EXTREME NORTHEASTERLY WIND EVENTS IN THE HILLS ABOVE MONTECITO, CALIFORNIA

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ABSTRACT

Extreme northerly wind events are a forecast challenge along the south coast of Santa Barbara County in southern California. Often called "sundowners" because of their tendency to occur during the evening hours, these extreme wind events can produce damaging gale force winds and dangerous fire weather conditions.

In the present study, the usefulness of mean sea level pressure (MSLP) gradients are examined with regards to forecasting extreme northeasterly winds, specifically in the hills above Montecito. It is found that MSLP differences from Santa Barbara to Santa Maria (SBA-SMX) and Santa Barbara to Bakersfield (SBA-BFL) show similar skill in predicting extreme northeasterly wind gusts near Montecito. However, it is shown that the SBA-BFL MSLP difference may be a better predictor when it reaches extreme values. It is also demonstrated that there are factors other than MSLP differences that need to be considered when forecasting gusty northeast winds in the hills above Montecito.

INTRODUCTION

Mean sea level pressure (MSLP) gradients are one important factor that forecasters have to look at when forecasting surface winds in southern California. Forecasters at the National Weather Service Forecast Office in Oxnard, CA regularly use MSLP differences between Automated Surface Observing System (ASOS) stations to diagnose these MSLP gradients and forecast surface winds. Forecasters at the Oxnard office have suspected that a strong offshore MSLP difference between Bakersfield (BFL) and Santa Barbara (SBA) is associated with gusty and damaging northeast winds in the hills above Montecito (See Fig. 1a-b for a geographical overview). These gusty northeast winds are often associated with "sundowner" events and can result in rapidly spreading wildfires such as the devastating "Tea Fire" of 13-17 November 2008. They are often referred to as "sundowner" winds because of their tendency to occur during the evening hours.

Ryan (1996) established that a strong Santa Maria (SMX) to SBA MSLP difference is associated with strong sundowner winds along the southern facing slopes in western sections of the Santa Ynez Mountains. These winds result when strong north to northwest winds funnel through canyons and passes, many of which are oriented from north to south in the western portion of the Santa Ynez Range. Meanwhile, little attention was given to the SBA-BFL MSLP difference and its association with gusty northeast winds in the eastern portions of the Santa Ynez Mountains, such as the hills above Montecito, where many of the canyons and passes are oriented from northeast to southwest (Fig. 1b).

Given the northeast to southwest orientation of the canyons and passes in the eastern portions of the Santa Ynez Mountains (Fig. 1b), it seems reasonable to assume that the SBA-BFL MSLP

difference (SBA-BFL$_{\Delta MSLP}$) would be a better predictor of extreme northeasterly winds in the hills above Montecito than the SBA-SMX MSLP difference (SBA-SMX$_{\Delta MSLP}$). This is because the path from SBA-BFL is oriented from northeast to southwest (almost parallel to the canyons and passes in the eastern Santa Ynez Range), while the path from SBA-BFL is oriented from northwest to southeast (almost perpendicular to the canyons and passes in the eastern Santa Ynez Range) (Fig. 1a-b). Thus, the goals of this study are as follows:

1. Determine the strength of the relationship between SBA-BFL$_{\Delta MSLP}$ and gusty northeast winds in the Montecito hills.
2. Compare the usefulness of SBA-BFL$_{\Delta MSLP}$ to that of SBA-SMX$_{\Delta MSLP}$ when forecasting for extreme sundowner wind events in the hills above Montecito.

This will be achieved by examining a five year climatology of SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$, along with wind reports from a sensor in the hills above Montecito (MTIC1). A case study of the 13-17 November 2008 "Tea Fire" will then be used for comparison against the findings of Ryan (1996) and to demonstrate some of the results of the climatology.

DATA AND METHODOLOGY

Five years of hourly surface observations (1 January 2007 to 31 December 2011) from SBA, BFL, SMX and MTIC1 were examined in this study. SBA, BFL, and SMX are ASOS sites, while MTIC1 is a Remote Automated Weather Station (RAWS).

MTIC1 is located along the southwestern facing slopes in the eastern portion of the Santa Ynez Mountain Range and is positioned at the base of a canyon that is oriented from northeast to southwest (Fig. 1b). This canyon results in any strong northerly winds becoming northeasterly at MTIC1. In this portion of the Santa Ynez Mountains, the ridge line is at an elevation of about 3500 ft (or about 880 mb), while MTIC1 is at an elevation of 1619 ft (Fig. 1b).

SBA-BFL$_{\Delta MSLP}$ is defined as the MSLP at SBA minus the MSLP at BFL, such that a negative value indicates an offshore (i.e. northerly) gradient. Similarly, SBA-SMX$_{\Delta MSLP}$ is defined as the MSLP at SBA minus the MSLP at BFL, such that a negative value also indicates an offshore (i.e. northerly) gradient.

Hourly observations were broken down into four 6-hr periods as follows: "Morning" (1400-1900 UTC), "Afternoon" (2000-0100 UTC), "Evening" (0200-0700 UTC), and "Overnight" (0800-1300 UTC). For each 6-hr period, the strongest offshore (i.e. most negative) SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ and maximum northeasterly wind gust at MTIC1 were recorded. If a 6-hr period did not have a complete set of observations for at least three of the six hours, then the 6-hr period was not considered.

Quality control was performed for wind gusts at MTIC1 of 50 mph or greater. If a reported gust of 50 mph or greater was not from the northeast, the direction was changed to a northeasterly value if there was at least one report of a northeast wind in the hours immediately before and after the observation, or there were at least two reports of a northeast wind in the hours immediately before or after the observation. For the purpose of this study, a gust of 50 mph or

greater was considered to be from the northeast if the reported direction was between 345 and 90 degrees. Although this technically includes winds from the north-northwest and east, this was done to account for possible measurement errors taken by the MTIC1 sensor. Surface wind gusts exceeding 50 mph at MTIC1 that have any northerly component will almost certainly be from the northeast because the sensor is located within a deep canyon that is oriented from northeast to southwest (Fig. 1b).

CLIMATOLOGY RESULTS

As expected, the percentage of 6-hr periods with a northeasterly wind gust greater than or equal to 50, 60, and 70 mph increases as SBA-BFL$_{\Delta MSLP}$ becomes more offshore (Fig. 2). However, the percentage of 6-hr hour periods with extreme wind gusts is lower than one might expect at moderate SBA-BFL$_{\Delta MSLP}$ values. For example, when SBA-BFL$_{\Delta MSLP}$ was -4.0 to -5.0 mb, northeasterly gusts of 50 mph or greater only occurred in about 8 percent of those 6-hr periods (Fig. 2).

Breaking the results into 6-hr periods helps to delineate the probability of strong northeasterly gusts by time of day. As Figure 3 indicates, the evening is generally the most likely period to have a strong northeasterly wind gust for a given SBA-BFL$_{\Delta MSLP}$. For example, when SBA-BFL$_{\Delta MSLP}$ was -4.0 to -5.0 mb, northeasterly gusts of 50 mph or greater occurred in about 21 percent of the evening periods, whereas for the same SBA-BFL$_{\Delta MSLP}$, gusts of 50 mph or greater occurred in just 2 percent of the morning periods. These results support the term "sundowner" and the idea that these extreme northerly wind events tend to occur during the evening hours along this portion of the Santa Barbara coast.

Most importantly, northeast gusts greater than 50 mph at MTIC1 do not become likely (greater than 55 percent) until SBA-BFL$_{\Delta MSLP}$ reaches approximately -8.0 mb. At -8.0 to -9.0 mb, northeast gusts of 50 mph occurred in approximately 55 percent of all 6-hr periods combined (Fig.2). At the same SBA-BFL$_{\Delta MSLP}$, the afternoon and evening periods had northeasterly gusts of 50 mph or greater about 65 and 75 percent of the time, respectively (Fig. 3).

It should also be noted that the number of 6-hr periods that had a strong offshore (i.e. negative) SBA-BFL$_{\Delta MSLP}$ is far fewer than the number of 6-hr periods with a weak offshore SBA-BFL$_{\Delta MSLP}$ (Fig. 2). For example, there were 915 6-hr periods with a SBA-BFL$_{\Delta MSLP}$ of -1.0 to -2.0 mb, while there were only nine 6-hr periods with a SBA-BFL$_{\Delta MSLP}$ of -9.0 to -10.0 mb. While a sample size of nine is admittedly small, the fact that eight out of the nine 6-hr periods with a SBA-BFL$_{\Delta MSLP}$ of -9.0 to -10.0 mb experienced a northeast wind gust greater than 50 mph provides strong evidence that a SBA-BFL$_{\Delta MSLP}$ of this magnitude is very likely to produce extreme wind gusts in the hills above Montecito.

