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NOTAS Y CORRESPONDENCIA

A MAXIMUM TEMPERATURE FORECASTING METHOD FOR THE CITY OF PELOTAS, RIO GRANDE DO SUL

Natalia Fedorova[•2], M. H. de Carvalho[1], V. Levit[2], B. C. Marcelino[1], A. M. Gonçalves[1], E. P. Alves[1], E. Signorini[1], G. C. Pinheiro[1], J. Marques[1], V. M. de Oliveira[1], A. J. de Almeida[1], C. B. Botelho[1]

[1] Centro de Pesquisas e Previsões Meteorológicas, Faculdade de Meteorologia, Universidade Federal de Pelotas (UFPel), Brazil

[2] Centro de Ciências Exatas e Naturais, Universidade Federal de Alagoas (UFAL), Brazil

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RESUMEN

La predicción de la temperatura máxima es muy importante para la población. Con el objeto de ofrecer un método de prever esta temperatura, fue adaptado y testado un método que es basado en la altura de la capa con gradiente vertical adiabático seco. La base de datos consistió de tres años: 1998, 1999 y 2000. Los coeficientes de determinación y de correlación fueran determinados y las dos series, temperatura máxima observada y temperatura máxima prevista, fueron comparadas. Los resultados muestran que el método testado es bueno, al menos, para la región de Pelotas.
Palabras clave: temperatura máxima, pronóstico del tiempo, capa límite

UN MÉTODO DE PRONÓSTICO DE TEMPERATURA MÁXIMA PARA LA CIUDAD DE PELOTAS, RIO GRANDE DO SUL

ABSTRACT

Forecasting maximum temperature is very important for the population. In order to offer a way of forecasting this temperature, a method was adapted and tested based on the height of the layer with a dry adiabatic lapse rate. The database was formed over a period of three years: 1998, 1999 and 2000. Determination and correlation coefficients were calculated in order to verify the method validity. Also, several statistical characteristics were determined and the observed and forecasted maximum temperature series were compared. The results show that the method tested is a good one, at least for the region of Pelotas.
Key words: maximum temperature, weather forecasting, boundary layer

• E-mail: natalia@ccen.ufal.br

1. INTRODUCTION

Extreme temperatures (maximum and minimum) that occur in a certain region are of interest not only to meteorologists, but also to the community in general. Numerical prediction model products that are received at the Meteorological Research Center (MRC) o the Federal University of Pelotas do not include maximum temperature; however, the inclusion of this meteorological element for daily weather forecasting is obligatory, which verifies the necessity of having a method to forecast this parameter in Pelotas.

The first description of the formation of the dry adiabatic lapse rate layer, which happens during the day when maximum temperature is observed (generally, at 1:00pm or 2:00pm local time), was made by Petterssen (1940). He presented the process through which a nocturnal temperature inversion is created in the boundary layer and he also explained how a layer with a dry adiabatic lapse rate is formed near the surface. Based on Petterssen, and on special studies for the European region, a maximum-temperature forecasting model was developed for the regions of the middle latitudes in Russia (Manual, 1986). This method has been used operationally in Central Russia for many years.

Studies on temperature in Brazil have been made; for example that of Becker et al. (1992) in which this variable was grouped for the state of Rio Grande do Sul by applying cluster analysis. Monthly data was acquired over a thirty-year period from forty-one meteorological stations. Five homogeneous groups were found that clearly define isothermal bands and regional topography.

In their discussion of specialist systems applied to weather forecasting, Duarte and Rebello (1988) considered maximum temperature observed on the previous day, as well as other parameters that have influence in the determination of air temperature.

Menzies and Ferreti (1984) carried out frequency analyses of maximum and minimum temperatures series, adjusting them to the first asymptotic distribution of extremes and calculated the values corresponding to a thirty-year return period. They made maps for a representative month of each season presenting the real series of the highest maximum temperatures and the lowest minimum temperatures, and also maps of their corresponding theoretical values.

Klein and Lewis (1970) described an automatic system for forecasting maximum and minimum surface temperatures. The system used multiple regression equations derived for one hundred and thirty-one cities in the United States and twelve in southern Canada. They presented verification statistics for 18 months of operational forecasts that were obtained through the use of barotropic and Reed numerical models as input to the multiple regression equations. They concluded that, during that period, the automatic temperature predictions were superior to those using persistence and almost as good as the subjective ones.

Klein and Hammons (1975) developed an automatic system of maximum and minimum surface temperature forecasting based on MOS (Model Output Statistics) that combines numerical and statistical methods. With this system, they increased the accuracy of automatic forecasts.

