# DENVER EARLY ACTION OZONE COMPACT
Weight of Evidence to Support Attainment Demonstration

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## Introduction

EPA's draft guidance for regulatory modeling in support of 8-hr ozone attainment demonstrations (EPA, 1999) suggests that a complementary analysis of air quality, meteorological and emissions data be undertaken. The additional analyses are needed to design and focus modeling which underlies the attainment test and provide a broader technical basis for decision making than the photochemical model analysis alone. In addition to the EPA draft guidance, a report by the National Academy of Sciences (NAS) entitled **Air Quality Management in the United States (2004)** supports using a weight-of-evidence approach for air quality decision making.

Provided model results of the attainment and screening tests are not failed by a wide margin, an area may use evidence produced by corroborative analyses together with results of the tests in a weight of evidence (WOE) determination. The modeling guidance suggest that, if the results of the modeled attainment demonstration is between 84 ppb and 89 ppb at more than one site, a WOE determination should be performed. This is the case for the Denver Early Action Compact (EAC)

A weight of evidence determination includes the modeled attainment and screening test results, plus results of additional model outputs plus other analyses of air quality, meteorological and emissions data. A weight of evidence analysis may be used either to increase or decrease emission reductions identified as sufficient to meet the NAAQS by a modeled attainment test.

The key concept behind WOE is that the determination of attainment (based on monitored ozone concentrations) allows for some exceedances of the 8-hour standard. Thus, even though the model may show some areas with peak concentrations above 84 ppb, such modeled exceedances do not necessarily imply violations.

### Trends Analysis

This Weight of Evidence (WOE) analysis for the Early Action Compact provides additional information in support of meeting the Federal eight-hour standard for ozone by the 2004-2007 time frame. An assessment of anomalous temperatures and mixing heights during the summer of 2003 and the extraction of a baseline trend in ozone associated with long-term changes in emissions provide reasonable evidence that the region may be in attainment by 2007.

**Evidence for Anomalous Temperatures and Mixing Heights During the Summer of 2003**

The Denver metro area experienced record-setting temperatures during July and August of 2003. According to the National Weather Service (NWS) July 2003 had 24 days with maximum temperatures of 90 degrees Fahrenheit or higher (http://www.crh.noaa.gov/den/cli/climo.html). Three of these were above 100 degrees Fahrenheit. Based on mean temperature, July 2003 was the fourth warmest in Denver history. July 2003 was the warmest month on record for much of Colorado. (July, however, also saw record-setting heat in Denver in 2000, 2001, and 2002. July 2002 was the ninth warmest in history. July 2001 tied with July of 2000 as the sixth warmest in Denver history.) August 2003 had 19 days with maximum temperatures of 90 degrees F or higher. August was warmer than average but did not make the top ten for average temperature. According to the NWS: "in the temperature department ...August 2003 tried desperately to get into the top 10 warmest. It was either the hottest August or tied for the second hottest for nearly the entire month. Then came the last 3 days of the month with highs and lows well below normal and August 2003 fell out of the top ten warmest."

It is reasonable to believe that the high temperatures in July and August of 2003 contributed to an anomalous number of ozone exceedances. There were 17 days in 2003 with Denver metro area 8-hour concentrations of 0.085 ppm or higher. This compares to an average of 3.5 such days from 1993 through 2002. The numbers of high days per year are plotted in Figure 1.

While the summers of 2000 through 2002 were also warmer than normal, the summer of 2003 was set apart from these years by anomalously low mixing heights during the highest ozone days. Lower mixing heights can lead to higher concentrations of ozone and its precursors near the surface. The average late afternoon thickness of the mixing layer on those days responsible for the four highest 8-hour ozone concentrations each year at NREL, Chatfield, and Rocky Flats North is shown in the Table 1 below. The average mixing layer depth was significantly lower on the highest ozone days in 2003.

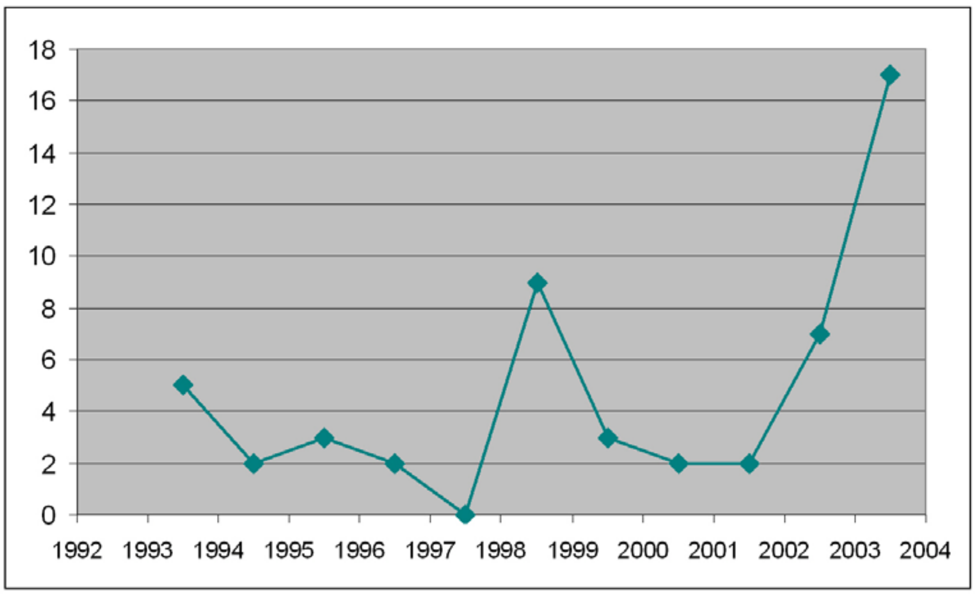



Figure 1: Number of days each year with Denver metro area 8-hour ozone concentrations of 0.085 ppm or higher.

Table 1: Average mixing depth in feet on those days responsible for the 4 highest concentrations each summer at NREL, Chatfield, and Rocky Flats North.

| Year | Average Worst Ozone Day Mixing Depth in Feet |
|---|---|
| 2003 | 6,500 |
| 2002 | 12,600 |
| 2001 | 9,300 |
| 2000 | 11,800 |

The afternoon mixing heights on July 11 and 12 of 2003 were extremely low. These two days were responsible for the violations of the 8-hour ozone standards recorded at NREL and Chatfield. Without these two high days, the three-year average fourth max ozone levels at both of these sites would have been below the standard. An afternoon atmosphere that was only well mixed to a depth of 1000 to 3000 feet, with few clouds, no storms, and temperatures around 90 degrees Fahrenheit characterized the July 11-12 episode.

According to the contouring of estimated mixing depths in Figure 2, mixing depths may have been as low as 500 to 700 feet in parts of northern Jefferson and Douglas Counties on July 11. This is an extremely unusual occurrence for a summer afternoon on a day with clear skies and high temperatures in the upper 80's and low 90's (Fahrenheit). Normally the intense daytime solar heating in July would create a much deeper mixed layer and prevent the persistence of this kind of thin mixed layer, which is more characteristic of winter conditions. A meso-scale low pressure west of Pueblo, Colorado, and a modified, shallow Canadian air mass in Northeastern Colorado created a shallow layer of "cooler" surface air in the Denver metro area. The mechanism for the persistence of the unusually shallow surface layer seems to be adiabatic cooling associated with a shallow layer of brisk upslope winds moving toward the Palmer Divide.

This flow tapped into relatively cooler air north of a stationary front and advected this air towards the south. The resulting effects on the boundary layer probably represent a cross between the effects of typical diurnal summer upslope and the effects of so-called terrain blocking patterns more typical of winter. Both are described in detail by Banta (1990). Terrain blocking can lead to pooling or "damming" of cooler air along the slopes of terrain feature such as the Palmer Divide.

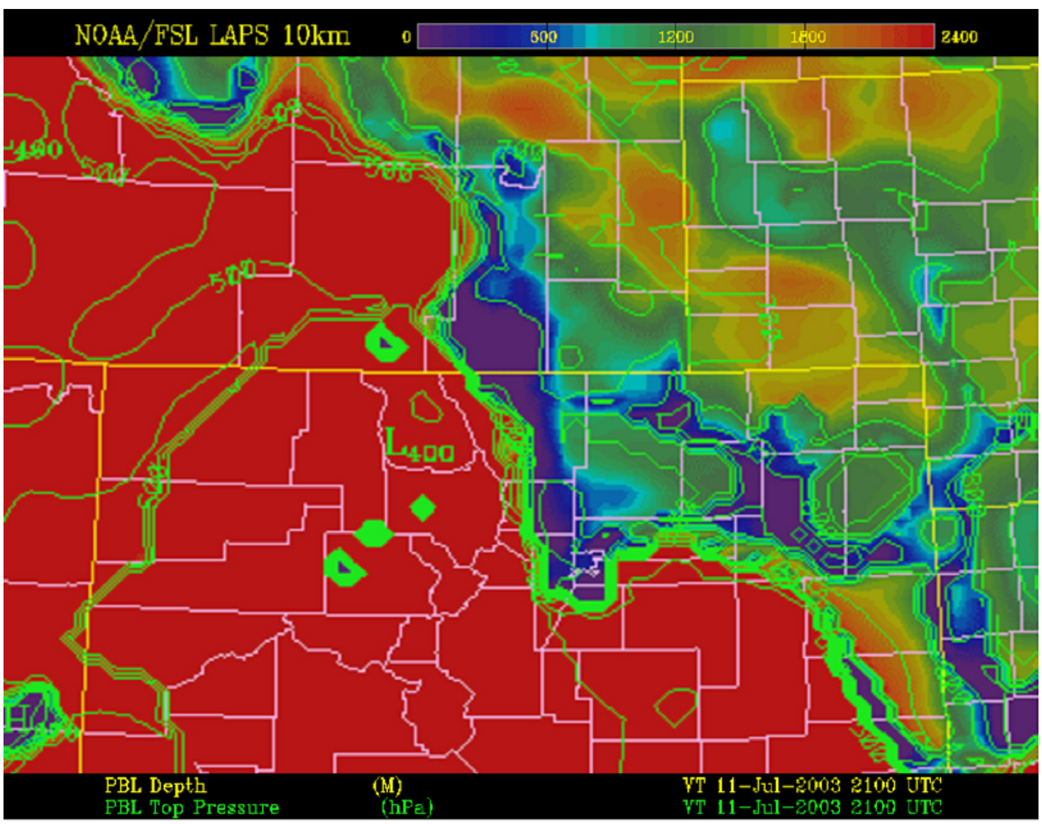


Figure 2: The NOAA Forecast Systems Laboratory boundary layer map showed estimated mixing depths much less than 1500 feet at 3:00 PM MDT on July 11, 2003, especially in Jefferson and northern Douglas Counties.

## Trends in Fourth Max 8-hour Ozone Concentrations at Rocky Flats North

In recent years, Rocky Flats North has measured the highest fourth maximum 8-hour ozone concentrations in the Denver metro area. Figure 3 shows the annual fourth max values for 1993 through 2003. Also shown are curves derived from the application of a three-year moving average, and a three-year moving average applied twice. The first application of the moving average filters out cycles of less than three-years duration. The procedure used for the Series 3 curve has the effect of filtering out cycles of less than about four years in duration. The properties of these Kolmogorov-Zurbenko filters are explained in greater detail in the next section of this report. Application of these filters provides a better indication of long-term trends.

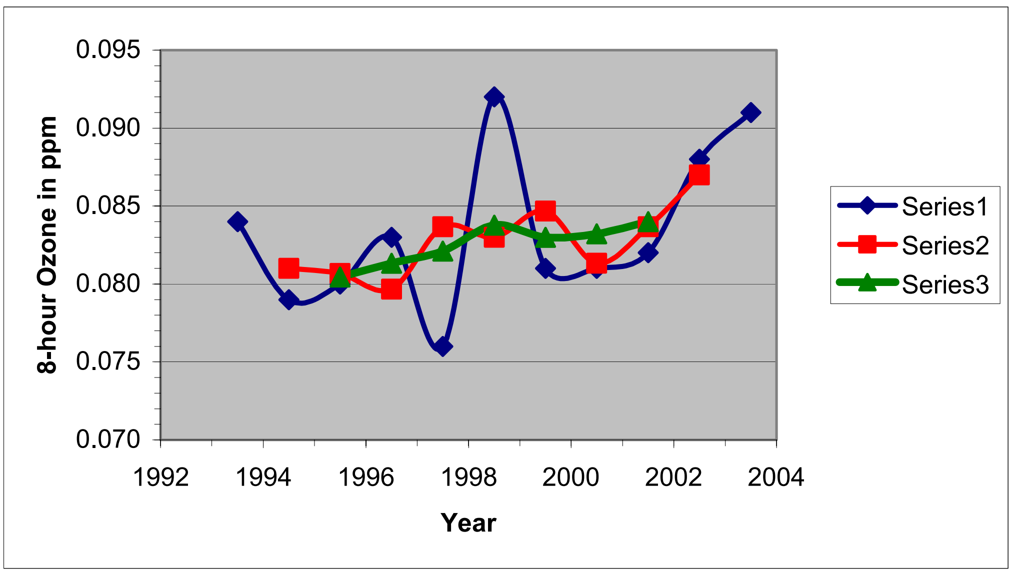



Figure 3: Series 1 in blue shows the annual fourth max 8-hour ozone concentration at Rocky Flats North, Series 2 in red shows the fourth max data smoothed with a three-year moving average, Series 3 in green is the fourth max data smoothed twice with a three-year moving average.

Series 1 in Figure 3 shows an increase in the fourth max values during the last three to four years. In series 2 and 3, there is an increasing trend in the fourth max values during the 1994-2002 and 1995-2001 periods, respectively. Is this trend a function of the underlying increase in ozone during the period or does it reflect the influence of the high values during the summer of 2003?

As indicated, there are good reasons to believe that the summer of 2003 was an anomaly as far as ozone concentrations are concerned. If the data for 2003 are excluded from the fourth max trend analysis, the new smoothed trend curves (Series 2 and 3) are generally flat for the last several years of the series. Plots of time series without 2003 data are shown in Figure 4.

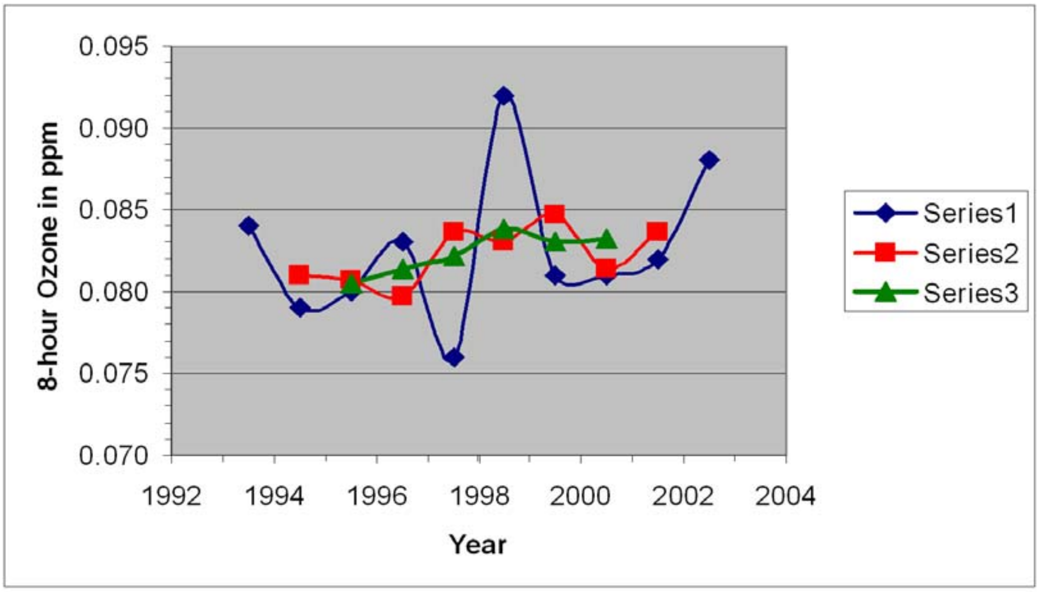



Figure 4: Series 1 in blue shows the annual fourth max 8-hour ozone concentration at Rocky Flats North, Series 2 in red shows the fourth max data smoothed with a three-year moving average, Series 3 in green is the Series 2 data smoothed with a three-year moving average. 2003 data have been excluded.

**Zurbenko-Rao Trend Decomposition Methods**

The Zurbenko-Rao method is widely used to cleanly separate ozone time series into distinct short and long-term components (Porter et al., 1996; Eskridge et al., 1997; Rao et al., 1997). This method has been used in this analysis to decompose the time series of the natural logs of the daily maximum 8-hour ozone concentrations at Rocky Flats North. According to Porter and coauthors (1996), the components of the ozone time series to be separated and analyzed are defined by:

$$O(t) = e(t) + S(t) + W(t) \quad \textbf{(1)}$$

Where O(t) is the natural logarithm of the original ozone time series, e(t) is the long-term or trend component, S(t) is seasonal change, W(t) is short-term variation, and t is time. Log scales are essential to the clear separation of the components of ozone (Porter et al., 1997).

Separation of the natural log of ozone time series, O (t), into distinct components is achieved by the application of Kolmogorov-Zurbenko filters or "KZ" filters (Zurbenko, 1986). The KZ filter isolates component frequencies by repeated iterations of a simple, point-centered moving average. The details of KZ filter application can be found in Porter et al. (1997), Eskridge et al. (1997), and Zurbenko (1986). One of the benefits of the KZ filter is that gaps in the time series data do not bias the results. As Eskridge et al. (1997) point out, "the KZ filter can be applied directly to datasets with missing observations because missing values are simply left out of the computation…"

Eskridge et al. (1997) used Zurbenko-Rao techniques to separate time scales in ozone time series for over 400 monitoring sites in the United States. They found that a KZ filter with a moving-average width of 15 days applied 5 times ($KZ_{15,5}$) effectively separated the baseline (the sum of the long term trend and seasonal components) from the short-term variation. The effective filter width is 15 X $(5)^{1/2}$, or about 33.5 days. The baseline is affected by weather and emissions influences which have a period longer than 33.5 days. The $KZ_{15,5}$ filter is a low pass filter since it removes the short-term day-to-day variations from the dataset. Eskridge et al. (1997) also indicated that one "would not go too far wrong if they used (these) filter parameters for all ozone monitoring sites." It is based on this recommendation that a KZ filter with these parameters has been chosen as a tool to isolate the long-term trends in ozone at Rocky Flats North.

Porter et al. (1996) define the baseline as the sum of seasonal and long-term components:

$$Baseline = S(t) + e(t) \tag{2}$$

They estimated the baseline by applying the KZ filter to the time series of the natural log of ozone:

$$baseline = KZ_{ozone15,5} \tag{3}$$

Over the course of a year, maximum 8-hour ozone concentrations are well correlated with maximum temperatures. Because of this relationship, temperature data can be used to remove much of the weather-related variability in the ozone time series. The maximum temperature time series (not log-transformed) can also be separated into component time series. Porter et al. (1996) applied a $KZ_{15,5}$ filter to the temperature data and regressed the baseline from equation (3) onto the resulting baseline temperature data. They used a lagged temperature series in their work because they found that the seasonal components of temperature and ozone exhibit a phase difference. Temperature time series lagged by 0, 5, 10, 15, and 20 days were tested in this analysis, but the ozone baseline at Rocky Flats North was most highly correlated with the zero-lagged temperature baseline. The regression is defined as:

$$KZ_{ozone15,5} = B0 + B1 * KZ_{temp15,5} \tag{4}$$

where $KZ_{temp15,5}$ is the baseline of daily maximum temperature. The resulting equation in the right side of (4) provides an estimate of the temperature-dependent component of the ozone baseline.

Porter et al. (1996) were able to estimate the temperature-independent portion of the baseline of the log-transformed ozone by subtracting this regression from the ozone baseline:

$$O(t)_{temperature-independent} = KZ_{ozone15,5} - (B0 + B1 * KZ_{temp15,5}) \tag{5}$$

The resulting dataset (which is a residuals or "differences" dataset) will contain the trends due to changes in control strategies, emissions of ozone precursors, as well as any year-to-year changes in weather and climate not captured in the temperature time series.

In a WOE trend decomposition, the temperature-independent dataset is further filtered to remove short-term cycles. A $KZ_{365,3}$ filter is applied. This has an effective width of about 632 days. An example of this stage of the process can be found in Figure 14 in the document at the following EPA web site:

http://www.epa.gov/air/oaqps/pams/analysis/trends/txtsac.html

The last step is to fit a linear regression through the resulting $KZ_{365,3}$ data set. The trend identified by the slope of this line will reflect long-term changes in emissions and can be used to assess progress and predict future improvements under the assumption that the trend will continue.

Zurbenko-Rao Trend Decomposition Applied to Rocky Flats North Ozone and Temperature Data
Daily maximum 8-hour ozone concentrations and daily maximum temperatures were acquired for the Rocky Flats North monitoring site for 1993 through September of 2003. These data sets are plotted in Figures 5 and 6, respectively. The natural log of the ozone series was calculated and has been plotted in Figure 7. The temperature values were converted to degrees Kelvin to avoid any possible problems with correlations between temperature and ozone (see Figure 8).

The $KZ_{15,5}$ low pass filter was applied to the log-transformed ozone and temperature values yielding the baseline time series presented in Figures 9 and 10. It is clear from these plots that short-term cycles and noise have been removed. What remains are the seasonal cycles and the long-term variations.

To remove the effects of temperature (and all weather effects for which temperature is a good surrogate), a linear regression was fit between these two datasets, with the ozone baseline as the independent variable. The resulting equation is listed below:

$$baseline = -10.1968 + 0.02457 * KZ_{temp15,5} \quad \textbf{(6)}$$

The r-squared for the fit is 0.67, and the slope is significantly non-zero. The right side of this equation was substituted in equation (5) above, and the results are shown in Figure 11. This new time series, which can be thought of as a set of residuals, still exhibits some relatively short-term frequencies or cycles. A $KZ_{365,3}$ filter was applied to this time series and the results have been plotted in Figure 12.

The smooth curve in Figure 12 should show the effects of longer-term changes in emissions and those aspects of climate and weather that are not well-represented by temperature alone. The large swing in the curve from 2001 through early 2002 may be the result of year-to-year changes in emissions or weather or both. A line has been fit through this curve and its slope is -0.0117. ***This slope represents the long-term rate of decline in the original ozone time series before log-transformation, which is –1.2% per year***. The slope is significant at the 95% confidence level and yields a projected reduction of 1.2% or a reduction factor of 0.95 between the 2000-2002 and 2004-2006 periods.

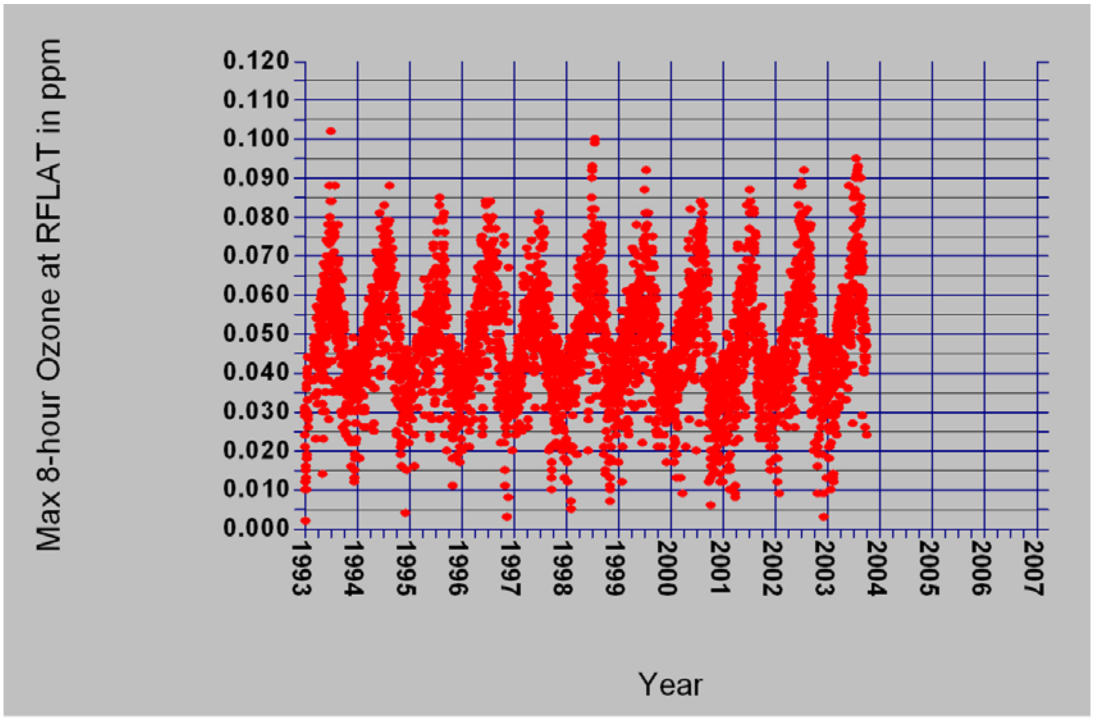



*Figure 5: Time series of maximum daily 8-hour ozone concentrations at Rocky Flats North from 1993-2003.*

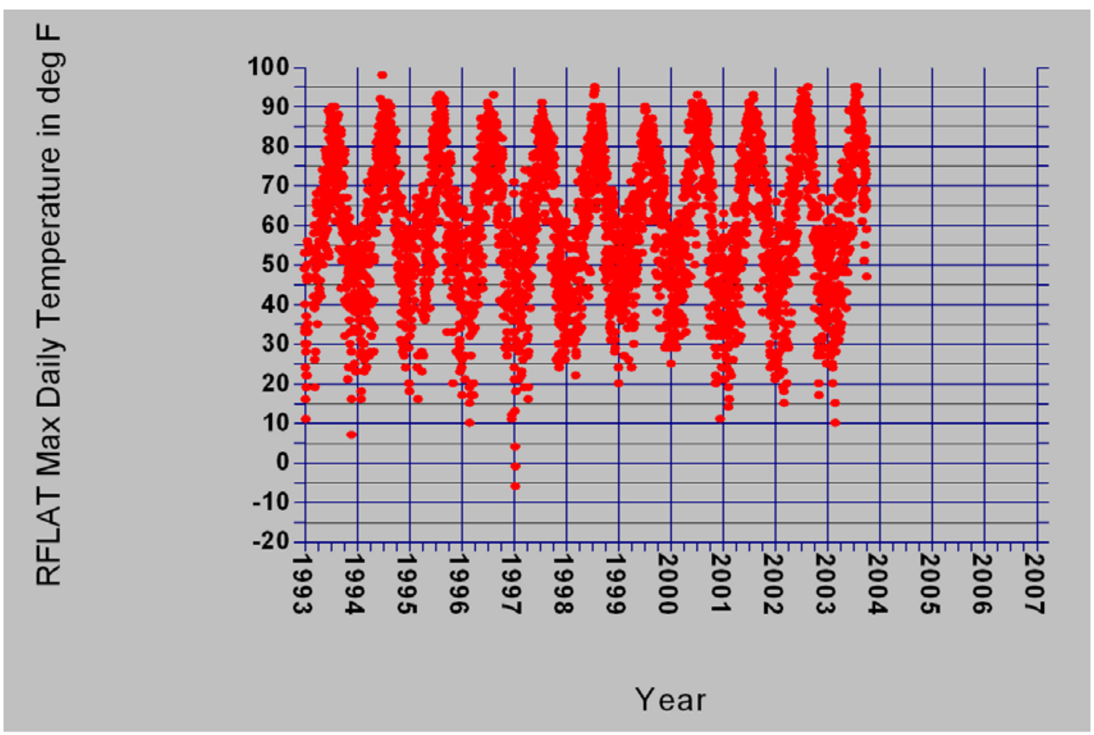



*Figure 6: Time series of maximum daily temperature in degrees F at Rocky Flats North from 1993-2003.*

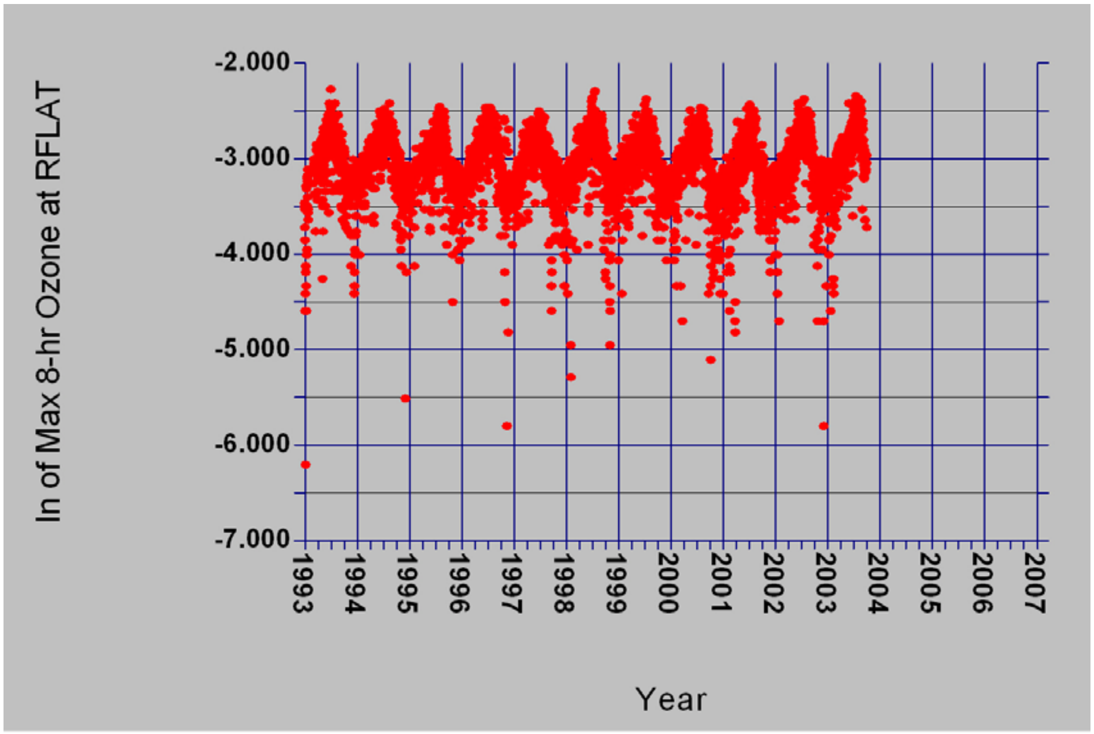



*Figure 7: Time series of the natural log of maximum daily 8-hour ozone concentrations at Rocky Flats North from 1993-2003.*

