日英気候共同研究
UK-Japan Climate Collaboration

Joint Weather & Climate Research Programme
A partnership in climate research

Global Climate Modelling: a High Resolution perspective

From UPSCALE to PRIMAVERA and HighResMIP

Pier Luigi Vidale University of Reading, National Centre for Atmospheric Science, Natural Environment Research Council

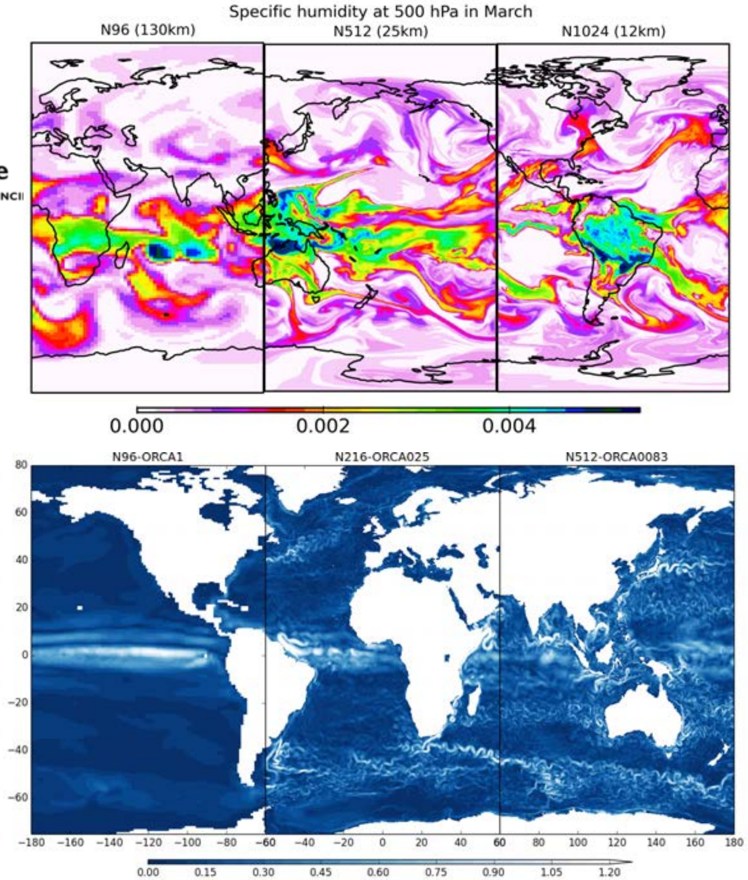
Benoit Vanniere, Reinhard Schiemann, Omar Müller, Kevin Hodges,
Alexander Baker, Liang Guo, Marie-Estelle Demory, Armenia Franco-Diaz

Malcolm Roberts Met Office

Jon Seddon, Segolene Berthou, Jo Camp, Lizzie Kendon
(Many Met Office groups involved in model development and elsewhere)

With thanks to PRIMAVERA/HighResMIP colleagues from:
AWI, KNMI,ECMWF, MPI, IC3, CMCC, SMHI

MAGIS DYNAMICA QUAM THERMODYNAMICA



Emerging processes in the atmosphere and ocean as model resolution is increased

PRIMAVERA

Malcolm Roberts, Met Office (coordinator)
Pier Luigi Vidale, Univ. of Reading (scientific coordinator)

PRocess-based climate s**IM**ulation: **A**d**V**ances in high resolution modelling and **E**uropean climate **R**isk **A**ssessment

Goal: **to develop a new generation of advanced and well-evaluated high-resolution global climate models, capable of simulating and predicting regional climate with unprecedented fidelity, for the benefit of governments, business and society in general.**

HighResMIP is a key deliverable of PRIMAVERA

The PRIMAVERA muse inspires us to seek beauty in simulation; however, **HighResMIP is about understanding;** it is not a beauty contest.

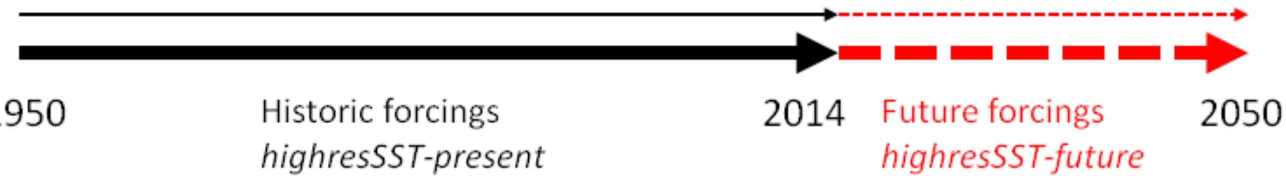
Consequently, we strongly recommended against model tuning, so that most models tune the base model and then **only change the resolution.**

Core integrations in PRIMAVERA will form much of the European contribution to CMIP6 HighResMIP, which is led on behalf of WGCM by PRIMAVERA PIs.

Institution	MO NCAS	KNMI IC3 SMHI CNR	CERFACS	MPI	AWI	CMCC	ECMWF
Model names	MetUM NEMO	ECEarth NEMO	Arpege NEMO	ECHAM MPIOM	ECHAM FESOM	CCESM NEMO	IFS NEMO
Atmosph. Res., core	60-25km	T255-799	T127-359	T63-255	T63-255	100-25km	T319-799
Atmosph. Res., FCM	10-5km						T1279-2047
Oceanic Res., core	¼°	¼°	¼	0.4-¼°	1-¼ spatially variable	¼	¼
Oceanic Res., FCM	1/12°	1/12°	1/12°	1/10°	1-1/14° spatially variable	*(1/16°)*	

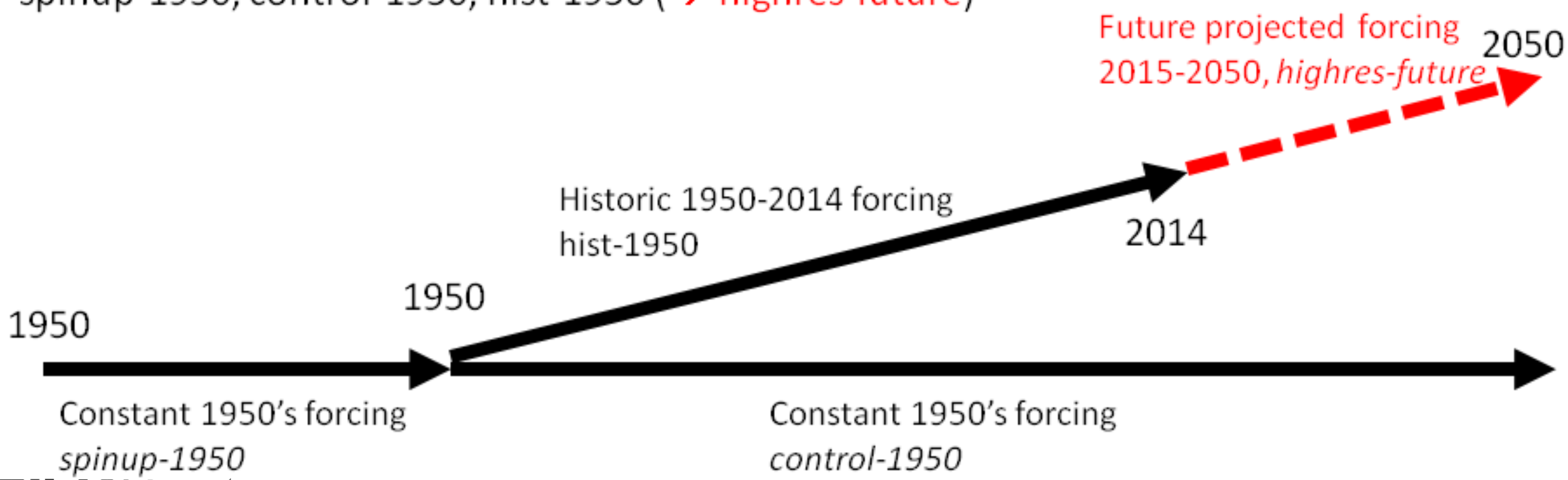
PRIMAVERA simulations for CMIP6-HighResMIP

Atmosphere-land-only, 1950-2014 (→ 2050)
Forced by observed SST and sea-ice and historic forcings (→ projected)
highresSST-present (→ highresSST-future)



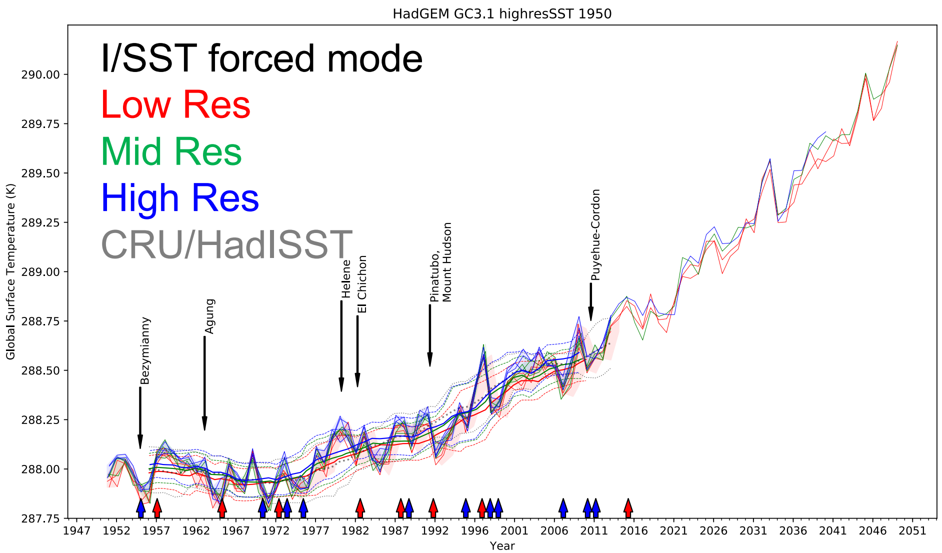
Generating up to 4PB of data, to be analysed for the next IPCC report (AR6)

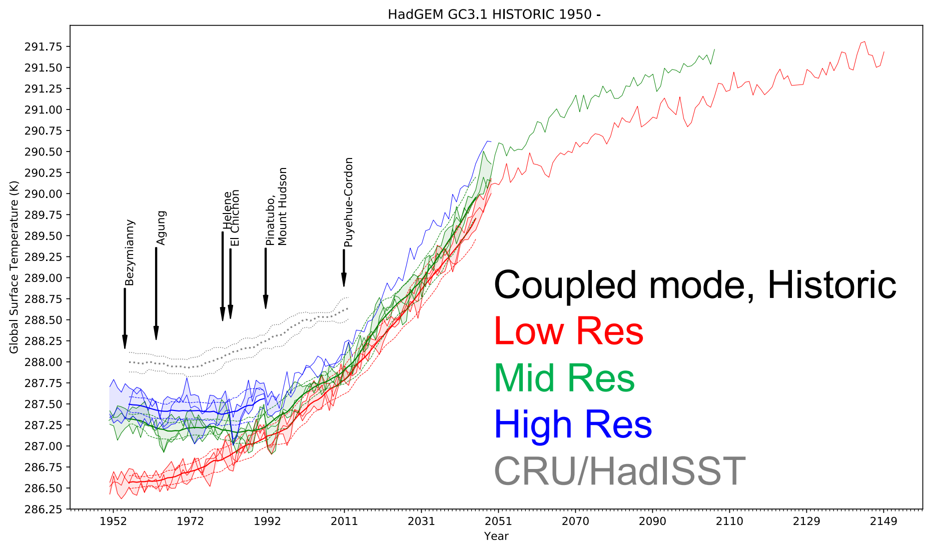
Coupled climate, 1950-2014 (→ 2050)
Forced by constant 1950 and historic forcings (→ projected)
Initial coupled spin-up period ~ 30-50 years from 1950 EN4 ocean climatology
spinup-1950, control-1950, hist-1950 (→ highres-future)

