STAHY - Workshop Advances in statistical hydrology

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PREVIVAZ – Improving Weekly Streamflow Time Series Forecasts With the Current Hydrologic State of the River Basin

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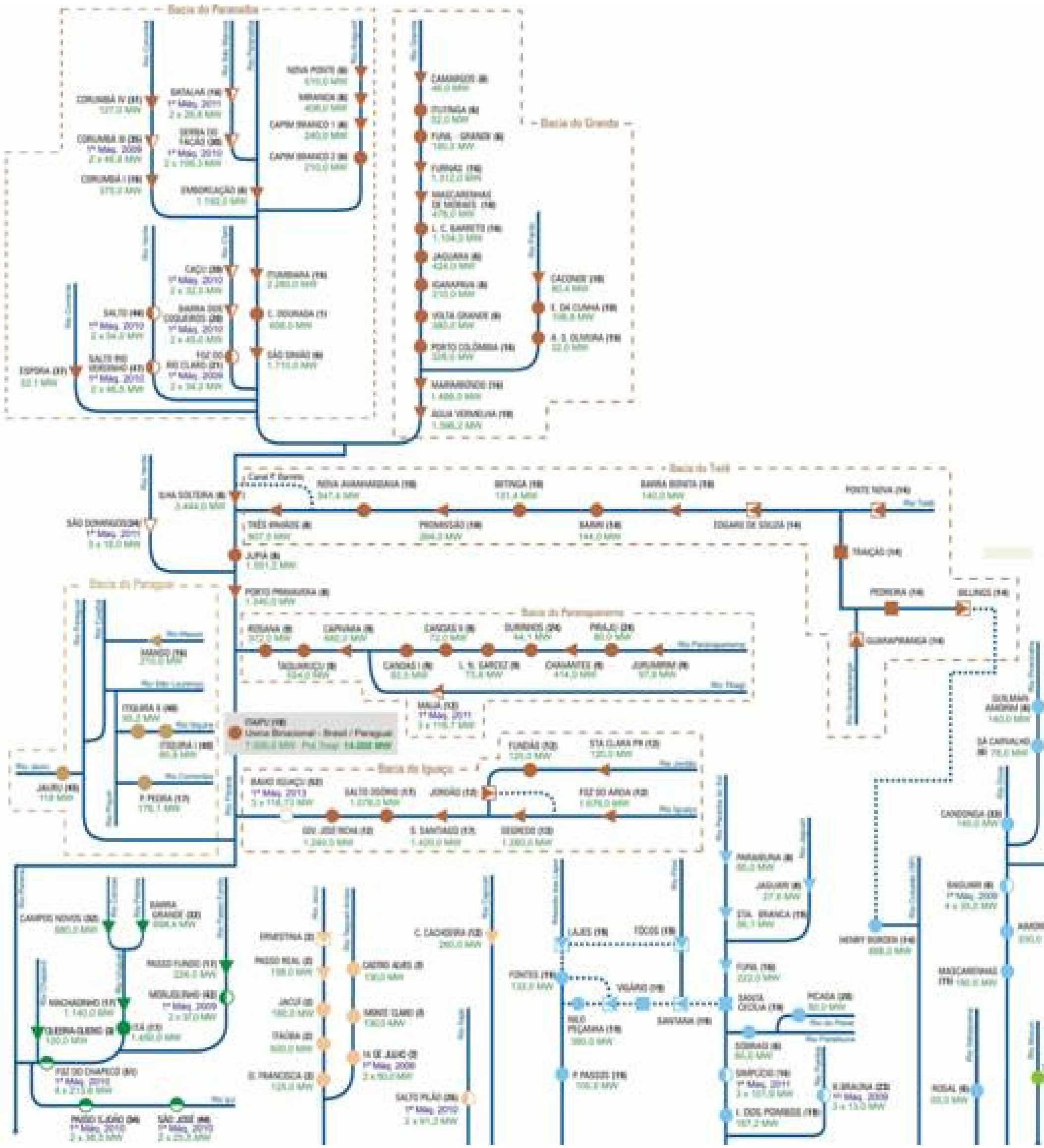
OPERATION PLANNING OF BRAZILIAN HYDRO THERMAL SYSTEM

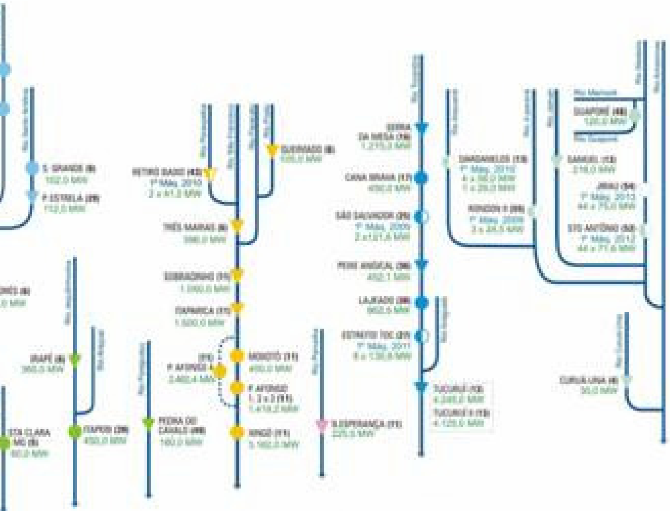
CEPEL 35 anos
Sistema Eletrobrás

- Hydraulic based (> 80% Total Power Generation)
  - 12 large watersheds (cascades)
  - Many large reservoirs **(> 1 km^3)**
    - Inter-annual streamflow regulation
    - Other uses (e.g.: Flood control)

