Climate indices projections based on the CORDEX-CORE, CMIP5 and CMIP6 ensemble

GERICS Climate Service Center Germany

The Abdus Salam International Centre for Theoretical Physics

Erika Coppola & Claas Teichman, and ....

the CORDEX Core team:

Daniela Jacob, Armelle Remedio, Thomas Remke, Arne Kriegsmann, Katharina Bulow,
Torsten Weber, Lars Buntemeyer, Kevin Sieck, Diana Rechid

Filippo Giorgi, Francesca Raffaele, Taleena Rae Sines, Abraham Torres,
Graziano Giuliani, Adriano Fantini, James Ciarlo, Sushant Das, Fabio di Sante,
Emanuela Pichelli, Russel Glazer, Ivan Girotto, Moetasim Ashfaq, Melissa Bukovsky, Gao Xuejie, Sabina Abba-Omar, Sebastian K. Müller

The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, Oak Ridge National Laboratory, NCAR, The Hong Kong University of Science and Technology, Institute of Atmospheric Physics, Chinese Academy of Sciences (IAP/CAS)

Climate Service Center Germany (GERICS), Helmholtz-Zentrum Geesthacht, Fischertwiete 1, 20095 Hamburg, Germany

CORDEX Coordinated Output for Regional Evaluation (CORE): Introduction

A new initiative that was recently launched within the framework of the Coordinated Regional Downscaling Experiment (CORDEX, Giorgi et al. 2009), called CORDEX-CORE (Gutowski et al. 2016) whose purpose is to provide a homogeneous ensemble of high resolution (25 km grid spacing) projections for regions worldwide.

Two RCM systems have been used (RegCM and REMO) with projections at 0.22 degree resolution using as driving boundary conditions three GCMs (medium, low and high climate sensitivity) for two scenarios RCP2.6 and RCP8.5. As a comparison, results from our CORDEX-CORE runs are compared with corresponding ones from the CMIP5 global driving models and available CMIP6.

Thanks to this dataset, an unprecedented resource to assess the issue of hazards under climate change in a global context has been provided.

Driving GCM	Ensemble	CORDEX-CORE 0.22
MOCH-HadGEM2-ES	r1i1p1	GERICS-REMO2015
MOCH-HadGEM2-ES	r1i1p1	ICTP-RegCM4-6
MIROC5	r1i1p1	ICTP-RegCM4-6
MPI-ESM-MR	r1i1p1	ICTP-RegCM4-6
MPI-ESM-LR	r1i1p1	GERICS-REMO2015
GFDL-ESM2M	r1i1p1	ICTP-RegCM4-6
NCC- NorESM1-M	r1i1p1	GERICS-REMO2015
NCC- NorESM1-M	r1i1p1	ICTP-RegCM4-6

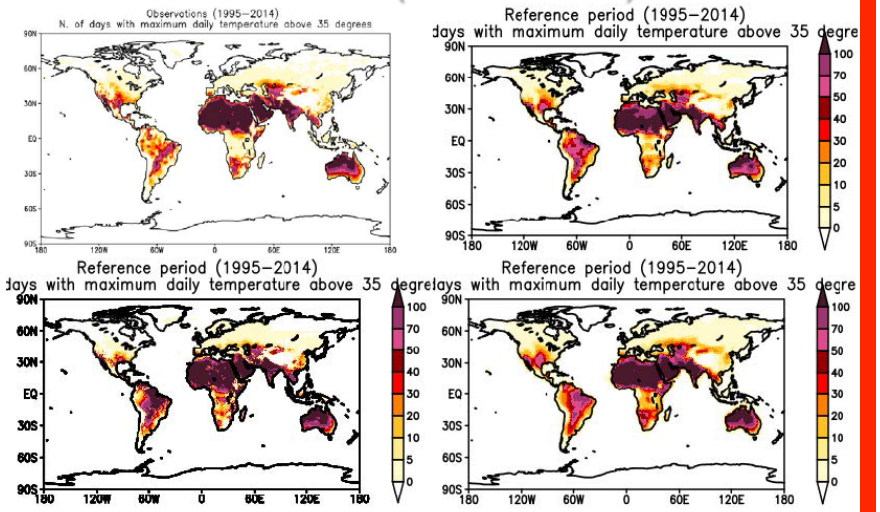
Climate and Hazard indices: Definitions

The climate indices analyzed to quantify a given hazard :

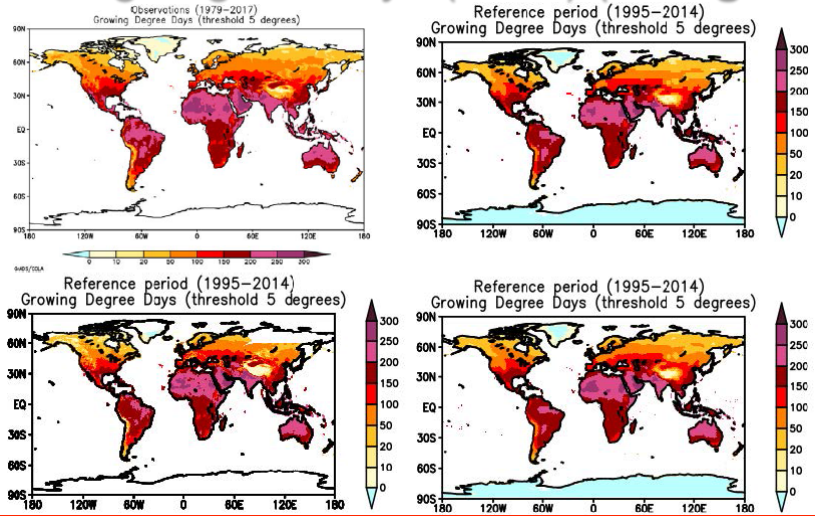
- **Growing degree-days (GDD):** the cumulative number of degrees above the threshold of 5 degrees, during a given growing period.
- **TX35:** the number of days with maximum daily temperature above 35 degrees.
- **99P:** the 99th percentile of precipitation
- **Drought Frequency (DF):** the total number of drought events computed on the base of the Standardized Precipitation Index, here considered for a time window of 6 months: a drought starts in the month when SPI-6 falls below −1 and it ends when SPI returns to positive values for at least two consecutive months, as in Spinoni et al. (2014).
- **Cooling Degree Day (CDD):** a measure of the energy consumption in hot environments. It is based on the daily mean, maximum and minimum temperature and it is computed as in Spinoni et al. (2015), except that here the sum is cumulated over the whole year (instead of 6 months) so that it applies to both Hemispheres.
- **Heating Degree Day (HDD):** similarly to the CDD, it is the energy demand for heating and it is computed as in Spinoni et al. (2015), but for the whole year.
- **Peak discharge (Q100):** the peak discharge corresponding to the 100-year return period (Alfieri et al 2015).

