Advancing Convection-Permitting Climate Projections: Coordinated Ensemble Experiments and the Path Ahead

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ICTP - Public Information Unit

09 May 2023

The Abdus Salam International Centre for Theoretical Physics

IAEA International Atomic Energy Agency

United Nations Educational, Scientific and Cultural Organization

3 "Whys"

Why CP scale?

Need to represent *sub scale processes/interaction* crucial for a realistic representation of local climate

Reduce source of *uncertainty*

Investigate *new insights* possibly coming out at these scales

Why multi-model approach?

Build *robustness* of evidences from single-model studies

Generalize some aspects arising from single-area studies

Provide a collective assessment of our modeling capacity at the kilometer-scale and build robust evidences for *climate change* projections

Why is important a coordinated effort?

We need to keep the ensemble populated to ensure the robustness of results

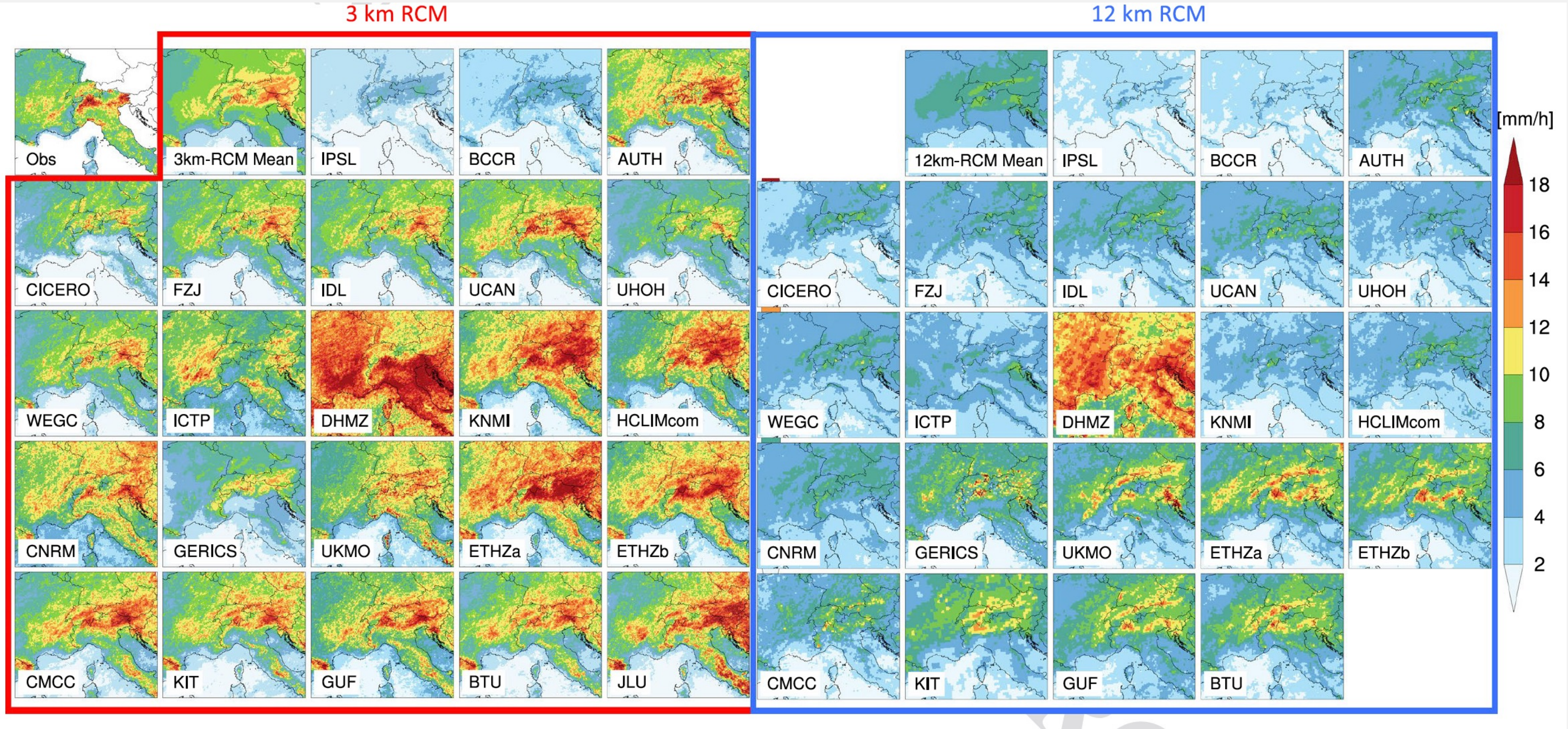
Leave room for complementary approaches (PGW & AI)

Work on model development "together"

What we didn’t know before starting the coordinated FPSs

CORDEX Flagship Pilot Study Europe

Heavy hourly precipitation in the summer season (p99.9)

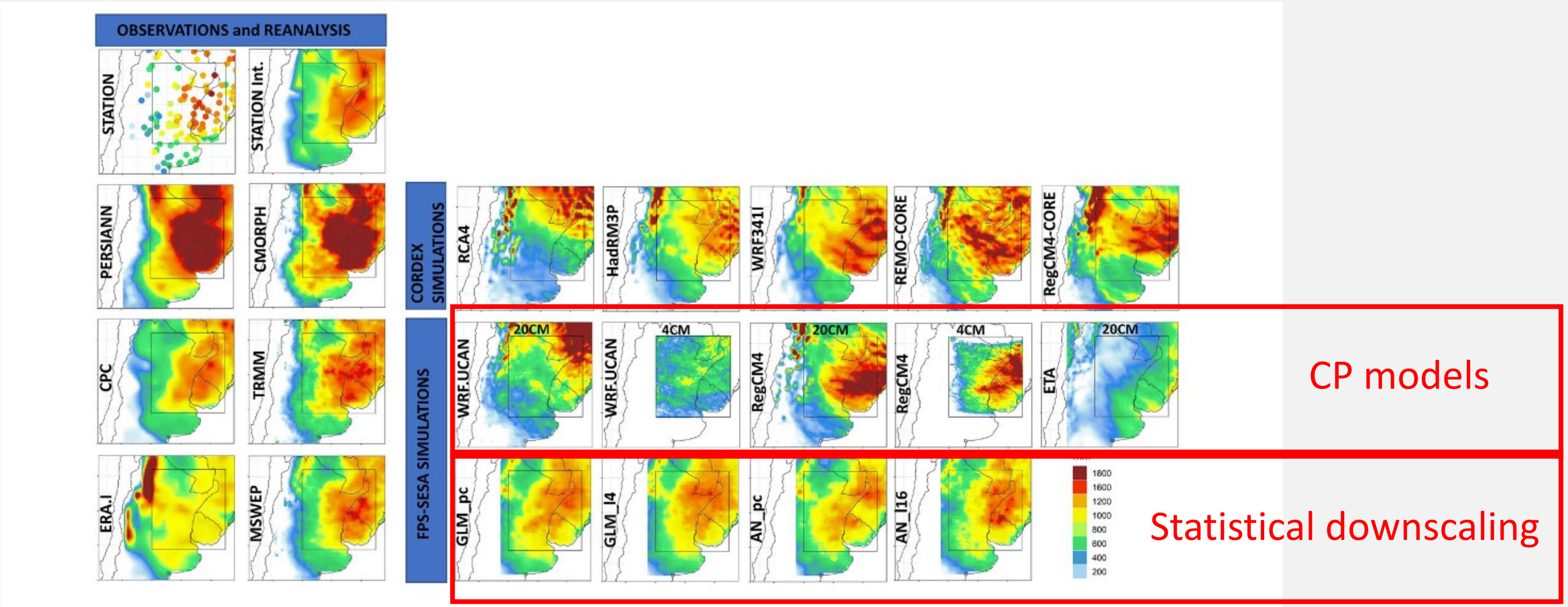


Large variability between the models, but a clear difference between the 3km and 12 km RCMs

(Ban, N., et al. 2021)