- Planning problem
  - Load supply with **minimum expected total cost** (Thermal Units operation + deficits)
  - Energetic Modeling System
    - Optimization models (planning, dispatch)
    - **Hydrological models (streamflow forecasting & scenarios generation**

OPERATION PLANNING OF BRAZILIAN HYDRO THERMAL SYSTEM





OPERATION PLANNING OF BRAZILIAN HYDRO THERMAL SYSTEM

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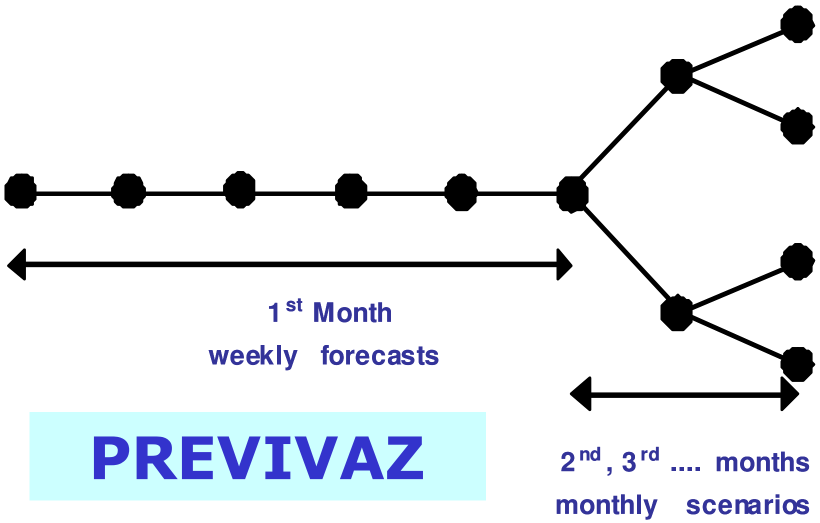
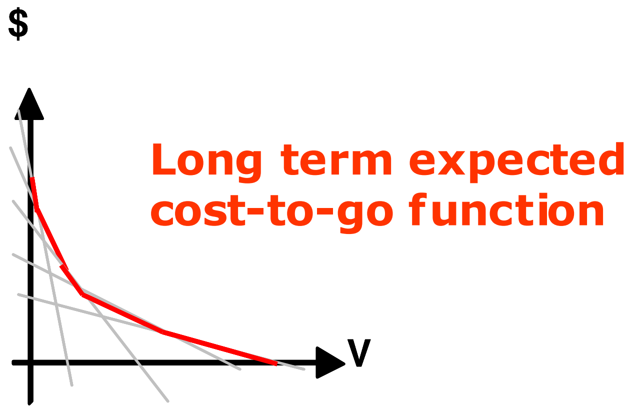
Inflow representation	Hydrological models		Planning Horizon
Monthly inflow scenarios	GEVAZP	NEWAVE	5 years
Weekly inflow forecasts Monthly inflow scenarios	PREVIVAZ GEVAZP	DECOMP	2 months
Daily inflow forecasts	PREVIVAZH	DESSEM	2 weeks

OPERATION PLANNING OF BRAZILIAN HYDRO THERMAL SYSTEM

- (Short-term) Weekly Operation Scheduling
  - Operational constraints
  - Initial reservoirs' storage
  - Last weeks observed inflows
  - Future inflows: Weekly forecasts + monthly scenarios





PREVIVAZ MODEL

- Stochastic univariate model
- Weekly streamflow forecasts (up to 6 weeks ahead)
- Used in short-term Planning Operation (DECOMP model)

PREVIVAZ model consider **different modeling strategies** based on:

- Linear ARMA(p,q) models, periodic/non-periodic
- Different **estimation methods** (moments, regression)
- Series transformation (Box & Cox)
- Best model: select by RMSE (cross-validation)

PREVIVAZ MODEL

- Models evaluated by PREVIVAZ

Forecasting Model	Characteristic	Estimation Method
Constant	*Annual average*	*Moments*
Seasonal	*Weekly average*	
AR(p) $(1 \leq p \leq 4)$	*Stationary correlation structure*	
ARMA(p,1) $(1 \leq p \leq 3)$		
PAR(p) $(1 \leq p \leq 4)$	*Seasonal correlation structure (weekly, monthly, quarterly, semi-annual)*	*Moments and regression*
PARMA(p,1) $(1 \leq p \leq 3)$		

