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Prediction of high and low-streamflow using sub-seasonal-to-seasonal probabilistic forecasting

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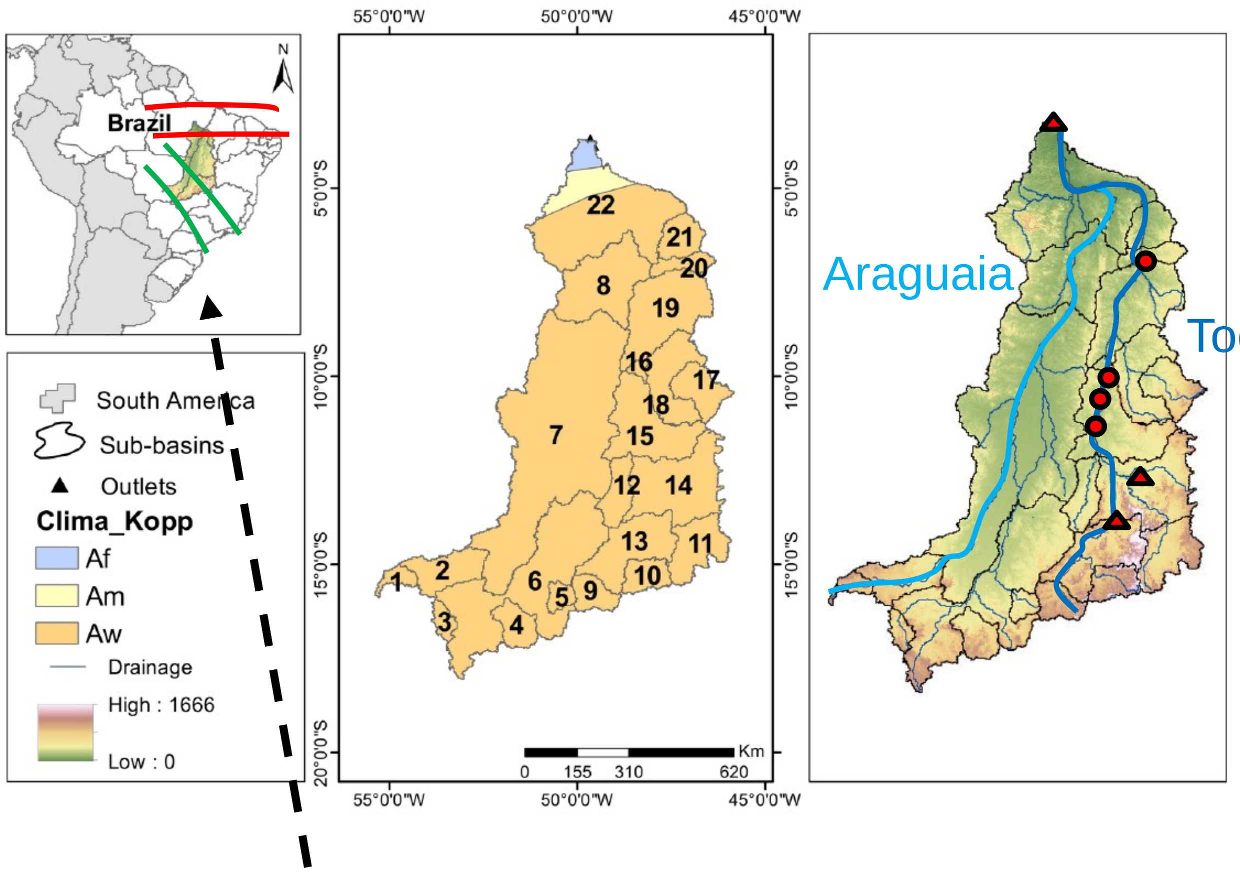
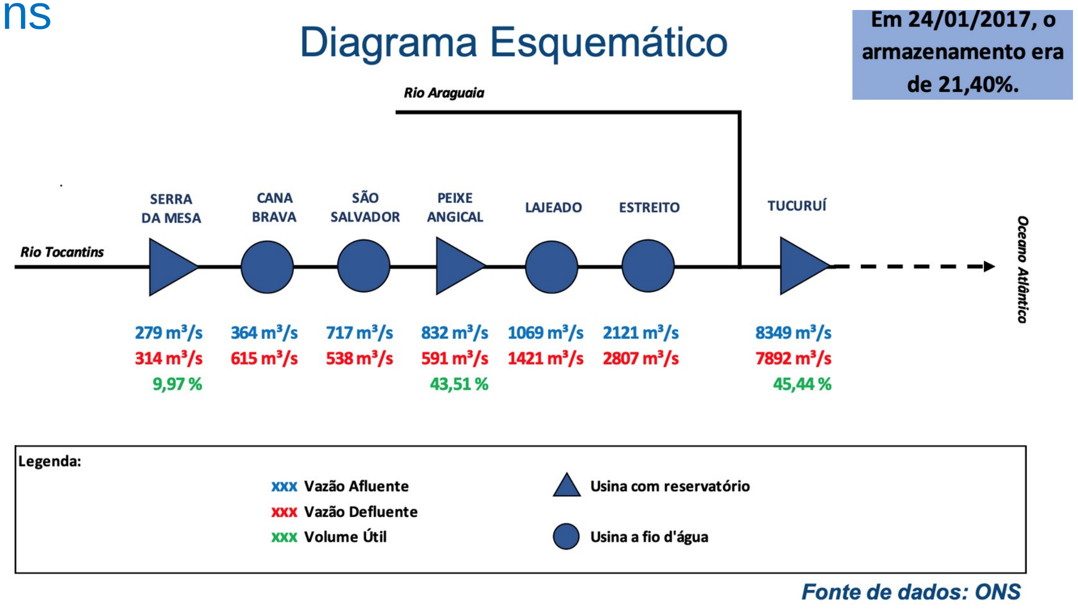
Study site: Tocantins river basin

The basin is formed by two large rivers, the Araguaia to the west, with a drainage area of approximately 377,000 km^2; and the Tocantins River to the east, covering an area of 387,000 km^2, which results in a total drainage area of 764,000 km^2. Average flow = 15400 m^3/s.

A cascade of reservoirs are installed at the Tocantins. The largest HPP Tucuruí, with an installed capacity of 11,500 MW, located in the lower basin; followed by HPP Serra da Mesa in the upper Tocantins with 1250 MW.



Meteorological systems



Motivation

Power generation capacity in Brazil is dominated by hydropower plants (HPP), which account for 60% of total installed capacity. HPP are integrated to other generation sources in a national grid known as the National Interconnected System (SIN)

Electricity generation in Brazil is programmed on a **monthly basis** based on updated information on the generation and transmission schedules, the storage of the reservoirs, updated forecasts of energy consumption, **predicted meteorological conditions, and forecasts of inflows to HPP in the main basins of the SIN**.

Although SIN operation optimization and simulation follow a monthly schedule, **weekly reviews** are carried out on a regular basis, incorporating updated information on the state of the system, weather conditions, and forecasts of power demand and reservoirs inflow.