Another paper in which statistical forecasting of maximum and minimum temperatures was used is that of Winkler and Murphy (1979). They used probabilistic temperature forecasting and considered alternative summary measures of a forecaster's probability distribution of temperature. They also suggested "credible intervals" as a suitable choice for operational forecasts of this continuous variable. In the paper, the term "credible interval" is defined as an interval of temperature values accompanied by a probability that expresses the forecaster's degree of belief that the temperature will actually fall inside the interval. The experimental results indicate that experienced forecasters can formulate reliable and skillful credible interval temperature forecasts.

Recently, Massie and Rose (1997) studied the relationship between forecasted geopotential thickness and observed maximum temperature, in order to examine the viability of using this parameter to aid in forecasting maximum temperature by means of regression equations.

The objective of this research is the development of a maximum temperature forecast method for Pelotas, using the height of the dry adiabatic lapse rate layer. In light of this, an existing method was tested for the specific region of Pelotas, RS. Moreover, a climatology of the height of the dry adiabatic lapse rate layer, *hd*, was obtained for each month and in differing situations of cloud cover.

2. DATA

Files of the data described below were compiled.

1. The temperature fields (12-hour forecasted temperature, from 00 UTC) for pressure levels 1000, 925, 850, 700, 500 and 400 hPa, which were obtained from NCEP (National Centers for Environmental Predictions - United States of America) model.
2. Meteorological data from the Meteorological Station (7m above sea level) at the MRC of the Federal University of Pelotas: maximum temperature (TMAX), dry bulb maximum temperature (TMBS), which were obtained using the maximum and dry bulb thermometers, respectively, and pressure. The observed data (which will be discussed in section 4.1) show that the difference between TMAX and TMBS is large, approximately 1^{o}C. That difference was registered consistently, and therefore, both of them must be taken into account. It should be noted that since those temperatures are different, the results of their use will also be different. Lack of information about which method is preferable (TMAX or TMBS) did not permit us to choose between them. Therefore, both temperatures were used. Cloud type and quantity were also specially recorded for this study at the MRC Meteorological Station.

The data in these files were collected over a period of three years, that is, from the 1st of August, 1997 to the 31st of July, 2000. Data for two years, from August 1, 1997 to July 31, 1999, were used to elaborate the forecasting method. In order to verify the validity of the elaborated method, data from the years – from August 1, 1998 to July 31, 1999, and from August 1, 1999 to July 31, 2000 – were used (but not for obtaining climatology).

3. METHODOLOGY

3.1 Maximum Temperature Calculation Method

A method for calculating the maximum air temperature near the surface (TMAX) was elaborated for Pelotas. This method is based on the relationship between this temperature and that at the top of the boundary layer. During the day, when maximum temperature is observed, an air layer with dry adiabatic lapse rate is formed (Petterssen, 1940). If there is information about the temperature at the top of this layer (T_h), then TMAX can be calculated using the equation:

$$TMAX = T_h + \gamma_d h_d,$$

in which γ_d is the dry adiabatic lapse rate and *hd* is the height of the dry adiabatic lapse rate layer.

Tmax may also be calculated using an adiabatic diagram, that is, starting from the point (T_h, h_d), one must follow the dry adiabatic, which passes through that point, down to the surface pressure value. The temperature at that point is TMAX. The method of calculating height *hd* and the values of *hd* obtained for Pelotas will be discussed later in sections 3.2, 3.3 and 4.1.

3.2 Vertical Temperature Distribution Graphs

The vertical temperature distribution graphs were made at 3:00pm (local time) on “SKEW-T, log P” thermodynamic diagrams for the geographical point with coordinates: 31^o 43’ S; 52^o 19’ W (Pelotas). These graphs were designed using temperature data from the fields of this variable supplied by the NCEP numerical model. The following pressure levels were used: 1000, 925, 850, 700, 500 and 400 hPa (fields from NCEP) and surface data from Pelotas. These data were used because there is no radiosonde station in Pelotas and also because meteorologists at MRC use NCEP model data for daily weather forecasting.

