Final report for Flagship Pilot Study - Southeastern South America (SESA)

Status and progress during the year including scientific highlights, end to end perspective and participants engaged in the project

The Flagship Pilot Study in Southeastern South America (FPS-SESA) initiative was endorsed by CORDEX to focus on the study of extreme precipitation events over SESA. This was done through coordinated science and application of regional climate downscaling models, based on inter-institutional collaboration and networking, following the CORDEX vision. The objectives of the FPS-SESA were to: 1) study multi-scale processes and interactions that result in extreme precipitation events; 2) develop actionable climate information based on statistical and dynamical downscaling models, in co-production with the impact modelers and user community.

To meet these objectives in FPS-SESA the work was organized in two phases. During the first phase, a targeted experiment was designed considering a single season (from October 2009 to March 2010) with a record number of extreme precipitation events within SESA. An ensemble of RCMs and ESD methods were set up to simulate these extreme precipitation events over the area. RCM simulations were conducted at two configurations: at 20 km resolution with the convective processes parameterized (non-CP) and at 4 km resolution with the convective processes resolved explicitly (CP). Also, a suite of ESD models based on different techniques contributed to the ensemble. This first experiment intercompared the downscaling approaches, identifying their benefits and weaknesses as well as setting the basis for an engaged downscaling community and inter-institutional networking. This intercomparison revealed that no single model performed best over all aspects evaluated, evidencing the need for multi-model simulations to better sample the uncertainties. The reproduction of the sequence of precipitation events, their intensity and timing suggested that FPS-SESA simulations based on both RCM and ESD yield promising results. However, errors in the location of the extreme events were identified as a major issue mainly due to discrepancies in the synoptic patterns, which led to discrepancies in the moisture flux convergence, which is an essential footprint of deep convection. Nevertheless, in general, CP simulations captured the observed spatial distribution of maximum precipitation at smaller scales better than non-CP simulations. Apart from the spatial structure of maximum precipitation, CP simulations showed added value in capturing the diversity of diurnal cycles observed over the region when compared with non-CP simulations. They also corrected the shift in daily peak precipitation shown by non-CP simulations, obtaining a better agreement with local observations.

FPS-SESA Phase 1 simulations allowed for a first insight into the capability of CPRCM and ESD simulations in reproducing precipitation extremes over SESA. However, some aspects of precipitation extremes remained to be comprehensively addressed due to the short simulation period used. In addition, from the dialog with impact modelers, the need for new RCM and/or ESD longer term simulations also became evident to take into account important aspects for impact modeling such as the interannual variability. A larger spatial domain and additional surface output variables needed to be considered as well. In this context, a second Phase of the FPS-SESA was envisioned with a focus on the evaluation of the impacts of heavy precipitation events on the Uruguay River streamflow and on crop yields in Southern Brazil. The FPS-SESA Phase 2 contemplated a new experimental setup engaging sectoral impact modelers. The spatial domain was extended to include the full hydrological catchment and crop areas to be analyzed. The simulation period has also been extended to cover all growing seasons and not only the purely meteorological rainy season. For this new agreed domain, 3-year long CPRCM and ESD simulations were conducted covering the period June 2018 to July 2021. Seven CP modeling systems based on WRF, RegCM and ETA RCMs contributed, as well as different ESD models based on convolutional neural networks. These simulations were used to drive the Variable Infiltration Capacity (VIC) hydrologic model to simulate the streamflow of the Uruguay river and the Agricultural Crop Simulator (AgS) to reproduce soybean and maize yields over Southern Brazil. All simulations of the second phase are completed and different analyses are in progress according to different scientific aims. They are mainly focused on: (a) the assessment of the uncertainty sources at the sub-daily time scale when addressing the evaluation of convection-permitting simulations (Raffaele et al 2023); (b)

the analysis of wind extreme events over the region and their synoptic drivers as depicted by the CPRCM simulations; (c) the study of the ability of CPRCM for capturing the urban-rural contrasts over selected cities in South America (Milovac et al. 2023; Solman et al. 2023); (d) sensitivity studies of machine learning-based models to different loss functions to model precipitation, configurations and architecture as well as their extrapolation capability in a climate change context (Bettolli et al. 2024); (e) to evaluate the response of the streamflow and yield to the intensity, duration and location of extreme hydroclimatic events (extreme precipitation in a generally dry period) but also how uncertainties propagate through the model chain (Vianna-Cuadra et al 2025). Each of the topics is being comprehensively addressed in separate papers.

