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A COMPARISON OF SEVERAL ANALYSIS SCHEMES IN THEIR ABILITY TO DIAGNOSE BOUNDARIES

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1. INTRODUCTION

There have been a number of recent additions and changes to analysis schemes available or potentially available to forecasters. A good high-resolution analysis available in real time is important for forecasters for a number of reasons, including diagnosing and tracking boundaries for nowcasting and to monitor how well short-term forecasts from high-resolution numerical model forecasts are performing.

Of course an analysis can serve many purposes in addition to monitoring model performance. For convective potential, forecasters typically use real-time analyses to monitor derived fields such as Convective Available Potential Energy (CAPE), Convective INhibition (CIN), and convergence. These are parameters that can be important to nowcasting and short-term forecasting but would be difficult to calculate without an analysis scheme. Another use for an analysis package would be to initialize a high-resolution model, either on a local National Weather Service (NWS) Weather Forecast Office (WFO) scale, or a much larger scale. And of course an analysis serves as a record of what actually occurred.

At the Forecast Applications Branch (FAB) of the Global Systems Division (GSD) of NOAA/ESRL, we have been running an analysis scheme since the 1980s known as LAPS, for Local Analysis and Prediction System (Albers et al. 1996). The philosophy behind the creation of LAPS was to provide a real-time high-resolution analysis using all available data sources. The analysis scheme has been a part of the Advanced Weather Interactive Processing System (AWIPS) and available to forecasters in real time for over twenty years. During this time a number of data sources have been added to the analysis, and the horizontal resolution increased from an original 10 km to 5 km, with the option to run at finer resolution at a WFO. Besides providing the forecaster with a high-resolution surface and three-dimensional analysis at hourly intervals, LAPS was envisioned as a starting point analysis to use for a local model that could be run even at a WFO.

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While LAPS over the years has been associated with the analysis system described above, in fact it is really a system composed of an analysis component and a predictive component. Within the analysis component, we have recently been testing LAPS at much higher space (down to 1 km in the horizontal grid) and time (every 15 min) resolutions. In addition, a different type of analysis scheme known as STMAS, for Space-Time Mesoscale Analysis System, has been developed and is being run at horizontal grid resolutions varying from 5 to 1 km (a paper at this AMS Annual Meeting describes STMAS; see Yuan et al. 2011).

STMAS is envisioned to one day replace the original “LAPS” analysis, and one of the motivations for this study was to compare STMAS analyses with those from “traditional LAPS” (hereafter we refer to this simply as LAPS). Since a typical forecaster use of an analysis scheme is to monitor boundaries and conditions along a boundary, one area where we concentrated the LAPS and STMAS comparisons was to look at cases where boundaries were present. In an earlier paper (Szoke et al 2010), we focused on applications to potential severe weather and a known and well-studied boundary that commonly occurs in Northeast Colorado called the Denver Convergence-Vorticity Zone (DCVZ, or “Denver Cyclone”, Szoke et al. 1984). In this paper we highlight cases that examine other more general boundaries, including a cold front and a fairly complex case with several boundaries. Analyses can also be important in non-boundary situations where the flow is complex and wind information critical. An example is trying to determine wind behavior for fire weather concerns. Two significant wildfires occurred near the Boulder area in the late summer and fall of 2010, and in this paper we will show a comparison of analyses and short-range forecasts for the one in late October.

While the focus of this study is to compare the various LAPS and STMAS analyses, we expanded the study to include another relatively new analysis that is available on AWIPS, the NCEP Real-Time Mesoscale Analysis (RTMA). Finally, for some of the cases we were able to include the 0-hour forecast time for the new High-Resolution Rapid Refresh model (HRRR), which is run in a predictive mode at 3-km resolution. There are caveats that must be considered when including the HRRR and RTMA in any comparison, and these are discussed further in the next section. Note also that for the wildfire case we also included comparisons for three short-range wind forecasts, one of which was from the HRRR.

2. OVERVIEW OF THE VARIOUS SCHEMES

In this section we provide some background information on the various analyses that are compared in this study. There are a number of variations, including the purpose or goal of each, which should be considered before any conclusions can be drawn from the comparisons.

As noted earlier, LAPS is a long-standing analysis scheme whose original purpose was to provide a rapid, high-resolution surface and 3-D analysis on an hourly basis on a WFO-type scale (Albers et al. 1996). The analysis could then be used to initialize a local-scale model for short-term forecasting applications. The original LAPS used a 10-km horizontal grid spacing and one-hour time resolution. The LAPS schemes used in the study here have the following characteristics:

- Horizontal grid resolutions varying from 5 km to 1 km.
    - Most operational versions are at 5 km at this time.
- Temporal resolution down to 15 min.
    - Operational versions generally at 1-h intervals.
- Full 3-D analysis.
- Available on AWIPS on WFO to sub-regional scales, but not CONUS.
- Uses all available observations including Doppler winds, satellite, METARs and mesonet, profilers, and ACARS.
- Utilizes variational methods and Kalman filtering techniques.
- Fairly liberal QC in order to catch smaller-scale features.

The STMAS scheme was motivated by work with the FAA to provide a quick, high-resolution surface analysis. As such, the goal is to provide a larger-scale analysis, which in the latest version is done down to 2-km horizontal grid resolution on the CONUS scale. Some of the characteristics include:

- Horizontal grid resolutions varying from 5 km to 1 km.
- Temporal resolution of 15 min.
- Full 3-D analysis.
- Goal is to use all observations, like LAPS, but currently does not use Doppler winds.
- Uses a multigrid technique combining the advantages of EnKF and 4DVAR.
- QC scheme similar but not identical to LAPS for this study.
- Not available on AWIPS.

The primary purpose of the RTMA is to provide a National Digital Forecast Database (NDFD) matching-resolution analysis to verify NWS digital forecasts. RTMA is available on AWIPS and has been running at a horizontal grid resolution of 5 km until a recent increase to 2.5 km. Although the primary purpose of the RTMA was for an "analysis of record", since it is available in real time on AWIPS it can of course be used as an aide in nowcasting (as discussed in the COMET module available at http://www.meted.ucar.edu/nwp/RTMA/). A summary of the features of RTMA include:

- Horizontal grid resolution now at 2.5 km (was 5 km).
- Temporal resolution of 1 hour.
- Primary input is from surface METAR and mesonet data.
- 2-D surface analysis (no fields requiring 3-D input such as CAPE and CIN).
- Available on AWIPS up to the CONUS scale.
- Uses GSI (Gridded Statistical Interpolation) with downscaling from the 13-km RUC.
- Different QC scheme than LAPS or STMAS.