CORDEX Flagship Pilot Study in southeastern South America

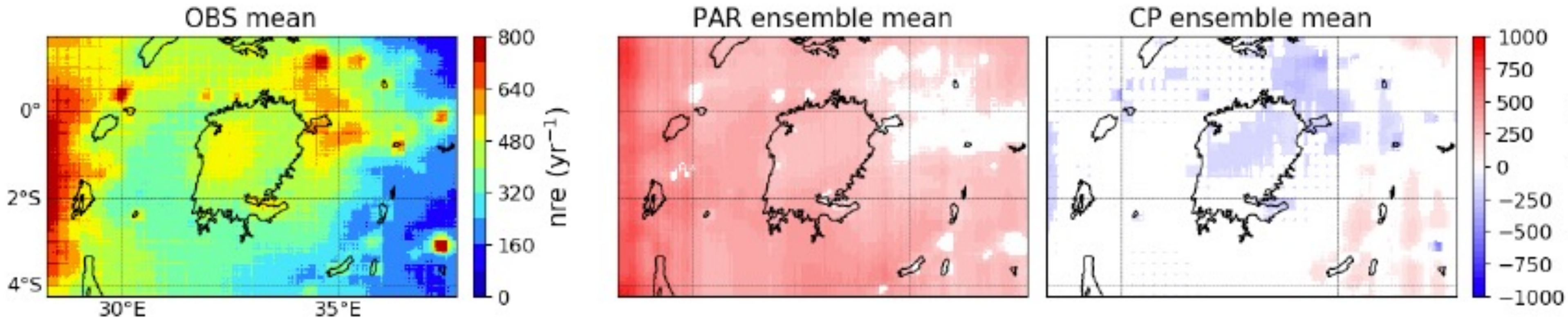
Total precipitation amount warm season 2009-2010



Bettolli, M. L., Solman, S. A., Da Rocha, R. P., Llopart, M., Gutierrez, J. M., Fernández, J., M. E. Olmo, · A. Lavin-Gullon, · S. C. Chou9 · D. Carneiro Rodrigues, · E. Coppola, · R. Balmaceda Huarte, ·M. Barreiro, · J. Blázquez, · M. Doyle, · M. Feijoó, · R. Huth, · L. Machado, Cuadra, S. V. (2021). The CORDEX Flagship Pilot Study in southeastern South America: a comparative study of statistical and dynamical downscaling models in simulating daily extreme precipitation events. Climate Dynamics, 56(5), https://doi.org/10.1007/s00382-020-05549-z, 1589-1608.

CORDEX Flagship Pilot Study ELVIC (Lake Victoria Basin)

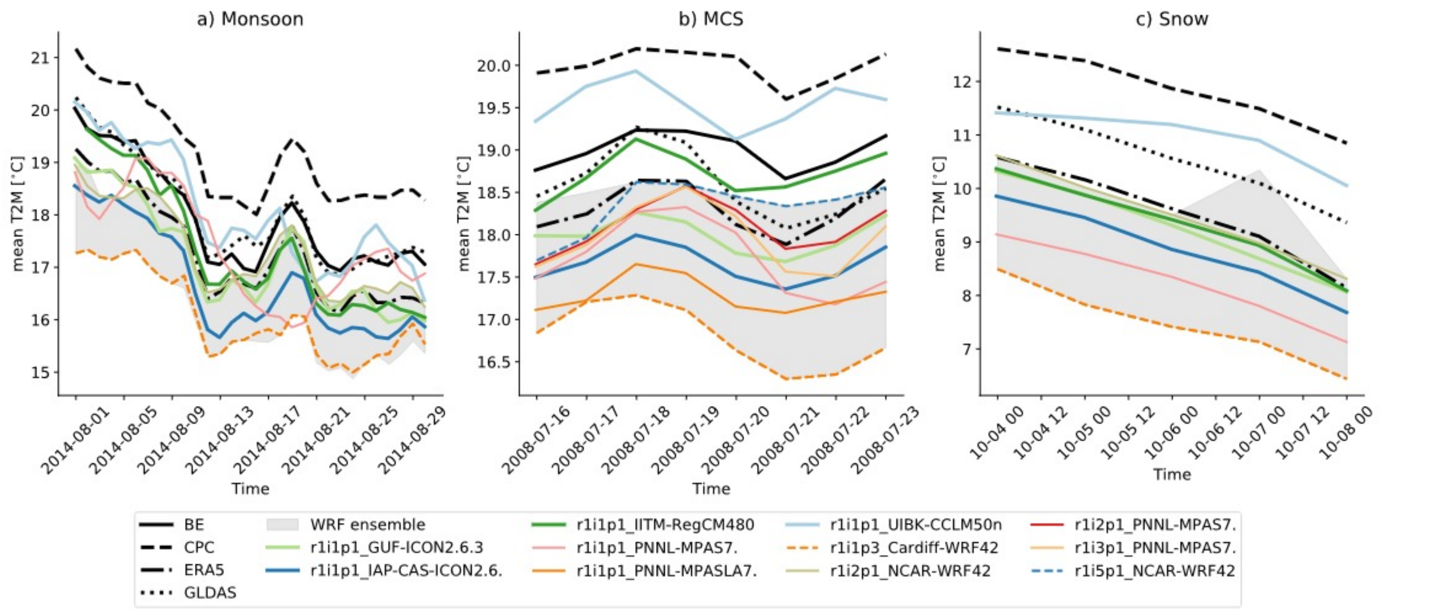
Number of rainy events per year (3h>0.125mm/3h)



Lipzig, N.P.M.v., Walle, J.V.d., Belušić, D. *et al.* Representation of precipitation and top-of-atmosphere radiation in a multi-model convection-permitting ensemble for the Lake Victoria Basin (East-Africa). *Clim Dyn* **60**, 4033–4054 (2023). https://doi.org/10.1007/s00382-022-06541-5

CORDEX Flagship Pilot StudyThird Pole

Domain average daily mean T2M



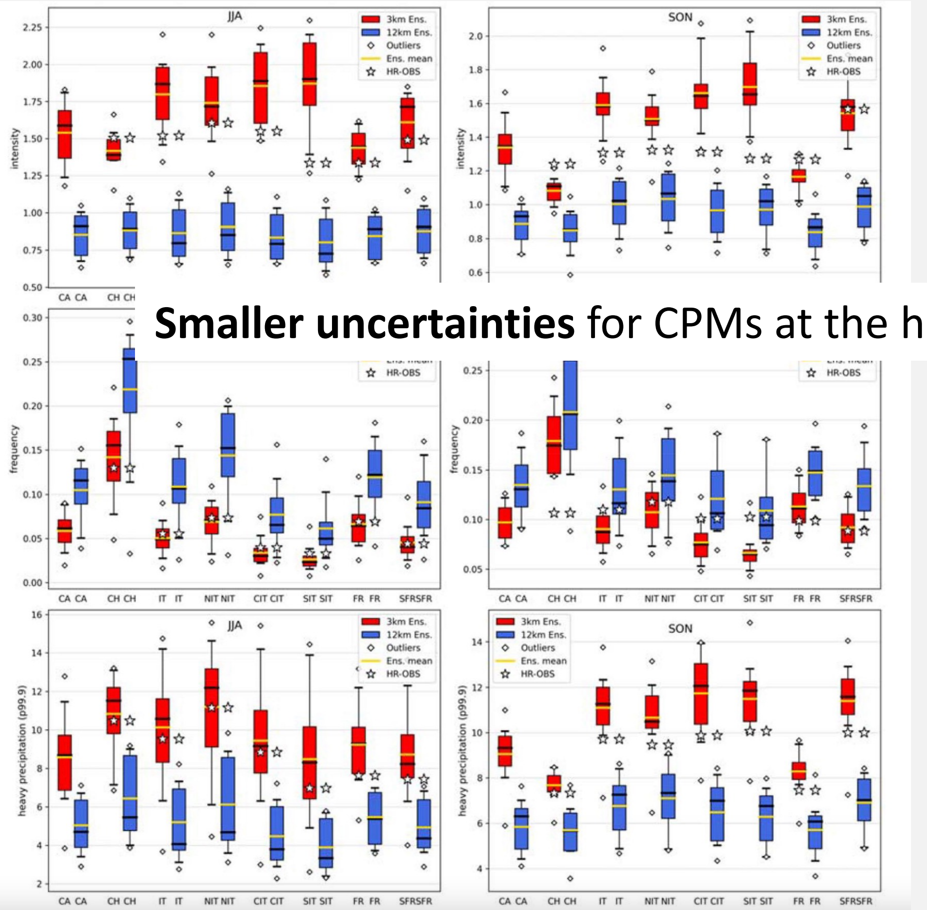
Prein AF et al. (2022) Convection-Permitting Third Pole Experiment – Towards Ensemble-Based Kilometer-Scale Climate Simulations over the Third Pole Region. Climate Dynamics, https://doi.org/10.1007/s00382-022-06543-3

