An Analysis of Back Door Cold Front Events at the Blue Hill Observatory from 2001-2020

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Introduction

Springtime in New England brings budding trees, melting snow, and warming temperatures. However, compared to those in the Mid-Atlantic, springtime in Southern New England can be anything but mild. Several times each spring, a phenomenon called a back door cold front (BDCF) passes through part, or all, of Southern New England, bringing with it a cold, raw wind off the chilly Gulf of Maine. These fronts abruptly shift winds from the SW or W to the E or NE, often dropping temperatures significantly over the course of a few hours.

These unique synoptic events occur when high pressure over Quebec or the Canadian Maritimes pushes cooler air from the Gulf of Maine and the North Atlantic into New England. The position of this high, to the north or northeast of New England, matters tremendously because the clockwise motion around the high funnels air from the east or northeast onto land. A traditional cold front, one that moves from northwest to southeast or from west to east, precedes the advance of high pressure from much farther west over Canada or the United States.

Many informal reports and articles are published every year by meteorologists after BDCFs occur, mostly to educate the public on this relatively unique phenomenon (Hopkins et al. 2024). In addition, several formal studies have been published on BDCFs in the northeastern United States that mostly date back at least 30-40 years. The term back door cold front has existed for the better part of a century. Papers from as early as 1951 indicate a deep understanding of the synoptic and atmospheric parameters that influence these fronts. Carr et al. (1951) focus heavily on the mechanics of BDCFs by discussing one particular BDCF event on the East Coast. They analyze the synoptic patterns across eastern North America and the characteristics of each atmospheric layer, including atmospheric cross sections, surface weather chart analysis, and 700 mb analysis. Bosart et al. (1973) analyze BDCFs across the region east of the Appalachians using precipitation, cloud cover, and synoptic features. Finally, Hakim et al. (1992) examine a side door cold front, which moves from east to west, and delve into atmospheric density currents as drivers of BDCFs. They also point out an interesting application of BDCF research, stating that better understanding of these events can help reduce some of their negative effects such as the threat to airline safety caused by an increase in low level wind shear.

This study aims to analyze BDCF trends and factors that affect BDCF strength and characteristics at the Blue Hill Observatory in eastern Massachusetts. It's well known that chilly ocean temperatures in springtime help fuel these events, or that winds tend to shift to the northeastern quadrant after the front's passage, but this study performs a careful analysis of the numbers and attempts to uncover specific trends or relationships between the relevant weather parameters. This study investigates (1) the most prevalent times of day when BDCFs pass, (2) the effects of time of day on several quantifiable variables related to BDCF strength, (3) correlations between temperature drop and the percent change in wind speed post frontal passage, (4) the relationship between temperature drop and water temperature, (5) the relationship between temperature drop and wind direction shift, (6) and the effects on time of year (by month) on temperature drops and wind changes.

Data Sources

All weather data provided for this project originated from Blue Hill Observatory and were obtained from either F6 monthly weather forms or B16 daily weather forms. Data used in this analysis covered the months of March through June for the years 2001-2020. The F6 monthly forms provided the maximum temperature, minimum temperature, average temperature, vapor pressure, surface air pressure, average wind speed, peak wind gust, wind direction, total precipitation, snowfall accumulation, and sunshine duration for each day. The B16 daily forms consisted of hourly weather data for each day of a given month, including hourly temperature, hourly wind direction, hourly wind speed, sky cover, precipitation (if any), relative humidity, sunshine duration, and visibility. All data times are in Eastern Standard Time (EST) regardless of month, following the convention used by the Observatory.

In addition to the weather data provided by Blue Hill Observatory, daily synoptic weather maps available from the NOAA Weather Prediction Center (https://wpc.ncep/noaa.gov) were used to examine the synoptic patterns involved. The Sea Temperature Info website (https://seatemperature.info/) was used to find archived ocean temperature data for Boston Harbor, which is as close as seven miles to the northeast of Blue Hill.

