ACCURACY OF NATIONAL WEATHER SERVICE WIND-DIRECTION FORECASTS AT MACON AND AUGUSTA, GEORGIA

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Abstract

National Weather Service wind forecasts and observations over a nine-year period (1985–1993) were analyzed to determine the usefulness of these forecasts for forestry smoke management. Data from Macon, Georgia indicated that forecasts were accurate to within plus or minus 22.5 deg about 38% of the time. When a wider plus or minus 67.5 deg window was used, accuracy increased to about 79%. When forecast wind speeds were 15 mph or more, forecast wind direction improved in accuracy by about 15%. Some bias was present in wind-direction forecasts. Errors of 22.5 to 67.5 deg to the left of the forecast direction (one semiquadrant left) were more common than similar errors to the right. This bias is most pronounced for forecasts verifying at night, with leftward errors occurring up to 2.5 times more frequently than rightward errors. The bias was much less during 1985–1986 than during later years. Some wind directions were forecast more accurately and with less bias than others. Limited data at Augusta, Georgia showed forecast accuracy and bias were generally similar to that at Macon. Forecast performance for specific wind directions varied considerably between Macon and Augusta.

1. Introduction

An estimated 6-8 million acres of forest land in the southern United States are treated annually by prescribed fire. The large number of fires required to maintain southern forest ecosystems challenges land managers charged with maintaining air quality and keeping smoke from sensitive areas. One of the major questions faced by land managers is, "Where does the smoke go?"

As southern woodlands become more urbanized, determining the direction smoke moves from individual prescribed fires will become more critical to planning and executing each burn. Wind-direction forecasts are the basis of such plans and execution. Their accuracy is clearly linked to the success of prescribed burning programs. The question of "Where does the smoke go?" becomes a question of "How accurate are the wind-direction forecasts provided by the National Weather Service?"

Public wind-direction forecasts used in most burning operations are made available early in the morning of the day of the forecast or during the late afternoon of the previous day. Wind directions are typically given to one or two of eight cardinal points, i.e., N, NE, E, etc. This paper investigates the frequency of success and mode of failures of public wind-direction forecasts by the National Weather Service (NWS) for Macon (MCN) and Augusta (AGS), Georgia.[1] Armed with this information, the forest land manager can better evaluate the risk of smoke problems from an individual fire even when a forecast is faulty. Other forecast users for whom wind direction is a critical element should also find this information valuable. Finally, the data can provide valuable feedback to the forecasting community itself.

2. Methods

a. Description of the sites, data, and analysis approach

Macon, Georgia is located at 32° 42' N and 83° 39' W at 354 feet elevation. The site is about 1.5 miles west of the Ocmulgee River and is surrounded by predominantly flat terrain that is well wooded except for a few farms. The wind instrumentation is on relatively high ground and is well exposed. The site is fairly representative of much of central Georgia, being less subject to cold air drainage than the Byron Agricultural Experiment Station a few miles to the southwest, but considerably more so than the author's residence 4 miles to the south on a low ridge of approximately 420 feet elevation.

Augusta, Georgia is located at 33° 22' N and 81° 58' W at 136 feet elevation. The site is about 2 miles west of the Savannah River, with hills about 200 feet higher than the site about 1 mile to the west and swampland located immediately to the north, east, and south. The site is greatly subject to cold air drainage and is representative of locations near the fall line well within substantial valleys.

National Weather Service wind forecasts and wind observations were analyzed and compared for Macon (MCN). The data for the nine-year period (1985–1993) contained few gaps. The data set used early morning forecasts (released at approximately 0500 LST) compared against hourly wind observations for the subsequent day-

[1] National Weather Service forecasts for Macon were issued from the NWS Forecast Office at Atlanta with rare modifications by the Macon NWS Office to period 1 forecast information only. Forecasts verified at Augusta were issued by the NWS Forecast Office in Columbia, South Carolina for the Savannah River Site. These forecasts were not modified.

light (period 1; 0800 to 1900 LST) and darkness (period 2; 2000 to 0700 LST the next day) intervals.