Data and models

1 Hydrometeorological, topographic and soil data

- Meteorological stations: INMET
- Streamflow stations: ANA & ONS
- SRTM, LULC (Mapbiomas)

2 Satellite Rainfall Estimates: MERGE-CPTEC

3 Distributed hydrological Model

- MHD-INPE
- Daily temporal resolution and spatial resolution of 0.25° x 0.25°

4 Subseasonal Forecast – S2S: ECMWF EPS

- Forecast lead time: 0–46 days
- Hindcast frequency: twice a week
- Ensemble: 10 members + control
- Total precipitation, wind speed at 10 m, Mean sea level pressure, air and dew point temperatures at 2 m, and Surface solar radiation downwards
- Period: 2000-2021

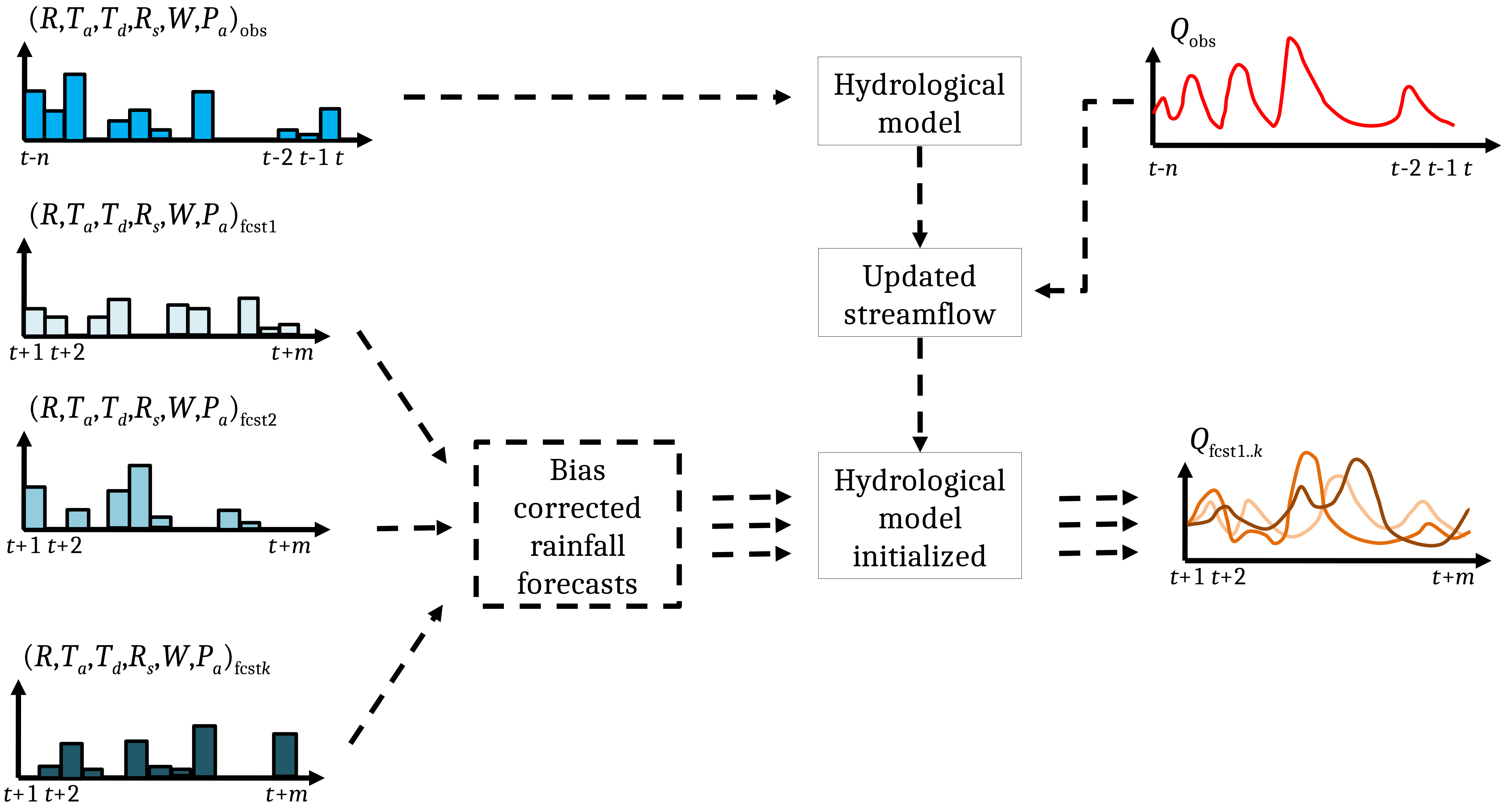
5 Bias Correction

- Empirical Quantile Mapping bias-adjustment (**EQM**)

- Calculation of monthly correction factors (ensemble average for individual ensemble correction).

Calibration 2000-2010 **Validation 2010-2020**

Probabilistic streamflow forecasts



Performance statistics

6 Hydrological model performance

- Nash–Sutcliffe Efficiency (*NSE*)
- Logarithm (*NSElog*)

