Weather Forecasts: How Reliable Are They?

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Abstract

How reliable are the weather forecasts? Based on data collected from one hundred and thirteen cities in the United States over 38 months on three variables, maximum temperature, minimum temperature, and Precipitation, accuracy of the weather forecasts was examined. The same day forecast has been extremely accurate, especially for the maximum temperature, while the forecast errors and variability increase as we go further out in days forecast. Some cities have larger or smaller forecast errors compared to others. For long-term weather forecasts, the maximum and minimum temperature forecast errors has decreasing correlations overtime, respectively; However, the correlation between maximum and minimum temperature forecast errors is positive and increasing overtime. The 7-days forecast errors of precipitation are pretty accurate.

Key Words: Accuracy, weather forecasts, temperature, precipitation

1. Introduction

One common usage of using models to predict an outcome is weather forecast. We see weather forecasts every day and use them in our daily planning, agriculture and industry. How accurate are these forecasts? For example, if the forecasted high temperature for a day is a couple of degrees different from the actual high temperature then it will not make much of a difference in whether we chose to wear a coat, jacket, or neither. But if the forecast had been off by 20 degrees, then it would have made a huge difference. Furthermore, large departures from long-term climatological patterns can produce considerable economic and personal hardship. Hence weather forecasting is important and relevant to societal problems, locally, nationally, and internationally (Hobbs, 1980). We examine the accuracy of both short-term and long-term weather forecasts in this paper.

One hundred and thirteen cities in the United States were selected such that the cities were fairly spread out, at least one city was chosen in each state. For comparison, the airport closest to the latitude and longitude of the city with data over the period was selected and historic data for those airports were recorded for approximately 3 years. The historical forecast data are compared to 7-day weather forecast data available for these cities. Note that the comparison of the predictions to the historical data is not truly fair. The predictions are an average over an area but the historical data was measured at an airport within or close to that area. The prediction areas may have changed over the 3 years as well.

The data consist of three data files, locations.csv, forecast.dat, and histWeather.csv which are available for download from `http://ww2.amstat.org/sections/graphics/datasets/DataExpo2018.zip`.

The locations.csv file is a comma separated value file that contains information on the cities for which the forecasts was made. The columns are city, state, longitude, latitude, and AirPtCd. The latitude and longitude columns were used to get the forecasts and the corresponding airport code (AirPtCd).

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The forecast.dat file is a white space separated file with about 3 years worth of forecasts. This file does not have a header row. The first column is the city number corresponding to the row in the locations.csv file. The second column is the date being forecasted, the 3rd column is the forecasted value. The 4th column indicates what value is being forecast (MinTemp, minimum temperature; MaxTemp, maximum temperature; and ProbPrecip, the probability of precipitation). The 5th column is the date that the forecast was made on. The temperatures are measured in degrees Fahrenheit. Note that there are 2 probabilities of precipitation forecasts for each day, the first is the morning prediction and the 2nd is the afternoon/evening prediction.

The histWeather.csv file is a comma separated file with the historic measures of weather from the airports. The main columns of interest are: AirPtCd which is the airport code for where the historical measurements were obtained and corresponds to the same column in the locations.csv file; Date which is the date of the measurement; Max_TemperatureF and Min_TemperatureF which are the maximum and minimum recorded temperature for the date; and PrecipitationIn which is the amount of precipitation in inches of water.

2. Data manipulation

The R software (R Core Team, 2018) and lots of R packages (Wickham, 2016) are used to manipulate and visualize the data. For convenience of comparison, the 3rd and 4th column are removed and the following 5 variables are added to the file forecast.dat: MinTemp (minimum forecast tempreture), MaxTemp(maximum forecast tempreture), ProbPrecip(probability of precipitation), Month(month of forecast), Time(the time point in month during the 39-month period), Year (year of forecast), and date_diff(the difference between date being forecasted and forecast date). That is, 10 variables are now available in the forecast.dat file: ID, date, ForecastDate, date_diff, Month, Year, Time, MinTemp, MaxTemp, ProbPrecip. Furthermore, this forecast file is split into four subset files based on the three variables: MinTemp, MaxTemp, and ProbPrecip. Notice that two files for the precipitation forecasts are produced: morning forecasts and afternoon forecasts.

Then the ID, Month, Year, Time variables are added to the histWeather file. To compare the historic data and forecast data, we merge the forecast and histWeather files for the variable MinTemp and MaxTemp.

There are only 27 observations about the 7th-day weather forecast. We remove these data values and define forecast errors as the difference between the observed data and the forecast data. For this, we add the forecast error variables $e_0, e_1, \ldots, e_6$ for both MinTemp and MaxTemp variables, where the subscript i in e_i denotes the difference between date being forecasted and forecast date (date_diff).

