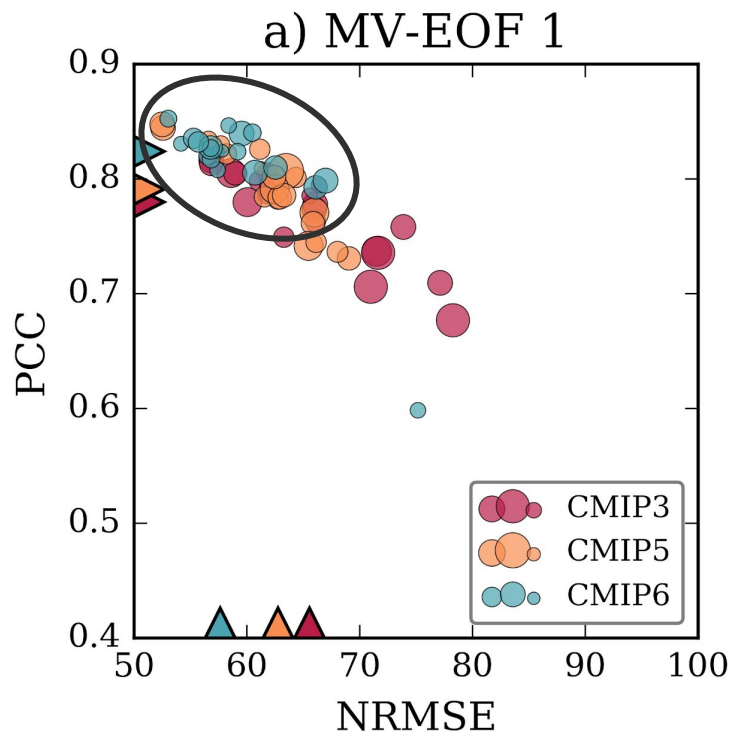
Model performance

Overall improvement
capturing leading modes

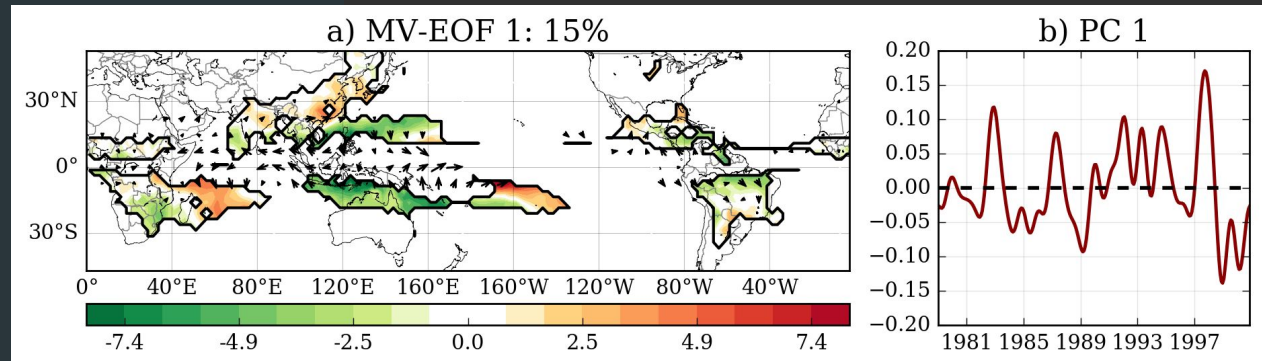


Model performance

Reduction of dispersion
among CMIP6 models



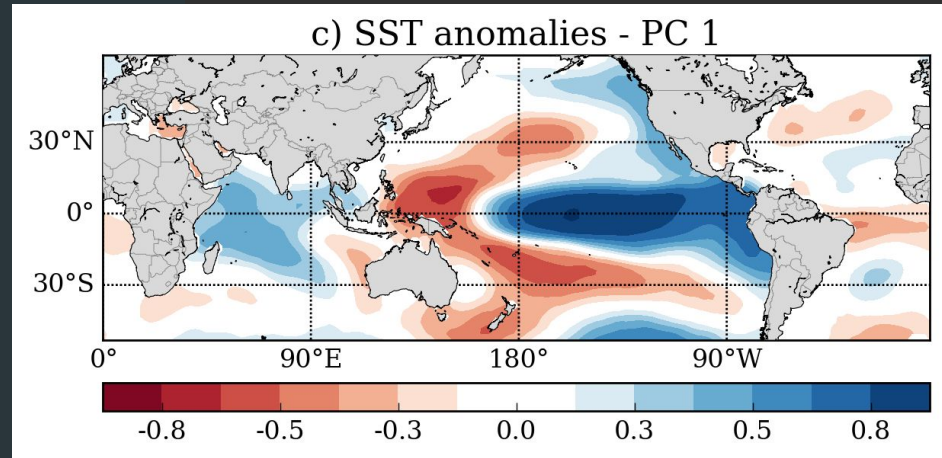
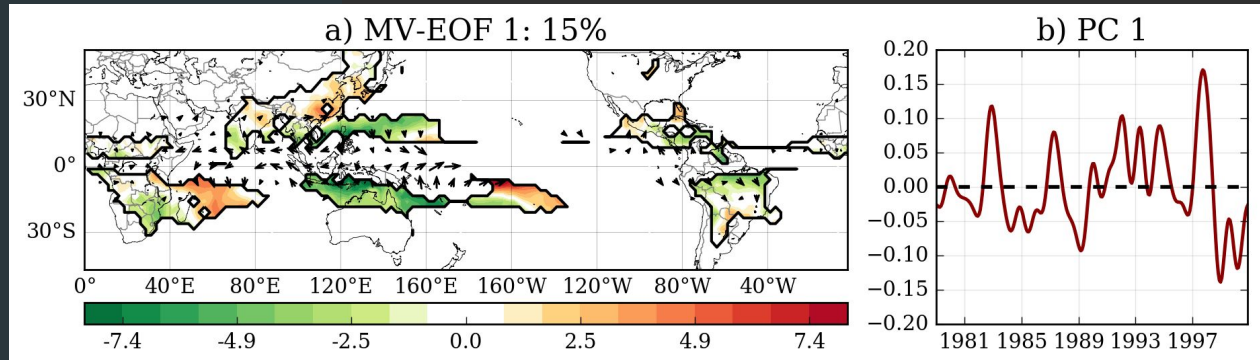
Inter-annual variability