Before determining whether or not SBA-BFL$_{\Delta MSLP}$ is an improvement over SBA-SMX$_{\Delta MSLP}$ with regards to predicting gusty northeast winds in the Montecito hills, it is important to examine their distribution over the five year period. As Figure 4 indicates, SBA-BFL$_{\Delta MSLP}$ exhibits a much broader range of values than SBA-SMX$_{\Delta MSLP}$, with SBA-BFL$_{\Delta MSLP}$ (SBA-SMX$_{\Delta MSLP}$) ranging from about +6.4 to -9.9 mb (+3.3 to -6.8 mb). This results from the fact that the distance

from SBA-SMX is approximately 48 mi, while the distance from SBA-BFL is about 81 mi (Fig. 1a). So to answer the question of whether or not an extremely negative SBA-BFL$_{\Delta MSLP}$ is a better predictor of gusty northeast winds at MTIC1 than an extremely negative SBA-SMX$_{\Delta MSLP}$, percentiles are used (Table 1).

The results in Table 1 suggest that SBA-BFL$_{\Delta MSLP}$ may become more useful than SBA-SMX$_{\Delta MSLP}$, when SBA-BFL$_{\Delta MSLP}$ becomes extremely negative (i.e. northerly). For example, when SBA-BFL$_{\Delta MSLP}$ was less than or equal to -8.0 mb (the top 99.5 percentile of strongest northerly values SBA-BFL$_{\Delta MSLP}$), gusts of 50 mph or greater were measured at MTIC1 64.5% of the time. Meanwhile, when SBA-SMX$_{\Delta MSLP}$ was less than or equal to -5.3 mb (the top 99.5 percentile of strongest northerly values for SBA-SMX$_{\Delta MSLP}$), gusts of 50 mph or greater were measured at MTIC1 42.9% of the time. In other words, a very strong northerly SBA-BFL$_{\Delta MSLP}$ is a better predictor of extreme northeasterly winds at MTIC1 than a very strong northerly SBA-SMX$_{\Delta MSLP}$. On the other hand, when SBA-BFL$_{\Delta MSLP}$ was less extreme, it does not appear to be any more useful than SBA-SMX$_{\Delta MSLP}$. In fact, SBA-BFL$_{\Delta MSLP}$ has a slightly lower percentage of 6-hr periods associated with a wind gust at MTIC1 exceeding 50 mph at the 95th and 90th percentiles.

CLIMATOLOGY DISCUSSION

One of the results of the climatology was that even for an extreme northerly SBA-BFL$_{\Delta MSLP}$ (stronger than -8.0 mb), wind gusts at MTIC1 exceeding 50 mph were not always observed (Fig. 2 and Fig. 3). This is because there are factors other than surface pressure gradients that need to be considered when evaluating the potential for extreme northeasterly winds in the hills above Montecito. Ryan (1996) established some criteria in addition to strong surface pressure gradients that are needed for extreme sundowner wind events along the southern facing slopes of the Santa Ynez Range, which included the following:

1. *Upper level support*. Ryan (1996) states that winds at about 3,000 ft should be between 335° and 25° and that strong sundowner events tend to shift from the Santa Barbara area eastward to the Montecito area when the 850 mb wind shifts from the north-northwest to the north-northeast. As previously mentioned, the ridge line of the Santa Ynez Mountains in the eastern portion is around 880 mb, so winds at the 850 mb level are critical for forecasting sundowner events.
2. *A low-level inversion*. The presence of a significant low-level inversion or stable layer near the top of the Santa Ynez Mountains (2,000 – 4,000 ft) as indicated by the Vandenberg (VBG) sounding is also important (location shown in Fig. 1a). A stable layer near the mountain top likely acts to deflect any mountain waves that develop, downward, helping to intensify downslope winds at the surface.
3. *Marine layer strength and depth*. Strong sundowners are often preceded by a moderate sundowner in the previous 24 hours, which can weaken the marine layer, allowing downslope winds to more easily reach the low lying areas along the Santa Barbara coast.
4. *Cold air advection*. Winds backing from about 360° to 250° between 3,000 and 18,000 ft indicating cold air advection (CAA) from the north.

In the following section, a case study of the "Tea Fire" (13-17 November 2008) will be used to examine some of the above criteria established by Ryan (1996), as well as help to explain some of the results of the climatology.

CASE STUDY: THE "TEA FIRE" (13-17 NOVEMBER 2008)

The "Tea Fire" started less than a mile to the southwest of MTIC1 and began at approximately 0150 UTC 14 November 2008 (or 550 PM PST 13 November 2008) as the result of a bonfire from the previous day, which then reignited and spread under critical fire weather conditions. The devastating wildfire burned over 1,940 acres, destroyed 210 residences, and cost an estimated $5,700,000 in fire fighting expenses, before finally reaching 100 percent containment by the morning of 17 November 2008 (Montecito Fire Department).

Leading up to the fire, a 500 mb trough was located over the western United States on 0000 UTC 10 November, while a 1024 mb surface high pressure system was located off the west coast (Fig. 5a). Over the next 96 hours, the 500 mb trough moved east while a ridge amplified and moved over the west coast (Fig. 5a-e). During the same period, the surface high pressure system built into Pacific Northwest, setting up a strong north-south pressure gradient by 0000 UTC 14 November 2008 (Fig. 5a-e). By 0000 UTC 15 November, the 500 mb ridge had further amplified and a northeasterly MSLP gradient had developed across California (Fig. 5f).

Figure 6a shows a summary of SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ from 1800 UTC 11 November to 1800 UTC 15 November, and indicates that both values reached their most negative (i.e. northerly) value on the morning of 13 November, prior to the start of the fire. At 1500 UTC 13 November SBA-BFL$_{\Delta MSLP}$ reached -9.1 mb, while SBA-SMX$_{\Delta MSLP}$ reached -4.8 mb at the same time. The gusty northeast winds that resulted, along with relative humidity values near or below 10 percent and temperatures near 85°F at MTIC1, created Red Flag conditions during the hours leading up to the start of the fire (Fig. 6b,c). Even though relative humidity values climbed above Red Flag criteria to around 20-25 percent in the hours following the start of the fire, sustained winds over 50 mph with gusts over 70 mph (Fig. 6b,c) allowed the wildfire to grow rapidly.

A closer examination of SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$, along with the winds at MTIC1, reveals some interesting details. With SBA-BFL$_{\Delta MSLP}$ close to -5.0 mb and SBA-SMX$_{\Delta MSLP}$ at about -4.0 mb, northeasterly gusts of 50 mph were barely reached around 0300 UTC 12 November (Fig. 7a). At this same time, 20 kt northerly winds at 850 mb were resulting in CAA (Fig. 8a). At 0000 UTC 12 November, this CAA was resulting in synoptic scale quasi-geostrophic (QG) forcing for descent (Fig. 9a).

Also interesting to note are the gusty northeast winds that exceeded 50 mph from about 1200-1400 UTC 12 November (Fig. 7a), at a time when strong northerly winds in this region rarely occur. At 1300 UTC 12 November, SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ dropped sharply to -7.2 and -4.0 mb respectively (Fig. 7a), providing possible evidence of a vertically propagating mountain wave. Once again, 850 mb winds of about 20 kt were producing CAA from the north (Fig. 8b), along with a region of synoptic scale QG descent at 700 mb (Fig. 9b). It should also be

noted that the 850 mb winds had turned more to the northeast at this time (Fig. 8b), as opposed to more northerly as they were 9 hours prior (Fig. 8a). The 1200 UTC 12 November VBG sounding (location shown in Fig. 1b) also shows evidence of CAA with backing winds from 800-400 mb, as well as a sharp near mountaintop inversion at 900 mb, which would have helped to deflect a mountain wave downwards (Fig. 10). Unfortunately there were no 0000 UTC VBG soundings available throughout this event to assess the presence of a near mountaintop inversion during the evening hours.

On the following evening, SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ reached their strongest northerly (i.e. most negative) value of about -7.0 and -4.3 mb respectively, between 0000 UTC and 0600 UTC 13 November (Fig. 7b), both of which were slightly stronger than the previous evening. Once again, gusty northeast winds were observed at MTIC1, however they did not quite reach 50 mph, with 49 mph being the highest observed gust at, 0500 UTC 13 November (Fig. 7b). With a stronger SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$, along with a persistent region of QG descent (Fig. 9c), one might have expected stronger winds than the previous night. However, the 850 mb analysis shows that the northeasterly winds at 0300 UTC 13 November were slightly weaker at about 10-20 kt (Fig. 8c).