The HRRR is a fairly new high-resolution model whose development was motivated by FAA needs for improved short-term prediction on the convective scale. The model runs at a 3-km horizontal grid resolution every hour with forecasts out to 15 h. The model initialization is derived from the 13-km RUC. Therefore, it must be noted that the 0 h "forecast" is not a separate analysis on a 3-km horizontal grid scale, so we should not expect it to resolve smaller-scale boundaries, although these can be generated in the model forecast. The HRRR is not routinely available on AWIPS as it is an experimental model, but it is available online (at http://ruc.noaa.gov/hrrr/). Because it has become so popular with operational forecasters, many WFOs download a subset of the full 3D HRRR output for display on AWIPS, and recently it has also been provide through some NWS regional servers. A summary of the features of the HRRR includes:

- Horizontal grid resolution of 3 km.
- Temporal resolution of 1 hour (forecasts are available on the web at 15 min intervals).
- Input is from the 13-km RUC and includes all types of data, similar to LAPS and STMAS.
    - Doppler winds are not used at this time but VAD winds are.
- Full 3-D analysis.
- Available online and on AWIPS at some WFOs.
- Uses GSI.
- Different QC scheme that is more restrictive than LAPS or STMAS.

As noted earlier, cases were chosen that focus on well-defined boundaries or for situations where a fairly complex wind and/or temperature pattern existed and was important to the forecast on that day.

In the comparisons then we focus on the basic wind analysis, and for some include analyses of convergence/divergence. The analyses are compared qualitatively to observations and to each other. There is no real "ground truth", since we are comparing analyses to analyses, so quantitative evaluation is difficult without a scheme whereby observations might be withheld, which was not done for any of these cases.

3. CASES

Cases are presented next to give an indication of how the analyses can differ for various weather situations, and to discuss some issues that arise in the analyses. As noted, an earlier paper presented at the recent AMS Severe Local Storms (SLS) Conference showed a couple of convective cases from 2010 where a quasi-stationary boundary was a main focus (Szoke et al. 2010). The boundary, known as the Denver Convergence-Vorticity Zone (DCVZ) can be an important feature for focusing convection as well as nonsupercell tornadoes. The earlier study showed that there can be significant differences amongst the analyses in wind and temperature, and these can be even more exaggerated when comparing derived fields, such as convergence and vorticity.

In all the comparisons in our previous paper and in this paper, we examine surface fields only. Although data is plentiful at the surface, different quality control (QC) schemes are used by the analyses and this often leads to a different analysis. One point that was noted with the different QC schemes is that analyses that accept more data types (that is, have a more “liberal” scheme, such as LAPS) can be prone to occasionally using a bad observation or two, and these can greatly influence the analysis. Usually it is through examining analyses that such bad data points, which otherwise may pass through a QC scheme, are identified and can then be “black-listed”, while still accepting other data from, say, the same mesonet. The penalty can be an occasional bad analysis, but the benefit of accepting more data should be a more representative analysis.

Another point discussed in the earlier paper and worth noting here is that quantitative comparison is not a straightforward matter. Ideally, one would want all the analysis schemes to use identical data, then a portion of the data could be withheld and used for verification. This is not the case here, since some of the schemes are operational (the LAPS at 5 km), or while experimental used by forecasters, such as the HRRR, and therefore use the maximum amount of data that each QC scheme allows and considers. Because of these considerations qualitative evaluation is done when comparing the analyses and the analyses to the actual data. Even with this consideration, it is certainly not an easy matter to say that one analysis is “correct” while another is not, particularly for derived parameters, as it is not obvious what could be considered “ground truth”.

With all these points factored into consideration, the main point of the comparisons is to demonstrate how variable analyses can be, and point out some of the issues and problems involved. Determining the “best” analysis will vary depending on the application of the particular analysis, as determined by the user.

3.1 *Case 1: 20 December 2010 – Southward-Moving Cold Front on the Eastern Plains of Colorado*

The first case is a fairly straightforward cold front moving southward across the northeastern plains of Colorado on 20 December 2010. Of course there are complications in how the surge of northerly winds makes its way southward, particularly for locations closer to the foothills, where ambient westerly downslope flow that typically develops ahead of such a southward-moving cold front can locally slow the progress of the front.

An overview of the various analyses and the weather situation is given in Figure 1. One can zoom in on the figure to examine the details. The position of the front is shown for the various observation times in the top row of the figure, which combines a low-level radar composite image with surface observations. Unlike in the summer where clear air reflectors (presumably bugs) are more abundant, the front is not very discernable in the reflectivity, except when it is near a radar site. In all the analysis figures the image is of temperature, with wind barbs also shown. The scale for all the LAPS and STMAS images is identical, so these can be directly compared. The RTMA and HRRR images are taken from AWIPS, and while the color table is close to the LAPS and STMAS (both are shown in the figure) it is not quite exact. Therefore, some caution must be used when comparing the RTMA and HRRR temperature analysis images to the others, but they can be directly compared to each other.

The increase in detail with the 1-km vs. 5-km analyses is easily seen in the temperature images in Figure 1, especially for locations in and closer to the higher terrain (western edge of each figure). Farther to the east on the plains the differences in resolution are not as easy to discern. Interestingly, the temperature gradient along the frontal boundary does not seem to vary much between the higher and lower resolution analyses. There are some differences in the HRRR and RTMA temperature analyses on the plains, and close examination shows some significant wind differences as well.