Methods

The first step in the analysis required combing through the F6 forms for any significant daily changes in wind direction, speed, and temperature. The dates of any notable events were recorded into an Excel spreadsheet. Each day was inspected in the B16 forms, especially the days already noted in the spreadsheet as potential BDCF events. If the wind direction was observed to shift to the northeast, accompanied by temperature stagnation or decrease and a plausible synoptic signal of a BDCF, data was recorded for that day. The temperature data recorded for each suspected frontal passage included the 1-hour temperature drop post frontal passage, 3-hour temperature drop, and 6-hour temperature drop. The standard metric used for identifying the exact hour of frontal passage was the last hour before a wind change to the northeastern quadrant. For example, if at 1300 EST the wind was out of the WSW, and at 1400 EST the wind was out of the NNE, the front was determined to have passed during the 1300 hour. From this method, the 1-hour temperature drop was the difference from 1400-1300 EST, the 3 hour temperature drop was the difference from 1600-1300 EST, and the 6 hour temperature drop was the difference from 1900-1300 EST. Wind direction data were recorded by averaging the direction of the wind in each of the six hours before frontal passage and averaging the wind direction in the six hours after the frontal passage, then finding the difference between those two values. Wind direction in degrees was converted to an azimuth range from 90° (east) to 450° for this analysis due to the prevailing wind direction of 270° (west) at BHO. For example, if the six hours prefrontal passage averaged a prevailing west wind, the data would show 270°. If the six hours post frontal passage averaged a wind from the northeast, the data would show 405°. If the wind direction shift passed through north, the wind direction change would be 135°, while if the wind direction shift passed through south, the wind direction change would be 225°. Data recorded for wind speed included the average wind speed for the six hours before frontal passage and six hours post frontal passage, as well as the numerical and percent differences between the two averages. Lastly, ocean temperatures were listed for the date of each event.

After preliminary data collection, BDCF events were categorized by their likelihood of occurrence on a 1-5 scale, 5 being the most likely. Upon further analysis of the synoptic scale patterns as well as hourly weather changes from the B16 forms, events categorized as a 1 or 2 were eliminated from the data set. In addition, a few events listed as a 3 were eliminated upon further data examination. A loose set of criteria was applied in the identification process, including the presence of a southerly or southwesterly moving cold front over New England on the synoptic scale and a significant (90° +) wind direction shift to the northeast quadrant. No strict temperature drop requirement was instituted because many BDCF events with clear synoptic confirmation didn't showcase temperature drops at all. Some BDCF events resulted in temperature increases, and these cases were not excluded if they satisfied other criteria. Wind change events likely due to the changing location of a broad high-pressure system were eliminated, as well as events that appeared as traditional cold fronts with a more southeasterly motion accompanied by a high pressure over Ontario. Following these criteria, it was concluded that throughout the 20-year period, 68 BDCF events occurred, though this number may be off by a couple in either direction due to shortcomings in the selected criteria. The 68 total events correspond to roughly 3-4 events on average per spring.

Results and Discussion

Timing of Frontal Passage

From all the BDCF data collected, it was found that 53% of presumed frontal passages occurred before noon, while the other 47% occurred after midday. Figure 1 shows the frequency of BDCF timing for four 6-hour time periods during the day. The largest concentration of BDCF events occur in the afternoon from the hours of 1200 to 1800 EST, followed closely by the morning hours of 0600 to 1200 EST. This data fits nicely with the interpretation that diurnal heating directly affects when BDCFs pass through the Boston area. A stronger temperature gradient between the warm, southerly air mass and the cool, marine air mass during the warmer afternoon hours commonly pushes the BDCFs through during these times of day.