Extreme & Hazards
Heat indices validation

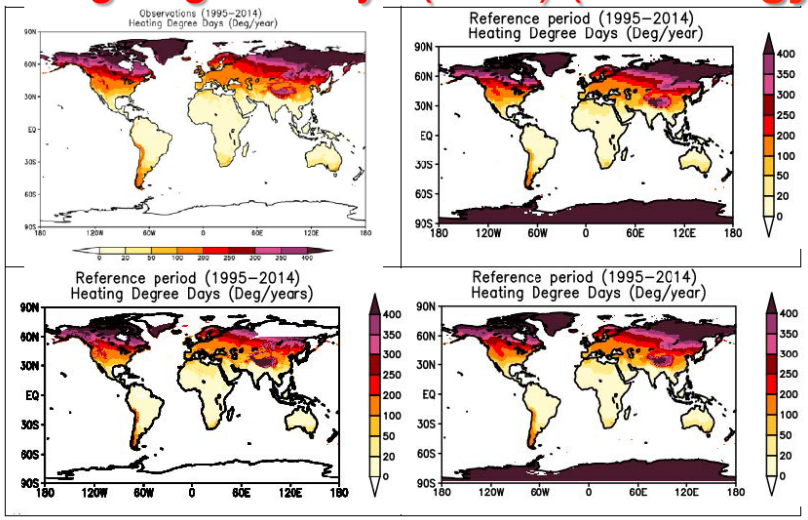
Tmax>35 (for **Health**)



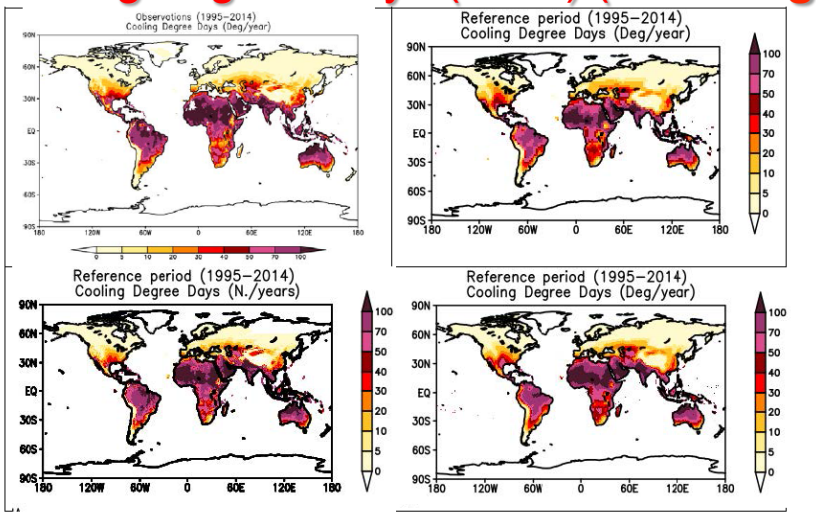
Growing degree-days (GDD) (for **Agriculture**)



Heating degree-days (HDD) (for **Energy**)



Cooling degree-days (CDD) (for **Energy**)



Extreme & Hazards
Heat indices validation

- Tmax>35 (for **Health**): All the model ensembles overestimate the number of days above 35 degrees in South America and in central Africa. In central, eastern and western US the CORDEX-CORE slightly underestimates the number of hot days, while an opposite behaviour is evident from both the CMIP5 and CMIP6 ensembles. Australia's north- south negative gradient and intensity is well represented by all models.

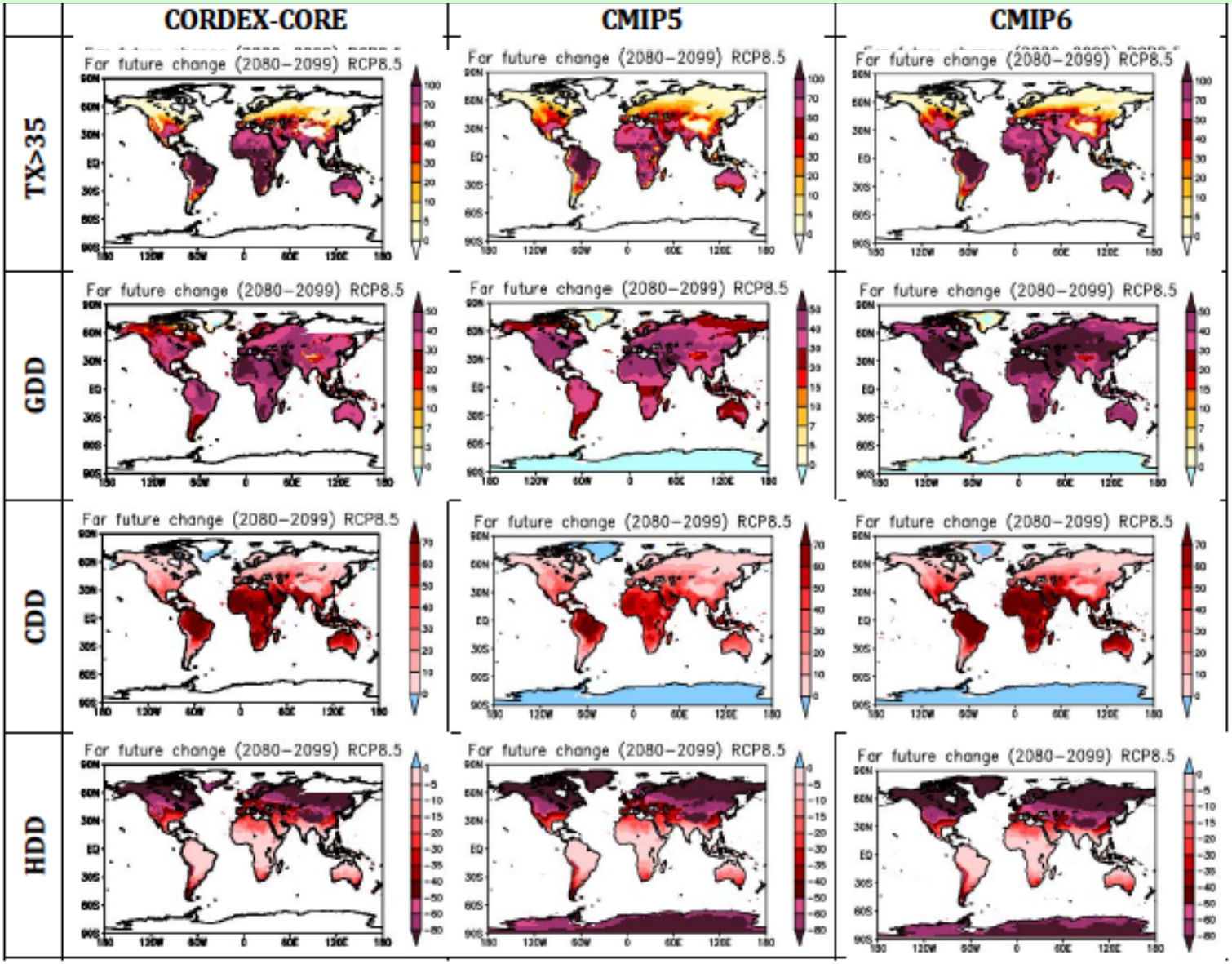
- Growing degree-days (GDD) (for **Agriculture**): all ensembles underestimate the maximum number of degrees per year over the Amazon basin, both GCM ensembles slightly overestimate this quantity in central Africa and underestimate it over the Tibetan plateau, but all ensembles show a good performance over Central and North America, Australia, South East and South Asia.