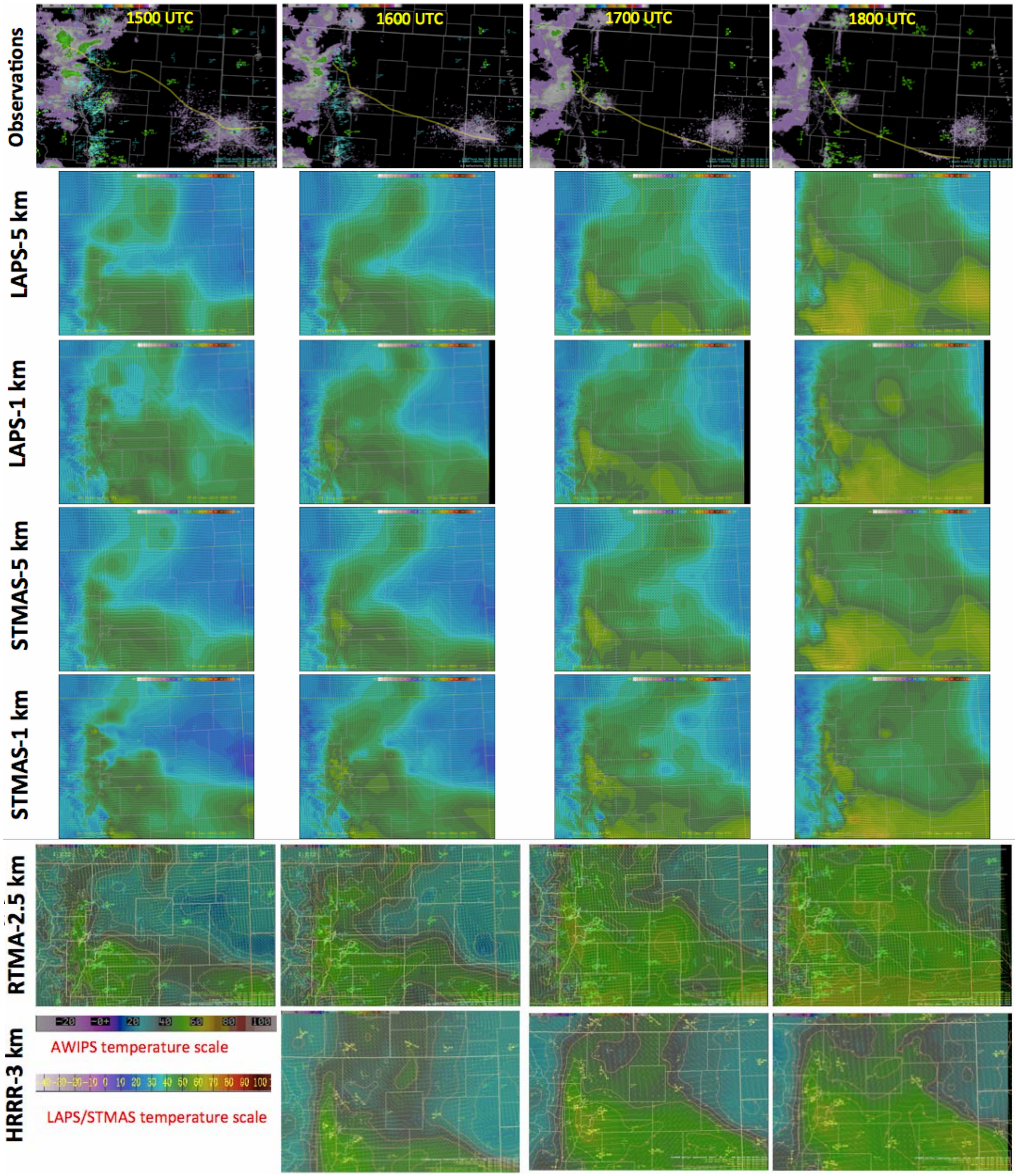

Figure 1. Comparison of the various analyses of surface temperature (image) and wind (barbs) from 1500 through 1800 UTC on 20 December 2010. The analyses are centered over northeastern Colorado, with state and county boundaries shown. The AWIPS temperature scale applies to the RTMA and HRRR images, and is similar to the scale used for the other analyses.

3.2 ***Case 2: 22 October 2010 – Complex Flow and Boundaries on the Eastern Plains of Colorado***

The second case involved a complex surface flow field in the presence of an upper-level low that was right over the area. Various bands of convection formed, some along two of the more prominent low-level boundaries. These two boundaries were resolved in the low-level velocity field from the KFTG WSR-88D radar, and are marked by the dashed yellow line in the image in Figure 2. Convection formed on the southernmost of these boundaries, which was located to the east and southeast of Denver (seen in the satellite image also shown in Figure 2 at 1800 UTC). The available observations showed converging flow into this boundary with a general southwest flow on the west side of the line and a more southeasterly flow on the east side (zooming in on the figures will reveal the observations).

For this case the same analyses that were shown in Figure 1 are displayed again, but in this example for a single time, 1800 UTC on 22 October 2010. The middle panels in Figure 2 display the wind field in the form of wind barbs with an image of wind speed. For this case the color table is scaled the same for all the figures, although the shade of some of the colors differs between the LAPS and STMAS images and the HRRR and RTMA images captured from AWIPS. However, for all the analyses in the wind speed images the first color band is from 0 to 10 knots, the next 10-20 knots, then 20-30 knots, so the figures can be directly compared. To aid in the comparison, the location of the southernmost boundary noted above is enclosed by a white oval, which is located in the same geographical position in all the figures. In this way we can easily compare the wind speed images from the various analyses.

Comparing the wind speed images we see evidence of more detail in the high-resolution (1-km) LAPS and STMAS analyses as compared to their 5-km resolution counterparts. The HRRR analysis/0-hour forecast also shows more detail, while the RTMA appears considerably smoother. As noted earlier, this smoother analysis may not be a bad result, depending on what the analysis is used for.

Also shown at the bottom of Figure 2 is a series of convergence analyses at the surface. For these analyses warm colors represent convergence, cool colors divergence. The scale is exactly the same for the LAPS and STMAS analyses, and the same for the RTMA and HRRR fields, but not quite the same when comparing the two sets of analyses. Note that the scale for the RTMA and HRRR analyses is distinct on either side of a value of zero, while the other scale is broader either side of the zero value. Nonetheless, we can get a nice idea of whether the analyses show any convergence along the two boundaries, particularly the southern one, in which case it should be near or within the white oval.

When the convergence fields are compared, the effects of resolution become far more apparent, with very fine-scale detail in both the LAPS and STMAS 1 km analyses. The detail appears to potentially be of some use over the plains (indeed, a point noted in the earlier study of the DCVZ cases was an apparent ability to even resolve small circulations, via the vorticity field, that developed along the DCVZ boundary (Szoke et al. 2010)). Over the higher terrain, however, the pattern may be so complicated as to be of limited practical use, even if it realistically represents the convergence/divergence field. All the analyses indicate convergence within the oval, or near the southernmost boundary, but the LAPS and STMAS analyses seem to focus the convergence more. Even more of a focus is seen in the 1-km analyses, particularly on the northern portion of the boundary. The RTMA field is considerably smoother, blending the area of convergence near the southern boundary with an area of convergence that extends northward and then to the northeast near the other identified boundary. The HRRR initial model field has its area of convergence more centered within the oval, but also several other areas of convergence.