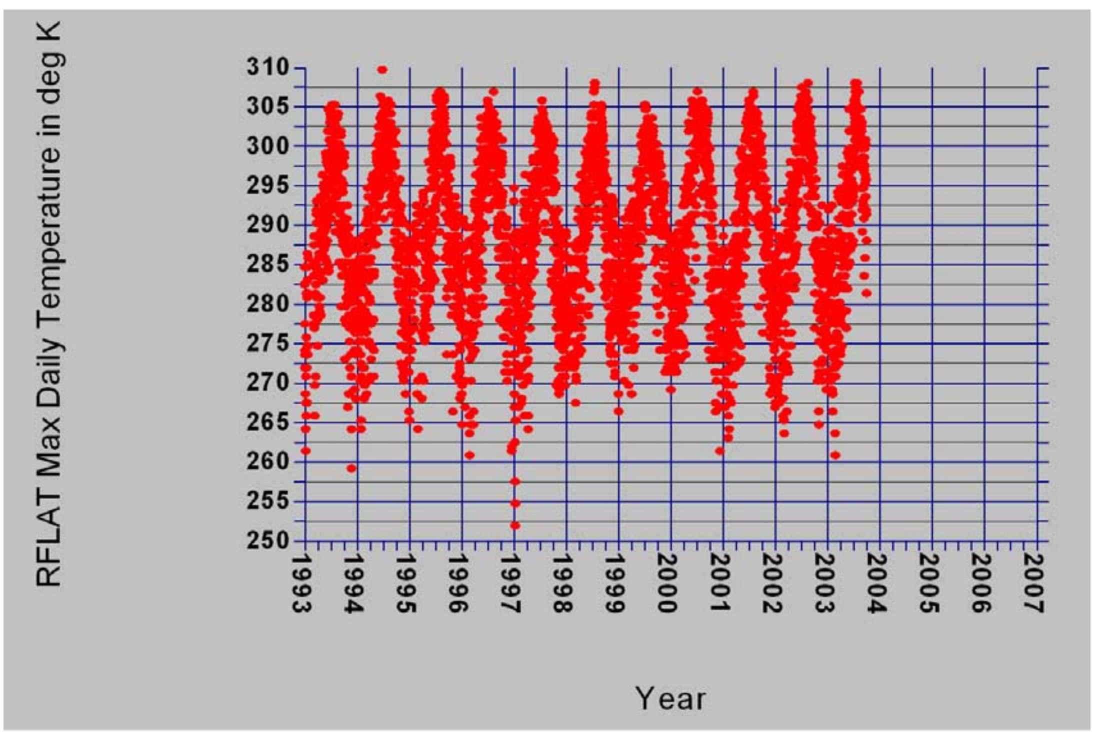



*Figure 8: Time series of maximum daily temperature in degrees K at Rocky Flats North from 1993-2003.*

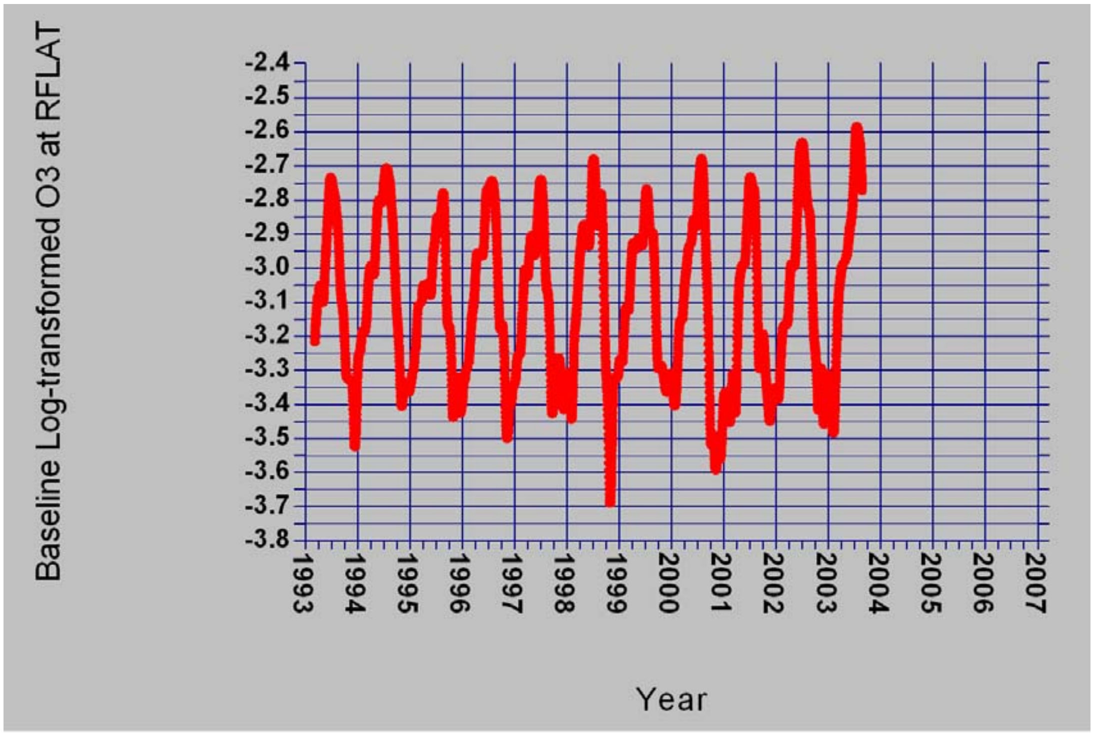



*Figure 9: Time series of baseline of log-transformed daily 8-hour ozone concentrations at Rocky Flats North from 1993-2003.*

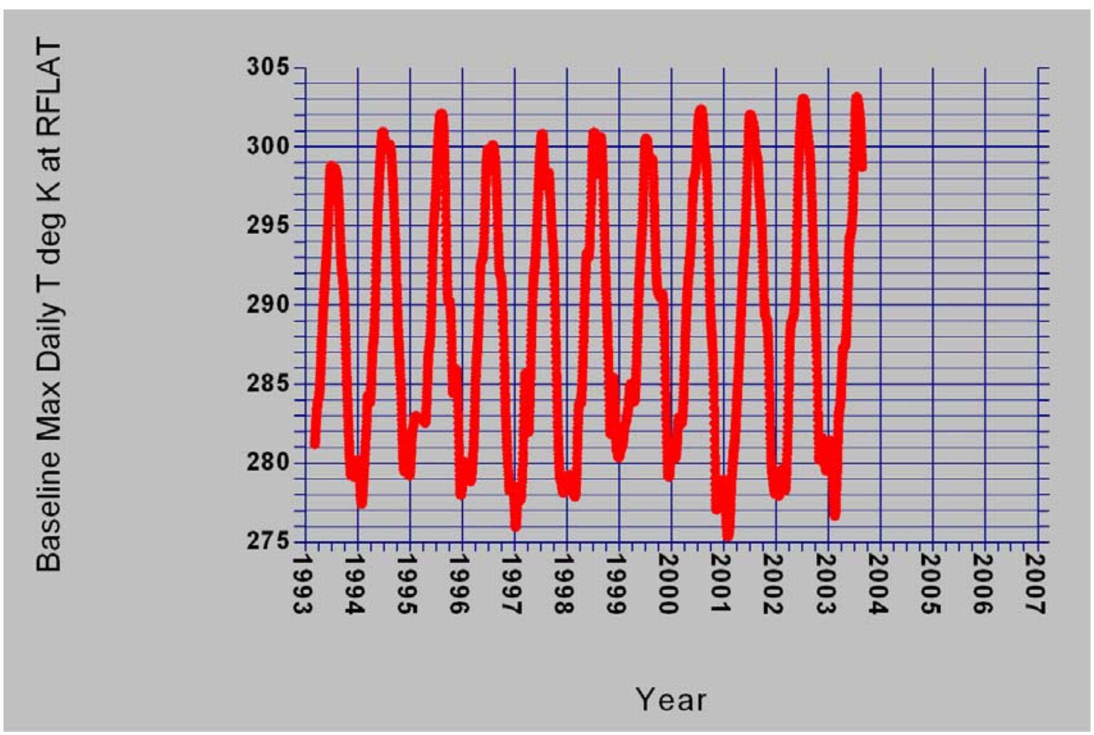



*Figure 10: Time series of baseline of maximum daily temperatures at Rocky Flats North from 1993-2003.*

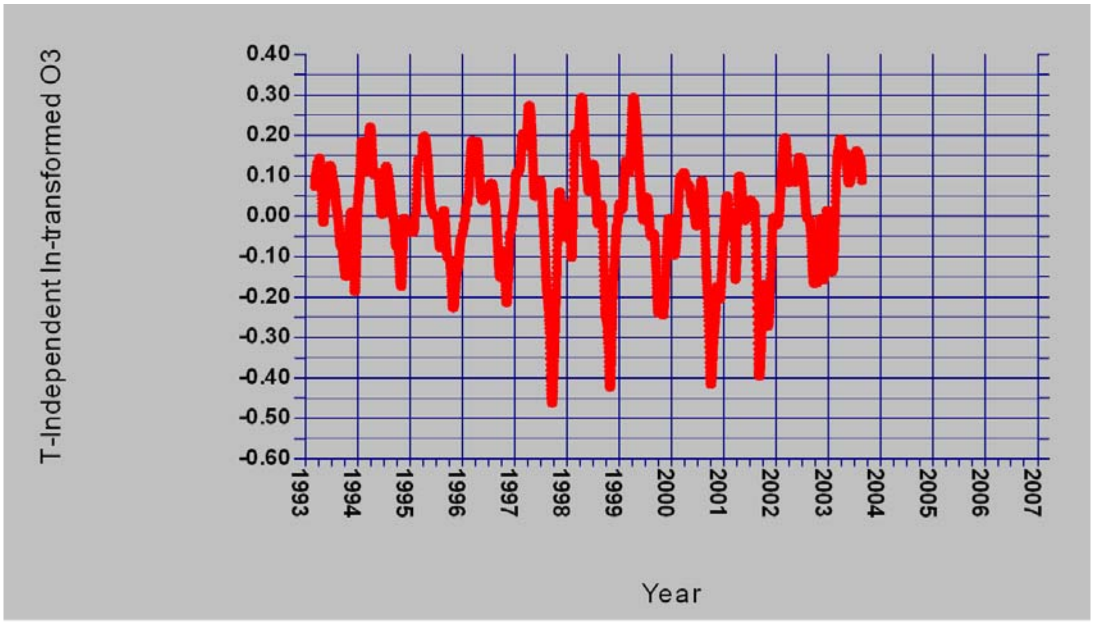



*Figure 11:* Time series of temperature independent component of log-transformed daily 8-hour ozone concentrations at Rocky Flats North from 1993-2003. This dataset represents a difference between a temperature-dependent and non-adjusted baseline of log-transformed ozone.

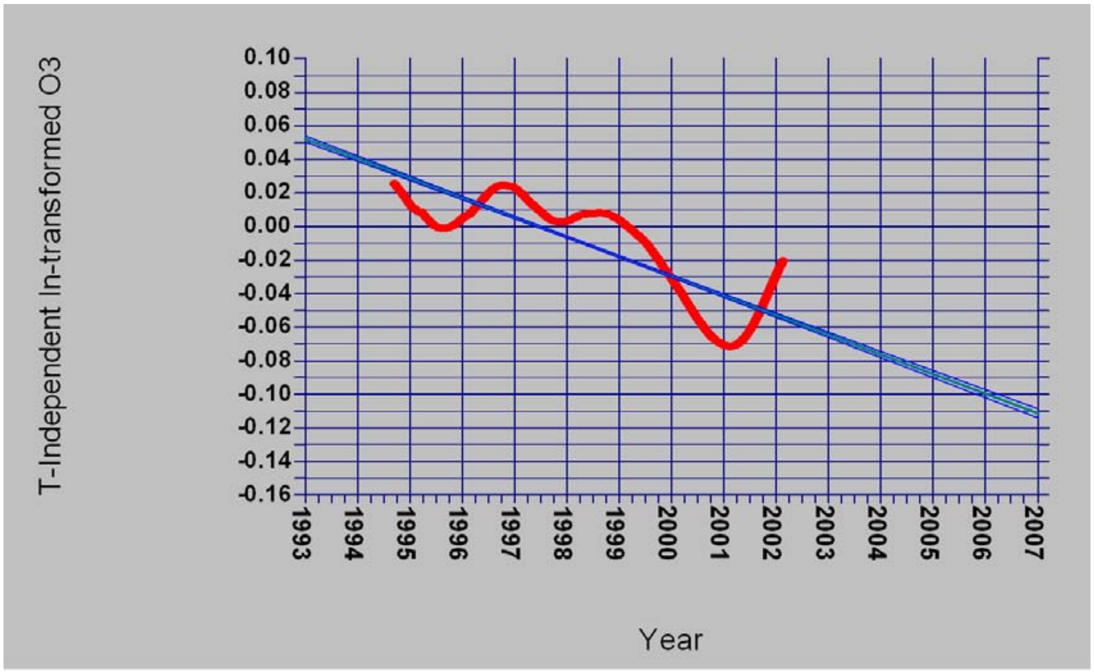



*Figure 12:Time series of temperature independent component of log-transformed daily 8-hour ozone concentrations at Rocky Flats North from 1993-2003 – after application of a $KZ_{365,3}$ filter to remove all but long-term frequencies. A line has been fit through the filtered data. The slope of this line represents the fractional changes due to the mean long-term trend. The slope of this line is -0.0117 which is equivalent to a 1.2% drop in baseline ozone each year.*

**Emission Inventory Trends**
Emission inventory estimates prepared for this Early Action Compact plan indicate a continued decrease in anthropogenic emissions for the Denver metro area. Volatile organic compound emissions drop from 984 tons per day in 2002 to 877 tons per day and 855 tons per day respectively, for 2007 and 2012. Nitrogen oxide emissions drop from 415 tons per day in 2002 to 355 tons per day and 316 tons per day respectively for 2007 and 2012. Likewise, summertime carbon monoxide emissions of 2897 tons per day in 2002 drop to 2473 tons/day 2339 tons/day respectively in 2007 and 2012.

**Trends Analysis Summary and Conclusions**
Anomalously high temperatures and anomalously low mixing heights characterized the summer of 2003. In particular, very low mixing heights on July 11 and 12 resulted in the highest metro-area ozone concentrations in 17 years. For a Weight of Evidence analysis, it makes sense to exclude these days as anomalous and to consider the effects of this exclusion on trends and projections. Moreover, the entire summer of 2003 can be considered anomalous because of the high temperatures, worst-day mixing heights, and unusually large number of exceedance days. Although record summer heat has been relatively common during the last 10 years, the combination of record heat, low mixing heights and an anomalous photochemical regime (described under the discussion of the weekend effect below) may have contributed to a 2003 summer ozone season that was unlike any other in the last 11 years. Therefore, it is reasonable as part of a weight-or-evidence analysis to look at where things would stand if the 2003 exceedances were dropped.

In this case the three-year average fourth max at Rocky Flats North would be about 0.084 ppm (for 2000-2002). The Zurbenko-Rao trend decomposition yields an average rate of decline of 1.2% per year. If this rate of decline were applied to 0.084 ppm and projected to the 2004-2006 time period, the resulting concentration would be 0.080 ppm. Both values are below the standard, and the analysis shows that there would continue to be improvement in ozone concentrations. Even if the 2001-2003 fourth max value of 87 ppb were used, the trend identified here would lead to a value of 84 ppb by 2004-2006, and this is below the standard.

Emission inventory estimates prepared for this Early Action Compact plan indicate a continued decrease in anthropogenic emissions for the Denver metro area The modeled Relative Reduction Factor (RFF) for Rocky Flats North is 0.9888. When this is applied to the 2001-2003 design value or average fourth maximum of 0.087 ppm, the resulting value for 2007 is 0.085 ppm. If 2003 is left out of the calculations and the 2000-2002 average fourth max of 0.084 is used instead, then the application of the RFF yields a value of 0.083 ppm, which is below the standard.

In summary, the Zurbenko-Rao trend decompositions correct for temperature and climate, to some extent, and yields a downward trend that shows compliance based on existing trends in emissions. A consideration of mixing heights, temperatures and a possible anomaly in the photochemical regime of 2003 (see discussion of the weekend effect below) suggest that the summer of 2003 is likely not representative. In either case, a consideration of the multi-year record suggest that compliance is achievable by 2007.

## Model Uncertainty

A common thread throughout the modeling and WOE analyses is the uncertainty in the modeling process. While modeling is by far the best tool for evaluating proposed control strategies, it is imperative to recognize its limitations and the uncertainty in the model predictions. The photochemical model input is almost entirely the result of other models - meteorological models, emissions models, chemistry models, forecast models - which themselves are built upon yet other models. Each component adds its own uncertainty to the process, so that the overall uncertainty is a composite of hundreds of individual uncertainties.

Fortunately, photochemical grid models have proven to be fairly robust in hundreds of applications, and provide reasonable answers under most circumstances. Nonetheless, the policy maker must be aware that the model can only provide general guidance for control strategy development, and cannot be expected to predict future ozone concentrations with high precision.

The uncertainties in the modeling process are inevitably reduced over time, but will never be entirely eliminated. Thus, controls must be implemented before it is possible to judge their impact with as much precision as we would like. The WOE process allows for a middle ground, where a reasonable control package is sufficient to demonstrate probable attainment.

## Effects of Model Uncertainties and Underprediction

Two episodes were originally modeled as discussed in the document, "*Episode Selection for the Denver Early Action Ozone Compact*". Although the model system achieved most of EPA's performance goals, it exhibited a general under prediction tendency so that less ozone was likely attributable to the local emissions in the model than occurred in reality. In general, the Denver base case photochemical model simulation for the Summer 2002 period consistently underestimates the observed ozone concentrations even after various sensitivity tests have been run and adjustments made to the model input conditions.

Modeled ozone concentrations for the June 25-July 1, 2002 episode generally achieved EPA's performance goals The conclusion is that the June 25 – July 1, 2002 episode is adequate for SIP planning purposes, especially when combined with other corroborative information.

Model performance during the July 18-21, 2002 episode did not meet the EPA performance goals for model acceptability and it was not be used as an episode for SIP planning purposes. Modeled concentrations at several key monitors continued to be severely underestimated and additional sensitivity analysis would be required beyond the scope of the EAC project.

EPA's guidance for ozone modeling suggests that a day may be excluded from consideration at a site if the nearby peak modeled 8-hour daily maximum ozone concentration on the day is < 70 ppb. The EPA guidance suggests that as the modeled concentrations approach 70 ppb, an overall overestimate of the future design values may occur. For the attainment demonstration, the criteria of excluding modeled values of < 70 ppb was followed. The overestimate of future design values has the effect of under estimating the effectiveness of future control measures.

EPA's approach toward scaling ozone Design Values using Relative Reduction Factors (RRFs) safeguards against using modeled ozone concentrations that are too low in the Design Value scaling by screening out any days in which the maximum modeled 8-hour ozone value near the monitor is less than 70 ppb. In the case of the Denver EAC 8-hour ozone Design Value projections, the RRFs are based in part on several maximum modeled 8-hour ozone concentrations near the monitor that are at or just over 70 ppb (when truncation is applied), which partially explains why the modeling results are so insensitive to changes in modeled emissions.

Table 2 presents the 2002-modeled concentration across the monitoring network. As shown in Table 2, only July 1, 2002 meets the criterion for concentrations of greater than 70 ppb over the entire network.

*Table 2: 2002 Modeled Concentrations Near 70 ppb and 2007 attainment scenario 1 result*

| Site | 2001-2003 Obs DV | June 25 | June 26 | June 27 | June 28 | June 29 | June 30 | July 1 | #Days>70 |
|---|---|---|---|---|---|---|---|---|---|
| Weld County Tower | 81 | 61.0 | 57.2 | 65.2 | 60.6 | 69.4 | 66.9 | 70.9 | 1 |
| Rocky Mtn. NP | 81 | 63.1 | 64.3 | 67.4 | 62.0 | 71.4 | 76.0 | 79.1 | 3 |
| Fort Collins | 71 | 63.2 | 62.6 | 69.5 | 59.0 | 65.4 | 70.7 | 73.5 | 2 |
| Welch | 70 | 58.9 | 66.5 | 69.8 | 71.7 | 65.7 | 73.0 | 87.2 | 3 |
| Rocky Flats Nor | 87 | 62.8 | 62.7 | 70.9 | 62.1 | 70.5 | 73.8 | 84.5 | 4 |
| NREL | 85 | 60.4 | 64.6 | 70.9 | 64.9 | 63.1 | 73.8 | 87.2 | 3 |
| Arvada | 76 | 59.8 | 60.0 | 70.8 | 63.1 | 69.1 | 71.8 | 85.1 | 3 |
| Welby | 66 | 56.6 | 55.2 | 62.6 | 66.5 | 70.0 | 66.2 | 72.7 | 2 |
| S. Boulder Cree | 77 | 63.0 | 62.8 | 70.9 | 63.0 | 70.9 | 74.1 | 84.5 | 4 |
| Carriage | 76 | 58.4 | 62.3 | 68.8 | 67.9 | 66.6 | 71.9 | 83.8 | 2 |
| Highland | 81 | 57.4 | 66.3 | 62.7 | 73.0 | 69.7 | 71.9 | 81.6 | 3 |
| Chatfield Res. | 85 | 57.9 | 66.5 | 63.4 | 73.0 | 69.7 | 71.9 | 85.9 | 3 |

Future Year: 07run11a.a1-attn

| Site | 2001-2003 Obs DV | June 25 | June 26 | June 27 | June 28 | June 29 | June 30 | July 1 | RRF | Scaled |
|---|---|---|---|---|---|---|---|---|---|---|
| Weld County Tow | 81 | 59.3 | 55.9 | 64.4 | 58.7 | 66.8 | 66 | 69.4 | 0.978 | 79.2 |
| Rocky Mtn. NP | 81 | 63.7 | 62.6 | 65.7 | 60.6 | 69.3 | 74.3 | 76.4 | 0.9711 | 78.7 |
| Fort Collins | 71 | 62.4 | 61.4 | 68.2 | 58 | 63.6 | 70.3 | 71.8 | 0.9854 | 70.0 |
| Welch | 70 | 59 | 66.9 | 68.8 | 69.8 | 64.5 | 72.4 | 85 | 0.9798 | 68.6 |
| Rocky Flats Nor | 87 | 64.4 | 61.7 | 70.3 | 61.1 | 69.1 | 74 | 82.9 | 0.9888 | 86.0 |
| NREL | 85 | 60.7 | 65.9 | 70.3 | 65.2 | 62.4 | 74 | 85 | 0.9891 | 84.1 |
| Arvada | 76 | 60.5 | 61.4 | 70.3 | 62.1 | 68 | 71.6 | 84 | 0.9923 | 75.4 |
| Welby | 66 | 56.4 | 55.5 | 64.3 | 64.5 | 68.7 | 68.6 | 73.9 | 0.9993 | 66.0 |
| S. Boulder Cree | 77 | 64.7 | 62.1 | 70.3 | 61.7 | 69.5 | 74 | 82.9 | 0.9879 | 76.1 |
| Carriage | 76 | 59.5 | 64.6 | 69.1 | 67.7 | 66.2 | 71 | 82 | 0.983 | 74.7 |
| Highland | 81 | 57.1 | 66.7 | 62.9 | 70.4 | 66.7 | 70.9 | 80.6 | 0.9795 | 79.3 |
| Chatfield Res. | 85 | 58 | 66.8 | 61.3 | 70.4 | 66.7 | 71 | 84 | 0.9761 | 83.0 |

ENVIRON (2004) also discussed other reasons why the photochemical model results appear to be "stiff", that is, the estimated 8-hour ozone Design Values are not very sensitive to local emission controls.

- The projected 8-hour ozone Design Values are based, in part, on 2003 ozone observations that occurred during more adverse ozone conducive formation meteorological conditions than 2002 producing ozone concentrations that are much higher than previous years including the July 2002 episode. Thus the contributions of local emissions to the July 2002 episode ozone is not as great as for the observed 2001-2003 Design Values that are being scaled. Although the model system achieved most of EPA's performance goals, it exhibited a general under prediction tendency so that less ozone was likely attributable to the local emissions in the model than occurred in reality.

- Table 2 shows that on some days, such July 1, the modeled 2002 8-hour ozone concentrations (85 ppb) is close to both the Design Value (87 ppb) and observed value on this day (89 ppb). In additional, the entire network shows much better performance on July 1 than for other days, therefore, the confidence in the control measure analysis is greater than for other episode days. This would indicate that using RRF factors for base year model greater than 75 ppb would yield a much more accurate assessment of the effectiveness of the proposed control strategies.

*Table 3: 2002 Modeled Concentrations > 75 ppb and 2007 attainment 1 scenario results*

| Site | 2001-2003 Obs DV | June 25 | June 26 | June 27 | June 28 | June 29 | June 30 | July 1 | #Days>75 |
|---|---|---|---|---|---|---|---|---|---|
| Weld County Tower | 81 | 61 | 57.2 | 65.2 | 60.6 | 69.4 | 66.9 | 70.9 | 0 |
| Rocky Mtn. NP | 81 | 63.1 | 64.3 | 67.4 | 62 | 71.4 | 76 | 79.1 | 2 |
| Fort Collins | 71 | 63.2 | 62.6 | 69.5 | 59 | 65.4 | 70.7 | 73.5 | 0 |
| Welch | 70 | 58.9 | 66.5 | 69.8 | 71.7 | 65.7 | 73 | 87.2 | 1 |
| Rocky Flats Nor | 87 | 62.8 | 62.7 | 70.9 | 62.1 | 70.5 | 73.8 | 84.5 | 1 |
| NREL | 85 | 60.4 | 64.6 | 70.9 | 64.9 | 63.1 | 73.8 | 87.2 | 1 |
| Arvada | 76 | 59.8 | 60 | 70.8 | 63.1 | 69.1 | 71.8 | 85.1 | 1 |
| Welby | 66 | 56.6 | 55.2 | 62.6 | 66.5 | 70 | 66.2 | 72.7 | 0 |
| S. Boulder Cree | 77 | 63 | 62.8 | 70.9 | 63 | 70.9 | 74.1 | 84.5 | 1 |
| Carriage | 76 | 58.4 | 62.3 | 68.8 | 67.9 | 66.6 | 71.9 | 83.8 | 1 |
| Highland | 81 | 57.4 | 66.3 | 62.7 | 73 | 69.7 | 71.9 | 81.6 | 1 |
| Chatfield Res. | 85 | 57.9 | 66.5 | 63.4 | 73 | 69.7 | 71.9 | 85.9 | 1 |

Future Year: 07run11a.a1-attn

| Site | 2001-2003 Obs DV | June 25 | June 26 | June 27 | June 28 | June 29 | June 30 | July 1 | RRF | Scaled |
|---|---|---|---|---|---|---|---|---|---|---|
| Weld County Tow | 81 | 59.3 | 55.9 | 64.4 | 58.7 | 66.8 | 66 | 69.4 | -- | --- |
| Rocky Mtn. NP | 81 | 63.7 | 62.6 | 65.7 | 60.6 | 69.3 | 74.3 | 76.4 | 0.9716 | 78.7 |
| Fort Collins | 71 | 62.4 | 61.4 | 68.2 | 58 | 63.6 | 70.3 | 71.8 | --- | --- |
| Welch | 70 | 59 | 66.9 | 68.8 | 69.8 | 64.5 | 72.4 | 85 | 0.9748 | 68.2 |
| Rocky Flats Nor | 87 | 64.4 | 61.7 | 70.3 | 61.1 | 69.1 | 74 | 82.9 | 0.9811 | 85.3 |
| NREL | 85 | 60.7 | 65.9 | 70.3 | 65.2 | 62.4 | 74 | 85 | 0.9748 | 82.9 |
| Arvada | 76 | 60.5 | 61.4 | 70.3 | 62.1 | 68 | 71.6 | 84 | 0.9871 | 75.0 |
| Welby | 66 | 56.4 | 55.5 | 64.3 | 64.5 | 68.7 | 68.6 | 73.9 | 0.9993 | 66.0 |
| S. Boulder Cree | 77 | 64.7 | 62.1 | 70.3 | 61.7 | 69.5 | 74 | 82.9 | 0.9811 | 75.5 |
| Carriage | 76 | 59.5 | 64.6 | 69.1 | 67.7 | 66.2 | 71 | 82 | 0.9785 | 74.4 |
| Highland | 81 | 57.1 | 66.7 | 62.9 | 70.4 | 66.7 | 70.9 | 80.6 | 0.9877 | 80 |
| Chatfield Res. | 85 | 58 | 66.8 | 61.3 | 70.4 | 66.7 | 71 | 84 | 0.9779 | 83.1 |

Table 4 presents an indication of model accuracy over the June 25-July 1, 2002 episode at the Rocky Flats monitor which supports the use of days greater than 75 ppb. Table 4 shows that the overall model accuracy for modeled days over 75 ppb increase dramatically. For two modeled days, June 26 and June 27, there were no ozone monitor data to pair the data and are indicated as "Na" in the table. However, June 27 is considered in the modeling analysis since the base year 2002 model results were greater than 70 ppb. June 25, 26, and 28 were not used in the attainment demonstration per EPA Modeling guidance because the 2002-modeled concentrations were less 70 ppb. The shaded areas (yellow) indicate the dates that were used for the attainment demonstration.

For all paired data, the overall model to monitored accuracy is 15.4%. For all paired data that was used in the attainment demonstration (i.e. 6/29,6/30,7/1), the model accuracy was 13.7%. For July 1, where both the model prediction and the monitored concentration is near the 8-hour ozone standard, the accuracy is 4.0%.

In all instances, the modeled value was less than the monitored concentration. Keep in mind that the absolute modeled concentration estimates were not used to determine attainment but rather modeled data was used in a relative manner to determine attainment. Also, the modeled values are the highest estimated concentrations "nearby" the Rocky Flats monitor.

