Thermometer Data Forecast for a Buttress Block of the Itaipu Dam

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Abstract. The article presents the temperature forecast of thermometers installed in a buttress block of the Itaipu dam, more specifically the D-38 block. The models used were ARIMA (Autoregressive Integrated Moving Averages) and Holt-Winters (simple exponential smoothing), additive and multiplicative. Temperature data from three thermometers were used: TI-D-001, TS-D-003 and TS-D-004. The analyzes were carried out with the help of free software, R. The series with quarterly periodicity from 2008 to 2017 were considered for the modeling, with forecasts for the quarters of 2018, which were compared with the real data. The modeling that presented the best result, for the TI-D-001 and TS-D-004 instruments, was the additive Holt-Winters whose information criterion AICc obtained the lowest value and, in addition, presented the lowest MAPE in relation to the ARIMA model , which makes it the most suitable model. As for the TS-D-003 instrument, the model that best fitted, according to the AICc criterion, was the multiplicative Holt-Winters, but for the 2018 quarters, it presents MAPE superior to those of the ARIMA model.

Keywords: R Software, time series, ARIMA, HOLT WINTERS, temperature.

1 Introduction

Itaipu Binacional is the world leader in the production of clean and renewable energy, having produced more than 2.6 billion Megawatts-hour (MWh) since the beginning of its operations in 1984. With 20 generating units and 14 thousand MW of installed power, provides 15% of the energy consumed in Brazil and 90% in Paraguay [1] and [2].

Concrete dams are monitored with the help of instruments installed in their structure. In the case of Itaipu, there are more than 2,400 instruments (1,358 for concrete, 881 for foundations and 161 for geodesy) installed, providing data to technicians and engineers [1] and [2].

Among the instruments installed, there are surface thermometers and one internal thermometer. These provide temperature data that can be used as boundary conditions for a thermal analysis of a concrete block and one internal thermometer that can be used to validate a thermal model applied to the block [3].

According to [4], [5] and [6], a time series is any set of observations generated sequentially in time, having as a characteristic the dependence between the observations. Therefore, the data measured over time from thermometers can be statistically interpreted as time series.

Therefore, this study presents the analysis and prediction of the temperature obtained by three thermometers of the D-38 block of the Itaipu dam (one internal and two superficial) using the ARIMA [5] and Holt-Winters [7] methods.

2 Materials and Methods

The data used come from block D-38, located in the right-side dam of the plant. The block, also called the key block, has a large number of instruments that monitor its performance and safety levels, including 3 surface thermometers (TS-D-002, TS-D-003 and TS-D-004) and 1 internal thermometer (TI-D-001), as shown in Fig. 1.

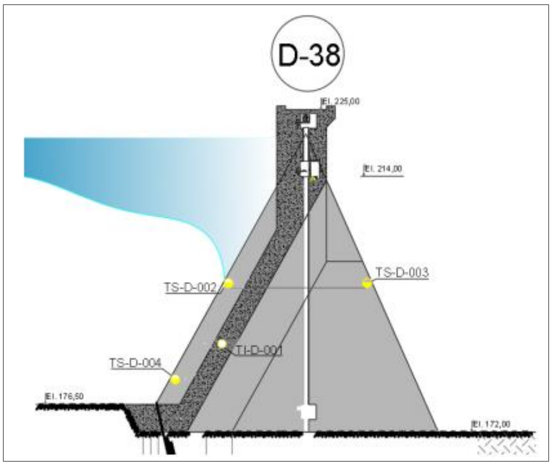

Figure 1. Cross section of the D-38 block

Quarterly temperature data from 2008 to 2018 for surface thermometers TS-D-003 and TS-D-004 and indoor thermometer TI-D-001 were considered, totaling 44 observations. The surface thermometer TS-D-002 was not considered in this study because it was deactivated in the 1980s. It was necessary to process the data to follow a defined periodicity, that is, organize them with the same time interval, in order to characterize a time series. The data used are represented in Fig. 2.