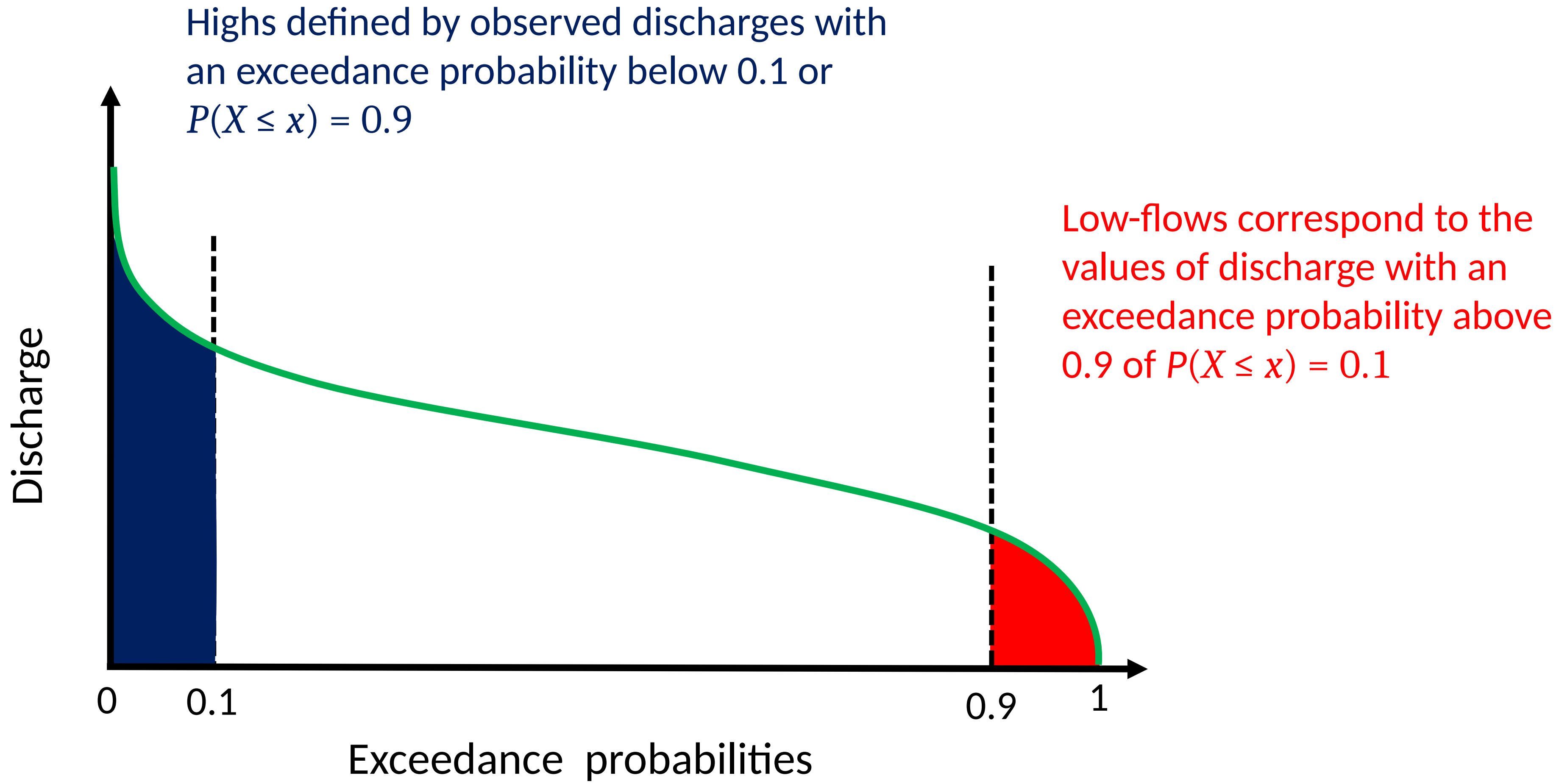
7 Ensemble Precipitation/Flood Forecast Performance

- rBIAS
- ROC diagram: evaluate the ability of the forecast
  ,
- ROC Skill Score

- The hydrological model was calibrated using streamflow data only for the sub-basins upstream the reservoirs, and naturalized discharges downstream hydropower dams.
- Because reservoir operation is continuously adapted, intraseasonal forecasts cannot be validated using the observed reservoir outflows.
- All the statistics were calculated for high and low flows.

Selecting high flows and low flows

Based on the Flow Duration Curve – FDC, which is the empirical probability function of daily discharges



Results: Hydrological model calibration and validation

					Calibration		*Validation*	
SB	*Size*	*Station*	*River*	*Area* (km^2)	*NSE*	NSE_{log}	*NSE*	NSE_{log}
SB01	Small	Rio das Mortes	Mortes	5,230	0.710	0.740	0.735	0.770
SB02	Medium	Xavantina	Mortes	25,300	0.821	0.842	0.751	0.825
SB03	Small	Tesouro	Garças	5,280	0.584	0.682	0.592	0.659
SB04	Small	Peres	Caiapó	12,000	0.695	0.794	0.627	0.666
SB05	Small	Travessão	Vermelho	5,310	0.664	0.816	0.288	0.531
SB06	Medium	Luiz Alves	Araguaia	117,000	0.842	0.900	0.857	0.892
SB07	Large	Conceição do Araguaia	Araguaia	332,000	0.853	0.890	0.562	0.660
SB08	Large	Xambioá	Araguaia	377,000	0.897	0.901	0.538	0.700
SB09	Small	Ceres	Almas	10,600	0.745	0.804	0.693	0.789
SB10	Small	Ponte Quebra Linha	Maranhão	11,200	0.631	0.792	0.549	0.741
SB11	Small	Nova Roma (Faz.Sucuri)	Paraná	22,600	0.743	0.767	0.630	0.660
SB12	Small	Jacinto	Sta Tereza	13,900	0.714	0.683	0.628	0.478
SB13	Medium	HPP Serra da Mesa	Tocantins	51,233	0.807	0.879	0.721	0.805
SB14	Medium	HPP Peixe Angical	Tocantins	125,884	0.846	0.919	0.773	0.837
SB15	Medium	HPP Lajeado	Tocantins	183,718	0.878	0.940	0.728	0.837
SB16	Medium	Miracema do Tocantins	Tocantins	185,000	-	-	-	-
SB17	Small	Jatobá (Faz. Boa Nova)	Sono	16,900	0.590	0.660	0.331	0.584
SB18	Medium	Porto Real	Sono	44,100	0.795	0.864	0.621	0.754
SB19	Large	Carolina	Tocantins	275,000	-	-	-	-
SB20	Large	HPP Estreito	Tocantins	285,491	0.868	0.892	0.657	0.800
SB21	Large	Descarreto	Tocantins	297,000	-	-	-	-
SB22	Large	HPP Tucuruí	Tocantins	764,000	0.944	0.962	0.709	0.846