*Table 4: Accuracy of Modeled vs. Monitored Data at Rocky Flats during the June 25-July 1, 2002 Episode*

| Date | Modeled | Monitored | % Difference |
|---|---|---|---|
| **6/25/2002** | 62.8 | 80.0 | 21.5% |
| **6/26/2002** | 62.7 | Na | Na |
| **6/27/2002** | 70.9 | Na | Na |
| **6/28/2002** | 62.1 | 73.0 | 14.9% |
| **6/29/2002** | 70.5 | 89.0 | 20.8% |
| **6/30/2002** | 73.8 | 88.0 | 16.1% |
| **7/01/2002** | 84.5 | 88.0 | 4.0% |
| Mean | 70.7 | 83.6 | 15.4% |
| **Mean of 6/29,6/30,7/1** | 76.3 | 88.3 | 13.7% |

## Weekend Effect

Lawson (2003) reports that research conducted for the LA Basin and other urban areas shows a significant increase in ozone on weekend days compared with weekdays. This is known as the weekend effect. For the LA Basin study he reports that "Hypothesis testing using empirical observations, data analysis, and different modeling approaches suggested that decreased weekend NOx emissions, resulting mostly from fewer trucks on the roads on weekends, was the largest single contributor to elevated weekend ozone…" Lawson says that the weekend effect offers us a real world analogue of a NOx control strategy experiment. The existence of the weekend effect is also evidence that an area is VOC limited.

Based on an analysis of daily maximum 8-hour ozone levels from June through August for 1998 through 2002, the Denver metro area weekend effect ranges from about 3% to 7% at the highest ozone sites such as NREL, Chatfield, and Rocky Flats to 7% to 12% at sites such as Arvada, Carriage and Welby. The spatial distribution of the effect is mapped in Figure 13. While year-to-year variations in the summer weekend effect can be seen in Figure 14, these maps also suggest that the basic pattern was consistent from 1998 through 2002. In contrast, July and August of 2003, saw weekend effects of only -6% to 1% at many of the high sites and negative effects at many sites that had been strongly positive during previous summers (see Figure 15.)

In a recent study of the weekend effect in Southern California, Blanchard et al. (2003) concluded that "Nearly all VOC-limited sites exhibited higher weekend peak O3 concentrations, whereas NOx-limited sites did not show significant differences between mean weekday and weekend peak O3 levels. Thus an interpretation of the site's responses as an indication of spatial patterns of VOC or NOx limitation was supported."

If we were to assume that this finding also applies in the Denver metro area, it follows from the logic presented by Blanchard et al. (2003) that ozone may be somewhat VOC-limited at many metro-area sites in 1998 through 2002. It may be that the metro area as a whole is transitional between NOx and VOC limitation. During the months of July and August of 2003, however, the metro area appears to have been NOx-limited or at least more NOx-limited than normal. Could there have been higher emissions of VOC's on these days?

Plots of mean hourly Sunday ozone concentrations versus mean hourly midweek (Tuesday-Thursday) concentrations for 2001-2002 are shown for Rocky Flats, NREL, and Chatfield in Figures 16-18. These show that the hourly concentrations on Sundays are generally higher than the hourly concentrations for the same times during the midweek. This supports the existence of the weekend effect, with higher Sunday ozone levels because of lower NOx emissions from mobile sources in a VOC–limited environment.

Similar plots for July and August of 2003 are shown in Figures 19-21, and these show a much different pattern for July and August of 2003. In general, Sunday hourly values were slightly higher or equivalent to midweek values during the morning hours. During the afternoon hours, however, midweek values were higher than Sunday values. This suggests that the afternoon periods were NOx limited during the high-ozone months of 2003.

The weekend-weekday difference supports a hypothesis that the source of the anomaly in 2003 may have been from mobile sources (in recent years, Sunday traffic counts were 25% lower than weekday counts in the Denver metro area.) The anomaly's peak during the heat of the day is likely related to increased evaporative or tail pipe emissions or both. A combination of the high ethanol market share of 65% in the summer of 2003 (compared with 20%, 35%, and 60% in 2002, 2001, and 2000, respectively), low mixing heights, and higher than normal temperatures may have shifted the photochemical regime in the summer of 2003. Whatever the cause, there is good empirical evidence in the weekend effect indicators that the emissions or photochemical regimes in 2003 were anomalous. For this reason and since the 2003 ozone season was marked by record heat and lower-than-normal worst-day mixing heights it makes sense to consider trends and projections without including 2003, and this is part of the rationale for the approaches discussed in the weight of evidence documentation.

Modeled control scenarios and sensitivity analysis done so far for the Denver EAC, indicate that VOC controls are most effective. NOx controls show very little improvement to ozone concentrations and in some cases, ozone concentrations increase. Reduction of VOC and NOx at the same time has not been as effective as an all VOC reductions control scenario.

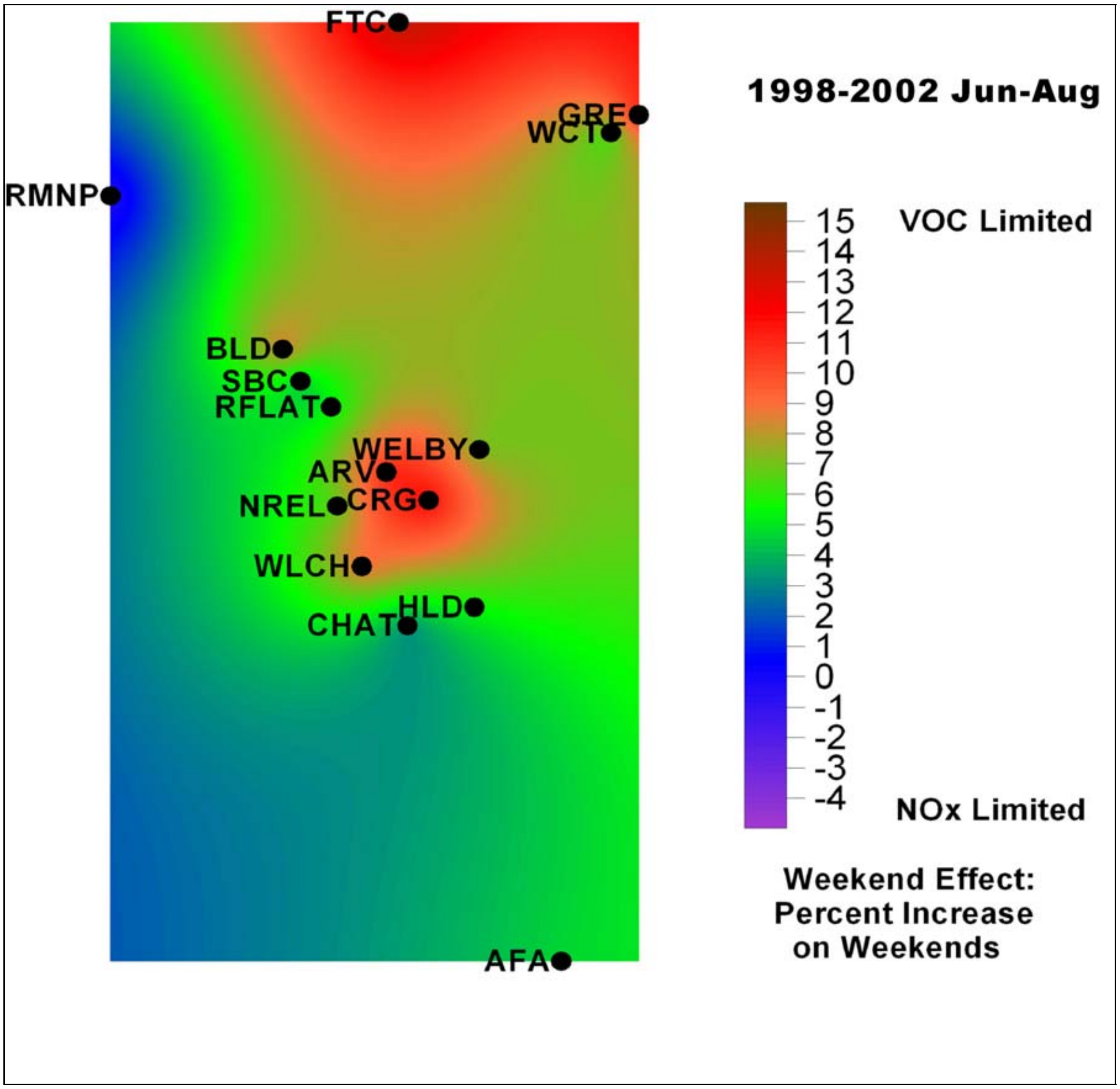



*Figure 13: Spatial distribution of the weekend effect (percent increase in maximum 8-hour ozone concentrations on weekends versus weekdays) for Colorado's Front Range Urban Corridor monitoring sites from June through August for 1998-2002.*

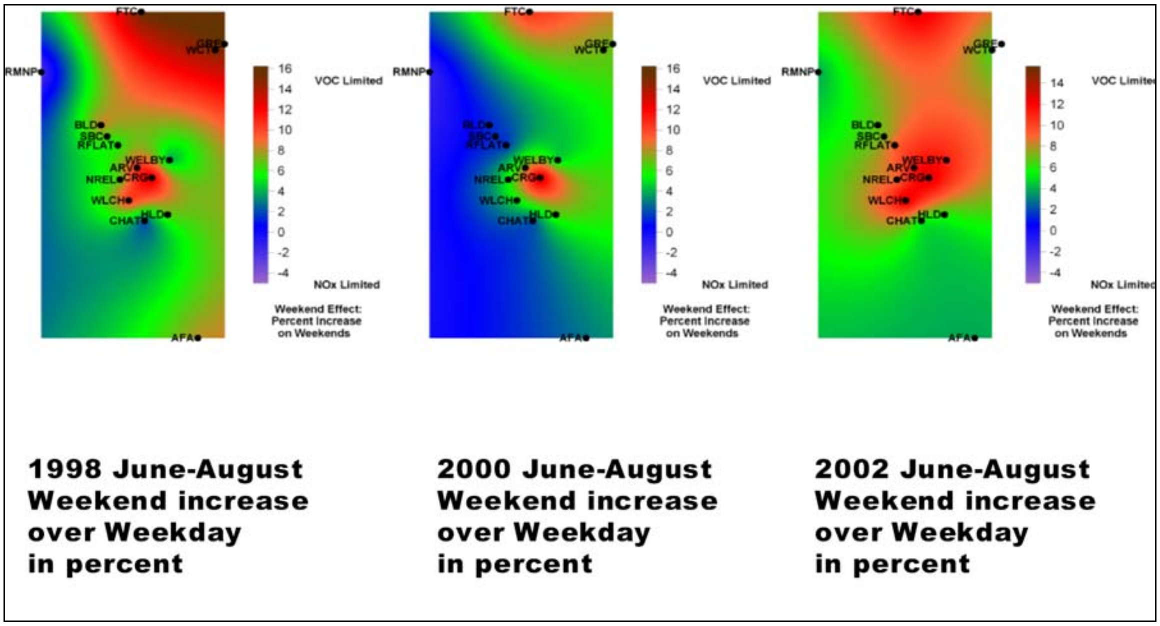



*Figure 14:Spatial distribution of the weekend effect (percent increase in maximum 8-hour ozone concentrations on weekends versus weekdays) for Colorado's Front Range Urban Corridor monitoring sites from June through August of 1998, 2000, and 2002.*

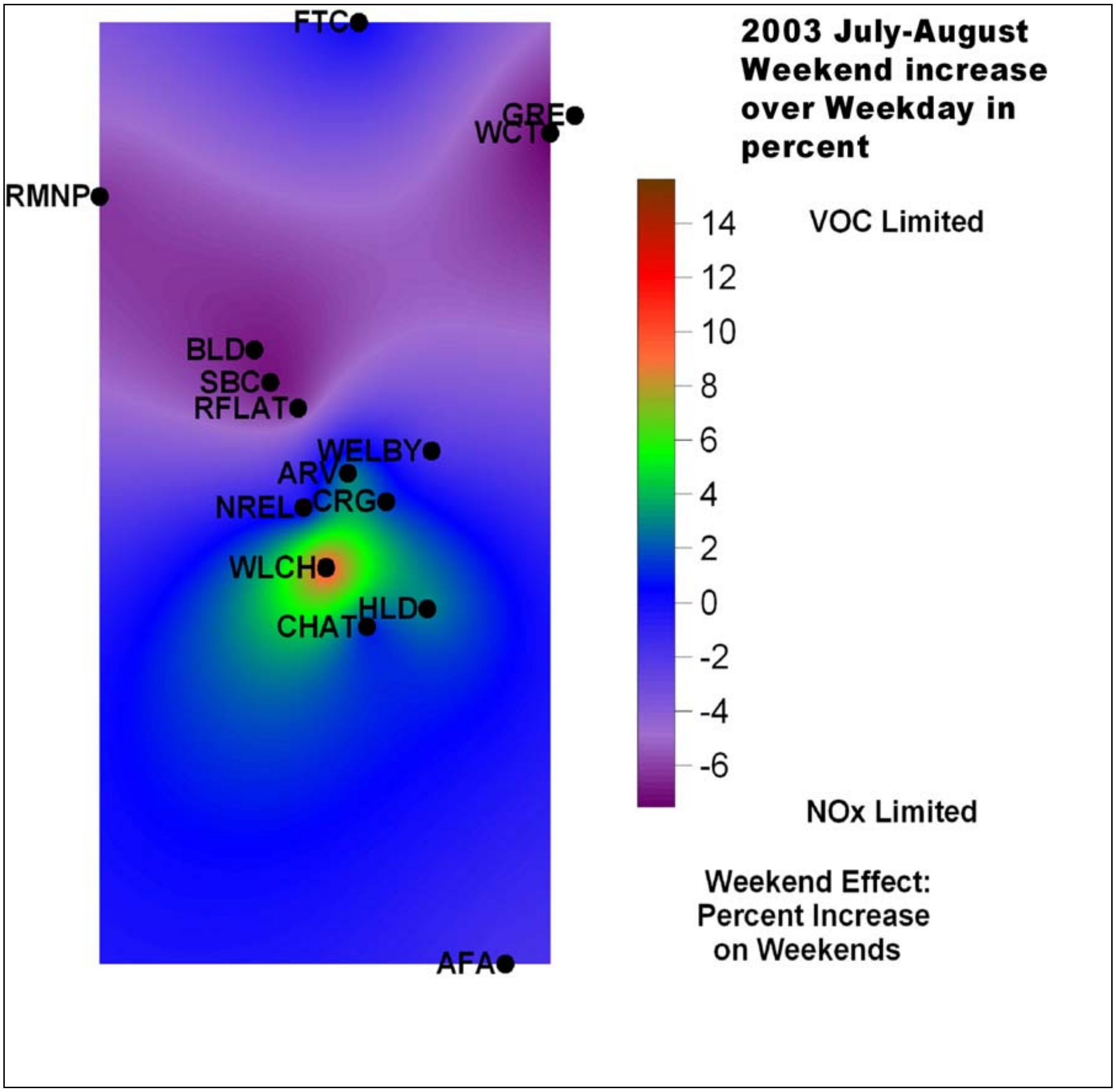



*Figure 15: Spatial distribution of the weekend effect (percent increase in maximum 8-hour ozone concentrations on weekends versus weekdays) for Colorado's Front Range Urban Corridor monitoring sites from July through August of 2003.*

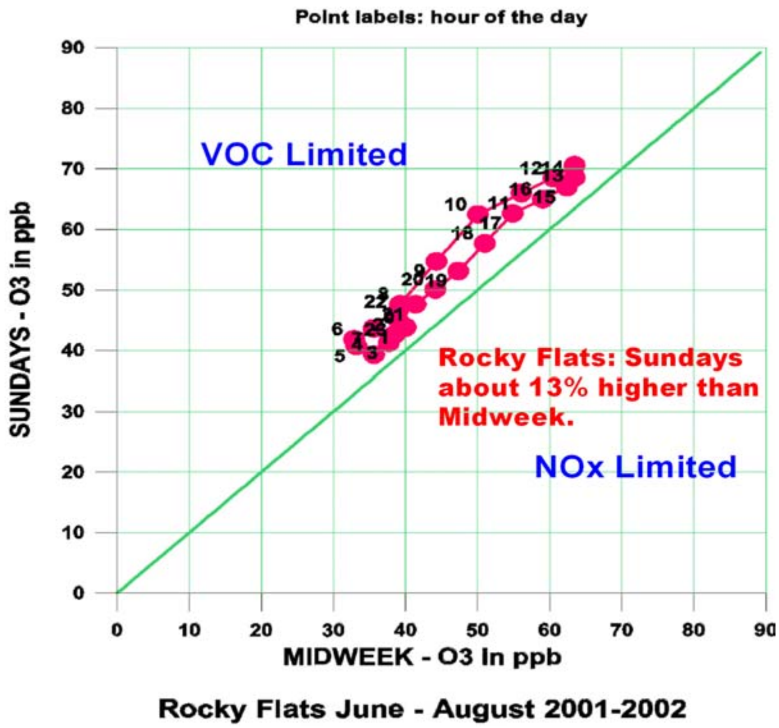



*Figure 16:Mean hourly Sunday versus midweek ozone concentrations at Rocky Flats 2001-2002.*

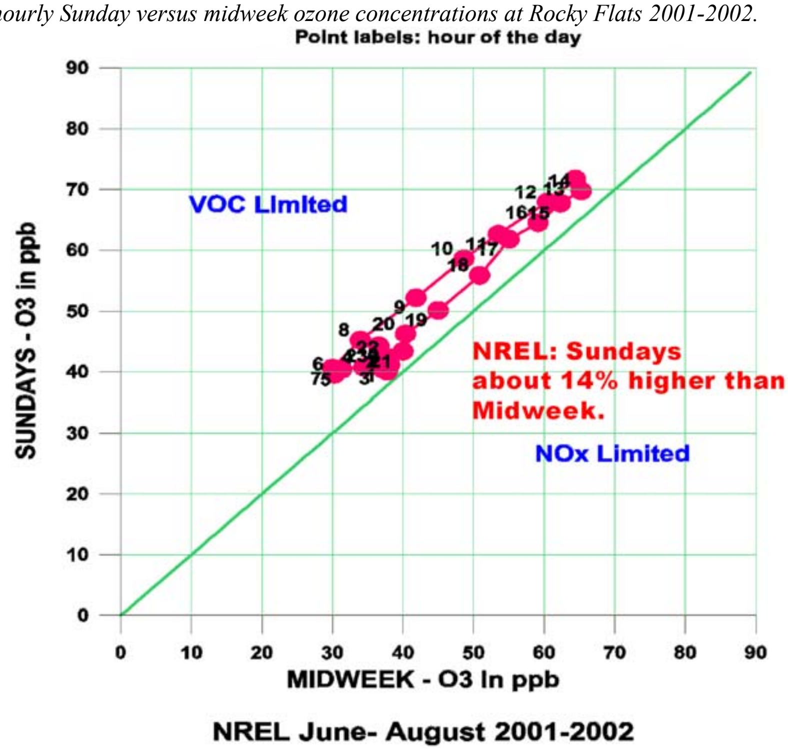



*Figure 17: Mean hourly Sunday versus midweek ozone concentrations at NREL 2001-2002.*

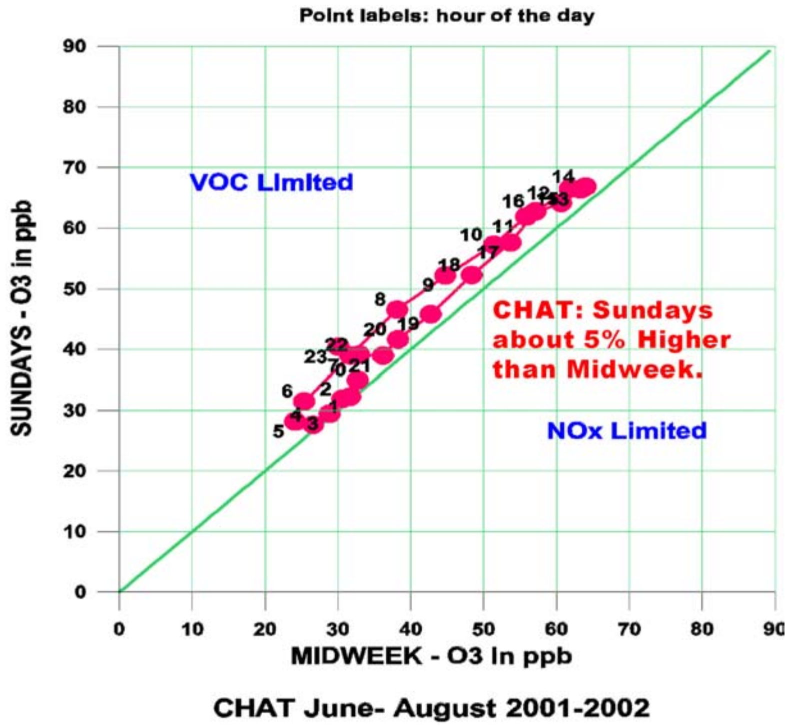



*Figure 18: Mean hourly Sunday versus midweek ozone concentrations at Chatfield 2001-2002.*

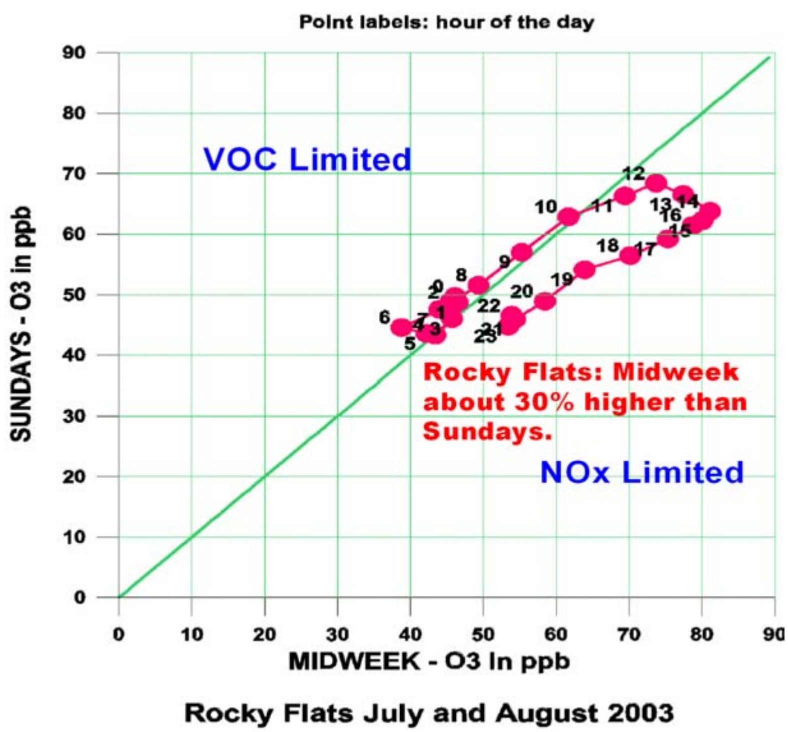



*Figure 19: Mean hourly Sunday versus midweek ozone concentrations at Rocky Flats July-August 2003.*

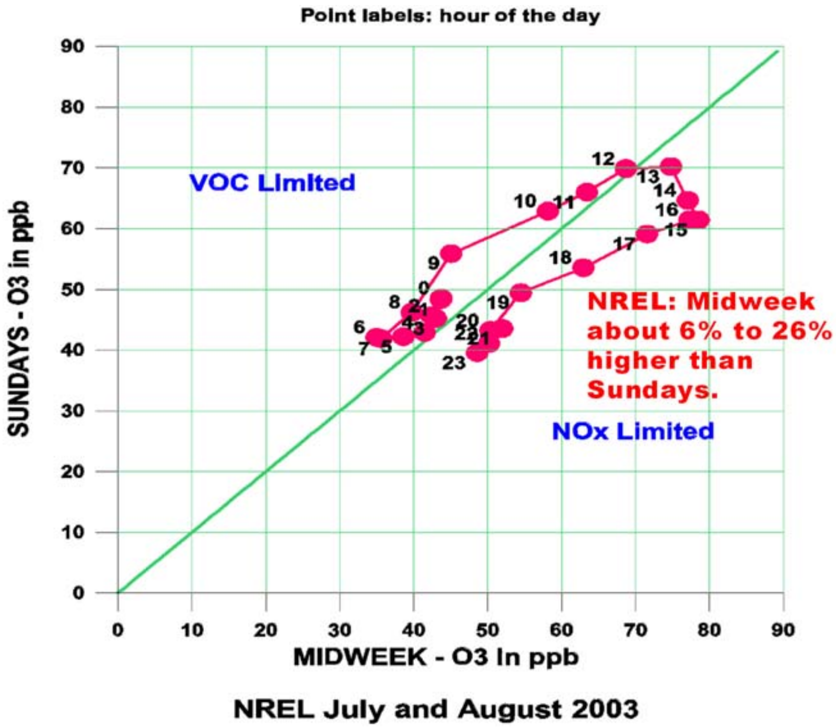



*Figure 20:Mean hourly Sunday versus midweek ozone concentrations at NREL July-August 2003.*

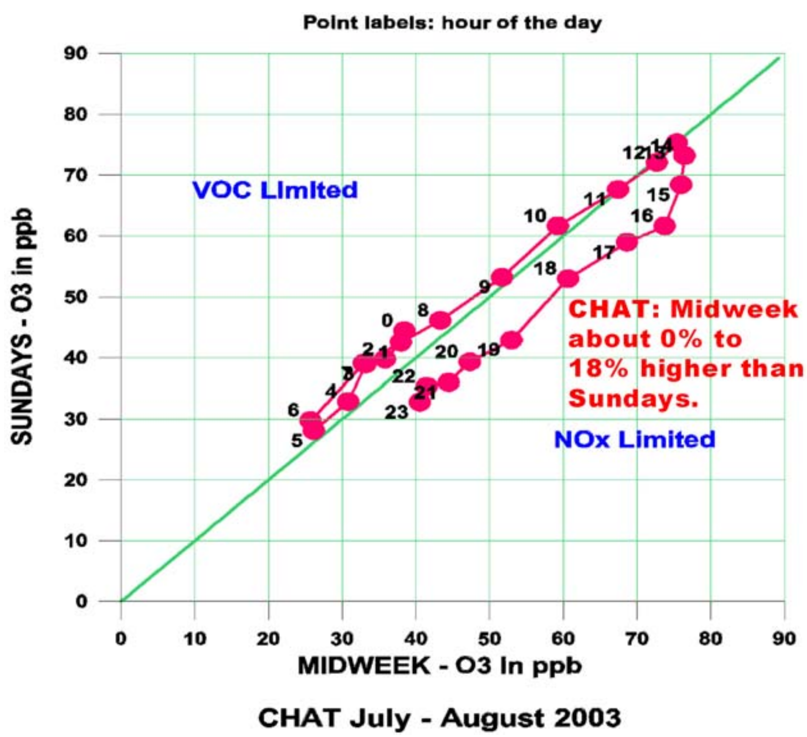



*Figure 21: Mean hourly Sunday versus midweek ozone concentrations at Chatfield July-August 2003.*

## Trajectory Analysis

Back trajectory calculations to the monitor at the time of the 8-hour ozone exceedance are recommended as part of the WOE attainment demonstration. The purpose of analyzing back trajectories include:

- Comparing trajectories derived from different meteorological models to add validity to the local meteorological model (MM5) and to finer grid used for photochemical modeling;
- When the trajectory analysis is limited to daylight hours, the computed trajectory could be compared with observed surface air quality observations. If the timing of high ozone observed along the path of the trajectories is consistent with expectations, given the configuration of sources, this would be an indicator that the meteorological model is performing adequately;
- Daytime surface trajectories using *observed* wind data. These trajectories could also be compared with air quality patterns. By comparing the two sets of trajectories with observed air quality patterns, it would then be possible to assess whether the meteorological model increases the skill with which ozone plumes are oriented.

ENVIRON/ALPINE Geophysics (Feb. 2002) produced two-day (48 hour) back trajectories from the Rocky Flats monitor using three different approaches:

1. Use of the NOAA HYSPLIT model driven by the 80 km resolution Eta Data Assimilation System (EDAS) wind fields;
2. Use of the NOASS HYSPLIT model driven by the 2.5 degree (250-275 km) resolution Global NCAR/NCEP fields; and
3. Use of 36/12/4 km MM5 data developed as part of the Denver EAC modeling (McNally, Tesche and Morris, 2003).

In addition, CDPHE produced 36-hour trajectories as part of the episode and domain selection (CDPHE, Jan. 2003). Given the complex terrain of the Denver Front Range region, the coarse wind resolution of the EDAS and NCAR/NCEP wind fields may not capture the proper back trajectories. Thus, the back trajectories calculated using the MM5 fields are likely more reliable.

Appendix A in this document displays the 48 hour back trajectories for several key high days" shows that the HYSPLT back trajectories are usually in agreement with each other. The back trajectories using MM5 data are sometimes in agreement and sometimes not in agreement with the coarse grid EDAS and Global produced trajectories. The back trajectories suggest that emissions from the Denver metropolitan area (DMA) contributed in part to the high ozone at Rocky Flats during June 25-July1 episodes.

CDPHE produced 10-hour trajectories from 7 o'clock AM until 5:00 PM for those days in 2001 through 2003 that had 8-hour ozone concentrations greater than 84 ppb at the Rocky Flats Monitor. This 10-hour period was selected because it includes the warmest part of the day, the cycle of precursor transport from source regions, and the time of the typical peak one-hour ozone concentrations.

