Analysis of One- to Five-Day-Out Global Temperature, Probability of Precipitation and Wind Speed Forecasts

2015 - 2017

By ForecastWatch.com,
a Service of Intellovations, LLC

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Executive Summary

For the many businesses that make important decisions based on weather and weather predictions, forecast accuracy is crucial. It's critical for businesses in many industries, including recreation, construction, sports, energy and utility, safety and insurance. Understanding and evaluating the past is key to assessing future risk and opportunity.

The ability to provide accurate forecasts is also the bedrock of companies that specialize in weather predictions. These organizations have substantial investment in producing accurate forecasts and in demonstrating their ability to provide that accuracy. When they provide reliable predictions to their clients, they solidify relationships and build long-term success.

This report contains three separate analyses of important aspects of weather forecasts—temperature, precipitation, and wind—for the one- to five-day-out forecast period. Data for these analyses was gathered from 1,145 locations around the world for the 3-year period ending December 31, 2017. Nearly 95 million forecasts were obtained and analyzed from six providers: AccuWeather, Dark Sky, Foreca, Intellicast, The Weather Channel, and Weather Underground. Foreca was not included in the analysis of probability of precipitation because no PoP was provided on Foreca.com.

In the overall analysis, AccuWeather was the most accurate provider for wind and precipitation forecasts, and was a co-leader in accuracy for temperature forecasts. For temperature forecasts, AccuWeather was the most accurate for high temperature forecasts, while The Weather Channel was the most accurate for low temperature forecasts.

Accuracy in the three major forecast areas is summarized below:

Temperature Forecasts. AccuWeather's high temperature forecasts had the lowest average absolute error and the greatest percentage of high temperature forecasts within 3°F. For low temperature forecasts, The Weather Channel was the most accurate.

Precipitation Forecasts. AccuWeather was the most accurate among the five providers analyzed in the evaluation of POP forecasts compared to observed precipitation events.

Wind Speed Forecasts. AccuWeather was the clear leader in wind speed forecast accuracy among the six providers. AccuWeather's wind speed forecast accuracy was the best in both average absolute error and average bias.

Analysis of Temperature Forecasts

Forecasts were collected from six top global providers of consumer weather forecasts. Results are expressed as **mean absolute error**—an average of the absolute temperature errors—and the **percentage of forecasts within 3°F**.

AccuWeather was the most accurate for high temperatures, having both the lowest absolute error and highest percentage of forecasts within 3°F. The Weather Channel was most accurate for low temperature forecasts.

High Temperature Forecasts

The mean absolute error for one- to five-day-out high temperature forecasts for 2015 - 2017 is shown in **Table 1**.

Findings: AccuWeather had the lowest mean absolute error among the six providers, slightly ahead of The Weather Channel and Weather Underground. AccuWeather's mean absolute error was 7% better than fourth-place provider Foreca and 25% better than Dark Sky.

Rank	Provider	Mean Abs Error
1	AccuWeather	2.737
2	The Weather Channel	2.759
3	Weather Underground	2.768
4	Foreca	2.937
5	Intellicast	2.971
6	Dark Sky (forecast.io)	3.637

Table 1: One- to five-day-out high temperature forecast mean absolute error for 2015 - 2017

Table 2 below shows the percentage of one- to five-day-out high temperature forecasts within 3°F of the actual observed temperature.

Findings: At 72.48%, AccuWeather had the highest percentage of forecasts within 3°F of the observation. This percentage was slightly higher than The Weather Channel (72.25%) and Weather

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Underground (72.14%). Intellicast and Foreca were further behind while Dark Sky lagged well behind at 59.94%.

Rank	Provider	% within 3°F
1	AccuWeather	72.48%
2	The Weather Channel	72.25%
3	Weather Underground	72.14%
4	Intellicast	70.23%
5	Foreca	69.67%
6	Dark Sky (forecast.io)	59.94%

Table 2: One- to five-day-out high temperature forecasts within three degrees for 2015 - 2017

Low Temperature Forecasts

The error in low temperature forecasts tends to be higher than the error in high temperature forecasts. The reasons for this include both definition and collection methodology. Low temperatures are defined (and collected) as the low temperature from 7:00 p.m. to 8:00 a.m. while high temperatures are defined (and collected) from 7:00 a.m. to 7:00 p.m. Therefore, the one-day-out low temperature forecast occurs overnight **after** the one-day-out high temperature.