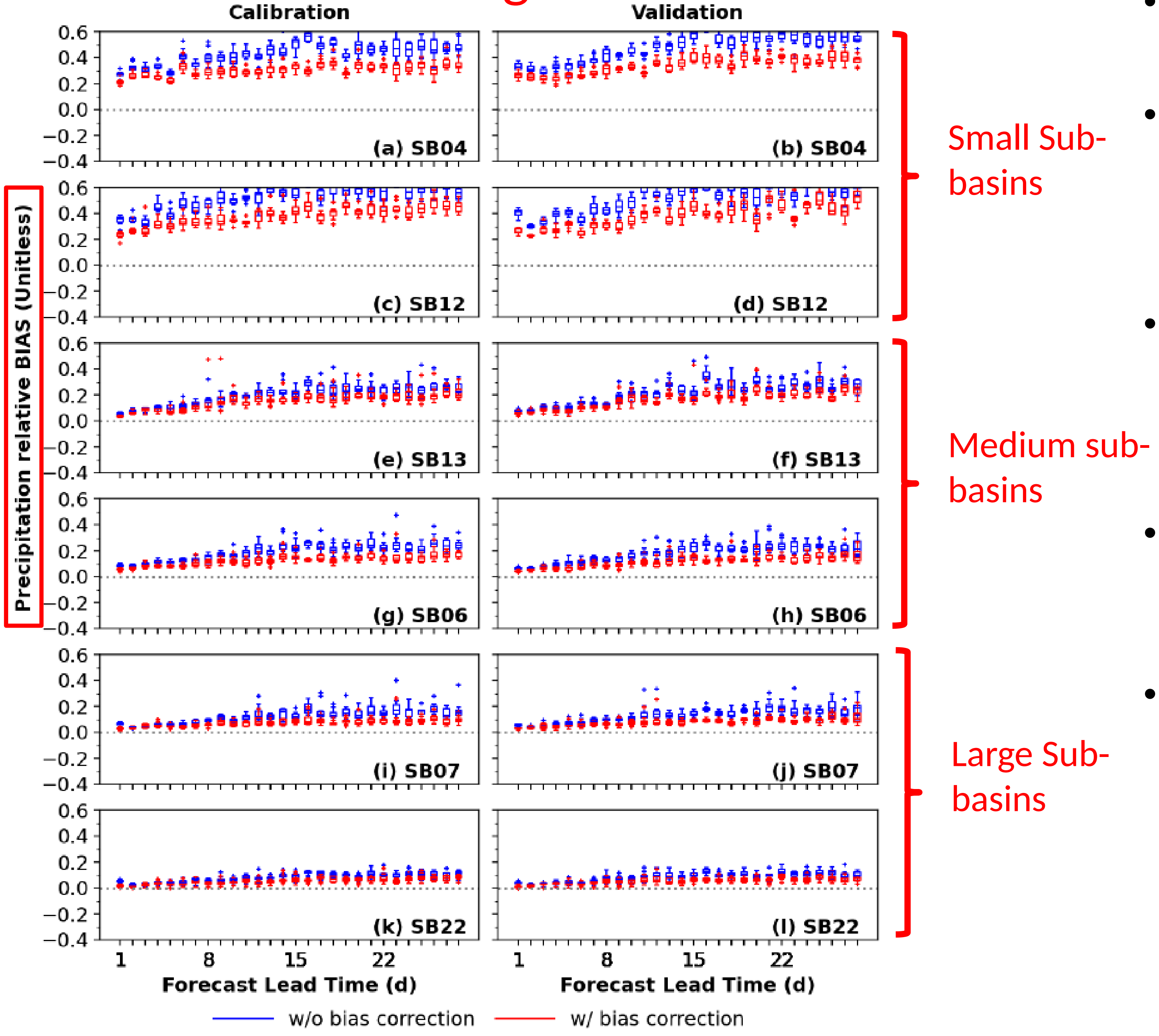
Arbitrary classification

“Small” sub-basins < 25,000 km^2

Large Sub-basins > 200,000 km^2

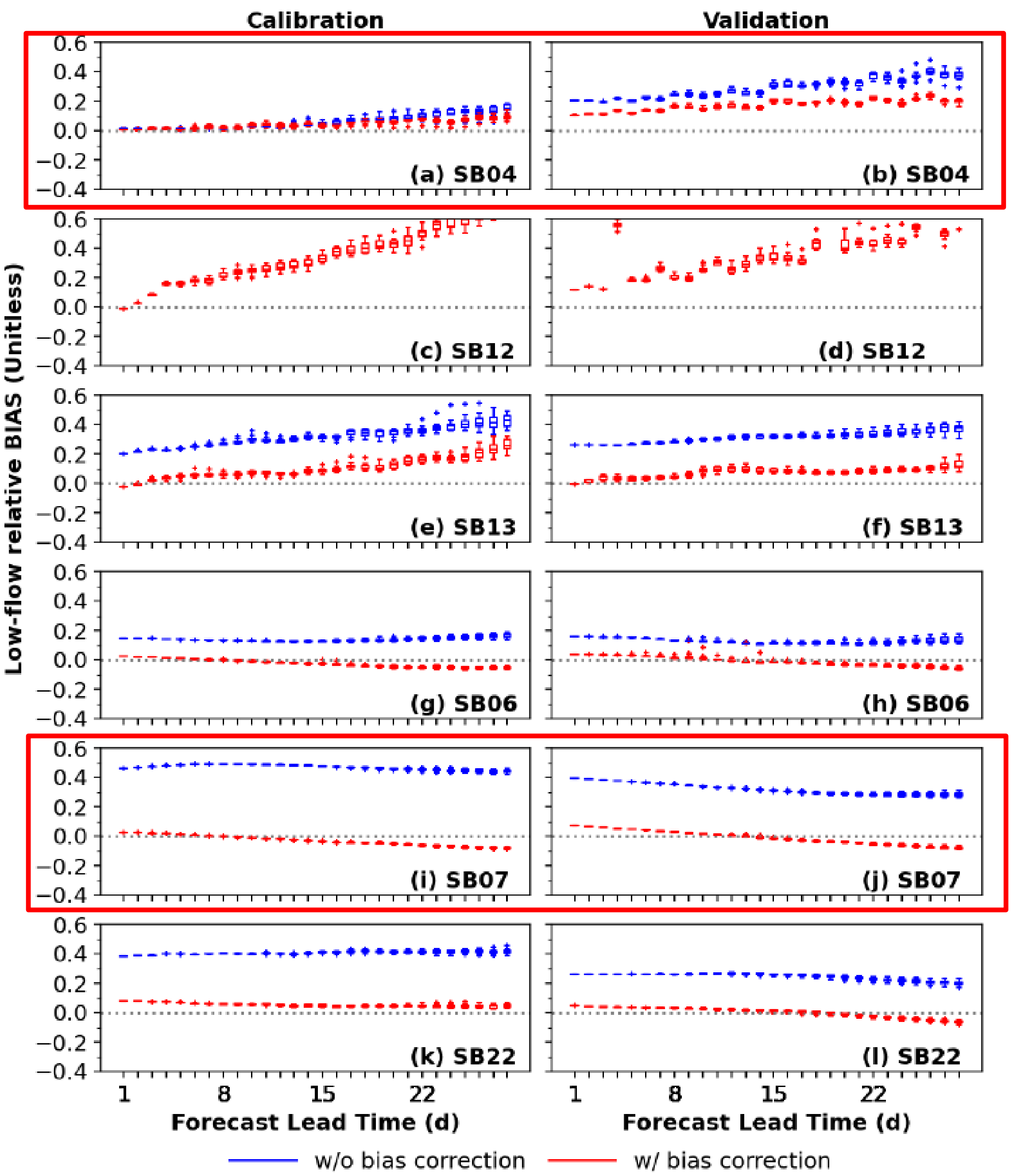
Medium sub-basins in between

Rainfall forecasting evaluation



- The rBIAS is higher for small sub-basins and decreases with the catchment area.
- For all basins, it is possible to observe corrections of the order of 20% for small basins, from 10% to 20% for medium-sized basins, and below 10% for medium and large basins.
- The predictability reduces with lead-time until 10-13 days, and, after that, remains relatively stable up to the end of the forecast period (30 days).
- As expected, it is possible to observe that the spread of the ensemble is larger for smaller sub-basins, and smaller for large sub-basins.
- This is due to difficulties in predicting & estimating precipitation in more mountainous areas (i.e., at headwaters of the basin) and to limitations in predicting the meridional position of rainfall systems and localized precipitation events.