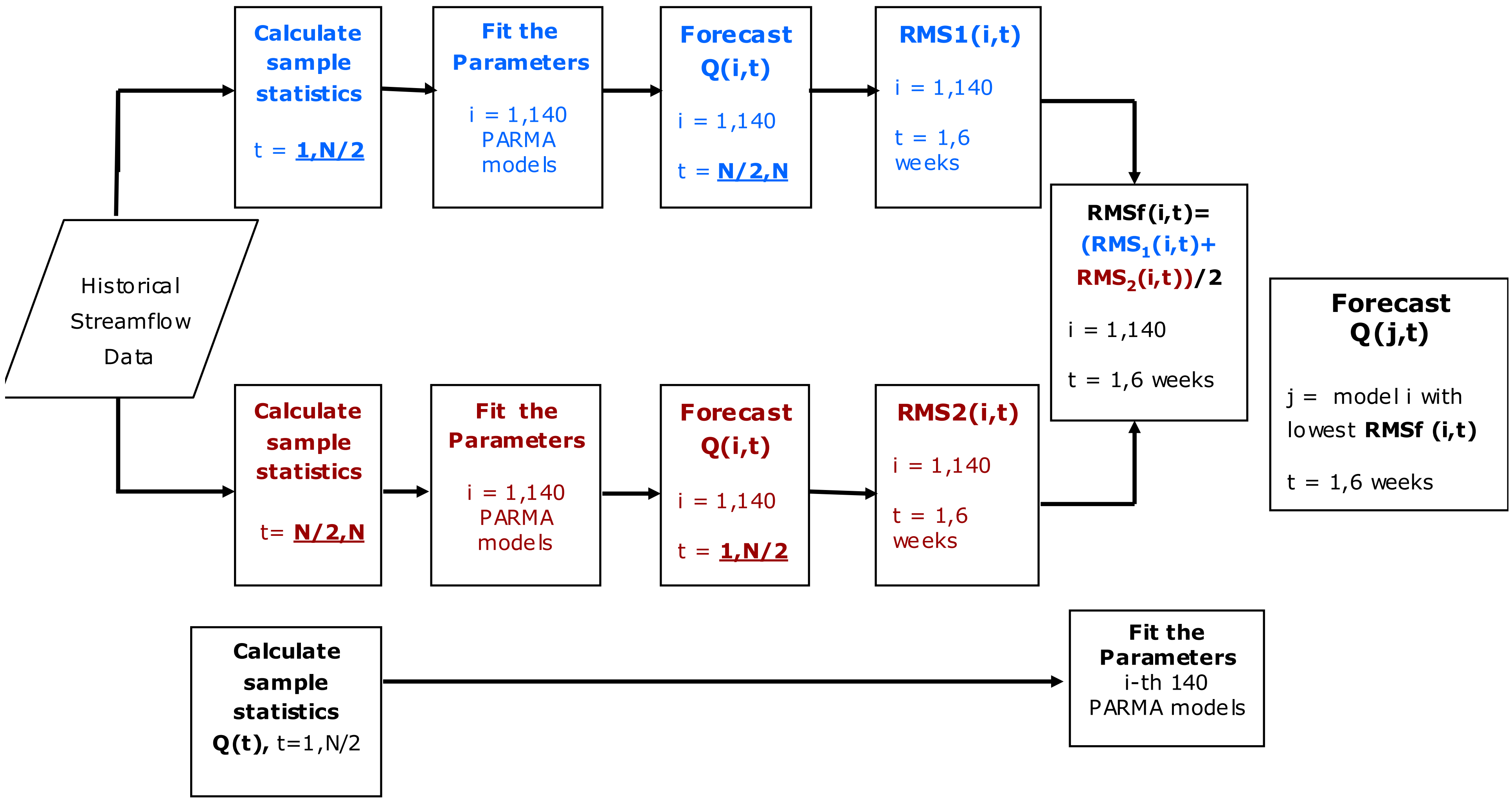
=> Up to 140 models (including B&C transformation)

PREVIVAZ: estimation procedure

1. Evaluate the discharge series statistics for week t;
2. Taking into account these series statistics, estimate M different linear PARMA models (up to 140);
3. For the i-th PARMA model, forecast Qi(t) on the period spanning the first half of historical record and calculate the mean RMS error over this period, $RMS_1 i$; repeat this for the M alternative PARMA models;
4. The same as 3, but for the period spanning the second half of historical record;
5. Evaluate each PARMA Model forecast, i=1,..,M, taking into account their mean RMS error, RMSi (average of $RMS_1 i$ and $RMS_2 i$);
6. Rank the M alternative models with respect to their average RMSi errors; chose the best one (k = 1);
7. With the model chosen in Step 6, forecast the discharge Q*(t) to week t and calculate the forecast confidence intervals;
8. Repeat the procedure describe in Steps 1 to 7 for the next weeks (t+1 to t+5). The last weeks (t,…,t-4) forecast will be considered as trend to the model’s choice for the next weeks(t+1,..,t+5)

PREVIVAZ MODEL

PREVIVAZ: estimation procedure



PREVIVAZ MODEL

- Problem: some **great errors** caused by
  - Unlikely large/small forecasts obtained on calibration period (inducing the rejection of an alternative model)
    - Weak time correlation structure
    - Last observed values statistics different from the historical record ones (short record?)
  - Unlikely large streamflow forecasts after inversion (from B&C transformed values)

=> Unlikely Q(t) variations

How could these unlikely forecasts be eliminated on estimation procedure?

PREVIVAZ MODEL

How could these unlikely forecasts be rejected on estimation procedure?