From this interdisciplinary perspective, the project assembled different scientific goals and challenges for the regional climate modeling community in South America. These can be summarized as follows:

- to evaluate the sensitivity of simulations in a multi-model and multi-physics CPRCM ensemble in reproducing different precipitation features over Southeastern South America.
- to better understand processes and phenomena relevant for regional climate change.
- to develop new ESD models based on more sophisticated machine learning techniques
- to contribute to the identification of the respective limits and merits of both approaches that may have potential implications for long-term climate change simulations and in the development of novel strategies such as the emulation of RCM using machine learning techniques.
- to establish an engaged downscaling and impact modeling community which provided the foundation for coordinated experiments.

The inter-institutional collaboration and networking, which facilitated addressing different research needs from computation resources and storage capacities to knowledge sharing, were key elements for the success of this initiative.

Summary of each workshop/activity held during the year

Title, date, short description, location, website, links	Responsible person/-s	Funder
FPS-SESA: Follow-up meeting, University of Sao Paulo, Sao Paulo, Brazil, 21-22 August 2024	Maria Laura Bettolli	CORDEX
Mini-Course “Statistical downscaling techniques” 25-26 March 2024 - CAPES-PRINT DCA-IAG-University of Sao Paulo, Brazil (29 participants in person+online)	Maria Laura Bettolli	CAPES-PRINT DCA-IAG-University of Sao Paulo, Brazil
FPS-SESA Side Event at the ICRC2023: In this FPS-SESA event, the South American CORDEX community was invited to participate in order to discuss the prospects for future collaborative research and coordinated activities for the SAM domain. CORDEX-ICRC-2023, Trieste, Italy	Bettolli, Maria Laura	WCRO-CORDEX-ICTP

Related publications during the year

Title, journal and link to publication	Author/-s	Date
On the ability of convection permitting models for capturing the urban- rural contrasts over selected cities in South America. WCRP Open Conference,23-27 October 2023, Kigali, Rwanda	Solman S, Milovac J, Fernandez J, da Rocha RP, Coppola E, Raffaele F, Blazquez J, Bettolli ML	23-27 Oct 2023

Daily cycle of the urban-rural contrast in South America derived from the FPS-SESA multi-model, convection-permitting RCM. VII Convection-Permitting Climate Modelling Workshop, Aug 29 - 31, 2023, Bergen, Norway.	Milovac J, Solman S Fernandez J, da Rocha RP, Coppola E, Raffaele F, Blazquez J, Prein A, Bettolli ML (2023).	29-31 Aug 2023
Modeling local precipitation in Southern South America using Deep Learning: A sensitivity analysis on the choice of input features and loss function in the climate change signal. EGU24, 14-19 April 2024, Vienna, Austria. https://doi.org/10.5194/egusphere-egu24-786	Bettolli ML, Baño-Medina J, Olmo M, Balmaceda-Huarte R.	14-19 April 2024
Convection-Permitting simulations over South America: a look at the uncertainty sources at the sub-daily time scale. EGU24, 14-19 April 2024, Vienna, Austria. https://doi.org/10.5194/egusphere-egu24-9342	Raffaele F, Coppola E, Silva L, Bettolli ML, Blazquez J, Fernandez J, Milovac J, Porfirio da Rocha R, Solman S.	14-19 April 2024
How well do deep learning-based downscaling and convection permitting simulations represent temperature and precipitation individual and compound daily extremes over Southeastern South America? VIII Convection Permitting Climate Modeling Workshop, September 3-6, 2024, Fort Collins, USA.	Bettolli ML, Olmo M, Balmaceda-Huarte R, Baño Medina J	3-6 Sep 2024
High-resolution deep-learning and dynamical climate downscaling for impact modeling in southeast South America. Bettolli ML, da Rocha RP, Milovac J, Fernandez J, Balmaceda-Huarte R, Baño-Medina J, Blázquez J, Carneiro Rodrigues D, Chou SC, Coppola E, da Silva ML, Doyle M, Gutiérrez Llorente JM, Olmo M, Prein AF, Raffaele F, Solman S, Vianna Cuadra S. Earth Systems and Environment.	Bettolli ML, da Rocha RP, Milovac J, Fernandez J, Balmaceda-Huarte R, Baño-Medina J, Blázquez J, Carneiro Rodrigues D, Chou SC, Coppola E, da Silva ML, Doyle M, Gutiérrez Llorente JM, Olmo M, Prein AF, Raffaele F, Solman S, Vianna Cuadra S. Earth	Under review November 2024
Application of high-resolution Regional Climate Model simulations for crop yield estimation in southern Brazil. AgriEngineering.	Santiago Vianna Cuadra, Monique Pires Gravina de Oliveira, Daniel de Castro Victoria, Fabiani Denise Bender, Maria Laura Bettolli, Silvina Solman, Rosmeri da Rocha, Jesús Fernández, Josipa Milovac, Erika Coppola, Moira Doyle	Under review January 2025