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

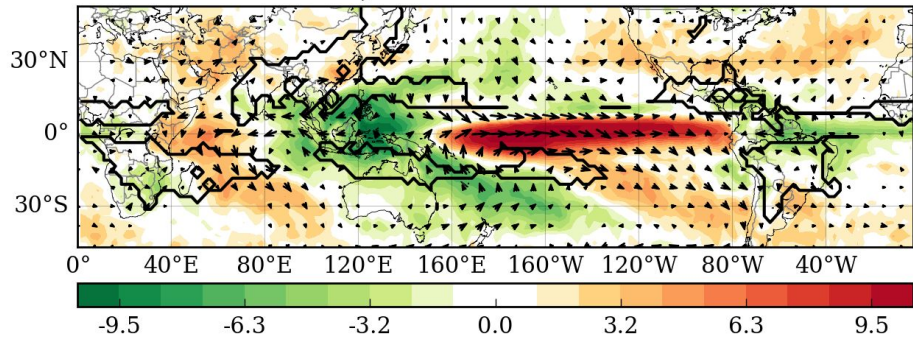
Inter-annual variability

ENSO-related mode



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

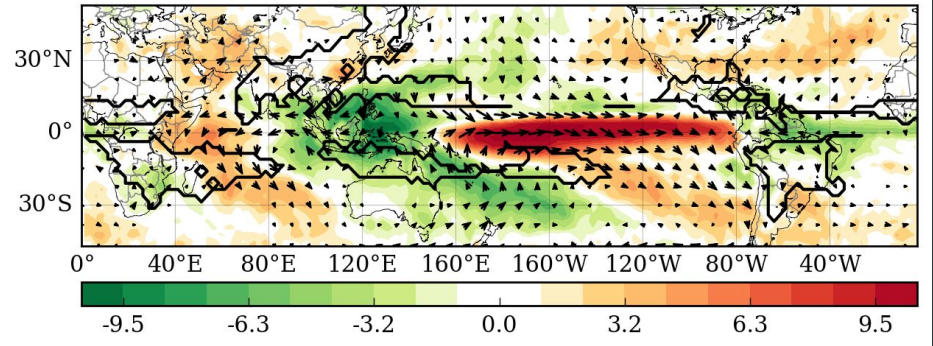
a) MV-EOF 1: 15%



**Global anomalies
projected onto
inter-annual leading mode**

Global anomalies projected onto inter-annual leading mode

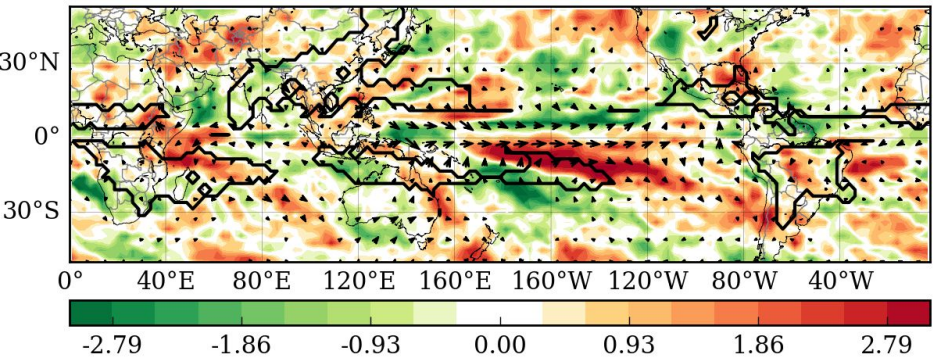
