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Toward a regional-scale seasonal climate prediction system over the Mediterranean basin: evaluation and comparison of RegCM- and WRF-based dynamical downscaling approaches

L. Sangelantoni [1,2], V. Mazzarella[1], A. Ricchi[1,2], R. Ferretti [1,2] and G. Redaelli [1,2]

[1] CETEMPS – Center of Excellence of Physical and Chemical Sciences Department of L'Aquila University
[2] Department of Physical and Chemical Sciences of University of L'Aquila

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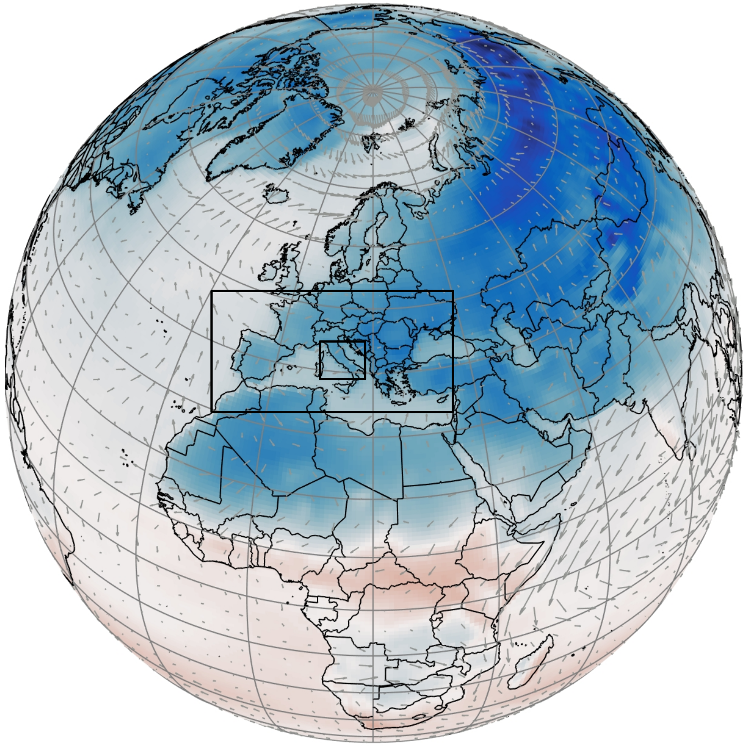
Introduction and Research questions

This study investigates potential added value of dynamical downscaling in the context of seasonal climate predictions. Simulations of winter seasons of a 21-year period have been performed with RegCM4.1 and WRF3.9.1 Regional Climate Models (RCMs), driven and compared to the global-scale NCEP Climate Forecast System (CFS) version 2.

Two nested simulations domains are considered:

- D1 centered on Northern Mediterranean basin.
- D2 centered on Central Italy.

On these areas global-scale seasonal forecasting systems traditionally provide only elusive representation of the year to year seasonal fluctuation.



Research questions

- If and to what extent nested simulations improve driving global-scale CFS forecasts in terms of climate variable physical values and anomalies inter-annual variability predictability.
- At what extent the large scale forcing from the driving global-scale CFS affects the inter-annual variability reproduced in the two RCMs.
- Potential further improvement deriving from the further nesting within the RegCM and WRF RCMs.

Modeling and methodological approach

Fig. 1. Geographical domain of the nested RegCM and WRF simulations.

- 21-year winter season (1982-2002) re-forecasts performed by the NCEP CFSv2 General Circulation Model, 100 km resolution, 8-member lagged ensemble, provide initial and boundary conditions for the two nested models RegCM and WRF.
- RegCM and WRF perform a first downscaling at 60 km over a domain centered over Northern Mediterranean basin. A second downscaling is performed over Central Italy at 12 km resolution.
- Surface variables (T2m and precipitation, mean sea level pressure) and geopotential height at different pressure level will be assessed in the global-scale system and in the two nested simulations set.
- Reference product: ECMWF ERA-5.
- Analyses consider deterministic metrics i.e., considering ensemble mean skills (e.g., Anomaly Correlation Coefficient (ACC)) and probabilistic metrics which consider distributional properties of the ensemble members (e.g., CRPS, slide 6).