What the coordinated effort contributed to the science advancement

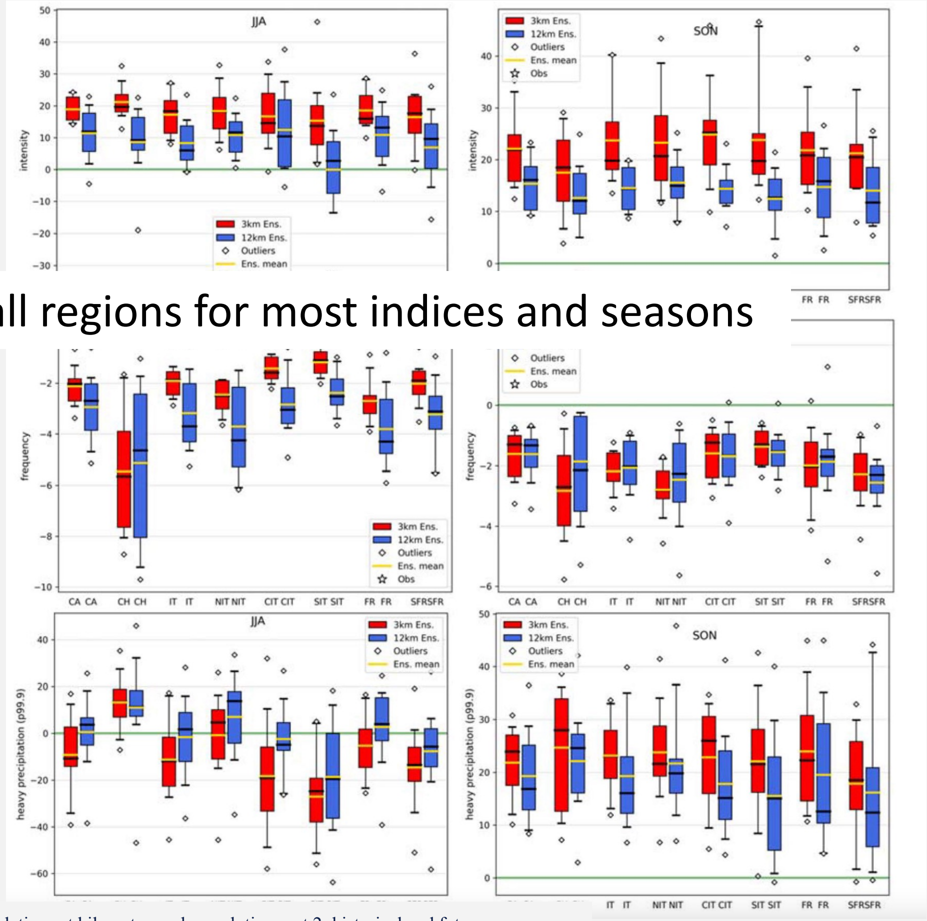
CORDEX Flagship Pilot Study Europe

CP ensemble seems to show less uncertainty

Present Hourly Precipitation



Future Hourly Pr. change



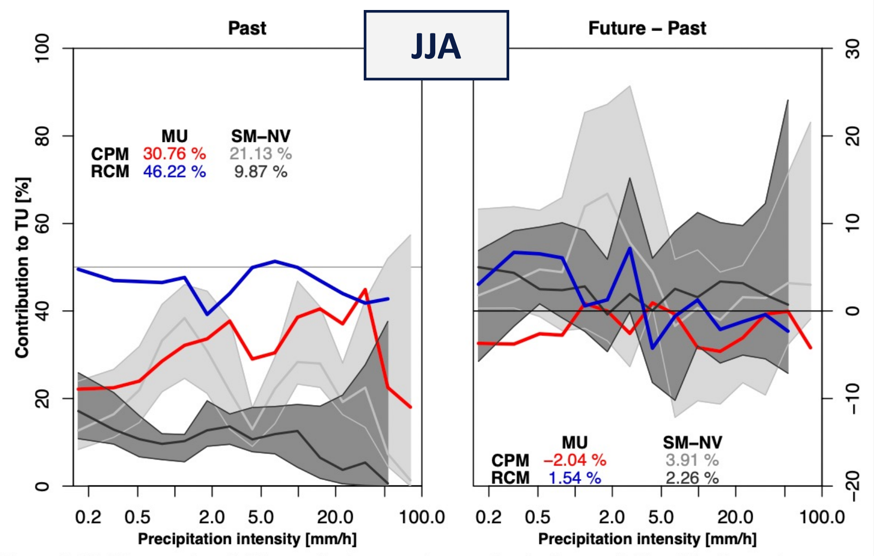
Smaller uncertainties for CPMs at the hourly scale in all regions for most indices and seasons

Pichelli, E., Coppola, E., Sobolowski, S., Ban, N., Giorgi, F., Stocchi, P., ... & Vergara-Temprado, J. (2021). The first multi-model ensemble of regional climate simulations at kilometer-scale resolution part 2: historical and future simulations of precipitation. *Climate Dynamics*, *56*(11), https://doi.org/10.1007/s00382-021-05657-4, 3581-3602.

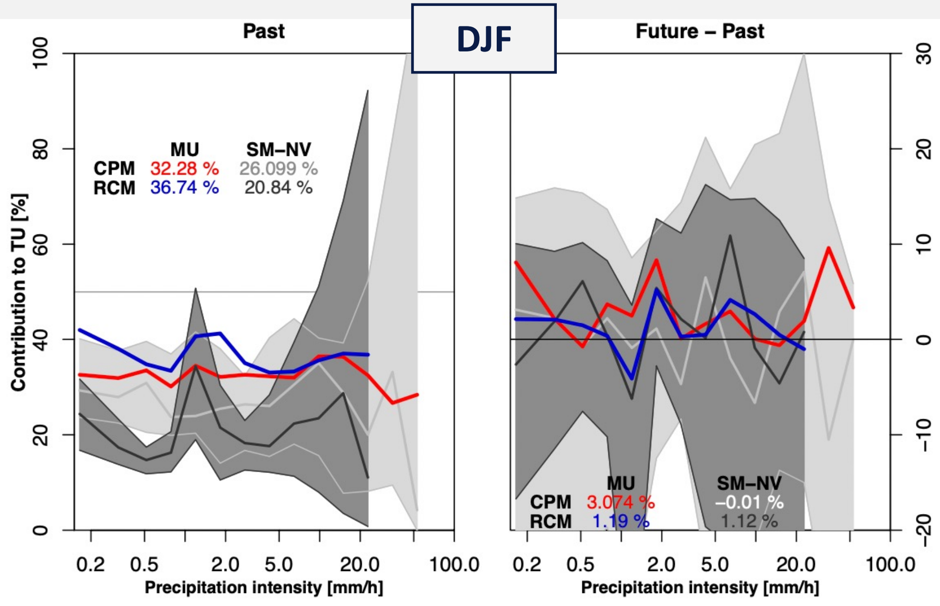
Ban, N., Caillaud, C., Coppola, E., Pichelli, E., Sobolowski, S., Adinolfi, M., ... & Zander, M. J. (2021). The first multi-model ensemble of regional climate simulations at kilometer-scale resolution, part I: evaluation of precipitation. *Climate Dynamics*, https://doi.org/10.1007/s00382-021-05708-w, 1-28.