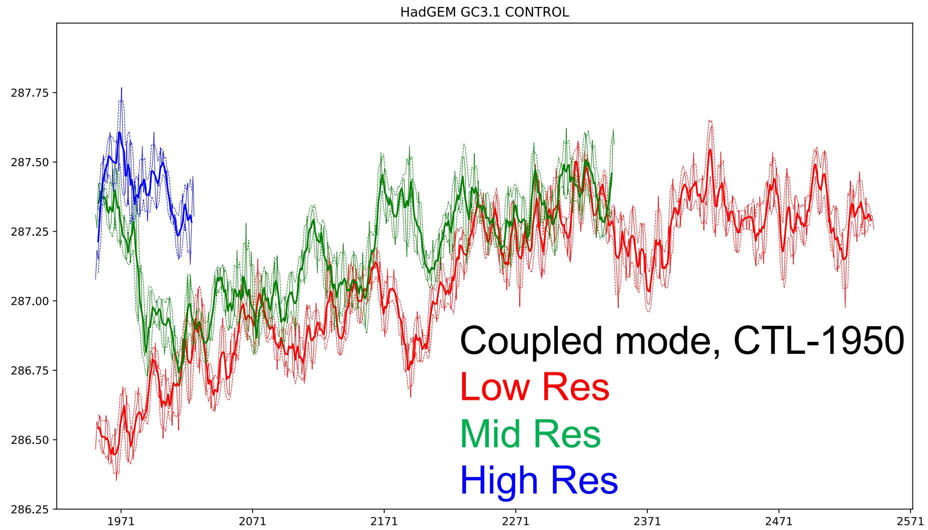


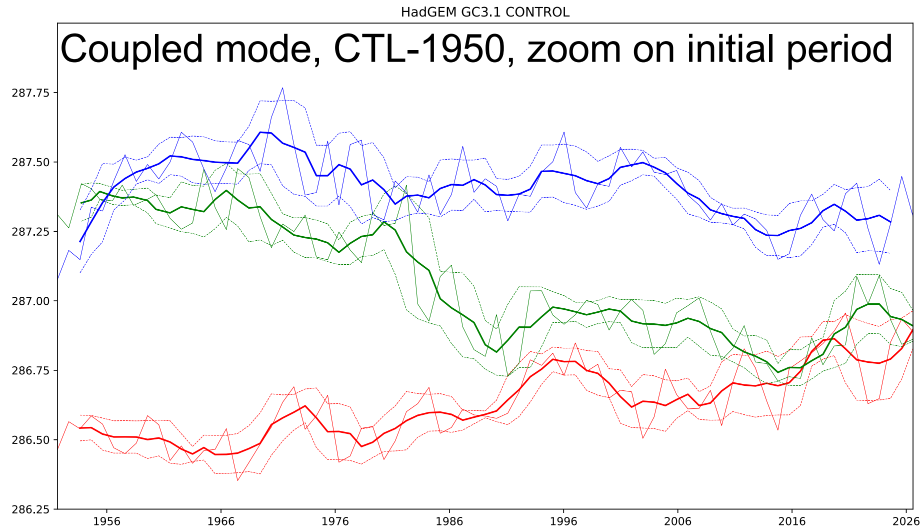
PRIMAVERA

Climate change in HighResMIP
HadGEM-GC3.1

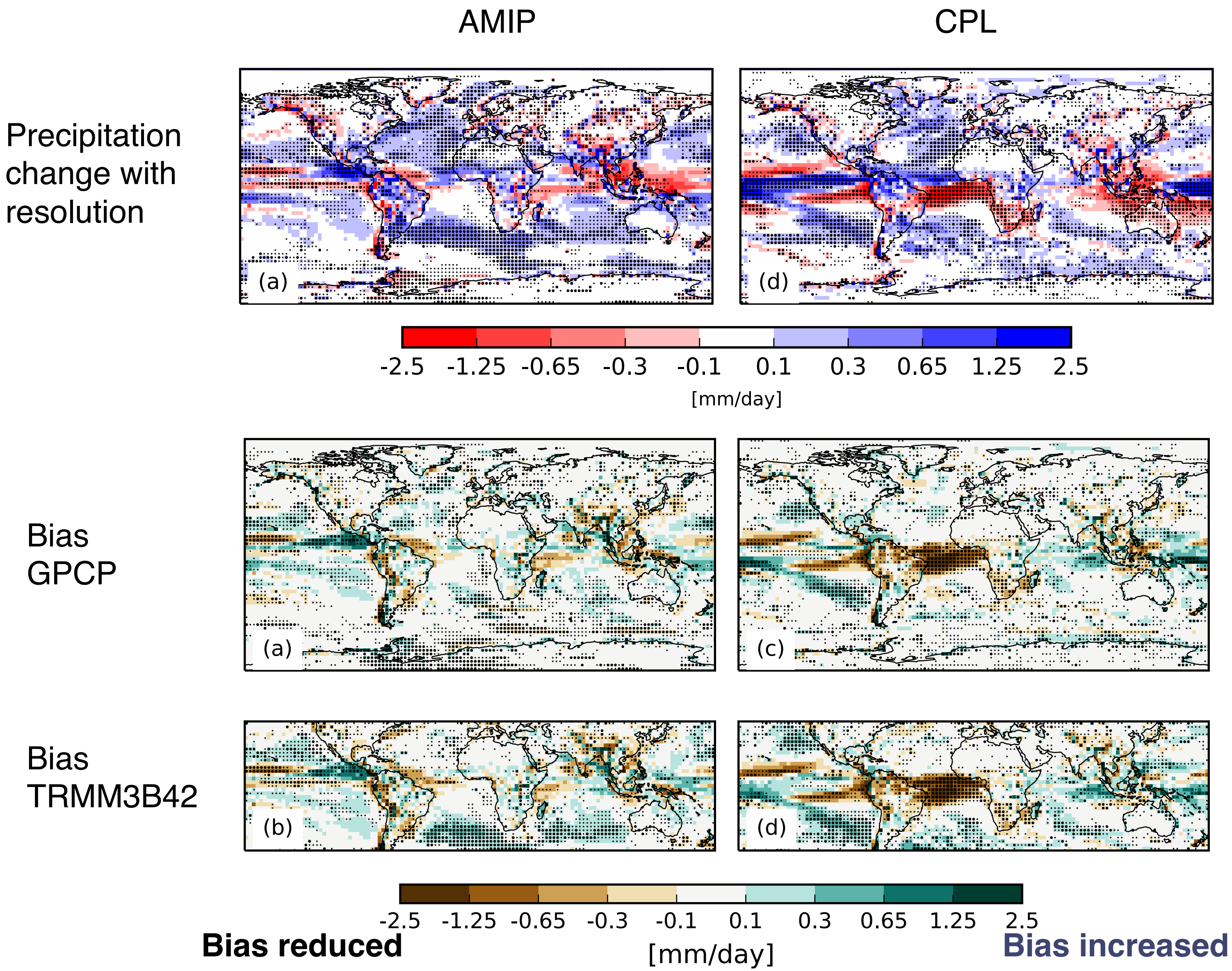






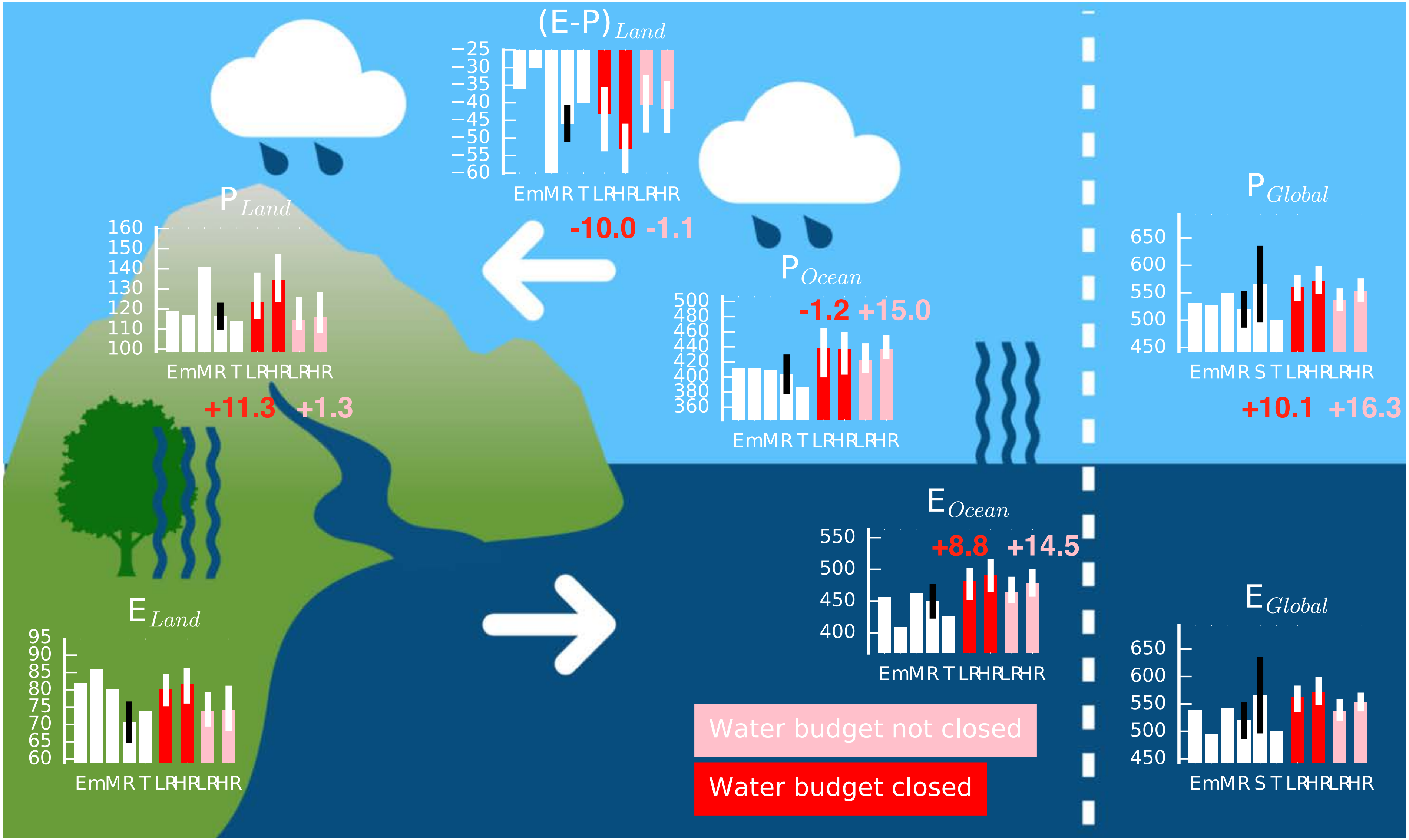


Global precipitation biases as we increase GCM resolution



Vanniere et al. Clim Dyn 2019

Overview hydrological cycle in **AMIP** models



E ERA-Interim **m** MERRA **M** MERRA-2

R Rodell (2015) **S** Stephens (2012) **T** Trenberth (2011)