After falling to about -9.1 mb at 1500 UTC 13 November (Fig. 7b), SBA-BFL$_{\Delta MSLP}$ began to weaken slightly throughout the day on 13 November, but remained strong at -7.0 to -8.0 mb into evening hours (Fig. 7c). Meanwhile, SBA-SMX$_{\Delta MSLP}$ fell to about -4.8 mb at 1500 UTC 13 November (Fig. 7b), then weakened slightly and hovered between -3.5 to -4.0 mb during the evening hours (Fig. 7c). The gusty northeast winds exceeding 50 mph that helped to rapidly spread the wildfire began around 2200 UTC 13 November and lasted through 0800 UTC 14 November (Fig. 7c). At the peak of the event, MTIC1 measured some impressive sustained northeast winds over 55 mph, with gusts exceeding 70 mph. Although the QG descent at 0000 UTC 14 November (Fig. 9d) did not appear quite as strong as the previous two evenings, there was still evidence of CAA across the region (Fig. 8d). However, the big difference from the previous two evenings was the strength of the 850 mb winds. The Rapid Update Cycle (RUC) model analysis at 0000 UTC 14 November shows, northeast winds of 35-40 kt in the Montecito area (Fig. 8d).

SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ continued to weaken on the morning of 14 November (Fig. 7c). By 0000 UTC – 0300 UTC 15 November, SBA-SMX$_{\Delta MSLP}$ weakened to about -1.0 mb, while SBA-BFL$_{\Delta MSLP}$ remained moderately strong at about -5.0 mb (Fig. 7d). After 1500 UTC 14 November, the winds at MTIC1 remained relatively light and variable for the remainder of the event (Fig. 7c-d). Despite SBA-BFL$_{\Delta MSLP}$ remaining moderately strong at about -5.0 mb on the evening of 14 November, the light winds at the surface can be easily explained by noting that the 850 mb winds had weakened to 10-20 kt and had shifted to the east by 0000 UTC 15 November (Fig. 8e), thus shutting off the channeling effect of the northeast to southwest oriented canyon in which the MTIC1 sensor is located.

CASE STUDY DISCUSSION

A comparison of SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ during the "Tea Fire" showed that SBA-BFL$_{\Delta MSLP}$ can be more useful for predicting strong northeast winds in the hills above Montecito. On the evening of 11 November 2008, SBA-BFL$_{\Delta MSLP}$ was around -4.7mb, while SBA-SMX$_{\Delta MSLP}$ was about -4.0mb. This equates to a gradient value of -3.9mb/100km and -5.6mb/100km for SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$, respectively. On the following evening, SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ were about -7.0mb and -4.3mb respectively, which equates to a gradient of -5.8mb/100km and -6.1mb/100km respectively. On the evening of 13 November 2008, when the northeast winds at MTIC1 peaked in intensity, SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ were around -7.5mb and -4.0mb, respectively. This is the equivalent of a gradient of -6.3mb/100km and -5.6mb/100km for SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$, respectively. On the following evening, when the winds at MTIC1 were light and variable, SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ were at about -5.0mb and -1.0mb, or -4.2mb/100km and -1.4mb/100km respectively. In summary, SBA-BFL$_{\Delta MSLP}$ showed a wider range of values than SBA-SMX$_{\Delta MSLP}$ throughout the event and did a better job of highlighting what evening the strongest northeast winds at MTIC1 would occur.

The "Tea Fire" case study also demonstrated that strong northeast winds at MTIC1 can occur at modest SBA-BFL$_{\Delta MSLP}$ values of -4.0mb to -5.0mb. Furthermore, the case study showed the importance of looking at additional factors besides the surface pressure gradients when considering gusty northeast winds in the hills above Montecito.

The first factor in addition to the surface pressure gradients mentioned by Ryan (1996) was the importance of upper-level wind support. The importance of upper-level wind support was evident in the "Tea Fire" incident by the fact that the strongest northeasterly winds at MTIC1 occurred on the evening of 13 November 2008, when the 850 mb winds were from the northeast at 35-40 kt. In contrast, on the evening of 11 November 2008, the 850 mb winds were from the north at about 20 kt, while on the evening of 12 November 2008, the 850 mb winds were from the northeast but only at about 10-20 kt. On the evening on 14 November 2008, the 850 mb winds had become easterly and weakened to 10-20 kt, resulting in light and variable winds at the surface.

The second factor discussed by Ryan (1996) was the importance of a near mountaintop inversion. On the morning of 12 November 2008, there was evidence of a vertically propagating mountain wave in the surface pressure fields, along with a strong near mountaintop temperature inversion in the VBG sounding. This strong inversion may have helped to deflect a mountain wave downwards, resulting in gusty winds at the surface during a time of day when strong northerly or northeasterly winds are rarely observed.

The third characteristic that Ryan (1996) said was necessary for extreme sundowner wind events was a weakened marine layer as the result of a less significant sundowner during the previous 24 hours. Although some strong sundowner winds were observed at MTIC1 on the evenings of 11 November and 12 November, the event peaked in intensity on the evening of 13 November, possibly due to a diminished marine layer influence.

The fourth and final factor in addition to the surface pressure gradients mentioned by Ryan (1996), was the importance of CAA. Cold air advection from the north was evident throughout the "Tea Fire" event.

Also of particular interest in the "Tea Fire" incident was that SBA-BFL$_{\Delta MSLP}$ reached its strongest offshore value of -9.1mb during the morning hours on 13 November 2008, but the strongest winds at MTIC1 did not occur until later that evening when SBA-BFL$_{\Delta MSLP}$ was trending upward (Fig. 6). The increase in winds during the evening hours can partially be explained by the 850mb winds. During the morning hours the 850mb winds were approximately 20-30kt out of the northeast as analyzed by the RUC(not shown here), then increased to 30-40kt during the evening hours (Fig. 8d).

The increase in 850mb winds may partially explain why the strongest winds occurred during the evening hours for the "Tea Fire", but it seems unlikely from a climatological perspective that the 850mb winds can explain why strong northeasterly winds at MTIC1 are generally most likely during the evening hours and least likely during the morning hours for a given SBA-BFL$_{\Delta MSLP}$ (Fig. 3). One possible explanation for the decreased likelihood of strong winds during the morning hours is that the marine layer temperature inversion is typically strongest during the early morning hours, thus making it more difficult for strong winds to reach the surface south of the ridgeline of the Santa Ynez Mountain Range. This possible explanation may be an area for future research.

CONCLUSIONS

The main goals of this study were to:

1. Determine the strength of the relationship between SBA-BFL$_{\Delta MSLP}$ and strong sundowner wind events in the hills above Montecito.
2. Compare the usefulness of SBA-BFL$_{\Delta MSLP}$ to that of SBA-SMX$_{\Delta MSLP}$ when forecasting extreme sundowner wind events in the hills above Montecito.

It was found that as SBA-BFL$_{\Delta MSLP}$ becomes more offshore (i.e., more negative), there is an increasing potential for extreme northeasterly wind gusts. Furthermore, this relationship becomes the strongest during the evening hours, hence the term "sundowner." However, when looking exclusively at surface pressure gradients from a climatological perspective, it was found that northeast wind gusts in excess of 50 mph in the Montecito hills do not become likely until SBA-BFL$_{\Delta MSLP}$ approaches about -8.0 mb.

When comparing SBA-BFL$_{\Delta MSLP}$ and SBA-SMX$_{\Delta MSLP}$ from a climatological perspective, it was found that SBA-BFL$_{\Delta MSLP}$ may be a better indicator of extreme northeasterly winds in the hills above Montecito, but only when SBA-BFL$_{\Delta MSLP}$ approaches extreme values of about -8.0 mb. However, on a case-by-case basis extreme northeast winds in the hills above Montecito can occur when SBA-BFL$_{\Delta MSLP}$ is weaker than -8.0mb because there are other factors that need to be considered by the forecaster. These additional factors include upper-level support, the presence

of a near mountaintop inversion, marine layer influences, and the presence of CAA producing synoptic scale descent.

Therefore, it is suggested that forecasters be particularly aware of the increased potential for extreme northeast winds in the eastern portions of the Santa Ynez Range when SBA-BFL$_{\Delta MSLP}$ values reach -6.0mb to -7.0mb, but understand that when looking exclusively at the surface pressure gradients, wind gusts in excess of 50mph do not become *likely* until SBA-BFL$_{\Delta MSLP}$ reaches about -8.0mb. Forecasters should also be aware that for a given SBA-BFL$_{\Delta MSLP}$ value, strong northeast winds in the Montecito area are much more likely during the evening hours than the early morning hours. Furthermore, it is critical that the 850mb wind is out of the north-northeast or northeast for strong sundowner winds in the eastern portions of the Santa Ynez Range.

It is suggested that any future research focuses on getting a more precise understanding of what combinations of surface pressure gradients and the additional factors discussed above, are capable of producing extreme northeasterly winds in the Montecito area. It may also be beneficial to look at more in depth case studies to gain a better understanding of why these strong winds tend to occur in the evening hours as opposed to the morning hours, even when the morning offshore surface pressure gradients are equal to or stronger than the evening offshore surface pressure gradients.