Low-flow forecasting evaluation



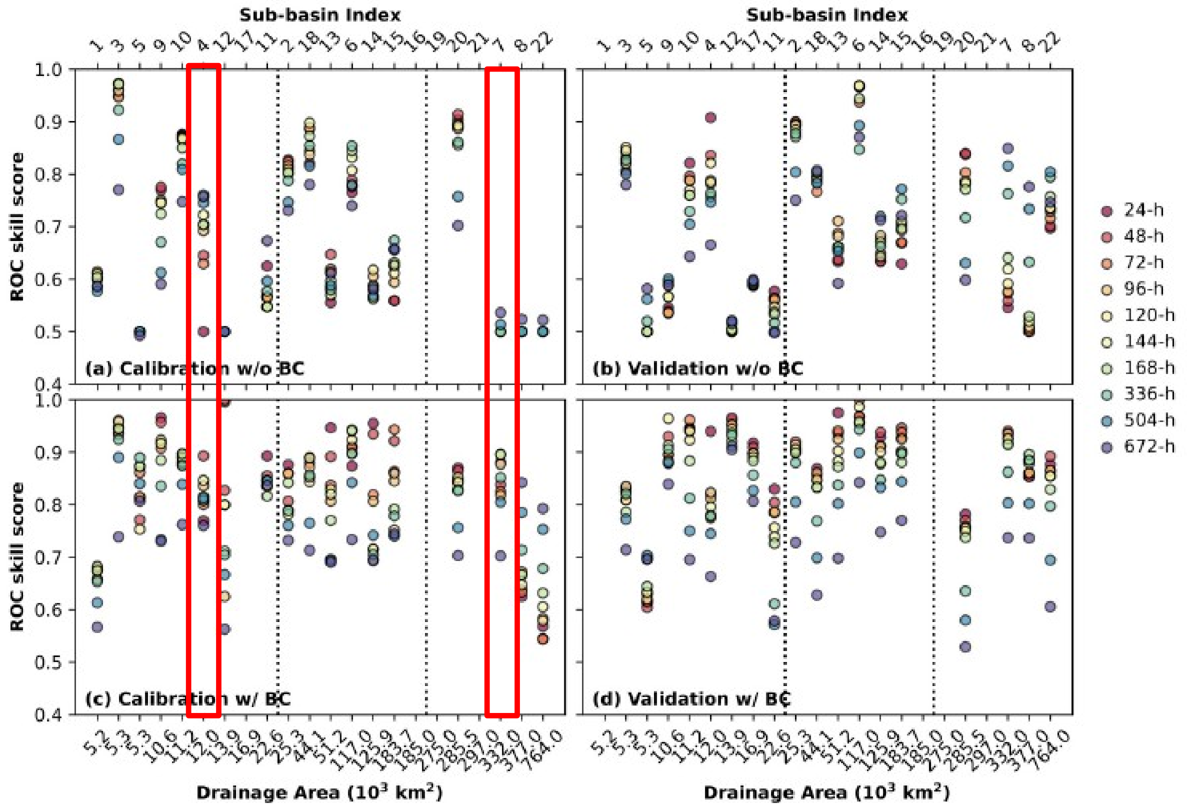


Figure 4. ROC skill score for low flow for 22 sub-basins of the Tocantins-Araguaia basin for first 7 consecutive days, 14, 21 and 28 days lead-times as function of catchment area for low-flow with probability level 0.1. Calibration period (a) without bias correction and (c) with bias correction; and validation period (b) without bias correction and (d) with bias correction. The vertical dotted lines divide the drainage catchment area in small, medium and large sub-basins.

The larger the drainage area, the higher the impact of bias correction due to the magnitude of the rBias

Low-flow forecasting evaluation

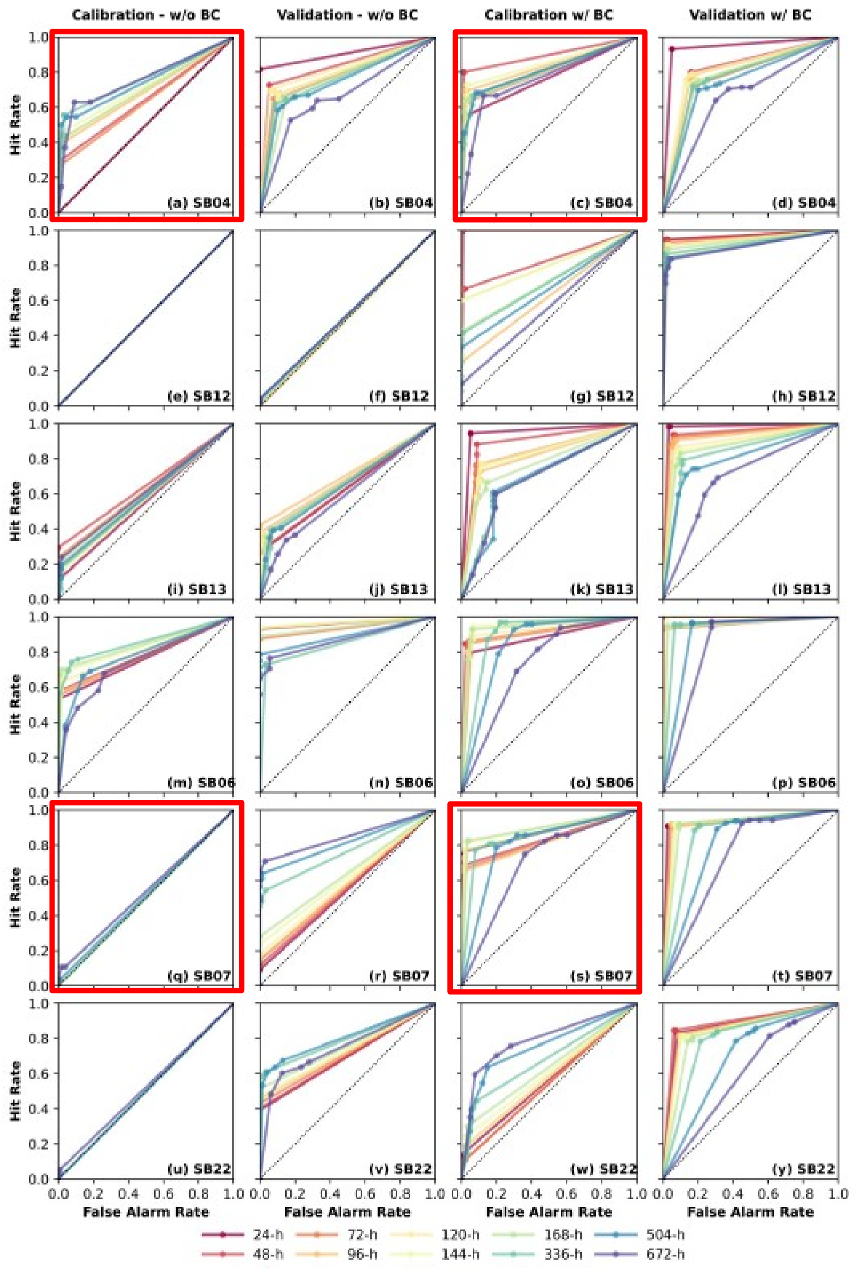
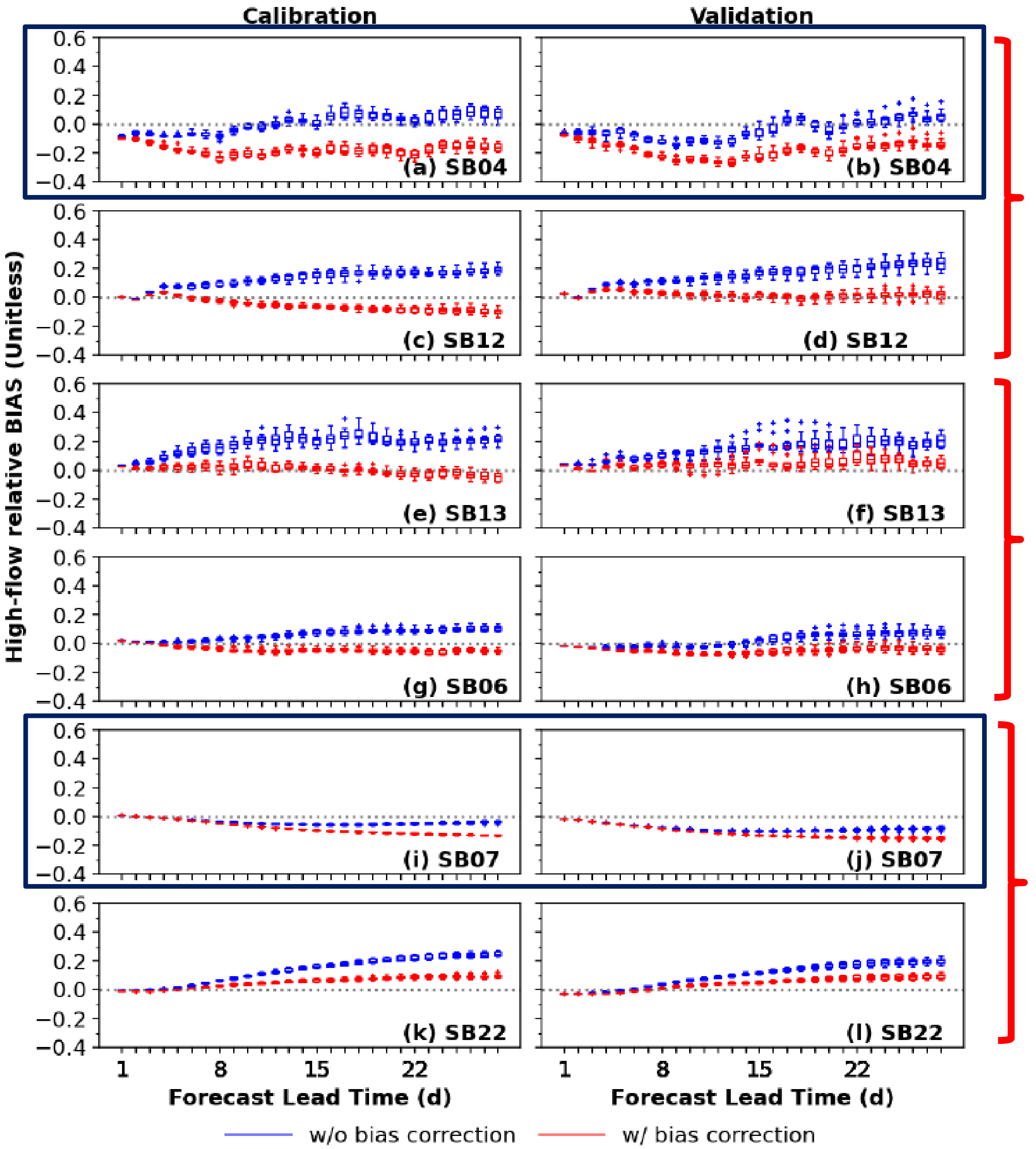