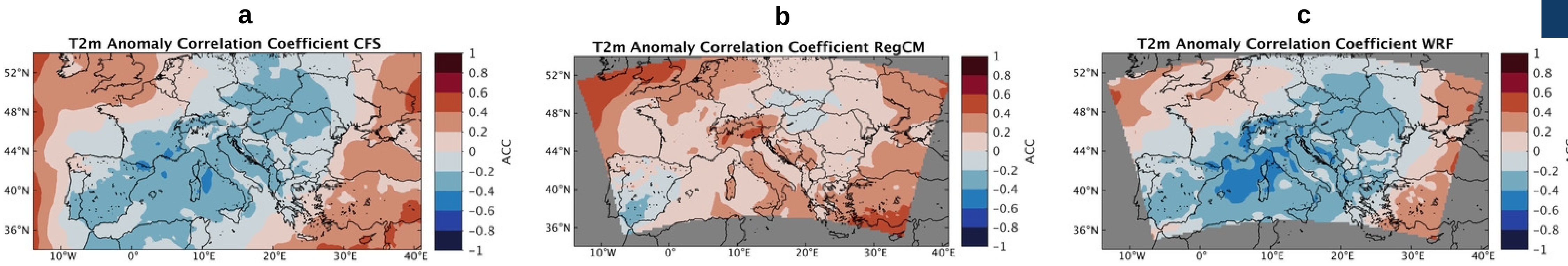


Fig. 2. Temporal correlation of the mean winter temperature anomaly during the climatological period (1982-2002). Driving 100 km resolution CFS (a), 60 km resolution RegCM (b) and WRF (c) simulations.

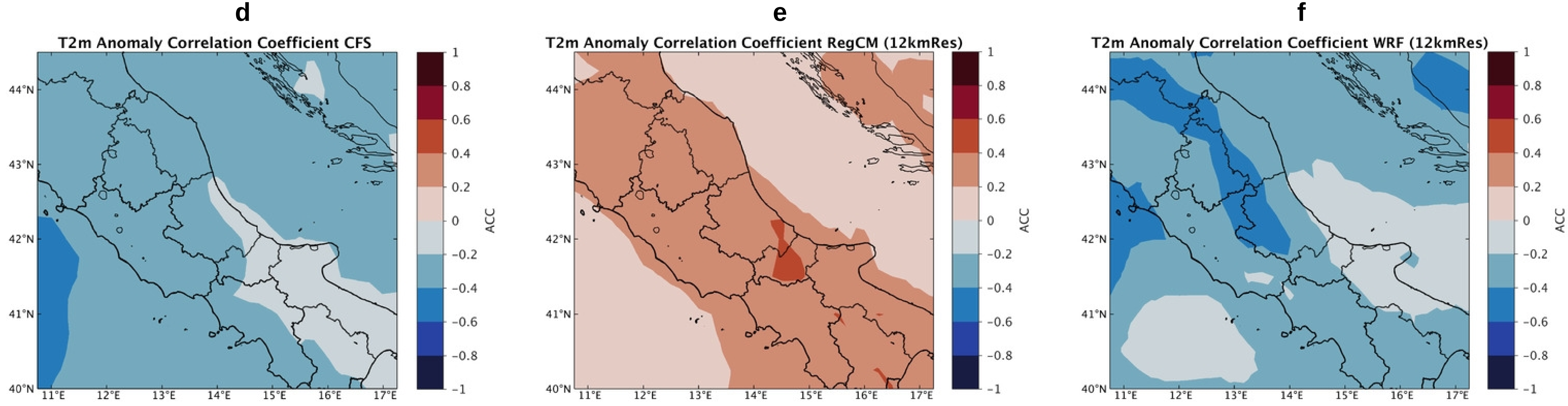


Fig. 3. As in Fig. 2 but considering the second nested simulations of from RegCM (e) and WRF (f), both at 12 km resolution.

The western-central Mediterranean basin is characterized by negative correlation produced by the driving CFS model. It indicates a substantially poor representation of the year-to-year variability of winter temperature anomalies. In this context, RegCM shifts to positive correlation values, especially over Italian peninsula (ACC ~0.4). Conversely, WRF model inherited spatial pattern and negative ACC values from the CFS model, with no improvement compared to the driving model. What observed over the D1 is confirmed also in the second nesting, where the higher resolution does not improve anomaly inter-annual variability reproduction.