There are less than 800 historical observations in the last month, September 2017, thus these data values are removed and we consider the data from the 38 months only for convenience of comparisons by month.

3. Analysis of forecast errors for MaxTemp and MinTemp

In this section, we analyze the forecast errors for both the MaxTemp and MinTemp variables. The sample sizes for MaxTemp and MinTemp are 806,770 and 765,340, respectively. It is noted that almost all forecast errors are within 30 Fahrenheit degrees. It is highly likely that these forecast errors are measurement errors. Thus

we consider the forecast errors with absolute values no more than 30 Fahrenheit degrees. As a result, the sample sizes are decreased to 806,667 and 764,901, respectively.

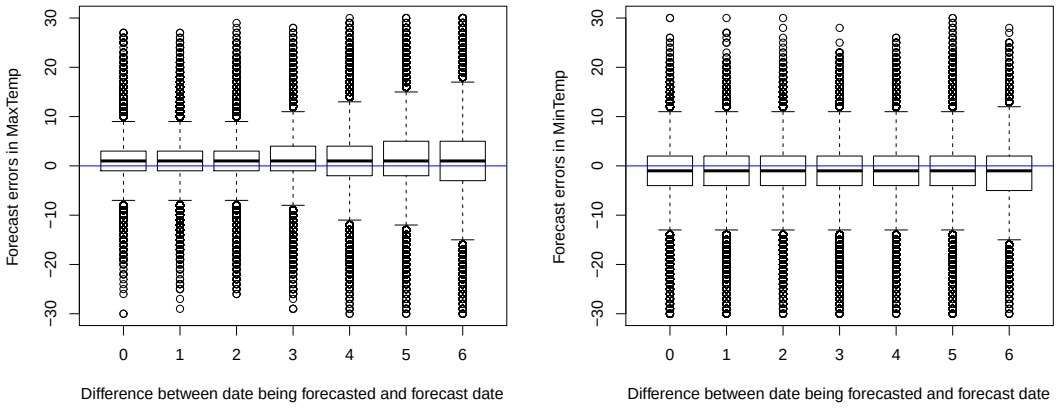

Figure 1: Seven days' MaxTemp and MinTemp forecast errors

From Figure 1 the box-plot of the forecast errors, it can be seen that all seven-day forecasts have medians very close to 0, while as the forecasted date gets further, the variation of the forecast error as shown by the IQR (Interquartile Range) becomes larger. It is desired to check all seven-day forecast errors.

First, let's see the same-day forecast errors by month. Figure 2 the box-plot is the same-day forecast errors from January to December in a year. Again, all forecast errors have medians very close to 0. Furthermore, the forecast errors for the summer season (May, June, July, August and September) has less variation than those in other months. The mean and standard deviation statistics for the twelve months are listed in Table 1. It can be seen that in general, the MinTemp forecast errors are larger than the MaxTemp forecast errors.

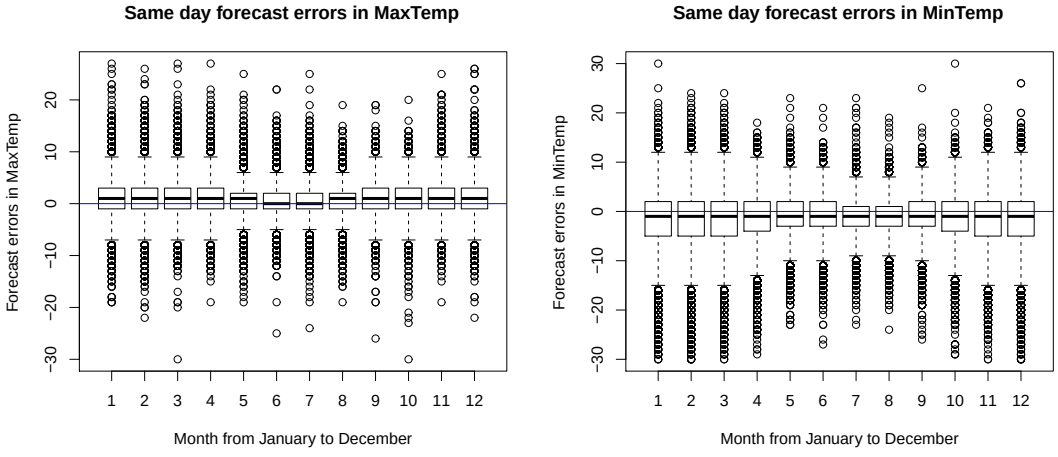

Figure 2: Same-day MaxTemp and MinTemp forecast errors

The forecast errors for one-day to six-day forecast have similar pattern which can

Table 1: Same day forecast errors for twelve months in a year.