CORDEX Flagship Pilot Study Europe

Fractional contribution of total precipitation



- ✓ Model uncertainties contribute to total uncertainties substantially more in RCMs than in CPMs especially for extremes

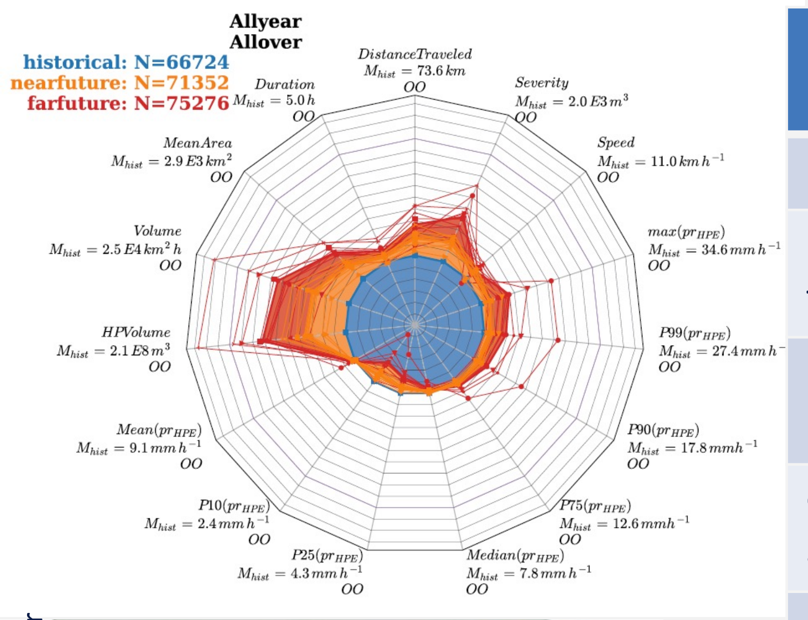


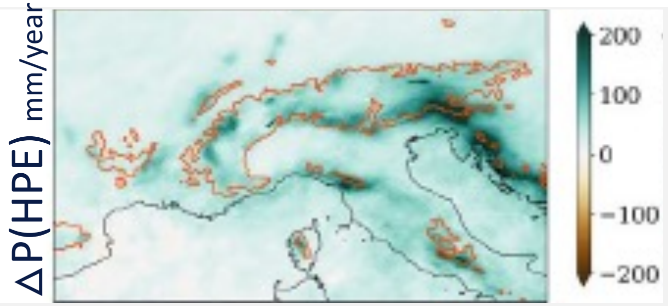
- ✓ The convergence in CPMs is likely to be linked to the explicit representation of convection

Fosser et al. Convection-permitting climate models offer more certain extreme rainfall projections. npj Climate and Atmospheric Science, submitted

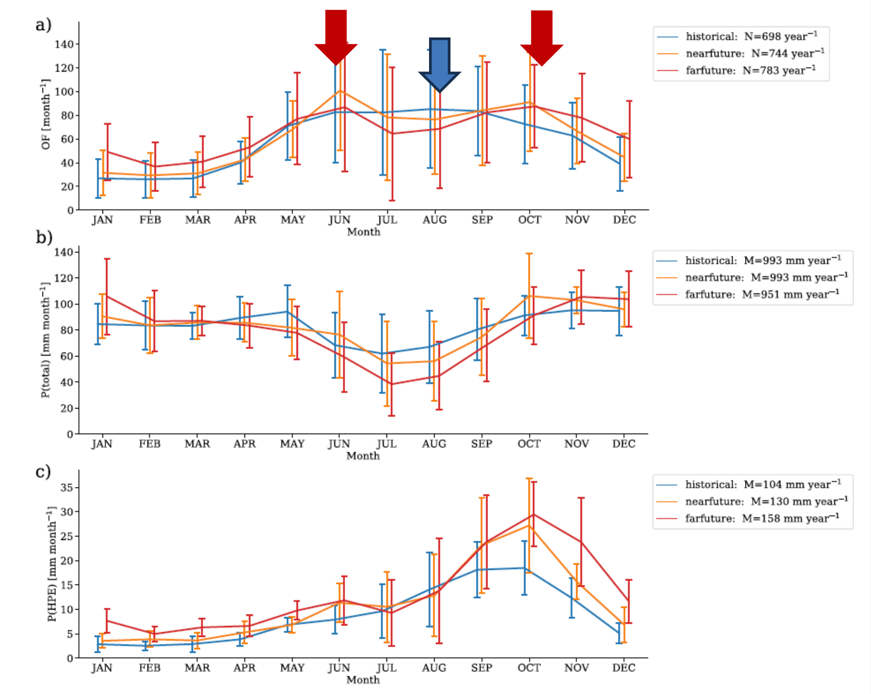
CORDEX Flagship Pilot Study Europe

Climate Change impact on the HPE by mean of a tracking algorithm





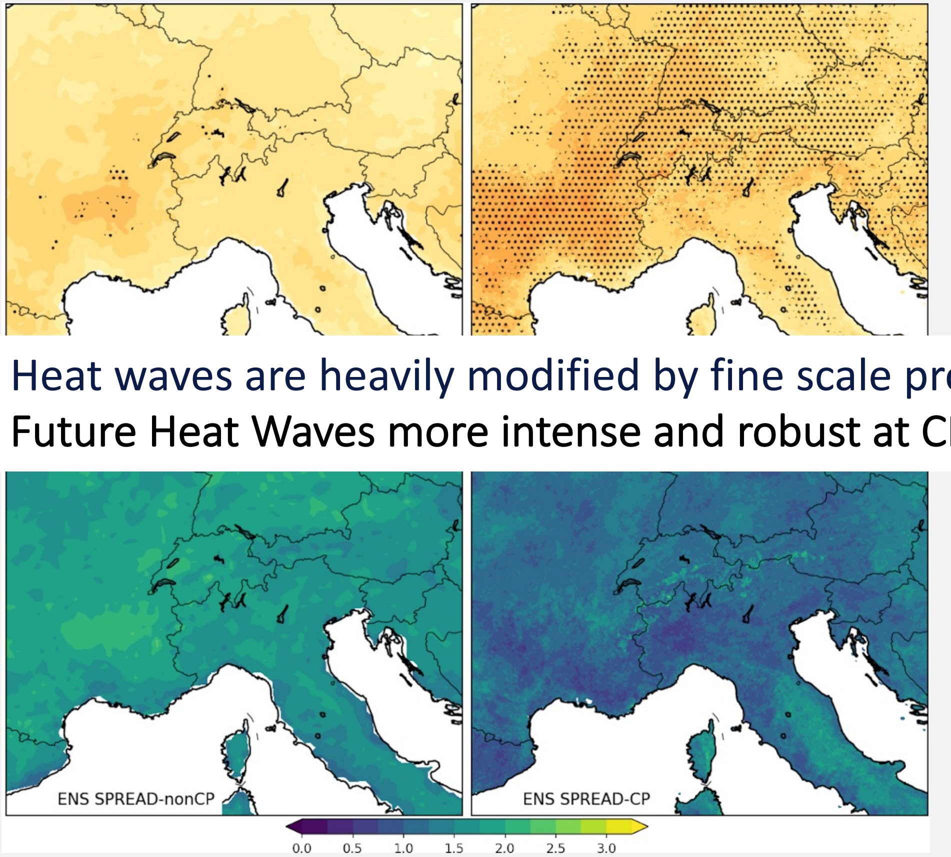
HPE property	Percent of change %
Duration	5
Distance traveled	15
Propagation speed	13
Geometrical volume	30
Mean P	3
HPVolume	35
Severity	21



Frequency of the HPE change distribution shape from unimodal to bimodal

Müller, S.K., Pichelli, E., Coppola, E., et al. (2023). The climate change response of alpine-mediterranean heavy precipitation events. *Climate Dynamics*, https://doi.org/10.1007/s00382-023-06901-9.