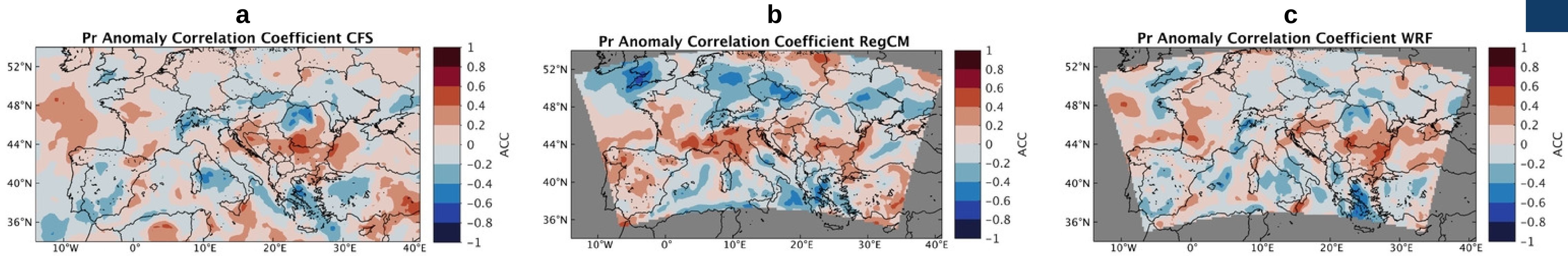


Fig. 4. Temporal correlation of the winter precipitation anomaly during the climatological period (1982-2002). Driving global-scale model 100 km res. CFS (a), 60 km RegCM (b) and WRF (c) simulations.

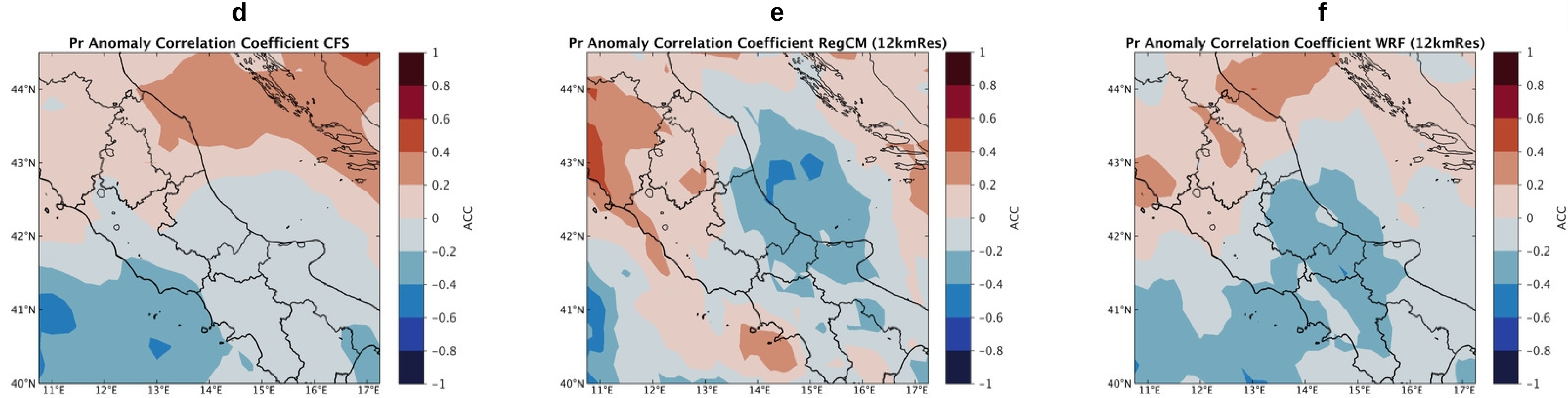


Fig. 5. As in Fig. 4 but considering the second nested simulations of from RegCM (e) and WRF (f), both at 12 km resolution.

Differently from the temperature, none of the two downscaling in both domains provide improvement in terms of precipitation anomaly inter-annual variability. An exception is provided by the RegCM where, over central-northern Italy, consistently increase the ACC up to ~0.6. The second downscaling over the D2 does not improve ACC in both the RegCM and WRF models. As seen for the temperature ACC WRF more coherently reproduces ACC spatial patterns characterizing the driving CFS model.

Continuous Ranked Probability Score

The continuous ranked probability score expresses distance between the PDF of the forecast ensemble ρ(x) and the observed occurred value x_a (Hersbach, 2000).

$$CRPS = CRPS(P, x_a) = \int_{-\infty}^{\infty} [P(x) - P_a(x)]^2 dx ;$$

$$P(x) = \int_{-\infty}^{x} \rho(y) dy ;$$

$$P_a(x) = H(x - x_a)$$

$$\text{Where } H(x) = \begin{cases} 0 & \text{for } x < 0 \\ 1 & \text{for } x \geq 0 \end{cases}$$

CRPS can be decomposed into a "reliability" and a "potential" components.

- The reliability component tests if, on average, the frequency of the observed value occurrence is forecasted with the same probability. **Perfect forecast, reliability = 0.**
- The "potential" component is sensitive to the average spread of the ensemble. **The narrower the ensemble spread the lower will be the potential component value.**

  In this study the CRPS has been computed considering the seasonal anomalies instead of the mean physical value of the variables (t2m and pr).