- Heating degree-days (HDD) (for **Energy**): all ensembles validate quite well throughout all domains, with few locations such as the Rocky Mountains in the US where a more detailed spatial structure is evident for the regional ensemble.

- Cooling degree-days (CDD) (for **Energy**): The CORDEX-CORE ensemble shows a much more detailed spatial structure of CDD compared to the GCMs, and it is closer to the observations. This is evident in particular over South America in the Amazon basin, North and Central America, the African continent, the Indian peninsula, China and Indochina. The GCMs show a tendency to underestimate the maximum values of CDD over these regions.

Extreme & Hazards

Heat indices projections RCP8.5 end of century



Extreme & Hazards
Heat indices projections RCP8.5 end of century

- Tmax>35 has a maximum over all the **African continent** and over north and central **South America**. These two maxima are projected to be **above 100 days more per year** from the CORDEX-CORE and the spatial extension of the regional ensemble is higher in South America (SAM) and much broader in Africa where the global models show only limited regions in west, central and southern Africa. Other maxima are located in **Australia**, **India** with values between **50 and 100 days more per year** and with higher values shown by the regional ensemble and in **the north west US** over land area around the **Gulf of Mexico** and in the **Mediterranean basin** with CMIP6 showing the highest values.

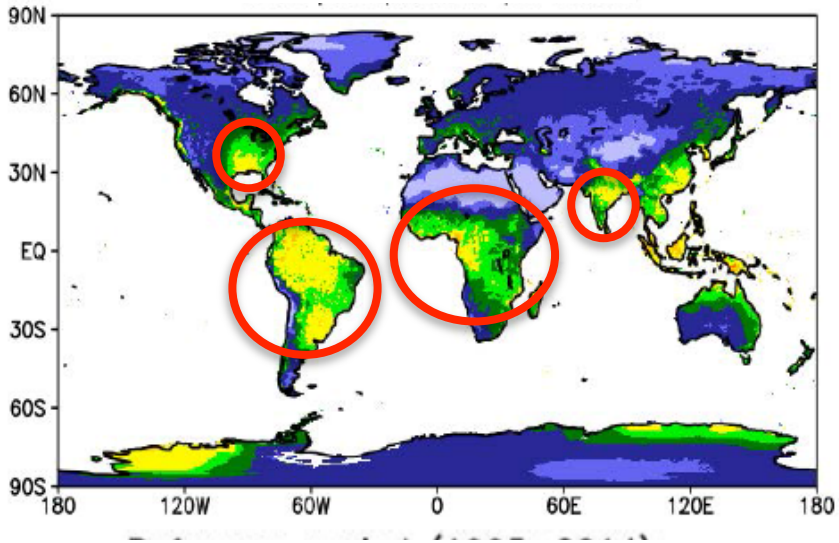
- Growing degree-days (GDD) **increases more than 50 degree days per year in central Europe**, the **Mediterranean** and **north Africa**, east Europe **Siberia**, **Central Asia** and the whole **US** for the northern hemisphere. In the southern hemisphere the maxima are in central and southern **South America, South Africa** and **Australia**.

- Heating degree-days (HDD) and Cooling degree-days (CDD) show a quite **symmetrical structure** since they represent one the energy demand for cooling that we expect to be maximum at the equator and the other the heating demand that we expect to be maximum at the higher latitude.
  - The **CDD** shows a **maximum of above 70 degree more per year** for the CMIP6 in **South- America**, **Africa**, **Asia**, and northern **Australia**. This projection are closely followed by CORDEX-CORE and drop down to values between 50 and 70 degrees for the CMIP5. Areas with **an increase between 50 and 60 degrees per year** are highlighted in the **Gulf of Mexico**, **Mediterranean basin** and **west central Asia** for the CMIP6. The same regions do not cross the 50 degree threshold in the other two ensembles.
  - The **HDD decreases up to -50 degrees per year** above the 40 degree latitude north with values corresponding to roughly -50% in region like **Europe**, **US** and **China**. In regions like the **Mediterranean** and **Mexico** the changes are **up to -100%** . The minimum values are once again reported by the CMIP6 models with also a more southward extend of the minimum area. CORDEX-CORE and CMIP5 show slightly higher values with CMIP5 being the one with minor changes. In the southern hemisphere changes are limited between -20 and -40 degree per years corresponding to **less than -50%** for **South Africa**, south of **Australia** and southern **South America**

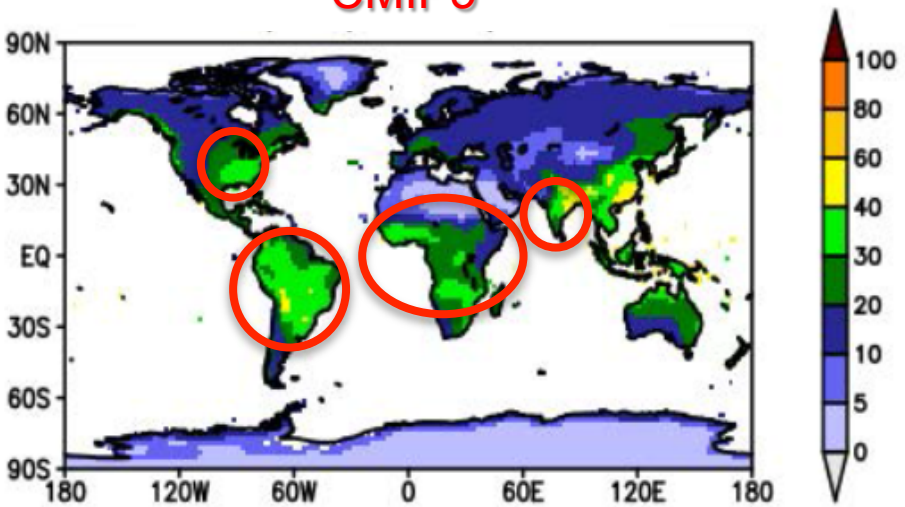
Extreme & Hazards

P99 validation (wet indicator)