Temperature forecast error, whether high or low, increases as the forecast time moves further out, and the low temperature observations occur approximately twelve hours after the corresponding high temperatures. However, this doesn't account for the entire difference in accuracy between high and low temperature forecast. In general, low temperatures tend to be slightly less predictable than high temperatures.

Table 3 below shows the mean absolute error for global one- to five-day-out low temperature forecasts.

Findings: The Weather Channel was the most accurate provider for low temperature forecasts with a mean absolute error of 2.986. Weather Underground was a close second while AccuWeather's mean absolute error of 3.017 followed closely in a third-place. (Note: Weather Underground and The Weather Channel forecasts were generated by the same company.) As with high temperature forecasts, Intellicast and Foreca were notably less accurate, with Dark Sky the least accurate provider.

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Rank	Provider	Mean Abs Error
1	The Weather Channel	2.986
2	Weather Underground	2.992
3	AccuWeather	3.017
4	Intellicast	3.162
5	Foreca	3.225
6	Dark Sky (forecast.io)	3.786

Table 3: One- to five-day-out low temperature forecast mean absolute error for 2015 - 2017

Rank	Provider	% within 3°F
1	The Weather Channel	67.70%
2	Weather Underground	67.60%
3	AccuWeather	67.26%
4	Intellicast	66.16%
5	Foreca	64.39%
6	Dark Sky (forecast.io)	57.99%

Table 4: One- to five-day-out low temperature forecasts within 3°F for 2015 - 2017

Table 4 shows the accuracy rate for low temperature forecasts within 3°F.

Findings: The Weather Channel had the highest percentage of low temperature forecasts that were within 3°F at 67.7%, closely followed by Weather Underground at 67.6%. AccuWeather ranked third in the category with 67.26%, a percentage that was less than 0.5% behind The Weather Channel. Dark Sky's low temperature forecast accuracy was the lowest at 58%.

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Analysis of Probability of Precipitation Forecasts

Accurate precipitation forecasts are vital to organizations that must count on dry weather to perform certain tasks or make alternative plans when wet weather is forecast. For example, concrete pouring and asphalt paving are more successful on days without precipitation. When these operations are performed in the rain, the integrity of the material used can be compromised, necessitating costly re-installation. At the same time, however, it's also costly to reschedule these services when precipitation that was forecast does not materialize. AccuWeather's performance for probability of precipitation (POP) forecast accuracy (expressed as average absolute error for comparison between POP forecasts and observed precipitation events) was the best among the five providers analyzed.

How Precipitation Forecasts Are Evaluated

Precipitation forecasts are expressed as probability of precipitation (POP). Probability forecasts cannot be evaluated individually, because a precipitation observation either happened or it didn't. However, in aggregate, the most accurate POP forecasts would describe the percentage of time precipitation happened. For example, of all the times 10% probability of precipitation was forecast, ideally there should have been precipitation on 10% of those days. To analyze accuracy, the difference between the percentage of precipitation days for a given POP forecast was used, and then averaged over each POP value. If there was precipitation observed on 13.05% of days where 10% POP was forecast, the error would be 13.05-10 or 3.05.

POP Analysis

Table 5 reflects the percentage of time that measurable precipitation occurred for the full range of POP forecasts. AccuWeather's forecasts were most accurate in the middle probability levels. This includes the 40% POP level, where precipitation occurred 41% of the time, and at the 50% POP level, where precipitation occurred 52% of the time. In contrast, Intellicast, The Weather Channel and Weather Underground all had better accuracy for the 90% and 100% prediction levels. Dark Sky never forecasted a 100% POP, so its performance was not ranked.

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Provider	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
AccuWeather	5%	13%	32%	46%	41%	52%	67%	81%	85%	85%	83%
Dark Sky (forecast.io)	9%	24%	37%	43%	49%	56%	66%	74%	75%	74%	n/a*
Intellicast	5%	16%	38%	48%	54%	62%	70%	81%	78%	88%	94%
The Weather Channel	5%	16%	38%	48%	55%	62%	70%	82%	78%	88%	95%
Weather Underground	5%	16%	38%	48%	55%	62%	70%	82%	78%	89%	95%

Table 5: Percentage of time measurable precipitation occurred given different POP forecasts, 2015 - 2017.
*Dark Sky never forecasted a 100% POP so there is no data to report.