A shorter data set, with numerous gaps in coverage, was analyzed for NWS forecasts made for the Savannah River Site, South Carolina during the period 1989–1993. Augusta (AGS) about 20 miles distant was used as the verification site for the forecasts. The data set used afternoon forecasts (released by 1500 LST) compared against hourly wind observations for subsequent darkness (period 1, 2000 to 0700 LST the next day) and daylight (period 2, the next day at 0800 to 1900 LST) intervals.

b. Analysis technique

National Weather Service wind-direction forecasts are generally given for one of eight directions, i.e., NE (45 deg), E (90 deg), SE (135 deg), S (180 deg), SW (225 deg), W (270 deg), NW (315 deg), or N (360 deg). Sometimes no wind direction is forecast, as in "calm" or "light and variable" — these forecasts were discounted in the statistics. Hourly observed wind directions are available in 10-degree increments (wind observations of "calm" were not considered). If an observed wind blew out of the correct predicted direction, i.e., to the nearest eight-point compass direction to the observed, the forecast was labeled a direct hit for that hour. For example, if 190 deg was observed and a S wind was forecast, the forecast was labeled a direct hit (the next closest possible forecast point is 225 deg). A forecast was labeled a near miss to the left if the direction of travel of wind-borne smoke was approximately one compass point to the left of that indicated by the forecast. For example, given a NE forecast and a 350-deg observation, the forecast wind would take smoke southwestward, while the observed wind took smoke southward (to the nearest compass point). Because south is adjacent and to the left of southwest when facing SW, the forecast was labeled a near miss to the left for that hour. A similar tabulation was made for forecasts that were near misses to the right. Forecasts that were a direct hit, a near miss to the left, and a near miss to the right were combined into a near/direct-hit category, all others were labeled a missed forecast. Occasional multiple wind-direction forecasts may "bracket" an observed wind direction, e.g., a forecast of SW, shifting to NW brackets an observed 270 deg direction. Such cases were scored 1/2 "a near miss to the left" and 1/2 "a near miss to the right".

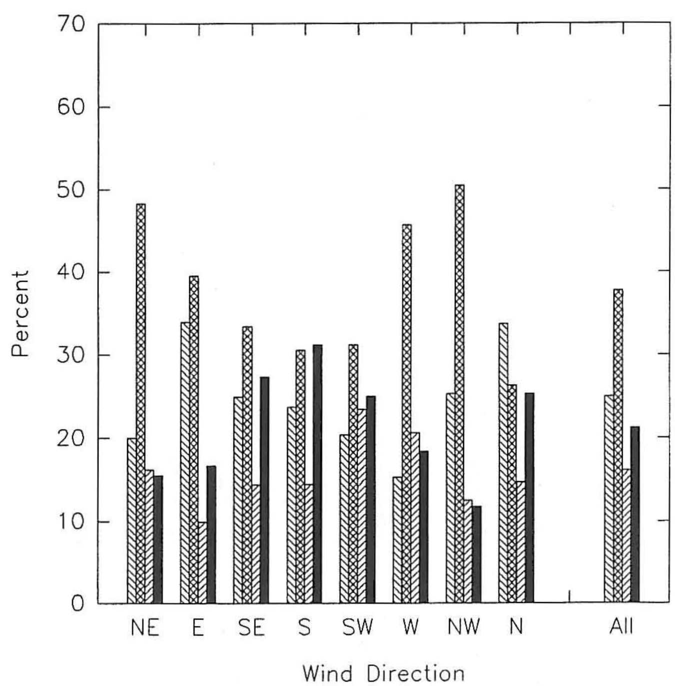

Fig. 1. Percent of forecasts off one semiquadrant left (slashed to upper left), scoring a direct hit (cross slashed), off one semiquadrant right (slashed to upper right), and missed (solid), by wind direction at Macon, Georgia.