Heat Waves at CP-scale



- Heat waves are heavily modified by fine scale processes
- Future Heat Waves more intense and robust at CP-scale

Stipples: >= ¾ of models with statistically significant changes (t-test, alpha=0.05), **Tebaldi et al., 2011**

General considerations for *all* the HW metrics CCS

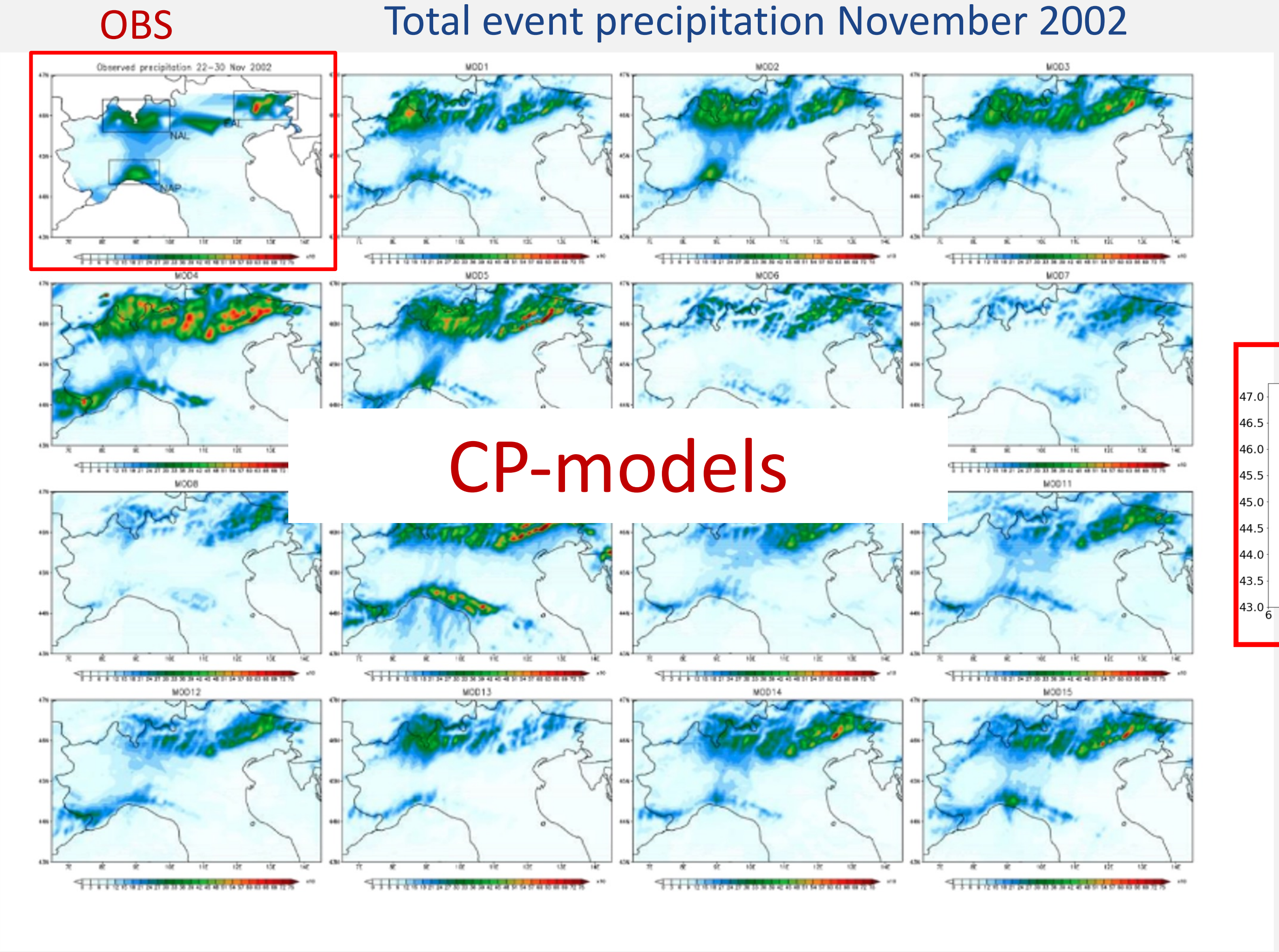
magnitude

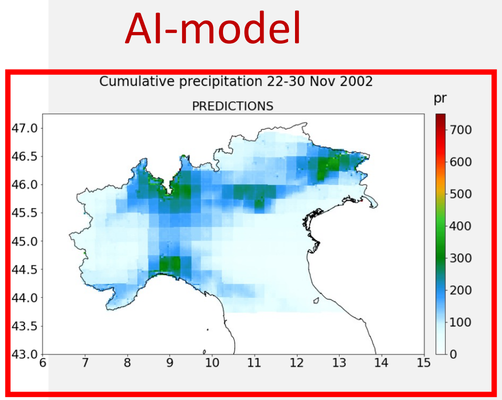
- CP ensemble is more robust than coarser resolution counterparts
- CP ensemble also characterized by reduced uncertainty (i.e., inter-model spread).

Sangelantoni, L., Sobolowski, S., Lorenz, T. *et al.* Investigating the representation of heatwaves from an ensemble of km-scale regional climate simulations within CORDEX-FPS convection. *Clim Dyn* (2023). https://doi.org/10.1007/s00382-023-06769-9

CP AI emulators

Total event precipitation November 2002





courtesy of Valentina Blasone

Contribution of the coordinated effort

CONSOLIDATING

- Better represent the spatial patterns and variability of precipitation at daily and hourly time scales
- Improve the representation of hourly frequency and intensity of precipitation events
- Improve representation of the summer diurnal cycle of precipitation both in terms of timing and intensity at the sub-daily scale
- Improve the representation of extreme events
- Refine and enhance the projected patterns of change of coarse resolution

ADDING

- Uncertainty reduction for present day climate and future climate projection
- Reduction in model uncertainty contribution to total uncertainty in summer precipitation
- CP further improve the precipitation distribution compared to RCM at all percentiles and the regions where the added value is found correspond to the region where the climate signal changes differenciate most
- Possibility to study the change of HPE properties: all properties are increasing proportionally to the global warming
- Heat waves modified at the CP scale: more intense and spatially robust in the future

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ADVANCE

- Can we trust these results?
- What would we need to add robustness to them
- What should we concentrate to work on

Future directions

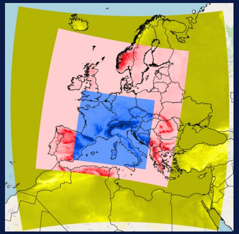
CPM Strategy

- ✓ Larger domains (e.g. continental)
- ✓ Longer, more transient simulations and/or using a GWL strategy
- ✓ Keep the multi-model ensemble approach
- ✓ Exploit the complementarity between dynamical and statistical approaches to explore uncertainties (AI emulators)
- ✓ Consider a world wide valid strategy for collaboration by mean of the CORDEX framework
- ✓ Overlapping domains – to build on communication between global and regional modelling communities
- ✓ Long-term target (not yet achievable) is to cover continental domains at km scale