There are certainly areas where the convergence analyses differ by a large margin. But one area where there is rather excellent agreement is near the northeast corner of the analysis area (in far northeastern Colorado) where all but the RTMA have a rather narrow zone of convergence, even the 5-km LAPS and STMAS analyses. The RTMA also has convergence in this area, but it covers a much broader area. This convergence zone may be a northeastward extension of the northern boundary shown by the dashed line in the 88D velocity field shown in Figure 2. However, there were not very many observations in this area, so it is difficult to determine how sharp the convergence zone really is at this location, or, for that matter (without further study not yet done) on what the analyses based this sharper convergence zone.

3.3 *Case 3: 29 October 2010 – Boulder County "Dome Fire"*

The second substantial wildfire of the dry 2010 autumn in the Boulder County area broke out suddenly on the morning of 29 October 2010 from an illegal campfire about 15 km west of the city of Boulder in Boulder Canyon. The fire began near 0800 LT or 1500 UTC and rapidly spread towards Boulder, aided by strong downslope winds in the foothills that had spread across the city of Boulder. Although not nearly as large or destructive as the Four Mile Canyon fire that began on Labor Day 2010, this fire was closer to the Boulder area, and close to 2000 residents on the western side of the city were under mandatory evacuation orders by the evening of 29 October. In this case wind information in the local area near Boulder was critical to NWS forecasters, who were providing frequent updates to firefighters. We will examine the various analyses, as well as some short-term forecasts, near the time of the start of the fire for this case.

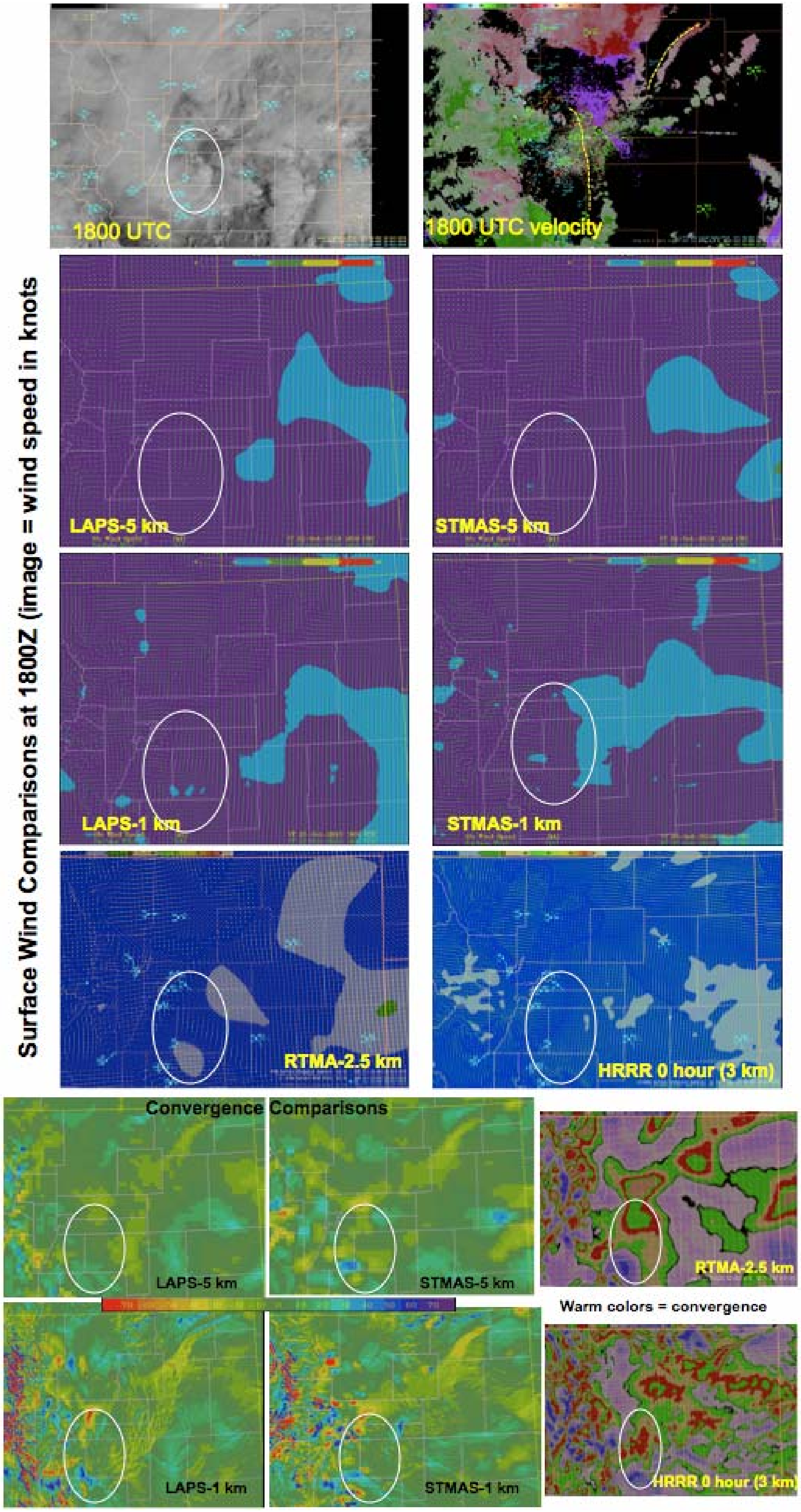

Figure 2. Comparison of various observations and analyses for 1800 UTC on 22 October 2010 in northeastern Colorado. White oval is a common location in the figures and surrounds one of the surface boundaries.

The analyses and forecasts that will be shown focus on the area of Boulder County. A map of the approximate area of the analyses, with locations and topography is given in Figure 3, which also shows the location of the fire. Some images of the fire are shown in the montage in Figure 4. A collection of analyses for 1200 UTC, about three hours before the fire began, is shown in Figure 5. A similar presentation is given in Figure 7, but this time for analyses at 1500 UTC, as well as some forecasts. We have included analyses and 3-h forecasts in these plots from the North American Mesoscale model (NAM), which has 12-km horizontal grid spacing, and a WRF model run locally at ESRL/GSD and available at the Boulder NWS Weather Forecast Office (WFO, co-located with ESRL/GSD), which has a 5-km horizontal grid spacing. In Figure 6 both the HRRR 1500 UTC analysis and the 3-h forecast from the 1200 UTC run of the HRRR (whose 0-h forecast is shown in Figure 5) are also shown.