ACKNOWLEDGEMENTS

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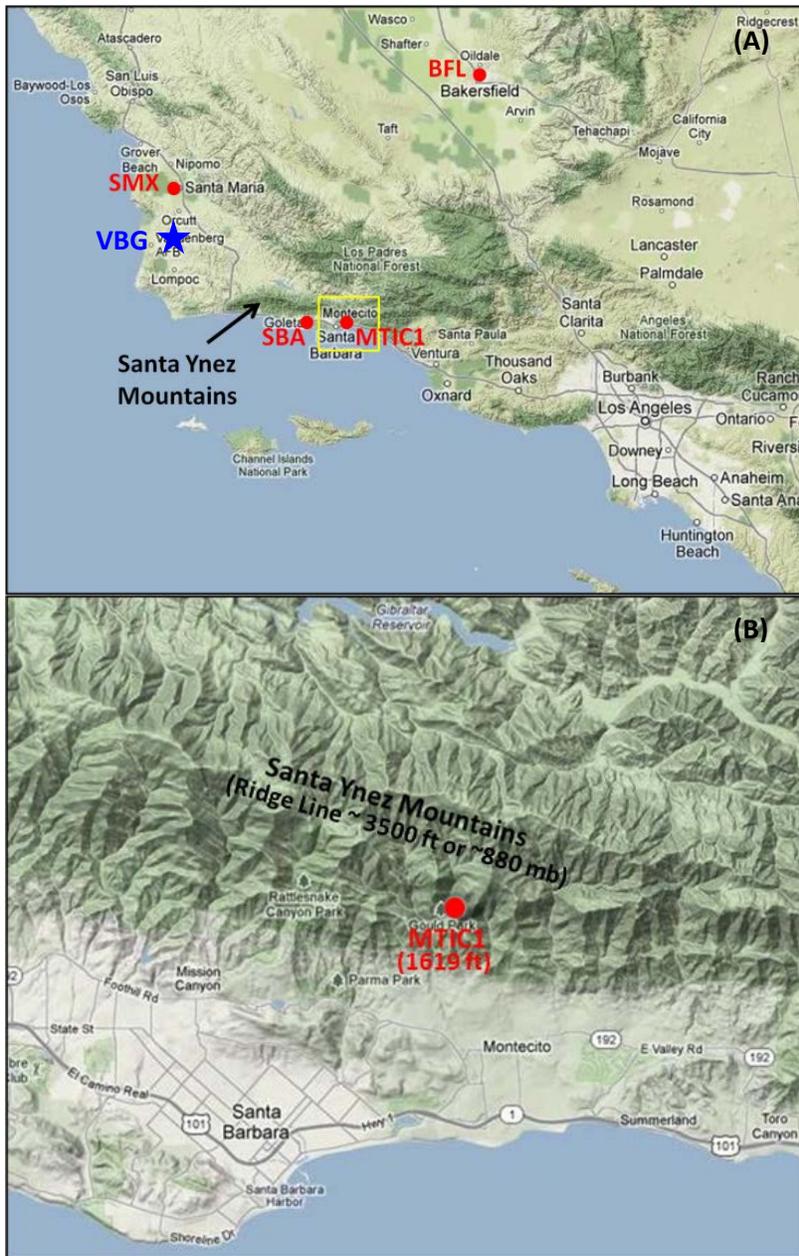
Fig. 1. Geography of the Montecito area. Panel (A) shows the location of Montecito along the south coast of Santa Barbara County, including the locations of Santa Barbara (SBA), Bakersfield (BFL), Santa Maria (SMX), Vandenberg (VBG), and the Montecito Hills RAWS sensor (MTIC1). The yellow box around MTIC1 in (A) indicates the area shown in (B). Panel (B) is a close-up view of the Montecito area that shows the location of MTIC1 along the southwestern facing slopes of the eastern Santa Ynez Mountain Range. Source: Google Maps.
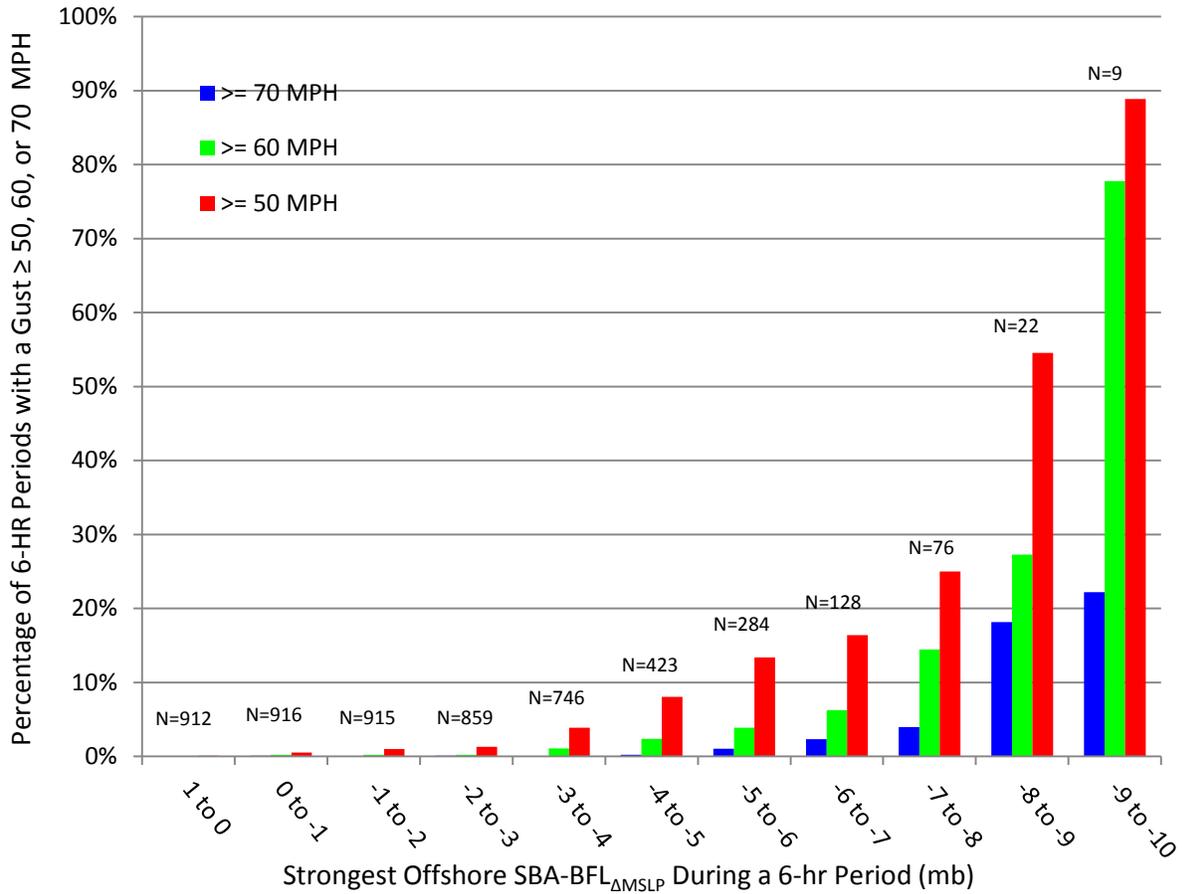
Fig. 2. Percentage of 6-hr periods with a northeast wind gust at MTIC1 greater than or equal to 50, 60 or 70 mph vs. the strongest offshore (i.e. most negative) SBA-BFL$_{\Delta MSLP}$ during a 6-hr period. The values of "N" are the number of 6-hr periods that had SBA-BFL$_{\Delta MSLP}$ in the specified bin. For example, there were 423 6-hr periods with a SBA-BFL$_{\Delta MSLP}$ of -4 to -5 mb and approximately 8 percent of those 423 6-hr periods had a northeast wind gust greater than or equal to 50 mph.