3.3 Calculation of the top of the dry adiabatic lapse rate layer

The height of the top of the dry adiabatic lapse rate layer (*hd*) was calculated daily and then monthly averages were determined. These values of the monthly average *hd* were used afterwards to calculate the daily forecasted maximum temperature (TmaxF). This was done because of the lack of data for many years. The values of *hd* were obtained using vertical distribution graphs of 12-hour forecasted temperatures for Pelotas in the thermodynamic diagram “SKEW-T, Log P” (as it was described in Section 3.2). To find the value of *hd* one must follow the dry adiabatic curve in an upward direction, starting at the point of the maximum temperature value at the surface pressure level, and then continue in an upward direction to the level where that adiabatic curve crosses the vertical temperature distribution curve. This crossing level is the top of the dry adiabatic lapse rate layer, that is, the height *hd*.

There are two types of maximum surface temperature data at the MRC station, that is, TMAX and TMBS. Because of this, two values of *hd* were calculated; they are HMAX, using TMAX data and HMBS, using TMBS data. The depth *hd* depends on the type and quantity of clouds and also, on the season. Thus, the relationship between the depth of this layer and cloudiness was studied for each season.

In order to use *hd* in forecasting daily maximum temperature, a new table was designed, with the rounded averages of HMAX and HMBS.

3.4 Analysis Methodology of maximum temperature forecasting errors

In order to verify the validity of the method presented, the following quantities were calculated: the residual mean square, regression sum of squares and residual sum of squares for the maximum temperature. The linear equation for the graphs of TMAX and forecasted maximum temperature (TmaxF) was determined. The correlation coefficients of TmaxF and TMAX, or TMBS for years 1999 (101 days) and 2000 (110 days), were also calculated.

With the objective of evaluating the method utilized, the determination coefficient, r^2, was also calculated. It is given by the following equation: $r^2 = 1 - \frac{V_{ne}}{V_t}$,

in which $V_{ne} = \frac{1}{N-1}\Sigma(y_i - f_i)^2$ is non-explained variance and $V_t = \frac{1}{N-1}\Sigma(y_i - \overline{y})^2$ is total variance, that is, the variance of points around $\overline{y}$ (Stevenson, 1981). Y_i denotes the observational data; f_i represents the forecasted values and $\overline{y}$ is the average of the observational data**.** This coefficient indicates how much of the total variance is represented by the one explained by regression.

Curves for the time series of forecasted and observed maximum temperature (TMAX and TMBS) at MRC, for two years (1999 and 2000,) were developed. In the abscissa, the word “Days” refers to days when there were both TMAX data and a vertical temperature profile, which permitted the calculation of the forecasted maximum temperature. The calculations were not made for every day of the period studied due to discontinuities in the TMAX data on weekends when observations were not made, and also due to discontinuities in the model data.

4. RESULTS

4.1 Depth of the dry adiabatic lapse rate layer

First, the values of TMAX and TMBS, used for the calculation of *hd*, were analyzed. The average values of TMAX and TMBS are presented in Table I in all seasons during the period of study. These data show that the average values of TMAX (TMBS) had varied during the year, from 18.8^o C (18.0^o C) to 26.0^o C (25.0^o C), respectively. TMAX is higher than TMBS in all seasons. The difference between TMAX and TMBS is minimum in autumn (0.7^o C) and maximum in spring, when it reaches 1.0^o C. This difference is significant, but there is not any reason for leaving one of them out; therefore, both temperatures were used in the investigation.

Season	**TMAX**	**TMBS**
Winter	18,8	18,0
Spring	24,0	23,1
Summer	26,0	25,0
Autumn	20,2	19,5

Table I: Average values of TMAX and TMBS (^{o}C) in all seasons

The average values of HMAX were 910hPa for winter and higher for summer (870hPa) (Table II). For HMBS, those values were 923hPa and 887hPa, respectively.

Similar to the observed difference between TMAX and TMBS, there is a difference between HMAX and HMBS (Table II). In all seasons, the depth of the layer with dry adiabatic lapse rate is greater when the height of this layer is calculated using TMAX data. The difference between HMAX and HMBS varies from 13 to 22 hPa. This layer is deeper in summer and shallower in winter.

Season	HMAX	HMBS
Winter	910	923
Spring	906	928
Summer	870	887
Autumn	910	937

Table II: Average values of HMAX and HMBS (hPA) in all seasons

The analysis of the depth of the layer with dry adiabatic lapse rate was made by relating it to cloud types and quantities. Using the data file of TMAX and TMBS the values of HMAX and HMBS were calculated. These values are presented in Table III. In all seasons, the height of the dry adiabatic lapse rate layer was the largest on days with no clouds or with high clouds (HMBS and HMAX were 885 and 879hPa, respectively). Days with low cloud cover >6/10 were associated with the lowest height of this layer (921 e 918hPa). The height of the dry adiabatic lapse rate layer has the lowest values in winter and the highest in the summer for all types of clouds. The variances of these heights during the year were less for low-cloud days than for the days without clouds or days with high clouds.