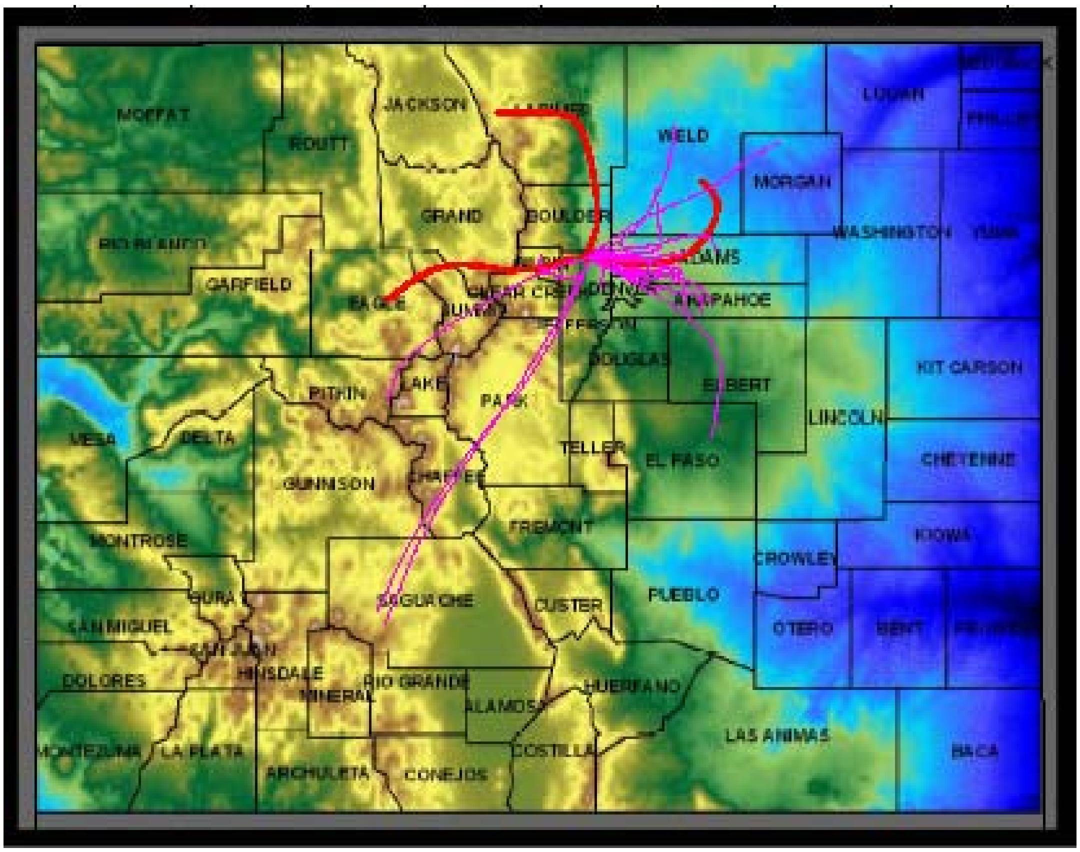
A composite of those trajectories with 8-hour ozone concentrations > 84 ppb that were monitored between 2001 and 2003 are presented in Figure 22. The red trajectories (darker grey) are those days that are within the June 25-July 1 episode and were model as part of the attainment demonstration. The fuscia colored trajectories (lighter grey) are those days with monitored value greater than 84 ppb for those days not in the episode.

Analysis of the day specific trajectories from Figure 22 reveal several items of note:

- The June 25-July 1 episode contains days in all sectors where precursors may occur;
- The June 30$^{th}$ trajectory (north easterly) trajectory is representative of those days with the highest frequency of 8-hour exceedances. The July 1 trajectory brackets those emissions precursors coming from the north.
- For a few exception, the trajectories would indicate that high ozone concentrations generally occur when there is an easterly to northeasterly component.

The conclusion from the back trajectory analysis indicates that the episode that is being modeled (i.e June 25-July 1, 2002) is representative of the general regime where high ozone is monitored at Rocky Flats. The back trajectory analysis shows that the proposed emission reductions in Weld County may be more effective than is modeled given the “stiffness” in the model.

*Figure 22:Composite 10-hour Trajectory Analysis from EDAS*



**Additional Ozone Modeling Metrics**

EPA recommends that at least 3 additional model outputs be examined in the weight of evidence (WOE) determination to provide assurance that passing or nearly passing the recommended attainment and screening tests indicates attainment (EPA, 1999, pg. 544-60). These tests measure how much estimated elevated 8-hour ozone concentrations are reduced from the current year base case condition to the future-year control strategy. The three recommended metrics are as follows:

> # Grid-Hours > 84 ppb: Compute the relative change in the number of grid cell – hours during the modeling episode in which the estimated 8-hour ozone concentrations are greater than 84 ppb.
>
> # Grid-Cells > 84 ppb: Compute the number of grid-cells in which the daily maximum 8-hour ozone concentrations is greater than 84 ppb.
>
> Relative Difference (RD): The Relative Difference (RD) in 8-Hour ozone concentrations greater than 84 ppb is the ratio of the average of estimated excess 8-hour ozone above 84 ppb of the future-year simulation to the base-year base case.

The first two metrics above represent a type of 8-hour ozone exposure metric. The #Grid-Hours with 8-hour ozone > 84 ppb is the number of grid cell-hours that the model estimated 8-hour ozone concentrations exceeds the health-based standard. The #Grid-cells 8-hour ozone is greater than 84 ppb represents the areal extent of modeled exceedances. The Relative Reduction metric is more of a dosage calculation that is weighted by how much the 8-hour ozone concentration is above 84 ppb.

As part of the WOE, EPA guidance states that "large" reductions in these metrics are desirable (EPA, 1999). By "large" EPA suggests an 80% reduction (EPA, 1999). For the RD metric, an 80% reduction would be equivalent to a 0.20 value.

Table 2-7 below summarizes these metrics for the 2002 Base Case, 2007 Base Case and two 2007 Control Strategy package simulations.

**Table 2-7.** Summary of additional modeling metrics recommended by EPA in a WOE determination.

| | **# Grid-Hours 8-hr > 84 ppb** | | **# Grid-Cell > 84ppb** | | **Relative Difference** | |
|---|---|---|---|---|---|---|
| | **(#)** | **(%)** | **(#)** | **(%)** | **(ppb-hr)** | **(%)** |
| 2002 Base | 33 | | 15 | | | |
| 2007 Base Case | 8 | 76% | 6 | 60% | 0.16 | 84% |
| 2007 Control Stratey Pkg. w/8.1 RVP | 4 | 88% | 3 | 80% | 0.08 | 92% |
| 2007 Control Stratey Pkg. w/7.8 RVP | 4 | 88% | 3 | 80% | 0.07 | 93% |

The # Grid-Hours 8-hour ozone > 84 ppb (88%), #Grid-Cell 8-hour ozone > 84 ppb (80%) and the Relative Difference (RD) (92%-93%) metrics all exhibit "large" (> 80%) reductions for the two 2007 Control Strategies thereby satisfying EPA's WOE goal. For the 2007 Base Case, the Relative Difference (RD) (84%) achieves the "large" reduction goal, whereas the #Grid-Hours (76%) and #Grid-Cell (60%) metrics fall a little short.

## Additional Analyses

In preparation of the technical documents for the Denver EAC, there are other data that support the attainment modeling and WOE demonstrations. These additional analysis include:

- Monitored Speciation Data: Recent ambient monitored precursor data indicates similarity between ambient data and emissions estimates. Very close correlation between flash emissions speciation data and ambient measurements in Weld County the source of almost all of the Flash emission in the inventory. TSD Appendix C & N
- Ambient Monitoring & Emissions Trends: Monitored trends and emissions trends of CO and PM10 and emissions trends are declining supporting the concept that aver all air quality is improving due to controls in place in the region. TSD Appendix C
- Design Value and Emissions Trends: Analysis of 3-year period design values for 8-hour ozone and precursor emissions indicates that both are trending down. TSD Appendix C
- Planetary Boundary Layer Height and Boundary Condition Analysis: Modeling of the 2002 base case investigated the impacts of changes in PBL Heights and Boundary conditions to maximize appropriate assumptions in future modeling. TSD Appendix G & H

## Conclusions

The Weight of Evidence (WOE) provided in this document indicate that attainment of the 8-hour ozone standard serves to demonstrate attainment will be achieved by 2007 with the emission reductions in the current attainment scenario photochemical modeling. The emission inventories presented in Appendix C clearly show an emissions trend downward between 2002 and 2012 that will result in lower ozone concentrations. The base year 2002 base year was modeled in accordance with EPA procedures and guidance. In fact, EPA chose 2002 as the base year for the Early Action Compacts as well as ozone and regional haze attainment SIPs. However, the meteorological conditions and emissions that caused anomalously high ozone concentrations and occurrences in 2003 are not well represented by the modeled episode from 2002.

This document discusses the meteorological conditions that lead to the 2001-2003 design value for the Denver metro area. It is apparent that the 2003 meteorological conditions were anomalous. When the affects of this anomalous meteorology are removed from the Design Value, the dispersion modeling shows attainment.

An emission trends analysis and "weekend effect" analysis were also conducted. When the effects of meteorology are filtered out of the ambient monitoring concentrations, the controlling design values are reduced to 80 ppb when 2003 is excluded and 84 ppb when 2003 is included. Sensitivity analysis of control scenarios and the "weekend effect" analysis indicate that VOC controls are the most effective for the Denver metropolitan area and VOC emissions may have been enriched.

The benefit of the 2007 attainment scenario level of emissions control may be somewhat understated because of model uncertainty and model under predictions. Trajectory analysis for the area indicate that the present control scenarios are within those areas that may effect ozone concentrations in the area. However, because of model underprediction, the effectiveness of those controls are likely understated.

Other metrics indicate that the geographical areas where ozone levels exceed 84 ppb will dramatically decrease with the attainment control scenario. In addition, the time periods where concentrations exceed 84 ppb will also decrease.

References:

Banta, R. M., 1990. The role of mountains in making clouds, in *Atmospheric Processes over Complex Terrain, Meteorological Monographs Volume:23 Number 45*, American Meteorological Society, pp 229-283.

Eskridge, R. E., J. Y. Ku, P. S. Porter, S. T. Rao, and I.G. Zurbenko. 1997. Separating different scales of motion in time series of meteorological variables. *Bulletin of the American Meteorological Society 78:7*, pp 1473-1483.

Porter, P. S., S. T. Rao, I. Zurbenko, E. Zalewsky, R. F. Henry, and J. Y. Ku. 1996. Statistical characteristics of spectrally-decomposed ambient ozone time series data. Final report prepared for the Ozone Transport Assessment Group by the University of Idaho, the State University of New York at Albany, and the New York Department of Environmental Conservation.

Rao, S. T., I. G. Zurbenko, R. Neagu, P. S. Porter, J. Y. Ku, and R. F. Henry. 1997. Space and time scales in ambient ozone data. *Bulletin of the American Meteorological Society 78:10*, pp 2153-2166.

Blanchard, C.L. and S. J. Tanenbaum. Differences between weekday and weekend air pollutant levels in Southern California. ***J. Air & Waste Manage. Assoc. 53***:816-828, July 2003.

Lawson, D.R. The weekend ozone effect – the weekly ambient emissions control experiment. ***EM* 2003**, July, 17-25.

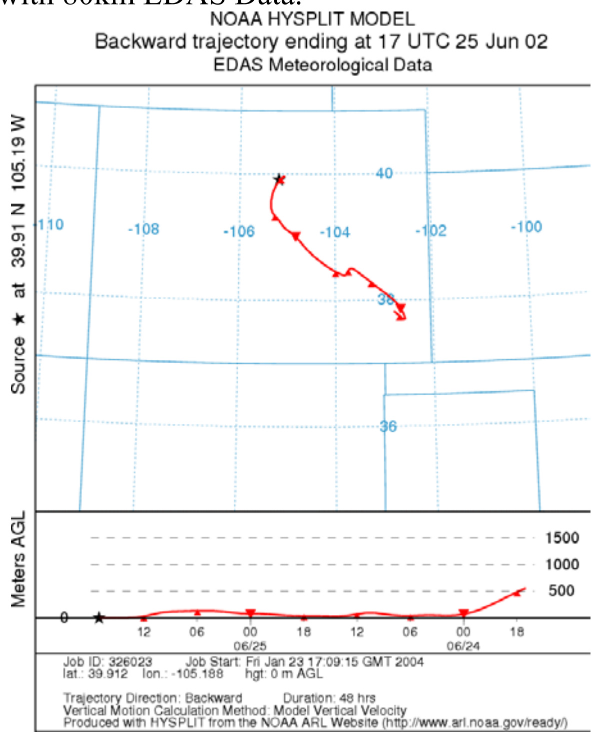
## Appendix A

## HYSPLIT and MM5 Trajectory Analyses

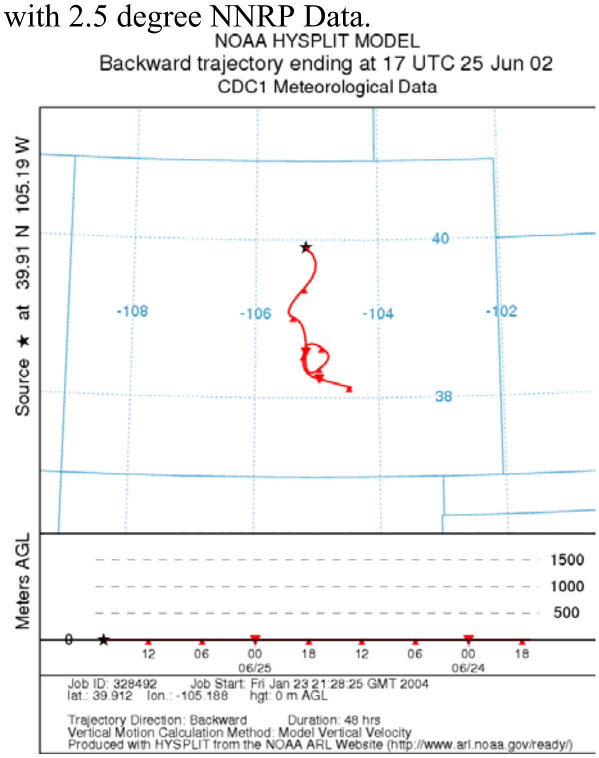
Trajectory simulations were performed to assess the path air parcels travel before impacting the Rocky Flats ozone monitor. For each episode day, 48-hour back trajectories were calculated for a ground level parcel. Trajectories arriving at the Rocky Flats monitor at 1000 MST, 1200 MST and 1400 MST are presented in Figures 1-21. In each figure the first frame (a) present the NOAA HYSPLIT model results using the 80km Eta Data Assimilation System (EDAS) archive. The second frame (b) presents the NOAA HYSPLIT model results using the 2.5 Degree Global NCAR/NCEP Reanalysis Project (NNRP) archive. The third frame (c) presents the trajectories using the MM5 simulation used in the CAMx modeling with the trajectory being computed using the RIP processor. For the RIP processing, a 10 minute time step with hourly meteorological model output were used.

**Figure 1.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1000 MST 25 June 2002. The Peak 8-hour Monitored Ozone Concentration was 81 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

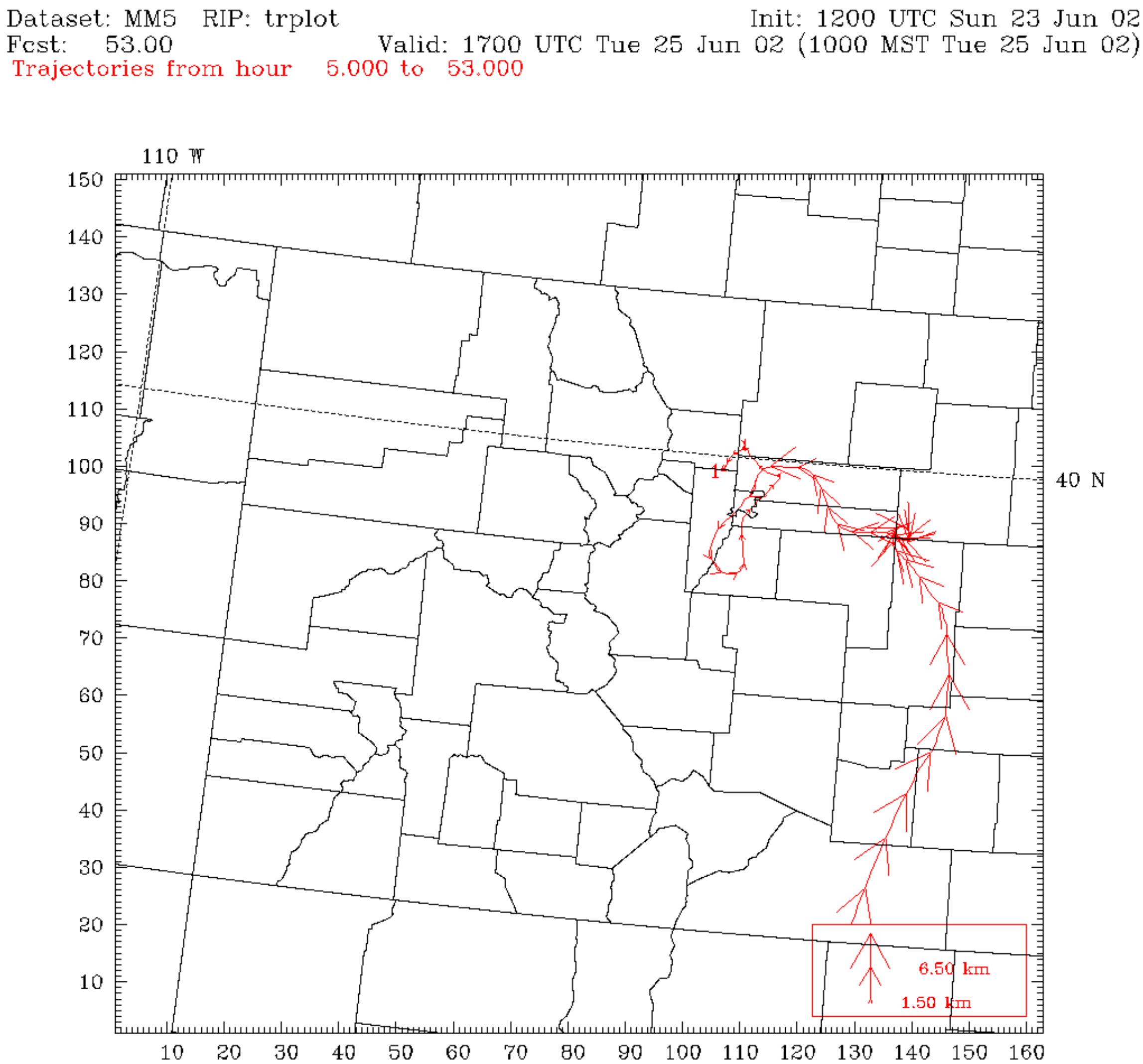
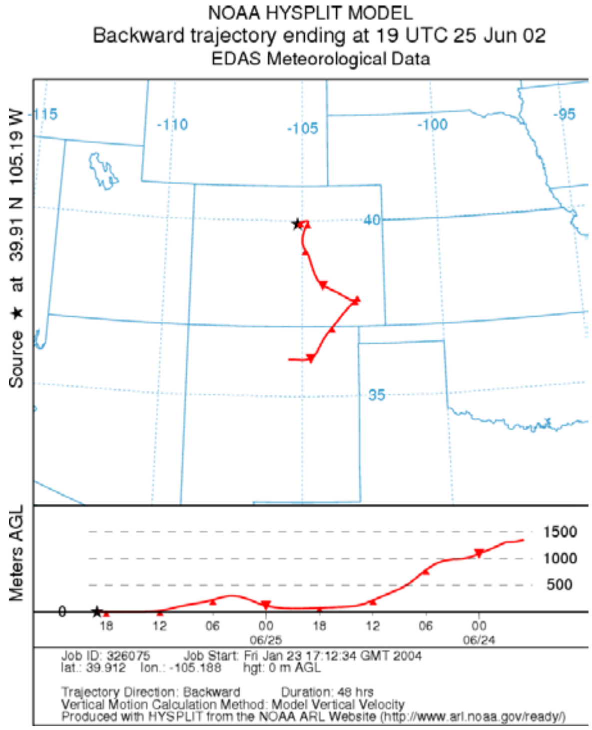
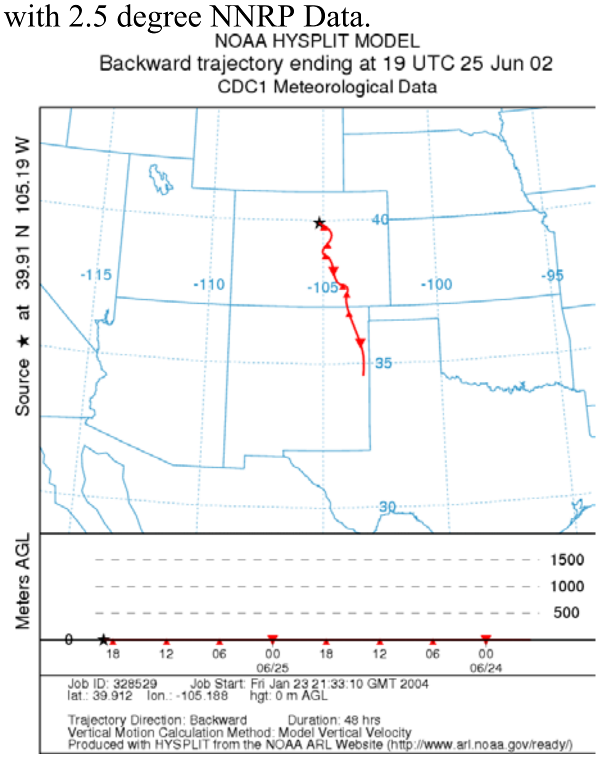


**Figure 2.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1200 MST 25 June 2002. The Peak 8-hour Monitored Ozone Concentration was 81 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

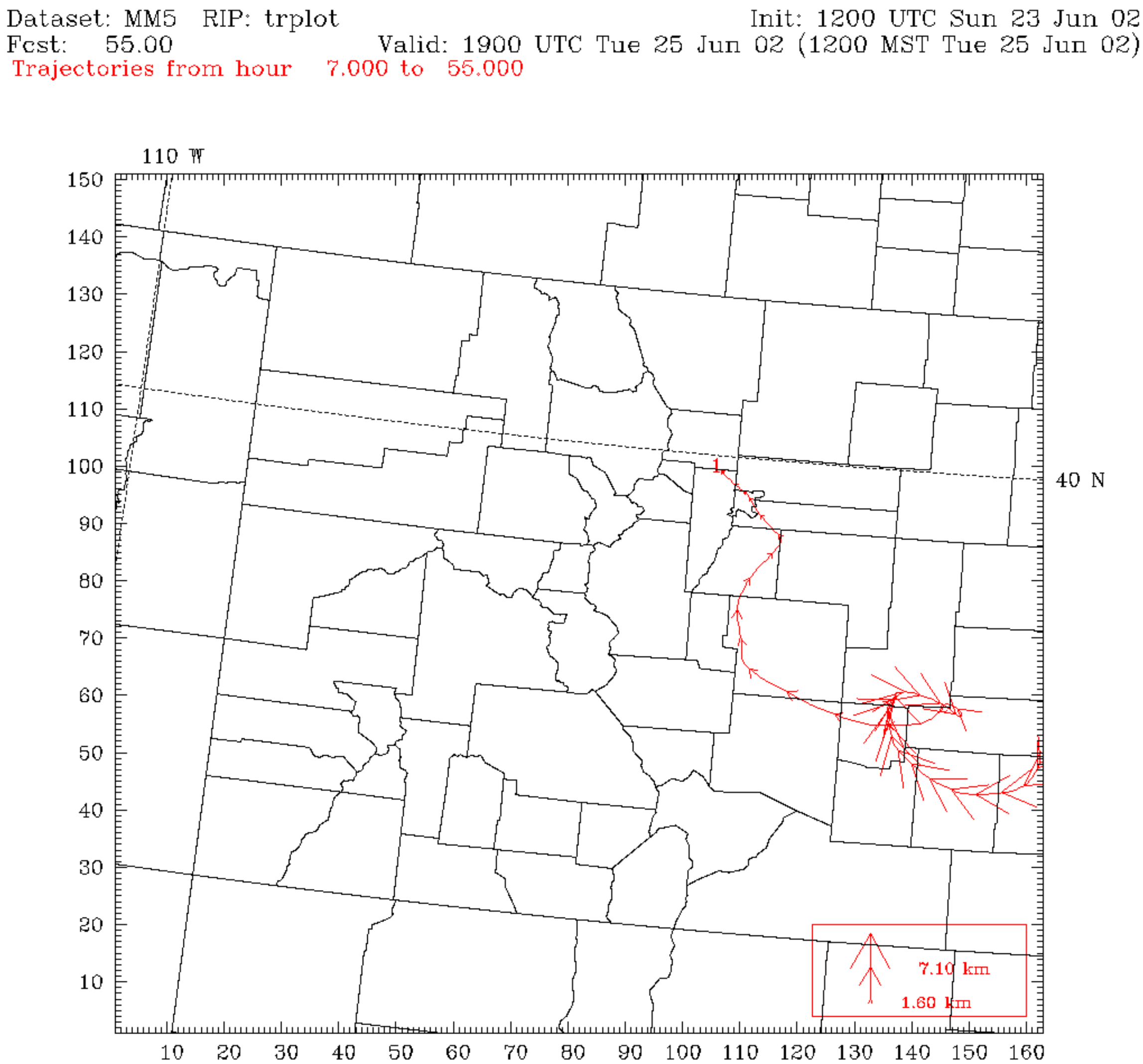
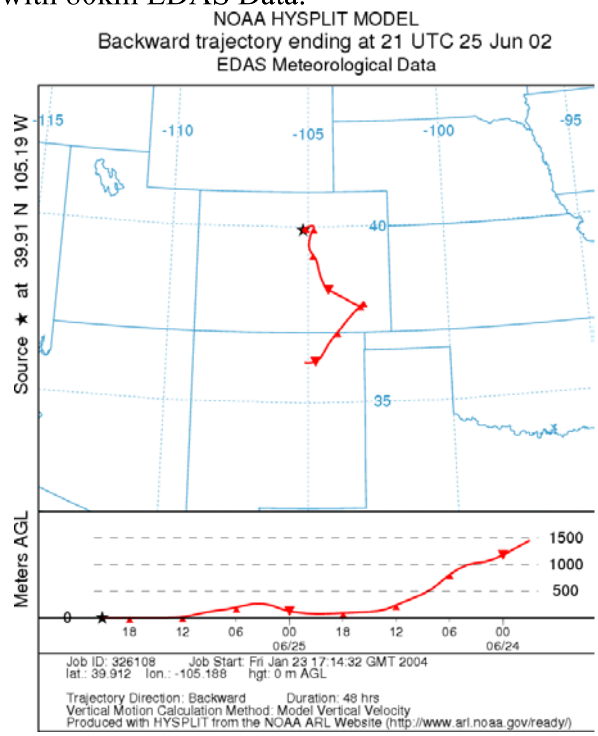
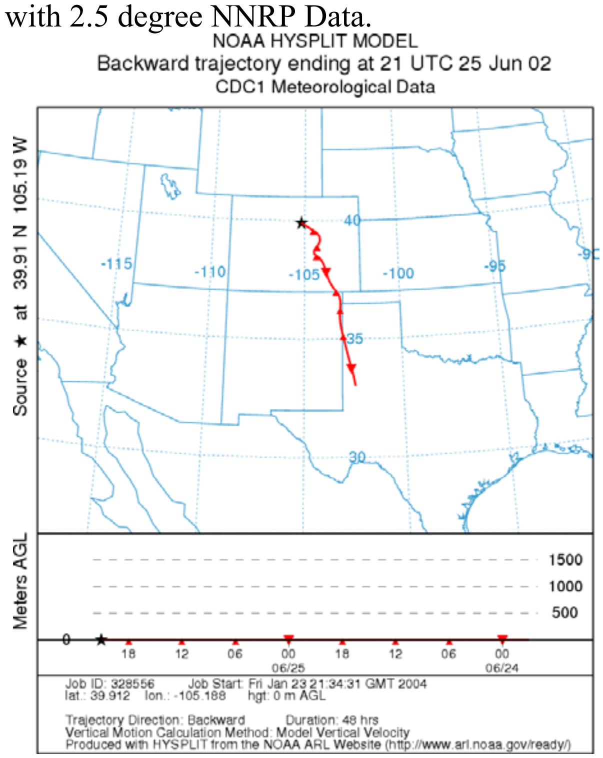


**Figure 3.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1400 MST 25 June 2002. The Peak 8-hour Monitored Ozone Concentration was 81 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