Variable	Statistics	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
MaxTemp	Median	1	1	1	1	1	0	0	1	1	1	1	1
	Mean	1.19	1.34	1.12	0.88	0.57	0.60	0.47	0.55	0.85	0.83	1.11	0.88
	S.D.	3.90	3.95	3.75	3.49	3.42	3.13	3.20	3.04	3.06	3.03	3.43	3.75
MinTemp	Median	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Mean	-1.93	-1.96	-1.64	-1.42	-1.05	-0.85	-0.77	-0.87	-1.03	-1.50	-1.80	-1.73
	S.D.	6.50	6.67	6.14	5.36	4.35	4.10	3.68	3.63	4.18	5.16	5.98	6.40

be seen from Figure 3 and 4. Note that there were no six-day weather forecast data after the seventeenth month. So the last graph in Figure 4 looks a little different.

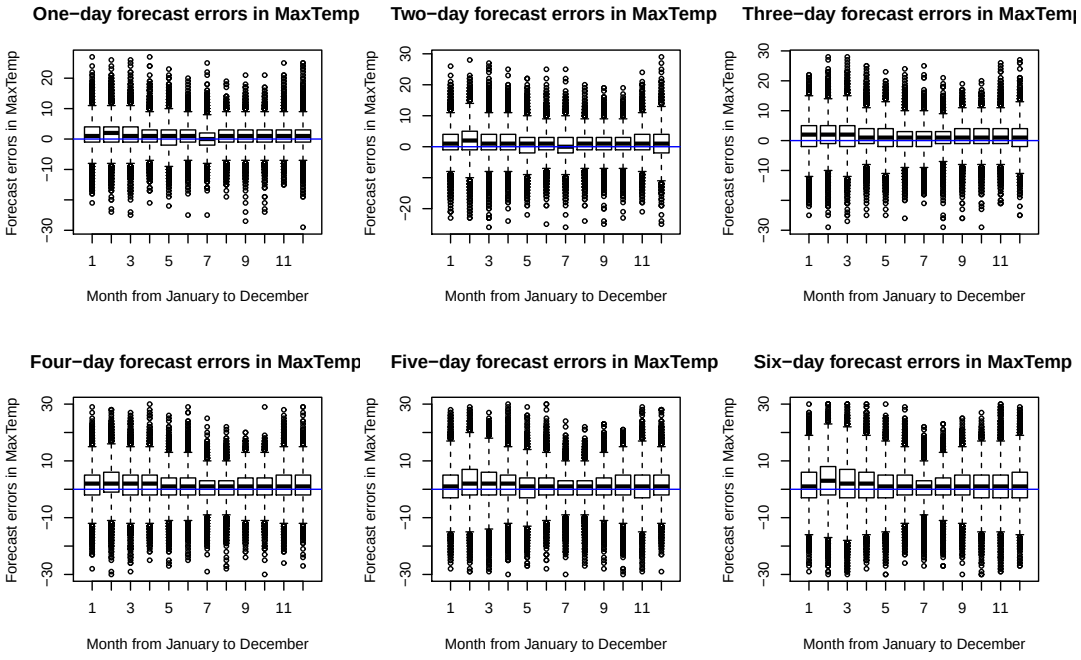

Figure 3: One-day to six-day MaxTemp forecast errors by month

Furthermore, the variability of the forecast errors increase as we go further out in days forecast. The variability for the seven-day weather forecast indicated by standard deviations is summarized in Table 2.

Mean and standard deviations of MaxTemp and MinTemp Seven-day forecast errors by month are summarized in Figure 5 and 6. It can be seen from these two figures that forecast errors and variances increase over time. And again, the MinTemp forecast errors are larger than the MaxTemp forecast errors. Furthermore, the MinTemp forecast errors differ from month to month much larger than the MaxTemp forecast errors.

Did some cities have larger/smaller forecast errors? It can be seen from Figure 7 and 8 that some cities have larger mean and standard deviation in forecast errors.