The difference between HMAX and HMBS for all cloud types remains between 0 and 70 hPa. The largest differences were observed in the months of December (55 hPa for days with low cloud cover >6/10), April (45 hPa, also with low cloud cover >6/10) and February (70 hPa, for middle or low cloud cover ≤ 6/10). This means that depth values of the dry adiabatic lapse rate layer are less reliable during these months. On the average, for middle or low cloud cover ≤ 6/10 and for low cloud cover > 6/10, this difference was a little bit smaller than 20 hPa. For high cloud cover, the difference is smaller, 8 hPa.

Month	Cloudiness								
	Without clouds or high clouds			Middle clouds or Low clouds (≤ 6/10 of cover)			Low clouds (>6/10 of cover)		
	HMBS	HMAX	D	HMBS	HMAX	D	HMBS	HMAX	D
January	863	855	08	855	845	10	895	913	18
February	860	845	15	898	828	70	893	883	10
March	---	---	---	862	824	38	887	902	05
April	887	876	11	894	898	04	950	905	45
May	911	912	01	921	912	09	953	939	14
June	948	928	20	951	932	19	973	956	17
July	904	892	12	910	894	16	957	934	21
August	922	920	02	912	916	04	942	935	07
September	889	884	05	878	869	09	941	943	02
October	873	872	01	937	937	00	921	920	01
November	829	824	05	915	913	02	921	915	06
December	850	860	10	912	950	38	822	877	55
Mean	885	879	8	904	895	18	921	918	17

Table III: Height (hPa) of the dry adiabatic lapse rate layer (HMAX and HMBS) for each month, with respect to cloud cover and the level of clouds. The symbol indicates that this kind of cloudiness does not appear in the database. D is the difference between HMBS and HMAX

Table IV was designed with the rounded averages of HMAX and HMBS, which were used as *hd* to predict the maximum temperature. In June the height *hd* was smaller than in other months for any kind of cloudiness. The height *hd* reached its maximum value (830 hPa) in November, on days without cloudiness or with high clouds. On days with middle or low clouds and sky cover ≤ 6/10, the deepest layer (850 hPa) was observed in January and March. In December, on days with low clouds or sky cover greater than 6/10, the height *hd* presented the greatest value (850 hPa).

Month	Cloudiness					
	Without clouds or high clouds		Middle clouds or low clouds (≤ 6/10 of cover)		Low clouds (>6/10 of cover)	
	h_d	(%)	h_d	(%)	h_d	(%)
January	860	25	850	35	900	40
February	850	11	860	26	890	63
March	-	3	840	38	900	59
April	880	28	900	36	930	36
May	910	16	920	39	950	45
June	940	41	940	23	960	36
July	900	26	900	34	950	40
August	920	25	910	23	940	52
September	890	18	870	36	940	46
October	870	18	940	27	920	55
November	830	17	910	40	920	43
December	860	14	930	32	850	54
Mean	880	21	900	32	920	47

*Table IV: Height (**h_d**, hPa) of the dry adiabatic lapse rate layer for each month with respect to cloud cover and the level of the clouds; percentage of days (%) for each situation. The symbol – indicates that this kind of cloudiness does not appear in the database*

4.2 Calculation of maximum temperature forecast in Pelotas

First, it is necessary to make a vertical temperature profile for Pelotas using forecasted temperature fields at all available levels.

Using values of *hd* obtained for Pelotas (Table IV) maximum temperature forecast calculations were made. To obtain that temperature, one must start from the point where the vertical temperature profile reaches the top of the dry adiabatic lapse rate layer and then to go down along the dry adiabatic to the surface pressure level. The value found is the forecasted maximum temperature. The results of the error analysis of this forecast will be discussed in section 4.3. An example of a vertical profile for the 8th of December, 2000 and the determination of the forecasted temperature may be seen in Figure 1.