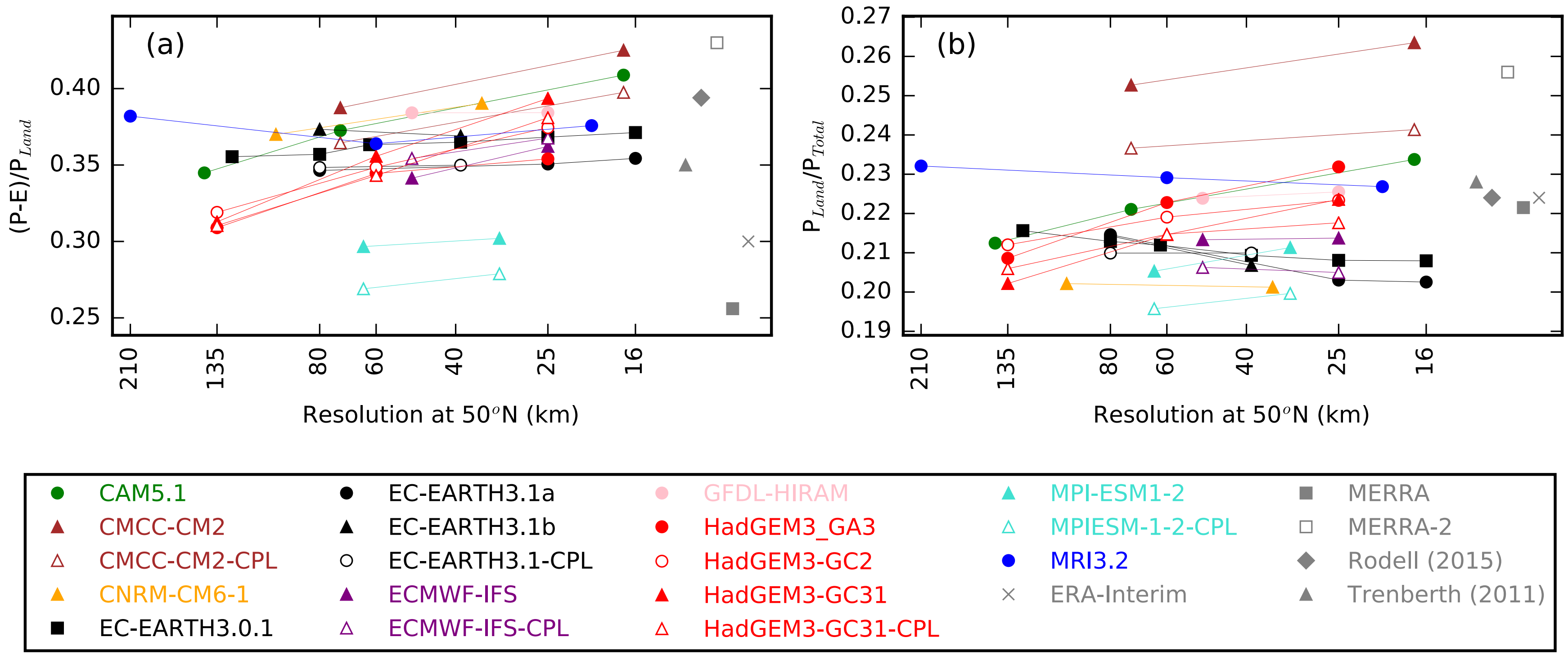
Units: 10^3 km^3 $year^{-1}$

Vanniere et al. Clim Dyn 2019

Moisture convergence to land and land precipitation

Land precipitation due to moisture convergence

P_{land} / P_{total}



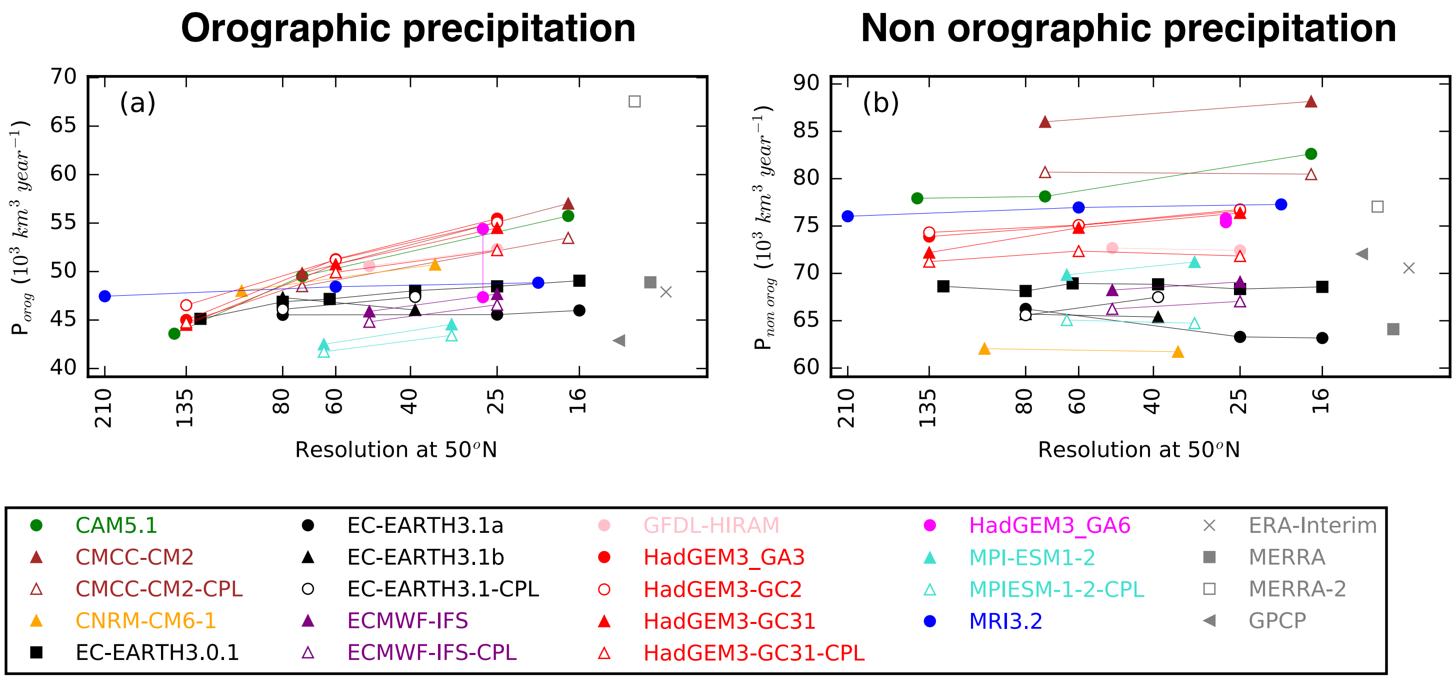
- Grid points models show a large increase of the fraction of land precipitation explained by moisture convergence but the increase is moderate in spectral models.
- Grid points models show an increase of the fraction of total precipitation falling over land, whereas spectral model show a decrease.

Vanniere et al. Clim Dyn 2019

PRIMAVERA

Role of orography

Partitioning of precipitation with a mask based on orographic precipitation model of Sinclair (1994) applied to ERA-Interim.



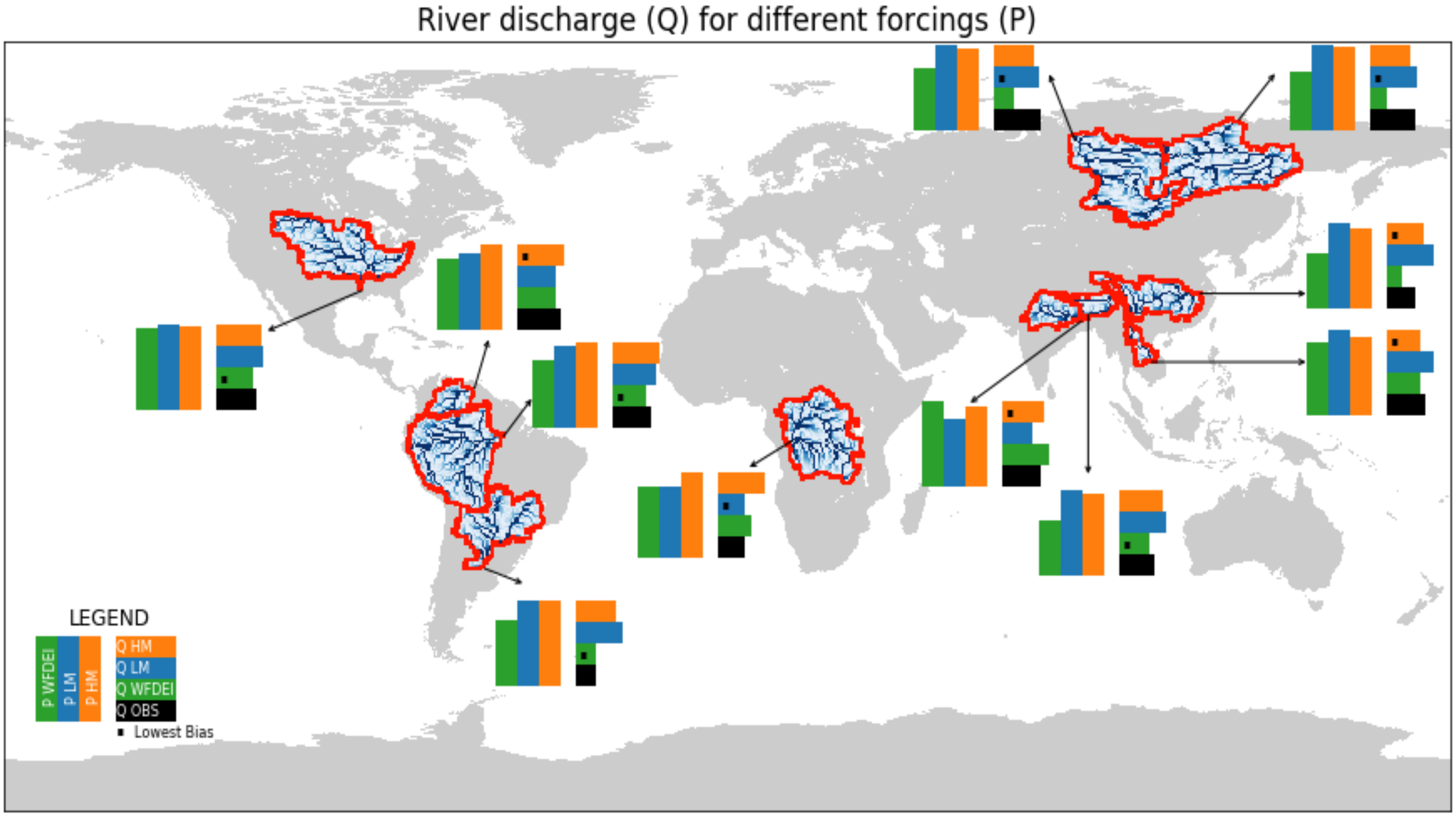
Units 10^3 km^3 $year^{-1}$

- Strong dependence of orographic precipitation on model resolution, especially in grid points models (ex:CAM5.1, HadGEM3).
- Large inter-model variations of non-orographic precipitation.