Figure 5. ROC Diagram low-flow

- Low-flow forecasts improves after bias correction for all basins and all lead times.
- Comparisons of the ROC diagram without and with bias correction of **large basins** revealed no predictability for the raw forecasts and high predictability after the bias correction.
- The loss of predictability for increasing lead times is, in general, more significant in large basins compared with the small ones.

High-flow forecasting evaluation



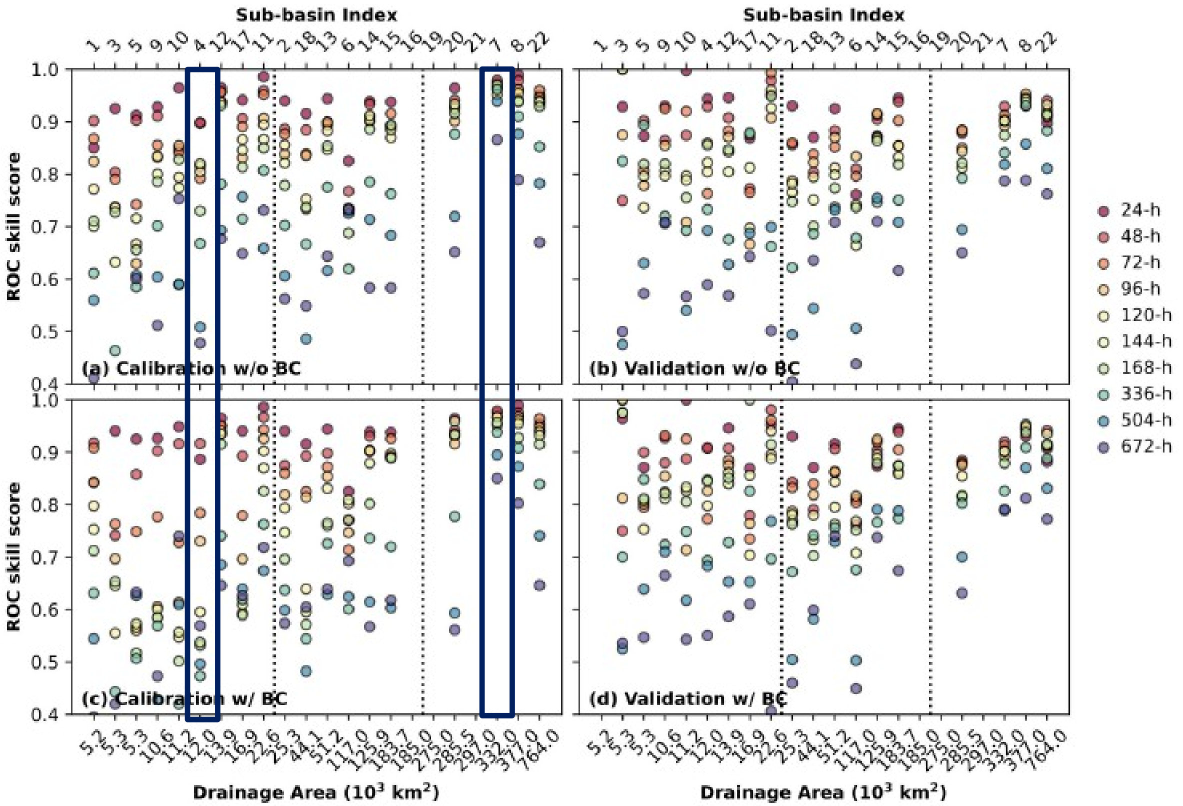


Figure 7. ROC skill score for low flow for 22 sub-basins of the Tocantins-Araguaia basin for first 7 consecutive days, 14, 21 and 28 days lead-times as function of catchment area for high-flow with probability level 0.9. Calibration period (a) without bias correction and (c) with bias correction; and validation period (b) without bias correction and (d) with bias correction. The vertical dotted lines divide the drainage catchment area in small, medium and large sub-basins.