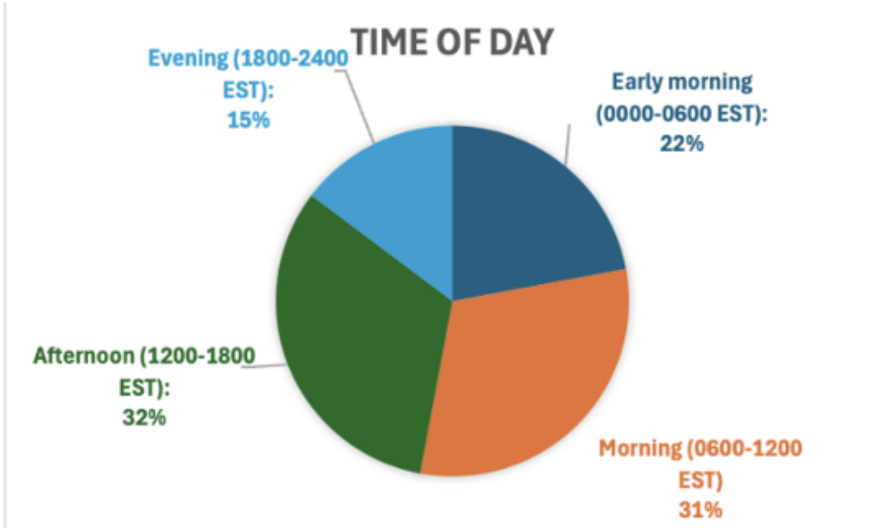

Figure 1: Number of total BDCF passings for years 2001-2020 by time of day category (n=68).

It was also found that the time of day of BDCF passage affects the 3-hour and 6-hour temperature drops after frontal passage. As depicted in Figure 2, fronts that pass through in the latter half of the day, during the peak of the diurnal heat cycle, feature much larger 3-hour and 6-hour temperature drops than fronts that pass during the cooler morning hours. A statistical t-test confirms this relationship with a high degree of significance ($p<0.01$). No significance was found between the early morning and morning time periods, as well as the afternoon and evening time periods ($p>0.05$). A reasonable interpretation can be made that the diurnal heating cycle amplifies the effects of BDCFs due to the contrast between the rapidly warming land and the cool approaching air mass. If a BDCF passes through during the morning in mid-May, when the average low hovers near 50 °F, a small or negligible temperature drop may result because the passage of the front aligns with the trough of the diurnal heating cycle. Perhaps temperatures don't drop much but instead stabilize at the morning temperature through the afternoon.

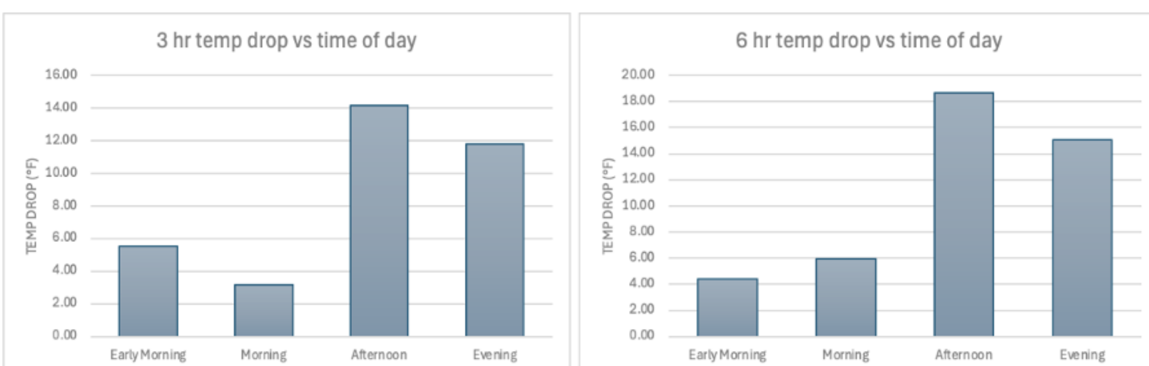

Figure 2: Average 3 hour and 6 hour temperature drops by time of day category; early morning (0000-0600 EST), morning (0600-1200 EST), afternoon (1200-1800 EST), evening (1800-2400 EST).