a) MV-EOF 1: 15%



PCC: 0.41
NRMSE: 87%

CMIP5 HadGEM2-ES

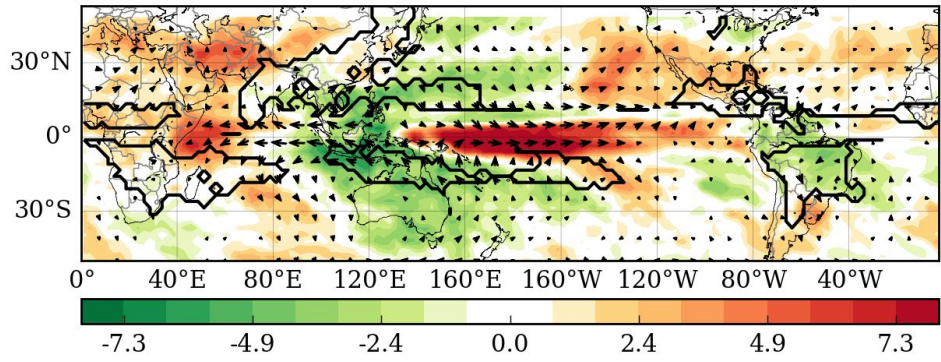
MV-EOF 1



PCC: 0.63
NRMSE: 73%

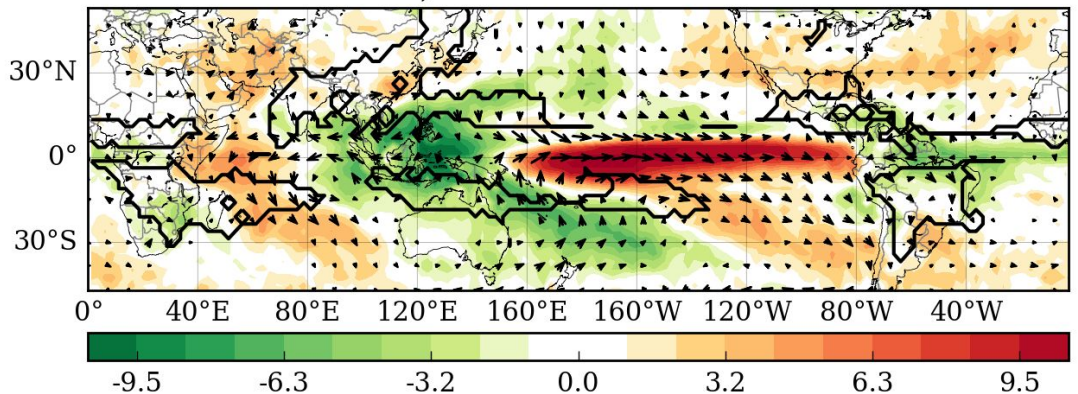
CMIP6 HadGEM3-GC31-LL

MV-EOF 1



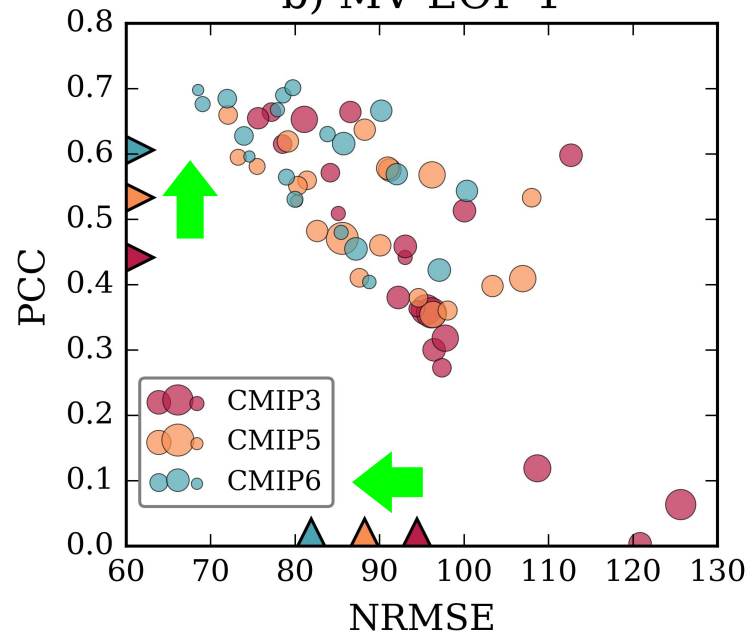
Model performance

a) MV-EOF 1: 15%



Lower performance compared to annual variation

b) MV-EOF 1



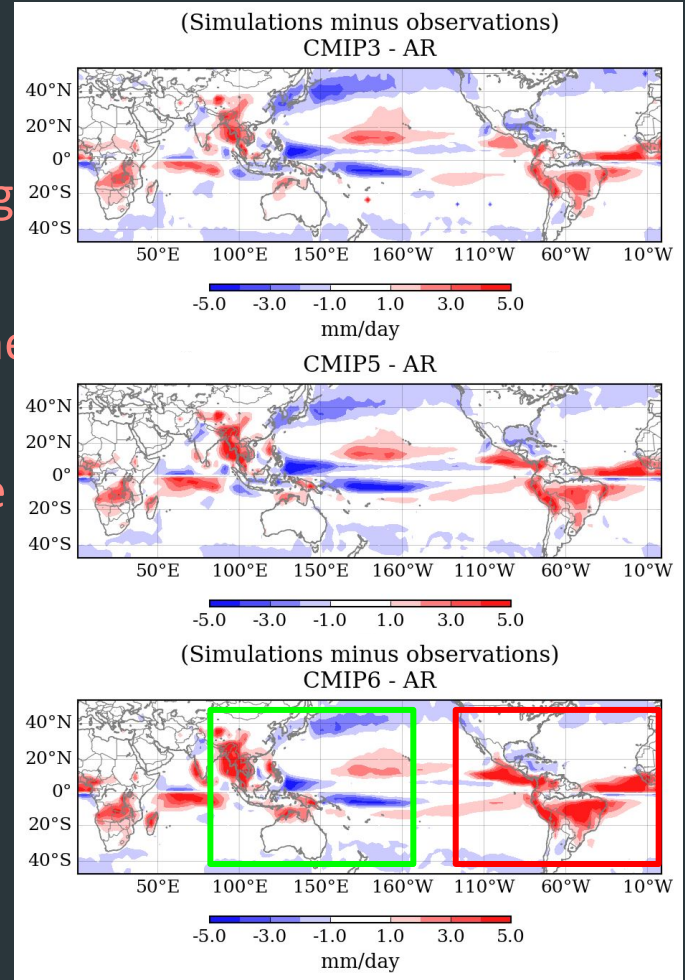