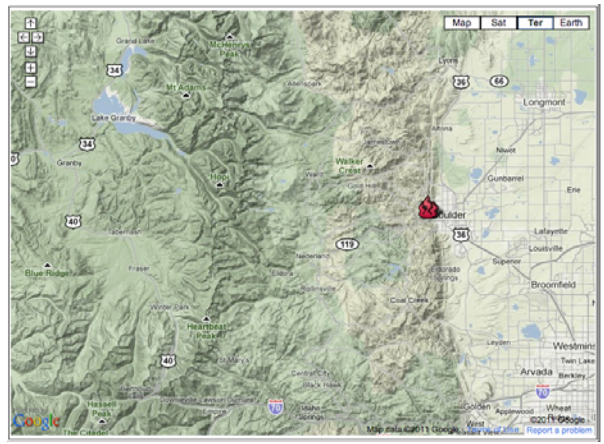

Figure 3. Topographic map of Boulder County.

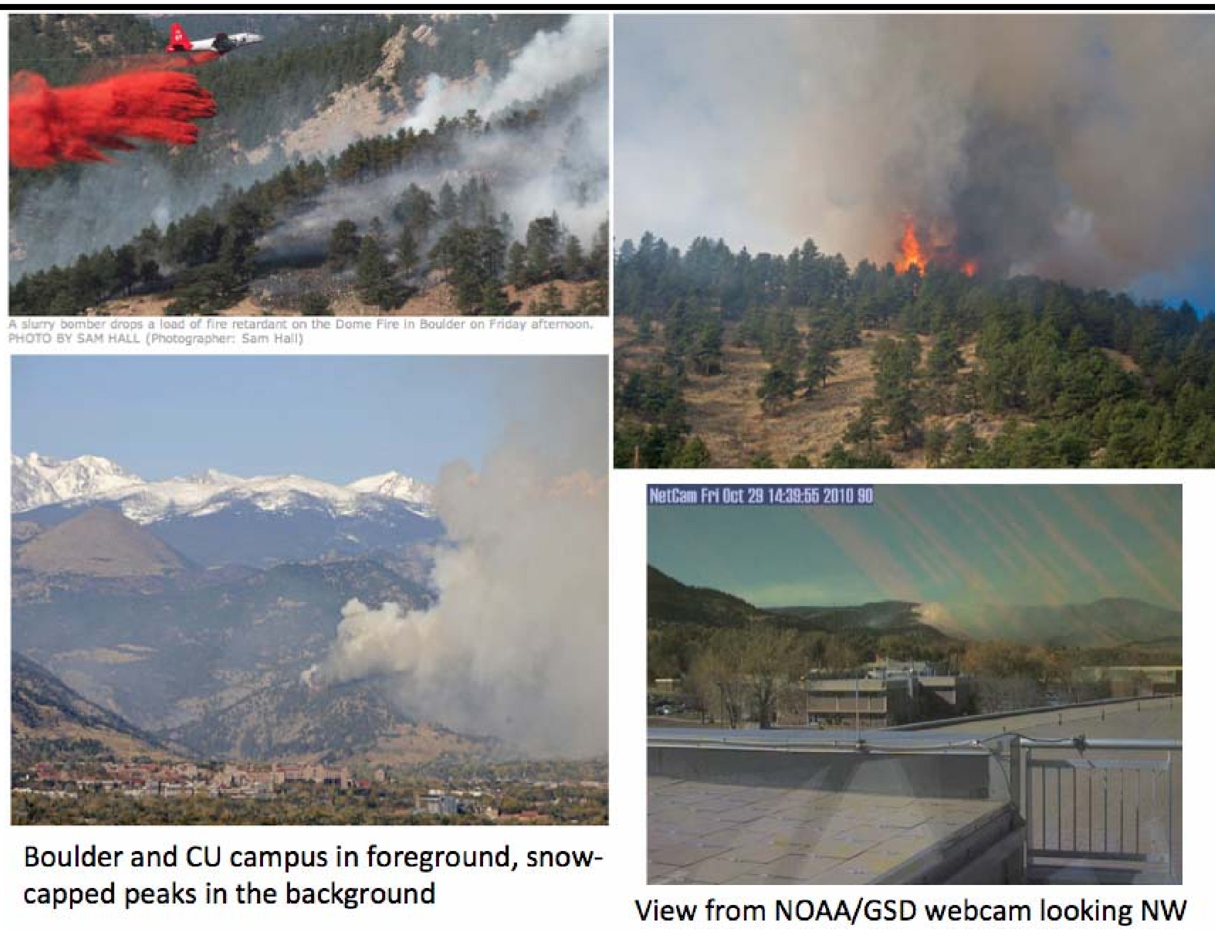

Figure 4. Montage of photos from the Boulder "Dome Fire" of 29 October 2010. Top two photos are from the Boulder Daily Camera web site.