3. Analysis of Forecasts

a. Macon, Georgia — overall

Figure 1 shows the analysis for MCN early morning forecasts for "today" and "tonight" at all wind speeds for each individual wind direction and for all wind directions. From left to right, the bar graph groupings show forecasts with verifying winds erring one semiquadrant to the left, direct hit forecasts, forecasts with verifying winds erring one semiquadrant to the right, and missed forecasts.

About 38% of all observed wind directions represented direct hits, while 21% were missed forecasts (i.e., 79% were near/direct hits). A marked left to right bias (more forecasts missing by a semiquadrant to the left vs. one to the right) existed in the overall near-miss verification categories. Roughly 25% of forecast verifications were off one semiquadrant left; only 16% being off one semiquadrant right. Accuracy and bias varied considerably as a function of forecast wind direction. Direct hits at MCN were most frequent for NE, W, and NW forecasts, while missed forecasts were most frequent for SE, S, SW, and N forecasts. Left to right bias was most notable for E and N forecasts, while SW and W forecasts actually had a small right to left bias.

b. Macon, Georgia — year-to-year performance

Interestingly, Fig. 2 shows forecast left to right bias nearly absent in the MCN data for 1985–1986 (21% left vs. 20% right). The bias is consistently strong (26% left vs. 15% right) during the remaining years (1987–1993), suggesting a change in wind-direction forecasting procedure that introduced bias at MCN.

c. Macon, Georgia — day, night, and resultant winds

Figure 3 compares overall wind-direction verification data against "day-only" forecasts, "night-only", and 12-h resultant winds (i.e., vector-averaged winds) used as verification. Modest differences appear between day and night forecast accuracy — day scored 40% direct hits while night scored 35%. Missed forecast scores were 20% day and 23% night. Left to right bias was much more pronounced for night than day — day scores were 22% left vs. 19% right, while night scores were 30% left vs. 12% right. The day forecasts were more accurate for MCN for

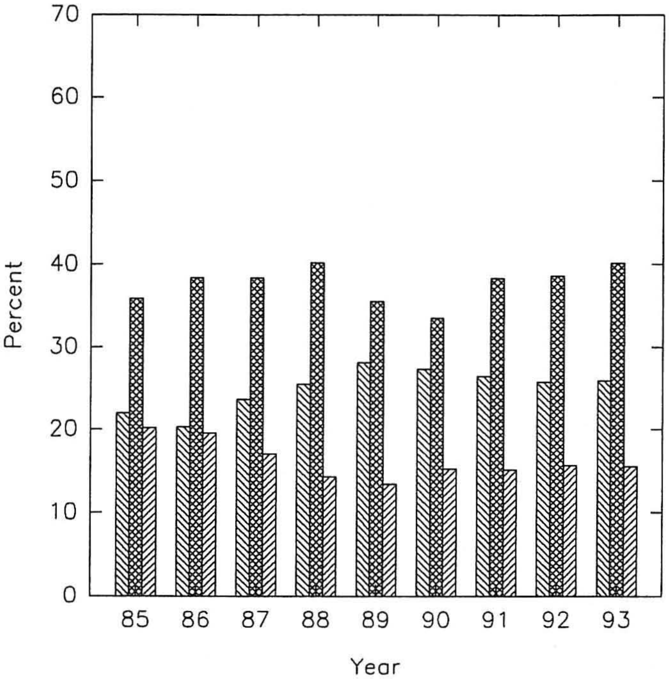

Fig. 2. Percent of forecasts off one semiquadrant left (slashed to upper left), scoring a direct hit (cross slashed), and off one semiquadrant right (slashed to upper right), by year at Macon, Georgia.