- When resolution of orography is degraded : ΔP_{orog} = -7.6 10^3 km^3 $year^{-1}$
  ΔQ = -7.2 10^3 km^3 $year^{-1}$

Vanniere et al. Clim Dyn 2019

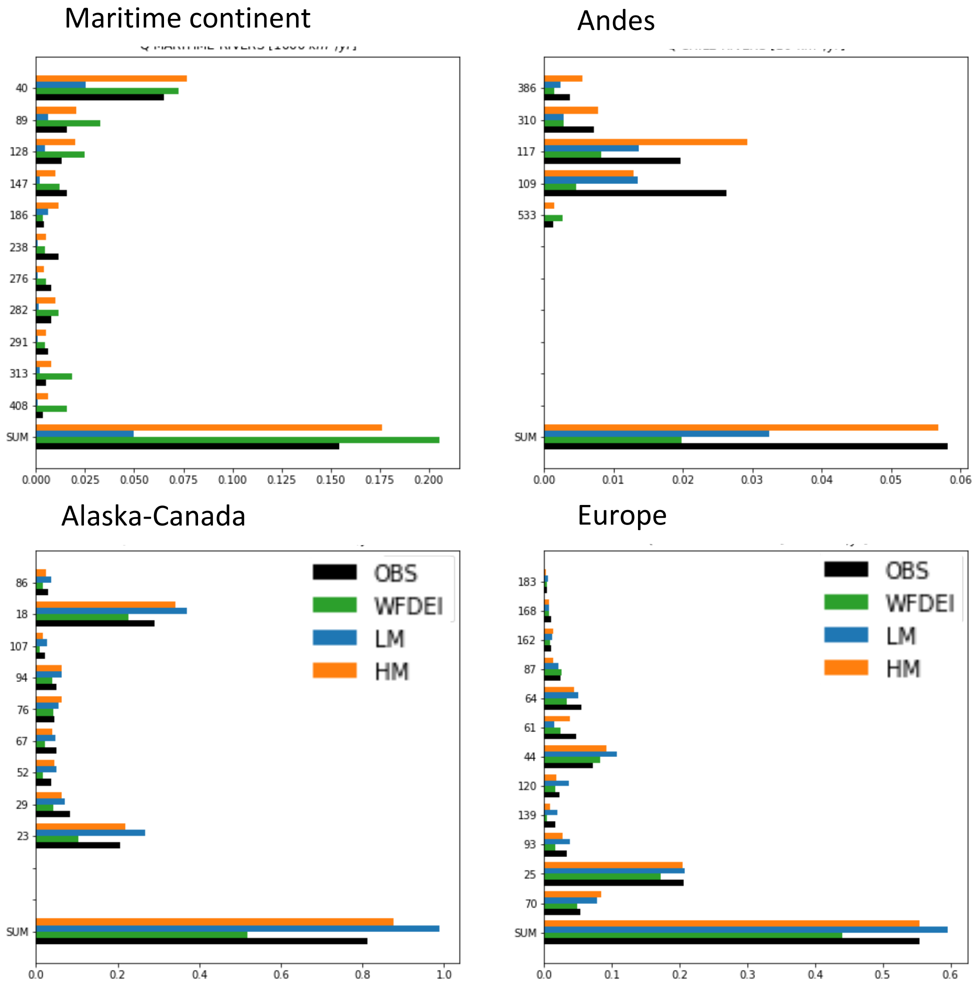
Understanding precipitation and its distribution via river discharge over large catchments



Omar Müller et al., in preparation

Understanding precipitation and its distribution via river discharge over large catchments

An assessment of model orographic precipitation based on direct observations of river discharge

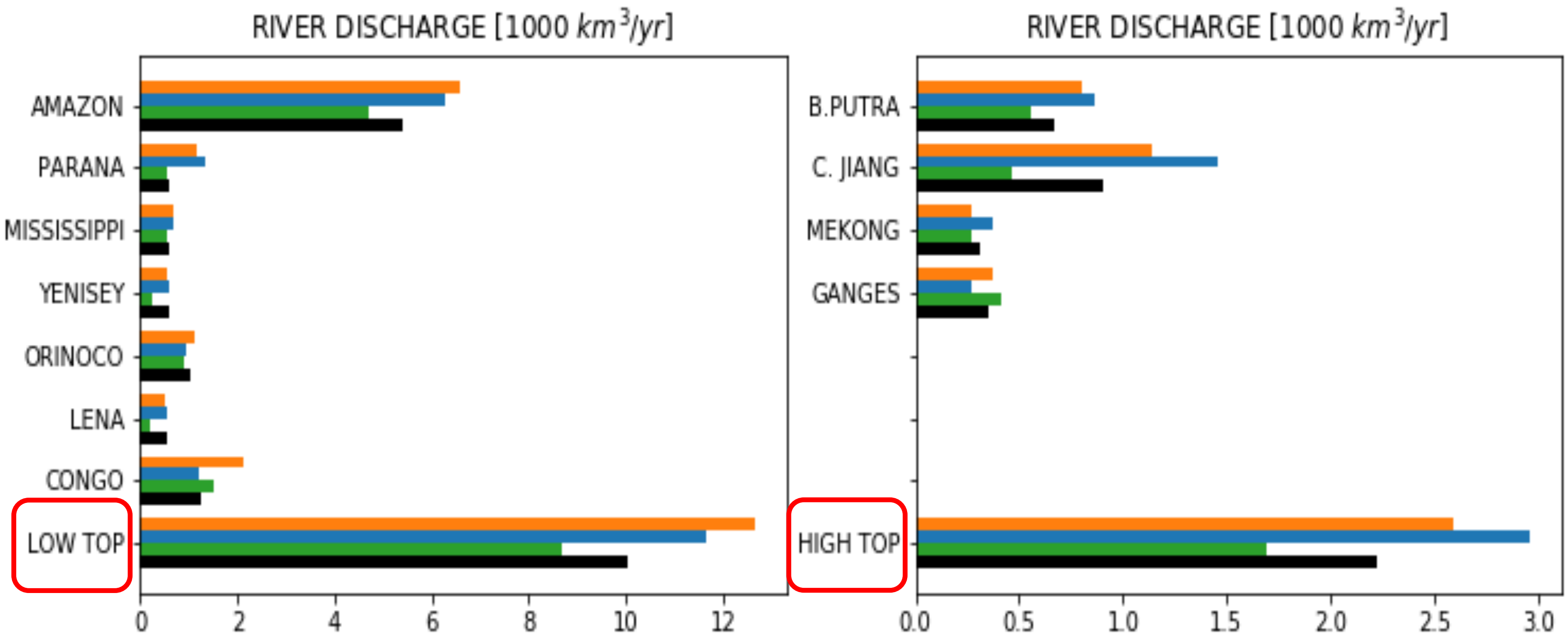


- Attempt to infer from observed river discharge which of LR and HR produce the amount of orographic precipitation closest to truth.
- Remarkable agreement between HR and OBS for catchements in four regions characterised by complex orography.

PRIMAVERA University of Reading

Omar Müller et al., 2019, in preparation

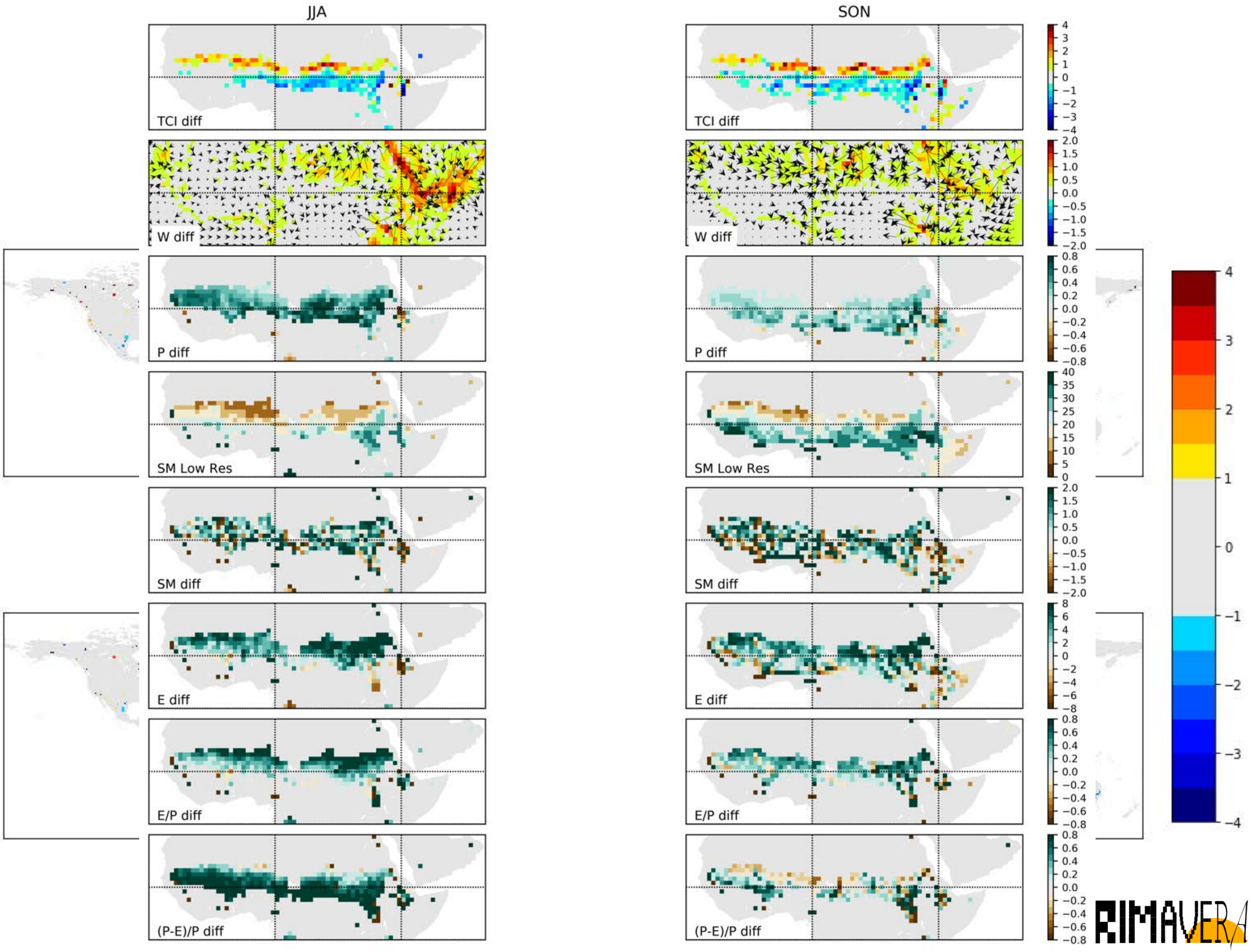
Understanding precipitation and its distribution via river discharge over large catchments