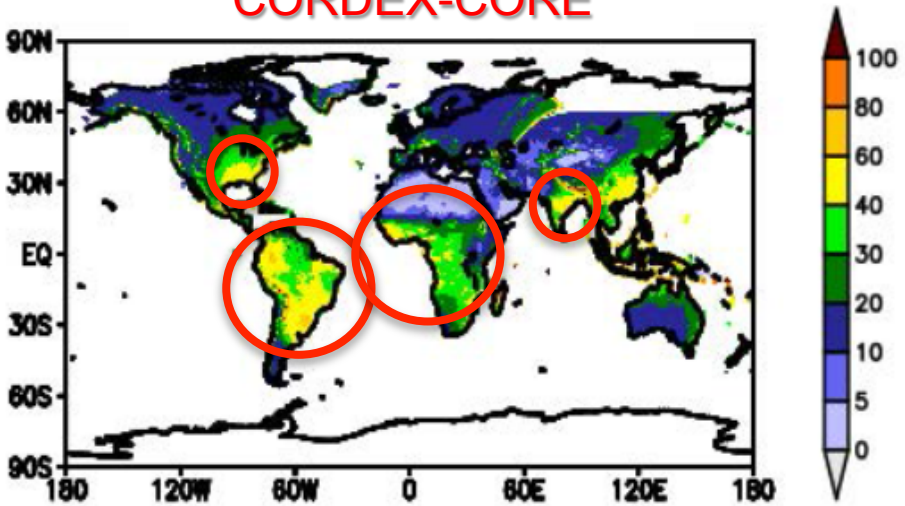
CPC OBS



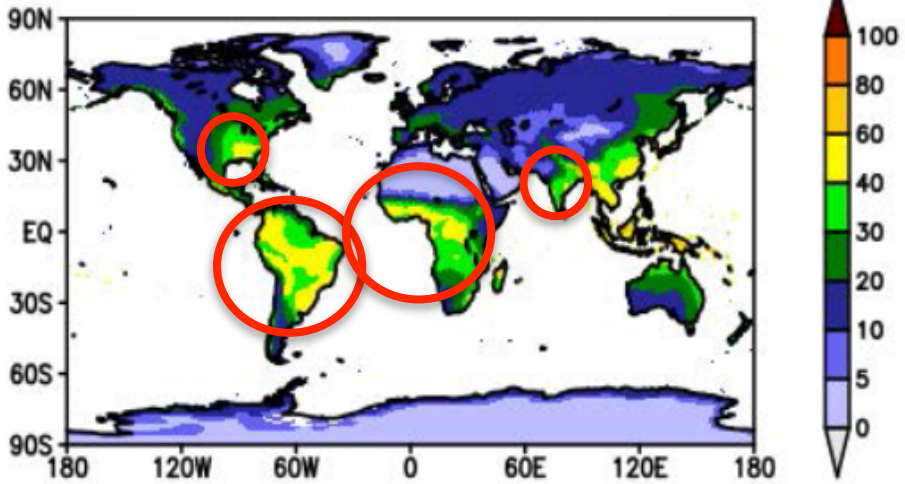
CMIP5



CORDEX-CORE



CMIP6



Extreme & Hazards
P99 validation (wet indicator)

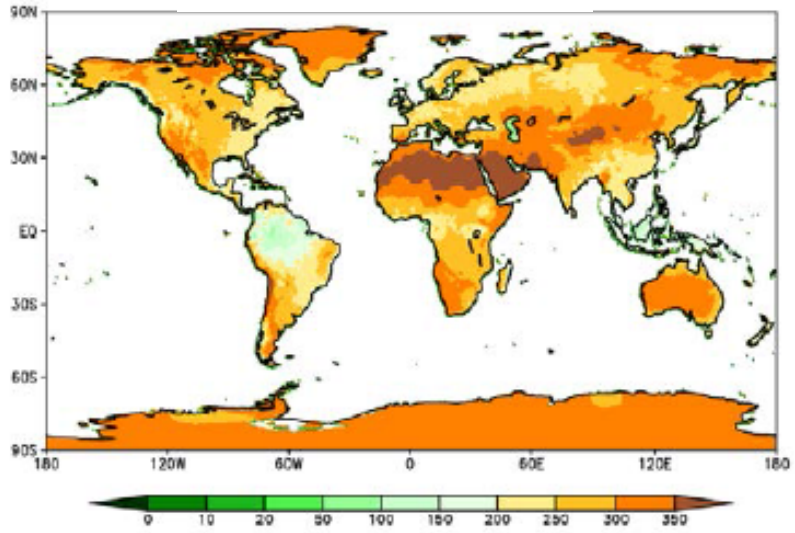
The three ensembles show substantially different performances over the various domains. In particular:

- the CORDEX-CORE ensemble reproduces the location of the La Plata basin maximum, while it displaces the Amazon maximum slightly to the west compared to observations, with some underestimation in the eastern side of the basin.
- The CMIP5 ensemble substantially underestimates the P99 throughout the continent and shows a misrepresentation of the spatial distribution.
- The CMIP6 ensemble still underestimated the two maxima but it improves their spatial distribution compared to CMIP5.

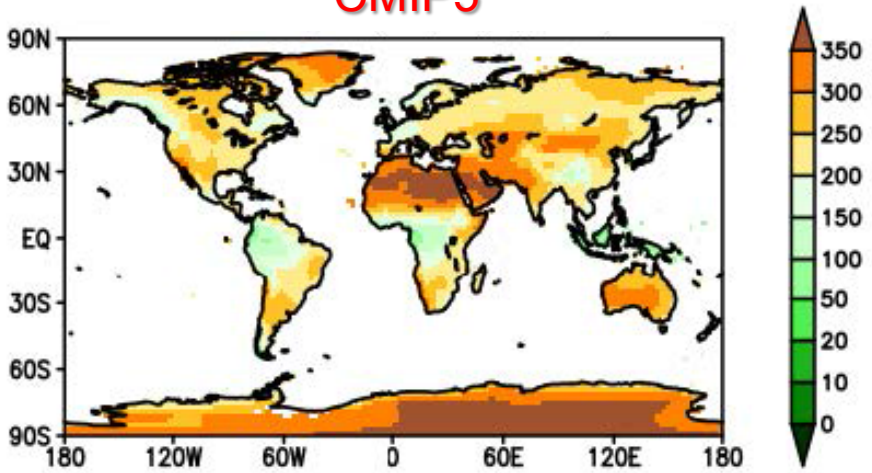
Conclusion: the higher resolution of the RCM may play a role in the better reproduction of the extreme precipitation signal for both cases of complex topography and local land surface feedback mechanisms. This may also be the reason why the CMIP6 ensemble that has a higher resolution compared to CMIP5, is occasionally closer to the CORDEX-CORE ensemble and show in general higher intensities.

Extreme & Hazards
NDD validation (dry indicator)