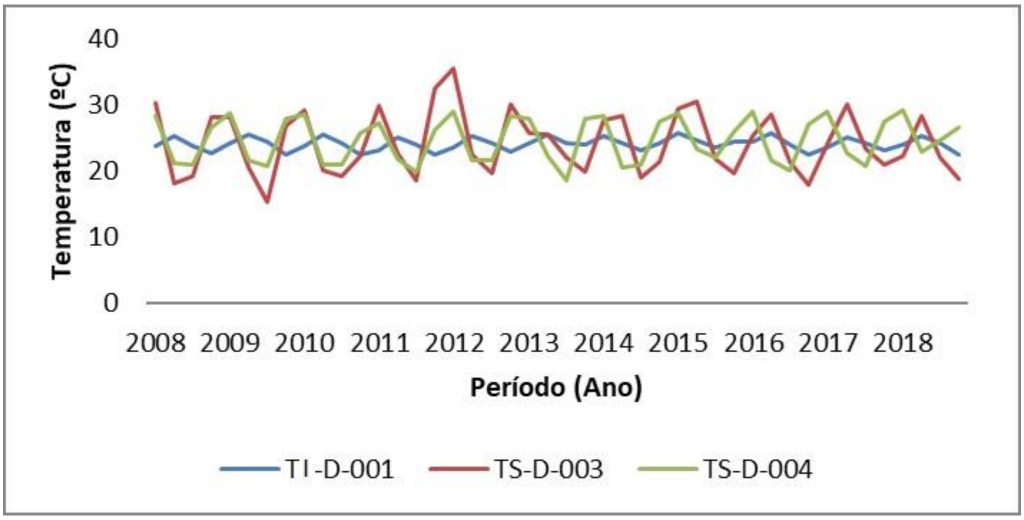

Figure 2. Temperature time series of block D-38 instrument TI-D-001, TS-D-003 and TS-D-004

The algorithms and modeling structures for forecasting the time series for the additive and multiplicative ARIMA and Holt-Winters models came from the forecast package of the R software. This algorithm automatically determines a suitable temporal model, estimates the parameters and calculates the forecasts, [7].

3 Results and discussions

Obtaining the models took into account the quarterly data from 2008 to 2017, leaving the quarterly data from the year 2018 for verification of the models obtained.

In order to guarantee the reliability and precision of the results, the validation of the ARIMA models was carried out, such as the correlation test and normality of the residues, as shown in Tab. 1. There are also the information criteria, Tab. 2, and the parameters of each ARIMA model, represented in Tab. 3.

Table 1. Residual normality and correlation test for TI-D-001, TS-D-003 and TS-D-004 instruments

Instrument	normality test	Correlation test
TI-D-001	0.141	0.5643
TD-S-003	0.526	0.3523
TD-S-004	0.3233	0.6394

An optimal ARIMA model was arrived at for each instrument:

1. TI-D-001: ARIMA (0, 0, 2) (0, 1, 2) [4];
2. TS-D-003: ARIMA (0, 0, 2) (0, 1, 1) [4];
3. TS-D-004: ARIMA (0, 0, 0) (0, 1, 2) [4].

Table 2. Information criteria of the ARIMA model of the TI-D-001, TS-D-003 and TS-D-004 instruments

Model	AIC	AICc	BIC	Sigma
ARIMA (0, 0, 2) (0, 1, 2) [4]	67.01	69.01	74.93	0.2682
ARIMA (0, 0, 2) (0, 1, 1) [4]	191.21	192.5	197.54	9,491
ARIMA (0, 0, 0) (0, 1, 2) [4]	101.54	102.29	106.29	0.7105

Table 3. Parameters of the ARIMA model of instruments TI-D-001, TS-D-003 and TS-D-004

Thermometer		ma1	ma2	sma1	sma2
TI-S-001	if	0.5065	-0.3006	-0.2822	-0.5716
		0.1995	0.1967	0.3598	0.2897
TI-S-003	if	0.4096	-0.4779	-0.4396	-
		0.162	0.1516	0.1567	-
TI-S-004	if	-	-	-1.1681	0.2758
		-	-	0.2776	0.1929

Subsequently, through the definition of the best ARIMA model for each series, forecasts were made for the next quarters of 2018.

Finally, for comparison purposes, the additive (SEHWA) and multiplicative (SEHWM) Holt-Winters model was applied, whose main parameters are represented in Tab. 4, moreover, in Tab. 5 are the information criteria AIC, AICc and BIC, used to choose the model that best suited the data.

It can be noted, from the criteria of additive and multiplicative modeling, that for the instrument TI-D-001, the model that best fits the series is the additive, as it has the lowest AICc values. This is also true for the TS-D-004 instrument.