- Approach: **to limit the Q(t) variations between two consecutive weeks:**
  - Analyzing the Q(t)/Q(t-1) *cumulative distribution function* (historical record)
  - Defining probabilities of **minimum/maximum acceptable** Q(t) variation
  - With the last observed Q(t-1) values, defining a **range (bounds) of acceptable** Q(t) forecasts
  - Once this range has been defined, taking it into account on model selection procedure

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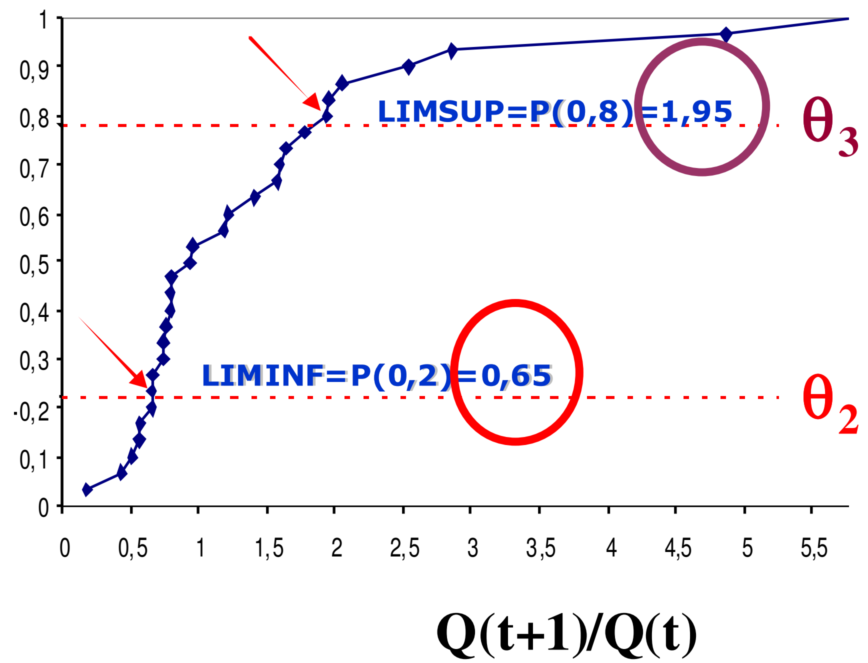
How the forecast bounds can be defined?

1) Build the Q(t+1)/Q(t) *cdf* (from historical record), having defined:

i) The **period** (week, month etc) where the *cdf* will be estimated;

ii) The θ_1 ranges of **Q(t) magnitude** to which the *cdf* will be estimated

2) Establish the minimum/ maximum **probabilities of non-exceedance** $\{\theta_2, \theta_3\}$



Thus, with the **Q(t-1) value** no week t-1:

Lower bound = Q(t-1)*(**value** corresponding to the θ_2 percentile)

Upper bound = Q(t-1)*(**value** corresponding to the θ_3 percentile)

How the forecast bounds can be defined?

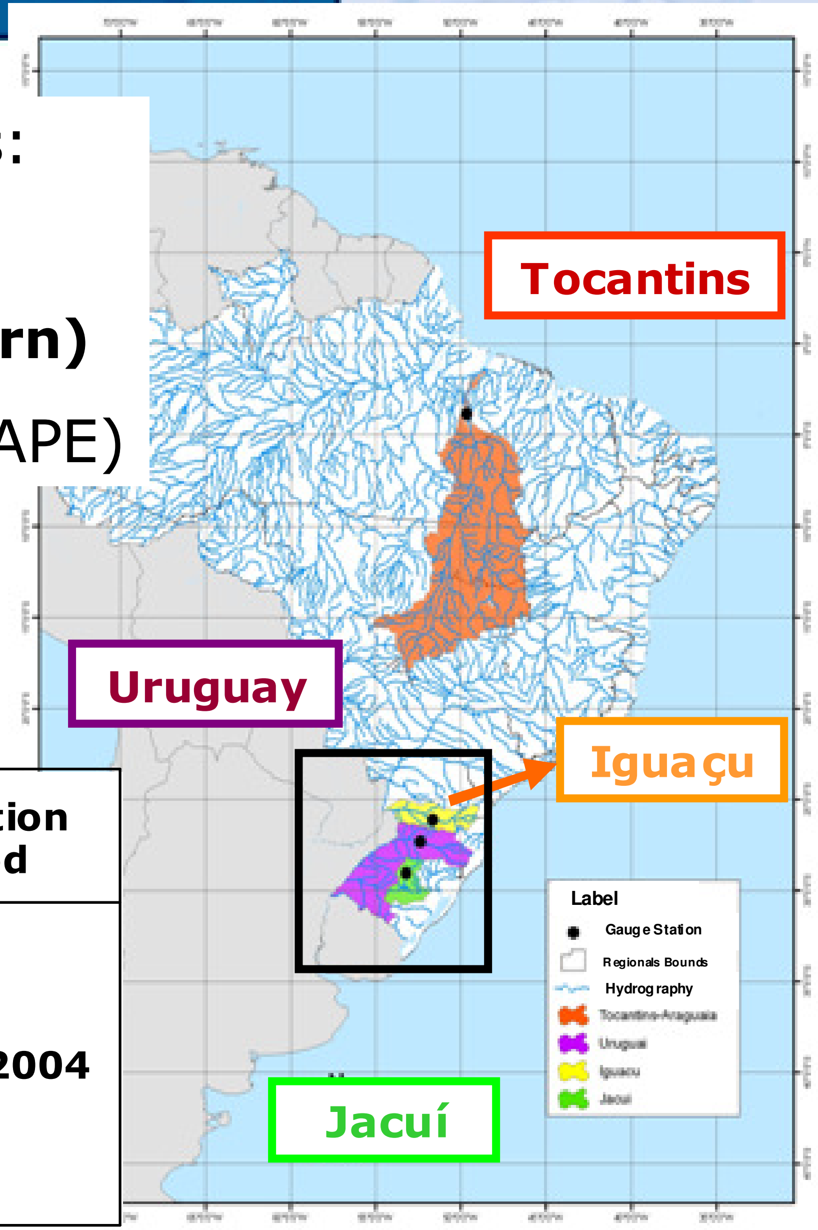
1. Define (i) the period on which the cdf will be estimated, (ii) the q1 streamflow magnitude ranges, (iii) the minimum/maximum allowed variation probabilities {q2,q3};
2. With the procedure described in Item 2.1 calculate the i=1,…,M alternative PARMA models to the week t and rank (k=1,…M) them following their average RMSi errors;
3. Estimate the q1 variation ratio (Q(t)/Q(t-1)) cdf's from the historical inflow time series;
4. From these q1 cdf's and the {q2,q3} values, calculate the q1 discharge variation bounds {LBk(t),UBk(t)};
5. For the k=1,…,M alternative models, calculate Qk(t) and verify if it lies in the correspondent (according to the magnitude of Qk(t)) bounds [LBk(t),UBk(t)]; if not, Qk(t) will be replaced by the lower or upper bound, and the their RMSk error, re-evaluated; a new ranking (k'=1,…,M) is then performed;
6. Taking into account the whole time series, and the ranking done in Step 5, evaluate if the best model (k'=1) forecast Q1(t) lies in [LB1(t),UB1(t)];
7. If the Step 6 verification does not hold, take the second best model (k'=2) and perform again the Step 5 verification; if this second verification does not hold neither, take the third best model (k'=3) forecast Q3(t) and so on, until finding the best model (k* = k') whose forecast respect the bounds defined in Step 4 and that will be retained thereafter;
8. Repeat the procedure described in Steps 1 to 6 to the next 5 weeks (t+1,…,t+5).