Provider	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	Average Abs Error
AccuWeather	5.41	3.05	12.41	16.08	1.31	1.91	6.65	10.96	5.13	5.40	16.88	7.74
The Weather Channel	5.25	5.83	17.54	17.70	14.62	11.95	10.02	11.91	1.62	1.39	5.12	9.36
Weather Underground	5.26	5.86	17.61	17.69	14.68	12.06	10.09	11.91	1.63	1.41	5.10	9.39
Intellicast	5.45	6.05	17.61	17.66	14.36	11.60	9.69	11.42	2.37	1.97	5.55	9.43
Dark Sky (forecast.io)	8.83	14.21	16.52	12.95	9.22	6.34	6.18	3.88	4.57	15.91	*	9.86

Table 6: Average error of POP vs. actual precipitation percentage, averaged over each cohort, 2015 - 2017.
*Dark Sky never forecasted a 100% POP so there is no data to report.

Table 6 shows the average error of POP versus actual precipitation. The data in this table is derived from the data in Table 8. For example, AccuWeather's 1.31 average error for the 40% POP that appears in Table 6 is calculated as 41.31% (shown in Table 8 as 41%) less the 40% POP.

Findings: AccuWeather's average absolute error in this analysis (across all probabilities) of 7.74 was the best among the five providers, and 21% better than second place Weather Underground.

AccuWeather's success comes largely as a result of its comparative proficiency with forecasts for the 10%, 20%, 40% and 50% probabilities. However, AccuWeather' had a larger error (16.88) than other providers for the 100% probability forecast. Weather Underground, The Weather Channel and Intellicast all had better precipitation forecasting success at the 90% probability level than AccuWeather.

Analysis of Wind Speed Forecasts

Accurate wind forecasts are critical for businesses that rely on wind for the efficient use of resources. In particular, wind farm operators and utility operators make crucial decisions based on anticipated wind conditions. Accurate forecasting allows operators to achieve favorable trading performances on the electricity markets. The further in advance an operator can make a reliable estimate about how much electricity that can be produced, the more profit they can make.

Wind forecast results are presented in two ways: 1) average absolute error – the difference between the average daily wind speed and the forecast wind speed, and 2) average bias – the positive or negative difference between forecast wind speed and actual wind speed.

AccuWeather's performance with regard to wind speed forecast accuracy was the best among the six providers analyzed. It ranked the highest for both average absolute error as well as average bias for the 3-year period ending December 31, 2017.

How Wind Accuracy Is Measured

There are several ways that wind accuracy can be assessed. This analysis calculated the absolute error between the observed daily wind speeds (an average of 24 hourly observations) and the provider's wind forecast. This analysis does not take wind direction (wind vector) into account and thus strictly measures the difference in wind speed.

The wind forecast accuracy is also assessed by examining bias in wind speed forecasts. Bias measures the tendency for a wind forecast to over- or underestimate actual wind conditions. Providers that have a positive bias are more apt to predict wind speeds that are higher than those actually observed. Conversely, providers whose forecasts have a negative bias tend to predict wind speeds that are lower than actual observed wind speeds.

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Average Absolute Error

Rank	Provider	Abs Error (kph) (lower is better)
1	AccuWeather	3.37
2	Foreca	4.49
3	The Weather Channel	4.70
4	Weather Underground	4.71
5	Dark Sky (forecast.io)	4.86
6	Intellicast	4.92

Table 7: One- to five-day-out average absolute error for 24-hour average wind speed forecasts 2015 – 2017

Table 7 shows the average absolute error for global one- to five-day out wind speed forecasts for 2015-2017.

Findings: At a mean absolute error of 3.37, AccuWeather ranked highest among the six providers. This was 1.12 kph (or 25%) better than Foreca, the second most accurate wind forecaster. The mean absolute error for the second through sixth providers ranged from 4.49 to 4.92, all well behind AccuWeather's score.