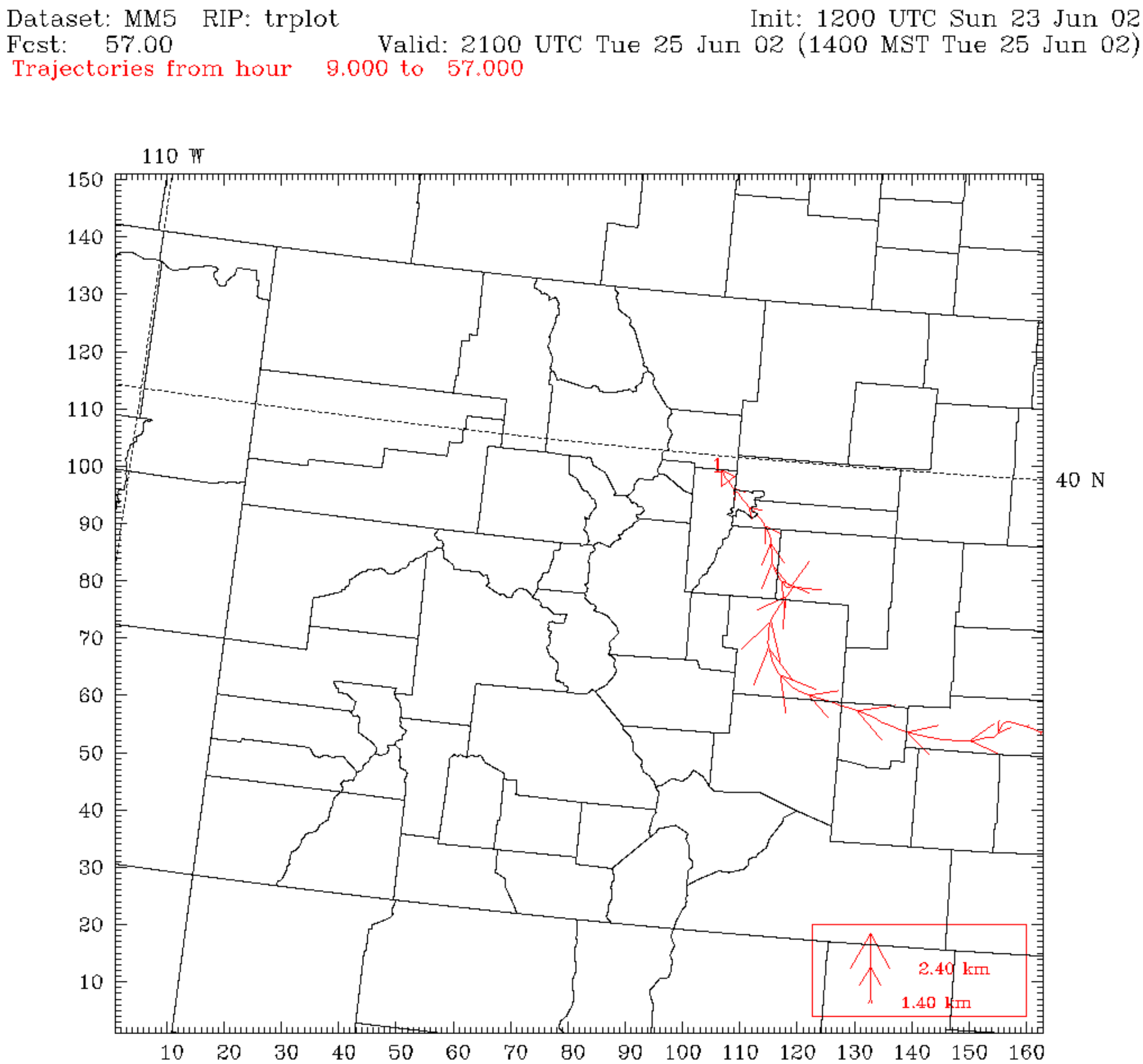
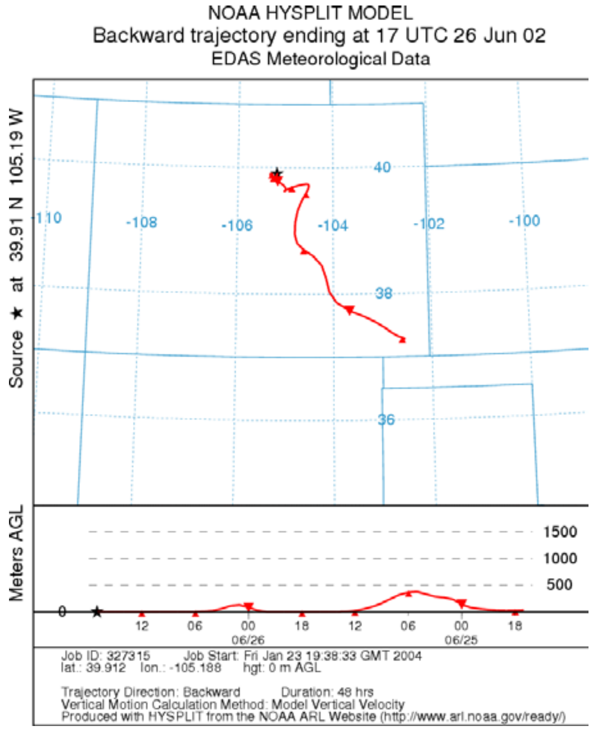
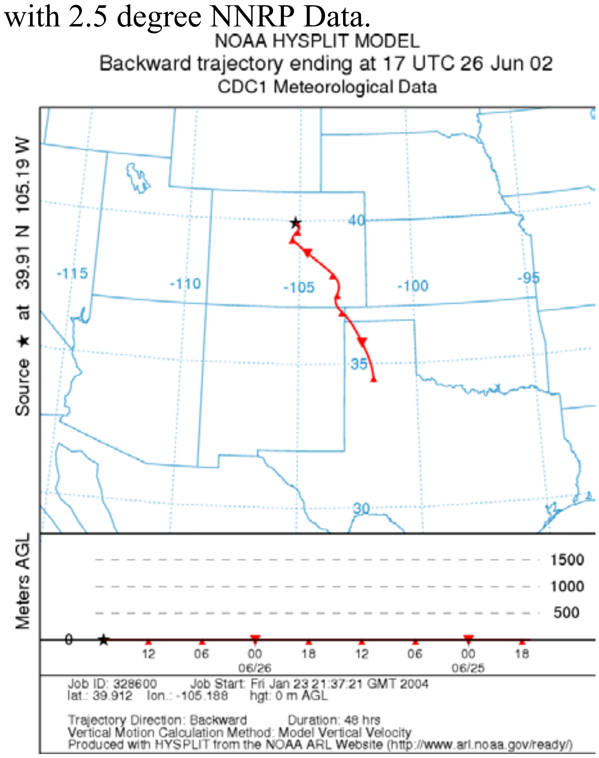


**Figure 4.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1000 MST 26 June 2002. The Peak 8-hour Monitored Ozone Concentration was Not Reported.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

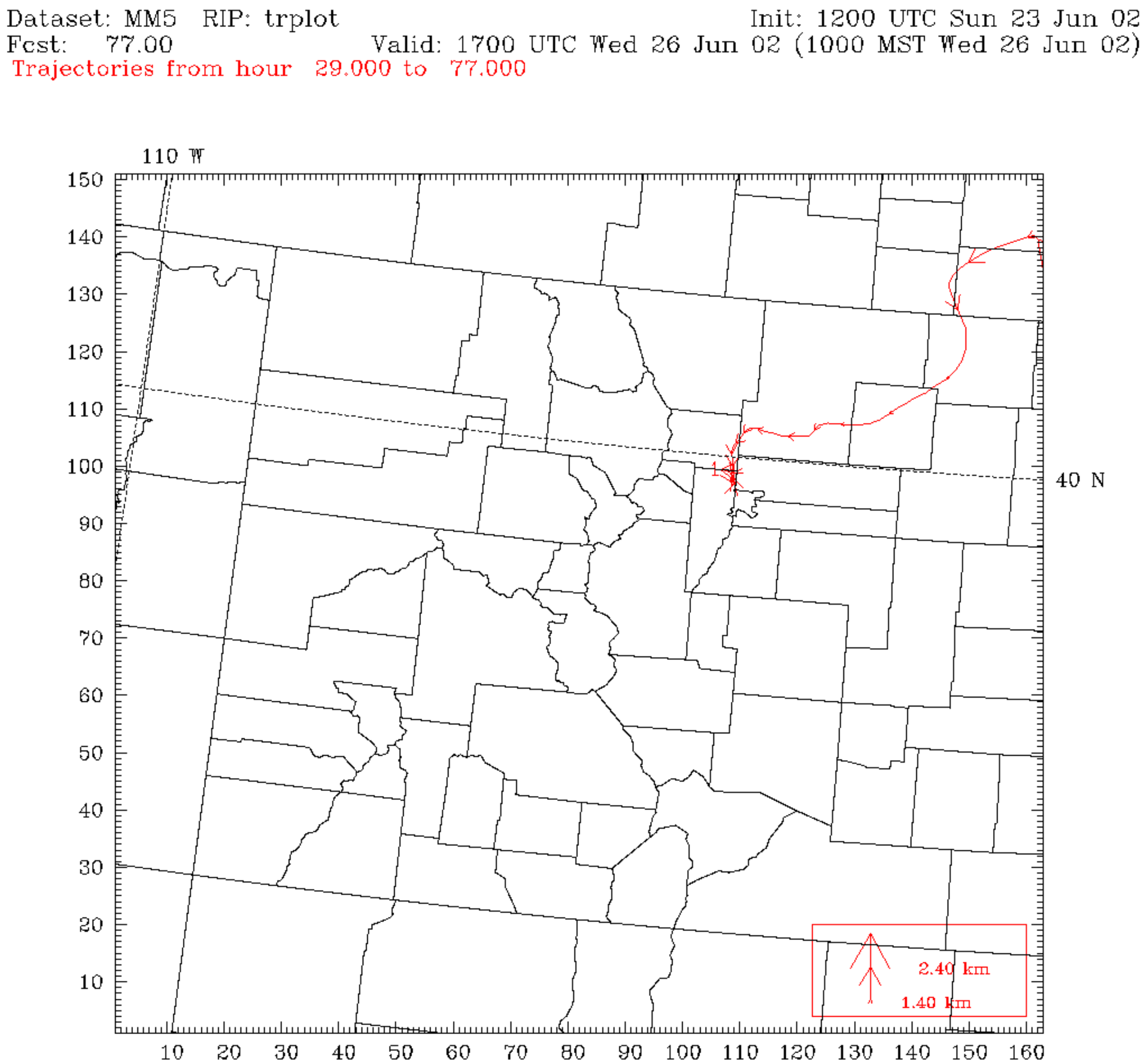
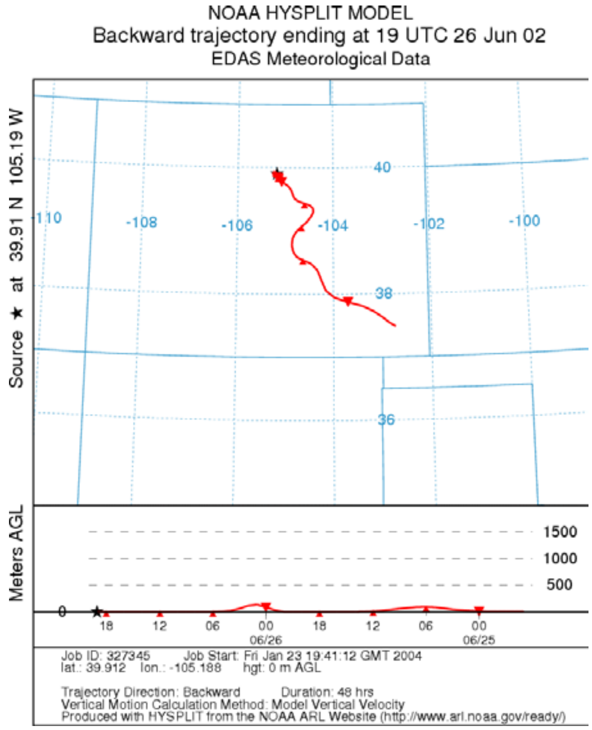
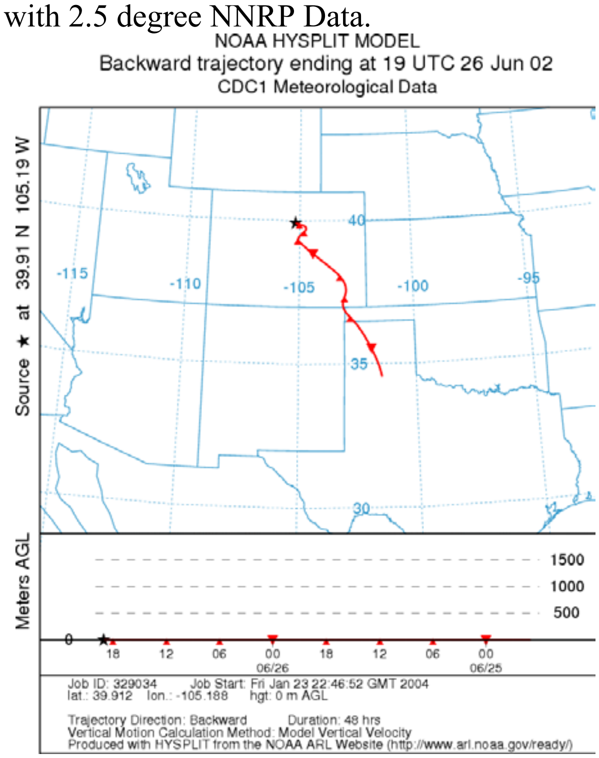


**Figure 5**. 48-Hour Back Trajectory from the Rocky Flats Monitor at 1200 MST 26 June 2002. The Peak 8-hour Monitored Ozone Concentration was Not Reported.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

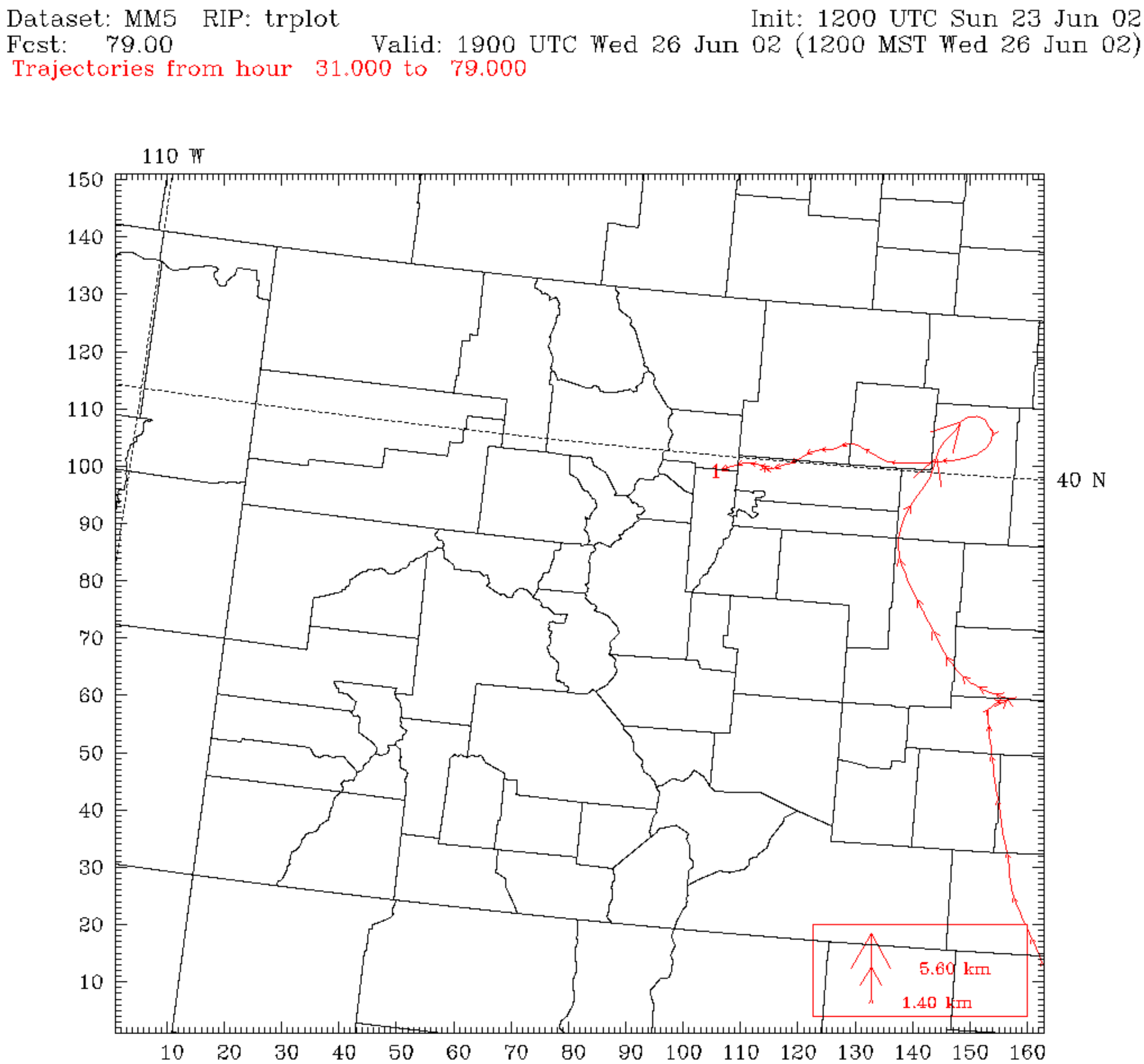
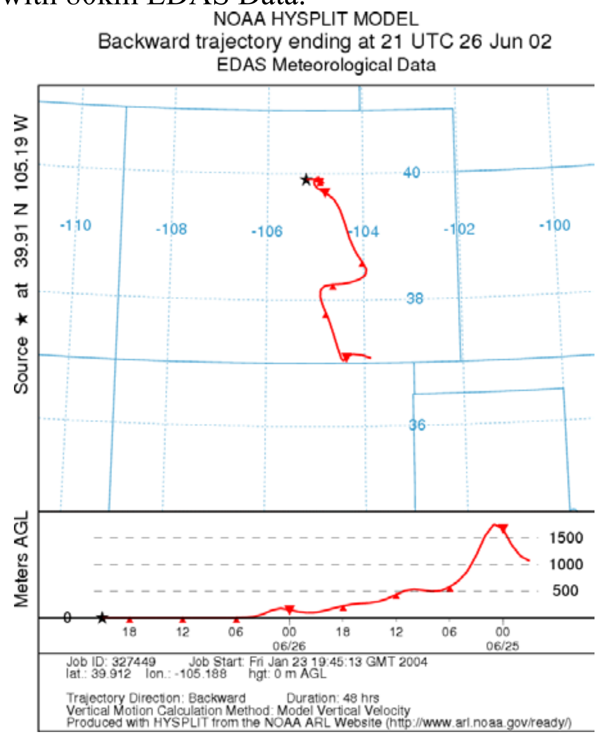
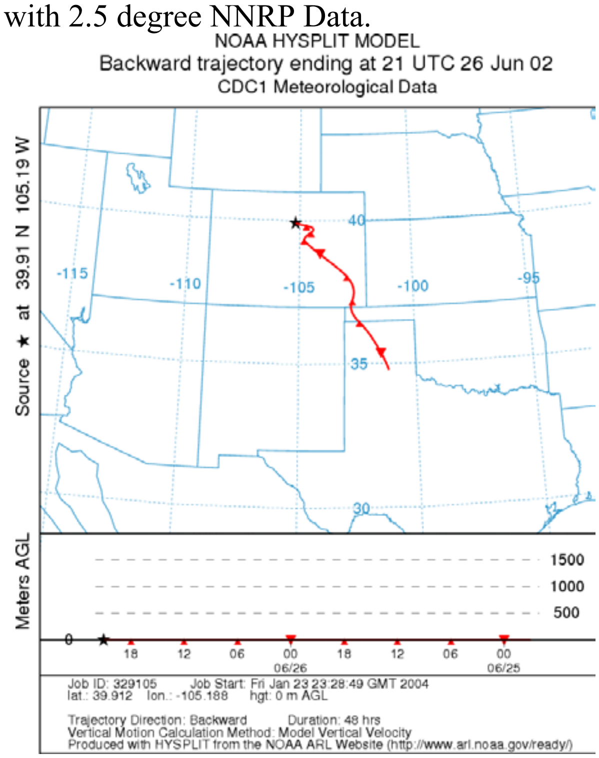


**Figure 6.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1400 MST 26 June 2002. The Peak 8-hour Monitored Ozone Concentration was Not Reported.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

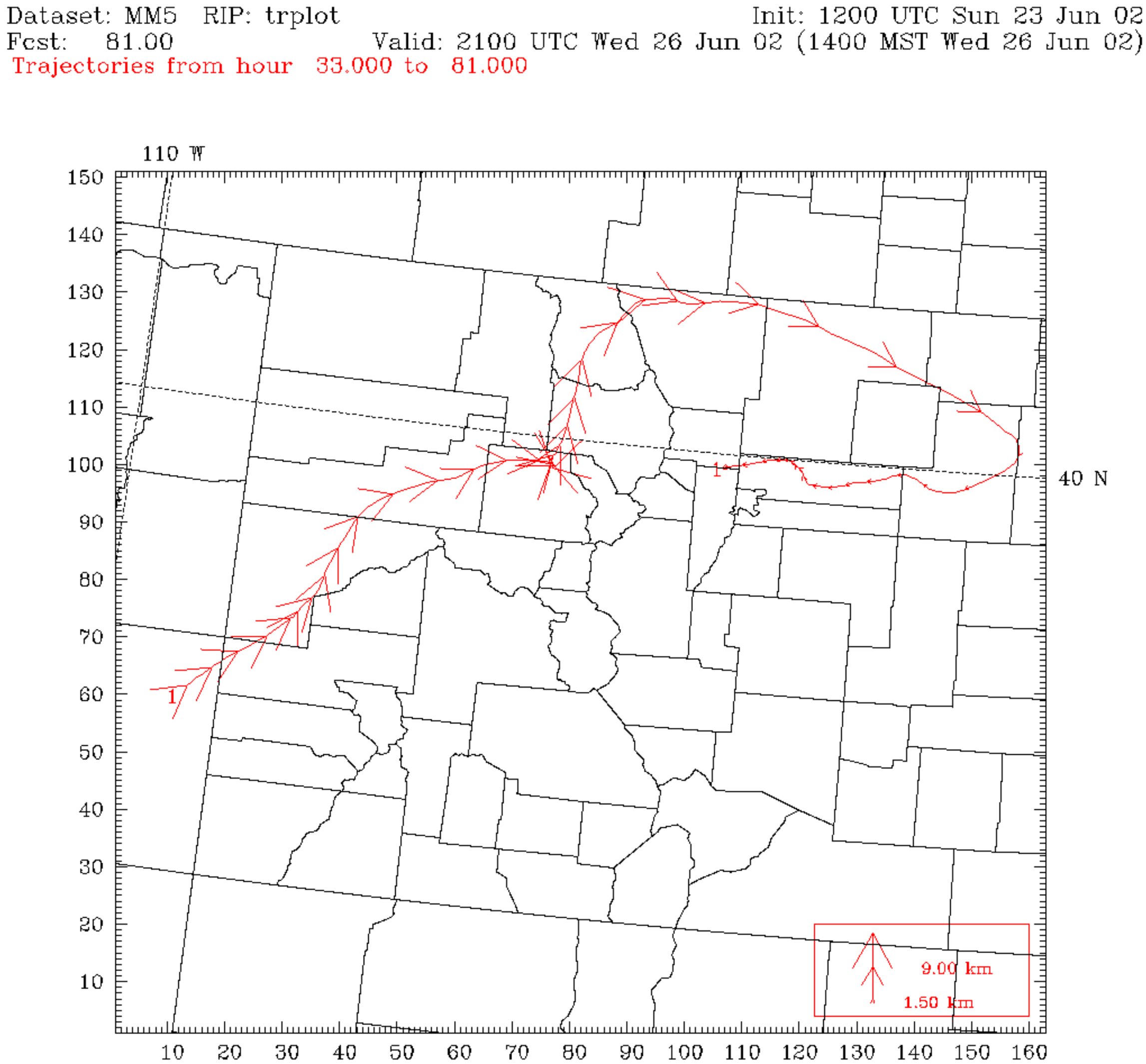
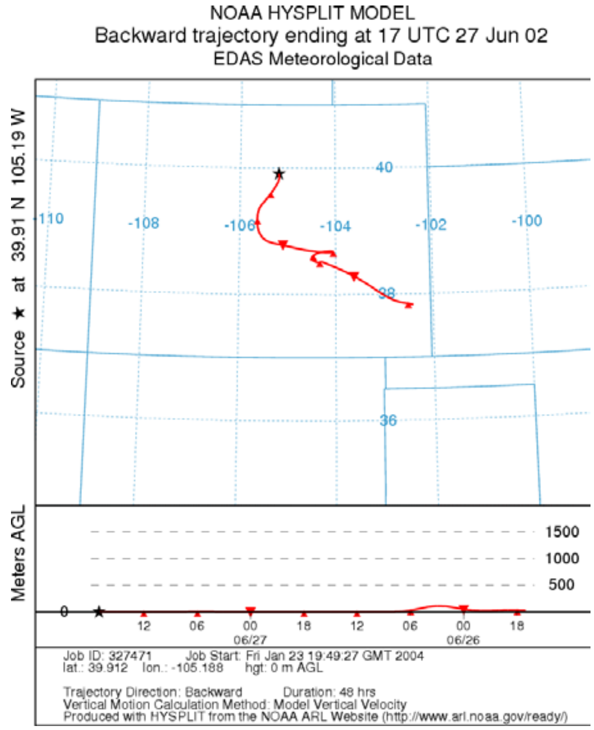
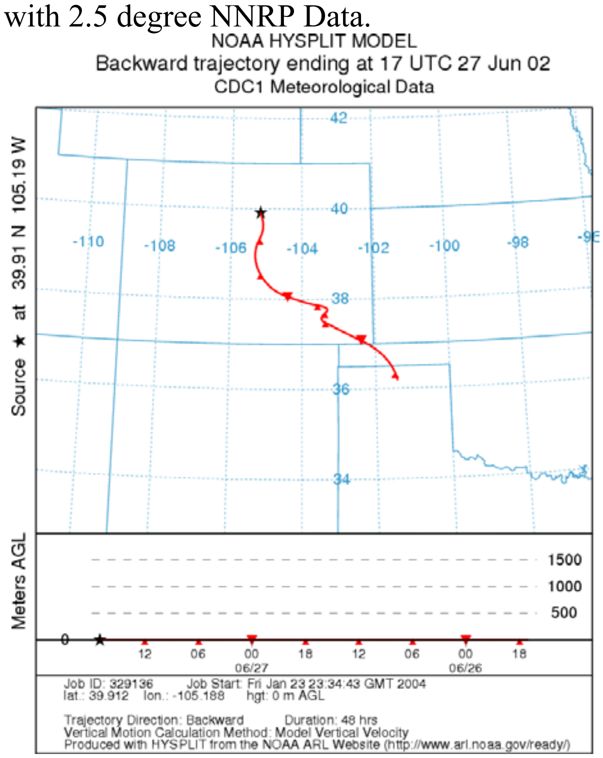


**Figure 7.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1000 MST 27 June 2002. The Peak 8-hour Monitored Ozone Concentration was 52 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

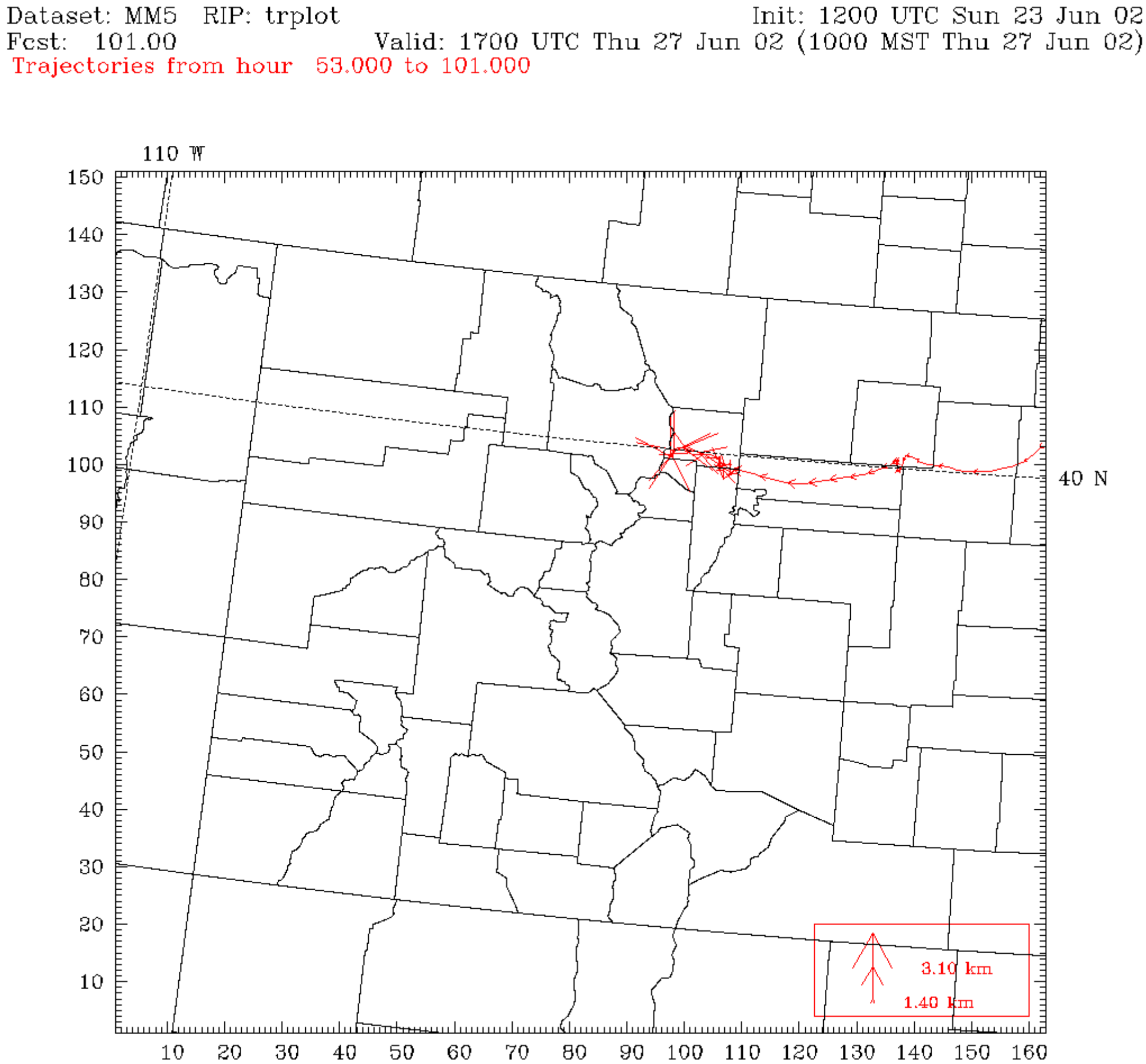
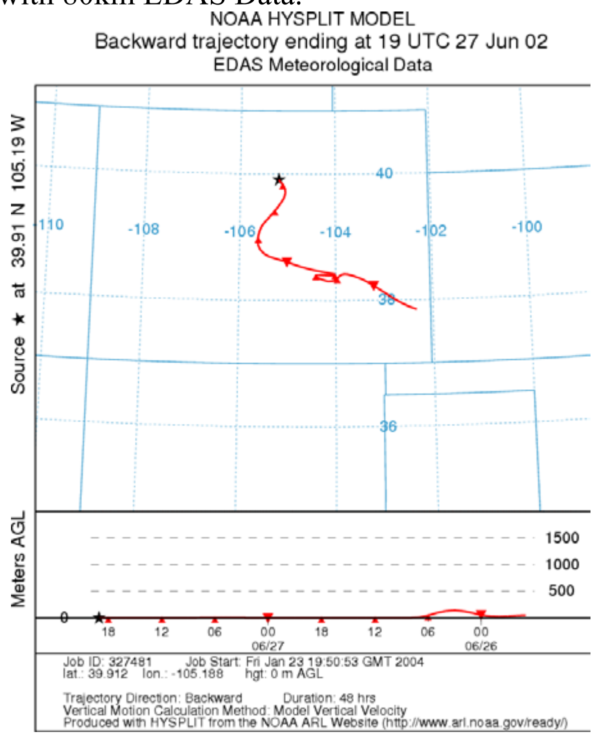
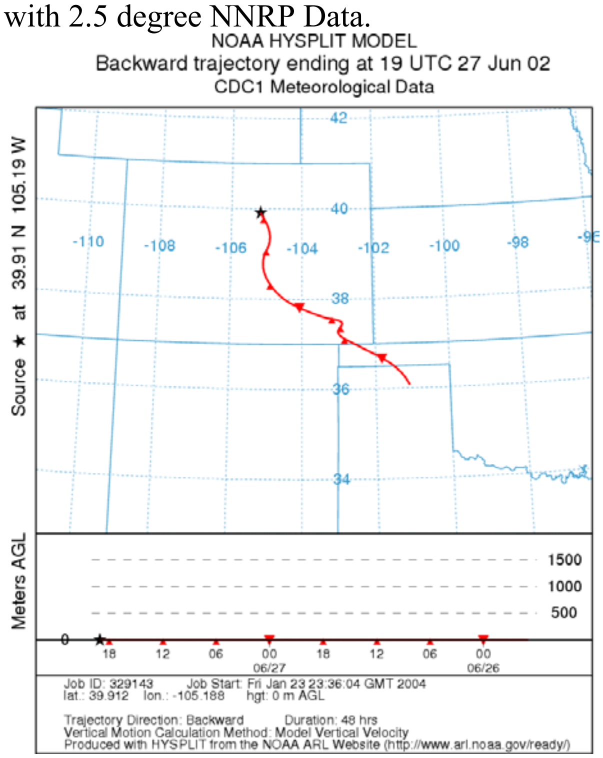