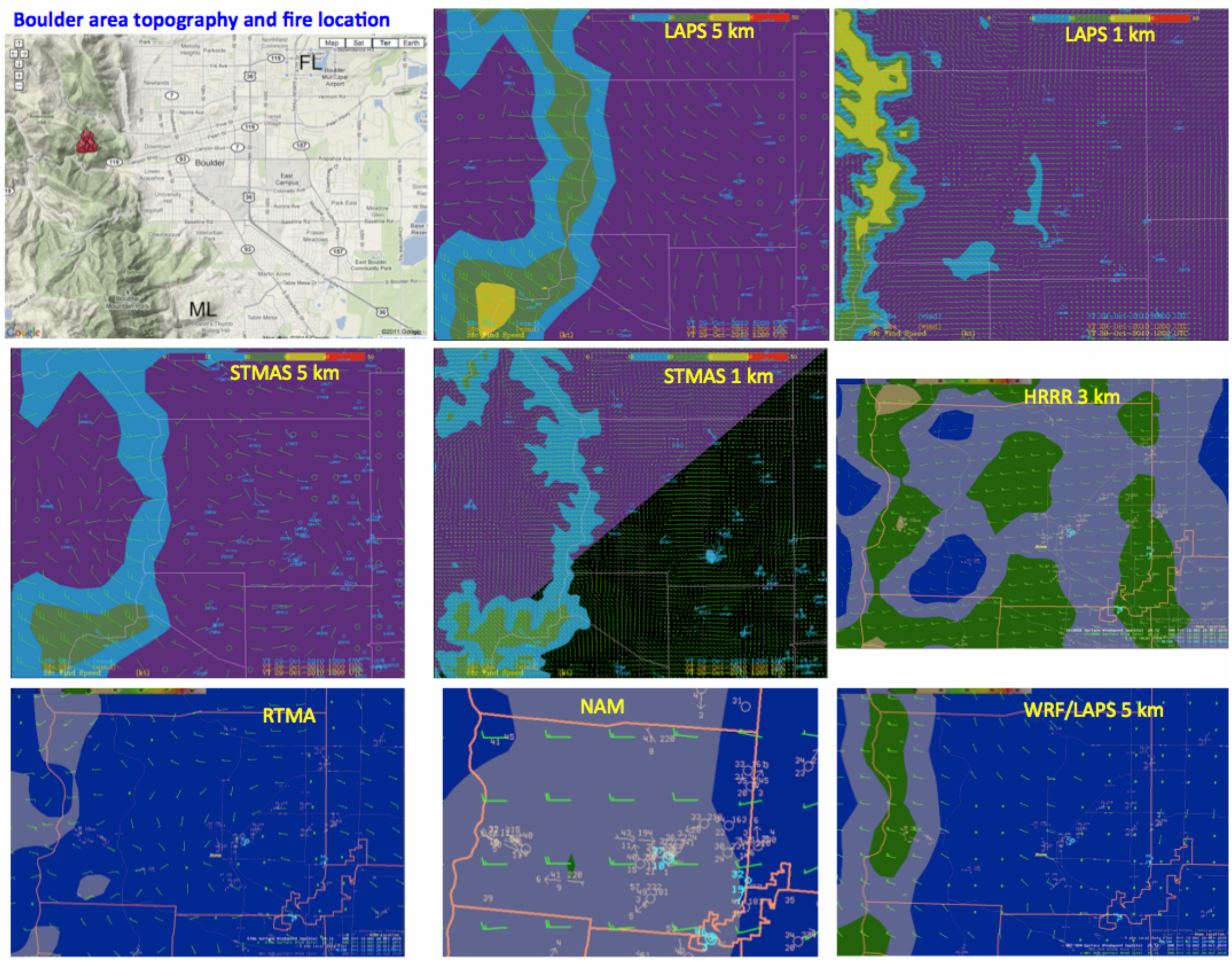

Figure 5. Analyses of wind (knots, barbs and image) at 1200 UTC on 29 October 2010 from the LAPS, STMAS and RTMA analyses, as well as the initial (0 h) forecast (or analysis) from the HRRR, NAM and WRF model initialized with the 5-km LAPS analysis. The map in the top left image is focused on Boulder, with the fire position noted.

The wind scale is the same in all the images in Figures 5 and 6, while the analysis area covered by each analysis is close to the area shown in Figure 3. The images can be compared to each other since they are all scaled at 10-knot intervals. Observations are also overlaid on the images, but are most easily visible on the NAM initial analysis. The locations of the NCAR Mesa Lab (ML) and Foothills Lab (FL) are shown on the map in Figure 5 because time series from an automated weather station at each site are shown in Figure 6. The time series nicely illustrate the complexities of the wind field and the gustiness of the winds, especially at the Mesa Lab, which is at an elevation of 1885 m (6184 ft). The fire was located only a few km west of the western edge of the city of Boulder, in rough terrain between about 2000 to 2500 m (approximately 6500 to 8000 ft).

Since the NWS WFO has responsibility for issuing fire-related forecasts to help support fire fighting efforts, they were extremely interested in any help in determining the wind direction and speed near the fire location, as well as its short-term prediction. The RTMA and LAPS/5 km analyses are both available on the WFOs AWIPS workstation. At the time of the fire the HRRR was available at hourly intervals out to 15-h on a separate AWIPS-like workstation, as was a version of the WRF model run by ESRL/GSD out to 24 h at 6-h intervals (surface fields from the HRRR are now available on the regular AWIPS workstation as well). One difference in the models is that the HRRR is initialized from the RUC 13-km operational run, while the WRF model (run at 5-km horizontal grid resolution) is initialized from the 5-km LAPS analysis. We had hoped to have the STMAS 5- and 1-km analyses as well as the LAPS 1 km analysis available on AWIPS (ideally on the regular AWIPS workstation) but this is still to be done. However, the analyses are available in