Average Bias

Rank	Provider	Bias (kph)
1	AccuWeather	0.51
2	Foreca	0.87
3	Dark Sky (forecast.io)	-2.95
4	Weather Underground	3.46
5	The Weather Channel	3.52
6	Intellicast	3.63

Table 8: One- to five-day-out 24-hour average bias in wind speed forecasts, 2015 - 2017

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Table 8 shows the average bias of one- to five-day-out 24-hour average wind speed forecasts.

Findings: At 0.51 kph, AccuWeather had the lowest average wind speed bias of any of the providers analyzed. This means that on average — for three years' worth of one- to five-day-out wind forecasts — AccuWeather over forecast wind speeds by 0.51 kph. The second-ranked finisher, Foreca, was the only provider close to AccuWeather with a bias of .87 kph for the period. The average wind bias for remaining providers ranged from Dark Sky's -2.95 to Intellicast's 3.63.

Methodology

Temperature

Error is determined by subtracting the actual temperature from the forecast temperature. A forecast that predicts too low a temperature will have a **negative error**, while a forecast that is too high will have a **positive error**.

After the error is established, the average absolute error can be determined. This calculation takes the absolute value of the error of each forecast, so that all errors are positive, and then averages all errors. This measures how far off the set of forecasts is on average without regard to whether they are too high or too low.

High and low temperature forecasts and observations were collected and stored as whole degrees **Fahrenheit**. Therefore, if the mean absolute error was three degrees or less, the forecast was considered within 3°F.

Probability of Precipitation

POP forecasts were compared against precipitation measured at the various locations analyzed. If 0.01 inches or more of liquid-equivalent precipitation fell during that day, it was considered to have been a precipitation event.

Wind Speed

Error is determined by subtracting the daily average wind speed from the forecast wind speed. A forecast that predicts too low a wind speed will have a **negative error**, while a forecast that predicts too high a wind speed will have a **positive error**.

After the error is established, the average absolute error can be determined. This measure takes the absolute value of the error of each forecast so that all errors are positive, and then averages all errors. This measures how far off the set of forecasts is on average without regard for if they are too high or too low.

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ForecastWatch employed the commonly used method of confidence intervals for a normal distribution of error to determine if providers should be considered statistically tied. This is based on the total number of samples, the mean absolute error of the samples, and the standard deviation of absolute error. A confidence interval is a set of values that are all reasonable estimates for a population (true) parameter, based on a particular sample. Not all intervals will actually contain the true value of the statistic, and the accuracy of the interval is dependent on the assumptions of independence and the underlying distribution of the sample. Because of such assumptions, other statistical means of assessing ties may occasionally lead to different results.

Providers

- **AccuWeather** http://www.accuweather.com. Forecasts were collected using the AccuWeather API at http://api.accuweather.com.

- **Dark Sky** http://api.forecast.io. Latitude and longitude of the observation station were used to retrieve specific forecasts.

- **Foreca** http://www.foreca.com. 10-day forecast page. Location parameter used was the city and state of the observation location.

- **Intellicast** http://intellicast.com. Extended forecast page. Location parameter was a site-specific code for the location.

- **The Weather Channel** http://www.weather.com. 10-day forecast page. Latitude and longitude of the observation stat were used to retrieve specific forecasts.

- **Weather Underground** http://www.wunderground.com/api. Location parameter used to retrieve specific forecasts was the International Civil Aviation Organization (ICAO) code or surface synoptic observations (SYNOP) of the observation station.

Observation Collection

Data was collected from eight regions at specific times during the day. In **Table 9**, for example, daily temperature forecasts were collected at 22:00 UTC (6 p.m. Eastern Standard Time) in the United States and continued until all forecasts were collected. For each location, forecasts from all providers were collected at the exact same time.

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Region	Collection Time	Number of Stations
United States	22:00 UTC	791
Canada	21:40 UTC	41
Europe	16:00 UTC	187
Asia Pacific	08:00 UTC	63
Africa	15:30 UTC	13
Middle East	13:00 UTC	21
Central America	23:00 UTC	10
South America	21:00 UTC	14

Table 9: Forecast collection times and regions

Validity

Forecasts were considered **valid** if they were complete (i.e. they contained a high and low temperature forecast, a POP forecast and a wind forecast), and if they passed both manual and automated audits. These audits checked for out-of-bounds values and other indicators that suggested the forecast should be marked as invalid. Forecasts that were simply **bad** (inaccurate or wrong) were not considered invalid. However, forecasts issues caused by system errors or delivery problems (such as a -32768 degree high temperature, a 120% chance of rain or a 270 kph wind speed) were declared invalid.

