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

Erika Coppola,
the Abdus Salam International Centre for Theoretical Physics, Trieste
The FPS coordinated efforts

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”
The past

What we didn’t know before starting the coordinated FPSs
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

CORDEX Flagship Pilot Study ELVIC (Lake Victoria Basin)

Number of rainy events per year \((3h>0.125\text{mm/3h})\)

CORDEX Flagship Pilot Study
Third 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](https://doi.org/10.1007/s00382-022-06543-3)
What the coordinated effort contributed to the science advancement
CP ensemble seems to show less uncertainty in most indices and seasons. Smaller uncertainties for CPMs at the hourly scale in all regions.


CORDEX Flagship Pilot Study Europe

Fractional contribution of total precipitation

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

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

Fosser et al. Convection-permitting climate models offer more certain extreme rainfall projections. npj Climate and Atmospheric Science, submitted
### Added value for the precipitation distribution

<table>
<thead>
<tr>
<th>Positive values:</th>
<th>Negative values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV in Hi-Res model</td>
<td>Loss of AV in Hi-Res model</td>
</tr>
</tbody>
</table>

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

- shows 80% agreement in direction of signal

<table>
<thead>
<tr>
<th>Positive values:</th>
<th>Negative values:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC signal greater in Lo-Res model</td>
<td>CC signal greater in Hi-Res model</td>
</tr>
</tbody>
</table>

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

---

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

Frequency of the HPE change distribution shape from unimodal to bimodal

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

<table>
<thead>
<tr>
<th>HPE property</th>
<th>Percent of change %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>5</td>
</tr>
<tr>
<td>Distance traveled</td>
<td>15</td>
</tr>
<tr>
<td>Propagation speed</td>
<td>13</td>
</tr>
<tr>
<td>Geometric volume</td>
<td>30</td>
</tr>
<tr>
<td>Mean P</td>
<td>3</td>
</tr>
<tr>
<td>HP Volume</td>
<td>35</td>
</tr>
<tr>
<td>Severity</td>
<td>21</td>
</tr>
</tbody>
</table>

Frequency of the HPE change distribution shape from unimodal to bimodal

Heat Waves 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:

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

CP AI emulators

OBS

Total event precipitation November 2002

CP-models

AI-model

courtesy of Valentina Blasone
Contribution of the coordinated effort

- 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.
- 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 regions where the climate signal changes differentiate 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.
- 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
Where we want to go with the coordinated effort and where do we stand compared to other global initiatives like Destination Earth.

Summer convection is generated inside the domain over the Alpine chain and over the Balcan region. Fall frontal precipitation is triggered by large scale dynamical forcing entering from the boundary and propagating.
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**: enhance 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 value 1**: 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

- Past, current, and future regional climate variability and change
- Policy timescales for disaster risk reduction, climate risk assessment, adaptation, and mitigation strategies
- Integrating societal and ecosystem dimensions from local contexts to regional global scales
- Regional climate change and system dynamics from global to regional to local scales
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

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
Priorities and challenges to address

Workshop on Climate Information for Risk Assessment and Regional Adaptation - from Global to Local Scales (5-9 June 2023)

Developing a community perspective

• Data gaps (esp. observational datasets, long term)
• **Enhance the availability of existing data**, how to use, open access
• Downscaling, sub-national and local scales
• Research and knowledge gaps (e.g. urban scale, wildfire, ENSO and natural variability, extremes, detection and attribution, biodiversity, crop modeling, tropical cyclones, process understanding, methods..)
• Socio-economic data availability, access, integration incl. across scales
• Monitoring and evaluation of adaptation, metrics, systems approach
• Barriers (e.g. political instability, transboundary aspects)
• Capacity and human resources
• **Funding mobilisation**
• Stakeholder engagement, co-production, local and indigenous knowledge
• Climate education and literacy
• ...

...
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
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

<table>
<thead>
<tr>
<th>Property</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{r_{\text{HPE}}}[\text{mm h}^{-1}]$</td>
<td>The precipitation field associated with a HPE</td>
</tr>
<tr>
<td>$N[-]$</td>
<td>The total number of HPEs identified</td>
</tr>
<tr>
<td>$\text{OF}[\text{time}^{-1}]$</td>
<td>Occurrence frequency, defined as the number of HPEs identified by unit time</td>
</tr>
<tr>
<td>$\text{OFD}[\text{time}^{-1} \text{ area}^{-1}]$</td>
<td>Occurrence frequency density, defined as the number of HPEs identified by unit time and unit area.</td>
</tr>
<tr>
<td>$P(\text{HPE})[\text{mm}]$</td>
<td>Accumulated heavy precipitation, given by the integration of $p_{r_{\text{HPE}}}$ for a given location</td>
</tr>
<tr>
<td>$P(\text{HPE})/P(\text{total})[%]$</td>
<td>Heavy precipitation fraction, with $P(\text{total})$ being total accumulated precipitation.</td>
</tr>
<tr>
<td>$\text{mean}(p_{r_{\text{HPE}}})[\text{mm h}^{-1}]$</td>
<td>The mean precipitation rate of a HPE</td>
</tr>
<tr>
<td>$\text{max}(p_{r_{\text{HPE}}})[\text{mm h}^{-1}]$</td>
<td>The maximum precipitation rate of a HPE</td>
</tr>
<tr>
<td>$P_r(p_{r_{\text{HPE}}})[\text{mm h}^{-1}]$</td>
<td>The $r$-th percentile of the precipitation field of a HPE</td>
</tr>
<tr>
<td>$D[\text{h}]$</td>
<td>The Duration of a HPE. (A HPE occurring only for a single time step will be attributed with 1 h of duration.)</td>
</tr>
<tr>
<td>$\bar{A}[\text{km}^2]$</td>
<td>The Mean Area of a HPE, averaged over its Duration, $D$</td>
</tr>
<tr>
<td>$\text{Volume}[\text{km}^2 \text{h}]$</td>
<td>The geometrical volume of a HPE: $D \times \bar{A}$</td>
</tr>
<tr>
<td>$\text{HPVolume}[\text{m}^3]$</td>
<td>Heavy precipitation volume of a HPE, given by the integration of its precipitation field</td>
</tr>
<tr>
<td>$d[\text{km}]$</td>
<td>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</td>
</tr>
<tr>
<td>$V[\text{km h}^{-1}]$</td>
<td>The Speed of propagation of a HPE, given by the division of Distance Traveled by Duration: $\frac{d}{D}$</td>
</tr>
<tr>
<td>$\text{Intensity}[\text{mm h}^{-1}]$</td>
<td>The mean of percentiles 75, 90 and 99 as well as of the maximum of $p_{r_{\text{HPE}}}$</td>
</tr>
<tr>
<td>$\text{Severity}[\text{m}^3]$</td>
<td>$D \times a \times \text{mean}(p_{r_{\text{HPE}}}) \times \bar{A} \times \frac{V}{D}$ with $a = \frac{1}{1000}$ and $V_{max} = 35 \text{ m s}^{-1}$</td>
</tr>
</tbody>
</table>