Wind Speed/Direction and Temperature Correlations

Another aspect of this paper aims to find relationships and correlations between specific variables in BDCF events, such as the relationship between temperature drops and wind speed. The scatter plots in Figure 3 depict a subtle positive correlation between the magnitude of temperature drops post frontal passage and the percent change in wind speed. Here, however, the limited data set size comes into play. Even though Excel parsed out a best fitting trend line from the data points, many of the points don't reside near the line whatsoever. In a much larger dataset, outliers would matter less because of the sheer number of data points resting near the trendline. In this study, however, outliers carry more weight, and they strongly influence the resulting linear fit. The slight positive correlation between these two variables does make sense though, since BDCFs that drop temperatures dramatically are likely stronger, therefore increasing winds by a larger proportion once they blow through in some cases. Overall, the correlation between wind speed and temperature drop during BDCF events is negligible.

The results in Figure 4 cluster closer to the best fit trendline of the scatter plot, indicating that in stronger BDCF passages with larger temperature drops, the wind direction shifts more drastically. In springtime in southern New England, the warmest winds originate from the southwest while the coolest winds come from the northeast. In BDCF events with larger temperature drops, the temperatures were likely high beforehand due to a southwesterly wind; thus, when the front blows through, the winds change almost a full 180° and temperatures plummet as the warm airflow suddenly ceases. Although the limited data sample size of 68 events still strengthens the influence of the outliers, the slope of the trend lines for the two scatter plots in Figure 4 is roughly double those in Figure 3, emphasizing a stronger correlation between temperature drops and change in wind direction. (Many data points in Figures 3 and 4 show a rise in temperature after a BDCF passage. Synoptic maps suggest that these events are BDCFs with buffered effects due to diurnal heating. Possible explanations for this phenomenon appear in the text for other figures.)

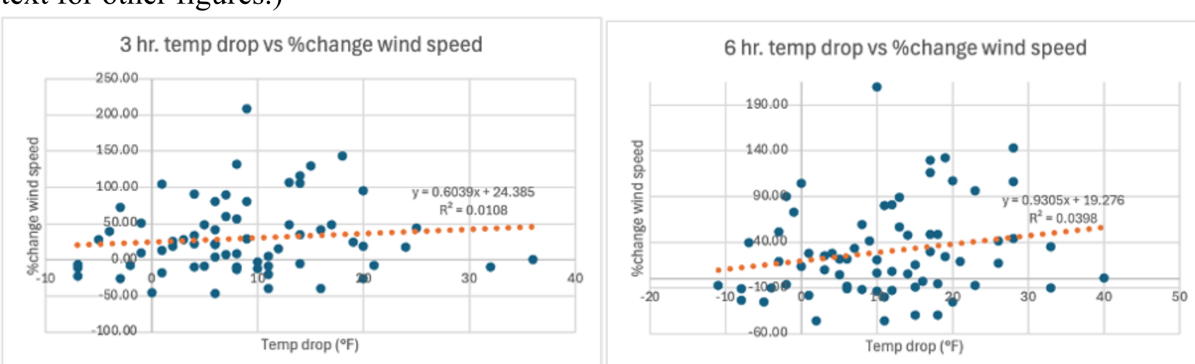

Figure 3: Correlation plots of temperature drop vs the percent change in wind speed for two time intervals, 3 hours and 6 hours (n=68). Trend Lines represent Excel's best fit linear line for the chart, and an equation for the trendline accompanies it. Correlation coefficient (r^2) values of 0.01 and 0.04 indicate that the scatter plots contain very low linearity.