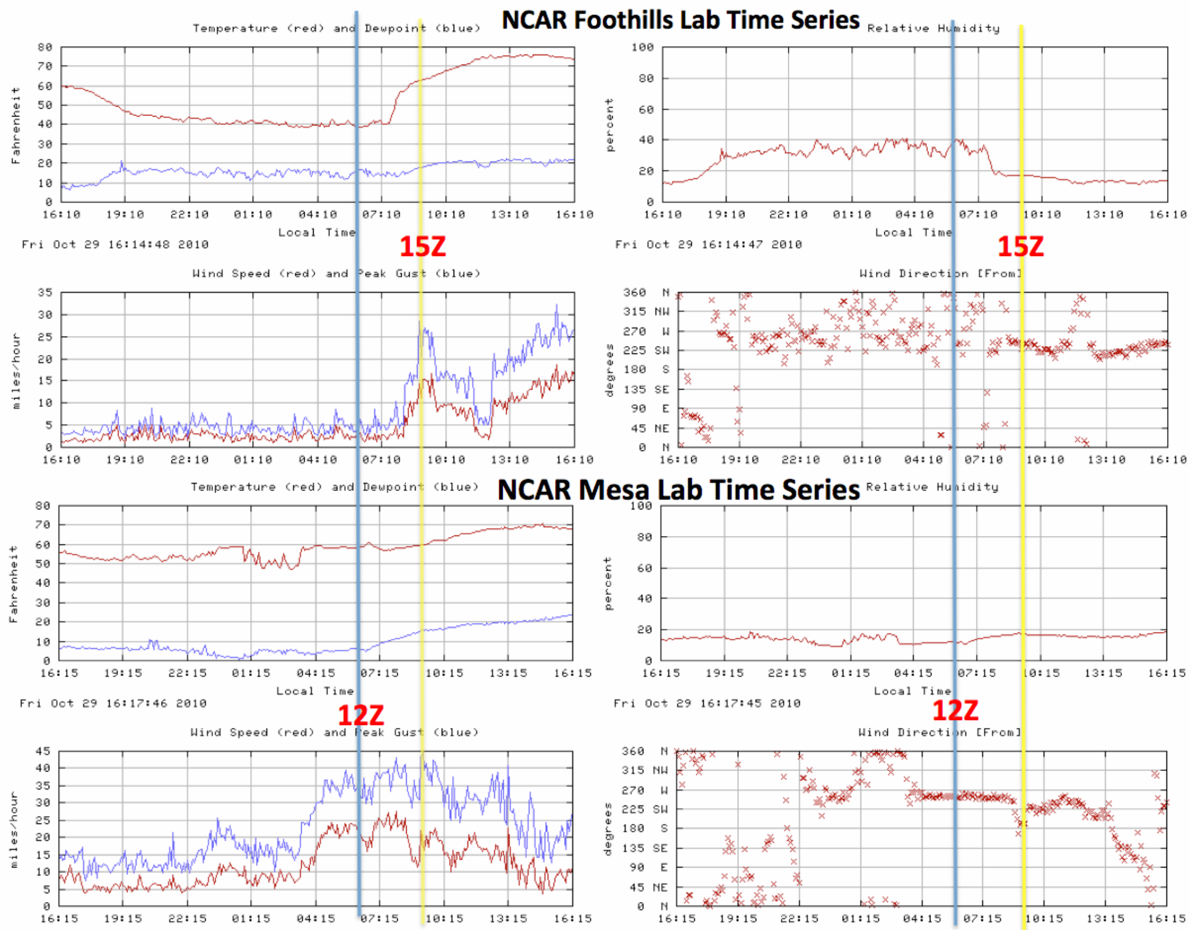

Figure 6. Time series from the two NCAR automated stations for the 24-h period ending 1610-15 LT (2210-15 UTC) 29 October 2010. Vertical lines highlight the two times (12 and 15 UTC) of the analyses and forecasts shown.

real time on the web, as noted earlier. One can also go to **HTTP://LAPS.NOAA.GOV/REQUEST/NPH-LAPS.CGI**,

a web site that allows for user adjusted displays, including zooming over a selected area. We took advantage of this opportunity to set up the displays on the web in a zoomed in mode over Boulder County for the STMAS at 5-km and the 1-km versions of LAPS and STMAS at the WFO, where they could be easily updated to provide the latest analysis over the fire area. The WFO forecasters appreciated any help in determining the complex and important wind flow pattern on that day, so they enjoyed the opportunity to see the different analyses.

A look at the meteorological time series from the two NCAR automated stations in Figure 6 highlights the difficulties in even short-term prediction of the wind at the site of the fire on this day. Although neither site is at as high an elevation as the fire location, as noted earlier (the FL site is at 1625 m or 5331 ft), they border (just to the east) the fire location on the north (FL) and south (ML) side. Additionally, their height difference (the ML site is at 1885 m or 6184 ft) allows for an illustration of the large changes that can occur in the vertical with cases of mountain wave-induced downslope winds. Note for example that the ML was already having west wind gusts over 40 mph before the time of the fire, but the wind at the FL had been quite light. The FL has a short-term peak gust just as the fire is beginning near 1500 UTC, but then quite a lull a couple of hours later before increasing again. Meanwhile the ML site, not far away in distance, goes through a much lighter period of winds even as the FL site shows steadily increasing winds.

Examination of the observation plots in Figure 5 shows that this wind complexity was also exhibited by the other surface stations near the fire. Winds were certainly more steady and strong out of the west at higher elevations, but as usual the big question was how long would the gusty downslope westerly winds prevail at the lower elevation fire site, or for that matter would they be stronger than the winds at the higher elevations (an amplifying mountain wave, for example).

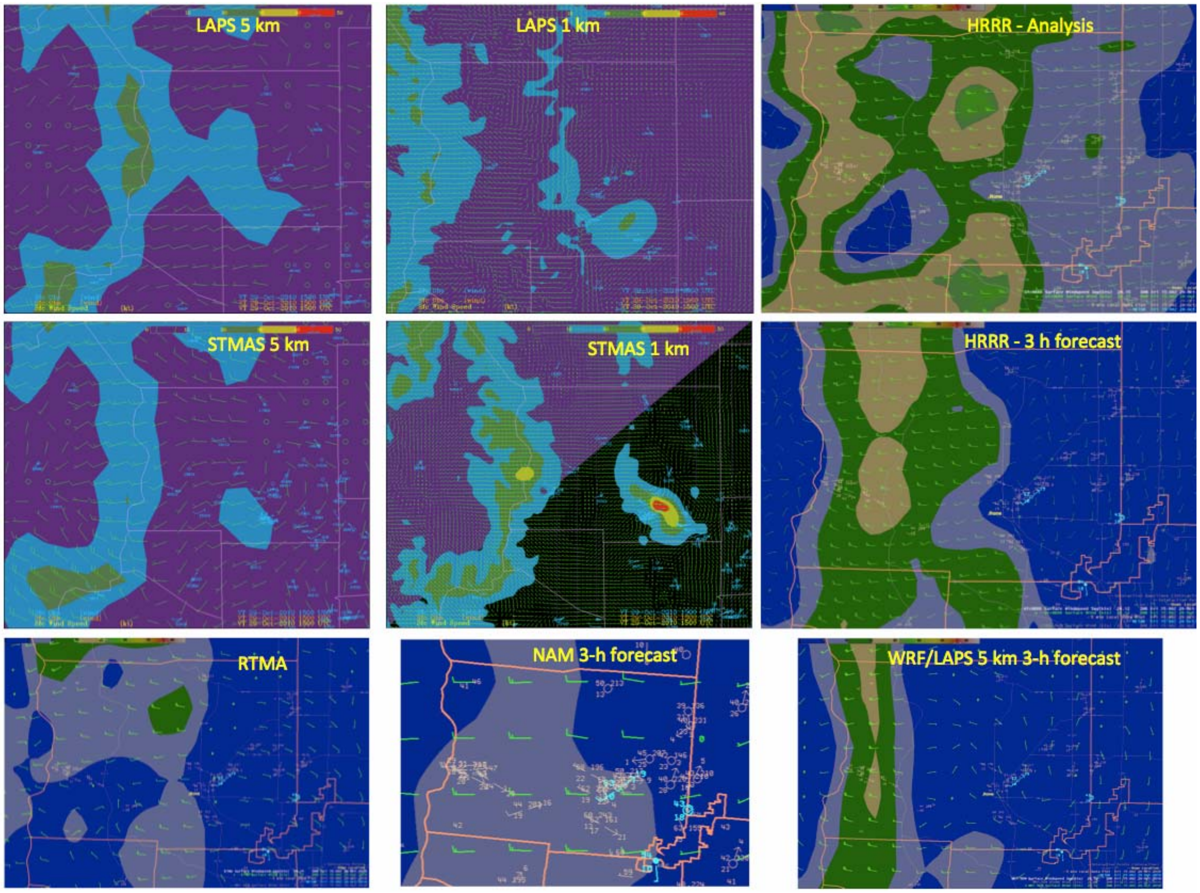

Figure 7. Similar to Figure 5, except for 1500 UTC on 29 October 2010. Also, 3-h forecasts from the 1200 UTC runs valid at 1500 UTC are also shown for the HRRR, NAM, and WRF models. As in Figure 5, the image is wind speed and the scale is similar in all the figures, with breaks for each color at 10-kt intervals.