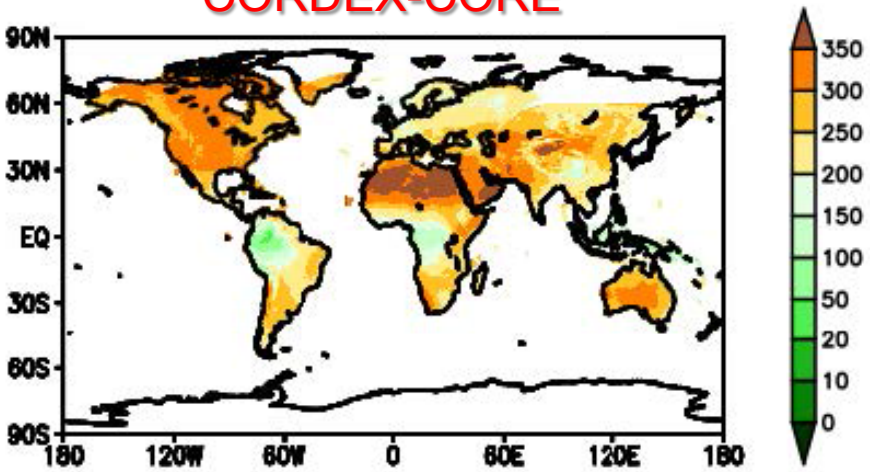
CPC OBS



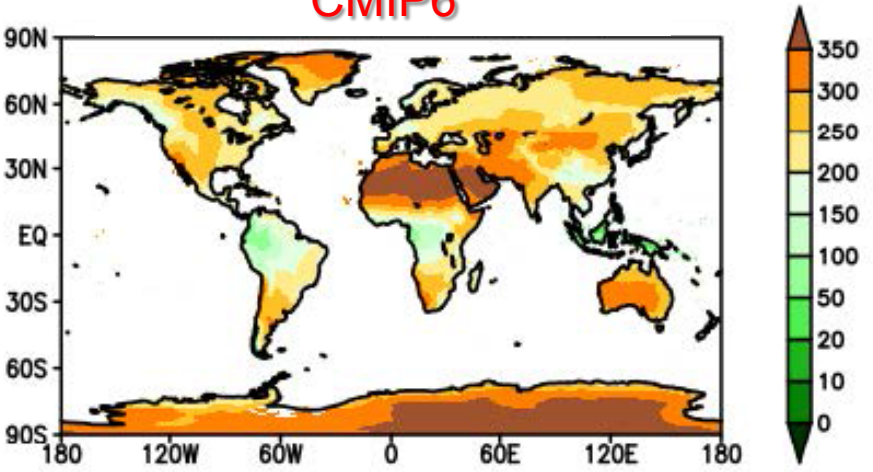
CMIP5



CORDEX-CORE



CMIP6



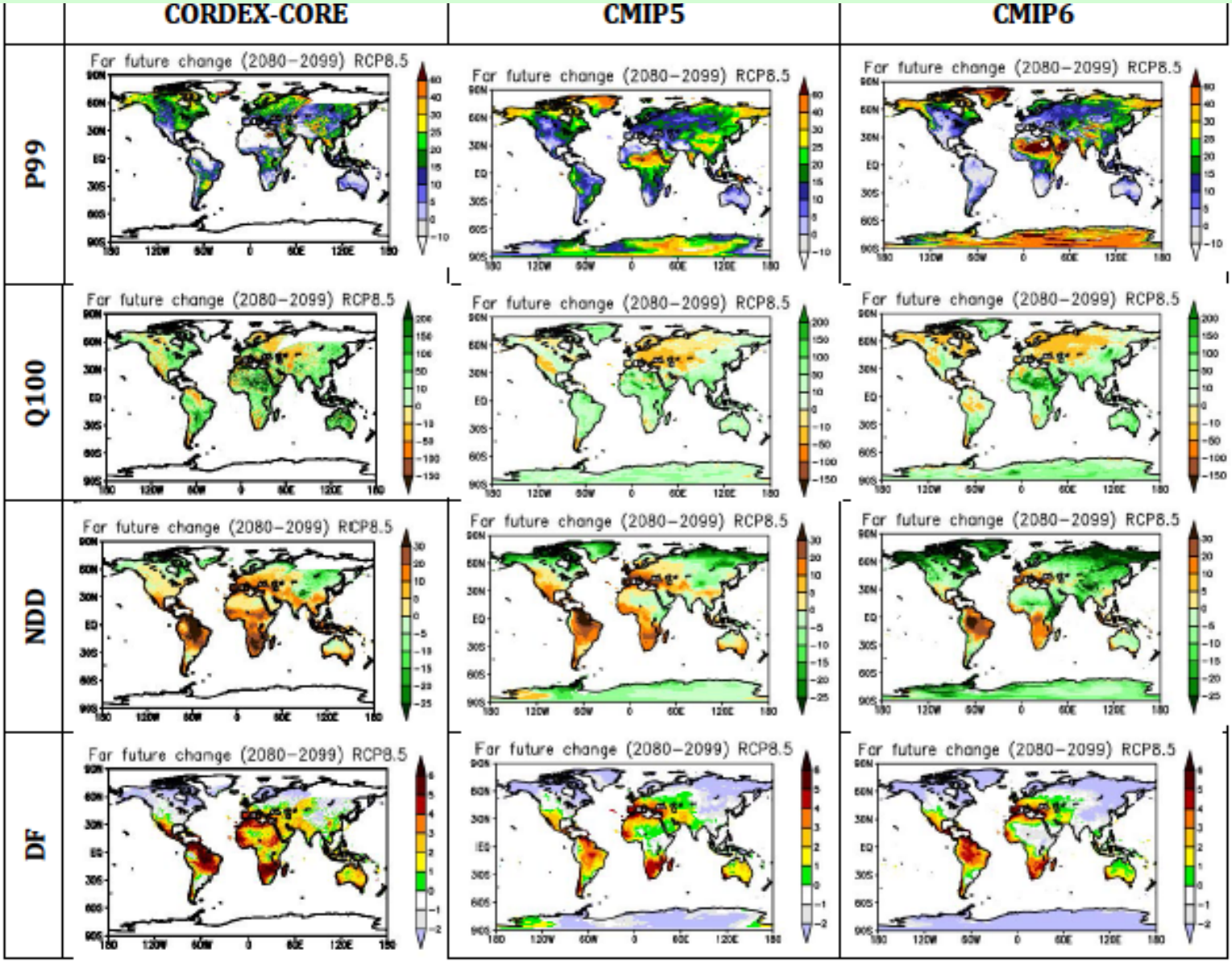
Extreme & Hazards
NDD validation (dry indicator)

- An overall underestimation is evident with only the South American continent showing a pretty good spatial representation from the models and the correct number of dry days per year.
- Central Africa Congo basin seems to be a region where all the models underestimate quite a lot the number of dry days with the global models having the same problem also over the Tibetan plateau, northern Europe, Alaska and north eastern Canada.
- The CORDEX-CORE have less underestimation over the Tibetan plateau and northern Europe and slightly overestimate for the whole north American regions.

The tendency to underestimate the number of dry days is the well known problem of the model drizzle phenomena , for which both RCM and GCMs tend to have a background of light rain all along the year, with too few episodes of zero rain.