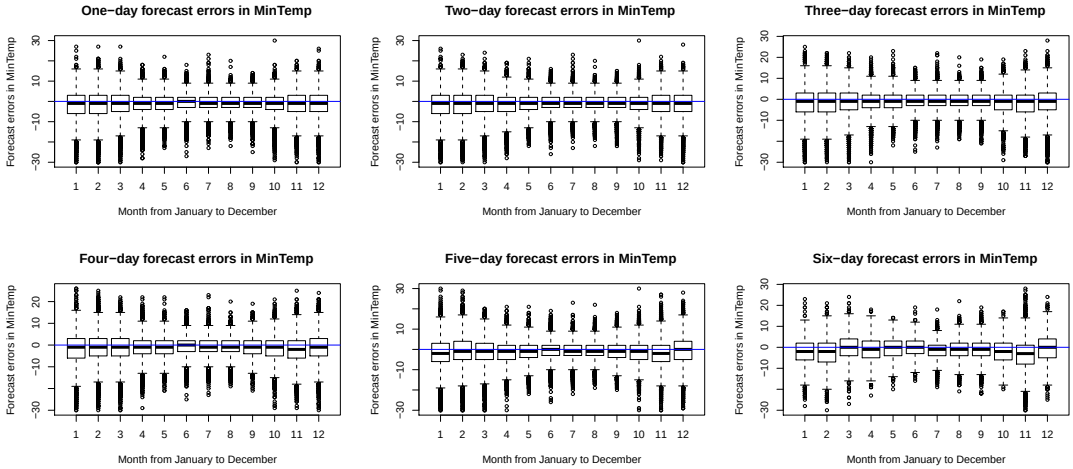

Figure 4: Same-day to six-day MinTemp forecast errors by month

Table 2: Standard deviations of Seven days' forecast errors in the variable Maximum Temperature for twelve months in a year.

Variable	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
MaxTemp	Same-day	3.90	3.95	3.75	3.49	3.42	3.13	3.20	3.04	3.06	3.03	3.43	3.75
	One-day	4.32	4.38	4.24	3.95	3.81	3.44	3.44	3.31	3.44	3.28	3.75	4.11
	Two-day	4.79	4.85	4.76	4.42	4.27	3.87	3.74	3.62	3.82	3.66	4.21	4.47
	Three-day	5.28	5.40	5.33	4.90	4.81	4.35	4.02	3.95	4.24	4.20	4.69	4.82
	Four-day	5.84	6.02	5.91	5.55	5.40	4.84	4.35	4.34	4.80	4.83	5.39	5.33
	Five-day	6.52	6.92	6.65	6.32	6.13	5.35	4.72	4.74	5.35	5.50	6.30	6.07
	Six-day	7.21	7.92	7.59	7.01	6.73	5.78	5.10	5.10	5.87	6.14	7.07	6.95
MinTemp	Same-day	6.50	6.67	6.14	5.36	4.35	4.10	3.68	3.63	4.18	5.16	5.98	6.40
	One-day	6.91	7.10	6.57	5.69	4.67	4.35	3.81	3.70	4.19	5.18	6.26	6.52
	Two-day	6.90	7.00	6.49	5.67	4.69	4.35	3.80	3.74	4.27	5.11	6.37	6.54
	Three-day	6.95	6.94	6.44	5.56	4.63	4.36	3.82	3.77	4.34	5.15	6.34	6.57
	Four-day	7.00	6.99	6.57	5.48	4.64	4.41	3.86	3.85	4.48	5.34	6.47	6.51
	Five-day	7.31	7.27	6.72	5.51	4.74	4.54	3.99	4.05	4.79	5.67	6.83	6.89
	Six-day	6.75	7.05	6.19	5.52	4.93	4.30	4.25	4.53	5.10	5.60	7.94	6.81