	LOW TOP. COMP	HIGH TOP. COMP	TOTAL
Q OBS	10.0	2.2	12.2
WFDEI	-13%	-24%	-16%
LM	+16%	+33%	+18%
HM	+26%	+16%	+23%

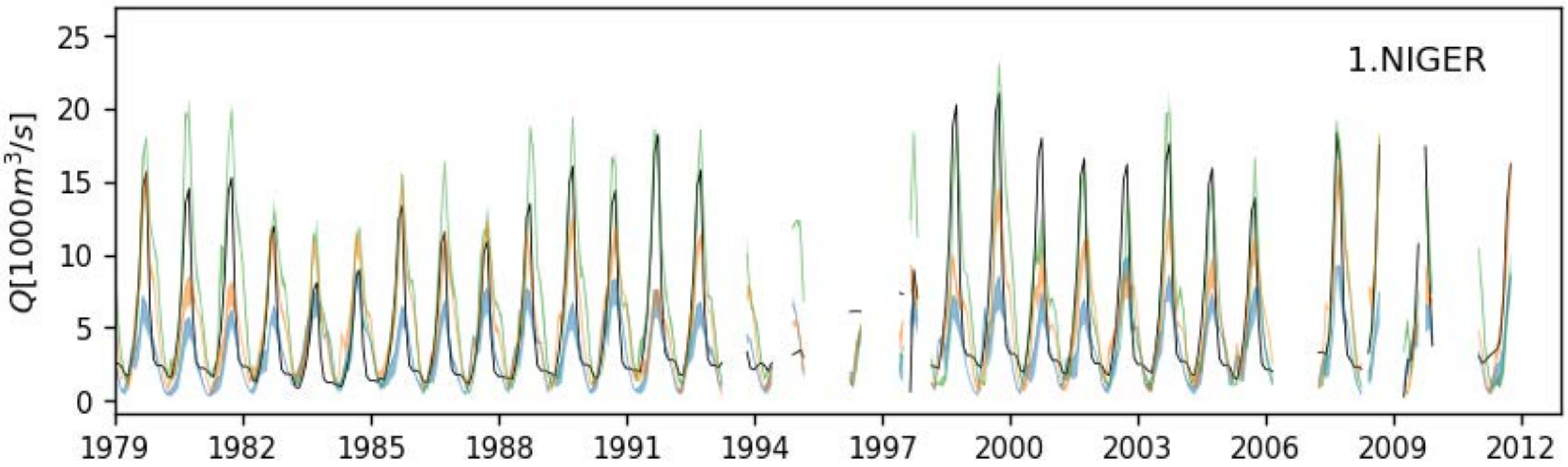
PRIMAVERA

Müller *et al.* 2019 In prep

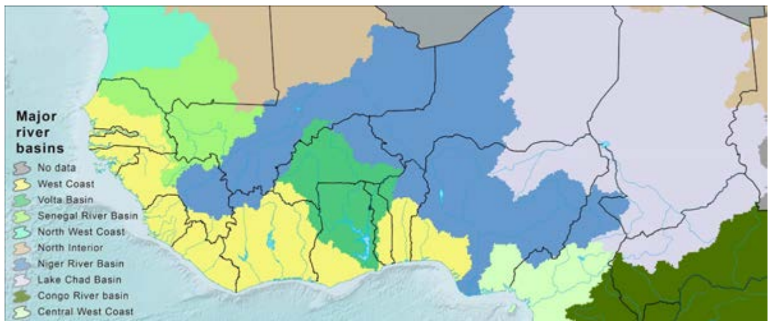

JJA
SON
TCI diff
W diff
P diff
SM Low Res
SM diff
E diff
E/P diff
(P-E)/P diff
4
3
2
1
0
−1
−2
−3
−4
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
40
35
30
25
20
15
10
5
0
8
6
4
2
0
−2
−4
−6
−8

Discharge for the Niger river, driven by OBS, LR, HR

Not all precipitation sensitivity to HR is due to orography: strong role of land-atmosphere coupling.

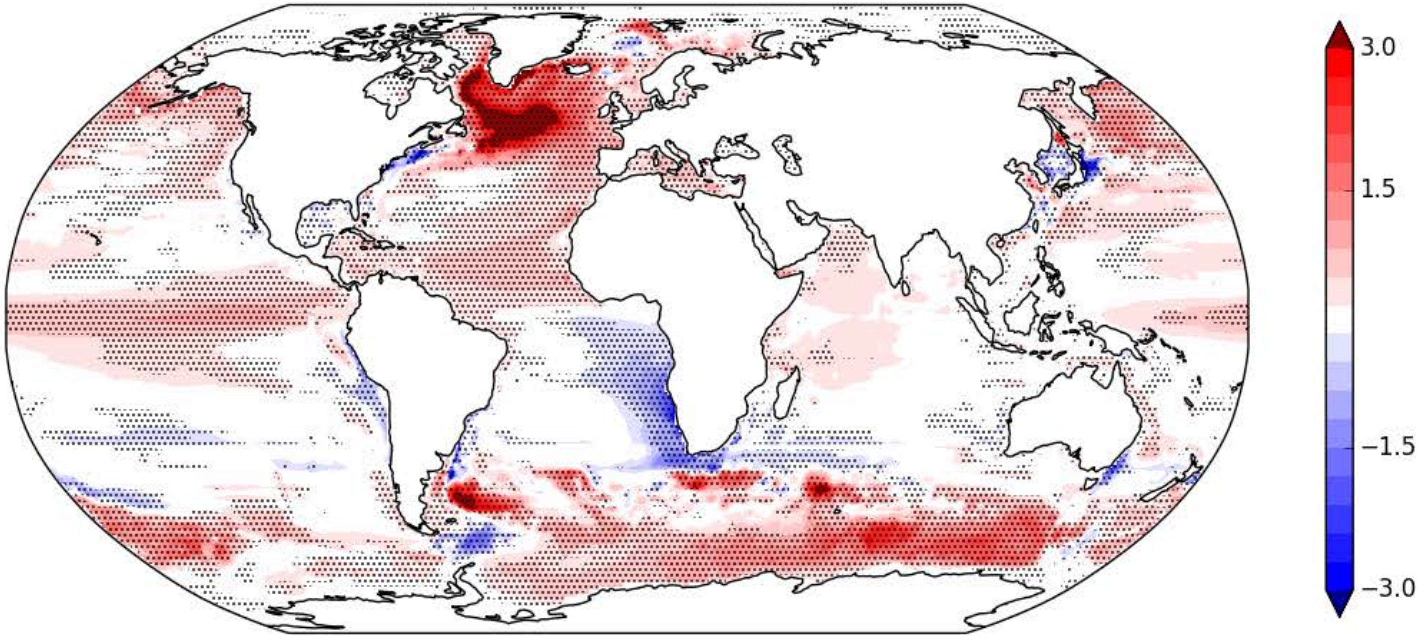


Year		**JJA**	**SON**
OBS=5.3	(black)	OBS=5.4	OBS=6.1
WFDEI=6.6	(green)	WFDEI=6.5	WFDEI=6.4
LM=3.2	(blue)	LM=3.1	LM=3.7
HM=5.0	(orange)	HM=4.3	HM=5.7

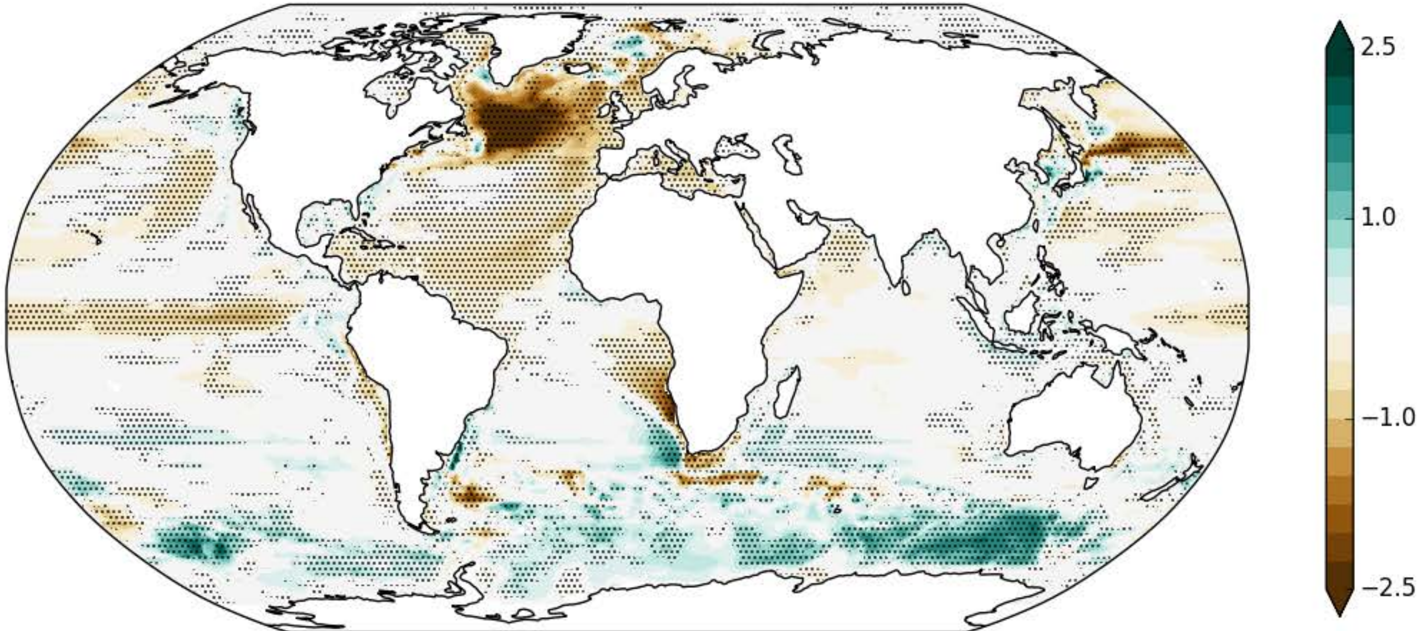


University of Reading

Omar Müller et al., 2019, in preparation



Multi-model mean SST difference between high and low resolution coupled models
5 models used, which have a different ocean resolution
Stippling indicates where at least half the models agree on the sign



Multi-model mean of the change in SST bias between high and low resolution coupled models (using RMS difference from EN4 1950-54 mean)
5 models used, which have a different ocean resolution
Stippling indicates where at least half the models agree on the sign