Planned activities for next year

Additional relevant information

The simulations conducted in the framework of the FPS-SESA initiative will be available for the community through the THREDDS catalog at https://data.meteo.unican.es/thredds/catalog/CORDEX/fps/sesa/catalog.html which allows raw data file downloads and also remote OpenDAP access to user-defined areas and/or time periods.

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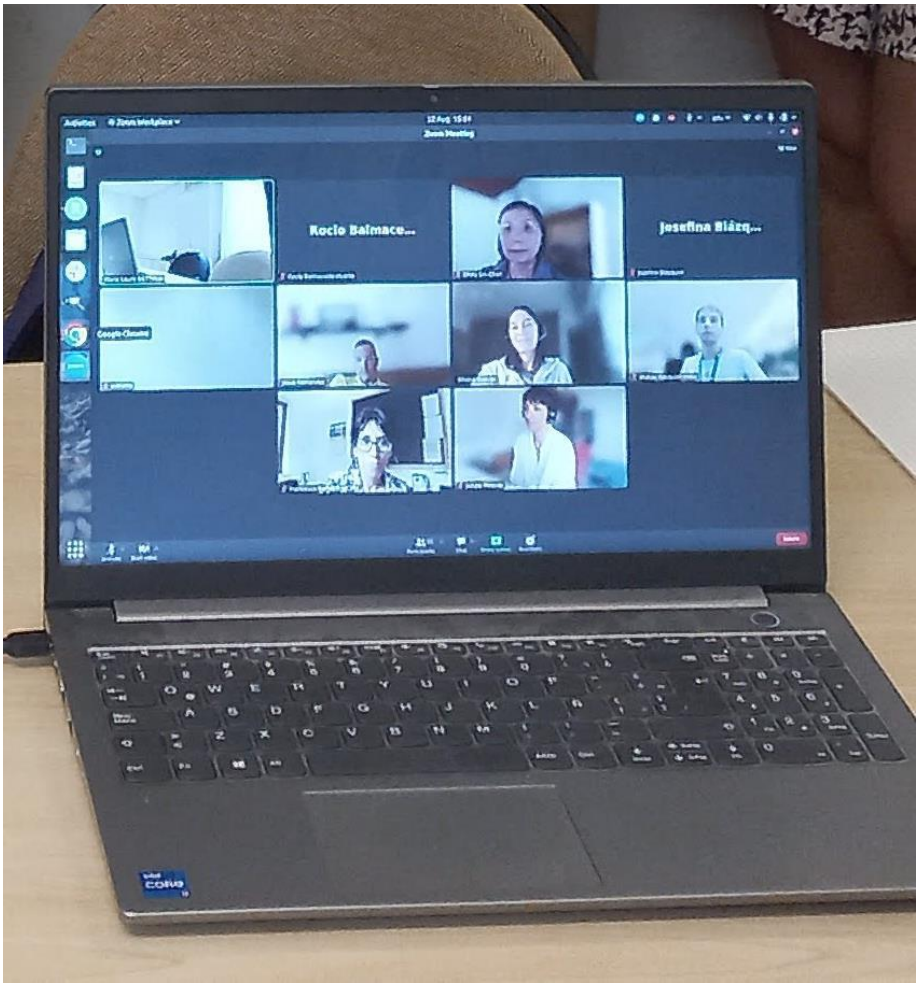
The report is due the 15th of February each year and should be sent to ipoc@cordex.org.

Pictures of the FPS-SESA: Follow-up meeting, University of Sao Paulo, Sao Paulo, Brazil, 21-22 August 2024


Rocio Balmace...
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