The larger the drainage area, the lower the impact of the bias correction because the rBias is lower

High-flow forecasting evaluation

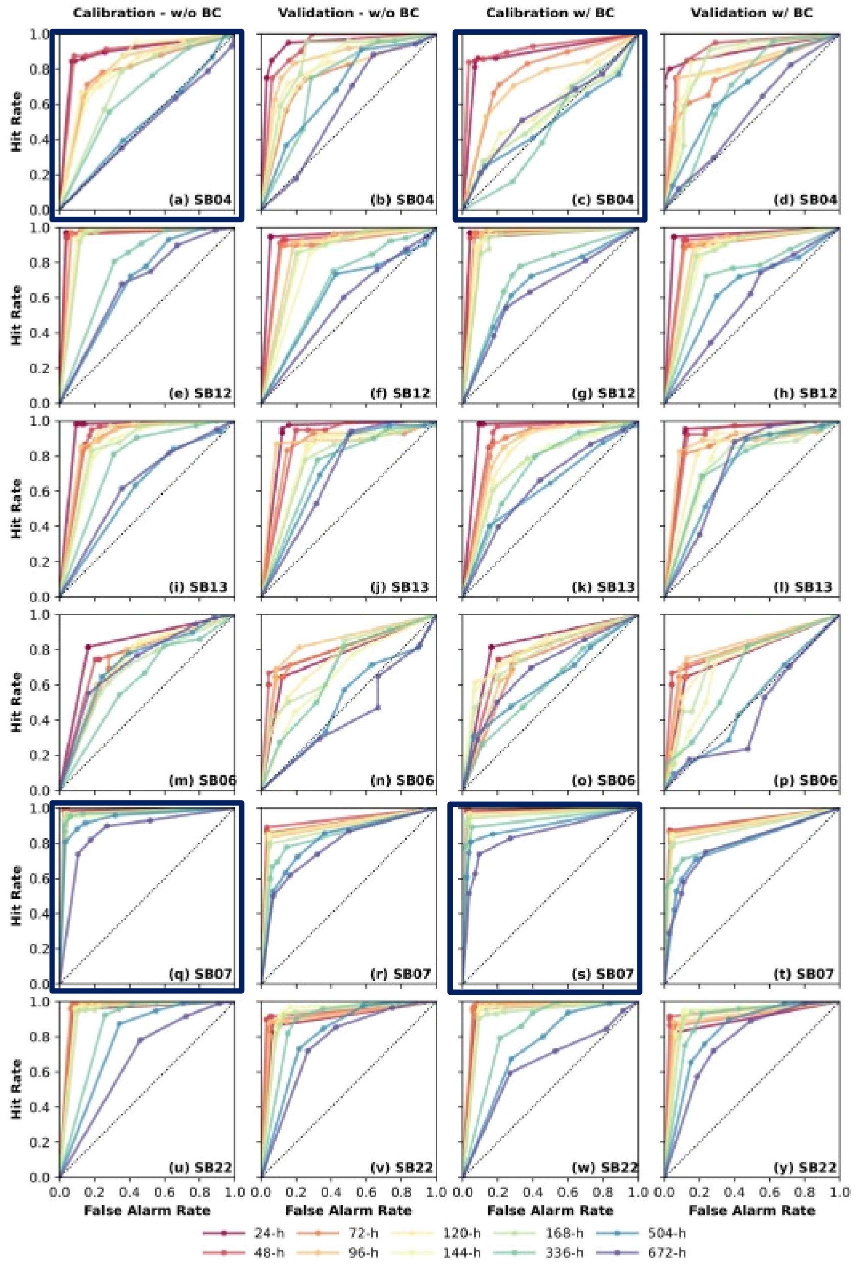
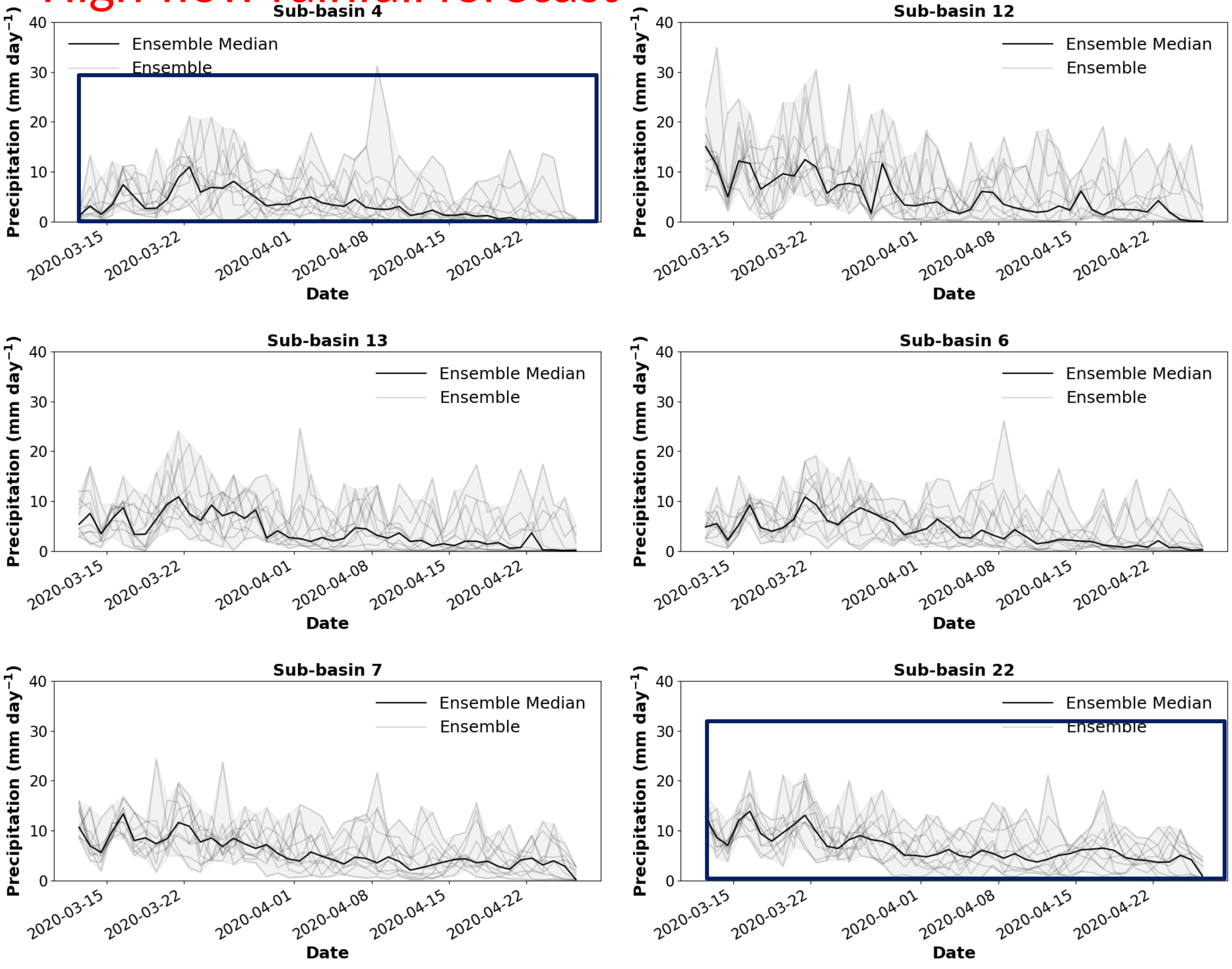