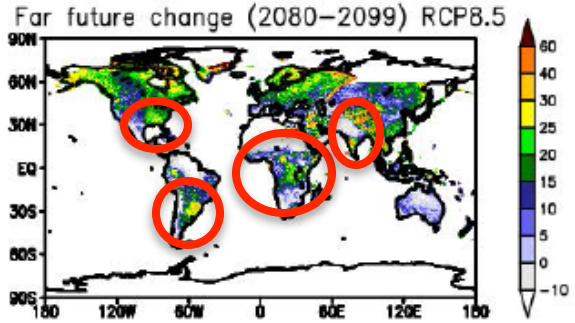
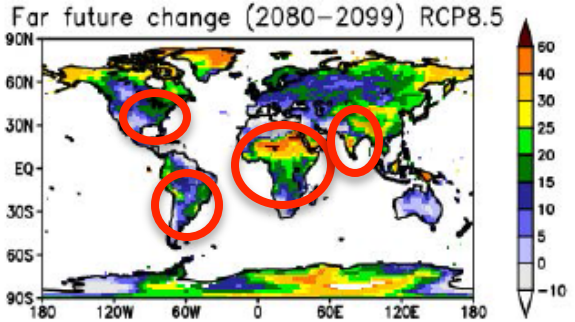
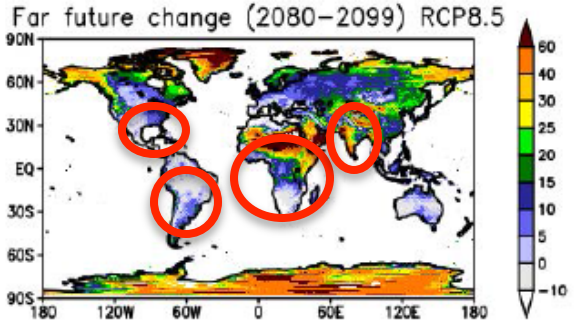
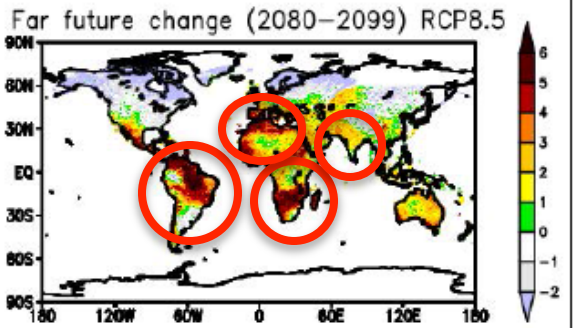
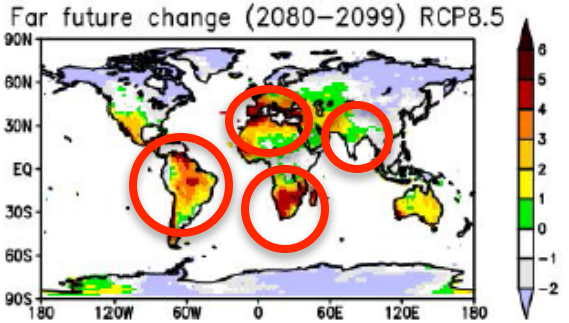
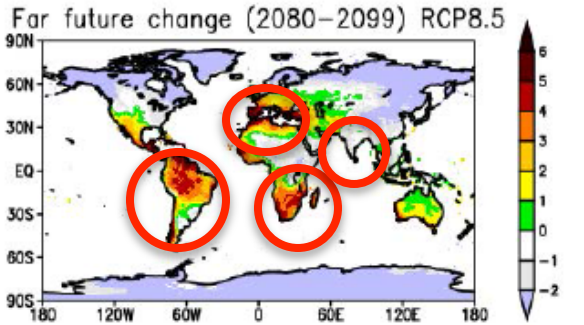
Extreme & Hazards

Future projections for wet & dry indicators



Extreme & Hazards

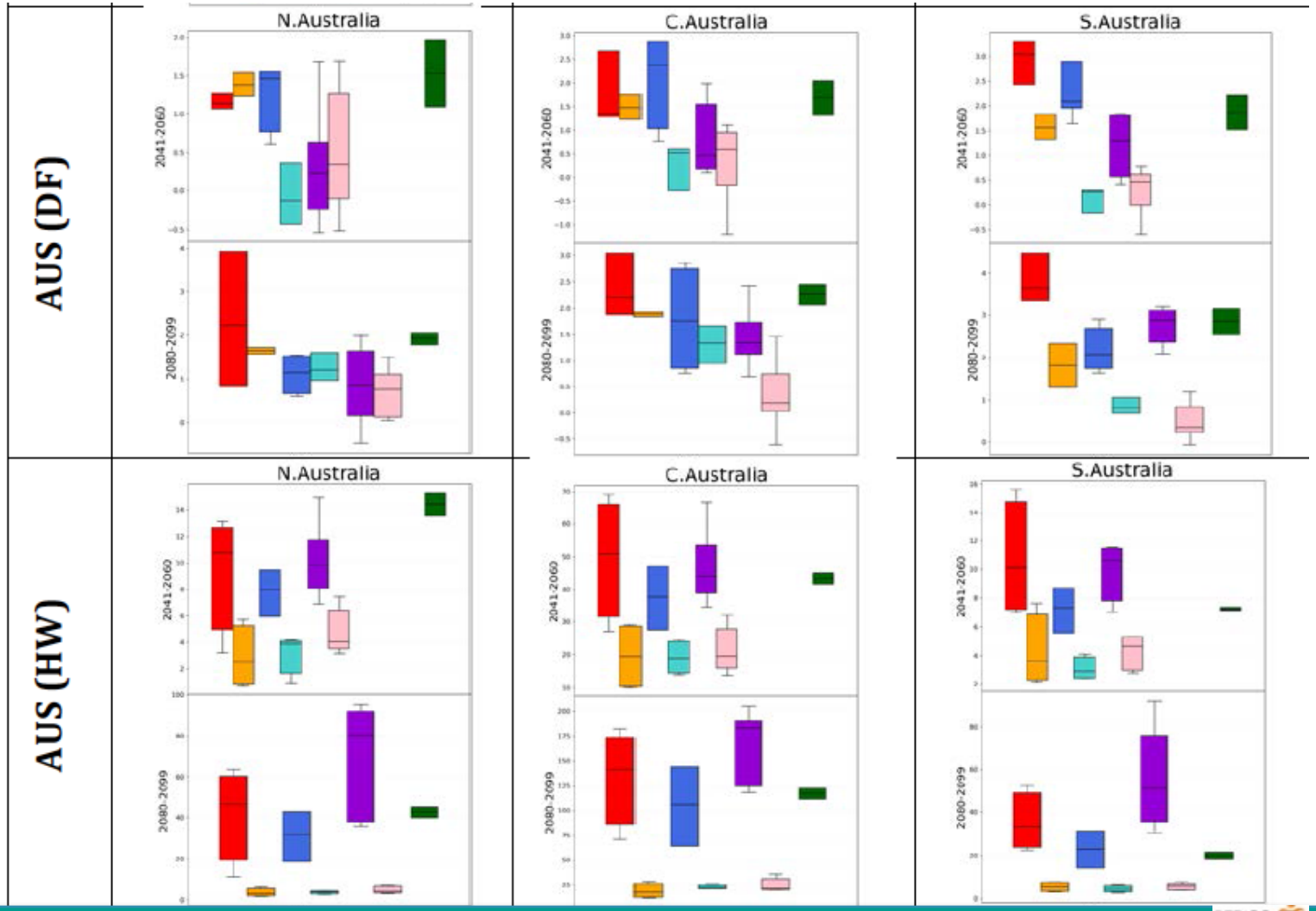
Future projections for wet & dry indicators

	CORDEX-CORE	CMIP5	CMIP6
P99			
DF			

Where the CORDEX-CORE simulations are most in agreement with observations, their future projections mostly differ from the GCM's ensembles (see red circles): if they give a better representation of reality, they can show a more realistic projection in the future.