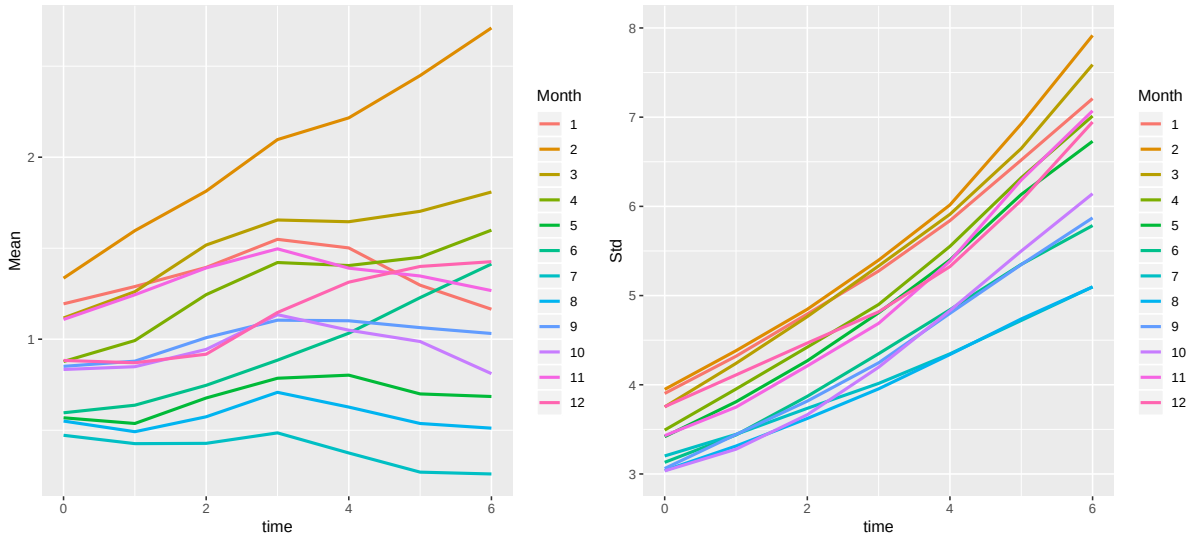

Figure 5: Mean and standard deviation of MaxTemp Seven-day forecast errors by month

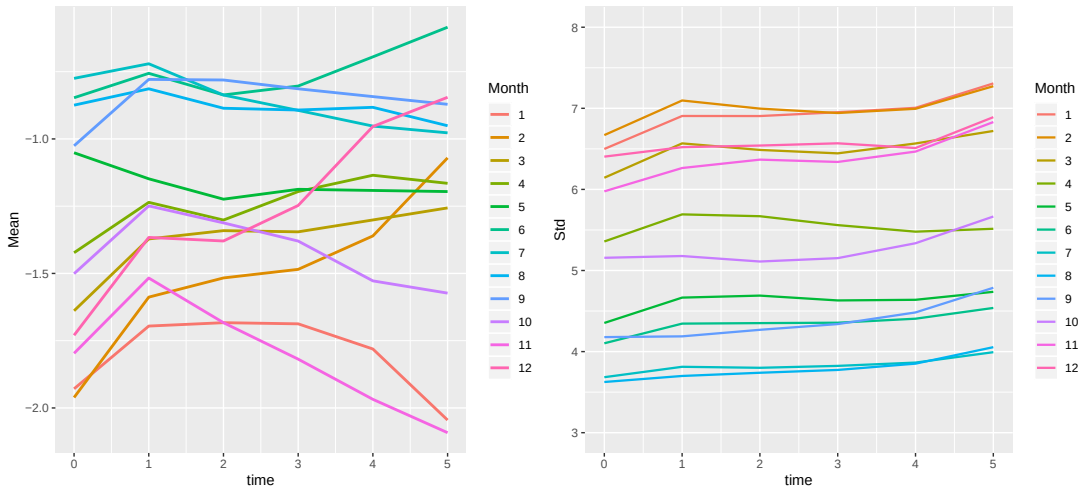

Figure 6: Mean and standard deviation of MinTemp Seven-day forecast errors by month

Furthermore, the standard deviations of MinTemp forecast errors remain approximately a constant for each city, while the standard deviations of MinTemp forecast errors increase as the forecasted date gets further for most cities.

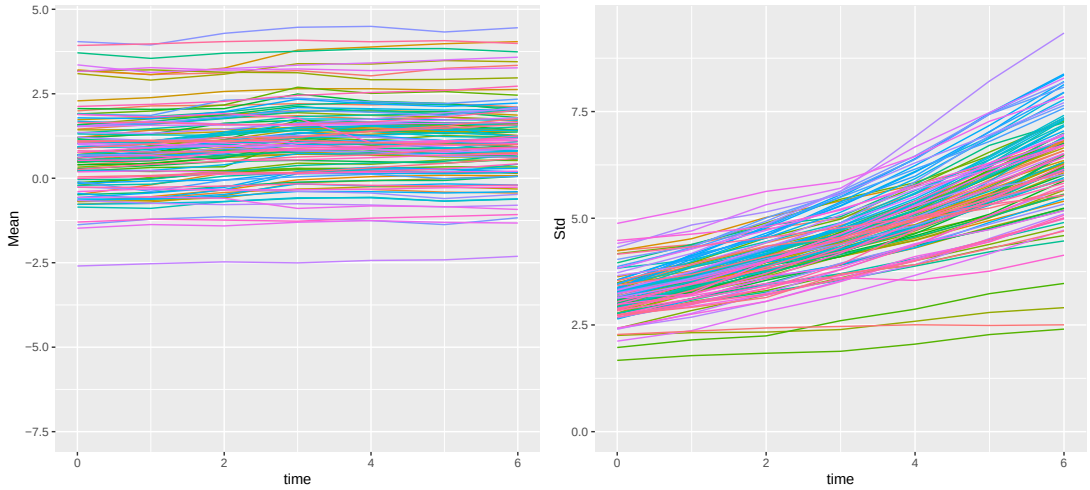

Figure 7: Mean and standard deviation of MaxTemp Seven-day forecast errors by city