M. Roberts et al. 2019, in prep.

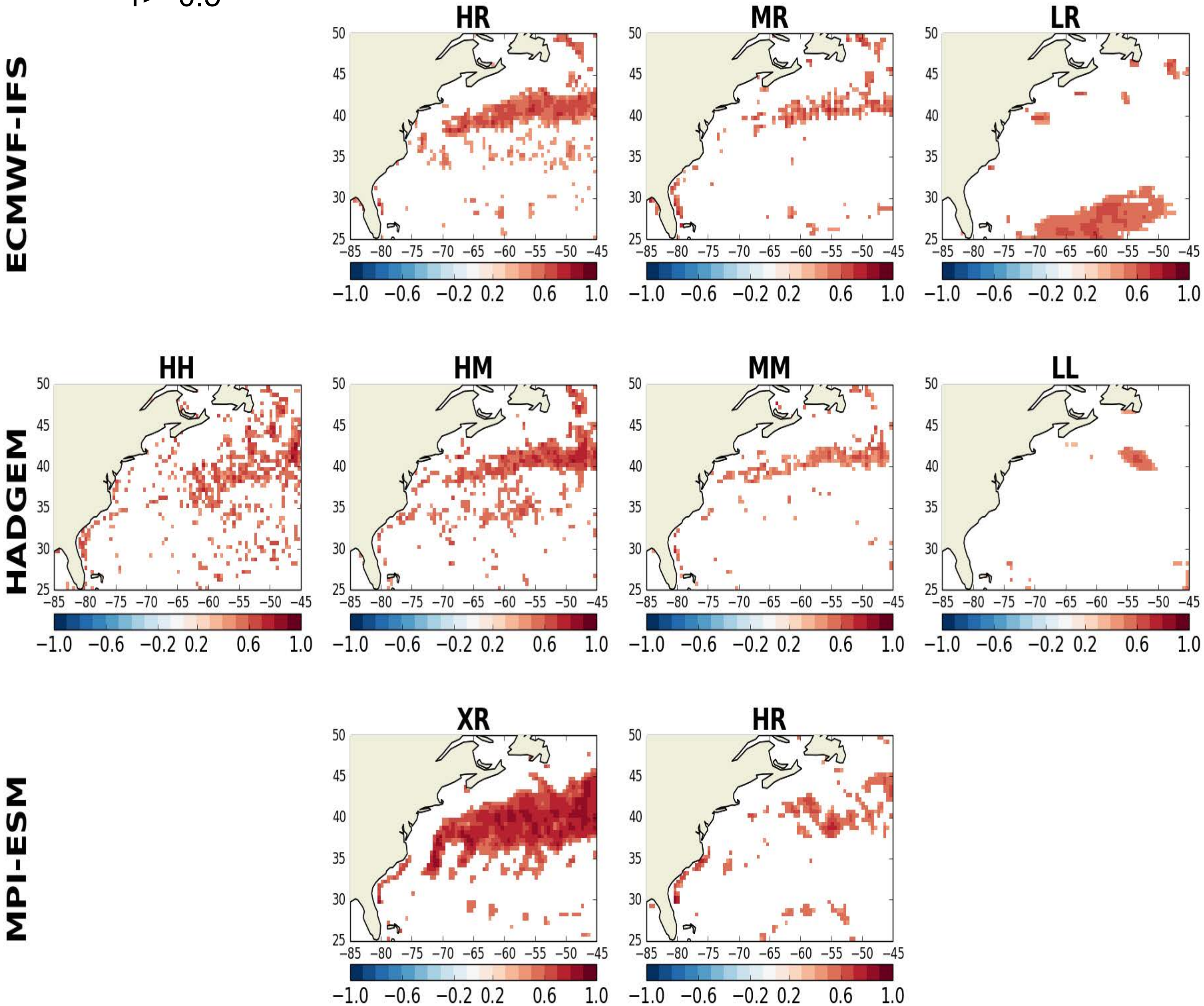
Co-funded by the European Union
PRIMAVERA

VMM

Wind Divergence vs Downwind SST gradient

Significance:
$p<=0.05$
$r>=0.5$

Coupling Coefficient

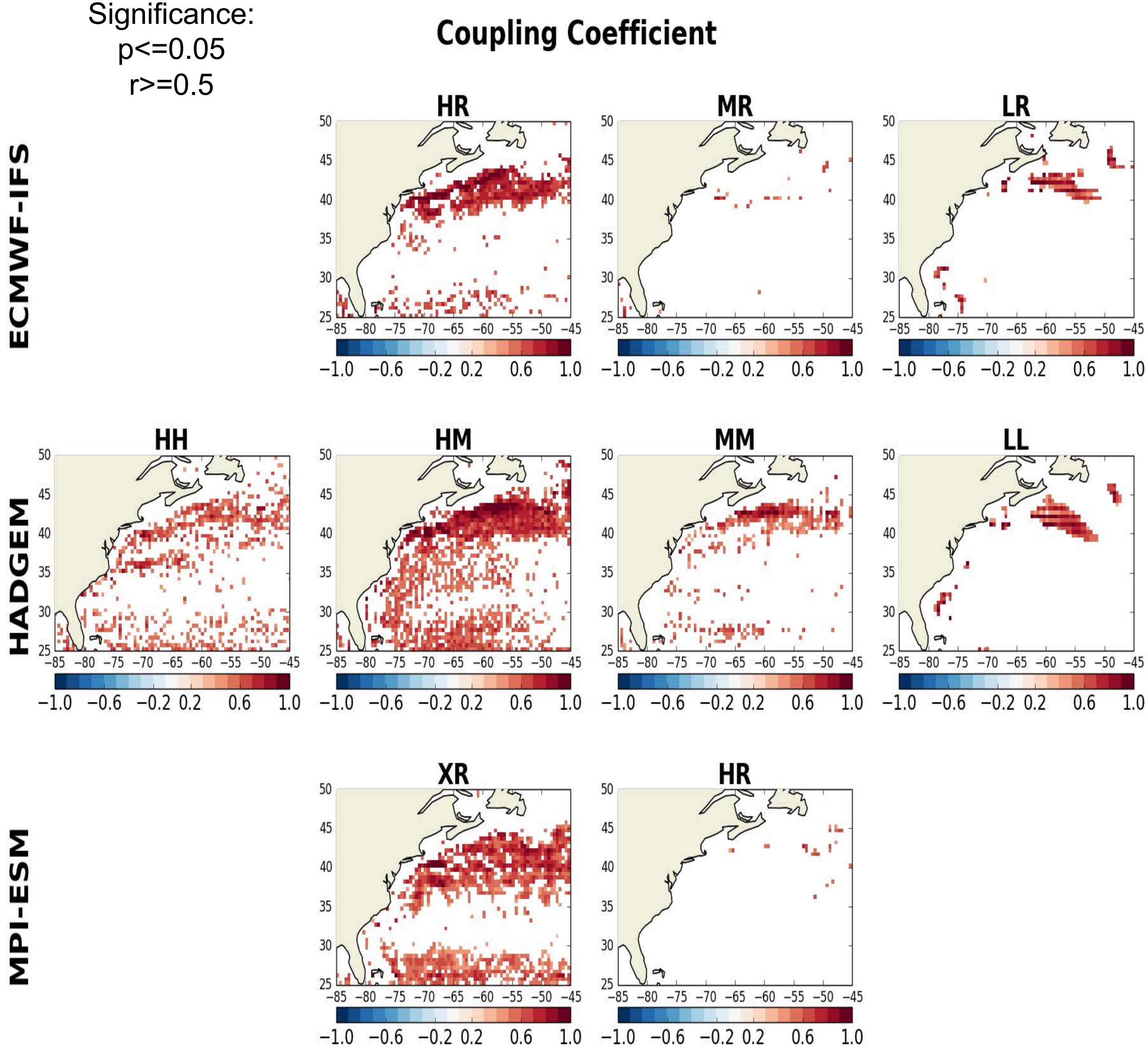


E Tsartstali, R. Haarsma, KNMI

PAM

MSLP Laplacian vs
-SST Laplacian

Significance:
$p<=0.05$
$r>=0.5$



E Tsartstali, R. Haarsma, KNMI

the European Union

Tropical Cyclones “emerge” at high resolution

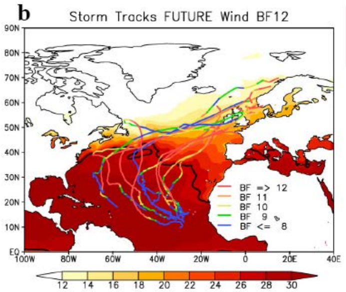
Results finally confirmed by the US CLIVAR Hurricane Working Group (HWG),

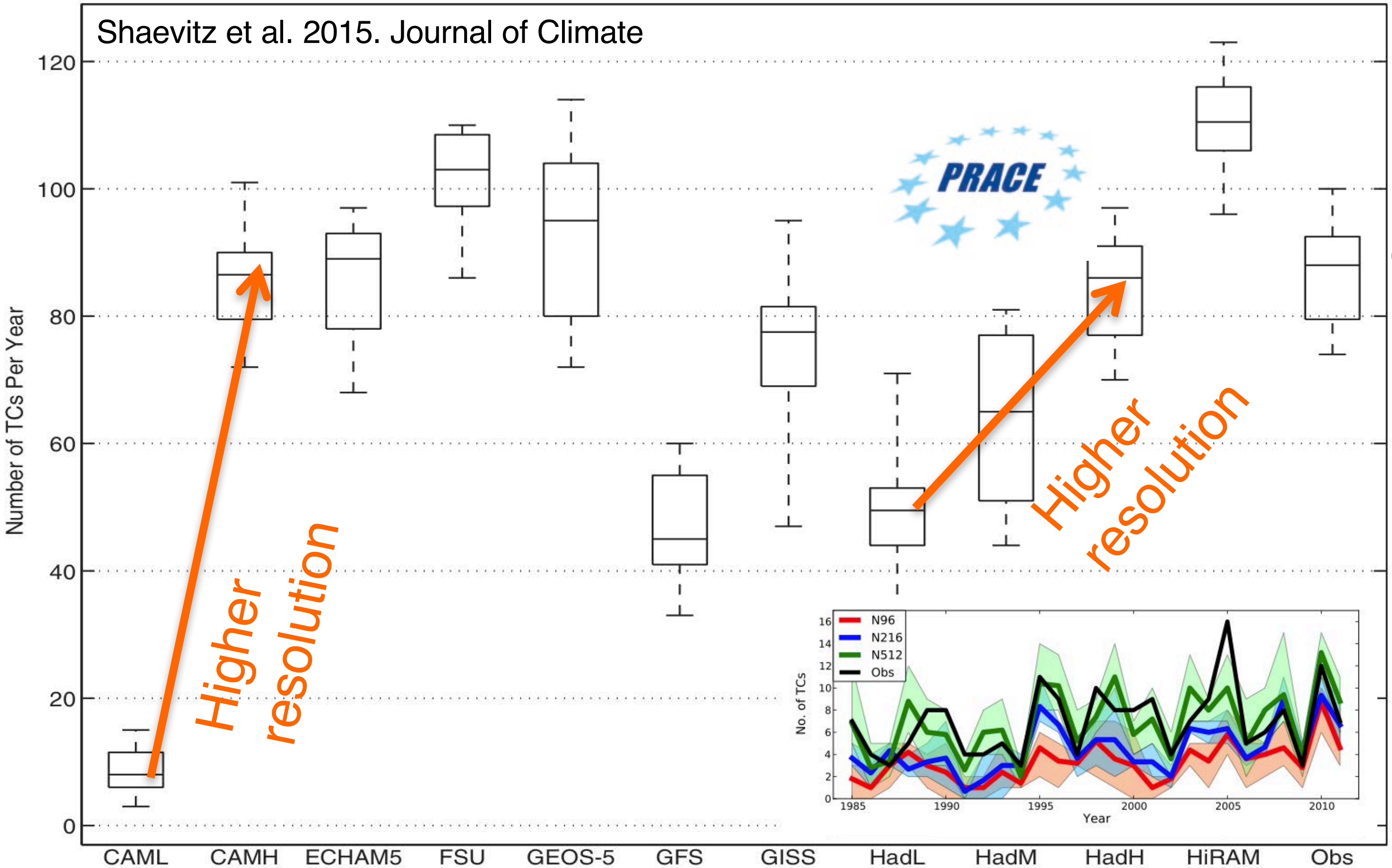
via a **systematic** multi-model intercomparison:

- TC tracks and interannual variability in frequency are credibly represented at 20km;
- however, intensity is still underestimated by some of the GCMs at this resolution
- HRCM

SPECIAL
U.S. CLIVAR Hurricanes
COLLECTION

TC Catarina (CAT2), South Brazil, 24-28 March 2004





Obs

Distribution of the number of TCs per year

Met Office

NATURAL ENVIRONMENT RESEARCH COUNCIL

Joint Weather & Climate Research Programme

A partnership in climate research

TCs as rare, albeit significant contributors to climate

Direct contribution to precipitation (%)

West Pacific

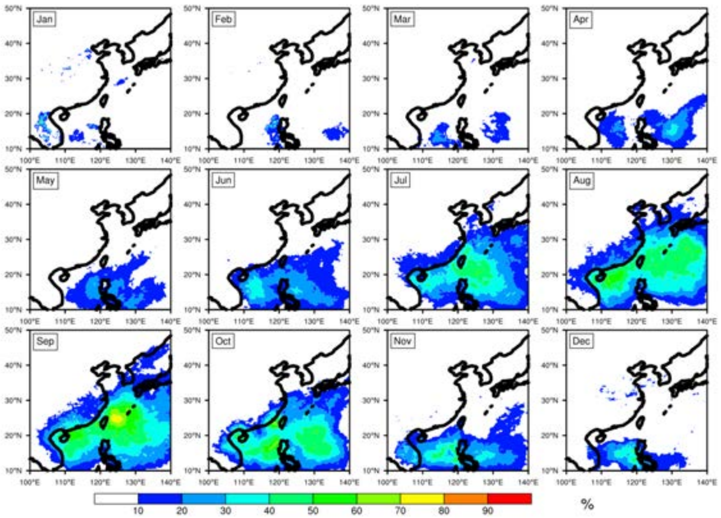
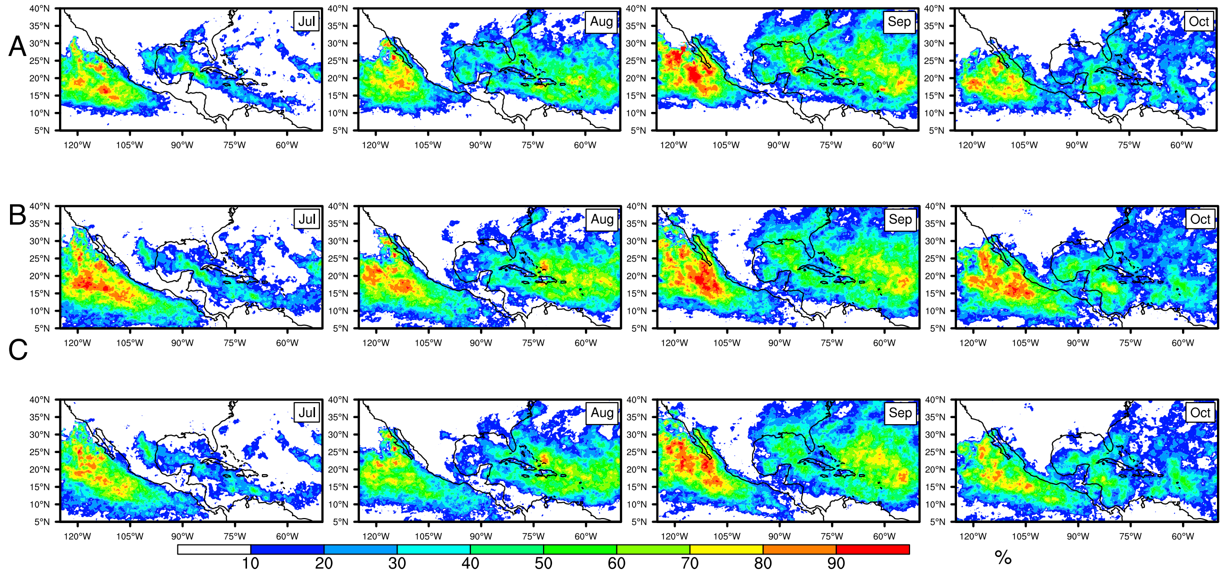


FIG. 2. Monthly mean fractional contribution of TC rainfall amount to the total rainfall calculated using TRMM 3B42 rainfall data. Units: %.

Guo et al. 2017

Meso-America



Contribution of TCs to the extreme rainfall (amount fraction) (%) from July to October, employing TCs tracks from (a) IBTrACS, (b) JRA-55 and (c) ERA-Interim. **Climatology for 1998-2015**

Franco-Diaz et al. submitted to Clim Dyn.

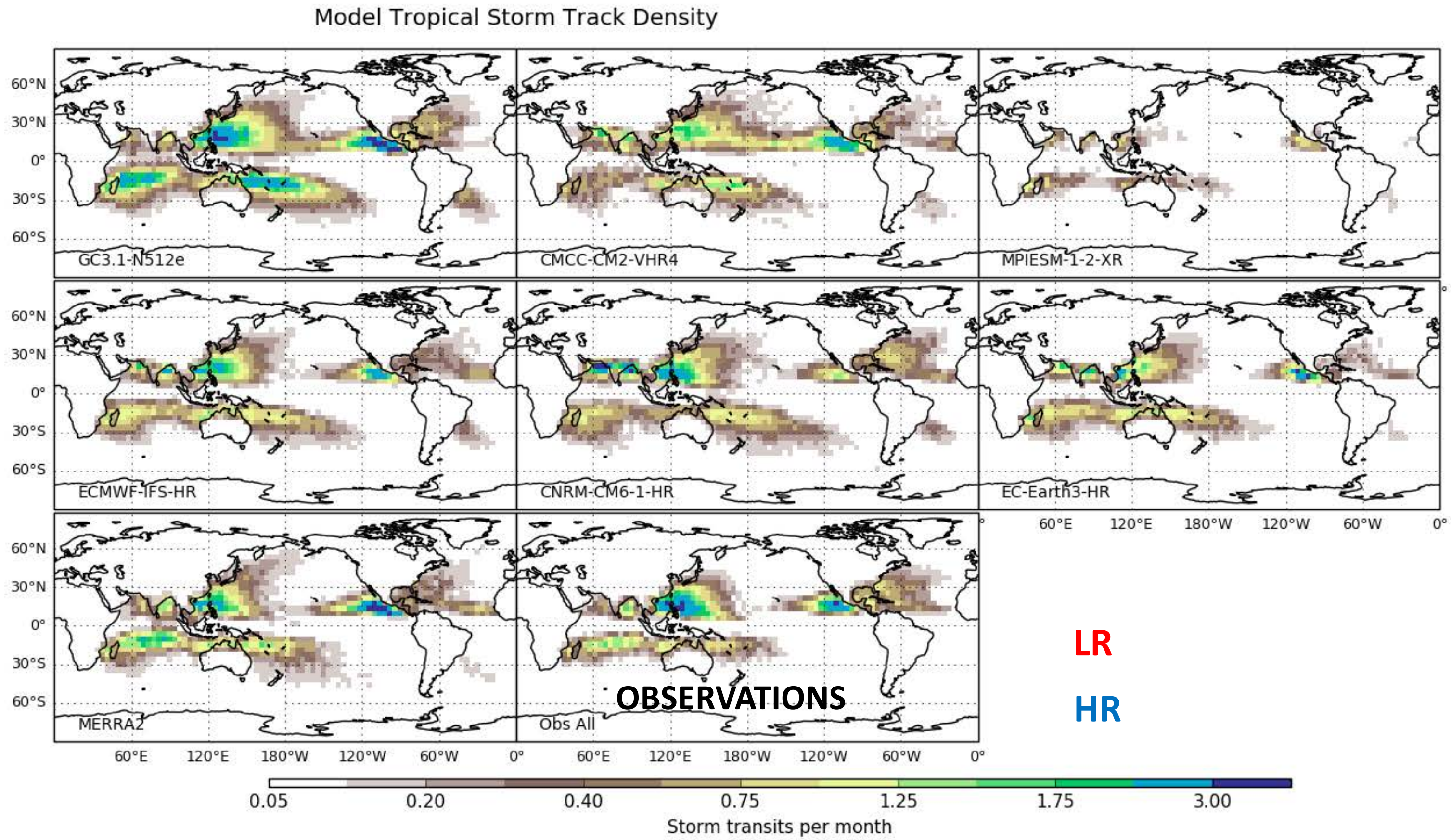
Method: extracted TC tracks from IBTrACS and/or re-analyses, then associated TRMM precipitation with each set of tracks, in a 5^{o} disk around each TC, every 6 hours.

Re-analyses very likely under-estimating the role of TCs in producing precipitation and moisture transports.

What is the role of GCM resolution, model physics, DA?

Tropical Cyclone **track density:**
65 year climatologies

(storm transits per month per 4 degree unit area)