Model components to be considered

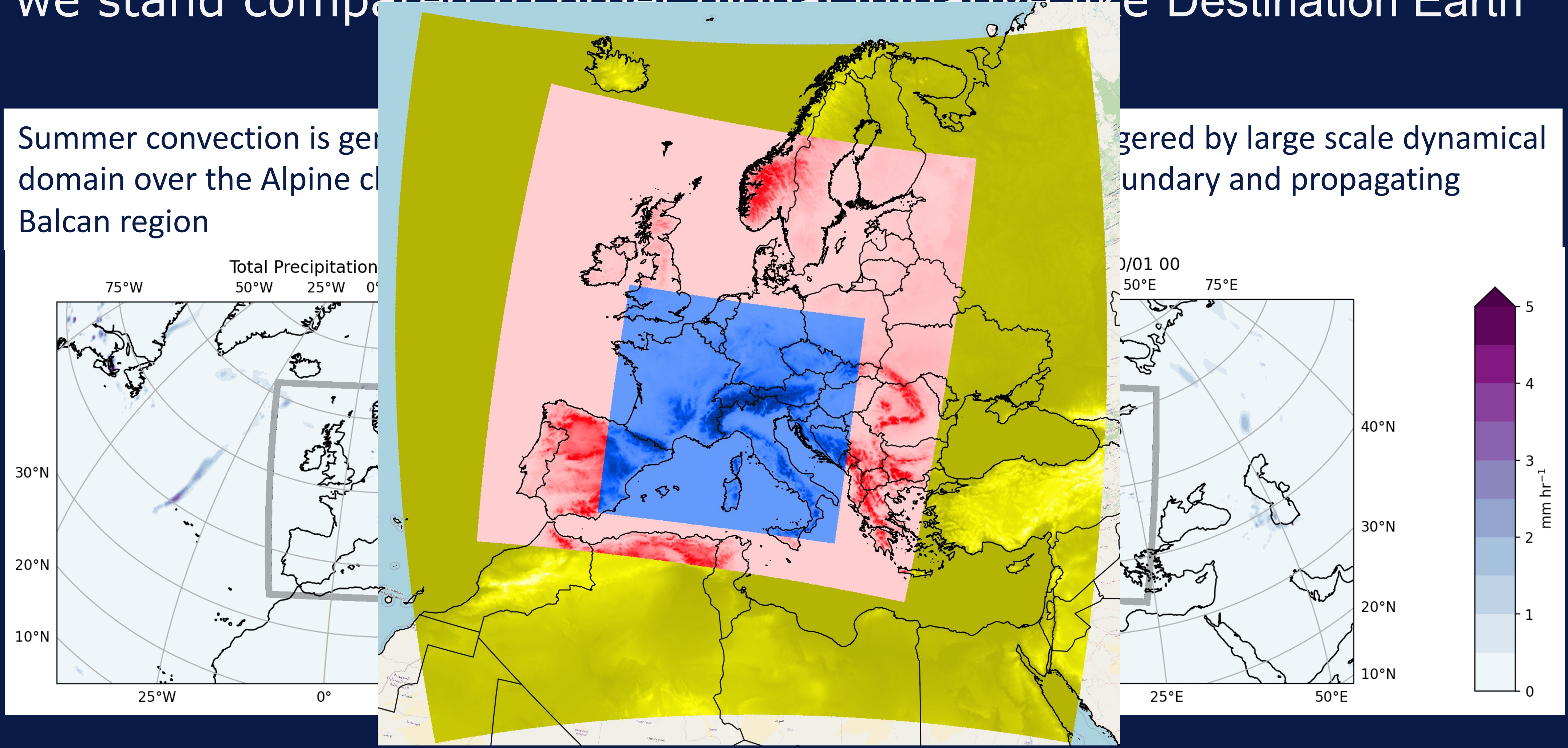
- ✓ Urban
- ✓ Vegetation - dynamic growth of roots and leaves
- ✓ Hydrology - groundwater, lateral flow, root zone soil moisture, irrigation
- ✓ Aerosols prescribed and evolving
- ✓ Sea ice
- ✓ Glaciers
- ✓ Land and water use scenarios (LUCAS like)
- ✓ Aerosol interactive
- ✓ Oceans
- ✓ Humans

The future



Where we want to go with the coordinated effort and where do we stand compared to other global initiative like Destination Earth

Summer convection is ger … gered by large scale dynamical
domain over the Alpine cl … undary and propagating
Balcan region



The coordinated Convection Permitting regional climate modelling development strategy over the CORDEX domains

Goals: addressing regional climate research challenges globally and in particular in the Global South for actionable climate change information.

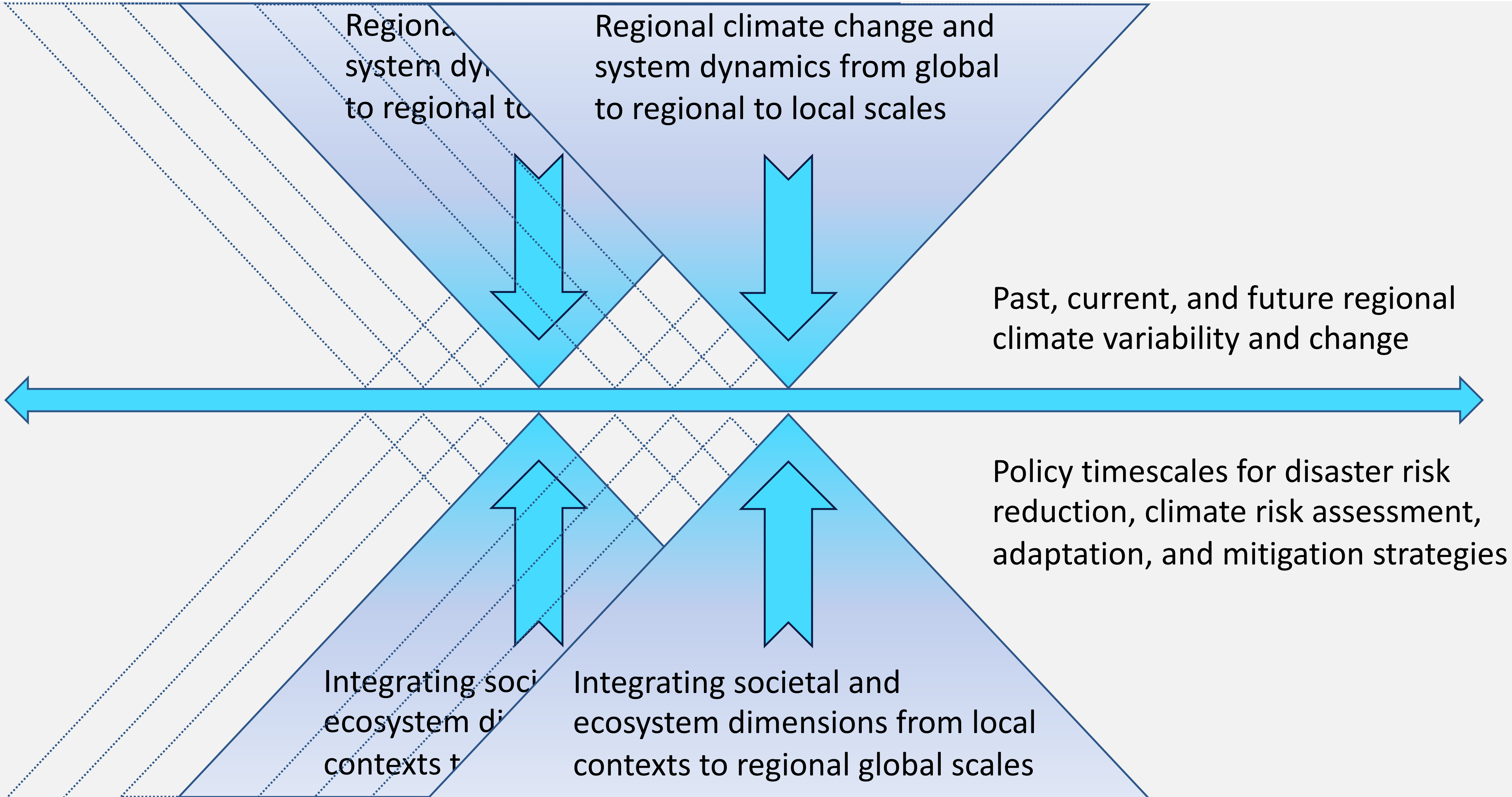
Example: Frontline research project in climate science as the development and optimization of *ultra-high resolution (~ 1 km) regional climate models (RCMs) as part of a hierarchy of modelling approaches for climate variability and change simulations*

Relevance: enanche understanding of *important physical processes*, such as tropical convection, but also relevant for the *provision through climate services of actionable climate change information for use in impact, vulnerability and adaptation assessments*

Added value1: Using a bottom-up approach *model development can often be tailored to the region* and to the most relevant research questions (interaction with local scientists)

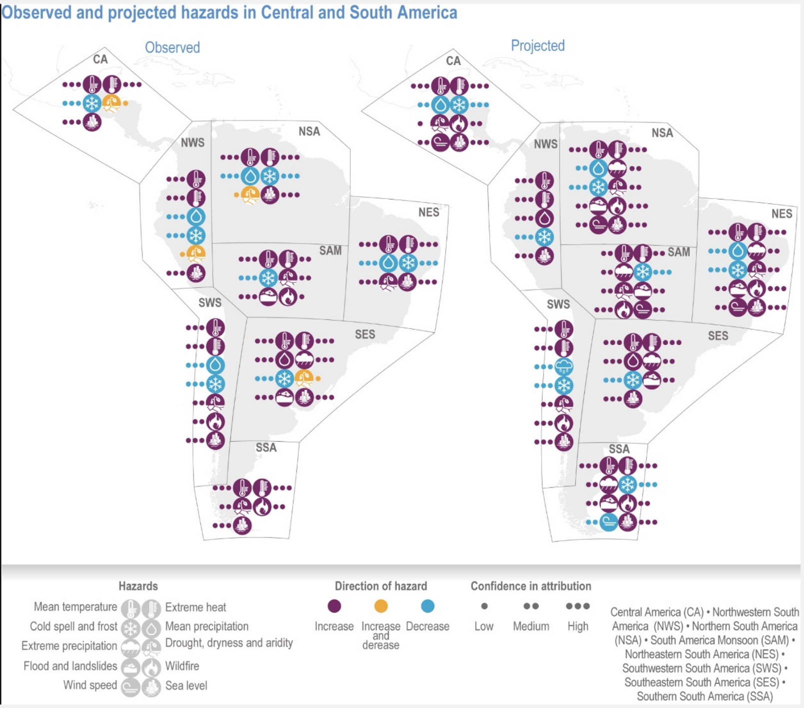
Added value 2: Removal of *data access barriers* that is one of the main reasons of *research development slowdown in the Global South*