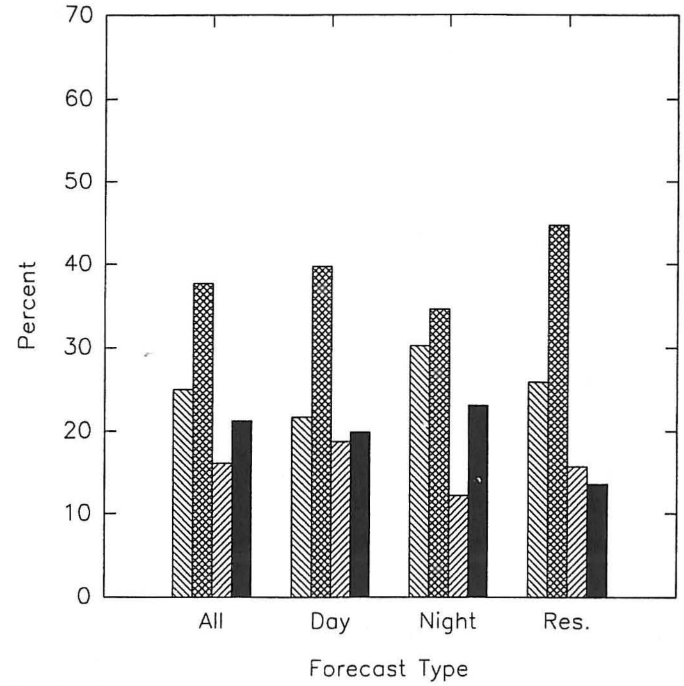

Fig. 3. Percent of forecasts off one semiquadrant left (slashed to upper left), scoring a direct hit (cross slashed), off one semiquadrant right (slashed to upper right), and missed (solid), by forecast type (All, Day, Night, and 12-h Resultant Winds) at Macon, Georgia.

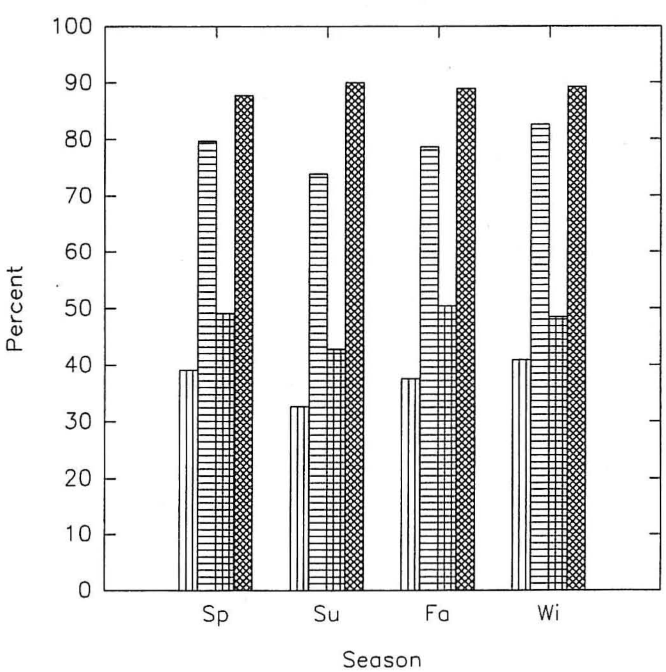

Fig. 4. Percent of forecasts scoring a direct hit (vertical lines), scoring a near/direct hit (horizontal lines) for all forecast cases; and scoring a direct hit (horizontal and vertical crossed lines), and scoring a near/direct hit (diagonal crossed lines) for forecast wind speeds greater than 10 mph at Macon, Georgia.