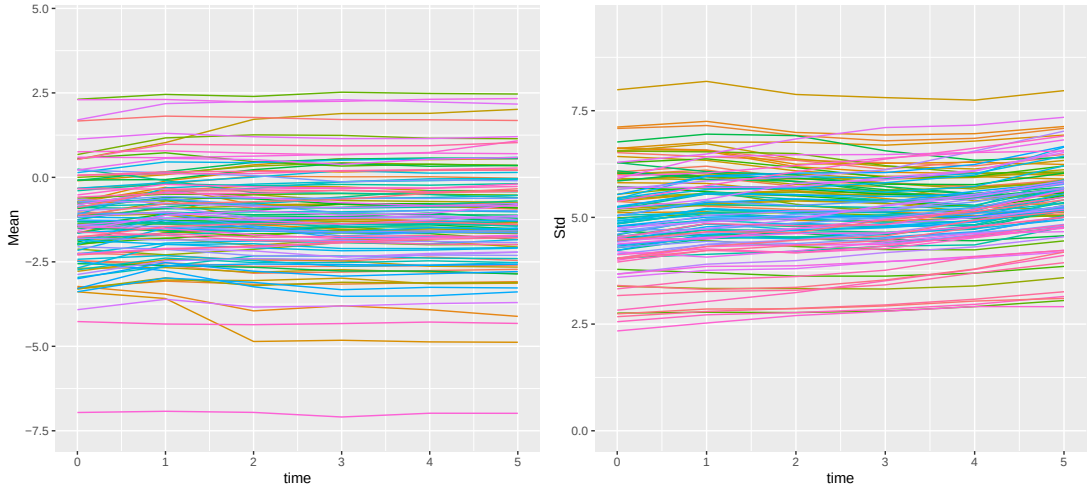

Figure 8: Mean and standard deviation of MinTemp Seven-day forecast errors by city

4. Relationship between MaxTemp and MinTemp forecast errors

For the 7-day weather forecast, both MaxTemp and MinTemp are forecasted on each day. Several questions are of interest. Are MaxTemp forecast errors serially correlated? Are MinTemp forecast errors serially correlated? Are MaxTemp and MinTemp forecast errors correlated?

It can be seen from Figure 9 that both MaxTemp and MinTemp forecast errors are serially correlated. It is not surprisingly that all correlations are positive. That

is, if there is a large forecast error for today's maximum temperature, a large forecast error for tomorrow's maximum temperature is expected. Furthermore, both MaxTemp and MinTemp forecast errors have decreasing correlations overtime. The closer the date being forecasted and the forecast date becomes, the stronger the correlation between the forecast errors gets.

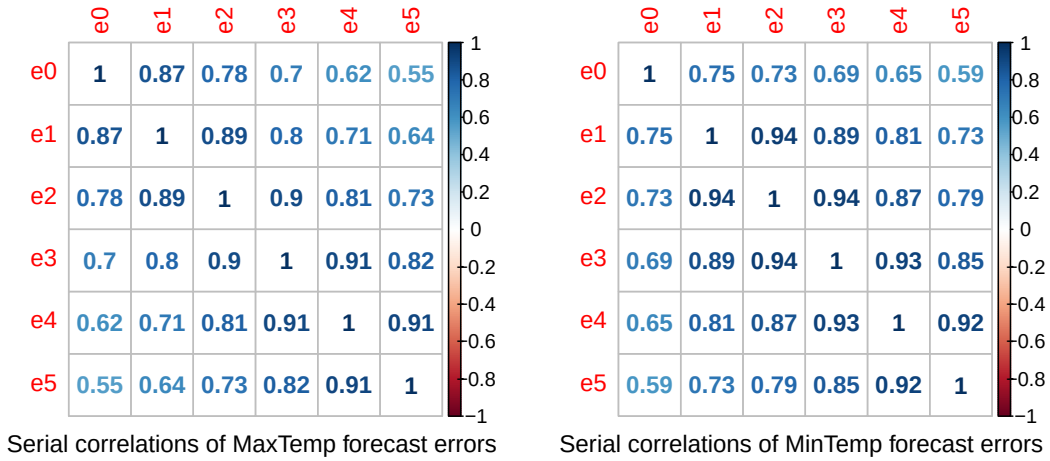

Figure 9: Serial correlation matrices of MaxTemp and MinTemp forecast errors

Moreover, all forecast errors show a linear correlation. For example, Figure 10 shows the scatter plots of the MaxTemp forecast errors when the date being forecasted and the forecast date differs by 1.