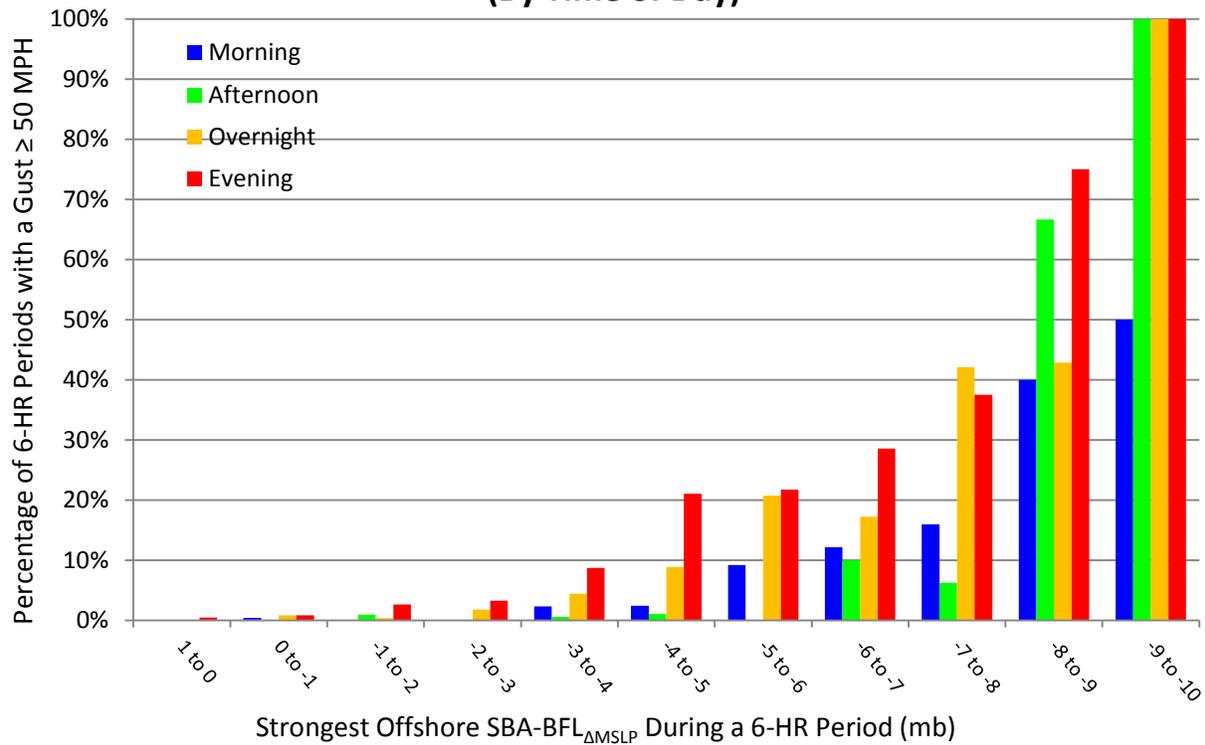
Fig. 3. Same as Figure 2, except only for northeast gusts greater than or equal to 50 mph. The results here are also broken down into 6-hr periods as follows: "Morning" (1400-1900 UTC), "Afternoon" (2000-0100 UTC), "Evening" (0200-0700 UTC), and "Overnight" (0800-1300 UTC).
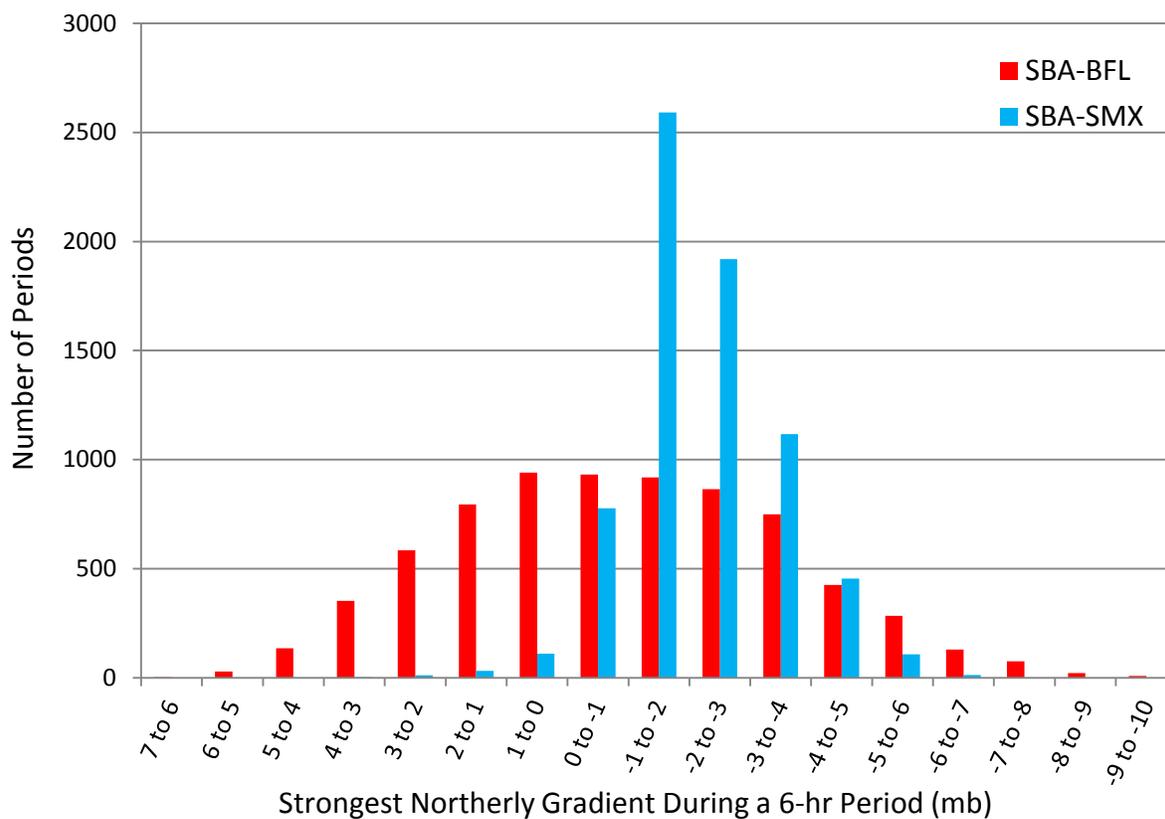
Fig. 4. Distribution of the strongest northerly values of SBA-BFL$_{\Delta MSLP}$ (red) and SBA-SMX$_{\Delta MSLP}$ (blue) during the defined 6-hr periods over the five year period (2007-2011).
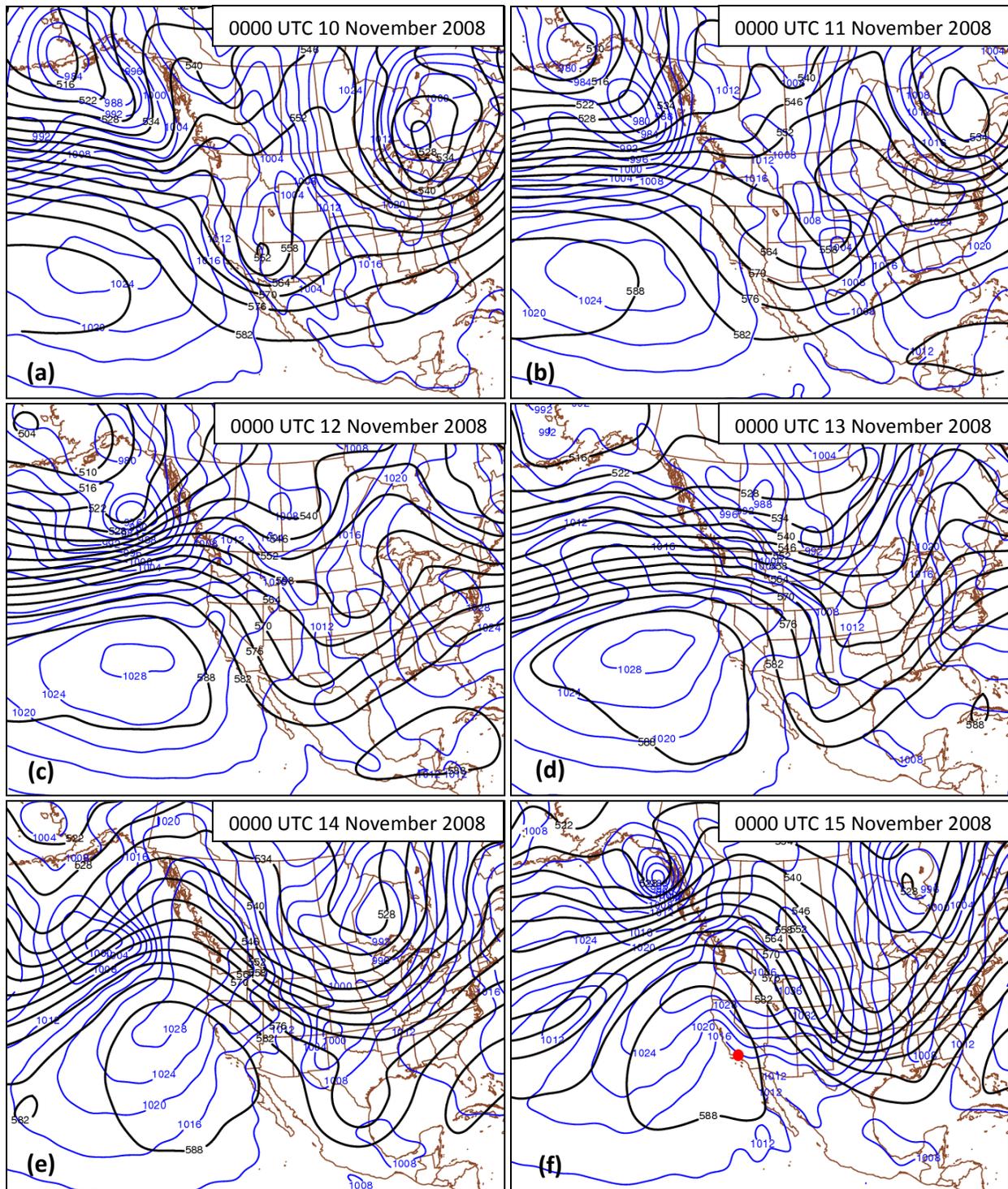
Fig. 5. Plots of 500 mb heights (dam, black contours) and MSLP (mb, blue contours) at (a) 0000 UTC 10 November 2008, (b) 0000 UTC 11 November 2008, (c) 0000 UTC 12 November 2008, (d) 0000 UTC 13 November 2008, (e) 0000 UTC 14 November 2008, and (f) 0000 UTC 15 November 2008. Data source: 0.5° GFS. The red dot in (f) gives a better indication of where Montecito is located along the west coast of the United States.