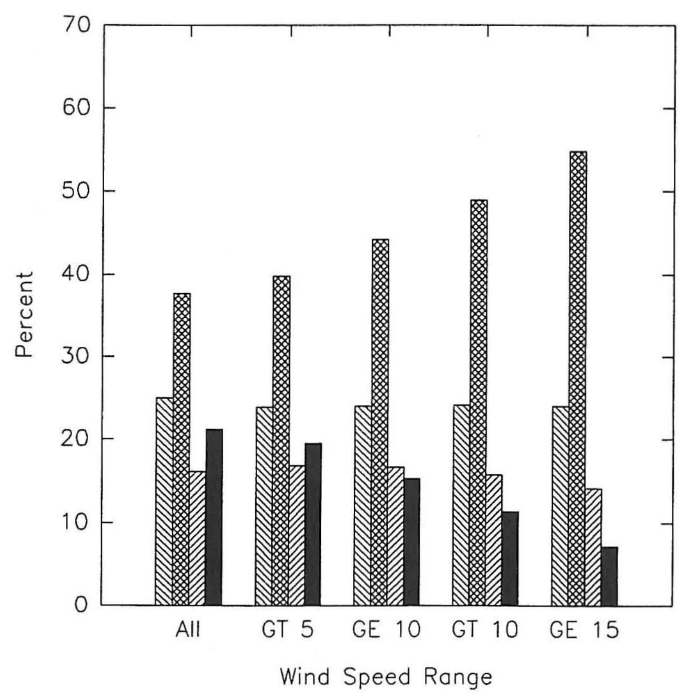

Fig. 5. Percent of forecasts off one semiquadrant left (slashed to upper left), scoring a direct hit (cross slashed), off one semiquadrant right (slashed to upper right), and missed (solid), by forecast wind speed (All, Greater Than 5 mph, Greater Than or Equal to 10 mph, Greater Than 10 mph, and Greater Than or Equal to 15 mph) at Macon, Georgia.

several reasons. They were all period 1 forecasts, verifying within about 12 h. The night forecasts were period 2 forecasts, verifying in the 12-24 h forecast period. Moreover, surface winds at night are generally more difficult to forecast because inversions are frequent and local scale phenomena tend to dominate flows.

Using 12-h resultant winds as the verification basis for wind-direction forecasts considerably improved forecast accuracy but did not significantly change the left to right forecast bias (Fig. 3). Both direct-hit and near/direct-hit forecasts improved by about 7%; however, left to right bias was 26% to 16%, compared to 25% to 16% for all hourly winds. The improvement in accuracy is expected for resultant winds because smaller scale fluctuations that may not have been considered in the forecasts would tend to be averaged out. The lack of improvement in bias scores suggests that a systematic error for forecasting wind direction at MCN may exist, particularly during night hours.

d. Macon, Georgia — by seasons and by forecast wind speed

Figure 4 shows the performance of wind direction forecasts for MCN by seasons. Seasons are defined as Mar-May = spring, Jun-Aug = summer, Sep-Nov = fall, and Dec-Feb = winter. The bar graphs show direct hits and near/direct hits for all cases, and direct hits and near/direct hits for forecast wind speeds of greater than 10 mph. There is a seasonal response (summer minimum/winter maximum) of about 8% for direct hits and near/direct hits for all cases as well as for direct hits for greater than 10 mph forecast. There is little response to near/direct hits for greater than 10 mph forecast. The seasonal response is due to pressure fields being generally better defined in the cooler part of the year. However, there is a greater response when forecast wind speed is directly considered. When the forecast wind speed is greater than 10 mph, there is roughly a 10% improvement in forecast verification statistics for each of the four seasons, both for direct hits and near/direct hits.

In Fig. 5, MCN combined day and night forecasts are grouped by forecast wind speeds. In determining forecast wind speeds, forecast gusts were ignored and where a range of speeds was given (e.g., 5-10 mph), the average was used. Figure 5 shows that overall verification statistics improved markedly (up to 15% for forecast wind speeds of 15 mph or more) with increased forecast wind speed, as would be expected. Forecast wind-direction bias did not significantly change with forecast wind speed.

e. Savannah River Site, South Carolina and Augusta, Georgia

Despite several problems with the Savannah River Site data set (including data gaps and a remote verification site), overall forecast performance was very similar to that of MCN. As should be expected, the performance for individual wind directions varies considerably between AGS and MCN. Figure 6 shows that about 39% of overall observations verified as direct hits while 23% were missed forecasts. These values were within 2% of