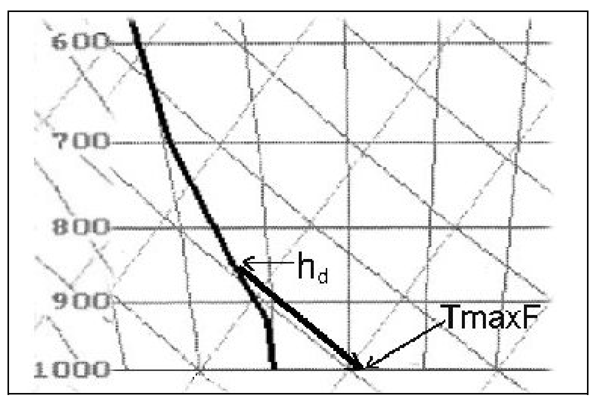

Figure 1: Example for December 8, 2000

The values of *hd* for various types of clouds, which will be used for forecasting maximum temperature, are presented in Table IV. During the day, in our example, *Ci* and *Cc* clouds were observed. The choice of the value of *hd* depends on the month and also, on the quantity and type of cloudiness forecasted. In our example, for the month of

December and for high-level cloudiness, the value of *hd* is equal to 860 hPa (Table IV).

After the value of h_d has been located on the vertical temperature profile, one must begin at that point (in our example, the temperature at that point is equal to 18^o C at the level 860 hPa) and then follow in a downward direction along the dry adiabatic to the surface pressure value (in our example, this value is 995 hPa). The temperature value, at this point, is the forecasted maximum temperature; in this case, the temperature is equal to 31.5^o C. The observed maximum temperature for this day was 31.8^o C.

4.3 Error Analysis of the maximum temperature forecast in Pelotas

The statistical characteristics (Downing and Clark, 1999) of the database of TMAX and TMBS and of TmaxF for the years 1999 and 2000 are presented on Table V.

The correlation coefficients between the forecasted maximum temperature and TMAX or TMBS for 1999 are 0.82 and 0.81, respectively. The same coefficients for the year 2000 are 0.89 and 0.88, respectively. There were more than 100 cases of observed data in each correlation analysis, with only one parameter (*hd*); therefore, all correlation coefficients obtained are statistically significant at a significance level of 5%.

Table VI presents the determination coefficients, the regression sum of squares, the residual sum of squares and the root mean square error of the forecasted maximum temperature in relation to TMAX for two years. All these characteristics show good agreement between TMAX and TmaxF for both years. The concordance was a little better for year 2000.

It should be emphasized that on some days in winter, there were stratiform clouds or fog. In these cases, the existence of a low-level temperature inversion did not allow the calculation of the forecasted maximum temperature for these days. Therefore, this method should not be used in situations where a low-level temperature inversion is observed.

Figure 2 presents the forecasted and observed maximum temperature time series, for two years. It presents all available data. On some days, for example on weekends, there were no observations made. Therefore, on the abscissa, "Days" does not mean every day of the year, but only the days on which observations were carried out.

Statistical characteristics	1999			2000		
	TMAX	**TMBS**	**TmaxF**	**TMAX**	**TMBS**	**TmaxF**
Mean	22,3	21,4	21,7	20,4	21,0	20,6
Median	22,6	21,2	22,0	20,8	21,3	20,5
Variance	20,6	18,0	17,6	31,8	33,7	32,8
Standard-deviation	4,5	4,2	4,2	5,6	5,8	5,7
Minimum	13,0	13,2	13,2	10,4	10,0	6,5
Maximum	32,2	30,0	30,0	35,2	35,0	32,0
Amplitude	19,2	16,8	16,8	24,8	25,0	25,5
Asymmetry	0,047	0,064	0,050	0,221	0,202	-0,107
Kurtosis	-0,794	-0,637	-0,572	-0,548	-0,520	-0,557

Table V: Statistical characteristics of the database of TMAX, TMBS and TmaxF for years 1999 and 2000

Statistical characteristics	**1999**	**2000**
Determination Coefficient, r^2	0.675	0.797
Average TMAX	22.3	21.4
Average TmaxF	21.7	20.6

Regression sum of squares	1192.4	2849.4
Residual sum of squares	573.4	725.7
Residual mean square, sigma-hat-sq'd	5.79	6.72

Table VI: Statistical characteristics of the correlation between TmaxF and TMAX for years 1999 and 2000.