**Figure 8.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1200 MST 27 June 2002. The Peak 8-hour Monitored Ozone Concentration was 52 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

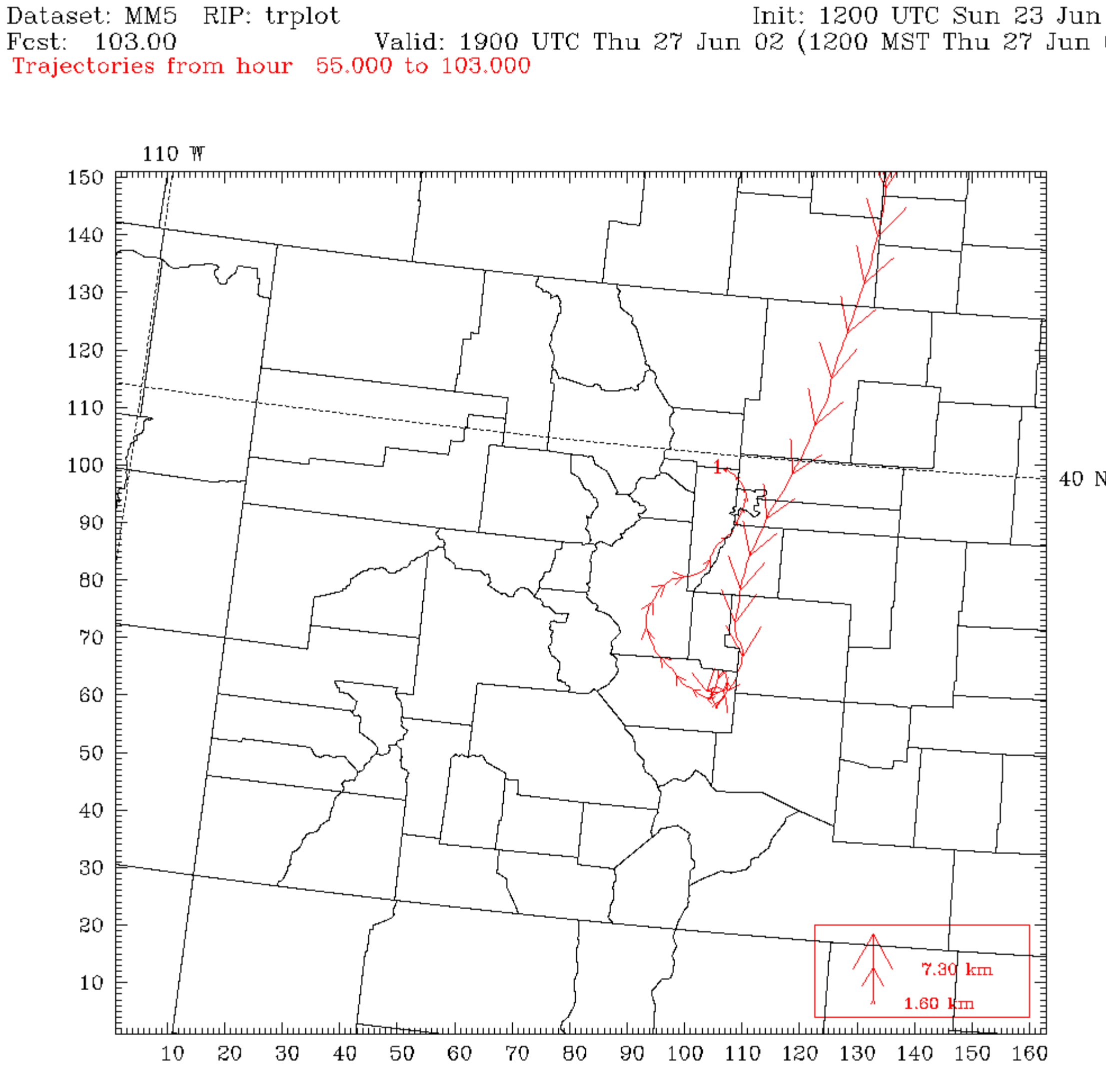
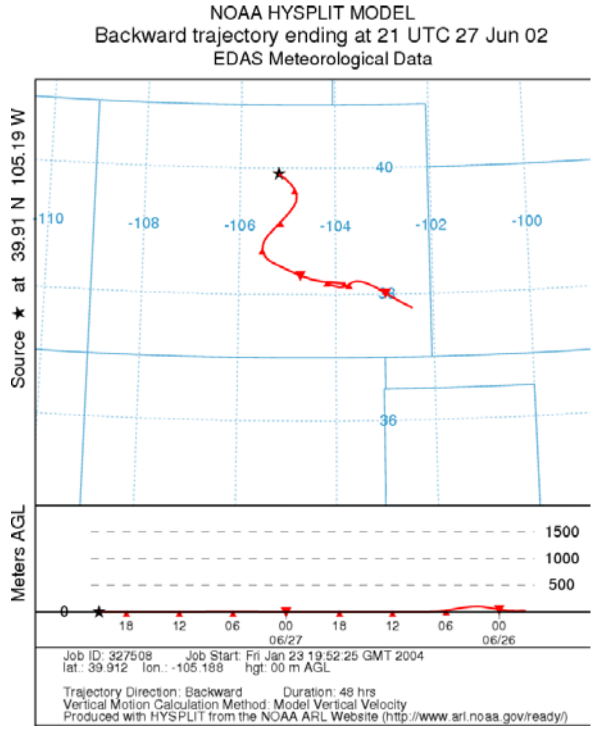
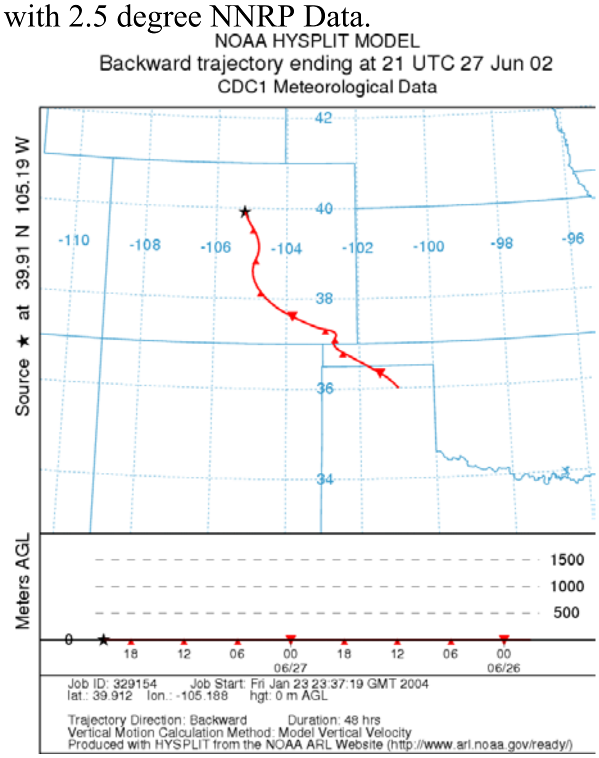


**Figure 9.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1400 MST 27 June 2002. The Peak 8-hour Monitored Ozone Concentration was 52 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

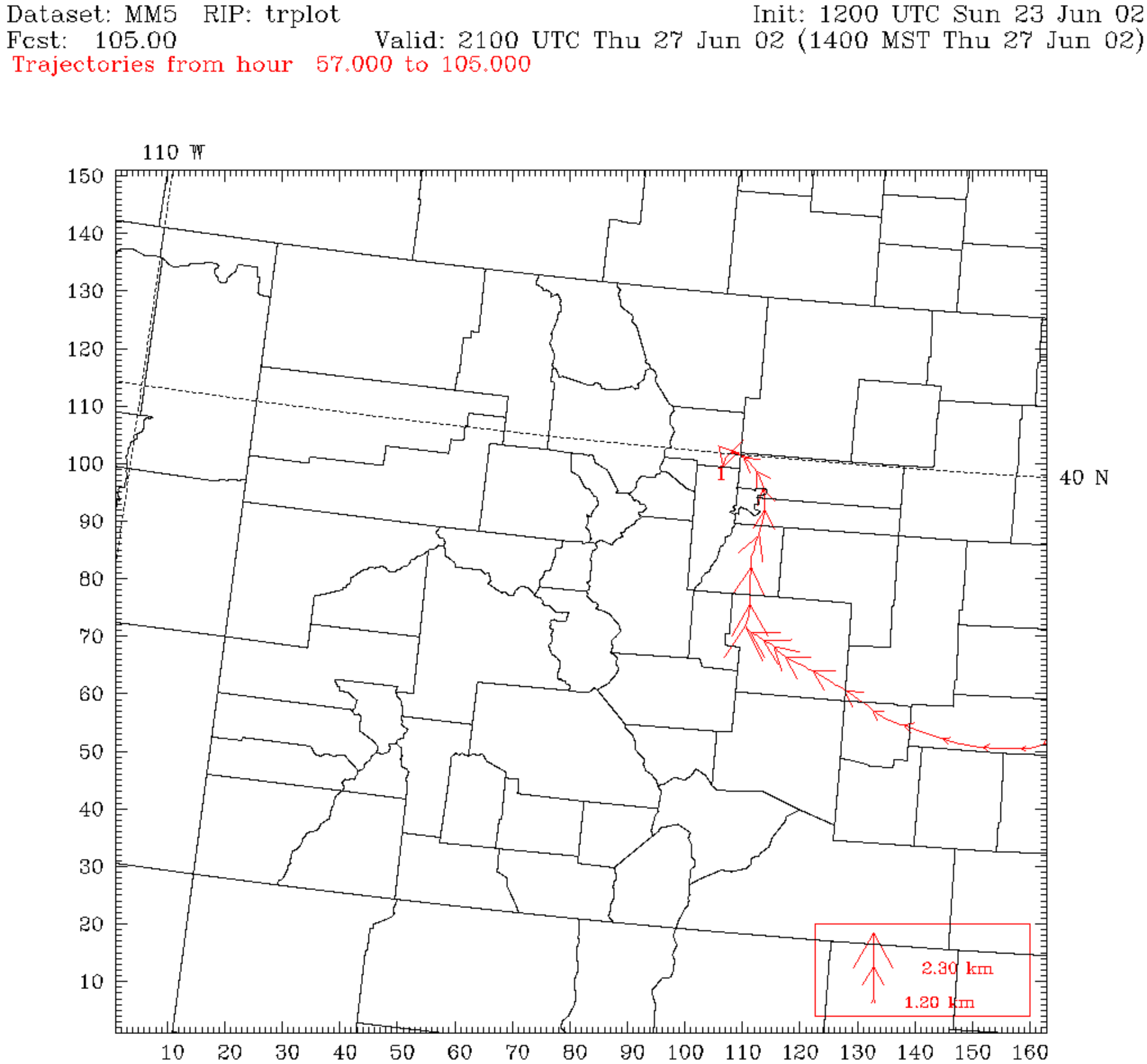
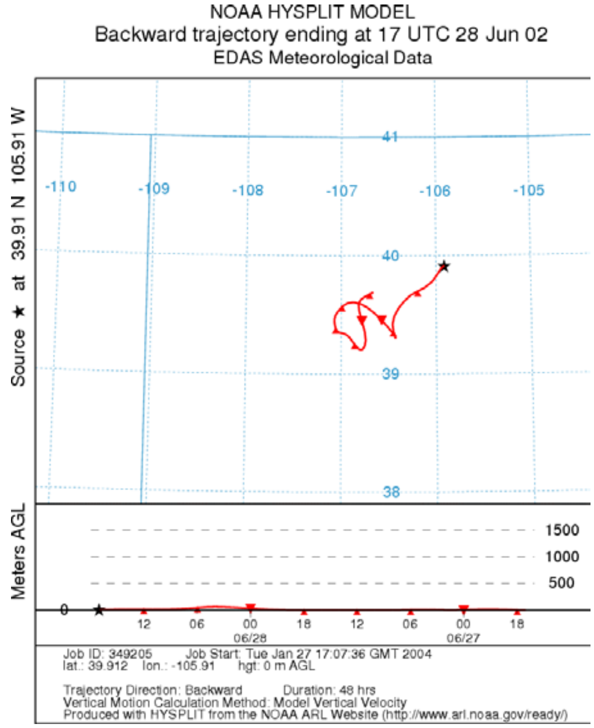
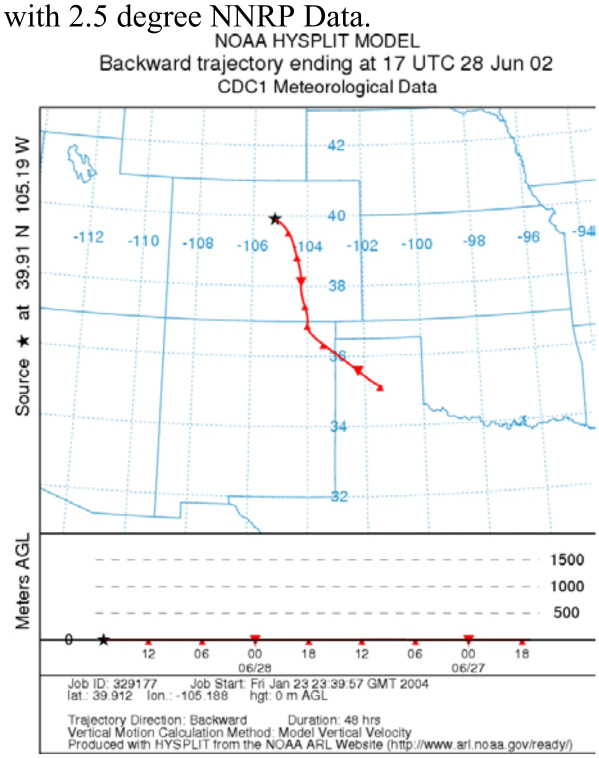


**Figure 10.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1000 MST 28 June 2002. The Peak 8-hour Monitored Ozone Concentration was 74 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

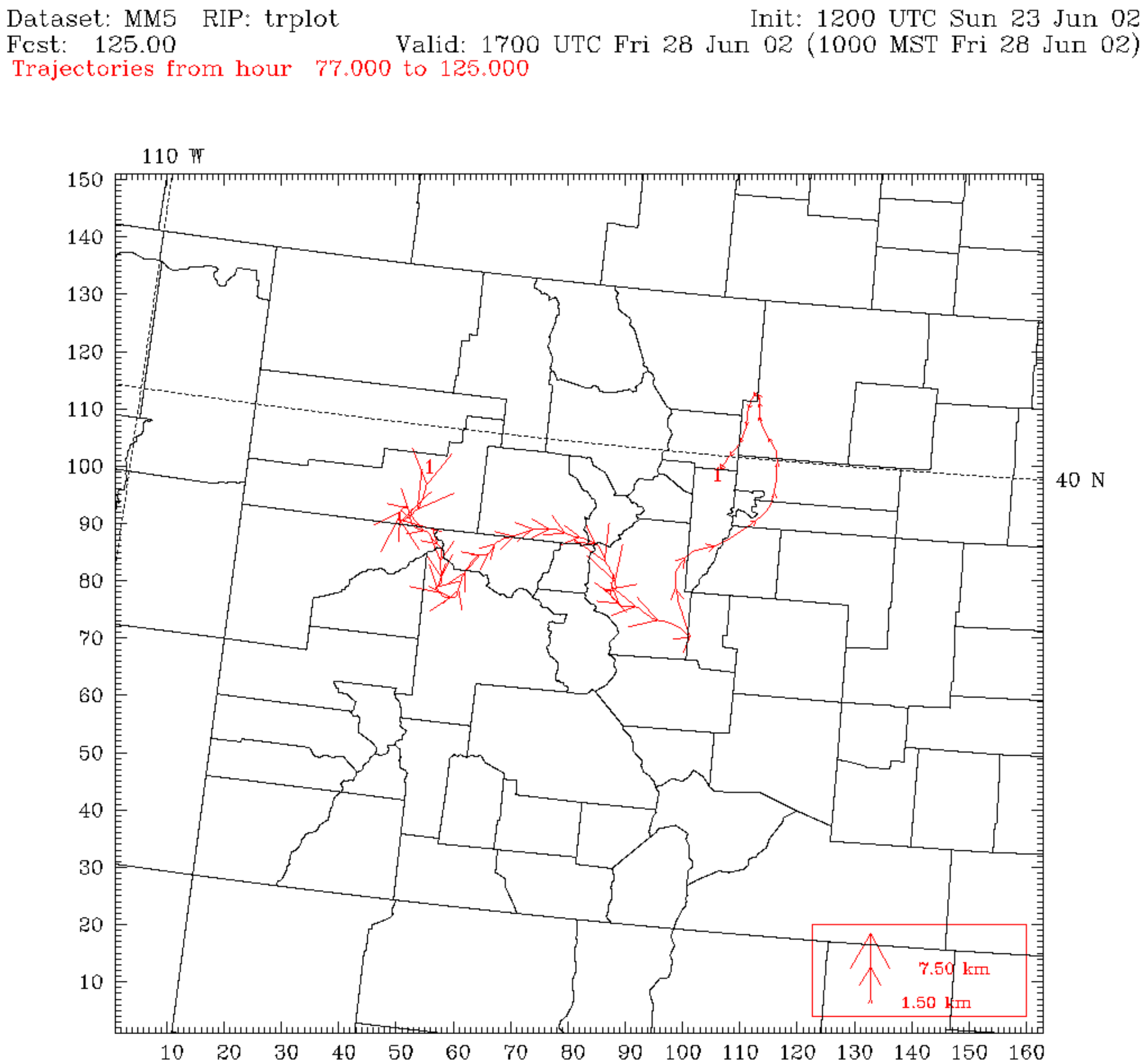
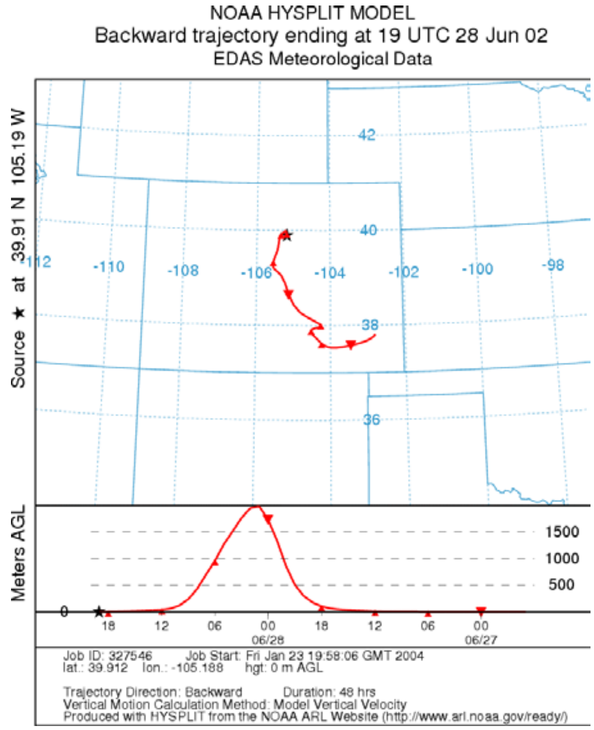
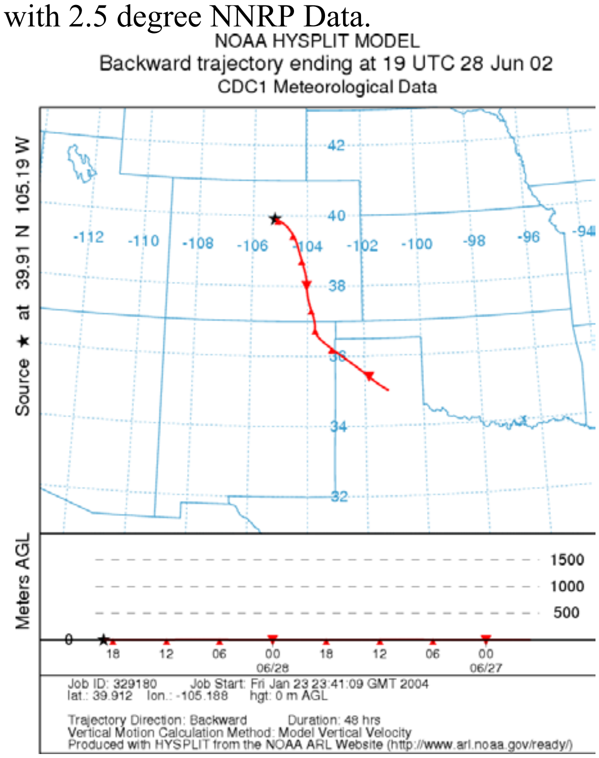


**Figure 11.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1200 MST 28 June 2002. The Peak 8-hour Monitored Ozone Concentration was 74 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

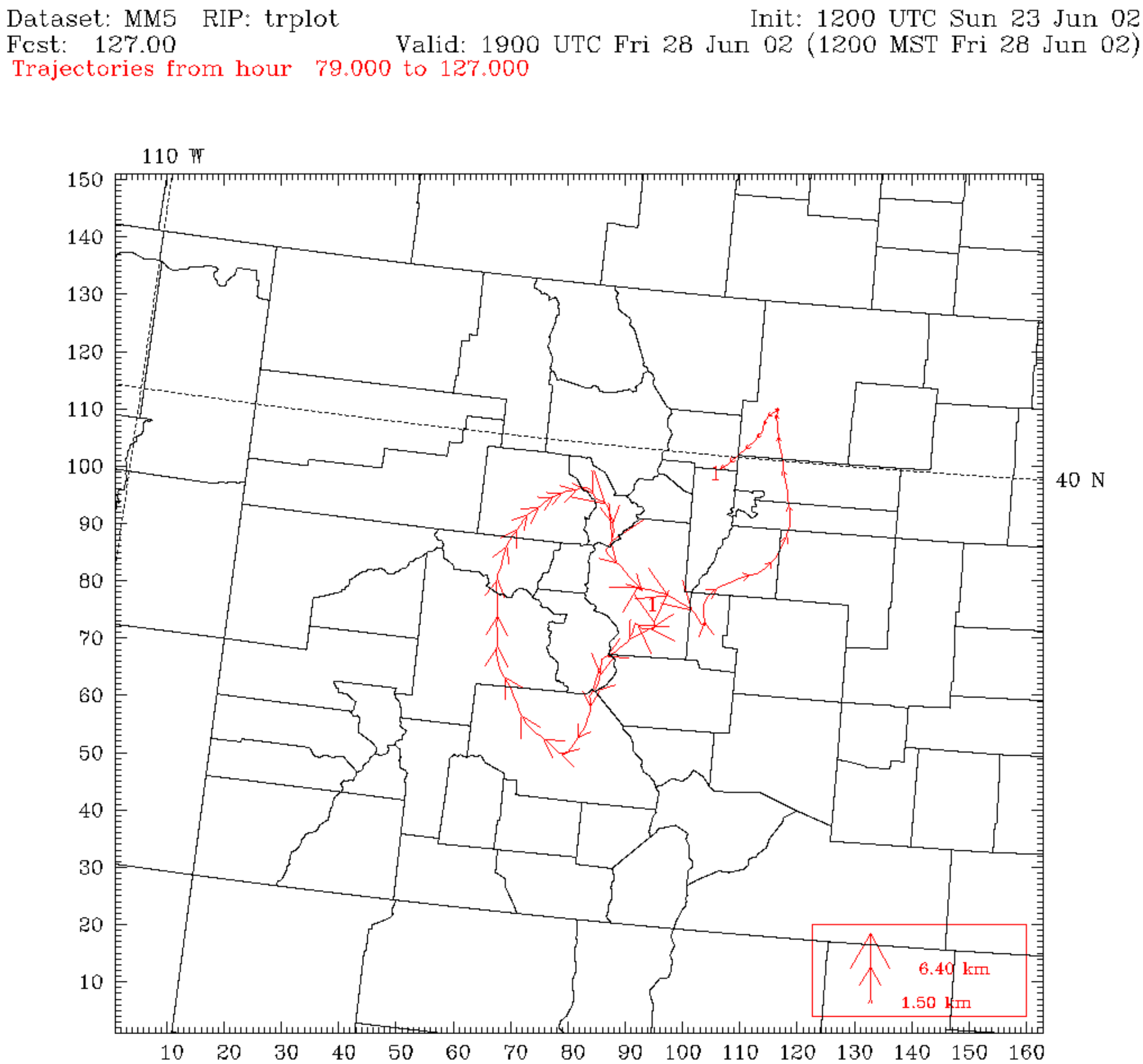
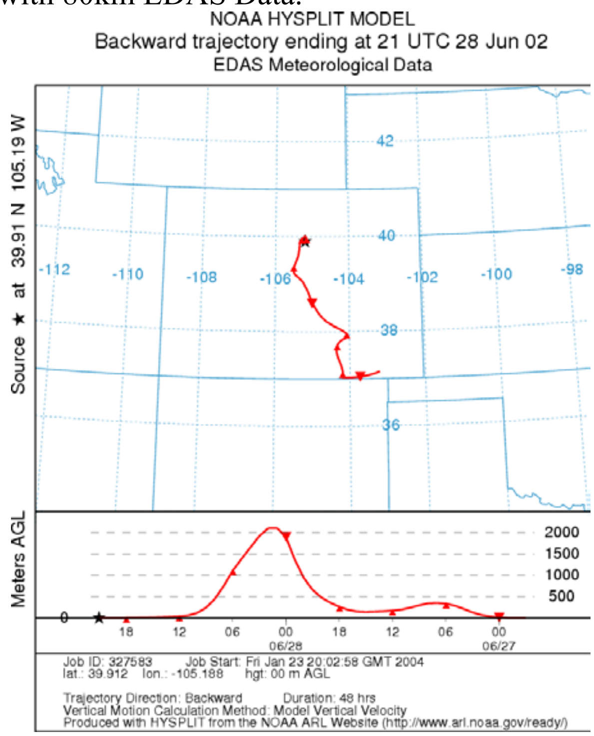
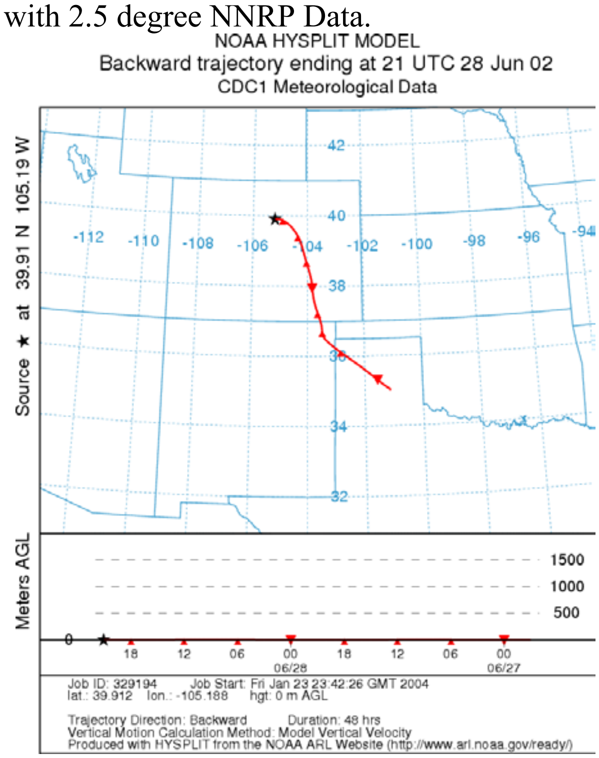


**Figure 12.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1400 MST 28 June 2002. The Peak 8-hour Monitored Ozone Concentration was 74 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