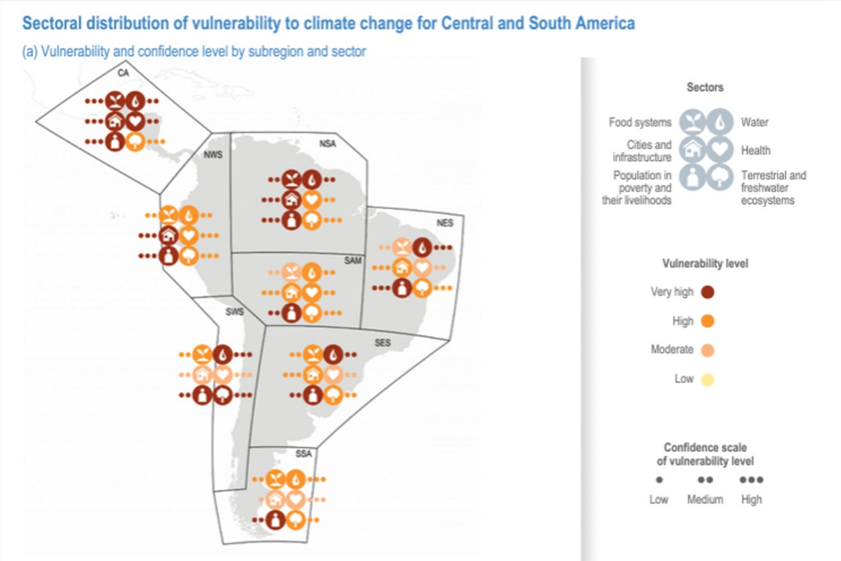
Research nexus for policy-relevant and actionable regional climate change information

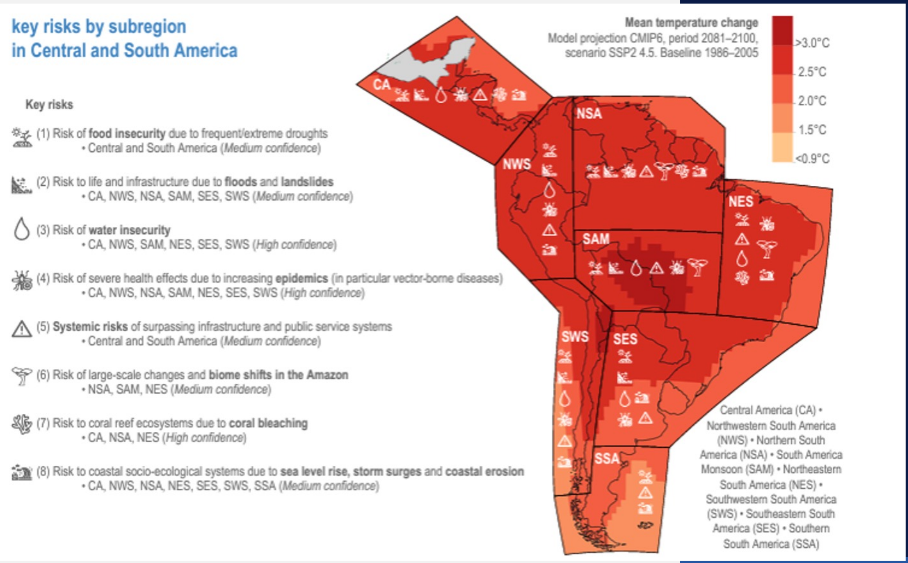


In practice.. IPCC AR6 handshake from regional climate to sectoral risk informing adaptation

observed and projected hazards | vulnerability and exposure | water sector climate risk assessment