Figure 8. ROC diagram high-flow

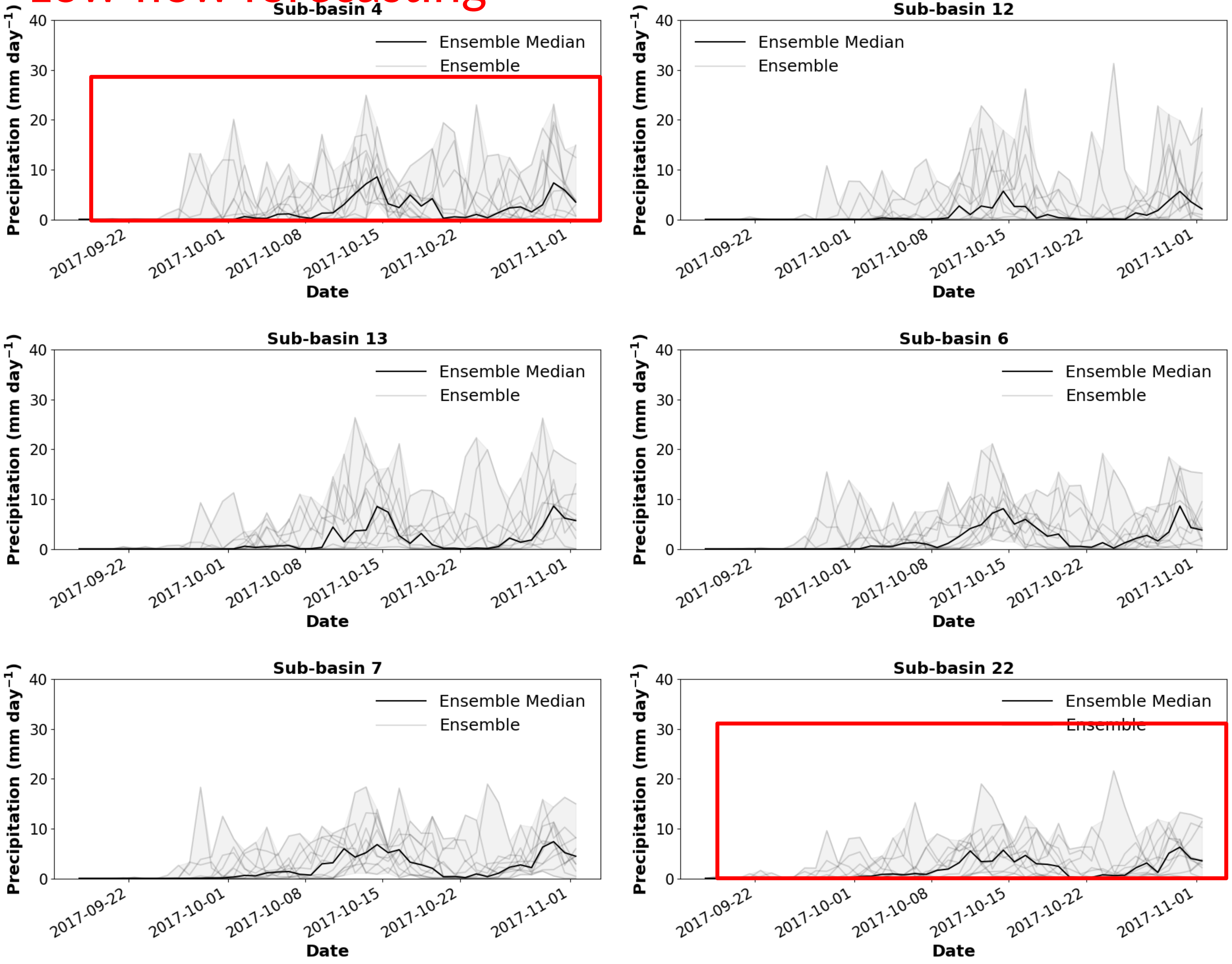
- For high-flow, the loss of predictability for increasing lead-times is more significant in **small scale basins**; and the opposite in the case of large scale basins.
- In small sub-basins, forecasts are less reliable for longer lead times during the wet season when compared to the dry period
- In large basins, forecasts are more reliable for longer lead-times compared to those of the dry season.

High-flow rainfall forecast



- More dispersion among members of the ensemble in the small sub-basins
- Probably related to uncertainties in the forecasts both in magnitude and spatial distribution.

Low-flow forecasting



- Dispersion among members of the ensemble is similar regardless the drainage area
- Probably the forecasts uncertainties tend to accumulate with the increase of drainage area.

Conclusions

- For small sub-basins, we observed a smaller relative bias correction for low flow forecasts.
- In contrast to the case of minimum flows, the bias correction of high flows has more impact on the forecast skill in small basins – relative bias large in small sub basins for high flows.
- The opposite effects of the precipitation bias correction for minimum and maximum flows as a function of the drainage area of the sub-basins may be related to the spatial distribution of precipitation in the rainy and dry seasons.
- In the rainy season, rainfall is more spatially uniform than in the dry season. Therefore, forecast errors in the spatial distribution of rainfall tend to be compensated in larger drainage areas. The spread of the members is greater in small sub-basins and “diluted” on larger scales
- In the dry season, on the other hand, rain events are localized and of smaller magnitude. The probability of these events affecting runoff in a small basin is lower compared to a sub-basin with larger drainage areas. Dispersion among members are similar across spatial scales and forecasts errors are accumulated downstream.

Conclusions

- Although the results of the study indicate that it is possible to generate reliable streamflow forecasts at the intraseasonal scales, the Tocantins basin can be considered a large-scale experiment considering the size of the basin (even the “small” sub-basins analyzed in this study are relatively to the whole basin).

- In addition, the basin is located in the tropics, where seasonal variation in rainfall is most of the time influenced by large-scale phenomena, which makes seasonal forecasts more accurate.

- Therefore, new experiments are needed in other basins, where both the scale and the climate system present more challenging conditions.

- In spite of these limitations, the results of this study revealed the potential of using intraseasonal forecasts for decision making and encouraging further developments. .

Thank you!

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