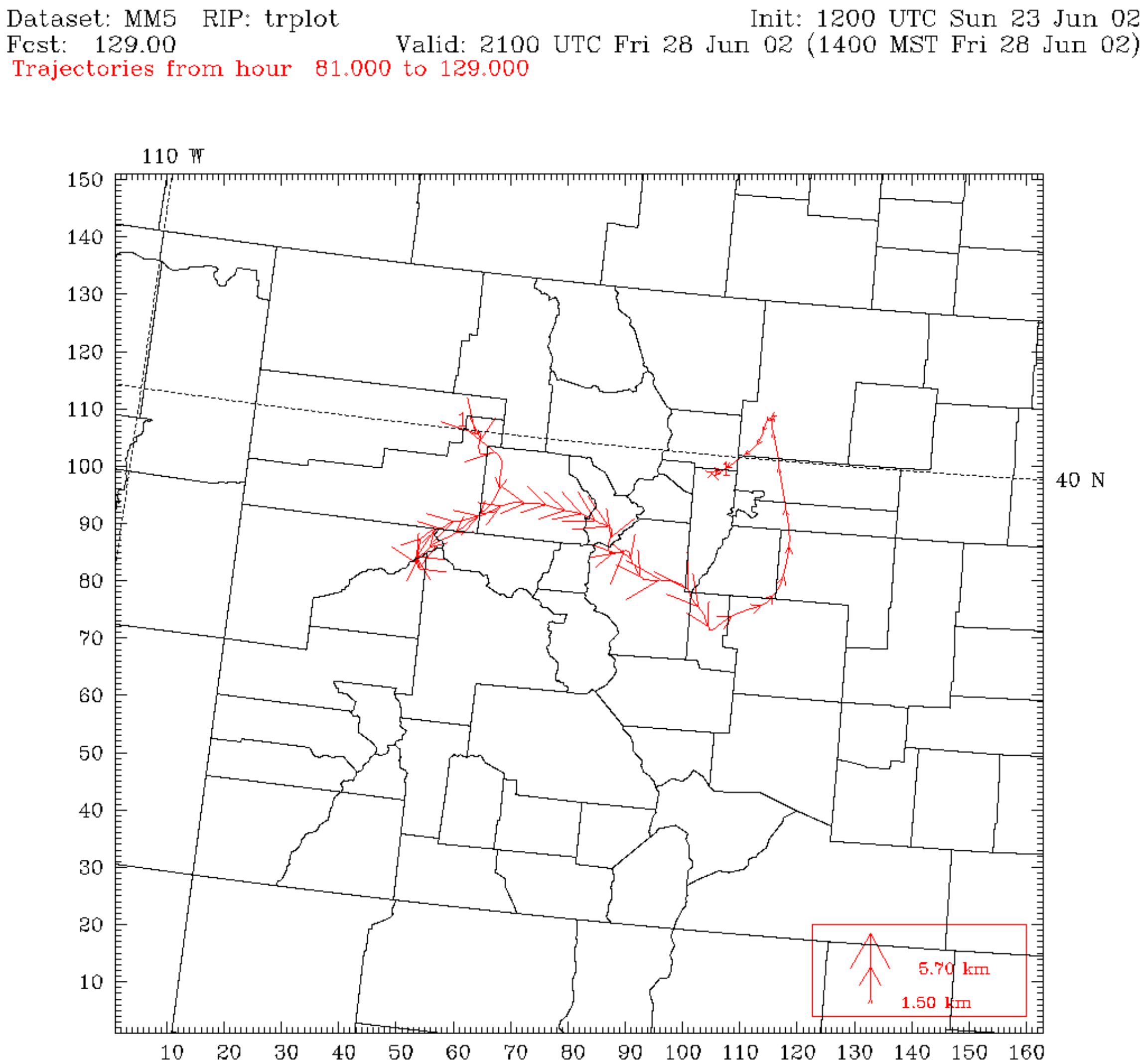
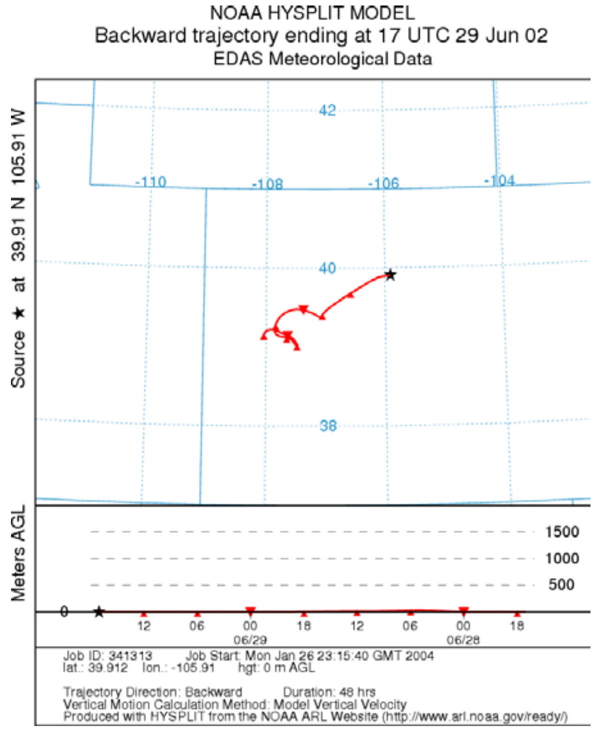
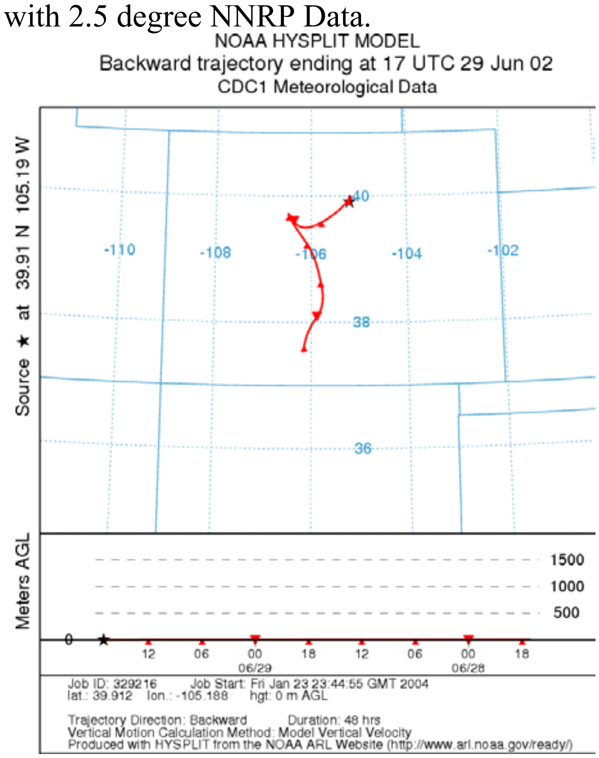


**Figure 13.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1000 MST 29 June 2002. The Peak 8-hour Monitored Ozone Concentration was 90 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

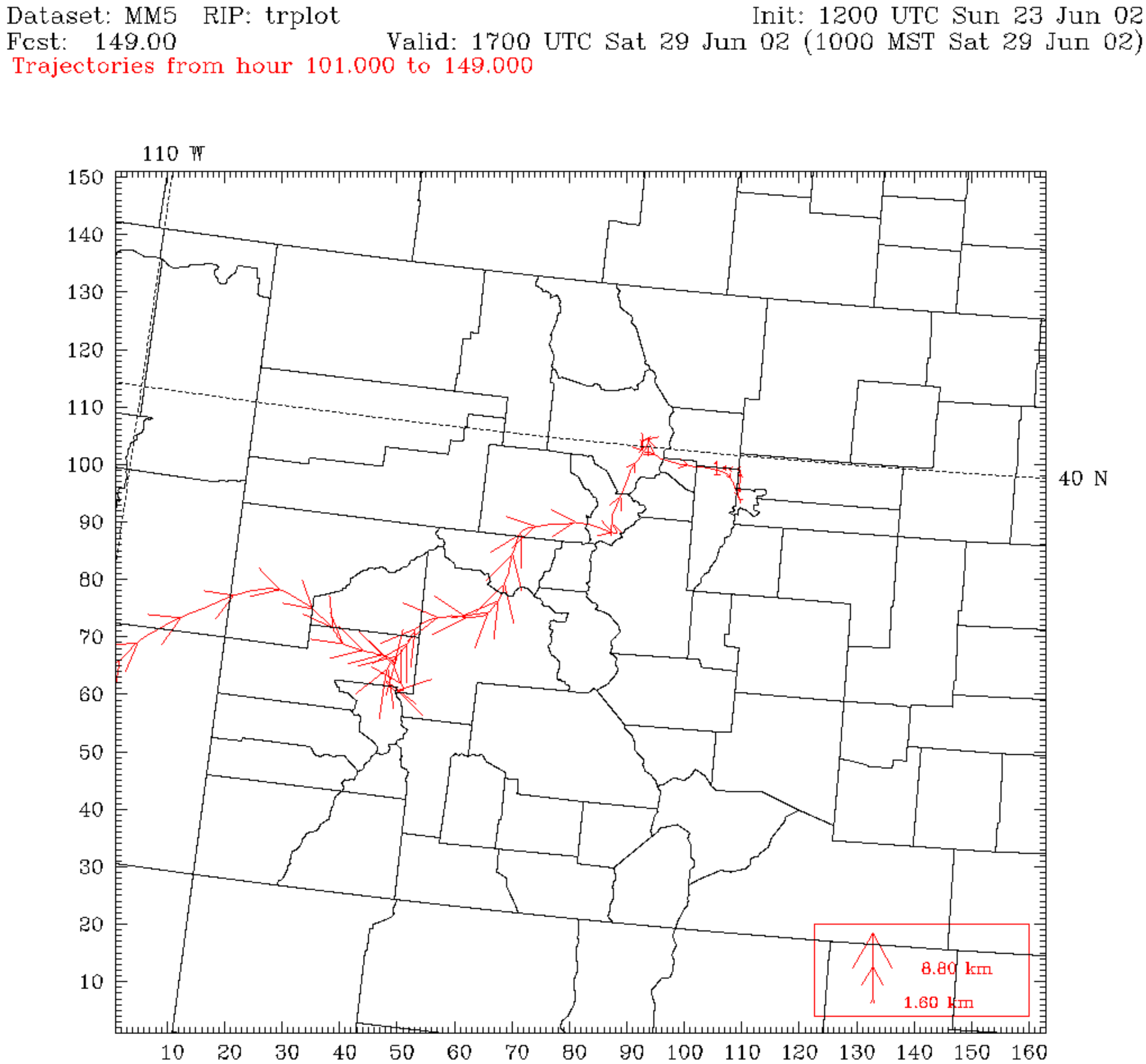
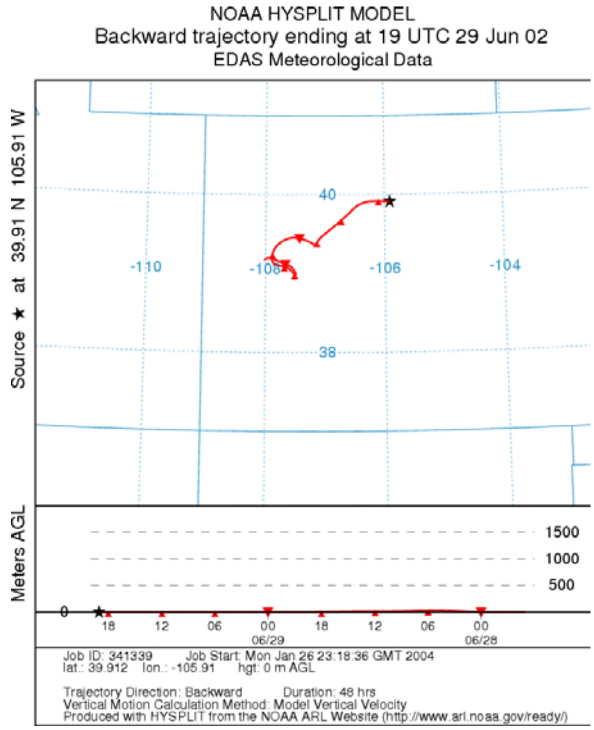
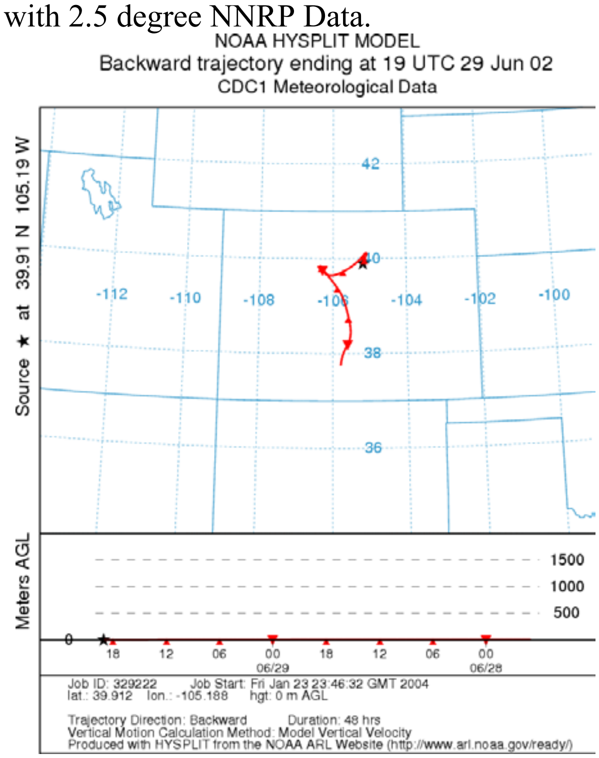


**Figure 14.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1200 MST 29 June 2002. The Peak 8-hour Monitored Ozone Concentration was 90 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

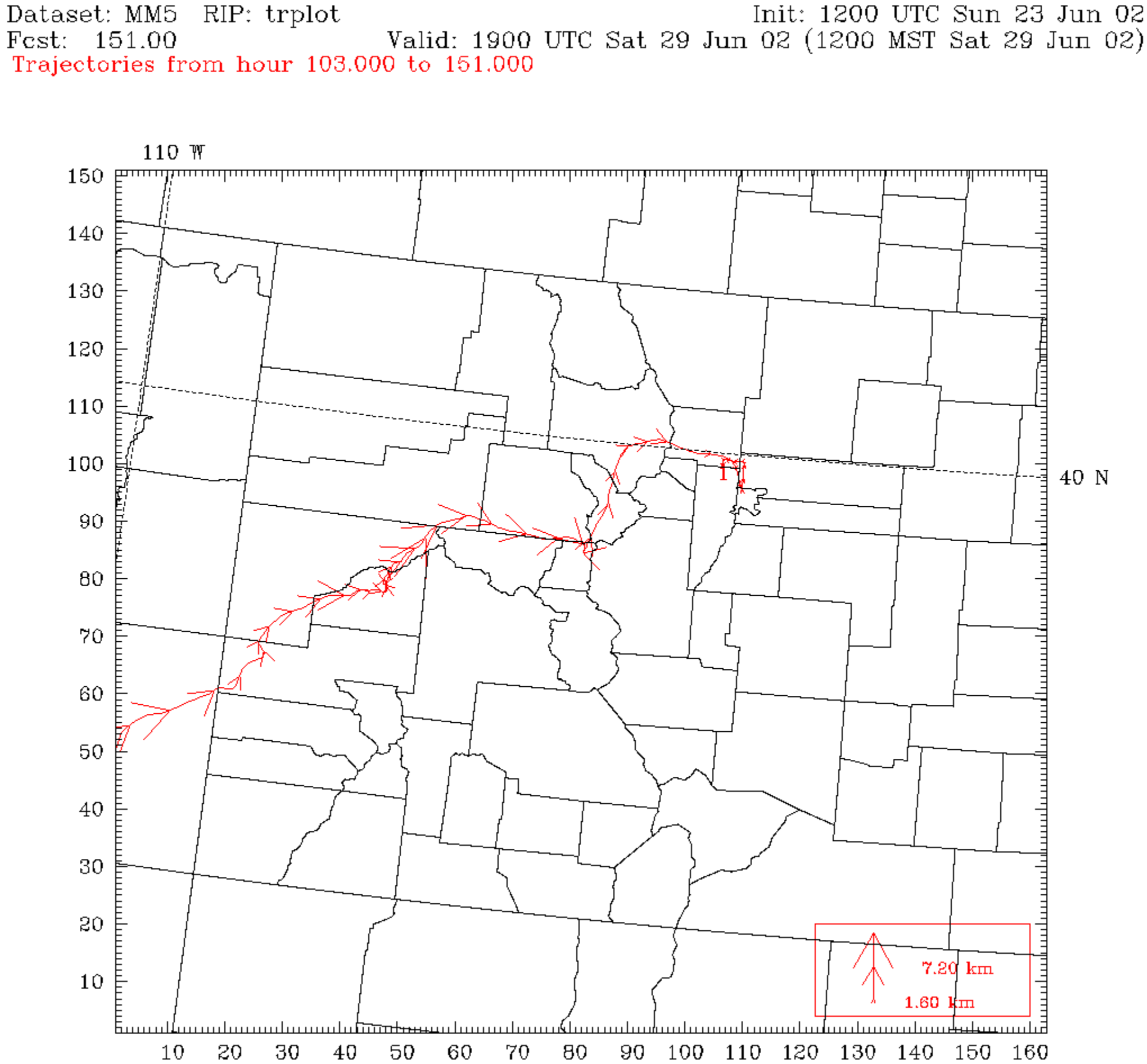
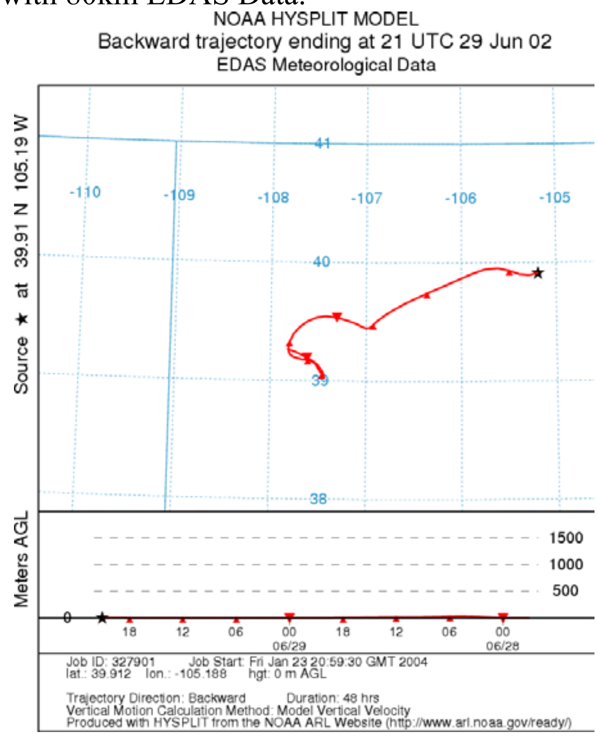
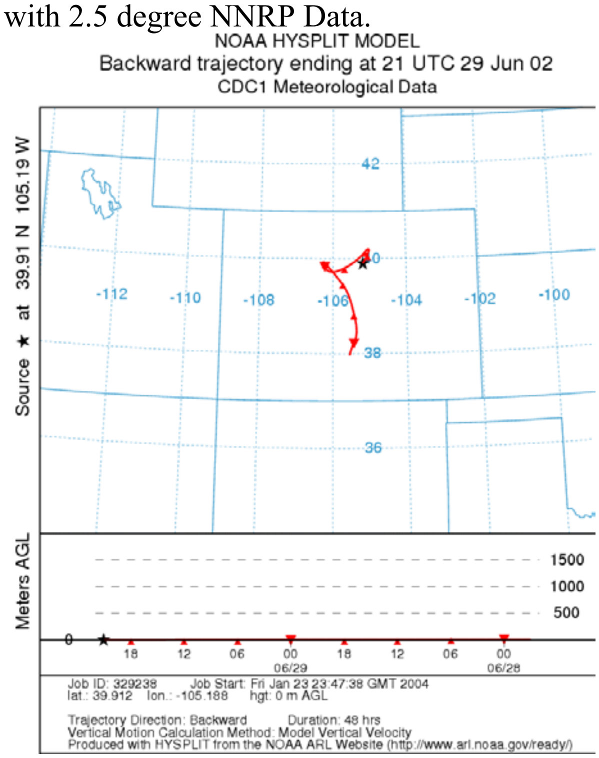


**Figure 15.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1400 MST 29 June 2002. The Peak 8-hour Monitored Ozone Concentration was 90 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

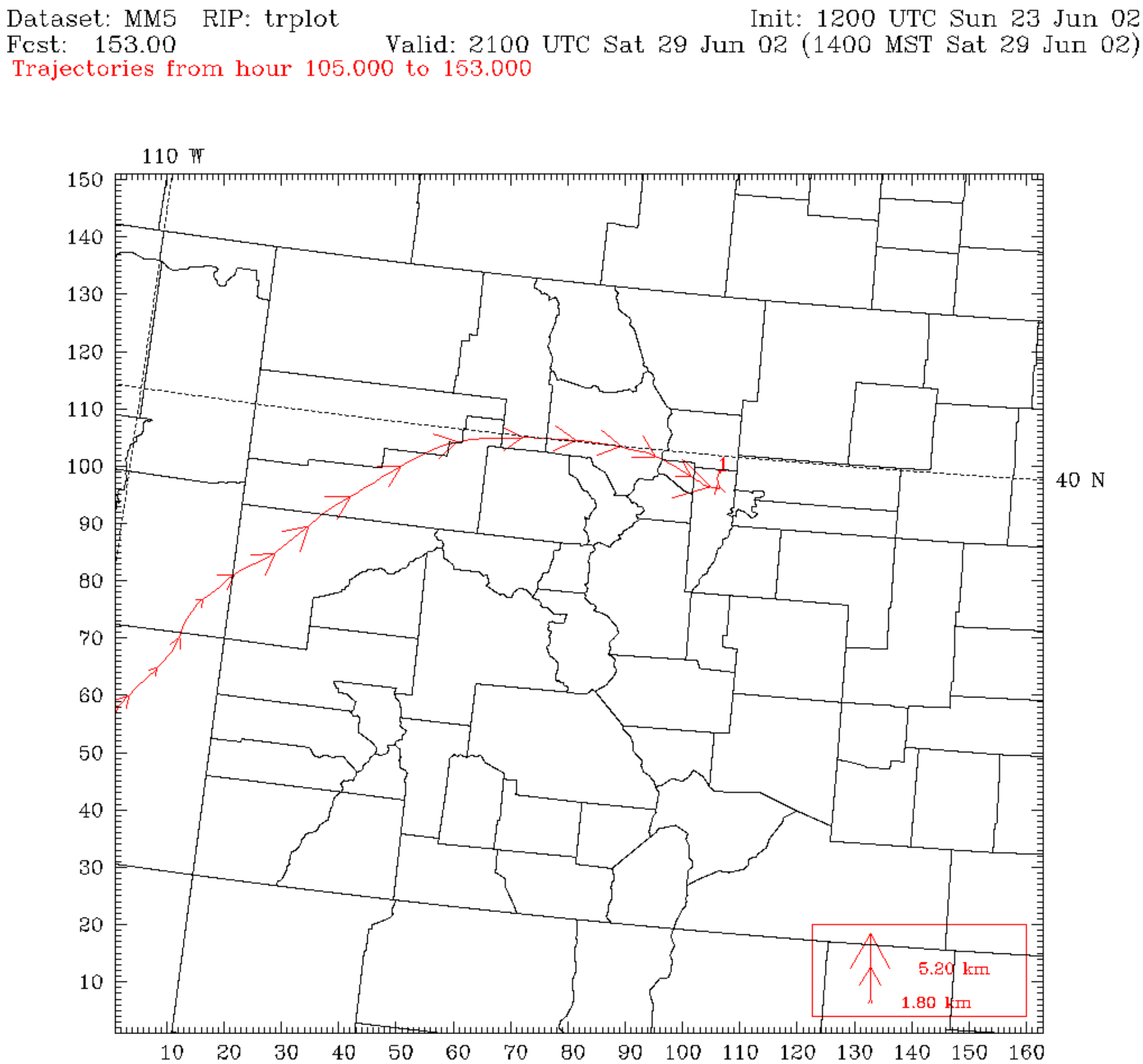
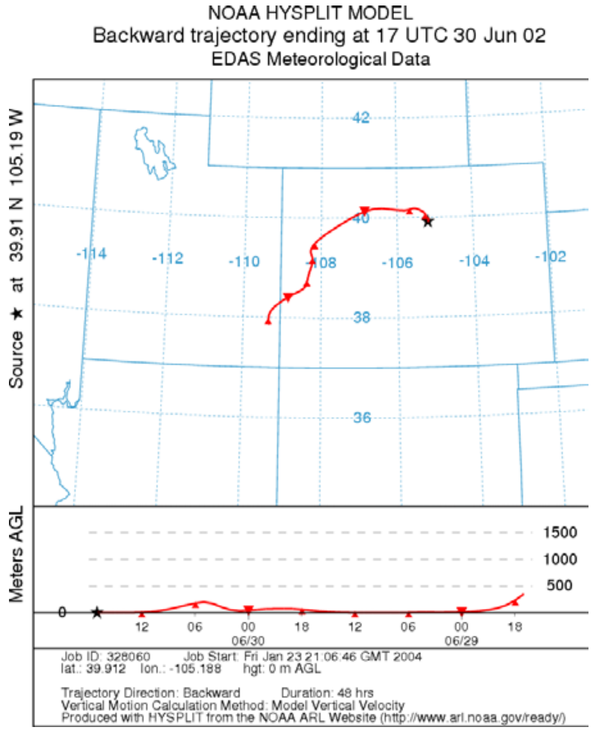
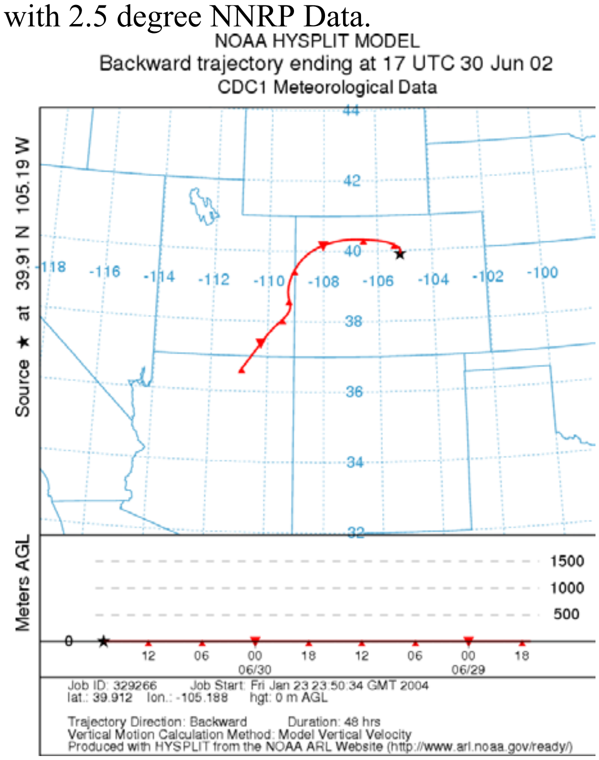


**Figure 16.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1000 MST 30 June 2002. The Peak 8-hour Monitored Ozone Concentration was 89 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

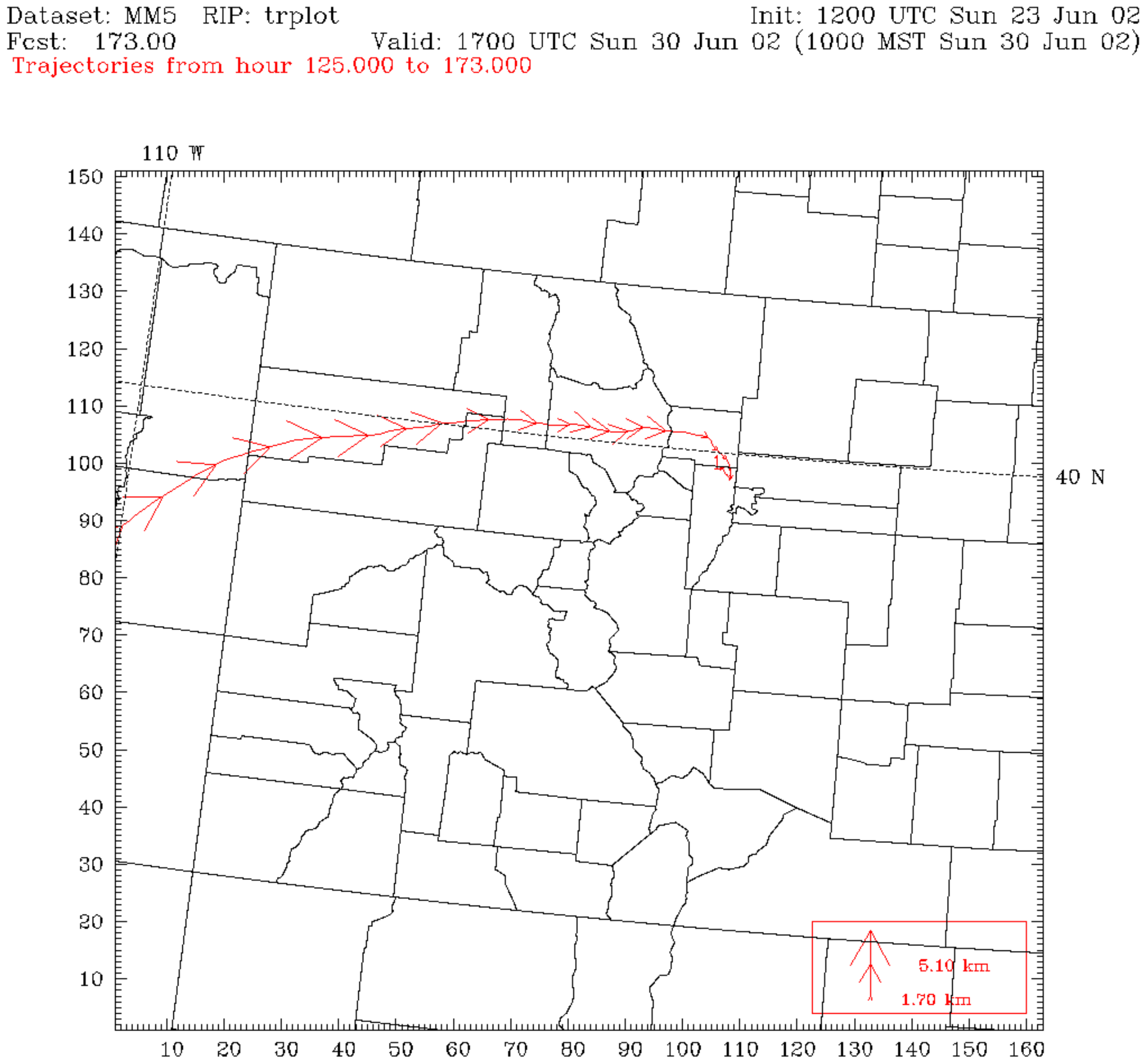
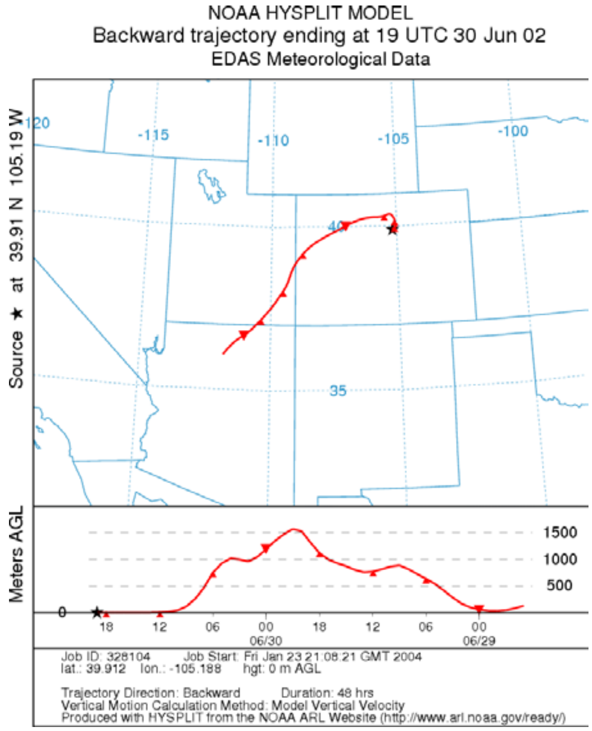
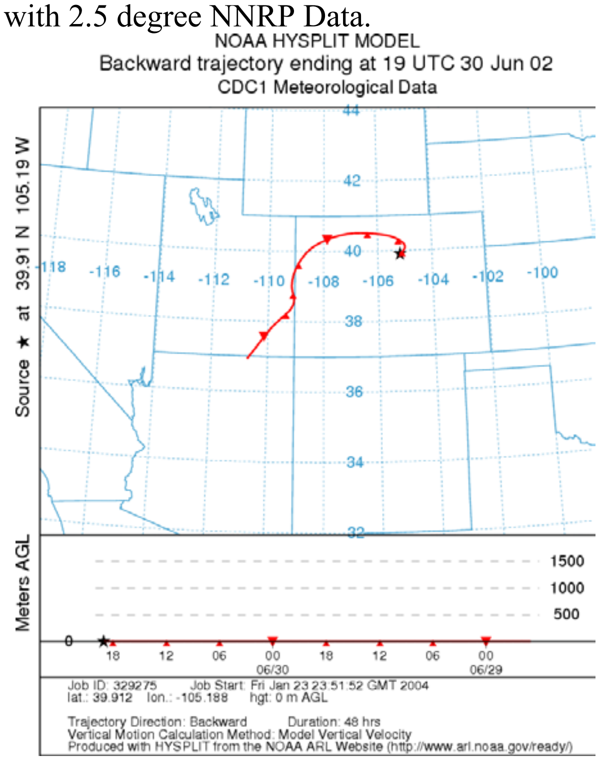