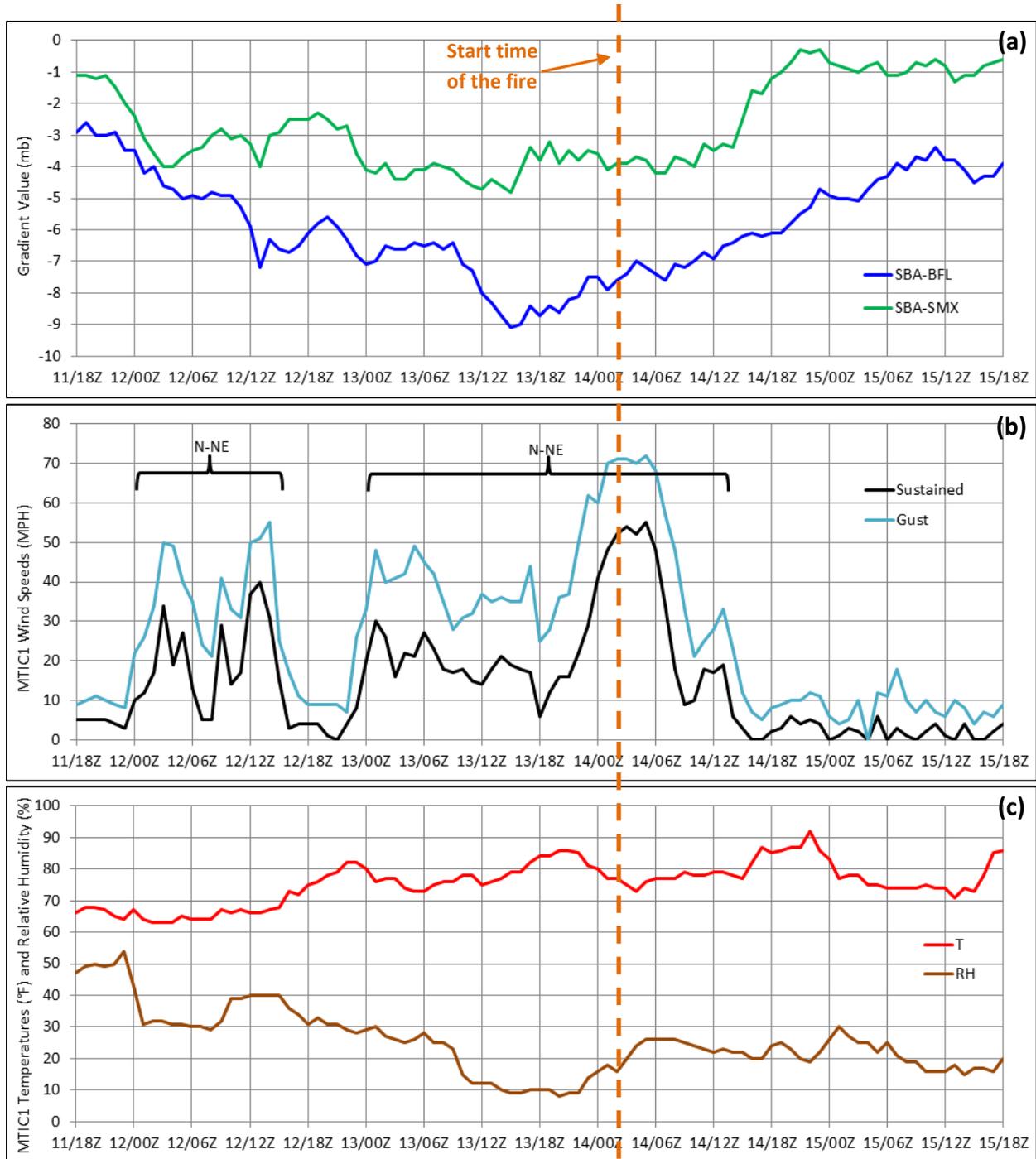
Fig. 6. Hourly observations of (a) SBA-BFL$_{\Delta MSLP}$ (blue) and SBA-SMX$_{\Delta MSLP}$ (green), (b) sustained winds (black, mph) and wind gusts (turquoise, mph) at MTIC1, and (c) temperatures (red, °F) and relative humidity (brown, percent) at MTIC1, from 1800 UTC 11 November 2008 to 1800 UTC 15 November 2008. The periods of north-northeast winds at MTIC1 are indicated on Panel (b) (see Fig. 7 for more detail on the winds at MTIC1). The orange, dashed, vertical line indicates the approximate start time of the "Tea Fire" at 0150 UTC 14 November 2008 (5:50 PM PST 13 November 2008).
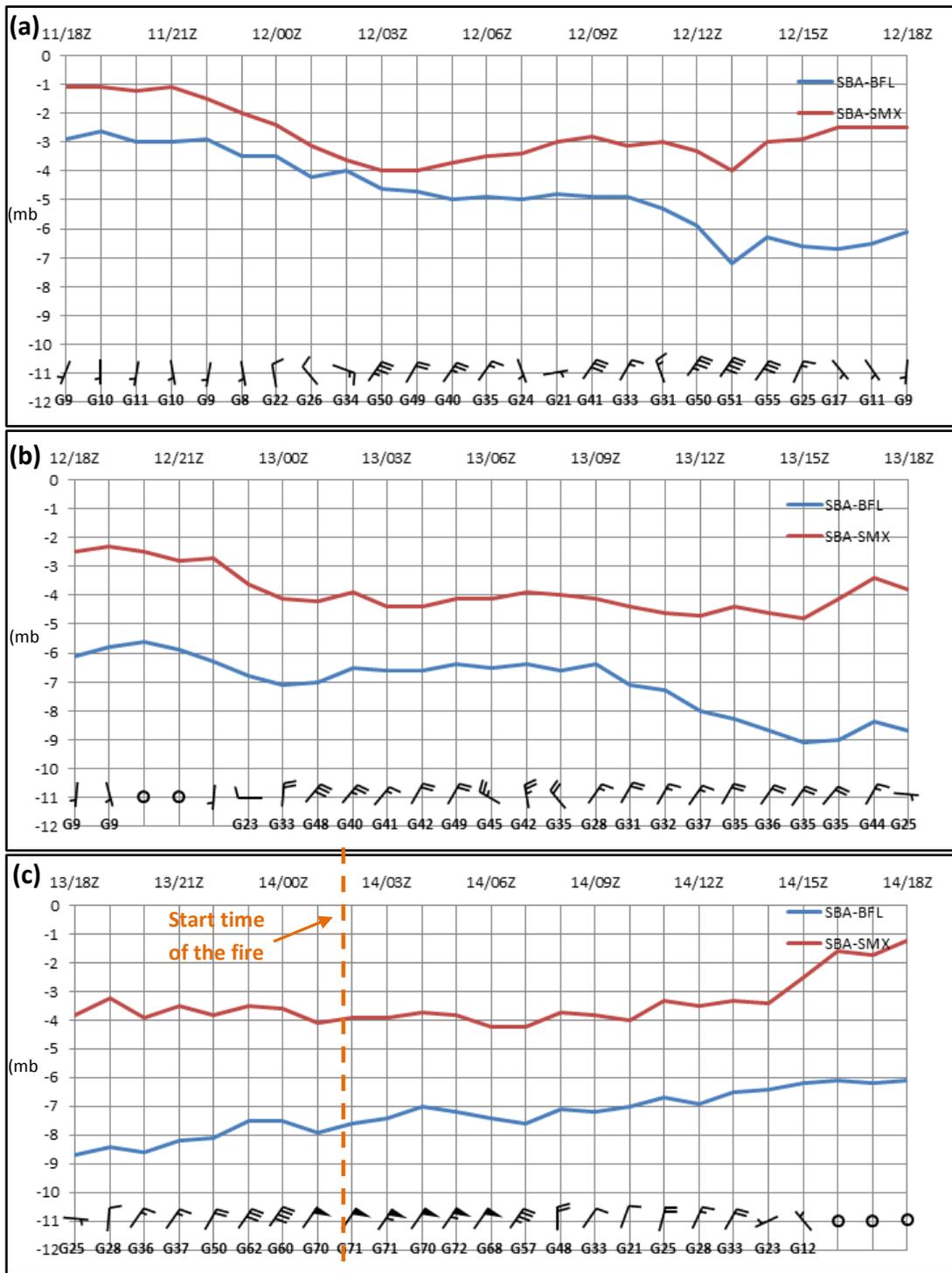
Fig. 7. Hourly observations of SBA-BFL$_{\Delta MSLP}$ (blue) and SBA-SMX$_{\Delta MSLP}$ (red), along with the hourly winds from MTIC1 for (a) 1800 UTC 11 November 2008 to 1800 UTC 12 November 2008, (b) 1800 UTC 12 November 2008 to 1800 UTC 13 November 2008, (c) 1800 UTC 13 November 2008 to 1800 UTC 14 November 2008, and (d) 1800 UTC 14 November 2008 to 1800 UTC 15 November 2008. The orange, dashed, vertical line in (c) indicates the approximate start time of the fire. Note: Wind barbs are plotted in mph, not knots.