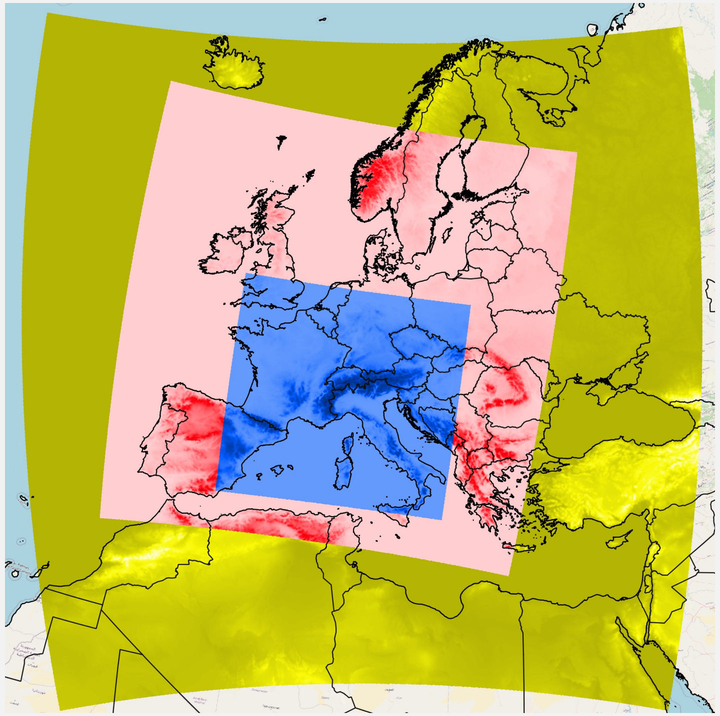




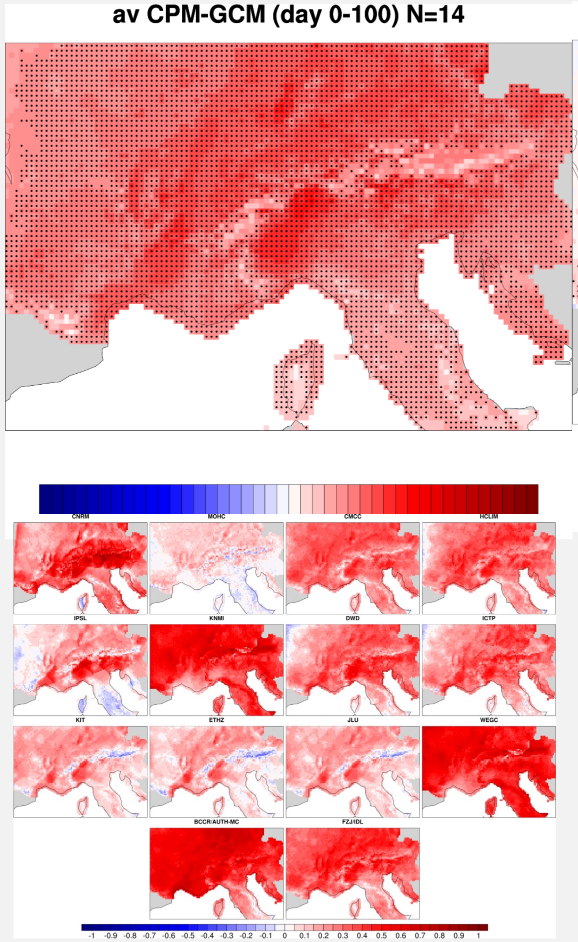
IPCC WGII Chapter 12

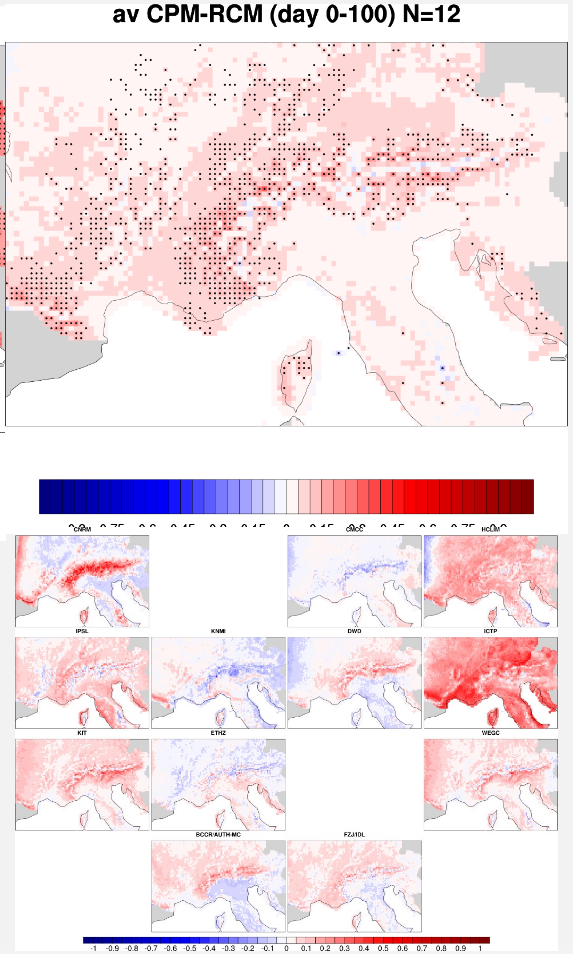
- Global to regional to local datasets on hazards
- National to subnational to local sectoral and human dimensions datasets
- *Data, knowledge and literature gaps mean this comprehensive sub-regional assessment was undertaken* ***only for Europe and Central and South America***

Thank you!



Added value for the precipitation distribution





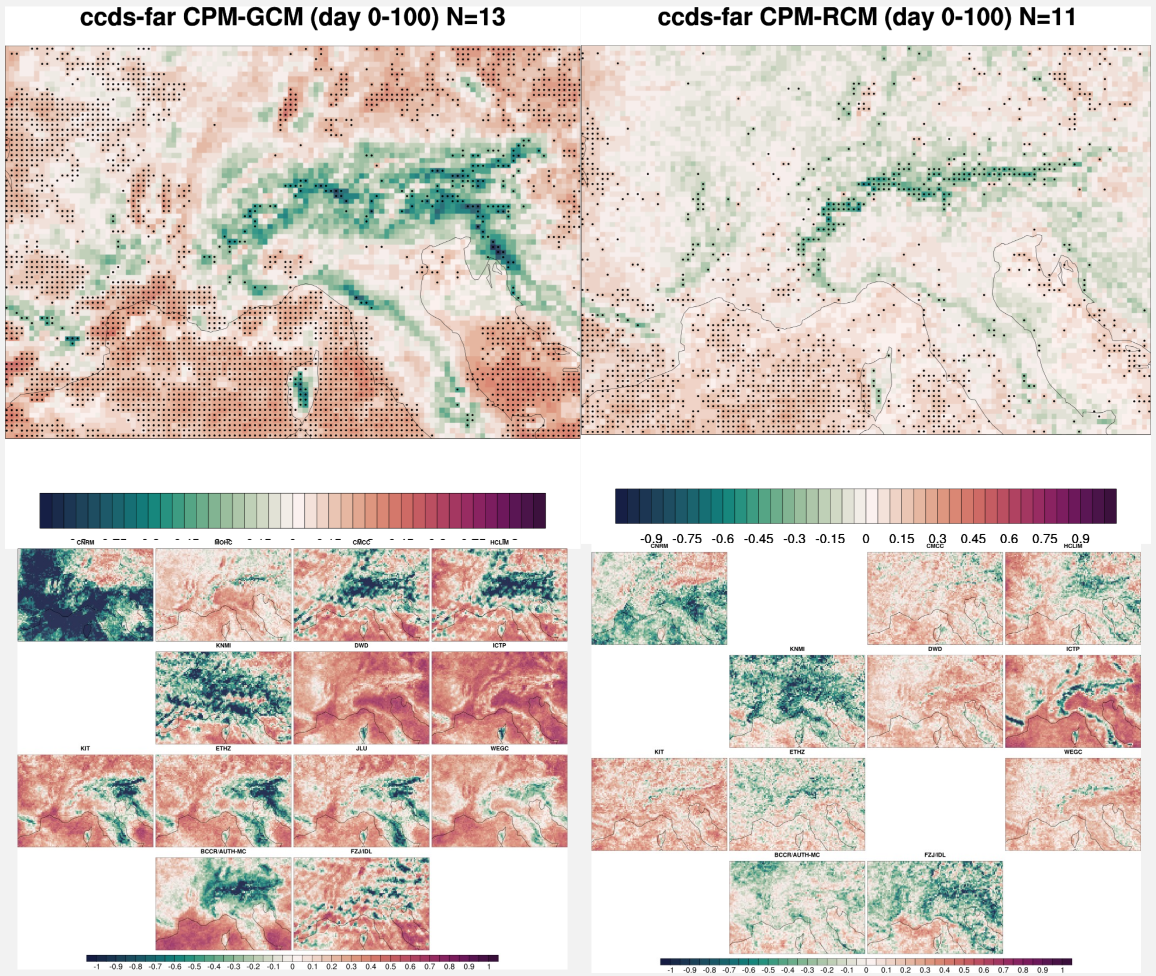
Positive values: AV in Hi-Res model
Negative values: Loss of AV in Hi-Res model

- shows 80% agreement in direction of signal

CPMs add value to the GCM and RCM precipitation distribution proportional to the resolution difference

Ciarlo` J, Coppola E, Pichelli E, Giorgi F, et al. (***in preparation***). Application of a new spatially distributed Added Value Index and Climate Change Downscaling Signal for Regional Climate Models to high-resolution convection permitting scale simulations.

Differences of the Climate change signal in the CP ensemble



Positive values: CC signal greater in Lo-Res model
Negative values: CC signal greater in Hi-Res model

- shows 80% agreement in direction of signal

CPMs amplify or reduce the climate change signal compared to the GCM and RCM proportionally to the resolution difference

Definitions of all variables and HPE properties

	Property	Definition
General Properties	pr_{HPE} $[mm\, h^{-1}]$	The precipitation field associated with a HPE
	N $[-]$	The total number of HPEs identified
	OF $[time^{-1}]$	Occurrence frequency, defined as the number of HPEs identified by unit time
	OFD $[time^{-1}\, area^{-1}]$	Occurrence frequency density, defined as the number of HPEs identified by unit time and unit area.
Eulerian Properties	P(HPE) $[mm]$	Accumulated heavy precipitation, given by the integration of pr_{HPE} for a given location
	P(HPE)$/P(total)$ [%]	Heavy precipitation fraction, with P(total) being total accumulated precipitation.
Lagrangian Properties	$mean(pr_{HPE})$ $[mm\, h^{-1}]$	The mean precipitation rate of a HPE
	$max(pr_{HPE})$ $[mm\, h^{-1}]$	The maximum precipitation rate of a HPE
	$P\tau(pr_{HPE}$ $[mm\, h^{-1}]$	The τ-th percentile of the precipitation field of a HPE
	D[h]	The *Duration* of a HPE. (A HPE occurring only for a single time step will be attributed with 1 h of duration.)
	$\overline{A}$ $[km^2]$	The *Mean Area* of a HPE, averaged over its *Duration*, D
	$Volume$ $[km^2 h]$	The geometrical volume of a HPE $:= D \times \overline{A}$
	$HPVolume$ $[m^3]$	Heavy precipitation volume of a HPE, given by the integration of its precipitation field
	d $[km]$	The *Distance Traveled* of a HPE, given by sum of distances measured between the HPE's centroids at each time step during its life time
	V $[km\, h^{-1}]$	The *Speed* of propagation of a HPE, given by the division of *Distance Traveled* by *Duration*: $\frac{d}{D}$.
	$Intensity$ $[mm\, h^{-1}]$	$\overline{((P75, P90, P99, max)}(pr_{HPE}))$, that is the mean of percentiles 75, 90 and 99 as well as of the maximum of pr_{HPE}
	$Severity$ $[m^3]$	$D \times \alpha \times mean(pr_{HPE}) \times \overline{A} \times \frac{V_{max}}{V}$ with $\alpha = \frac{1}{1000}$ and $V_{max} = 35\, ms^{-1}$