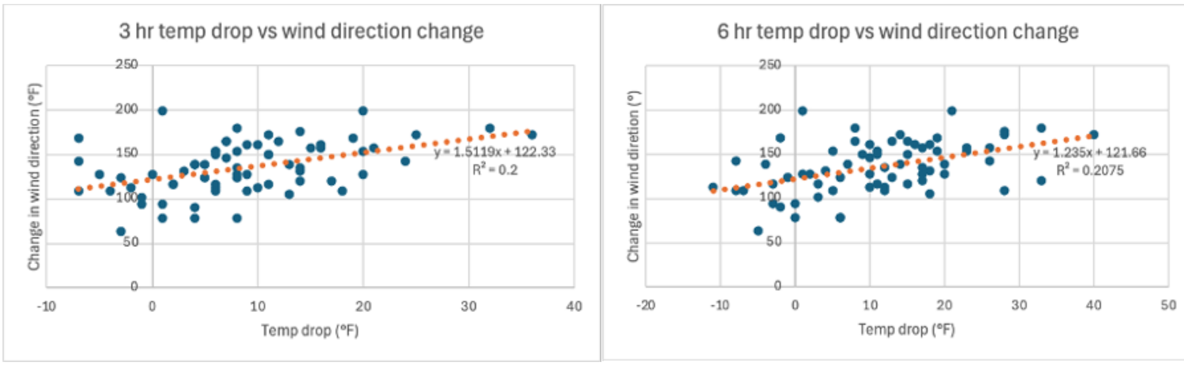

Figure 4: Correlation plots of 3-hour and 6-hour temperature drops vs. the change in wind direction from pre to post frontal passage. Best fit trend lines are depicted and are accompanied by their respective equations and r^2 values. The r^2 values of around 0.2 represent a weak linear relationship between variables.

Effects of Water Temperature on BDCF Strength

A well-known factor in BDCF strength is the ocean temperature, particularly the temperature of the waters off the coast of Massachusetts in the North Atlantic or Gulf of Maine. During spring, water temperatures remain stubbornly cold after the long winter. In contrast, warm air masses from the south attempt to nudge milder air into southern New England, creating a contrast in temperatures over a very small distance. This contrast is further amplified by diurnal heating over land, which causes air to rise during the day. Oftentimes, stiff sea-breezes near the coast result from this contrast and change in local circulation, but in more pronounced scenarios, back door cold fronts push south and overwhelm local sea-breezes. The graphs in Figure 5 indicate that lower water temperatures may lead to stronger temperature drops over land post frontal passage, an interpretation that is consistent with the previous explanation. However, the data points for the analyzed cases are extremely scattered; they don't cluster near the best fit trend line, and they provide limited support for this interpretation. While the proposed relationship certainly seems credible, a larger data set and a more comprehensive study are required to establish this correlation more rigorously.

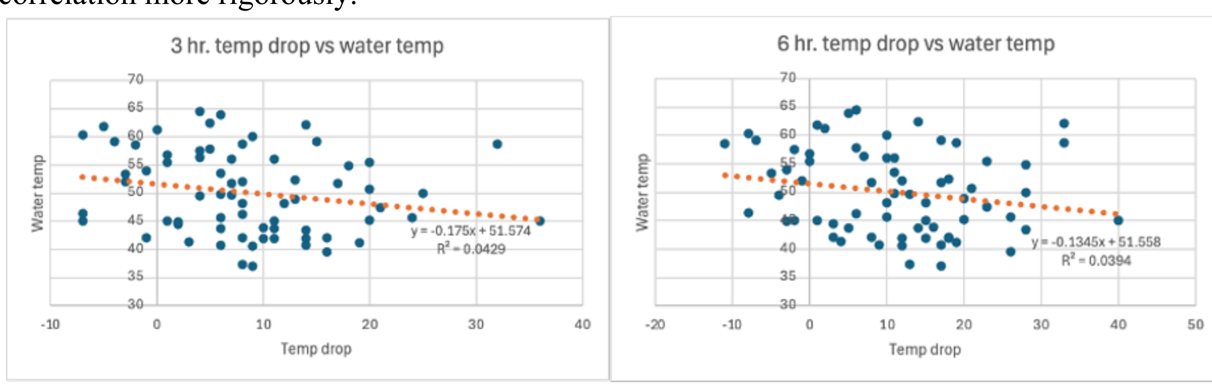

Figure 5: Correlation plots of 3-hour and 6-hour temperature drops post BDCF passage vs the water temperature of Boston Harbor on that given day. Best fit trend lines are depicted and are accompanied by their respective equations. R^2 values do not depict a strong linear correlation.