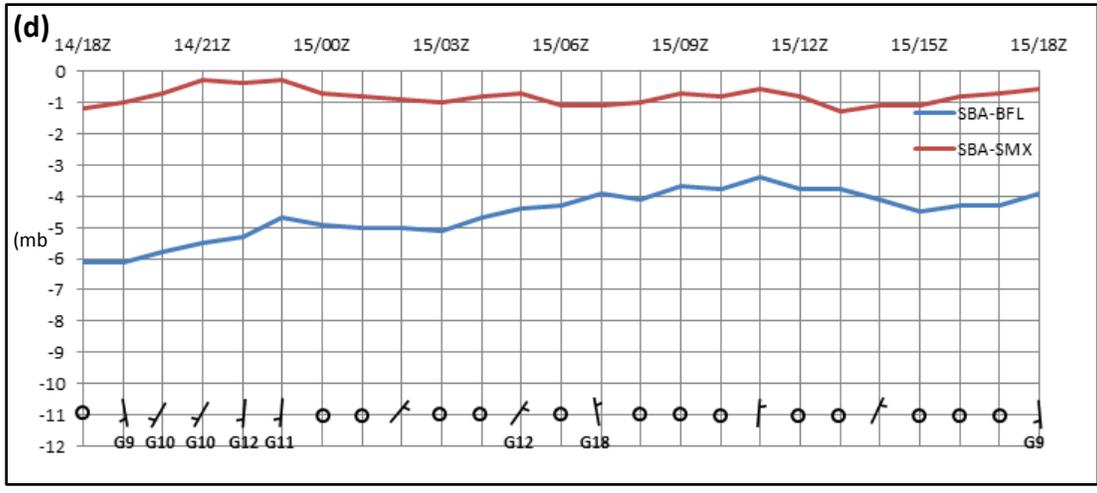
Fig. 7. (continued)
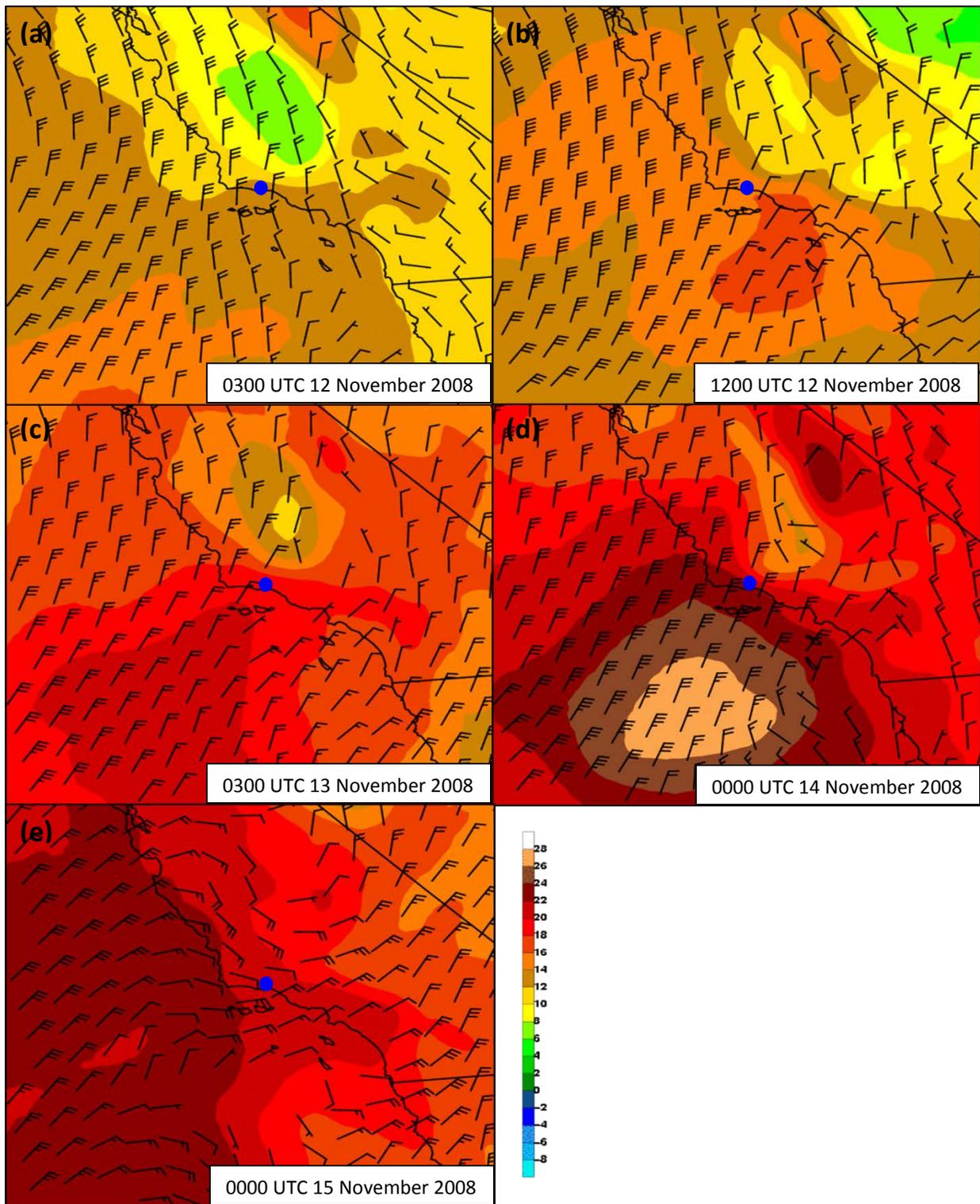
Fig. 8. Plots of 850 mb temperature (°C, shaded), and winds (kt, black wind barbs) for (a) 0300 UTC 12 November 2008, (b) 1200 UTC 12 November 2008, (c) 0300 UTC 13 November 2008, (d) 0000 UTC 14 November 2008, and (e) 0000 UTC November 2008. The blue dot indicates the location of Montecito. Data Source: 13-km RUC.
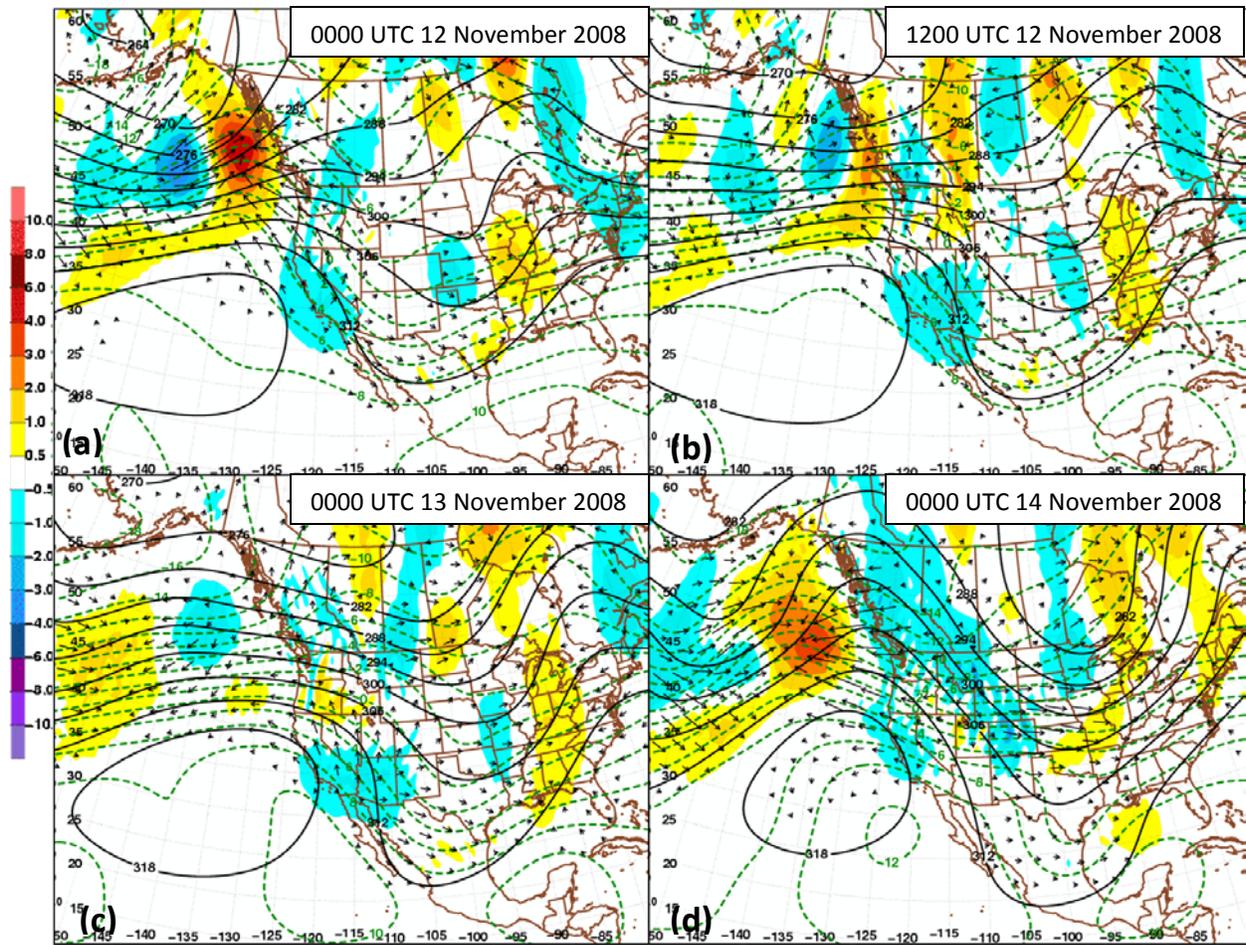
Fig. 9. Images showing 700 mb Q-vectors (arrows > 2.5×10^{-7} Pa m^{-1} s^{-1}), Q-vector divergence (shaded, 10^{-12} Pa m^{-2} s^{-1}), heights (solid black, dam), and temperatures (dashed green, °C), for (a) 0000 UTC 12 November, (b) 1200 UTC 12 November, (c) 0000 UTC 13 November, and (d) 0000 UTC 14 November 2008. Warm (cold) colors denote QG forcing for ascent (descent). Data source: 0.5 ° GFS.
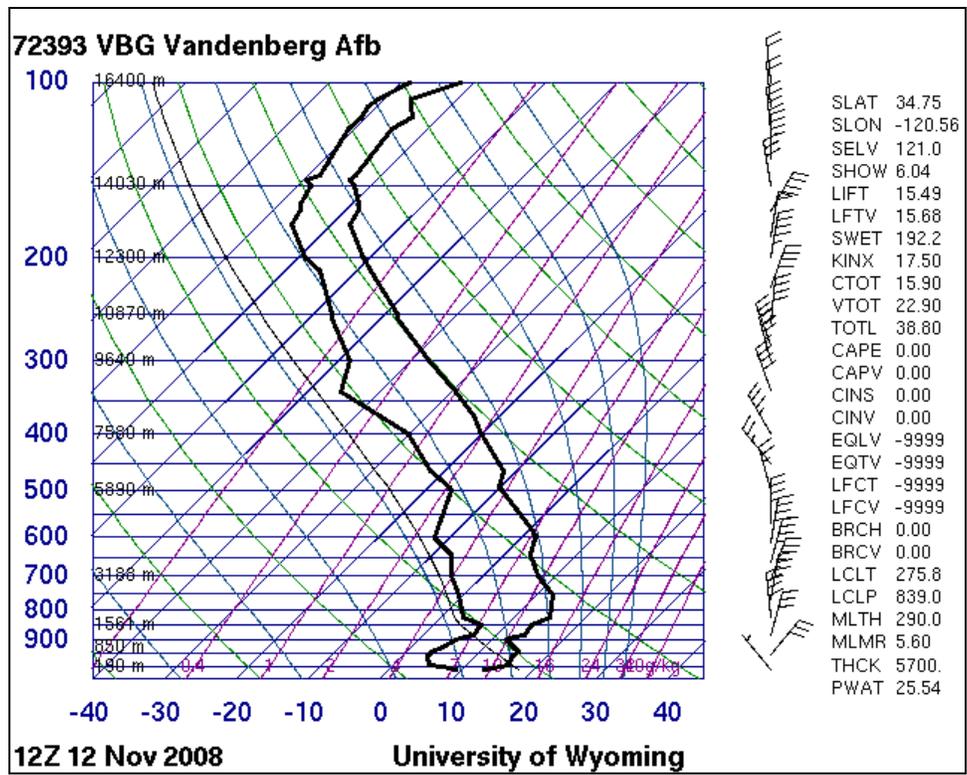
Fig. 10. A sounding from Vandenberg Air Force Base (VBG) at 1200 UTC 12 November 2008.