Continuous Ranked Probability Score

$$\overline{CRPS} = \overline{CRPS}_{reliability} + CRPS_{potential}$$

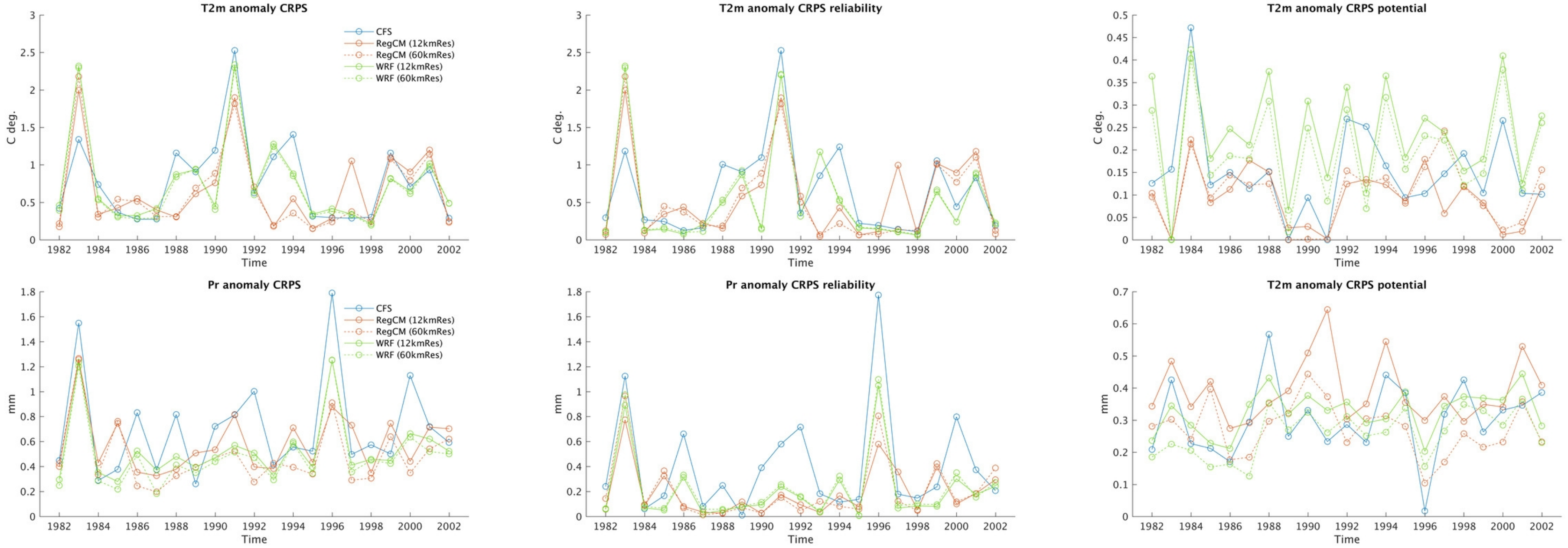


Fig. 6. Annual spatial-averaged over the D2 CRPS and related components (reliability and potential) for temperature (upper panels) and precipitation (bottom panels).

Temperature (C deg.)	CFS	RegCM 12 km | 60 km	WRF 12 km | 60 km
CRPS	0.80	0.66 | 0.62	0.76 | 0.73
CRPS_pot.	0.15	0.09 | 0.1	0.23 | 0.20
CRPS_reli.	0.64	0.57 | 0.53	0.53 | 0.53
Precipitation (mm)			
CRPS	0.70	0.58 | 0.47	0.53 | 0.48
CRPS_pot.	0.30	0.30 | 0.27	0.32 | 0.25
CRPS_reli.	0.40	0.19 | 0.20	0.20 | 0.22

Table 1. Temperature and precipitation CRPS with related decomposition metrics (potential and reliability) over the D2 for the three forecasting systems considered.

Preliminary considerations

- Driving CFS global-scale forecasting system presents poor skill in terms of seasonal inter-annual variability in both the considered domains and both variables considered.
- In this context, considering deterministic metrics, i.e., only ensemble mean of the forecasting systems, RegCM outperforms WRF model. This is both in terms of mean bias and inter-annual variability represented by the anomaly correlation coefficient, especially for the temperature.
- The second nesting (12 km resolution simulations) improves the physical representation of the mean seasonal values for both temperature and precipitation mainly for the RegCM model.
- Noteworthy is that inter-annual variability representation does not benefit of the further downscaling in both RegCM and WRF models.
- According probabilistic metric (CRPS) both the higher resolution forecasting systems generally outperform the driving global scale CFS (excluding the temperature potential CRPS component for the WRF model).
- However, the higher resolution ensemble (12 km) does not outperform the lower resolution ensemble (60 km). This can be seen seen in Table 1 where slightly lower values resulted for the 60 km resolution ensemble, indicating slightly higher skills respect to the 12 km resolution ensemble forecast.