Observation Data

Observation data was collected from the primary Automated Surface Observing System (ASOS) network in the United States as well as international equivalents. United States data was quality controlled by the National Climatic Data Center (NCDC) prior to delivery to ForecastWatch via the Quality-Controlled Local Climatic Data (QCLCD) product data set. Canadian data was collected from Environment Canada. Other international data came from the Integrated Surface Database (ISD) product. All products consisted of hourly and daily observation parameters.

Observed High and Low Temperature

The maximum temperature from the 7 a.m. to 7 p.m. local time hourly observations was used to construct the high temperature observation. The minimum temperature from the 7 p.m. to 8 a.m. local time hourly observations were used to construct the low temperature observation. No attempt to curve fit or otherwise determine an intra-hour temperature estimate was performed.

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Observed Precipitation

Precipitation measurements were taken from 24-hour local time precipitation observations. If 0.01 inches or more of liquid-equivalent precipitation fell during any hour of that day, it was considered to be a day with precipitation. The occurrence or non-occurrence of precipitation was then compared to the POP forecast.

Observed Wind

Wind conditions were taken from hourly observations over the course of a 24-hour period from local midnight to midnight. These observations were then averaged to construct the daily wind observation.

Calculation Methodology

Tables 10, 11, and 12 show the number of high/low temperature, POP, and wind forecasts collected and compared for each provider for the one- to five-day-out forecasts. The percent of possible forecasts collected and compared is less than 100% because of invalid forecasts, problems in collecting forecasts successfully, including the unavailability of a provider's website or feed due to network or other issues, and days in which observations were not available for a particular site. Overall, across all providers, the percentages of possible forecasts and observations available for comparison were 91.6% for temperature, 93.0% for POP, and 83.0% for wind.

Provider	Number of Temperature Forecasts	Percent of Possible Forecasts
AccuWeather	5,787,711	91.60%
Dark Sky (forecast.io)	5,805,313	91.88%
Foreca	5,768,161	91.29%
Intellicast	5,806,444	91.90%
The Weather Channel	5,806,727	91.90%
Weather Underground	5,745,377	90.93%

Table 10: One- to five-day-out high and low temperature forecasts analyzed and percent of possible forecasts, 2015 – 2017
NOTE: Thirteen stations that provided temperature observations did not provide precipitation observations

Provider	Number of Precipitation Forecasts	Percent of Possible Forecasts
AccuWeather	5,808,586	92.98%
Dark Sky (forecast.io)	5,820,559	93.17%
Intellicast	5,827,300	93.28%
The Weather Channel	5,827,573	93.28%
Weather Underground	5,764,480	92.27%

Table 11: One- to five-day-out POP forecasts analyzed and percent of possible forecasts, 2015 - 2017

NOTE: Sixteen stations that provided temperature observations did not provide wind observations. Numbers are lower because there weren't always wind observations or forecasts as regularly as temperature or precipitation.

Provider	Number of Wind Forecasts	Percent of Possible Forecasts
AccuWeather	5,164,511	82.89%
Dark Sky (forecast.io)	5,174,642	83.05%
Foreca	5,147,222	82.61%
Intellicast	5,180,616	83.15%
The Weather Channel	5,180,901	83.15%
Weather Underground	5,125,923	82.27%

Table 12: One- to five-day-out wind speed forecasts analyzed and percent of possible forecasts, 2015 - 2017

About ForecastWatch.com

ForecastWatch, a service of Intellovations, LLC, has been the world's premier weather forecast monitoring and assessment company since 2003, when it released the largest public weather forecast accuracy study at the time. ForecastWatch compiles weather forecasts and observations from more than 1,200 locations around the world, including the United States, Canada, Europe, South America, Central America, Africa and the Asian Pacific. ForecastWatch maintains a historical database of more than 800 million weather forecasts from a number of providers and provides unbiased reporting.

Meteorologists, utilities and energy companies depend on ForecastWatch's accurate data and analysis. Agriculture, futures traders and other companies whose business depends on being right about the weather put their trust in ForecastWatch to help them achieve success. The data meets the highest standard of scientific inquiry and has been used in several peer-reviewed studies.

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