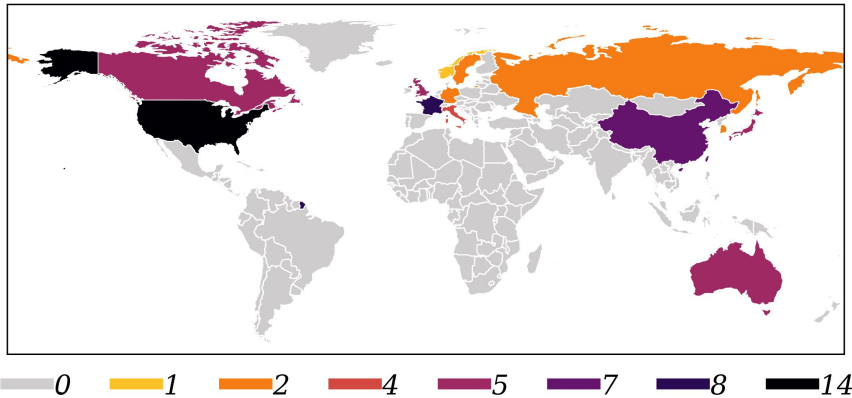
Summary and Conclusions

- 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.

Summary and Conclusions

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models by country - TOTAL



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.
- We do not find a direct relationship between model performance and **horizontal resolution**.

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