CASE STUDY

Gauge Stations in 4 Brazilian Basins:

- Tocantins (Northern)
- Jacuí, Uruguay and **Iguaçu (Southern)**

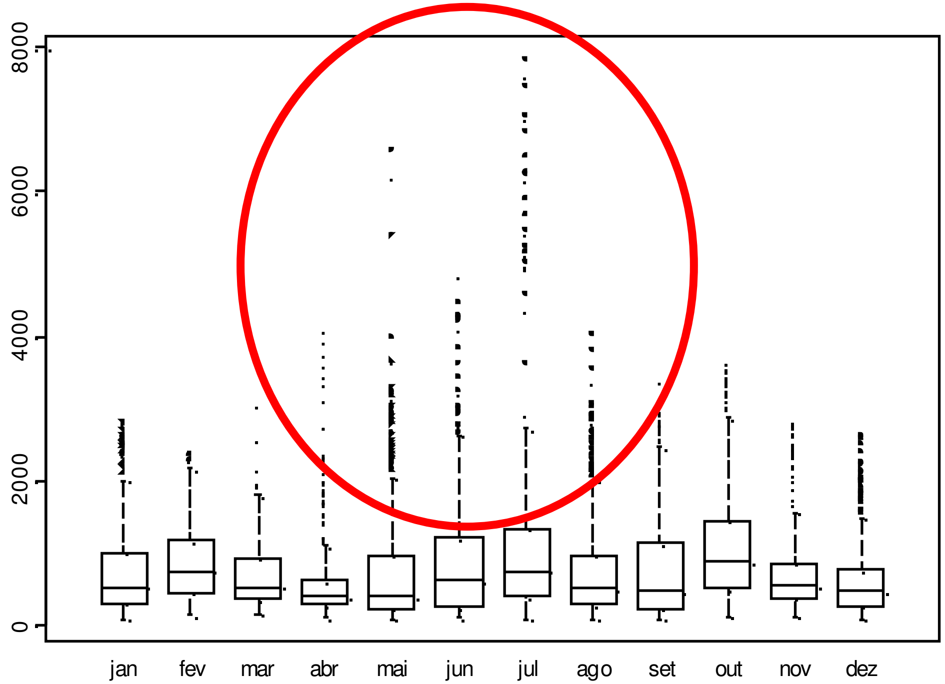
Different goodness-of-fit criteria (MAPE)