Table 4. SEHWM and SEHWA model parameters of TI-D-001, TS-D-003 and TS-D-004 instruments

Thermometer	Instrument	alpha	beta	gamma	Sigma
SEHWM	TI-D-001	0.007	7.00E-04	1.00E-04	0.0285
	TS-D-003	1.00E-04	1.00E-04	0.5634	0.1442
	TS-D-004	0.006	7.00E-04	1.00E-04	0.0373
SEHWA	TI-D-001	1.00E-04	1.00E-04	1.00E-04	0.6795
	TS-D-003	0.0225	1.00E-04	0.526	3,827
	TS-D-004	1.00E-04	1.00E-04	1.00E-04	0.8654

As for the TS-D-003 instrument, there is a better fit from the multiplicative modeling, which presents a smaller information criterion, AICc. Thus, we have the prediction for TI-D-001 by the multiplicative Holt-Winters model and by the ARIMA model in Fig. 3. In addition, Tab. 6 brings the predictions of the two models as well as their error metrics.

Table 5. Information criteria obtained by the multiplicative Holt-Winters and additive Holt-Winters model for the TI-D-001, TS-D-003 and TS-D-004 instruments

Thermometer	Instrument	TI-D-001	TS-D-003	TS-D-004
SEHWM	AIC	126.8371	255.2038	148.6321
	AICc	132.8371	261.2038	154.6321
	BIC	142.0370	270.4037	163.8320
SEHWA	AIC	125.7179	263.9917	145.0634
	AICc	131.7179	269.9917	151.0634
	BIC	140.9178	279.1916	160.2633

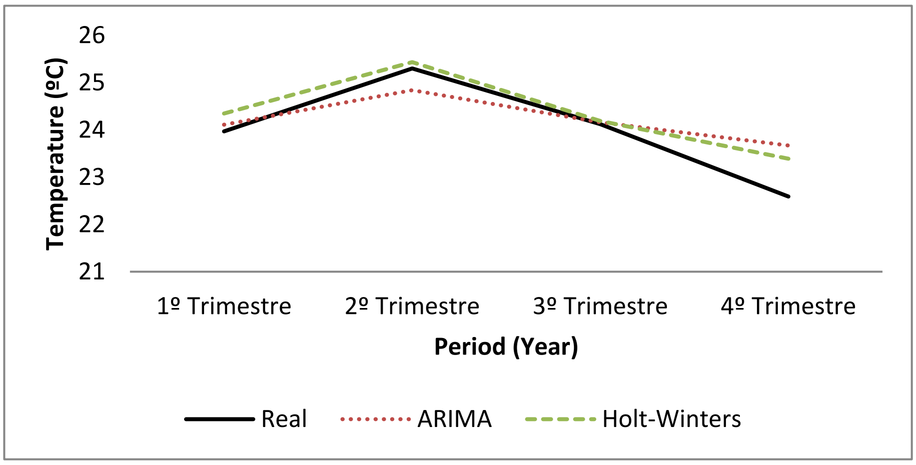

Figure 3. Temperature forecast of the TI-D-001 ARIMA instrument and additive Holt-Winters

Table 6. TI-D-001 thermometer temperature forecasts and forecast errors

Period (2018)	Real	Holt-Winters	ARIMA
1st quarter	23.97	24.34	24.11
2nd quarter	25.30	25.43	24.84
3rd quarter	24.12	24.19	24.16
4th quarter	22.59	23.39	23.67
MOTHER		0.34568	0.430000
RMSE		0.44904	0.591439
MAPE		1.48534	1.837240

The same methodology was followed for the TS-D-003 and TS-D-004 instruments where the predictions of the series in Fig. 4 and 5.

It can be seen, through Tab. 6, which compared to the real values of 2018, the closest model was the Holt-Winters, which for this instrument was considered the multiplicative model, so this is the one with the lowest MAPE