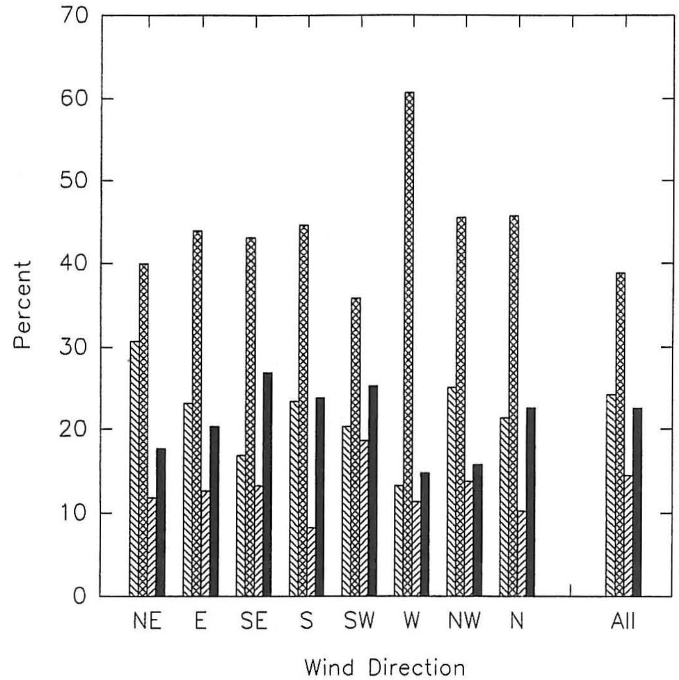

Fig. 6. Percent of forecasts off one semiquadrant left (slashed to upper left), scoring a direct hit (cross slashed), off one semiquadrant right (slashed to upper right), and missed (solid), by wind direction at Savannah River Site, South Carolina/Augusta, Georgia.

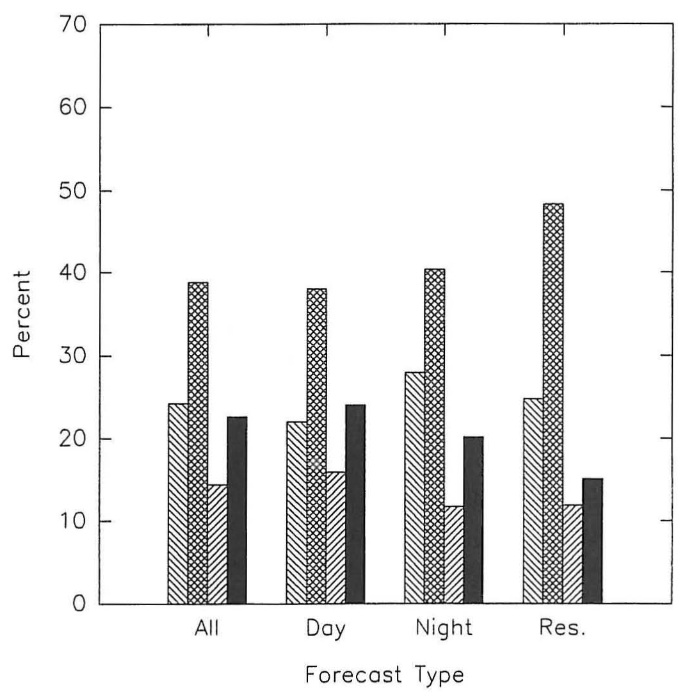

Fig. 7. Percent of forecasts off one semiquadrant left (slashed to upper left), scoring a direct hit (cross slashed), off one semiquadrant right (slashed to upper right), and missed (solid), by forecast type (All, Day, Night, and 12-h Resultant Winds) at Savannah River Site, South Carolina/Augusta, Georgia.

those shown for MCN. Forecasts of W winds were most accurate (61% for direct hits and only 15% missed forecasts). Forecasts of SW winds (36% direct hits) and SE winds (27% missed forecasts or 73% near/direct hits) were the least accurate. A 24% to 14% left/right bias (within 2% of the MCN statistics) is evident (Fig. 6). Significant bias was present for all years analyzed. Interestingly, bias was least evident for SW (one of the least accurate) and W (the most accurate) wind directions.