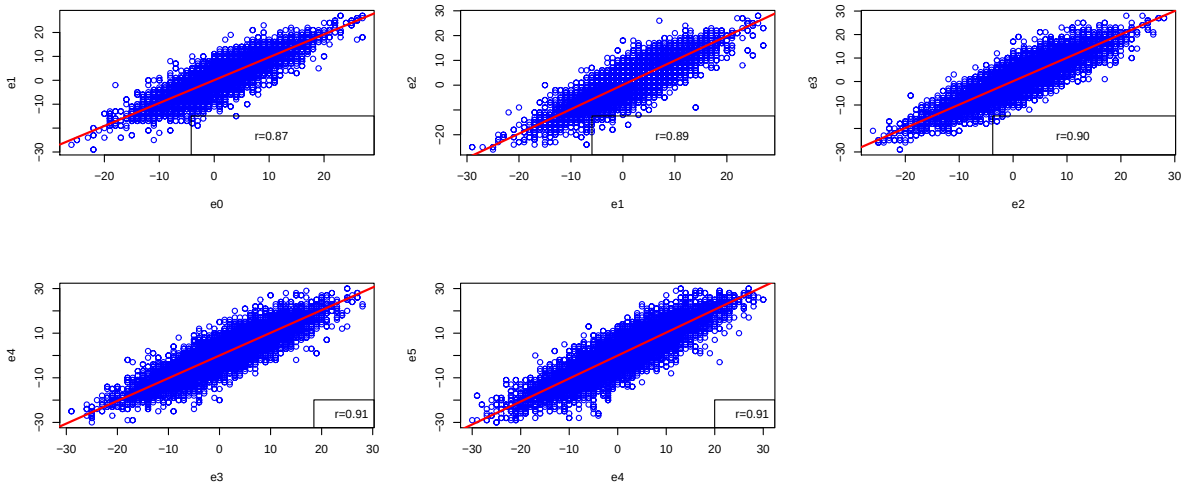

Figure 10: Scatter plots of the MaxTemp forecast errors when the date being forecasted differs from the forecast date by 1

When the forecast errors for MinTemp are large, are the forecast errors for MaxTemp large? For all 7-day forecast, the correlation between these two types of forecast errors is very weak though positive as can be seen from Figure 11. That is,

if the forecast error for MinTemp is large, the forecast error for MaxTemp is little affected.