SBA-BFL$_{\Delta MSLP}$ vs. SBA-SMX$_{\Delta MSLP}$

SBA-SMX$_{\Delta MSLP}$					SBA-BFL$_{\Delta MSLP}$			
Percentile	Count	NE ≥ 50 mph	Percentage		Percentile	Count	NE ≥ 50 mph	Percentage
99.5 (≤ -5.6 mb)	35	15	42.9%		99.5 (≤ -8.0 mb)	31	20	64.5%
99th (≤ -5.3 mb)	67	25	37.3%		99th (≤ -7.3 mb)	79	32	40.5%
95th (≤ -4.3 mb)	380	94	24.7%		95th (≤ -5.5 mb)	374	74	19.8%
90th (≤ -3.8 mb)	730	137	18.8%		90th (≤ -4.4 mb)	738	117	15.9%
75th (≤ -2.8 mb)	1845	176	9.5%		75th (≤ -2.9 mb)	1779	164	9.2%
50th (≤ -2.0 mb)	3611	186	5.2%		50th (≤ -0.9 mb)	3562	181	5.1%

Table 1. A comparison of the percentage of 6-hr periods having a northeast wind gust at MTIC1 greater than or equal to 50 mph for a given SBA-BFL$_{\Delta MSLP}$ or SBA-SMX$_{\Delta MSLP}$. The "Percentile" column is the percentile into which a given SBA-BFL$_{\Delta MSLP}$ or SBA-SMX$_{\Delta MSLP}$ falls. For example, when SBA-SMX$_{\Delta MSLP}$ was less than or equal to -5.3 mb, it fell into the 99th percentile of strongest northerly (i.e. most negative) values for SBA-SMX$_{\Delta MSLP}$. The "Count" column is the number of 6-hr periods that had SBA-BFL$_{\Delta MSLP}$ or SBA-SMX$_{\Delta MSLP}$ less than or equal to the corresponding value. For example, SBA-SMX$_{\Delta MSLP}$ had a value less than or equal to -5.3 mb during 67 6-hr periods for this five year study. The "NE ≥ 50 mph" column is the number of 6-hr periods where a northeasterly gust greater than or equal to 50 mph was measured at MTIC1 for a given SBA-BFL$_{\Delta MSLP}$ or SBA-SMX$_{\Delta MSLP}$. For example there were 25 6-hr periods when SBA-SMX$_{\Delta MSLP}$ was less than or equal to -5.3 mb and there was a northeasterly gust at MTIC1 of 50 mph or greater. The "Percentage" column is the percentage of 6-hr periods that had a northeasterly gust of 50 mph or greater at MTIC1 for a given SBA-BFL$_{\Delta MSLP}$ or SBA-SMX$_{\Delta MSLP}$. For example, when SBA-SMX$_{\Delta MSLP}$ was less than or equal to -5.3 mb during a 6-hr period, a northeast gust of 50 mph or greater was measured 37.3% of the time, or in 25 out of 67 occurrences.