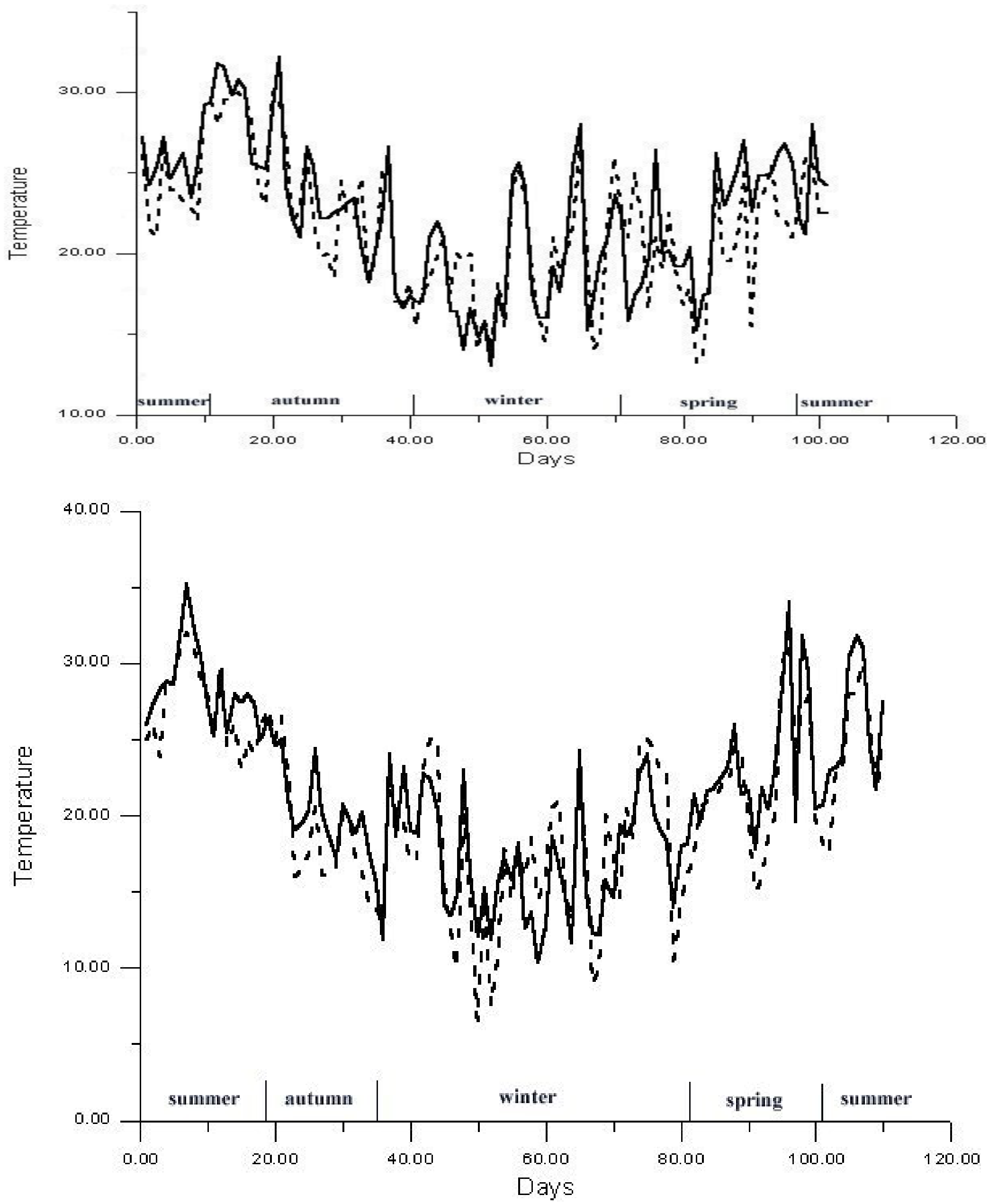

Figure 2: Time series of daily forecasted (----) and observed (___) TMAX for 1999 (a) and 2000 (b).

In all seasons of the two-year study, one verifies that the values of observed maximum temperature are, on some days, larger and, on other days, smaller than the forecasted maximum temperature, that is, systematic errors (TmaxF always greater or smaller than TMAX) were not observed. Figure 2 also indicates that there are, on the average, only 2 days in each season that show a difference between the forecasted and the observed maximum temperatures greater or equal to 5 ºC. In general, they appear similar, and therefore, it can be noted that for different seasons there is good agreement between the two series shown.

5. CONCLUSIONS

A method was elaborated for forecasting maximum temperatures in Pelotas using the height of the dry adiabatic lapse rate layer during the day. The authors thank the "Fundação de Amparo à Pesquisa do Rio Grande do Sul (FAPERGS)" for supporting the development of this research.

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As a result, a table with the values of the top of this layer was obtained with the intent to be utilized operationally for maximum temperature forecasting. The correlation coefficients of the forecasted maximum temperature and TMAX or TMBS are between 0.81 and 0.89 for the years 1999 and 2000. Therefore, that method may be used for maximum temperature forecasting.

Acknowledgments:

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