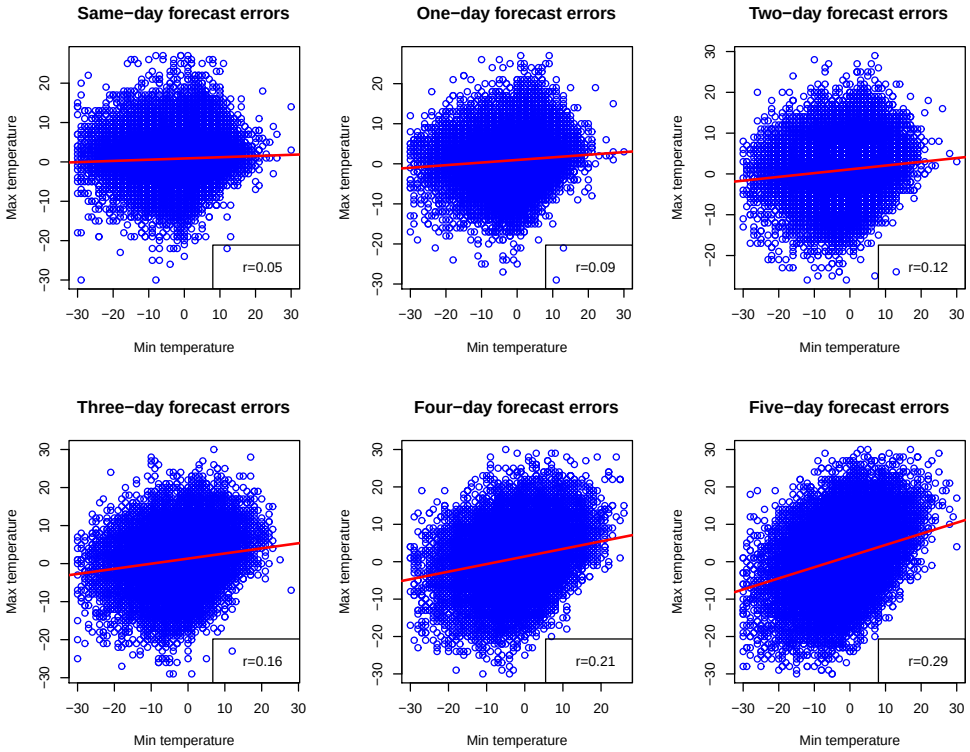

Figure 11: Correlation between Max and Min temperature forecast errors

5. Analysis of precipitation forecast errors

In this section, we analyze the accuracy of precipitation morning forecast and evening forecast. If the measured precipitation is too low, it does not greatly affect daily planning and it will has little effect on agriculture and industry. Therefore, we define that a precipitation occurs only if the accumulative precipitation is 0.04 inch (1 mm) or more. Table 3 summarizes the precipitation probabilities from morning forecast only and the percentage of days of precipitation. It can be seen that the forecasts of precipitations are pretty accurate though in general the chances of precipitations are higher than forecasted. This is true for the evening forecasts as can be seen from Table 4.

Table 3: Table of Precipitation probabilities(Morning) and Percentage of Days of Precipitation

	Probability of precipitation										
Precipitation	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Yes	17.9%	30.2%	36.7%	48.5%	57.7%	66.8%	75.1%	82.1%	87.6%	91.4%	94.4%

Then we investigate the accuracy all seven-day precipitation forecast. The percentage of days of precipitation versus the precipitation probabilities for morning

Table 4: Table of Precipitation probabilities(Evening) and Percentage of Days of Precipitation

	Probability of precipitation										
Precipitation	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Yes	18.9%	28.6%	36.2%	48.8%	56.8%	64.8%	72.0%	77.2%	82.6%	87.5%	92.0%

and evening forecast are summarized in Table 5 and Table 6, respectively.

Table 5: Table of Precipitation probabilities(Morning) and Percentage of days of precipitation for same-day forecast to six-day forecast

	Probability of precipitation										
Forecast Type	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
same-day	13.5%	38.1%	42.3%	55.1%	61.9%	68.0%	75.6%	78.8%	85.7%	91.3%	94.7%
one-day	11.2%	28.4%	35.0%	47.6%	56.1%	64.3%	72.2%	79.9%	86.6%	90.3%	93.9%
two-day 11.9%	27.8%	35.7%	47.2%	56.6%	65.6%	74.6%	81.5%	90.1%	91.9%	94.8%	
three-day	17.6%	27.3%	35.8%	47.3%	57.6%	66.8%	76.0%	85.5%	89.6%	94.9%	
four-day	21.4%	30.6%	36.3%	48.0%	59.1%	67.7%	78.2%	87.8%	89.6%	90.6%	
five-day	22.6%	28.5%	35.3%	47.9%	57.9%	69.0%	77.8%	88.2%	84.4%		NA
six-day	23.7%	28.8%	34.9%	48.1%	56.2%	67.7%	74.8%	81.5%			NA

Table 6: Table of Precipitation probabilities(Evening) and Percentage of days of precipitation for same-day forecast to six-day forecast

	Probability of precipitation										
Forecast Type	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
same-day	13.4%	27.7%	34.4%	49.4%	55.7%	64.1%	70.6%	75.2%	81.3%	86.4%	91.8%
one-day	13.4%	27.5%	35.4%	48.0%	55.1%	62.5%	70.5%	75.9%	81.9%	86.8%	92.9%
two-day	14.4%	26.4%	36.2%	48.0%	56.5%	63.6%	72.4%	78.9%	86.0%	92.2%	92.5%
three-day	21.8%	32.6%	38.6%	49.5%	57.6%	65.8%	74.4%	80.9%	89.1%	88.4%	
four-day	22.7%	32.3%	38.3%	50.1%	58.7%	68.4%	77.6%	79.8%	81.9%	94.3%	
five-day	22.6%	28.5%	35.3%	47.9%	57.9%	69.0%	77.8%	88.2%	84.4%		
six-day	22.0%	29.1%	34.6%	42.5%	54.3%	63.6%	70.2%	50.1%	75.0%		NA

6. Conclusions

In this paper, we examine the accuracy of weather forecast of 113 cities in the United States. The same day forecast, especially for MaxTemp, has been extremely accurate. It is not surprising that forecast errors increase over time and thus long-term weather forecast is less accurate. Some cities have larger/smaller forecast errors. Part of the reason is that the weather of some cities has great fluctuations while some other cities has an obvious tractable weather pattern. The Maximum and Minimum temperature forecast errors have strong serial correlations but decreasing overtime, respectively. However, the correlations between Maximum and Minimum temperature forecast errors are weak, though increasing overtime. The 7-days forecast errors of precipitation are pretty accurate and in general the chances of precipitation are a little higher than forecasted.

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