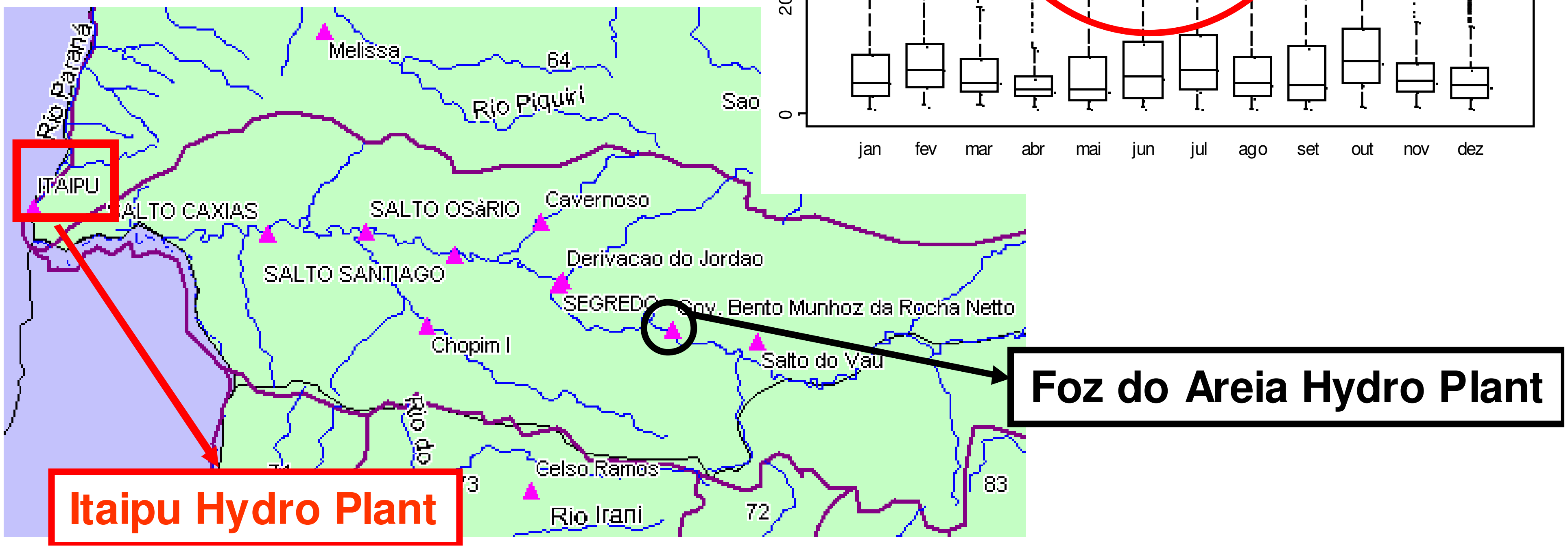


Watershed	Gauge station	Estimation period	Validation period
Iguaçu	**Foz do Areia**	**1969 – 1994**	**1995 – 2004**
Uruguay	**Itá**	**1973 – 1994**	
Jacuí	**Passo Real**	**1940 – 1994**	
Tocantins	**Tucuruí**	**1970 – 1994**	

CASE STUDY – Foz do Areia

Mean	**780 m³/s**
S.Deviation	**710 m³/s**
Maximum	**7830 m³/s**
Minimum	**68 m³/s**





CASE STUDY – Foz do Areia

- Foz do Areia gauge station
  - 1969 – 1994 : parameter estimation
  - 1995 – 2004 : validation

Bounds

- *Cdf* estimation: weekly, monthly, quarterly and semi-annual;
- 4 Q(t) magnitude ranges: {0;25%;50%;75%;100%};
- Minima/maxima probabilities: {10%;90%}, {20%;80%} and {30%;60%}

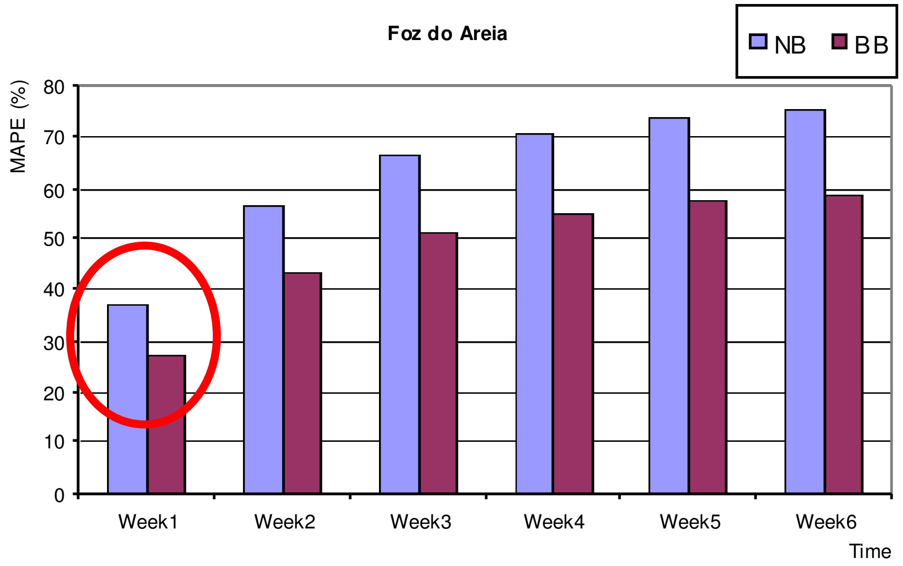
=> **48 bounds parameterizations to be evaluated**

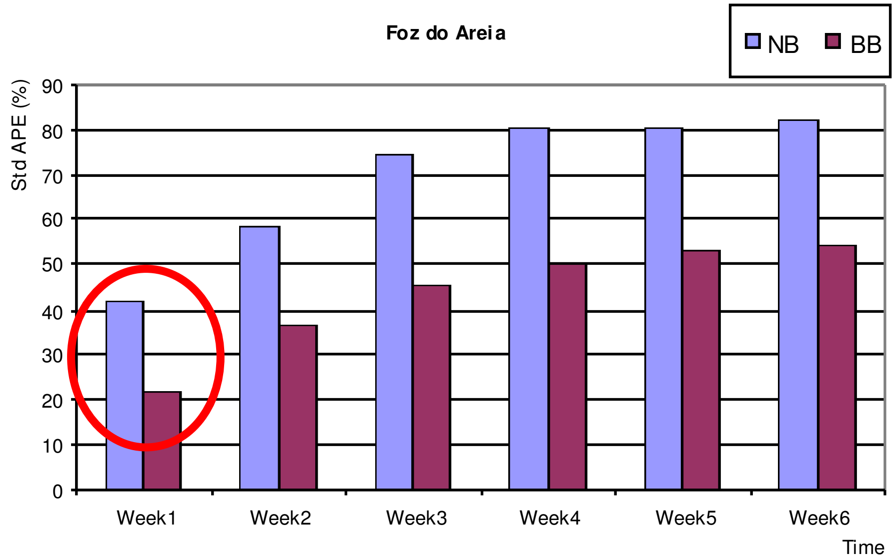
CASE STUDY – Foz do Areia

Goodness of fit criterion: Mean Absolute Percentage Error

Best bounds parameterization leads to:

- Average error reduction: **17.4 %** (6 weeks)
- Great reduction of Error standard deviation : **43.1%** (6 weeks)





Reduction : 26.4 % (1st Week)

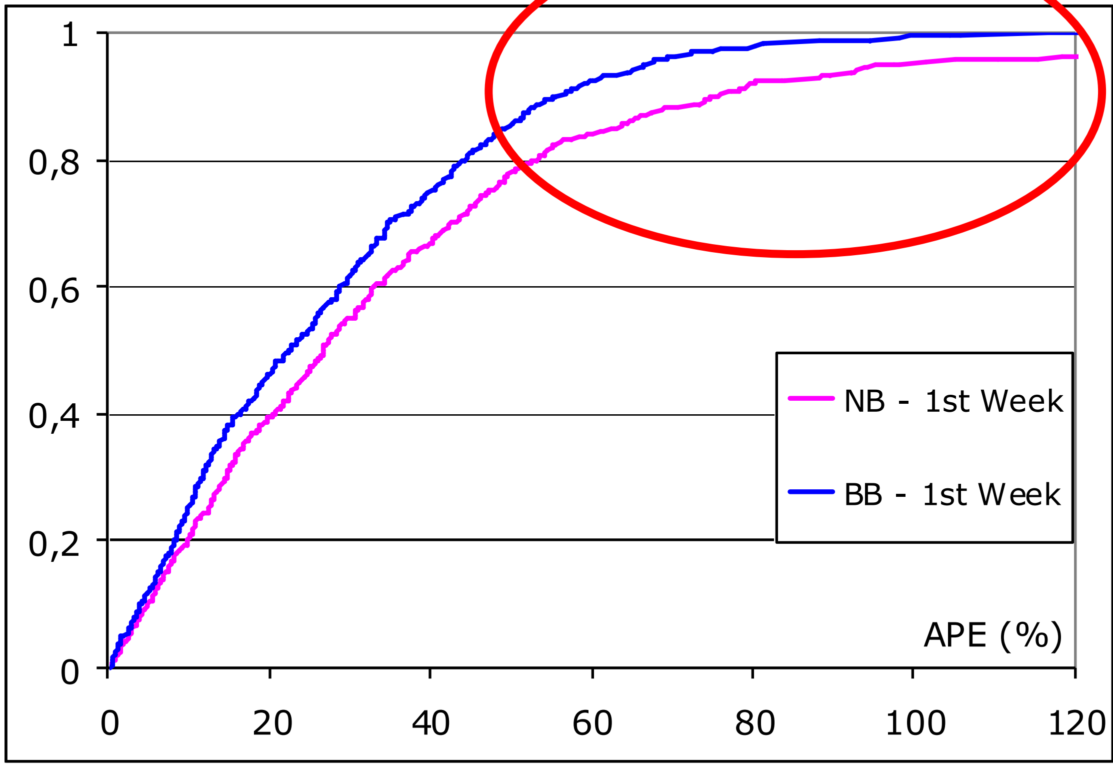
Reduction : 50.2 % (1st Week)

CASE STUDY – Foz do Areia

Goodness of fit criterion: Mean Absolut Percentage Error

Best bounds parameterization leads to:

- Remarkable reduction of large errors (over the whole period)



Week	Q25%	Q50%	Q75%	Q95 %
1	13,85	9,98	16,12	**33,91**
2	6,65	10,08	12,26	**31,42**
3	4,17	4,79	10,57	**31,26**
4	-4,05	1,98	14,56	**32,78**
5	0,76	-2,32	14,55	**28,75**
6	11,03	5,80	11,40	**28,27**