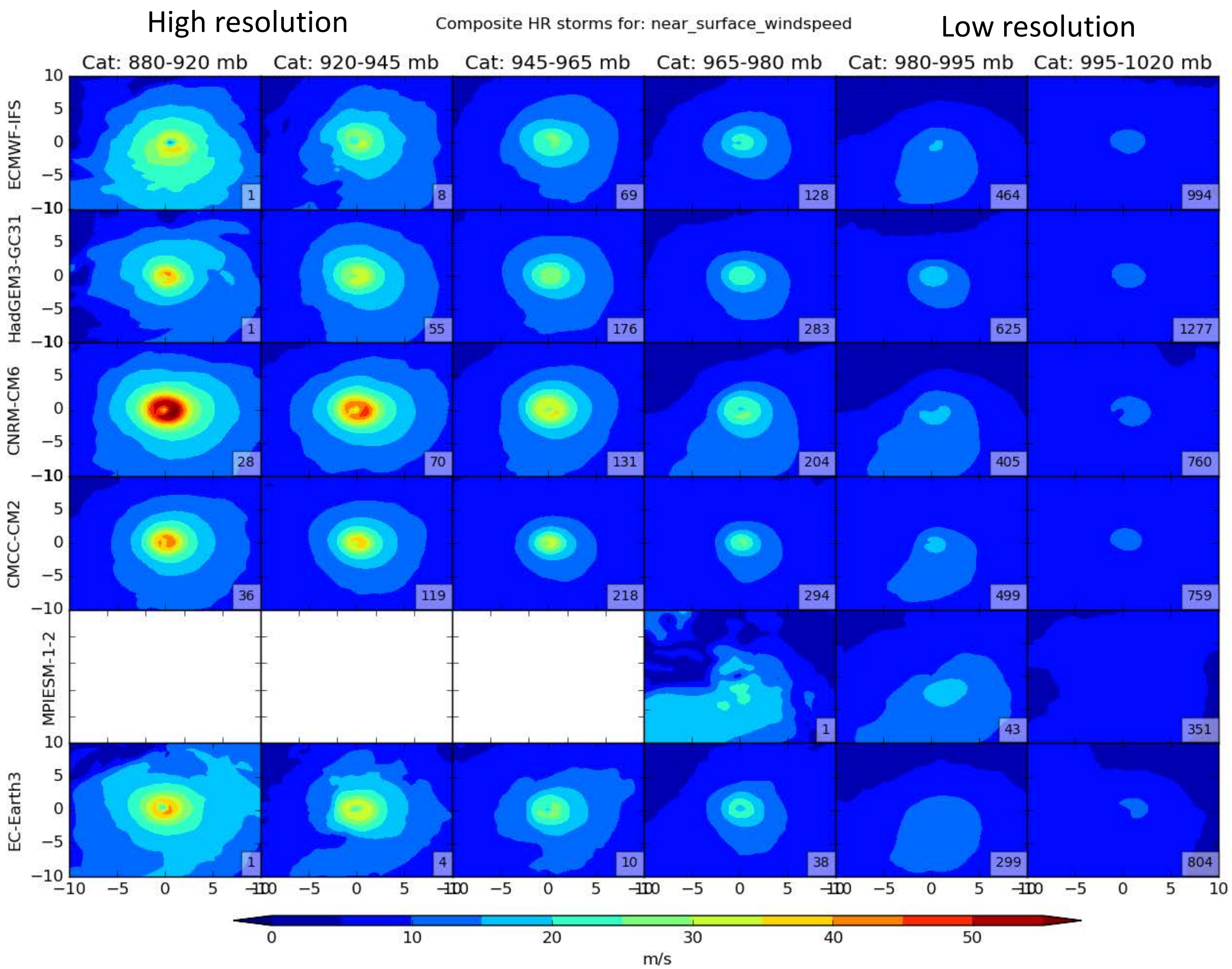


Roberts et al. 2018, in preparation

Co-funded by the European Union

PRIMAVERA

Top 100 Tropical Cyclone composite structures
by resolution and model



Roberts et al. 2018, in preparation

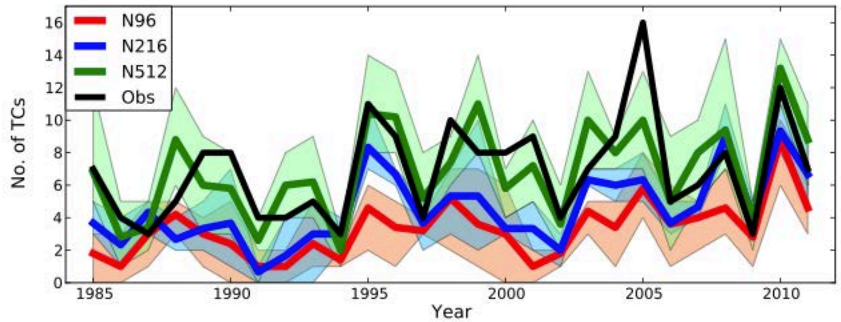
Interannual TC frequency correlation with observations (all/hurr) - 1 member

One of the most important results in the CLIVAR HWG experiment was this: **skill at representing interannual variability improves with model resolution.**

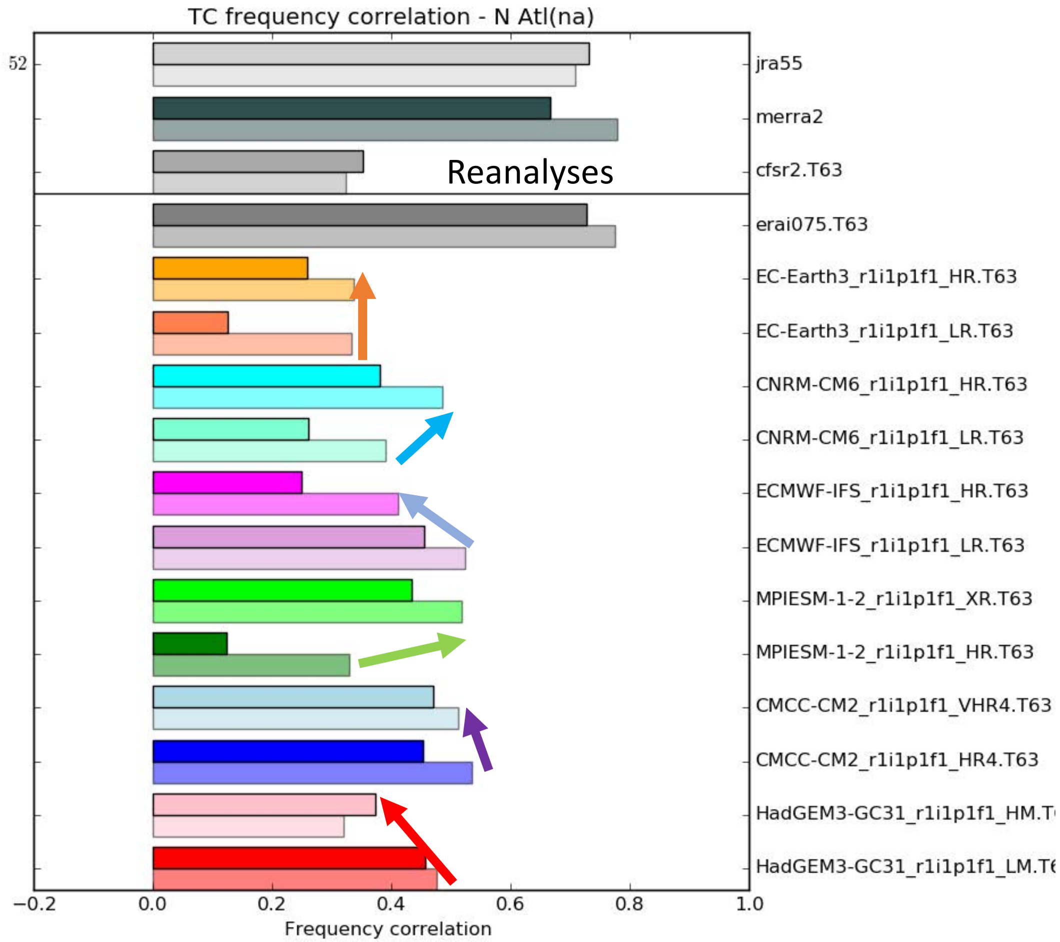
→ Key to seasonal prediction of hurricanes (and typhoons)

In 2015, as part of our work in the *US CLIVAR Hurricane Working Group*
using our 2012 PRACE-UPSCALE data:

TC frequency, track density and interannual



Roberts et al. 2015. Journal of Climate
Previously also shown in Zhao et al. (2010) and Strachan et al. (2011)

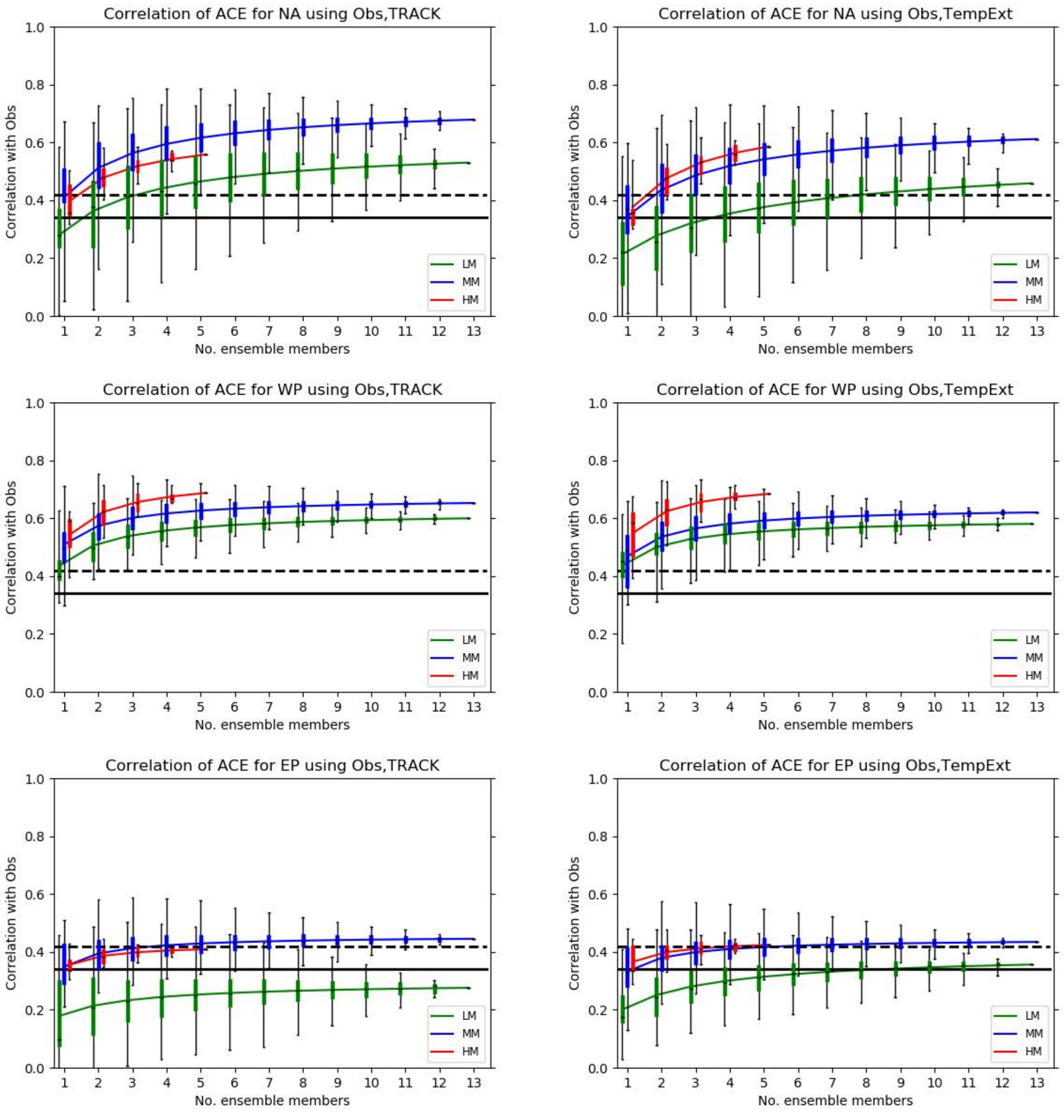


Roberts et al. 2018, in preparation

SPECIAL U.S. CLIVAR Hurricanes COLLECTION

Co-funded by the European Union

PRIMAVERA



Is using single ensemble members per GCM enough to robustly represent interannual variability?

Multiple GCM resolutions of ensembles, 2 tracking algorithms

At least **6 ensemble members needed** in the North Atlantic to understand skill in simulating interannual variability

3-4 ensemble members seem sufficient in the West Pacific.

We do have a heterogeneous ensemble in PRIMAVERA, but also small ensembles of each GCM. → need to revisit IV

Co-funded by
the European Union

Summary and early conclusions

- First results from PRIMAVERA/HighResMIP show that, as we increase resolution in the atmosphere and the ocean:
  - Some **historic biases have been finally reduced**: in the sea, in the atmosphere, on land
  - Models agree in their response to increased resolution, over large portions of the globe, and we can attribute the agreement to specific processes
  - Evidence of stronger coupling between climate system components, over narrow regions
  - The HighResMIP protocol seems successful, despite it being expensive and technically very challenging, but we must bear in mind its limitations
- Resolution is no panacea, but its benefits in terms of understanding outweigh the cost and shortcomings
- We will continue to focus on process-based analyses, to further understand their individual role, and how this changes with climate change (e.g. transports by cyclones, role of complex topography, role of ocean eddies).