A collection of analyses and some 3-h forecasts is shown in Figure 7 for 1500 UTC, like the presentation for 1200 UTC in Figure 5.

In both Figures 5 and 7 the difference in horizontal resolution is very apparent between the 1-km versions of LAPS and STMAS and their 5-km analyses, with much more detail in the 1-km analyses. For the most part, the highest wind speeds in the analyses for both times are found over the highest elevations near the Continental Divide (the western edge of Boulder County and the western portions of each figure). There are substantial differences in even this portion of the analyses in the wind speed, some of which can be explained by resolution, but certainly not all. For example, comparing the two 5-km analyses at each time we can see that the LAPS analyses have stronger winds near the Continental Divide than do the STMAS analyses. Presumably this reflects a better vertical interpolation in LAPS, which has a full 3-D analysis.

In terms of some of the other analyses, the RTMA in general is quite smooth over this complex terrain. The same is true of the NAM, although this is likely more a reflection of having the coarsest (12-km) horizontal resolution of any of the analyses and forecasts shown. The HRRR gets its analysis from the RUC-13 km model, so it also appears smoother overall in the analysis scheme and not representative of a 3-km scale in the 0-h field. The analysis itself at 1200 UTC and again at 1500 UTC shows what looks like a gravity wave signal downstream of the Continental Divide with a lull-peak-lull-peak wind pattern moving east away from the higher terrain. This is certainly a pattern that does occur with mountain wave activity, although in this case winds farther to the east were quite light to the east of Boulder, and even out of the east at some of the mesonet sites. The HRRR is a fairly new model and its developers are working on a better analysis scheme that more closely matches its finer horizontal scale. However, they note that the model will typically adjust quite quickly to a wind field that is more representative of its 3-km horizontal resolution than seen in the analysis. This in fact is demonstrated for this case, as can be seen by comparing the HRRR 3-h forecast in Figure 7 with the HRRR analysis for the same time. The forecast is quite different from the HRRR 1500 UTC analysis, and quite different from its own analysis at 1200 UTC (shown in Figure 5). Winds away from the foothills are much lighter in the forecast, in agreement generally with what was observed, and the overall wind pattern in the forecast looks more realistic than either HRRR analysis. How much better the forecast could be if it started with a better analysis is an open question.

The NAM simply does not appear to have enough resolution to capture the complex wind flow across Boulder County, as seen by the rather uniform looking wind speed in the 3-h forecast in Figure 7. Interestingly, this is not necessarily the case farther to the east on the eastern plains, where experience has shown that the NAM will frequently capture smaller-scale features such as the Denver Cyclone.

The WRF model shown in Figures 5 and 7 is initialized with the LAPS, both at 5-km horizontal resolution. The WRF analysis in Figure 5 looks very similar to the LAPS/5-km analysis at 1200 UTC. The 3-h forecast shows increased winds over the Continental Divide, but it is not particularly good downstream, with the winds too light.

East of the Continental Divide all the analyses tend to show a decrease in the wind speeds and then some amplification at lower elevations in the vicinity of Boulder, or what is probably a mountain wave signature. However, there is not a lot of data in some of the area where the lighter winds are shown west of the greater population and areas of more data near the base of the foothills, so we cannot really verify that the winds are indeed lower in this mid elevation range where shown in the analyses. This in fact was one of the big issues with trying to determine the winds at the fire site. Further investigation is needed to determine if some of these details can be verified, but based on what data we have at this point it is not certain one way or the other.

One interesting aspect of the analyses is the small area of higher wind speeds over the southeastern part of Boulder. The STMAS/1-km analysis is most dramatic in this regard, with a small area of 40-50-kt sustained winds at 1500 UTC (Figure 7). Close examination of the observations indicates that STMAS appears to have used a mesonet observation that was not used by the LAPS analysis. It is not clear whether the observation used is correct. It comes from a mesonet station located at a Boulder elementary school that is just downhill from the NCAR Mesa Lab, which recorded winds at 1500 UTC of near 20 mph, but with gusts to 45 mph, so it is certainly possible that winds could have been over 40 kts sustained in this area. Further investigation is needed to determine why the LAPS analysis scheme apparently did not use the same observation.

4. SUMMARY AND CONCLUSIONS

One conclusion that can be made is that a lot is involved in an analysis and it is too complex to state that one is better than the other in many cases. Verification issues include limited data in complex areas to determine whether some of the features shown are real. Quality control is a huge issue that has plenty of room for debate. The increasing amount of surface data that is available with easier and less expensive access to recording weather stations and better communication links to make this data available is remarkable. However, coincident with this data explosion is an increasing amount of questionable data that must be removed before an analysis is made. How best to do this removal is a good question. Some schemes tend to be more conservative and toss out a lot of data, perhaps from an entire mesonet type, even though a good portion of the data may be reliable. But the opposite, allowing too much data with some occasional bad data points has been demonstrated in our study and the earlier one (Szoke et al. 2010) to easily influence the analysis.

Another issue to address is the purpose of the analysis. Initialization of a model at the 5- or 10-km scale may not require a very high resolution (say, 1-km) analysis. On the other hand, over complex terrain such a high resolution analysis may be necessary to provide important information for applications such as fire behavior, as was seen for our last case. The best resolution for derived fields, such as convergence and vorticity, is also a good question. The complexities seen over the higher and complex terrain in the derived fields from the 1-km analyses suggest they may be of little use to the forecaster, but perhaps these complexities are useful for other applications.

We will continue to use cases such as these to improve the analyses in the future. One area we hope to pursue over the coming year is to make the higher resolution analyses available on AWIPS so that forecasters can have ready access to them and help assess their utility.

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