**Figure 17.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1200 MST 30 June 2002. The Peak 8-hour Monitored Ozone Concentration was 89 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

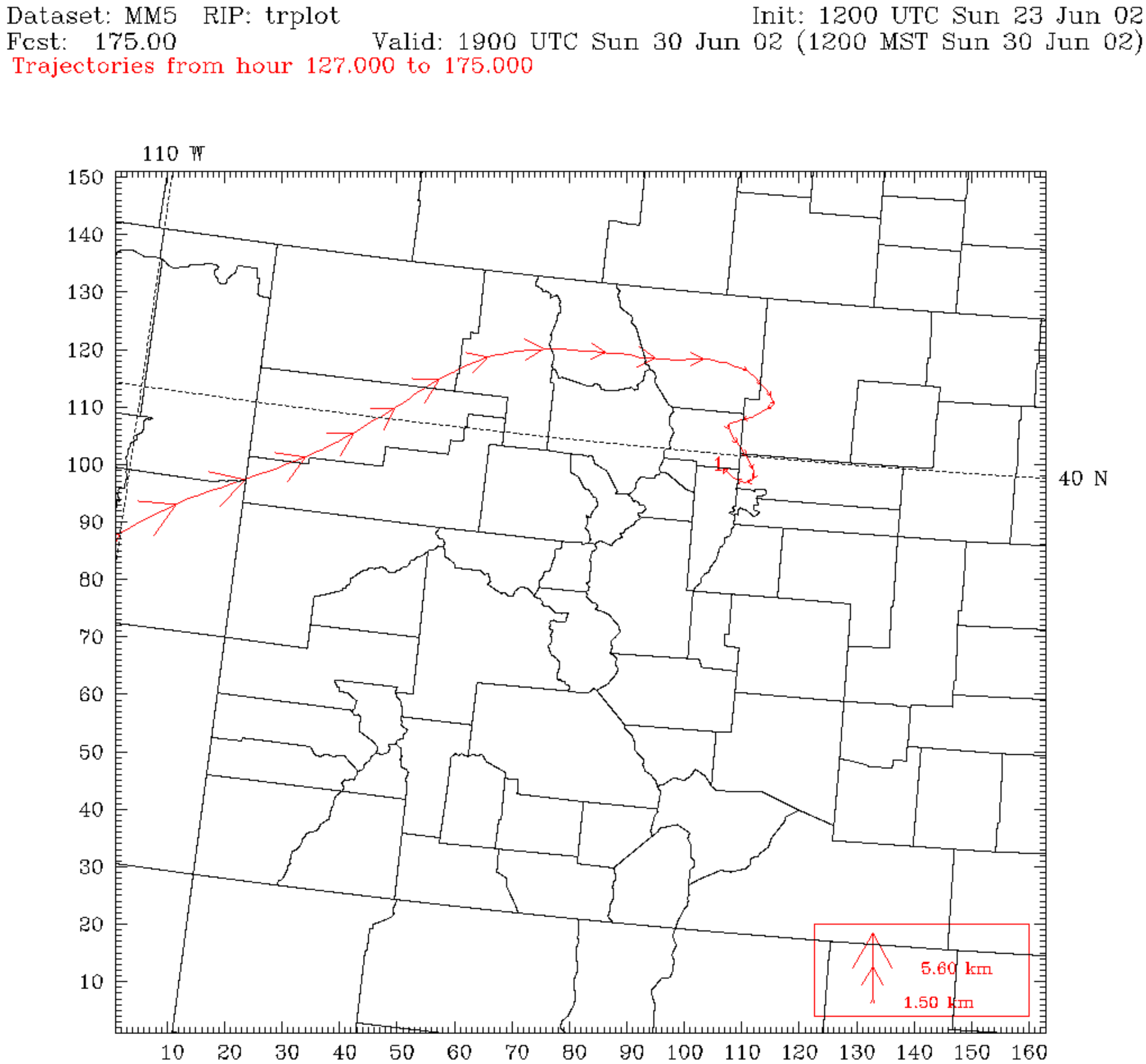
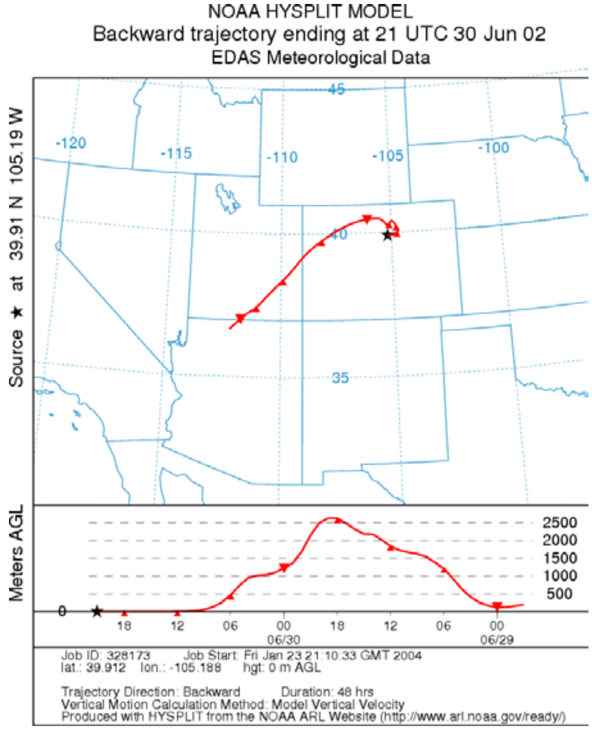
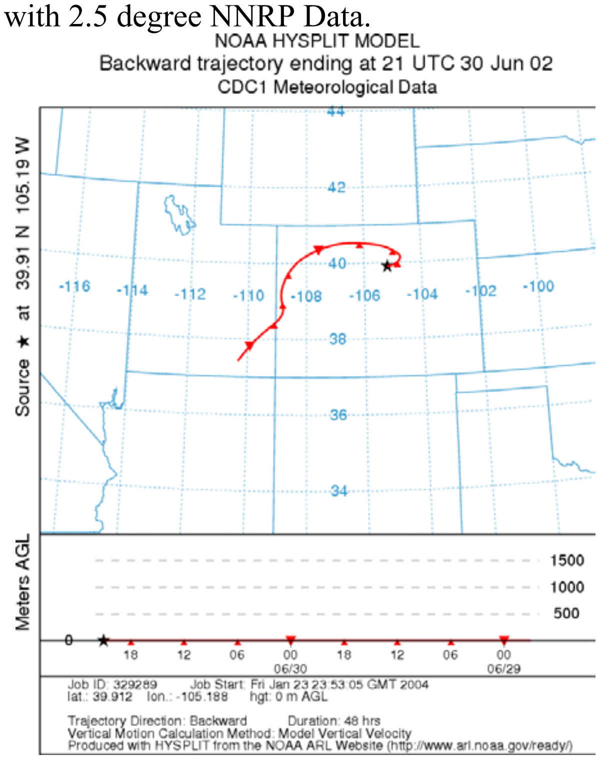


**Figure 18.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1400 MST 30 June 2002. The Peak 8-hour Monitored Ozone Concentration was 89 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

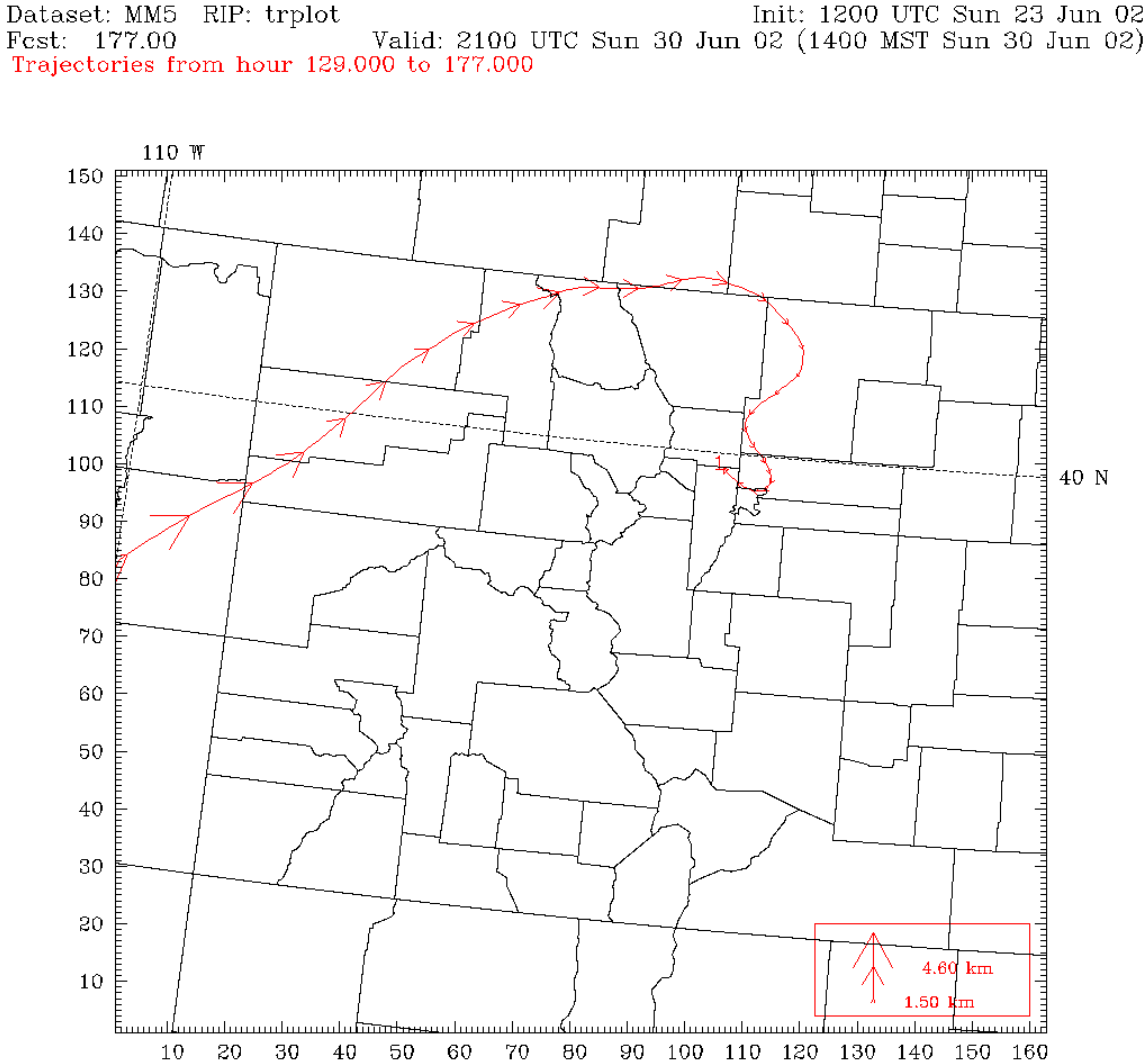
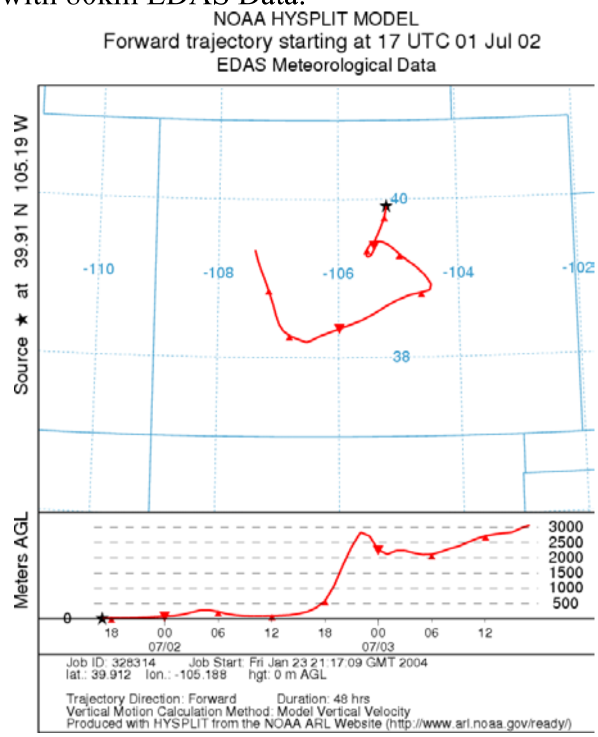
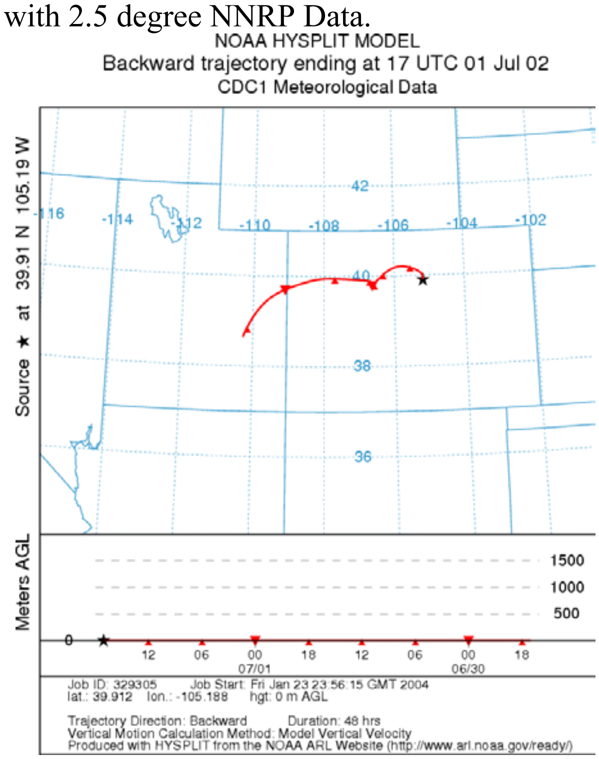


**Figure 19.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1000 MST 1 July 2002. The Peak 8-hour Monitored Ozone Concentration was 89 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

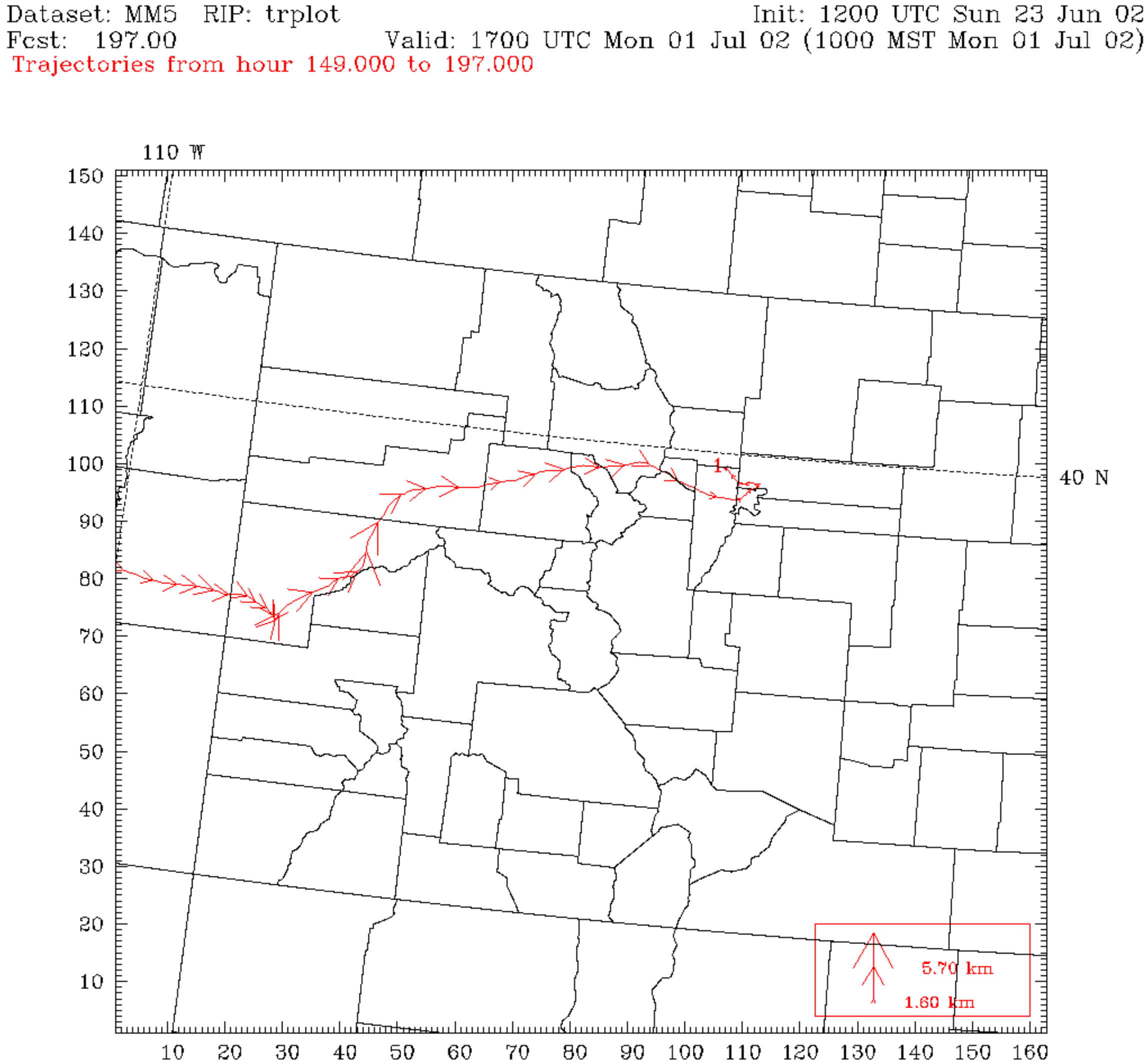
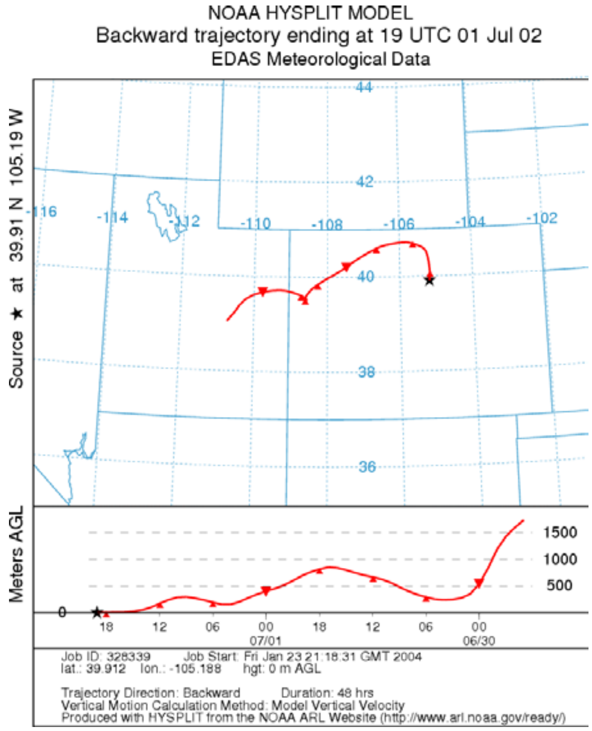
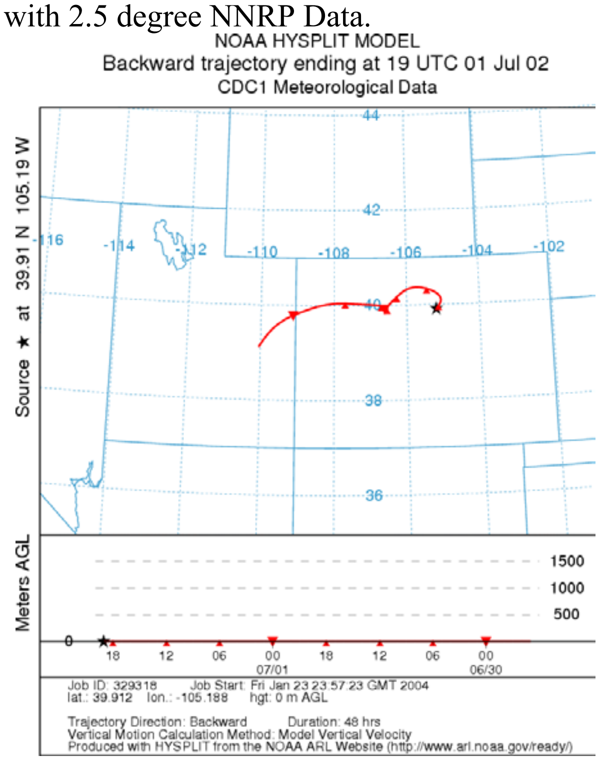


**Figure 20.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1200 MST 1 July 2002. The Peak 8-hour Monitored Ozone Concentration was 89 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.

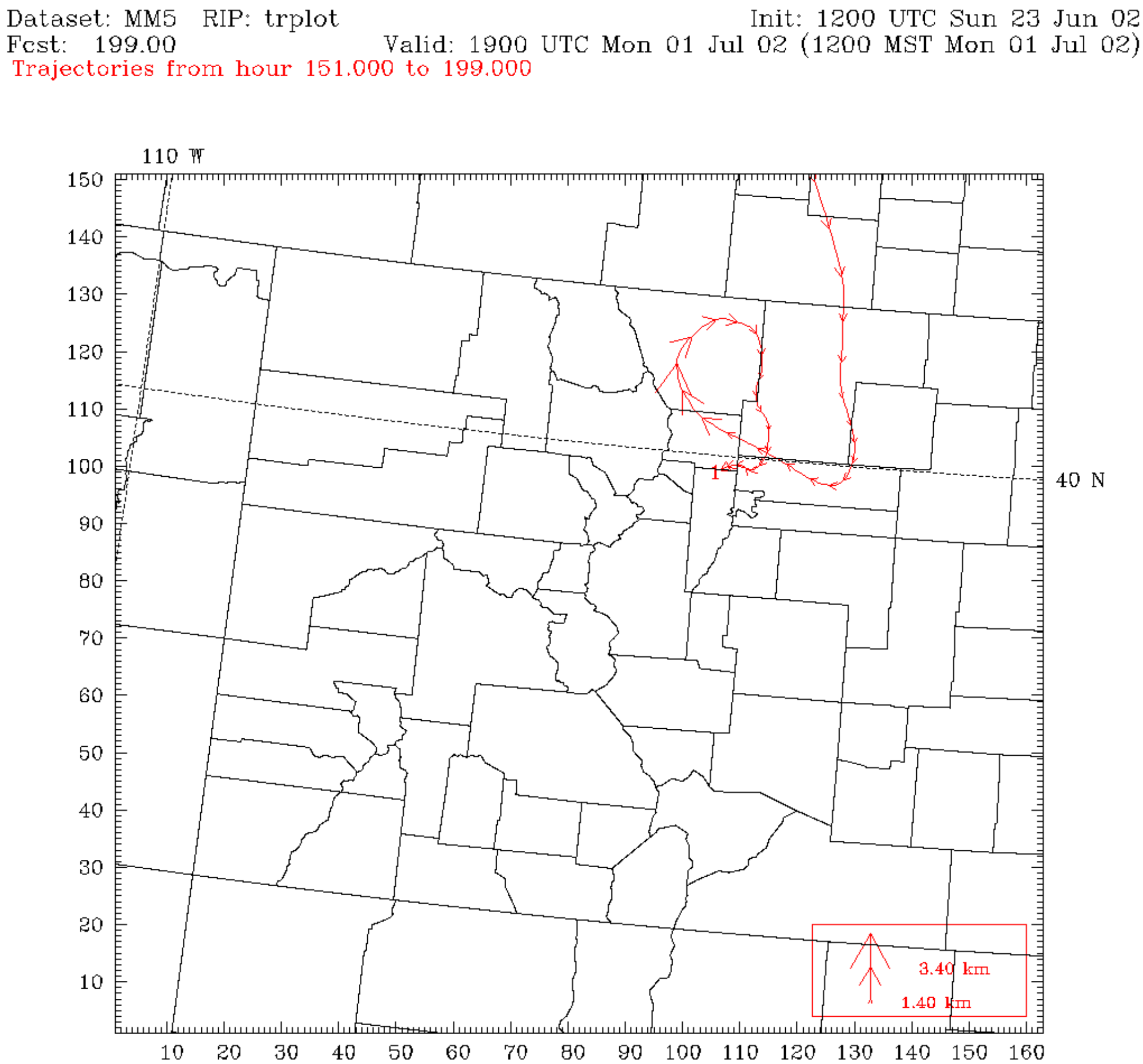
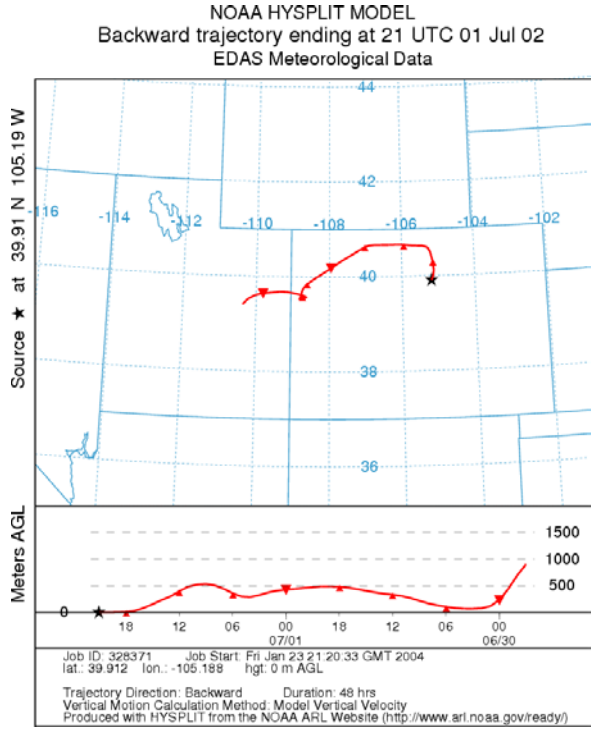
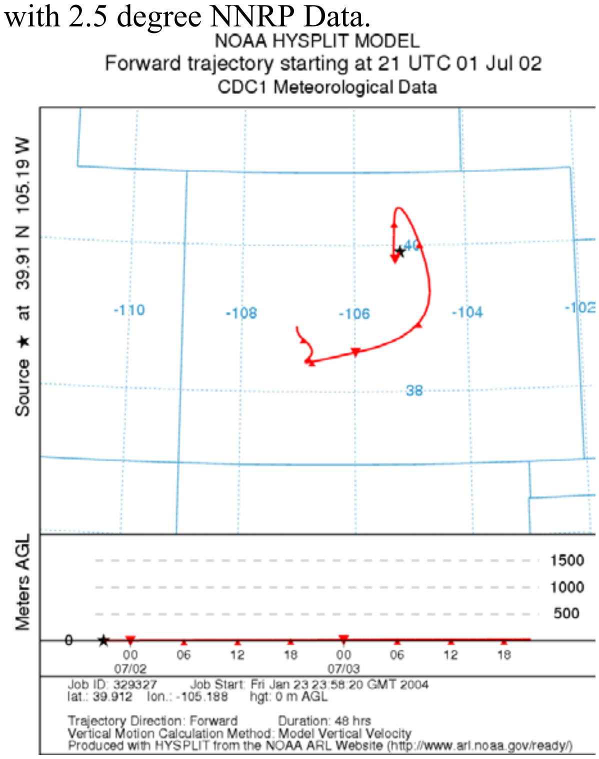


**Figure 21.** 48-Hour Back Trajectory from the Rocky Flats Monitor at 1400 MST 1 July 2002. The Peak 8-hour Monitored Ozone Concentration was 89 ppb.

a) NOAA HYSPLIT with 80km EDAS Data.




b) NOAA HYSPLIT with 2.5 degree NNRP Data.



c) RIP with 4km. MM5 Data.