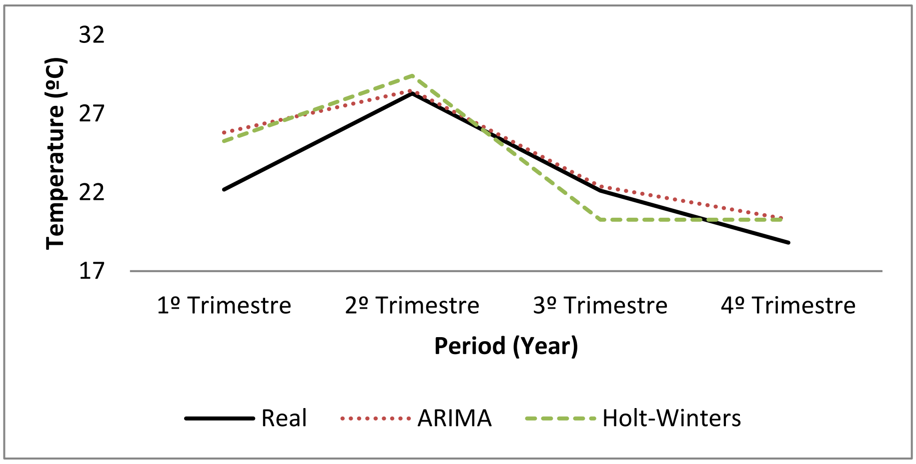

Figure 4. Temperature prediction of the TS-D-003 ARIMA instrument and multiplicative Holt-Winters

Table 7. TS-D-003 thermometer temperature forecasts and forecast errors

Period (2018)	Real	Holt-Winters	ARIMA
1st quarter	22.19	25.26	25.81
2nd quarter	28.29	29.41	28.48
3rd quarter	22.11	20.26	22.38
4th quarter	18.81	20.26	20.28
MOTHER		1.87510	1.39223
RMSE		2.01582	1.96345
MAPE		8.48020	6.52844

As for the forecasts of the TS-D-004 instrument, Tab. 8, the model that expresses the smallest MAPE, 2.47%, is ARIMA. This makes this model the most suitable for the thermometer, as its values are closer to the real data.

Table 8. TS-D-004 thermometer temperature forecasts and forecast errors

Period (2018)	Real	Holt-Winters	ARIMA
1st quarter	29.24	28.61	28.32
2nd quarter	22.95	22.07	21.55
3rd quarter	24.60	20.88	20.64
4th quarter	26.51	27.34	27.00
MOTHER		1.51374	0.69250
RMSE		1.98050	2.16379
MAPE		6.05489	6.79812

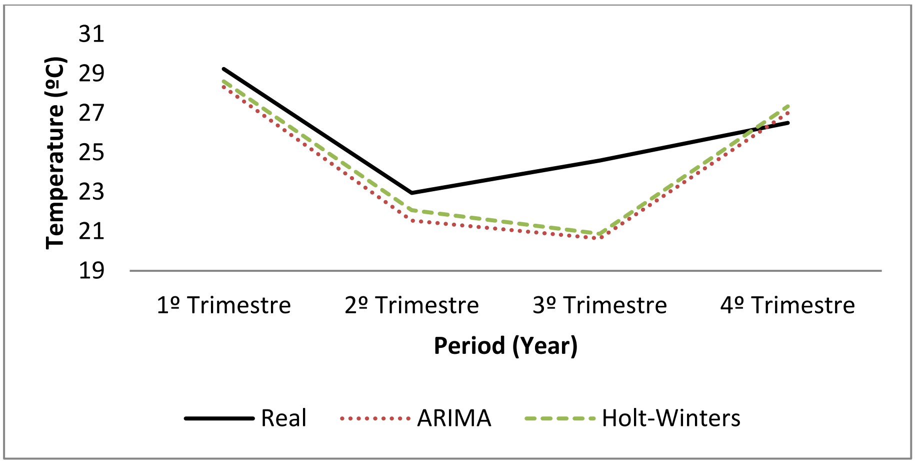

Figure 5. Temperature forecast of the TS-D-004 ARIMA instrument and additive Holt-Winters

4 Conclusions

The case study consisted of comparing the ARIMA, SEHWA and SEHWM methods in the prediction of temperature measured from thermometers installed in the block of buttresses D38 of the Itaipu dam. The series are published quarterly.

The TI-D-001 and TS-D-004 instruments obtained forecasts which show that the SEHMA modeling is very satisfactory for the time series studied since the MAPE of the forecast was 1.48% for the quarters of the year 2018, for TI-D-001, and 6.05%, for TS-D-004, respectively. As for the TS-D-003 instrument, the ARIMA modeling obtained a MAPE of 6.52%.

Note that for the series of instruments TI-D-001, TS-D-003 and TS-D-004, each data set has different characteristics, that is, although they come from the same type of instrument, some variations and properties are different.

As a suggestion for future research, we propose the application of other models that allow the insertion of more variables that influence the behavior of the observations. Furthermore, complementary studies can be carried out with, for example, the analysis of the structural behavior using the predictions obtained by the methods presented in this article, to obtain the future thermal behavior of the structure.

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