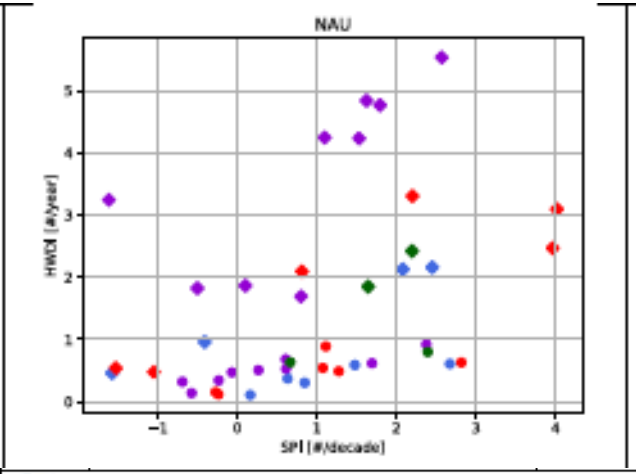
Hazards hot spots
based on model consesus and compound events:

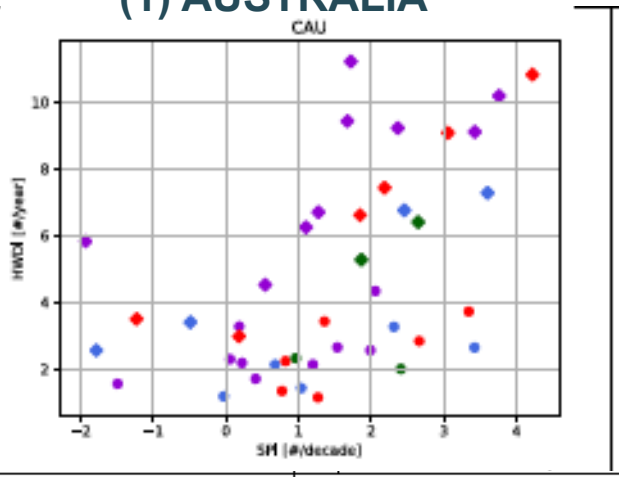
Few regions show clear and strong change in more than one hazard indicators. Based on that a selection of regions where compound hazards signal is observed is made by means of one heat indicator as HW and one dry indicator as DF: **(1) AUSTRALIA**

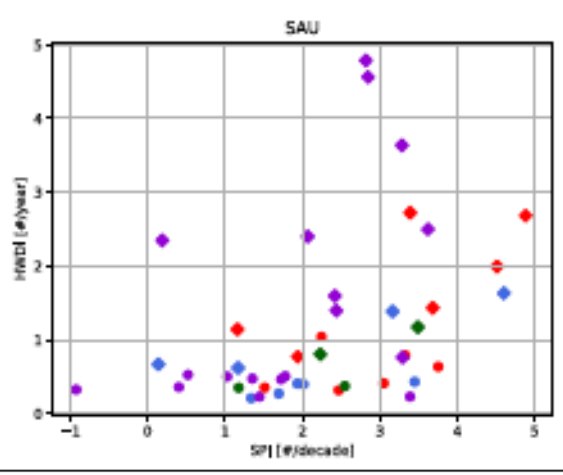


Hazards hot spots
based on model consesus and compound events:

(1) AUSTRALIA







far 8.5 CORDEX-CORE
far 8.5 CMIP6
far 8.5 CMIP5
far 8.5 OLD-CORDEX

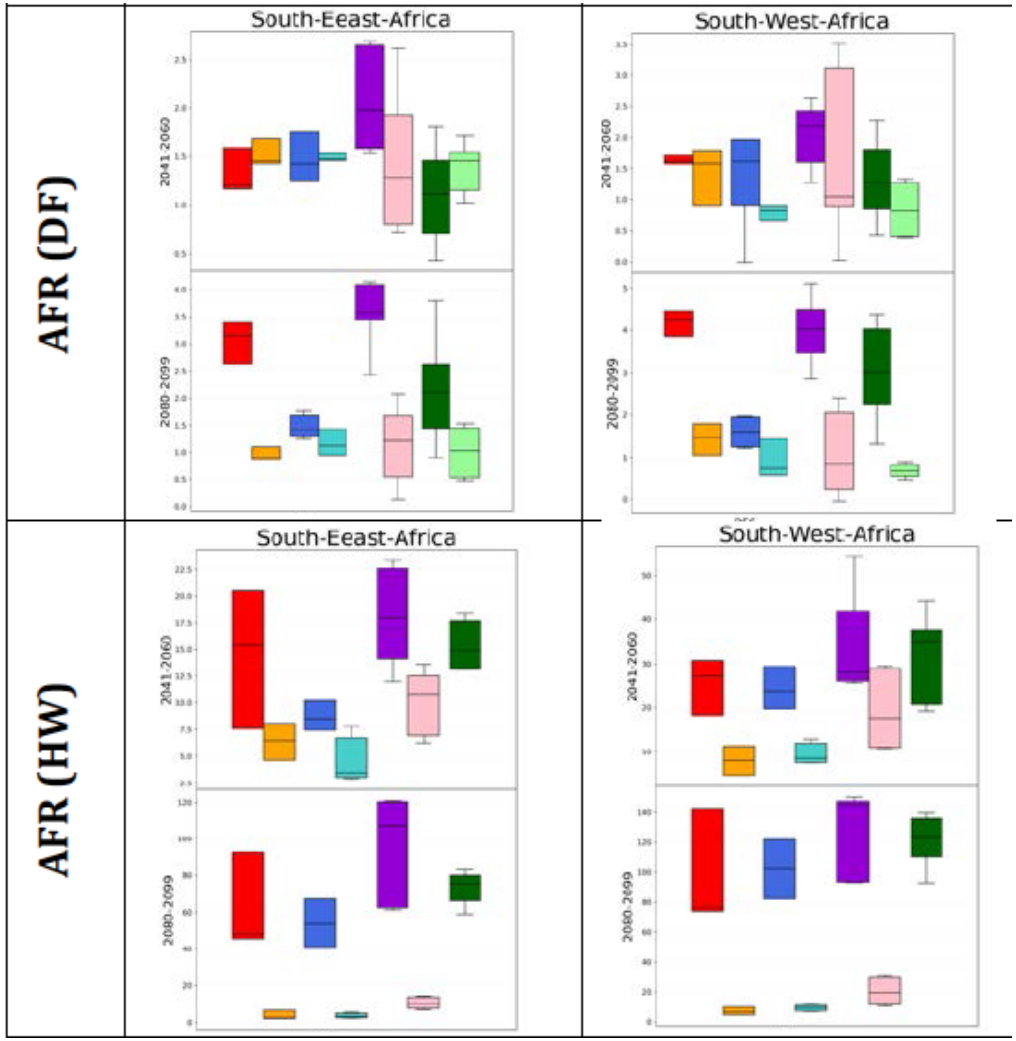
mid 8.5 CORDEX-CORE
mid 8.5 CMIP6
mid 8.5 CMIP5
mid 8.5 OLD-CORDEX

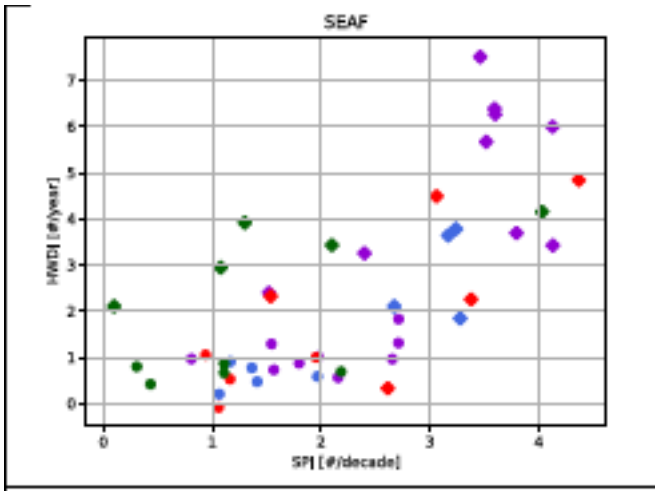
The correlation between HW and DF changes is quite evident.