CASE STUDY – Foz do Areia

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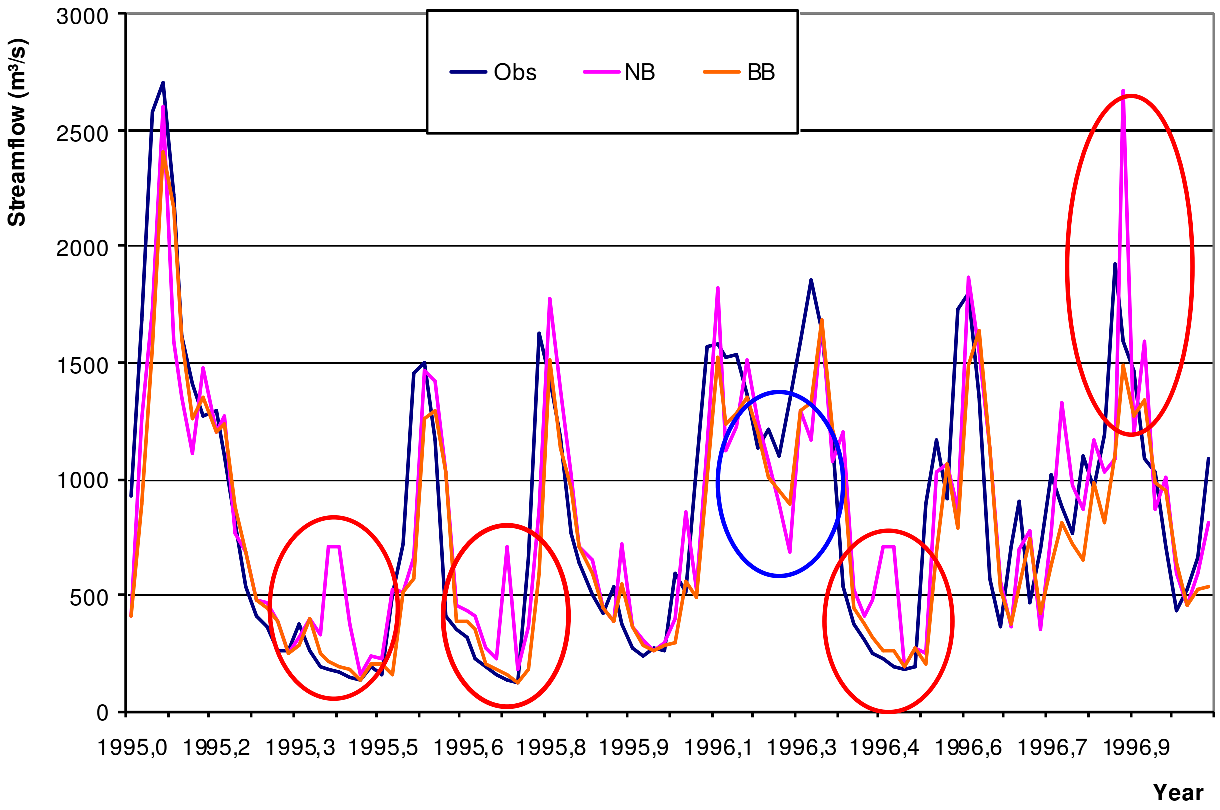
Goodness of fit criterion: Mean Absolut Percentage Error

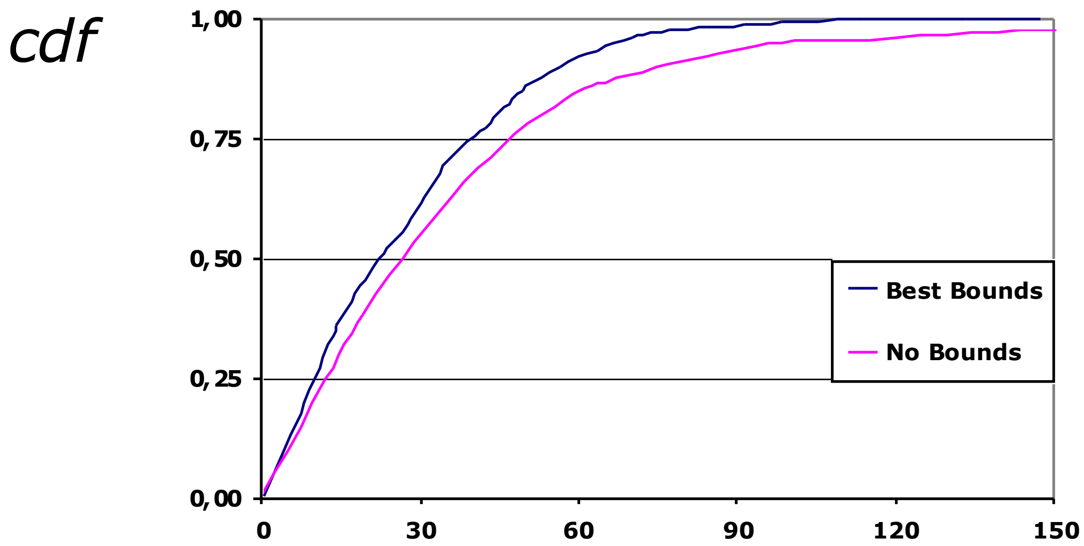
Best bounds parameterization leads to:

- Reduction of errors on recession periods



CASE STUDY – Foz do Areia

1st Week Statistics



1st Week	Mean	St. Dev.	Q25%	Q50%	Q75%	Q95%
No Bounds	37,16	42,07	12,43	26,79	47,32	98,26
Best Bounds	27,35	20,94	10,71	24,12	39,69	64,95
Reduction %	**26,39**	**50,23**	**13,85**	**9,98**	**16,12**	**33,91**

CONCLUDING REMARKS

- Considering the bounds on model selection led to smaller mean forecast errors over the validation period;

- A remarkable reduction of large errors has been obtained;

- The error reduction were observed to the 6 weeks;

- Similar results were obtained with the other metrics (RMSE, Nash-Sutcliffe index) considered in our study;

- Similar results were obtained to the other basins, especially to the other 2 basins in Southern Brazil (Uruguay and Jacuí);

- Other results (not presented) showed that the application of this approach to other watersheds whose hydrological features are similar to the ones considered herein leads to a similar error reduction pattern.

ONGOING WORK AND FUTURE DEVELOPMENTS

- Development of an automatic procedure aiming to define the “best bounds parameterization” to each series, taking into account:
    - Antecedent (wet/dry) conditions
        - Precipitation ; Moisture (estimated)
    - Seasonal hydrological response patterns
- Integrate daily forecasting (conceptual & stochastic) model results in 1st week PREVIVAZ modeling;
    - with forecasted “some-days ahead” precipitation
- Investigate the constraining of last weeks (5th/6th) PREVIVAZ modeling by a monthly forecasting model results.
    - Scenarios generation in 5th/6th weeks ahead?

Thank you !!!

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