Effects of time of year on BDCF strength

Data analysis using statistical testing shows that temperature drops in March following BDCF events are significantly larger than the temperature drops in June, meaning that a clear downward trend exists as the spring progresses. Figure 6 illustrates the average 3-hour (left) and 6-hour (right) BDCF temperature drop for the months of March through June. Competing events likely work together here to produce this result. In March and April, local ocean temperatures are near their yearly low, creating greater contrasts when warm air masses move in. The result also suggests that in June, the contrast isn't as significant, so BDCF events produce less pronounced temperature drops; in summary, water temperature and diurnal heating compete to produce this result. In addition, days with BDCFs in June could feature cloudier skies than in March or April, a phenomenon which would depress the temperatures in June relative to average. The role of cloud cover can be analyzed in future research.

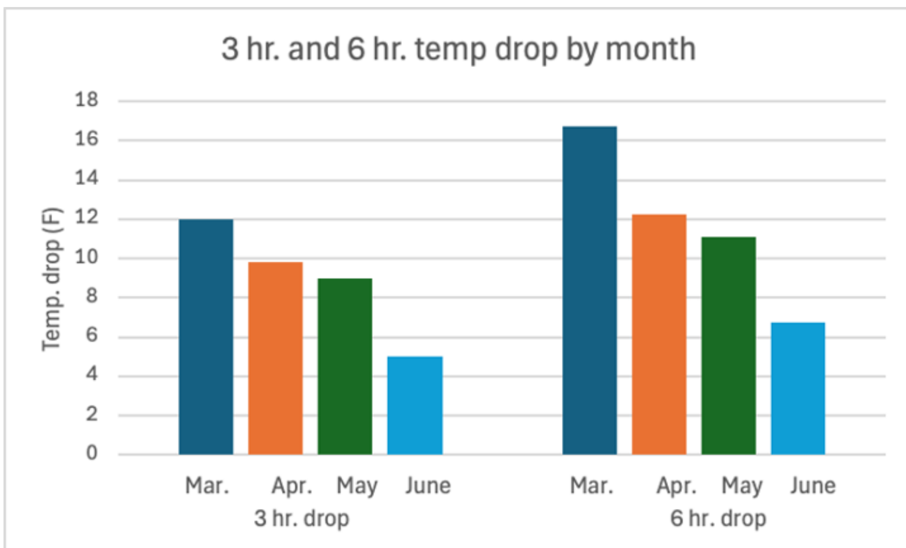

Figure 6: Average 3-hour and 6-hour temperature drops for the BDCF passings in years 2001-2020 by month (n=68).

Conclusions

This report describes an initial review of back door cold front events at the Blue Hill Observatory for the years 2001-2020. Using specific criteria that include changes in temperature, wind speed and direction, a total of 68 BDCF events were identified over this period. Any conclusions or interpretations drawn from the results must be considered against the size of the data sample. With only 68 events recorded, correlation plots lack clear trends and outliers carry a significant amount of weight that wouldn't be present in a much larger sample. The very low correlation (r^2) values in the scatter plots emphasize this result. However, interesting patterns and observations can still be deciphered from this analysis.

Several illustrations throughout the report, such as Figures 1, 2, and 6, delve into the effects of diurnal heating on BDCF passages. These figures conclude that diurnal heating, on the daily or monthly scale, influences when BDCFs pass and how forceful their effects are. Even the water temperature data depicted in Figure 5 relates to diurnal heating, since oceans are milder in the later spring months with more pronounced seasonal and diurnal heating. Figures 3 and 4 attempt to uncover relationships between certain variables of BDCFs, like temperature drops and wind changes; while the data depicted a slight relationship between these variables, statistical testing could not verify these trends due to the small and scattered nature of the data sample.

In conclusion, this study establishes a new analysis of BDCFs in southern New England, a topic with limited prior research. While the synoptic phenomena that promote BDCFs have been chronicled in past research, the quantifiable, surface level observational effects haven't been documented in detail. This research uncovered many plausible trends between variables and quantified the magnitude of these trends, albeit with a limited data sample. This study will be expanded in the future by identically analyzing another 20-year period, likely 1965-1984, to investigate whether climate change is affecting BDCF frequency, strength, and local impacts and to establish the consistency and validity of the patterns reported.

Acknowledgements

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