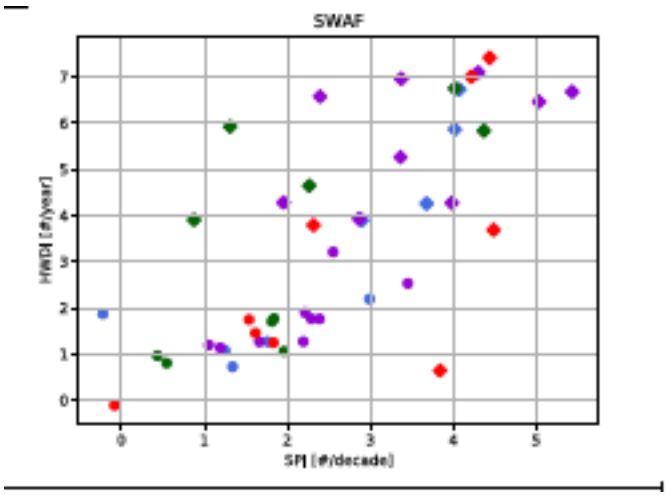
- The CORDEX-CORE projects the higher median increase of DF followed by CORDEX 0.44, with above 2 events per decade (NAU and CAU) and 3.5 (SAU) by the end of century, with the highest spread (except that for CAU where CMIP5 is higher) and the lowest spread for CORDEX 0.44. CMIP5 and CMIP6 have roughly 1 event less per decade.
- For HW changes CORDEX-CORE and CMIP6 project systematically higher changes values compared to CMIP5 and CORDEX 0.44. Within the range of 2-5 and 4-10 for NAU and CAU and 1-3 (CORDEX-CORE) and 1-5 (CMIP6) for SAU .

Hazards hot spots
based on model consesus and compound events:

(2) SOUTH AFRICA







Hazards hot spots
based on model consesus and compound events:

(2) SOUTH AFRICA

- Only CORDEX-CORE is projecting an increase of 2 more droughts per year and showing a linear relation with the HW increase.
- South east and south west Africa are the two regions with the highest correlation between HW and DF increase.
- The range of increase for DF projections among all models is between 2 and 5 events more per decade with CORDEX-CORE and CMIP6 being at the upper end of the distribution.
- For HW, CORDEX-CORE and CMIP6 are at the upper end of the distribution but also with the larger spread.

Summary

- All the indices have been validated against the observation and the CORDEX-CORE being the one with the highest resolution has proven a better validation in several regions and for several indices for bot the intensity and the spatial displacement
- All the temperature and heat indices are projected to increase, except the HDD index that is decreasing everywhere as expected.
- The differences in projections among the regional and global ensemble are more evident for the wet and dry indicators.
- Extreme precipitation maxima changes over la Plata basin, the Congo basin, North western US and north east Europe are only reported by the CORDEX-CORE ensemble that is also the one validating best for these regions.
- CORDEX-CORE ensemble is also the one showing stronger drying over the Amazon basin, Mexico, South Africa and the Mediterranean basin
- Compound hazard events can lead to significant impact to life and society therefore we attempted to identify compound hazard hotspot based on one heat and drought indicator. The Mexican region (NSA), the Amazon region (NES, NSA and SAM), the Mediterranean basin, Southern Africa regions SEAF and SWAF, the Indian peninsula (SAS) and the 3 Australia regions NAU, CAU and SAU show a correlation between heatwave change and number of droughts per decade.
- It is undoubted that the availability of such many datasets can be really valuable for impact oriented climate studies that can feed both the impact community and climate services.

Outlook

Entire Climate Dynamics Special Issue (SI) dedicated to the CORDEX-CORE effort

- 2 main general papers belong to the SI:
  - ✓ evaluation of mean climate and projections
  - ✓ evaluation of extreme and hazard climate and projection

- Data are CMOR-ized and all possible CORDEX variables will be available
- Distributed on the ESGF archive (CINECA Italy & DKRZ Germany nodes)
- Release date 15-10-2019 for the CORE variables
- Dowload of the CORDEX-CORE simulations at:
  https://esg-dn1.nsc.liu.se/search/cordex/

CORDEX phase I + CORDEX CORE are contributing to the **AR6 IPCC Atlas**

We encourage the use of CORDEX CORE for any scientific studies by the entire CORDEX reseach community

Bibliography

- Alfieri, L., Burek, P., Feyen, L., & Forzieri, G. (2015). Global warming increases the frequency of river floods in Europe. Hydrology and Earth System Sciences, 19(5), 2247–2260. https://doi.org/10.5194/hess-19-2247-2015

- Coppola, E., Raffaele, F., Giorgi, F., Giuliani, G., Xuejie, G., Ciarlo, J., et al. (submittedc). Climate hazard indices projections based on CORDEX-CORE, CMIP5 and CMIP6 ensemble. Clim. Dyn. (submitted).

- Giorgi, F., C. Jones and G. Asrar, 2009: Addressing climate information needs at the regional level: The CORDEX framework. WMO Bulletin, 58, 175-183.

- Gutowski JW, Giorgi F, Timbal B, Frigon A, Jacob D, Kang HS, Raghavan K, Lee B, Lennard C, Nikulin G, O'Rourke E, Rixen M, Solman S, Stephenson T, Tangang F (2016) WCRP COordinated Regional Downscaling EXperiment (CORDEX): A diagnostic MIP for CMIP6. Geoscientic Model Development 9(11):4087{4095, DOI 10.5194/gmd-9-4087-2016

- Spinoni, J., Naumann, G., Carrao, H., Barbosa, P., and Vogt, J. (2014). World drought frequency, duration, and severity for 1951-2010. *Int. J. Climatol.* 34, 2792–2804. doi:10.1002/joc.3875.

- Spinoni, J., Vogt, J., and Barbosa, P. (2015). European degree-day climatologies and trends for the period 1951-2011. Int. J. Climatol. 35, 25–36. doi:10.1002/joc.3959.

- Teichmann, C., Jacon, D., Remedio, A. R., Remke, T., Buntemeyer, L., Hoffmann, P., et al. (2019). Assessing mean climate change signals in the global CORDEX-CORE ensemble. Clim. Dyn. (submitted).