Figure 7 summarizes all wind directions for overall, day only, night only, and 12-h resultant wind statistics as verified at AGS. As might be expected, AGS day-only statistics were slightly less accurate while night-only statistics were slightly more accurate for AGS than those for MCN (Fig. 3). Due to the period 1 advantage, night forecast performance for the AGS data set was slightly better than day performance. The 12-h resultant wind results for AGS are also similar to those for MCN with direct hit and near/direct hit scores within 3% of those shown in Fig. 3. Except for night forecasts, the left vs. right bias was a little greater at AGS than at MCN. However, left to right forecast bias at AGS was more pronounced at night than at day, which indicates that forecast problems associated with night are more serious than the advantage gained by period 1 being at night for the AGS data set.

4. Summary

1) Wind-direction forecast accuracy (overall, day only, and night only) for direct hit verifications ranged from 35% to 40%, while near/direct hits ranged from 77% to 80%.

2) First-period forecasts (i.e., those that verify within about 12 h) showed a slight (5% or less) advantage in accuracy over second-period (12-24 h) forecasts.

3) Forecasts for day periods were marginally more accurate than those for night.

4) A pronounced left vs. right bias occurred in wind-direction forecasts, i.e., more observed winds verified as "off 1 left" than as "off 1 right." The overall bias at MCN was 25% vs. 16%.

5) The left vs. right bias was nearly absent in the first two years analyzed (1985-1986) at MCN. This bias was consistently present in all subsequent years, both at MCN (1987-1993), and AGS (1989-1993).

6) Left vs. right bias was most pronounced (approaching a ratio of 2.5:1) for forecasts that verified at night. Forecasts verifying during the day had relatively low bias (less than 1.25:1). Forecast wind speed seemed to have little effect on left vs. right bias.

7) Using a 12-h resultant wind for verification purposes improved the accuracy statistics of forecasts by 7% at MCN. This finding implies that long-range transport direction of smoke is forecast slightly better than short-range (1 h or less).

8) Using a 12-h resultant wind for verification did not greatly affect left vs. right bias. This finding suggests that the cause of the wind-direction forecast bias is real in a synoptic meteorology sense — implying that improvements in forecast techniques could reduce or eliminate it.

9) Forecasts made in winter were about 8% more accurate than those made for summer. The difference was even greater (about 10%) when wind direction forecasts for periods of high forecast wind speeds were compared to all cases. That is, the improvement in accuracy seen in winter was also observed during high wind cases in summer.

10) A forecast of high wind speed improved the accuracy (but not the bias) of the wind-direction forecast. The improvement at MCN was 17% for direct-hit statistics and 14% for near/direct-hit statistics, given a forecast speed of 15 mph or more.

11) Both the accuracy and the bias of a forecast was a strong function of forecast wind direction. Specifics, such as most or least accurate (or biased) wind direction were strongly dependent on the site.

5. Implications

Forecasting wind direction accurately over a time frame, useful to forestry prescribed burners, is difficult but crucial to the success of burning programs. Much of the problem results from the well-known vagaries of weather systems that produce wind fields in various spatial and temporal scales. This study has attempted to quantify the problem in a manner understandable and useful to forecast users, particularly those in forestry. The results of this study illustrate that users should not expect forecast winds to be confined to a narrow directional bandwidth and should allow for significant vagaries in the wind field.

The left to right bias found in wind-direction forecasts considered in this study is troubling, especially because the bias increased after 1985-1986. Future research should investigate the causes of this bias. With this information, others may be able to reduce it and improve forecasts of wind direction.

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